Training Materials

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

WATER AND SANITATION CORPORATION (WASAC)

PROJECT FOR STRENGTHENING NON-REVENUE WATER CONTROL IN KIGALI CITY WATER NETWORK

NRW Reduction Concept Manual

October 2016

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Contents

1. Approaches to Non-Revenue Water Reduction

1.1 Definition of Water Balance

With respect to the definition of water balance sheet (breakdown of water distribution), the definition provided by the International Water Association (IWA) is accepted as the global standard. Causes of non-revenue water are as shown in the table below. WASAC also follows this definition to calculate the non-revenue water rate. Accordingly, it is necessary to carry out a causal analysis for each item in this water balance sheet to reduce non-revenue water. The causal analysis will clarify the priorities to consider in developing the measures to reduce non-revenue water and enable efficient implementation of the operations to reduce non-revenue water by setting targets for the implementation.

Table 1 Water Balance Sheet of the IWA

System Input Volume (Water distribution)	Authorized Consumption (Effective water)	Billed Authorized Consumption	Billed Water Exported	Metered	Revenue water
			Billed Metered Consumption		
			Billed Unmetered Consumption	Unmetered	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Metered	Non-Revenue water
			Unbilled Unmetered Consumption	Unmetered	
	Water Losses (Ineffective water)	Apparent Losses （Commercial losses）	Unauthorized Consumption	Metered/Unmetered	
			Customer Meter Inaccuracies	Metered	
		Real Losses （Physical losses）	Leakage on Transmission and Distribution Mains	Leakage	
			Leakage and Overflows at Storage Tanks		
			Leakage on Service Connections up to point of Customer Meter		

Note.

***** Unbilled Authorized Consumption: Water for cleaning pipes, watering trees, firefighting, etc.

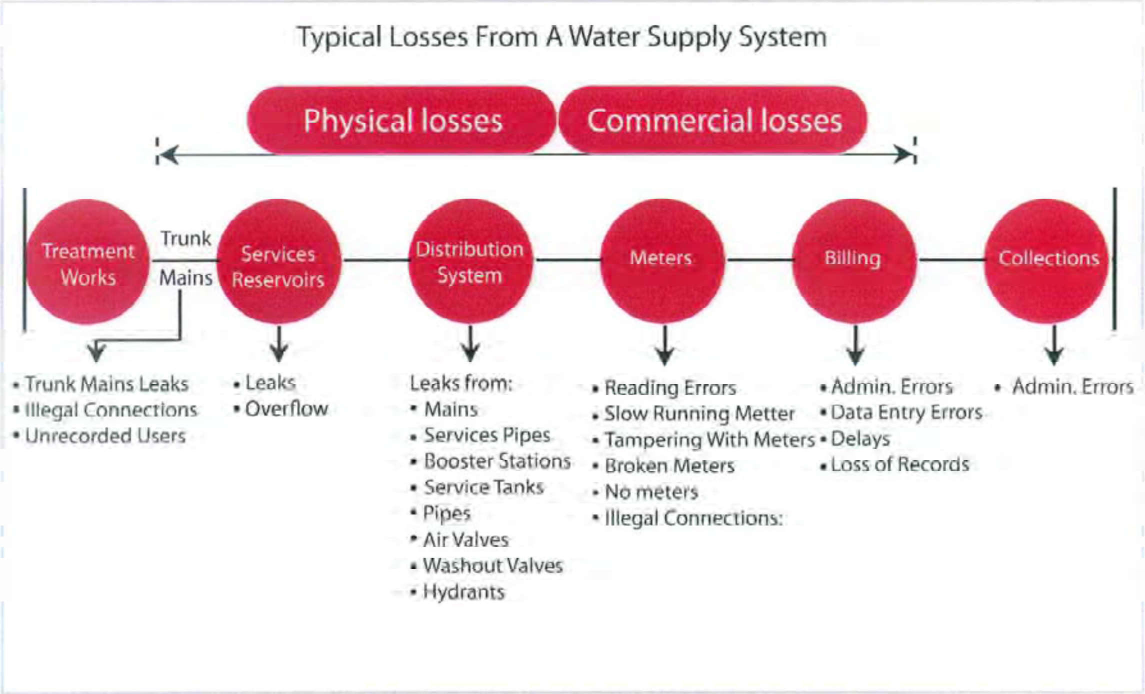
* Unauthorized Consumption: Water theft, unknown water

* Customer Meter Inaccuracies: Meter errors/non-detection, reading errors

Table 2 Water Balance Sheet of WASAC????

Water distribution	Effective water	Billed authorized consumption	Metered consumption		Revenue water
			Non-metered consumption	Use of average value	
				Use of estimated value	
			Water wagon		
		Unbilled authorized consumption	Water for firefighting		Non-revenue water
			Water for cleaning facilities	Water pipes, sewer pipes, water distribution tanks	
			Water for testing	Flow test, etc.	
			Water for other management uses	Surge tank	
			Water wagon	For use in water supply suspension and emergency	
	Ineffective water	Operating losses	Water theft (without contract)	Illegal use of fire hydrant	
				Non-contract use (bypass pipes, deteriorated pipes)	
				Water use by uncontracted industrial estates	
			Water theft (with contract)	Use of bypass pipes	
				Removal and direct connection of water meters (permanent, temporary)	
				Alteration of water meters	
			Metering errors	Malfunctioning of water meters (product defect, deterioration, failure, blockage)	
				Non-detection of water meters	
			Billing errors	Reading errors	
				Errors in billing of non-metered consumption (average value, estimated value)	
				Incomplete billing	
			Data processing errors	Billed water consumption	
		Physical losses	Leakage from primary distribution pipes	Visible, invisible	
			Leakage from secondary distribution pipes	Visible, invisible	
			Leakage from hydrants	Visible, invisible	
			Leakage from distribution reservoirs	Overflow	
			Unavoidable leakage		
			Losses from water wagon	Leakage when loading water without meter	

Other losses
- Errors in the measurement of water distribution volume
- Errors in the calculation process of non-revenue water rate



Conception Diagram of Non-Revenue Water

1.2 Benefits of Non-Revenue Water Reduction

- Business income (revenue from water charges) will increase by reducing the commercial losses to increase the billed water consumption in accordance with the actual consumption.
- By eliminating the wastage of water distribution by reducing the leakages, which are physical losses, water production cost and operation and maintenance cost of water transmission and distribution can be reduced. Also, water equivalent to the reduced leakages can be distributed to other water supply areas, which will further increase the income.

1.3 Points to be noted about Non-Revenue Water Rate

The following points should be noted in considering the measures to reduce the non-revenue water rate at WASAC.

- Definition of water balance by WASAC is in accordance with the definition by the International Water Association (IWA).
- Non-revenue water consists of unbilled authorized consumption, commercial losses (apparent losses) and physical losses (real losses).
- To reduce the non-revenue water, it is necessary to analyze the causes of each non-revenue water item in the water balance sheet, clarify the Non-revenue water volume and identify the priorities of reduction measures to be taken.
- The non-revenue water rate is calculated based on the "water distribution (system input volume)" and "billed consumption".

  Non-revenue water rate (%)

  = Non-revenue water volume/ Water distribution volume

  = (Water distribution volume − Billed consumption volume) / Water distribution volume
- An activity to reduce the non-revenue water rate should be carried out by focusing on the volumes of "water distribution" and "billed consumption" and considering how to reduce physical losses and how to transform commercial losses to billed consumption.

2. Measures to Physical Losses Reduction

2.1 Composition of the Measures to Physical Losses Reduction

Leakage reduction is important in non-revenue water reduction. Measures to reduce leakages are broadly classified into remedial (after-the-fact) measures, preventive measures and fundamental measures.

[Remedial (after-the-fact) measures]

1. Responsive operations (repair of visible leakages, call by local residents)
    - Early discovery of leakages appeared on the ground, accurate detection of leakage locations, real-time repair
2. Type of detection work (detection and repair of invisible leakages)
    - Detection work for selected area in advance: Detection of leakage points in the selected area after grasping the existing water leakage volume in some areas.
    - Patrol investigation: Leakage detection without grasping the existing leakage volume in advance
3. Flow monitoring operation
    - Monitoring of sudden water accidents and potential leakages through the minimum night flow measurement by using a monitoring system

[Preventive measures]

1. Water supply business plan
    - Formulation of “Annual work implementation plan” considering leakage reduction measures
2. Design and construction of waterworks facilities
    - Reinforcement of durability, corrosion resistance and watertightness
3. Replacement of decrepitude distribution pipes and service connection pipes with frequent leakages
4. Structural improvement of service connection pipe
    - Quality improvement of material and installation work of service pipes
5. Pressure control in water distribution area
    - Reformation of pressure zone, installation of pressure reducing valves or tank

[Fundamental measures]

1. Preparation for leakage reduction operations
   - Database preparation of pipeline information and repair history by using waterworks information system (GIS, etc.)
   - Securing budget, organization and equipment for implementing the activity for leakage reduction
2. Fact-finding investigation
   - Water distribution analysis (water distribution, billed consumption), water pressure measurement
   - Cause analysis of leakage and rupture accident of pipes by using data base
3. Improvement, development and standardization of piping materials
   - Quality improvement and standardization of the materials of distribution pipes, service pipes and accessories

2.2 Development Stages of Leakage Reduction Activity

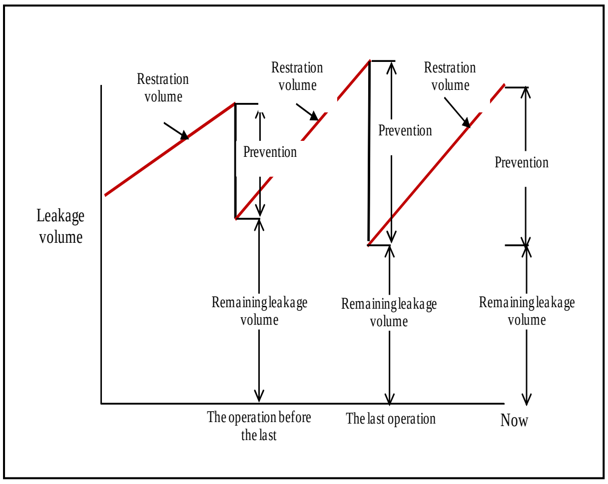
As shown in the table below, a non-revenue water reduction activity plan is generally composed of six stages, from setup period to the period in which the non-revenue water rate stabilizes at a low level. Currently, WASAC is in stages 1.

In the first and second stages, the leakage volume decreases by repairing, but generally, the leakage volume that has decreased as a result of leakage reduction operations always increases again because of the restoration of leakages. It is impossible to reduce the current leakage volume unless the volume detected and repaired is greater than the volume of restoration leakages.

Stages of Non-Revenue Water Reduction Activity

Stage	Tentative target of leakage rate	Major leakage reduction action
1	30% or higher	Reduction of on the ground leakages
2	20%－30%	Reduction of underground leakages
3	20%－25%	Prevention of leakage restoration
4	12%－20%	Thorough implementation of leakage reduction operations
5	5%－12%	Finishing of leakage reduction operations
6	5% or lower	Maintenance of minimum leakage rate

Restoration of Leakages



Prevention to restoring leakages

① Raise the effectiveness of leakage prevention operations so that the leakage prevention volume will exceed the restoring volume.

- Increase leakage detection work.
- Improve leakage detection skills by training and experience.
- Adopt efficient operation method for leakage detection.
- Quick repair detected leakages without fail.

② Replace deteriorated pipes to eliminate the restoring of leakages.

- Adopt piping materials that hard to leak water.
- Unification rearrangement the complicated plumbing to prevent from leakage.
- Perform pipe installation with an appropriate piping technology.

2.3 Target Leakage Rate

1) Unavoidable leakage rate

Unavoidable leakage is the leakage that cannot be expected to decrease any further no matter what leakage reduction measures are taken or efforts are made to reduce the leakage volume.

The IWA calls the unavoidable leakage UARL (Unavoidable Annual Real Loss) and represents it with the following equation.

$$UARL= (18.0 \times Lm + 0.8 \times Nc + 25.0 \times Lc) \times P$$

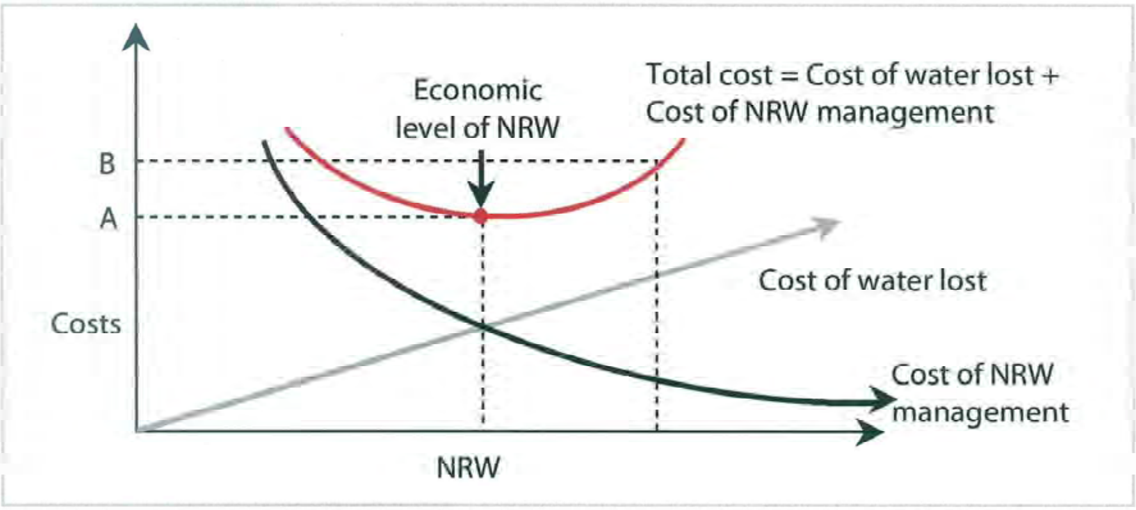
Where,

UARL: Unavoidable annual real loss (ℓ/day)
Lm : Total length of distribution pipes (km)
Nc : Number of service pipe branches
Lc : Total length of service pipes (km)
P : Average distribution pressure (m)

However, it should be noted that the value calculated in accordance with this equation is an estimate. Generally, the unavoidable leakage rate is said to be 2 – 4% of the total water distribution volume in any water utilities. As such, this value should be the ultimate target leakage rate for a water utility.

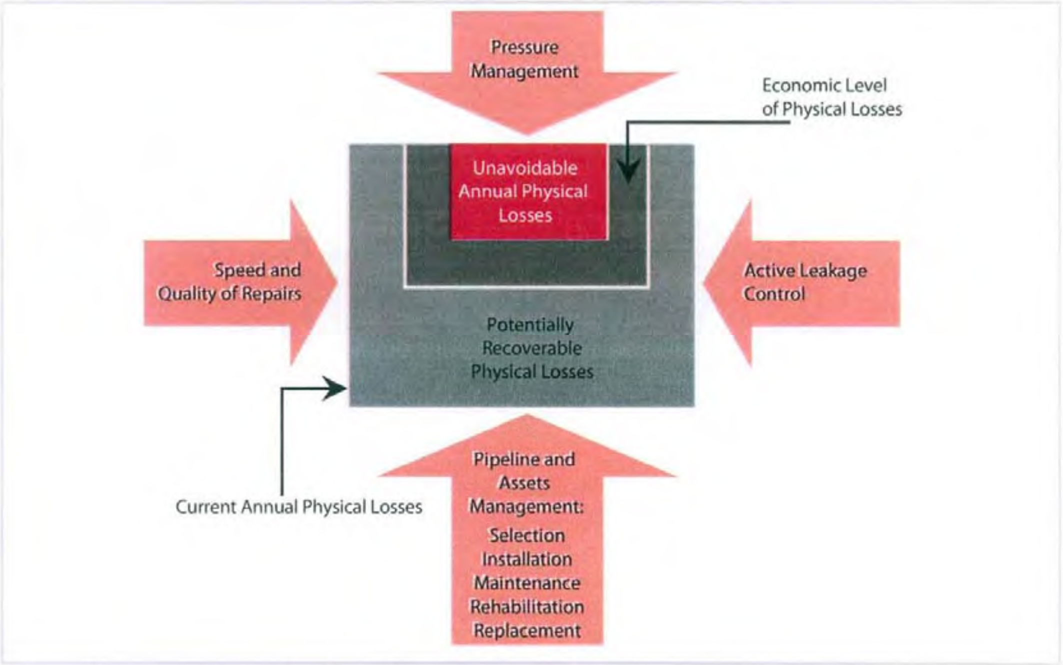
2) Allowable leakage rate

To arrive at the unavoidable leakage rate, it is necessary to take various leakage reduction measures, including the replacement of pipelines, which requires a huge amount of cost and time. As such, considering the cost performance, the leakage rate at the breakeven point where the cost required for the leakage reduction measures coincides with the loss caused by the leakage should be regarded as the allowable leakage rate and taken as a reference in determining the target for the leakage reduction measures.



3) Target leakage rate

If it is necessary to reduce the leakage rate before considering the cost performance of the leakage reduction measures as described above because of the scarcity of water resources or other reasons, it is required to set the target leakage rate by considering the current circumstances of the water utility. In most cases, the target leakage rate is set between the unavoidable leakage rate and the allowable leakage rate.



2.4 Planned Leakage Reduction Measures

As the remedial measures, leakages are investigated by patrolling, which is to directly conduct detection work without grasping the existing leakage volume within the DMA (District Meter Area) in advance, or by measuring the existing leakage volume in advance for selection the priority area to be detected.

Concept of measures to conduct leakage detection work;

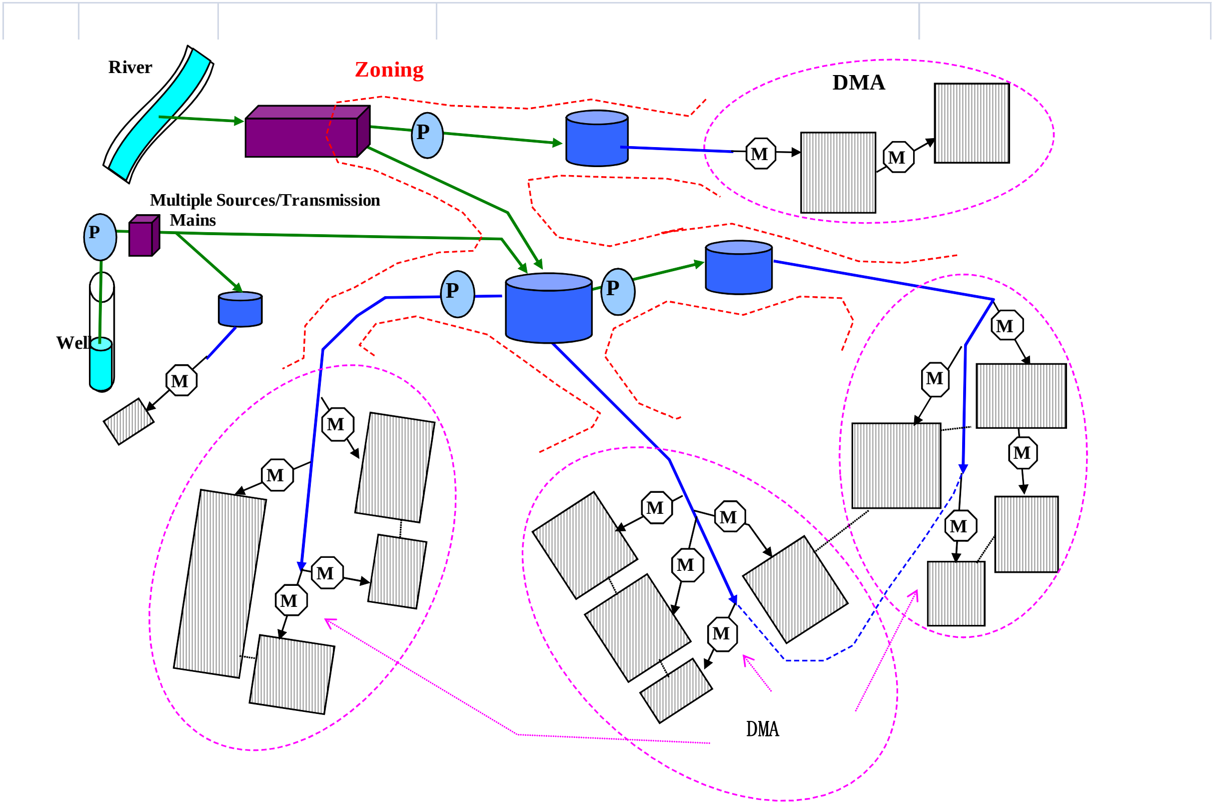
A. Patrolling detection work without selection the priority area to be detected
(the method without the measurement of existing leakage volume)
B. Selection the priority area for detection work
(the method gasp the existing leakage volume before detection work)

If the leakage density of each DMA (for example, leakage in m^3/day/km) is known in advance, it is possible to carry out leakage reduction work efficiently by investigating the area with the highest leakage density.

For this reason, it is desirable to perform the measurement of the existing leakage volume for selection in planning the works to take remedial measures.

Method of measuring the existing leakage volume (selection of priority area)

- **1. Direct measurement method**
- **2. Indirect measurement method**
  (Measurement of minimum night flow)



2.5 Activity within the DMA

The steps of non-revenue water reduction activity within a DMA are as described below. The existing leakage volume in each DMA before and after the leakage reduction work should be captured.

The work input volume should also be calculated and used as a basic reference for the analysis of cost-benefit performance.

① Grasp the area limit of DMA and hydraulic isolation of DMA.
② Grasp the location and status of existing distribution pipes, service pipes and valves.
③ Grasp the location of existing water meters (for common users and large users).
④ Grasp the situation of water tank equipped at individual water user’s facilities.
⑤ Grasp the leakage detection and leakage repair work history.
⑥ Prepare a work plan in order to measure the existing leakage volume at each sub-DMA in DMA.
⑦ Install valves to conduct step test in DMAs, if necessary.
⑧ Perform the measurement of the existing leakage volume of the sub-DMAs by direct measurement or indirect measurement (measurement of minimum night flow).
⑨ Select the sub-DMAs whose existing leakage volume is large and determine the priorities of the leakage detection work.
⑩ Perform the leakage detection works of the distribution pipes and the service pipes.
⑪ Repair the detected leaking pipes.
To calculate the volume of leakage reduction, whenever a leakage is found, the leakage volume should be measured and recorded before starting the repair work.
⑫ After repairing the leakages, the existing leakage volume of each sub-DMA should be measured.
⑬ As a preventive measure, it is important to prevent the leakage from service pipes. With respect to the sub-DMAs that were determined to have many leakages by the selection work, optimization and integration of the pipelines, replacement of old and deteriorated pipes and replacement of branches of service pipes from the distribution pipe should be considered.

3. Measures to reduce Commercial Losses

3.1 Major Causes of Commercial Losses

The causes of commercial losses are as shown in the table below and they are relevant to the billed consumption.

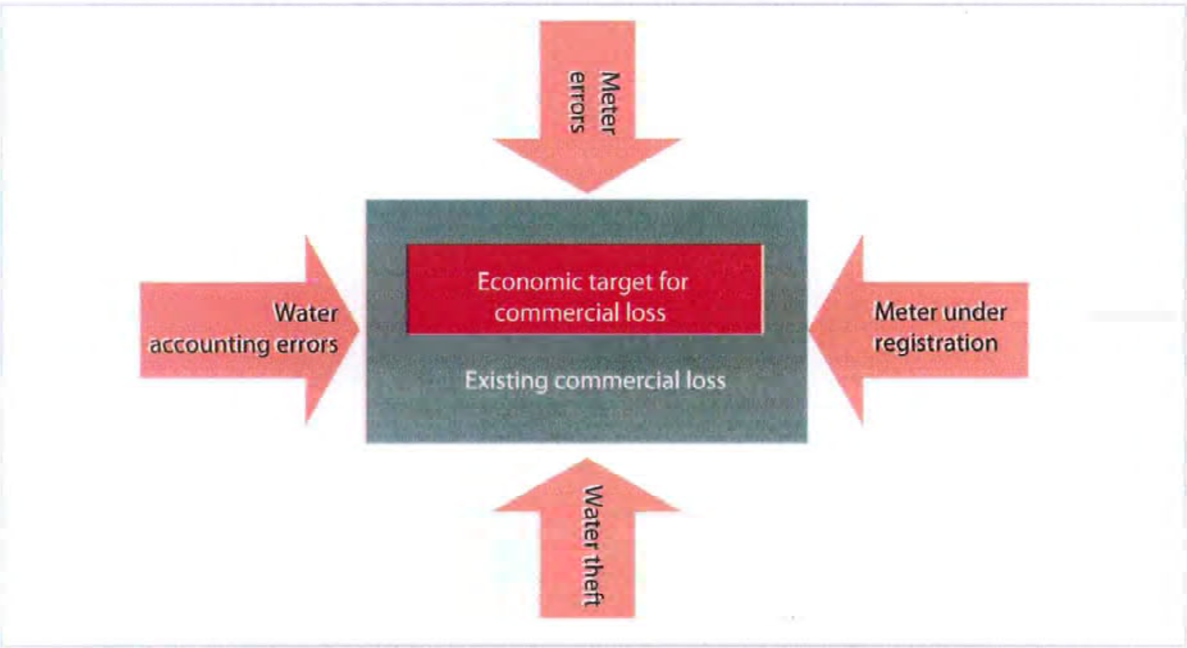
Causes of Commercial Losses

① Uninstallation of customer meter
② Measurement error of customer meter (failure, blocked, deterioration, vandalism)
③ Illegal connection of service pipes
④ Errors in reading meters and billing
⑤ Lack of management of billing database

Causes of Non-Revenue Water and Method of Operation

Cause items	Investigation method	Measures
① Uninstallation of meter	• Investigation of meter installation status	• Installation of meter
② Measurement error of meter • Product quality defect and failure • Deterioration due to expiration • Vandalism, unauthorized use • Inappropriate pipe size (Non-conformance to the water consumption) • Undetected consumption	• Pre-installation quality inspection • Analysis and listing of billed consumption data Trend analysis of year-on-year consumption Comparison with standard consumption (number of households, usage) • Listing of expired meters • Listing of meters with inappropriate pipe size • Certification of meters (on-site test meter, meter bench) • Measurement of instrumental error of meter and undetected consumption • Report from residents	• Replacement of defective meters • Replacement of expired meters • Correction of meters with inappropriate pipe size • Strengthening of penalty against vandalism • Activity to raise customer awareness
③ Illegal connection of service pipes (water theft)	• Analysis and listing of billed consumption data • Re-investigation of water supply suspension locations • Investigation of each household by commercial (opening and closing) the customer meter • Sound source detection by leakage detector • Test excavation of suspicious locations	• Removal of illegal connections • Strengthening of penalty against illegal use • Activity to raise customer awareness • Incentive to reporting of illegal use
④ Errors in reading meters and billing	• Investigation of each household	• Improvement of box

• Improper box location and structure • Errors in reading • Errors in reading data processing • Errors in the estimation of non-metered consumptions (average value, estimated value)	(when reading the meter) • Checking of reading • Checking of data processing • Checking the validity of non-metered consumptions	location and structure • Improvement of reading method • Correction of errors in processing • Proper calculation of non-metered consumptions
⑤ Lack of management of billing database	• Collation of customer database with actual on-site situation • Checking of customer meter information management map (GIS)	• Modification and updating of database • Strengthening of database analysis and management • Maintenance of customer meter information management map (GIS)



Concept of Measures to reduce Commercial Losses

3.2 Activity within DMA

The steps of non-revenue water reduction activity within a DMA focused on commercial losses are as described below.

① Collect and organize customer data to create a customer database of the DMA. Also, prepare a customer meter location map.

② Using the customer database, analyze the billed consumption data of the past several years and create an investigation list (list of customer meters suspected of abnormality) for the investigation of meter abnormality and illegal connections.

- Customer meters indicating water consumption although the water supply is suspended or the contract is cancelled
- Billed consumption of every month is always same figure.
- Billed consumptions that have suddenly changed (increased or decreased) in comparison with the billed consumption in the past.
- Billed consumptions that vary greatly
- Meter readings that tend to change (increase or decrease) steadily, following a certain pattern
- Though the customers listed as big consumer, whose billed consumption is small
- Billed consumptions that do not match the usage and have a discrepancy from the standard consumption
- Meters that have expired
- Meters whose pipe size is inappropriate for the water consumption

③ Analyze customer reports and grievance data to respond to meter abnormality, water theft, leakage, etc.

④ Conduct a simultaneous investigation of the customer meter of each household. The customer meters listed in ② and ③ above should be investigated in detail. Analyze the investigation results.

- Visual inspection of meters (connection and installation status, operating condition, specification)
- On-site certification of meters (portable test meter)
- Condition and location of meter boxes
- Leakage and piping abnormality around meters
- Hearing from customers (customer meter usage condition)

⑤ Calibration by test bench of meters suspected of abnormality.

- Meters suspected of abnormality from the database analysis
- Meters that were found to be abnormal in the investigation of each household

⑥ Conduct an investigation of illegal connection.

- Investigation around meters when reading the meters and investigating each household
- Investigation of each household by operating (opening and closing) the connection valve
- On-site investigation of the locations where water supply is suspended or the meter has been removed
- Investigation using leakage detection equipment (simultaneously with the leakage detection

operations or separately)

- Test excavation of suspicious locations

⑦ Measurement of meter instrumental errors and undetected consumption.

- Minimal flow that occurs when a tap is being opened or when a ball tap stops
- Performance deterioration of meters caused by the wear of gears, etc.

⑧ Conduct an investigation of unbilled authorized consumption.

- Water for firefighting, cleaning facilities, testing, water tank truck for water suspension and emergency use, etc.

⑨ Witness meter reading operations.

⑩ Summarize the investigation results and analyze the causes of non-revenue water.

⑪ Deal with the causes of non-revenue water.

a. Install meters (for customers with contract and without meter, etc.)

b. Replace defective meters.

- Expired meters
- Meters that are obviously out of order, meters that cannot be read and other defective meters
- Illegally altered meters
- Meters that did not pass the verification by test bench

c. For the meters whose pipe size is inappropriate for the water consumption, the pipe size should be corrected.

- Meters whose specification does not match the usage standard of WASAC

d. Correct the defects of meter boxes.

- Boxes at inappropriate locations
- Damaged boxes

e. Deal with illegal connection, meter alteration and other illegal acts.

- Removal of illegal connections
- Application of penalty against illegal acts

f. Repairing the leakages in meter boxes.

The descriptions of the NRW reduction measures are basically those shown in the table below.

Table 2.9 Descriptions of Guidance Related to NRW Reduction Measures

Category and description of NRW reduction measures				Description of measures
Category 1		Category 2		
Measures against Real Losses	Leakage	Pipelines	Pipe Mapping	Making of exact pipe drawings
			Zoning	Design & installation of DMAs & LMBs
			MNF Measurement	Grasp of leakage & its distribution
			Leak Detection	Utilization of leak detectors
			Leak Repair	Adoption of optimum repair method
			Pipe Rearrangement	Systematization of water supply area & block formation (DMZ formation)
		Facilities	Leak Detection	Leak detection of civil engineering facilities
			Leak Repair	Adoption of optimum repair method
			Facility Rearrangement	Rearrangement of pumping stations & distribution reservoirs & their optimum operations
Measures against Apparent Losses	Theft of Water	Survey		Detection of illegal connections
		Notification & Persuasion		Negotiation with thieves
		Repair		Disconnection of illegal connections, installation of customer meters
		Fine & Penalty		Collection of fine & imposing penalty
	Mere Error	Customer Meters	Survey	Abstraction of defect meters
			Replacement	Relocation of meters and adjustment of meter position
		Bulk Meters	Survey	Abstraction of defect meters
			Installation & Replacement	Installation of necessary meters, replacement of defect meters, relocation of meters and adjustment of meter position
	Meter Reading Error	Replacement of Meters		Adoption of easy-to-read meters, improvement of meter installation location
		Remote Meter Reading System		Introduction of remote meter reading system
	Data Handling Error			Careful work procedures and programming checks
Measures against Unbilled Authorized Consumption		Public Use		Review of unbilled water for public use
		Institutional Use		Improvement of drainage work for flushing
Fundamental Measures	Data Management	Data Acquisition and Recording		Abstraction, acquisition & record of data
		Data Analysis		Pipe network analysis, prediction of leakage & NRW rate, & improvement of NRW reduction measures
		Construction of Integrated Information System		Introduction of GIS, customer information system, SCADA system & Management Information System
	Planning	Planning of Pipe Rearrangement		Abstraction of pipes to be replaced, establishment of pipe replacement planning
		Planning of Water Supply Operation System		Introduction of optimum water pressure & quantity management system
		Structural Rearrangement		Structural planning (organization, staffing, work methods)
		Prediction of Leakage Rate or NRW		Cost-benefit performance analysis
		Consolidation of Legal System		Strength of penalties for water theft & intentional meter misreading, & award system for excellent staffs, qualification system for plumbers etc.

Category and description of NRW reduction measures			Description of measures
	Education and Training	Staff (including contractors) Training	Technical training & moral enhancement training
		Enhancement of Public Awareness	Utilization of public relations & hearings, publicity and education
	Survey/R&D		Survey and research & development regarding NRW reduction

Abbreviations

DMZ: District Metered Zone

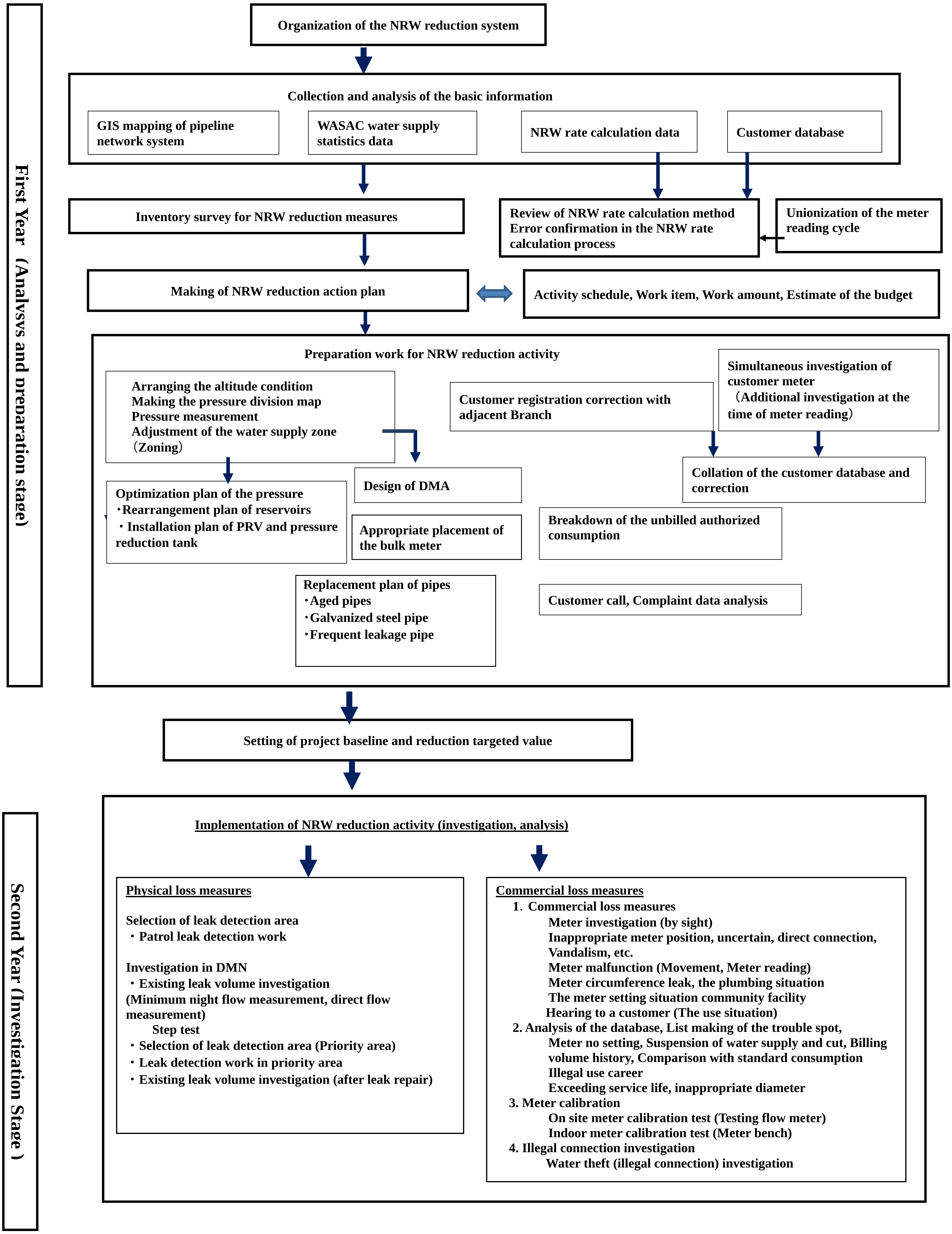
DMA: District Metered Area

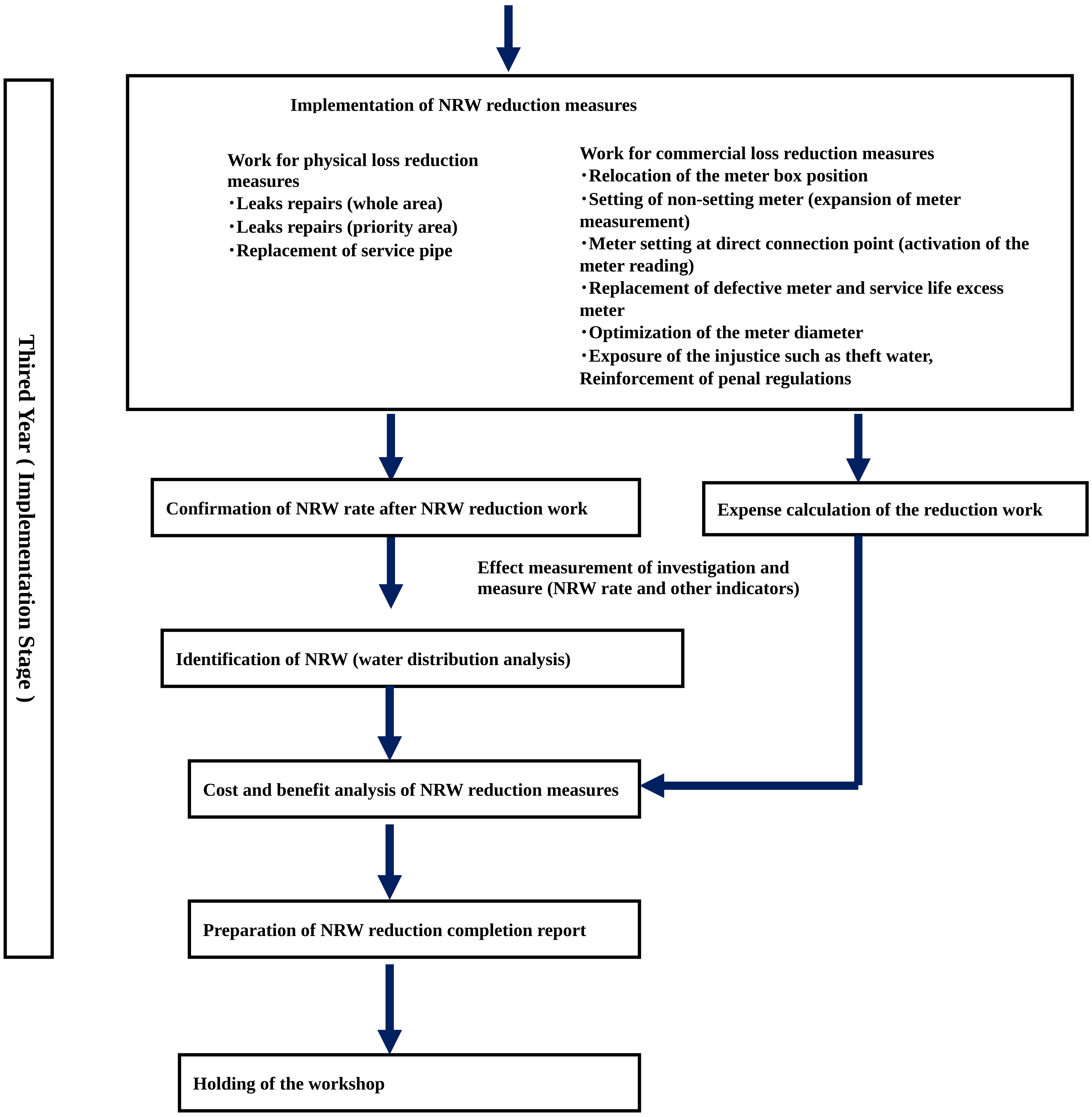
LMB: Leakage Monitoring Block

GIS: Geographic Information System of Mapping System

SCADA: Supervisory Control and Data Acquisition

NRW reduction flow of Branch Office




Thired Year (Implementation Stage)
Implementation of NRW reduction measures
Work for physical loss reduction measures
・Leaks repairs (whole area)
・Leaks repairs (priority area)
・Replacement of service pipe
Work for commercial loss reduction measures
・Relocation of the meter box position
・Setting of non-setting meter (expansion of meter measurement)
・Meter setting at direct connection point (activation of the meter reading)
・Replacement of defective meter and service life excess meter
・Optimization of the meter diameter
・Exposure of the injustice such as theft water, Reinforcement of penal regulations
Confirmation of NRW rate after NRW reduction work
Expense calculation of the reduction work
Effect measurement of investigation and measure (NRW rate and other indicators)
Identification of NRW (water distribution analysis)
Cost and benefit analysis of NRW reduction measures
Preparation of NRW reduction completion report
Holding of the workshop

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THE MANAGER'S NON-REVENUE WATER HANDBOOK FOR AFRICA

A GUIDE TO UNDERSTANDING WATER LOSSES

MARCH 2010

This publication was produced for review by the United States Agency for International Development.
It was prepared by DAI.

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THE MANAGER‘S NON-REVENUE WATER HANDBOOK FOR AFRICA

A GUIDE TO UNDERSTANDING WATER LOSSES

Program Title:	**Advancing the Blue Revolution Initiative**
Contract Number:	**EPP-I-00-04-00023-00**
Contractor:	**DAI**
Date of Publication:	**March 2010**

CONTENTS

TABLES, FIGURES, AND BOXES

TABLE

FIGURE

BOX

FOREWORD

One of the major challenges facing water utilities in the developing world is the high level of water losses—from physical losses (leakage), theft of water from the system, or because water users are not being properly billed. This difference between the amount of water put into the distribution system and the amount of water billed to consumers is known as ―Non Revenue Water" (NRW). This has a serious effect on the financial viability of water utilities through lost revenue, lost water resources, and increased operational costs, reducing their capacity to fund necessary expansions of service, especially for the poor.

For too long NRW management has been given low priority by government officials, utility managers, donors and the water sector in general. However, over the last decade perceptions have changed rapidly, particularly in the developed world. The International Water Association (IWA) has acknowledged this trend by forming the Water Loss Task Force (WLTF), which over the last 8 years has played a major role in developing, standardizing and disseminating methodologies for addressing NRW.

It is now widely acknowledged that NRW is a key indicator of a utility‗s operational and financial performance. A high level of NRW normally indicates a water utility that lacks good governance, autonomy, accountability, and the technical and managerial skills necessary to provide a reliable service.

The African Water Association (AfWA) has identified NRW as a priority issue within its capacity building programs, delivering technical sessions to raise the awareness of African water utilities to NRW. Challenges include:

- Old pipe networks dating from the independence period of the 1960s
- Lack of knowledge of the water networks (inadequate records, rapid urbanization)
- Low perception of NRW by utility management

Recently established in Kampala, Uganda, AfWA‗s African Water Academy is dedicated to leadership development and change management, specializing in capacity building for senior utility managers. The Water Operators‗ Partnership Africa Program (WOP Africa) is also enhancing utility to utility capacity building. These are two major instruments that AfWA will be using to deliver high level management and technical training to address NRW.

The Manager's Non-Revenue Water Handbook for Africa: A Guide to Understanding Water Losses—is a timely publication. Written in a clear style and in user-friendly language the Manual‗s structure gives managers and technical staff the opportunity to understand the factors that influence NRW and the solutions for managing it. Drawing on case study examples and key messages from African utilities the manual aims to offer practical solutions to the NRW challenges, so that in future utility managers will be in a better position to tackle the challenges associated with this issue.

Water utility managers are encouraged to use the Manual, taking advantage of the depth of knowledge and experience that has been developed in recent years. This will enable managers to build up a skilled NRW management team, and to acknowledge the challenges and shortfalls within their particular utility. This will in turn encourage the water sector in Africa as a whole to come closer to achieving the **Millennium Development Goals** for water and sanitation services.

Sylvain Usher
Secretary General, African Water Association

ACKNOWLEDGMENTS

The original version of this manual—The Manager‘s Non-Revenue Water Handbook - was published in July 2008 for Asian water utility managers. It was funded jointly by USAID – Regional Development Mission for Asia, Thailand, and Ranhill Utilities Berhad, Malaysia.

The manual has been adapted for African utility managers by Malcolm Farley, using case studies and other material from several sources:

Firstly, for permission to use the original manual as a base document, thanks are due to USAID/RDMA, Eco-Asia and Ranhill Water Services, from which organisations the original publication team was drawn:

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Secondly, for the African version of the manual, acknowledgements are due to The World Bank Institute (WBI) and WBI colleagues Jan Janssens and Roland Liemberger (in their former capacities as Programme Manager and Consultant), who provided case study material from Burkina Faso, Tanzania and Uganda, developed under the AfWA—WBI Program. Acknowledgement is also due to the International Water Association‘s Water Loss Task Force, from whose work many of the technical concepts and methodologies have been drawn.

Thanks are also due to Harrison Mutikanga (NWSC, Uganda), Ronnie Mckenzie (WRP, South Africa) and Alan Wyatt (RTI International, USA), for providing additional material, and to Mahmood Lutaaya (NWSC, Uganda) and colleagues from USAID and DAI, for reviewing the manual and suggesting additions.

Photographs courtesy of: Ronnie Mckenzie, Harrison Mutikanga and Malcolm Farley, and authors of the original manual.

The Manager‘s Non-Revenue-Water Handbook for Africa was commissioned by USAID, Washington, and funded and published by Development Alternatives Inc (DAI), under the Advancing the Blue Revolution Initiative (ABRI).

1. INTRODUCTION

1.1 BACKGROUND TO NRW

By reducing water losses, water utilities have additional supply to expand services to underserved areas.

The global volume of non-revenue water (NRW) is staggering. Each year more than 32 billion m^3 of treated water are lost through leakage from distribution networks. An additional 16 billion m^3 per year are delivered to customers but not invoiced because of theft, poor metering, or corruption. A conservative estimate of the total annual cost to water utilities worldwide is US$14 billion. In some low-income countries this loss represents 50-60% of water supplied, with a global average estimated at 35%. Saving just half of this amount would supply water to an additional 100 million people without further investment.[1]

Other benefits from reducing NRW include the following:

- Water utilities gain access to a further US$3 billion in self-generated cash flow
- Reducing illegal connections supports greater fairness between users
- More efficient and sustainable utilities improves customer service
- New business opportunities creates thousands more jobs

In Africa, many water utilities operate under the jurisdiction of municipal, provincial, or central governments. These utilities often rotate or appoint senior managers and directors with backgrounds in various disciplines beyond the water sector. As a result, senior managers entering these positions have limited knowledge of water supply operations, especially on the vital technical and institutional requirements for effectively managing NRW and water losses. This handbook serves to assist senior managers of water utilities in better understanding the definition, causes, and practical solutions to address NRW, a key performance indicator for a utility‘s operations. It provides the information that managers need when discussing NRW-related issues with their staff. By design, it is not a hands-on technical guide for engineers to manage NRW, but rather is a reference for senior managers.

Lessons from utilities‘ own experiences, case studies, and examples of twinning projects have contributed to the development of *The Manager's Non-Revenue Water Handbook for Africa*.

1.2 CHALLENGES IN AFRICAN WATER UTILITIES

There are areas of plentiful water across Africa, just as there are water-scarce areas, as a result of both regional geography and a country‘s ability to develop and efficiently manage water systems. The photos below illustrate the inequity of water availability between communities. Although reducing NRW cannot

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[1] Source: World Bank Discussion Paper No. 8, December 2006.

solve such regional contrasts, it can help to improve the quantity and quality of water available in water-scarce areas.

A NRW reduction strategy can help to improve the quantity and quality of water supplies, and the burden of collecting water, in water scarce areas.

Not all countries or regions of Africa have the infrastructure and established operational procedures to begin tackling NRW. Many are struggling to ensure that customers receive a reasonable water supply to sustain health and life. Water utility managers in most African countries will invariably face greater challenges including the following:

- Rapid urbanization
- Diminishing water supply
- Environmental pollution
- Outdated infrastructure
- Poor operations and maintenance policy, including ineffective record-keeping systems
- Inadequate technical skills and technology
- Greater financial constraints, including an unsuitable tariff structure and/or revenue collection policy
- Political, cultural, and social influences
- A higher incidence of commercial losses, particularly illegal connections

However, African utility managers also have a number of strengths they can build on:

- A high work ethic and level of industriousness
- Ability to make do with available resources and materials
- Motivated staff with the potential for developing high technical capacity

These factors all influence the scope for managing losses and demand, and affect the pace of change. At the same time, continued NRW limits the financial resources available to tackle these challenges facing water utilities in Africa. This handbook enables water utility managers in the region to address the limitations, acknowledge the challenges, and make gradual improvements to current policies and practices.

1.3 IMPACTS OF NRW: THE VICIOUS AND VIRTUOUS CIRCLES

The _Vicious Circle‘ of NRW (Figure 1.1) is one of the key reasons for poor company performance and results in both physical and commercial losses (see Chapters 5 and 6). Physical losses, or leakages, divert precious water from reaching customers and increase operating costs. They also result in larger investments than necessary to augment network capacity. Commercial losses, caused by customer meter inaccuracies, poor data handling, and illegal connections, reduce income and thereby financial resource generation.

The challenge for water utility managers is to turn the Vicious Circle into the _Virtuous Circle‘ (Figure 1.2). In effect, reducing NRW releases new sources of both water and finances. Reducing excessive physical losses results in a greater amount of water available for consumption and postpones the need for investing in new sources. It also lowers operating costs. Similarly, reducing commercial losses generates more revenues.

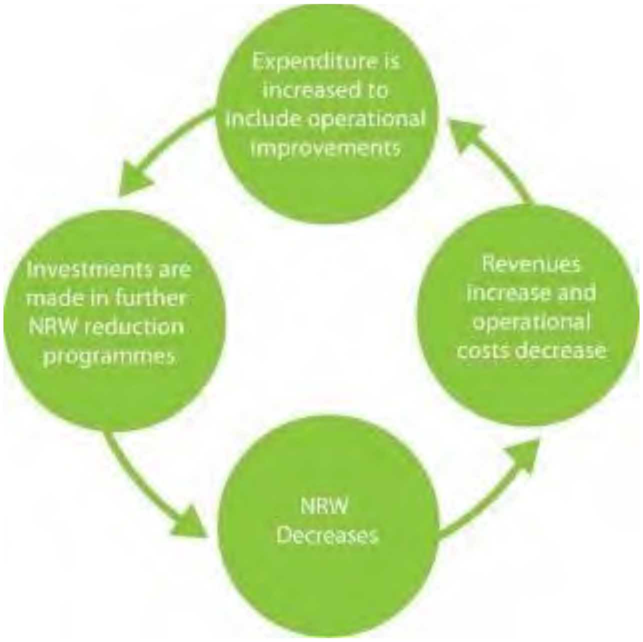
BOX 1.1: WHY DO UTILITIES STRUGGLE WITH NRW REDUCTION?

- Not understanding the problem (magnitude, sources, costs)
- Lack of capacity (insufficient trained staff)
- Inadequate funding to replace infrastructure (pipes; meters)
- Lack of management commitment
- Weak enabling environment and performance incentives

Bill Kingdom, Roland Liemberger, Philippe Marin, “The Challenge of Reducing Non-Revenue Water in Developing Countries--How the Private Sector Can Help: A Look at Performance-Based Service Contracting”, World Bank, Paper No. 8, Dec 06.

FIGURE 1.1: THE VICIOUS NRW CIRCLE

FIGURE 1.2: THE VIRTUOUS NRW CIRCLE



Replacing aging infrastructure requires financial capacity, which can be gained through NRW reduction.

1.4 ADDRESSING NRW

Water utilities anywhere in the world can use a diagnostic approach, followed by the implementation of solutions that are practicable and achievable to reduce NRW. The first step is to learn about the network and operating practices. Typical questions during this process include:

- How much water is being lost?
- Where are losses occurring?
- Why are losses occurring?
- What strategies can be introduced to reduce losses and improve performance?
- How can we maintain the strategy and sustain the achievements gained?[2]

1.4.1 REASONS FOR FAILURE—AND THE ROAD TO SUCCESS

Although minimising non-revenue water should be a priority for water utilities, many still struggle to achieve acceptable NRW levels. The reasons NRW strategies fail range from not understanding the magnitude of the problem to lack of financial or human resource capacity. There may also be inadequate funding to replace infrastructure, lack of management commitment, or a weak enabling environment and performance incentives.

NRW management is not a one-off activity, but one requiring a long-term commitment and involvement of all water utility departments. Many utility managers do not have access to information on the entire network, which would enable them to fully understand the nature of NRW and its impact on utility operations, its financial health, and customer satisfaction. Underestimating NRW‘s complexity, and the potential benefits of reducing NRW, often lead to reduction programmes‘ failure. Successful NRW reduction is not about solving an isolated technical problem, but is instead tied to overall asset management, operations, customer support, financial allocations, and other factors (Figure 1.3).

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[2] Kingdom, B., R. Liemberger, and P. Marin, 2006. —The Challenge of Reducing Non-Revenue Water in Developing Countries—How the Private Sector Can Help: A Look at Performance-Based Service Contracting", World Bank, Paper No. 8, Dec 2006.

FIGURE 1.3: REDUCING NRW IS EVERYONE'S RESPONSIBILITY

Poor governance also affects NRW reduction. Utility managers often lack the autonomy, accountability, and technical and managerial skills necessary to provide reliable service. The utility's management should also tackle organisational challenges, such as policy barriers, inadequate technical capacity, and aging infrastructure. Finally, poor project design hinders efforts to reduce NRW, particularly underestimating the required budget.

However, utility managers' understanding of the institutional dimension of NRW is growing. In addition, a number of tools are emerging to support sustainable NRW reduction:

- New methodologies that quantify physical and commercial losses more accurately
- More effective technical approaches to manage leakage and reduce system pressure
- New instruments for engaging the private sector, such as performance-based contracts

1.4.2 THE MANAGER'S NRW MANUAL FOR AFRICA

Most developed countries have a solid infrastructure and established operational practices for managing and controlling non-revenue water (NRW). This is not always the case in developing countries; many are struggling to ensure that customers receive a reasonable supply of safe drinking water, often via a pipe network that is inadequate, with poor record systems and a low level of technical skills and technology. Customer metering is not always universally applied, and tariff systems and revenue collection policies often do not reflect the true value of water supplied. This limits the utility‘s cost recovery and encourages customers to under-value the service.

Developing countries in Africa face similar challenges in reducing NRW, including aging infrastructure, financial constraints, poor governance, and poor project design. However, many utilities in the region can draw on examples of good practice by other utilities. They can also usually depend on motivated and industrious staff to implement solutions once the challenges of reducing NRW have been identified.

Using some key messages, the Manager‘s NRW Handbook for Africa leads the utility manager through the stages of addressing NRW; first, understanding and quantifying NRW, and then developing a strategy to address it.

Chapter 1 examines the scale of NRW, and emphasises the challenges to African water utilities. Utility managers and operational staff should be committed to managing NRW as a long-term process that incorporates numerous aspects of water operations. Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. Utilities must end a cycle, known as the _Vicious Circle‘, where companies face increased NRW, financial losses, limited investment and poor service. Instead, utilities should follow the _Virtuous Circle‘ that enables them to decrease NRW, improve efficiency, preserve financial resources and promote strong customer satisfaction and willingness to invest.

Chapter 2 highlights the need to understand and accurately quantify NRW as an indicator of a water utility‘s operating efficiency. The International Water Association (IWA) water balance is an excellent method for utility managers to break down and identify the key components of NRW. Ensuring the accuracy of data used to calculate the level of NRW is also essential in understanding the full problem. Collecting accurate data from production meters and customer meters helps to measure the true NRW level. In addition, the customer billing cycle must be factored into NRW calculations to ensure that the time period used for the consumption volume measurement matches the production meter volume measurement.

Chapter 3 considers the requirements to develop an NRW reduction strategy. Utilities need to consider establishing an NRW management team to develop a strategy, ensure that all components of NRW are addressed, and verify that the proposed strategy is feasible and practicable in terms of the workload and budget. Choosing the right team members promotes ownership among the various utility departments involved in the strategy‘s implementation, and also facilitates consensus at the senior management level. As a first step in developing the strategy, the team should set an initial utility-wide target for NRW reduction based on the economic level of NRW. The team can balance the financial and water supply objectives of the strategy using the water balance results, while aiming to shorten the awareness, location, and repair (ALR) times in addressing water losses. The NRW strategy may cover a period of four to seven years. As a result, pilot projects can help water managers understand the full budget and resources required to implement the entire strategy.

Chapter 4 emphasises the level of awareness required at all levels—from top decision-makers to the end consumer—that is critical for a successful NRW reduction programme. Support from the programme's top-level management, and the budget required, has a ‗cascade effect' on other levels of management and promotes the financial sustainability of the strategy. Middle management and staff must understand their roles and responsibilities in reducing NRW, since it requires a long-term, combined effort from all departments in the utility. Also, reaching out to customers helps increase their awareness of NRW and how reducing water losses results in improved water supply and quality.

Chapter 5 addresses commercial losses. Commercial losses represent lost revenue, and even a small volume will have a large financial impact. They occur mostly through tampered meters, aging and improperly maintained meters, unauthorised connections, administrative errors and even corrupt practices during the meter reading and billing process. Utilities should invest in training for meter readers, staff, and crews, as well as in accurate meters and a robust billing system, which can directly result in higher returns. In addition, collaboration from the public and certain government departments is required to overcome theft and illegal use of water.

Chapter 6 examines physical losses. These include leakage on transmission and distribution mains; leakage and overflows from storage tanks; and leakage on service connections up to the customer meter. Leakage from transmission and distribution mains are usually large events that can cause serious damage, but the public typically reports them rapidly, followed the utility repair on an emergency basis. Other types of leakage are more difficult to detect and repair. A successful leakage management strategy requires pressure management, active leakage control, pipeline and asset management, and speedy and quality repairs.

Chapter 7 deals with zoning. Dividing an open water supply network into smaller, more manageable zones or district meter areas (DMAs) is now internationally accepted best practice. It enables the utility to better understand the network, and to more easily analyse pressure and flows in problem areas. The criteria for establishing DMAs include the size (or number of connections); number of valves that must be closed; number of flow meters; ground-level variations; and visible topographic features that can serve as DMA boundaries. Utility managers use the minimum night flow (MNF) and legitimate night flow (LNF) to calculate the net night flow (NNF), along with commercial losses, to determine NRW in a DMA. Establishing DMAs helps to manage pressure, improve water quality, and enable continuous water supply.

Chapter 8 gives an indication of the range of performance indicators (PIs) available to utility managers. PIs are an aid to measuring progress in reducing NRW, developing standards, and prioritising investments. The International Water Association (IWA) recommends the Infrastructure Leakage Index (ILI) as the best performance indicator for physical losses. Currently, the best PI for commercial losses is to express them as a percentage of authorised consumption. The IWA is developing another indicator for commercial losses - the Apparent Loss Index (ALI). Utility managers should develop and implement monitoring programs to ensure their NRW targets are being met.

Chapter 9 discusses some options for building capacities for managing NRW through ‗twinning' arrangements, or utility to utility partnerships. Water service providers worldwide have demonstrated the value of twinning, or focused and sustained exchange between practitioners, in promoting the adoption of improved policies and best practices, and in building human and institutional capacity. Twinning partnerships rely on counterpart exchange to help strengthen the capacity of a utility to improve services delivery (such as NRW reduction), expand services or convert to continuous water supply. Effective twinning partnerships are demand driven, address the interests and priorities of partners, are results oriented and aim at the adoption and replication of best practices from one partner to another. There are several good examples of twinning projects in Africa, supported by AfWA and WOP, which disseminate, replicate, and strengthen the results of such twinning partnerships.

NRW is a global problem requiring a management strategy that can be globally applied. Developing such a strategy requires a diagnostic approach—firstly to identify the problem, and then to use the available tools to reduce or remove it. Following a step-wise process - asking some basic questions about the utility policies and practices—then applying the appropriate tasks to answer them—is the basis of a successful strategy development.

The philosophies, concepts and recommendations contained in the Managers‘ NRW Handbook closely reflect international best practice, particularly those recommended by the IWA and the World Bank Institute. If African utilities apply the approach recommended in the Handbook they will rapidly benefit from a greater understanding of their networks‘ performance, and will have an increased knowledge of the tools available to identify and reduce their levels of NRW.

Key Messages

- Reducing NRW increases both financial resources and the water available to utilities.
- Developing countries in Africa face challenges in reducing NRW, such as aging infrastructure, financial constraints, poor governance, and poor project design; however, they may draw on examples of good practice demonstrated by other African utilities to transfer knowledge and motivate staff.
- The Vicious Circle leads to increasing NRW and financial losses, while the Virtuous Circle leads to decreasing NRW and financial resources.
- Managing NRW is a long-term process that must incorporate numerous aspects of water operations.
- Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. *The Manager's NRW Handbook for Africa* can help utility managers identify sources of NRW and develop a strategy for reducing them.

2. KNOWING YOUR WATER LOSSES: THE WATER BALANCE

To most water utilities, the level of NRW is a key performance indicator of efficiency. However, most utilities tend to underestimate NRW because of institutional and political pressures, as well as a lack of knowledge to properly determine the NRW level. Reports of low levels of NRW are eagerly accepted by senior managers. However, *reported* low levels of NRW, whether due to deliberate misinformation or, more likely, a lack of accurate information, will not help the water utility to reduce its costs or increase revenue. Instead, it will mask the real problems affecting the water utility‘s operating efficiency.

Only by quantifying NRW and its components, calculating appropriate performance indicators, and turning volumes of lost water into monetary values, can the NRW situation be properly understood and the required actions taken. The utility manager now has a powerful tool to support this first step—the water balance calculation. This chapter introduces the water balance concept and gives two examples of water balance software, WB-EasyCalc and Aqualite. This software assists managers in developing the water balance while also indicating the level of accuracy of the NRW calculation.

2.1 HOW MUCH WATER IS BEING LOST?

The first step in reducing NRW is to develop an understanding of the _big picture‘ of the water system, which involves establishing a water balance (also called a _water audit‘ in the US). This process helps utility managers to understand the magnitude, sources, and cost of NRW. The International Water Association (IWA) has developed a standard international water balance structure and terminology that has been adopted by national associations in many countries across the world (Figure 2.1).

FIGURE 2.1: WATER BALANCE SHOWING NRW COMPONENTS

System Input Volume (allow for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorized Consumption	
			Customer Metering Inaccuracies and Data Handling Errors	
		Physical Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility‘s Storage Tanks	
			Leakage on Service Connections up to Point of Customer Use	

Water Losses refer to the total amount of water flowing into the water supply network from a water treatment plant, borehole system or imported bulk water supply (the ‗System Input Volume‘) minus the total amount of water that consumers (domestic, commercial, industrial and institutions) are ***authorised to use*** (the ‗Authorised Consumption‘)

Non-revenue water (NRW) is equal to the total amount of water flowing into the water supply network from a water treatment plant, borehole system or imported bulk water supply (the ‗System Input Volume‘) minus the total amount of water that consumers (domestic, commercial, industrial and institutions) are authorised to use ***and are billed for*** (the ‗Billed Authorised Consumption‘).

NRW = System Input Volume - Billed Authorised Consumption

This equation assumes that:

- System input volume has been corrected for any known errors
- The billed metered consumption period for customer billing records are consistent with the System Input Volume period

Utility managers should use the water balance to calculate each component and determine where water losses are occurring, as described in the next sections. They will then prioritise and implement the required policy changes and operational practices.

NRW components cover the entire water utility supply system from the water treatment plant, borehole system or imported bulk water supply outlet meters to the customer meters, which means that managing NRW is the responsibility of the entire operations department. Water utilities often set up a dedicated ‗NRW team‘, with disappointing results as everyone else in the company leaves NRW management to this team. As illustrated in Figure 1.3, and discussed further in Chapters 3 and 4, an NRW reduction strategy should encompass all staff with each department‘s responsibilities outlined in detail.

2.2 WATER BALANCE COMPONENTS: WHERE ARE YOUR LOSSES OCCURRING?

Abbreviated definitions of the principal IWA water balance components are outlined in this section (see Annex 1: Glossary for other definitions)[3]:

- ***System Input Volume*** is the annual volume input to that part of the water supply system.
- ***Authorised Consumption*** is the annual volume of metered and non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorised to do so (e.g. water used in government offices or fire hydrants). It includes exported water and the leaks and overflows after the point of customer metering.
- ***Non-Revenue Water (NRW)*** is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of Unbilled Authorised Consumption (usually a minor component of the water balance) and Water Losses.

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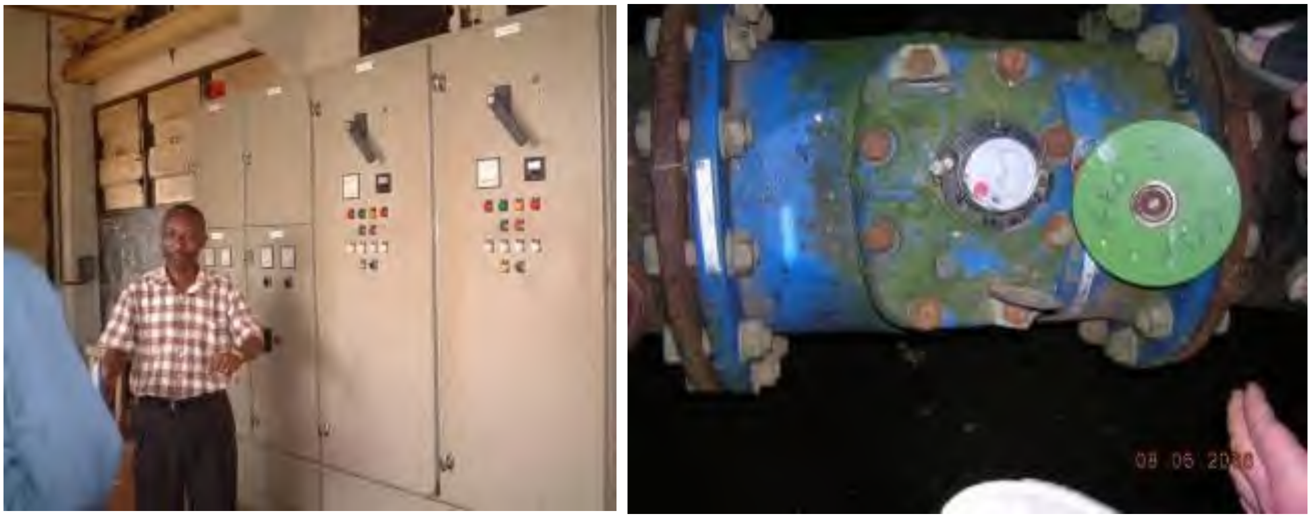
[3] See more detailed descriptions of each component and their measurement in the IWA reference manual by Farley, M. and S. Trow, 2003. *Losses in Water Distribution Networks—A Practitioner‟s Guide to Assessment, Monitoring, and Control.* IWA Publishing: ISBN 1 900222 11 6. http://www.iwapublishing.com/template.cfm?name=isbn1900222116

- ***Water Losses*** is the difference between System Input Volume and Authorised Consumption. It consists of Commercial Losses and Physical Losses
- ***Commercial Losses***, sometimes referred to as ‗apparent losses‘, consist of Unauthorised Consumption and all types of metering inaccuracies
- ***Physical Losses***, sometimes referred to as ‗real losses‘, are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

Sometimes even the most basic information, such as system input volume, average pressure, supply time, length of mains, and the number of service connections, is not initially available. The process of calculating each of the water balance components and performance indicators will reveal such deficiencies. The utility management should then take corrective action to close these data gaps and improve data quality. Using incomplete or inaccurate data for the water balance calculation will not produce useful results—‗garbage in, garbage out‘.



Water utility managers need to accurately measure water produced from the treatment facility. Total water produced is a key input for the water balance.

When the entire system input is metered, determining the annual system input volume is a straightforward task. Utility managers must collect meter records regularly and calculate the annual quantities of the individual system inputs. This includes a utility's own sources as well as imported water from bulk suppliers. Ideally the accuracy of the input meters is verified using portable flow measuring devices.

Billed metered consumption includes all of the water consumption that is measured and charged to domestic, commercial, industrial, or institutional customers. It also includes exported water that is measured and charged. The billed metered consumption period used in the calculation should be consistent with the audit period by processing it for time lags (see Section 2.4.3 on ‗Customer billing cycles‘ below). There is generally a lag of up to 30 days between the time when water is consumed and when the meter is read. In addition, NRW managers should determine the general accuracy of various domestic and non-domestic consumption meters for a possible 95% confidence limit by taking a sample of existing working meters from various locations and testing them on a standard meter test rig. Independent companies provide testing services if the water utility does not own a meter test rig. If several different customer meter brands are in operation, then the sample selection should include meters from each brand.

Determining the annual billed metered consumption goes hand in hand with detecting billing and data handling errors, information that utilities also require for estimating commercial losses. The volume of unbilled metered consumption should be established using a similar approach to that for billed metered consumption.

Unbilled unmetered authorised consumption is any kind of authorised consumption that is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well-run utility, it is a small component that is very often substantially overestimated. Unbilled unmetered authorised consumption, traditionally including water the utility uses for operational purposes, is often seriously overestimated. This is sometimes caused by simplification (e.g. using a percentage of total system input), or by deliberate overestimates to ‗reduce' the amount of NRW.

Note: The water balance is an annual **volume** calculation. Commercial Loss volumes result in a loss of income to the company but they are based on actual volumes distributed to the customer that have not been measured correctly or paid for.

Loss of **income** through poor collection efficiency, debt recovery etc. is a **financial** loss to the company - one that can be addressed through a more efficient bill collection policy. But it is not part of the standard annual water balance.

2.3 KEY STEPS FOR CONDUCTING A WATER BALANCE

The utility manager needs to have certain information about the network to conduct a water balance:

- System input volume
- Billed consumption
- Unbilled consumption
- Unauthorised consumption
- Customer metering inaccuracies and data handling errors
- Network data
- Length of transmission mains, distribution mains and service connections
- Number of registered connections
- Estimated number of illegal connections
- Average pressure
- Historic burst data
- Level of supply service (24-hour, intermittent, etc)

The four basic steps to conduct a water balance are summarised below (see a detailed description in Annex 3: Steps for Calculating NRW Using the IWA Water Balance):

- Step 1. Determine system input volume
- Step 2. Determine authorised consumption
  - Billed—total volume of water billed by the water utility
  - Unbilled—total volume of water provided at no charge
- Step 3. Estimate commercial losses
  - Theft of water and fraud
  - Meter under-registration
  - Data handling errors
- Step 4. Calculate physical losses
  - Leakage on transmission mains
  - Leakage on distribution mains
  - Leakage from reservoirs and overflows
  - Leakage on customer service connections

Confidence limits of 95% should be applied to all water balance data. These define the boundaries within which utility managers can be 95% sure that the true value for that particular component lies. Although the water balance is an important tool for understanding inflows, consumption, and losses, the general lack of data leads to problems. Data gaps make it difficult to quantify commercial losses and to pinpoint the nature and location of physical losses. However, the water balance can be improved using two other methodologies[4]:

- Component analysis of physical losses (see Chapter 6), using the network information required listed in Table 2.1
- Measurement of leakage, using analyses of night flows into District Meter Areas (DMAs) (see Chapter 7)

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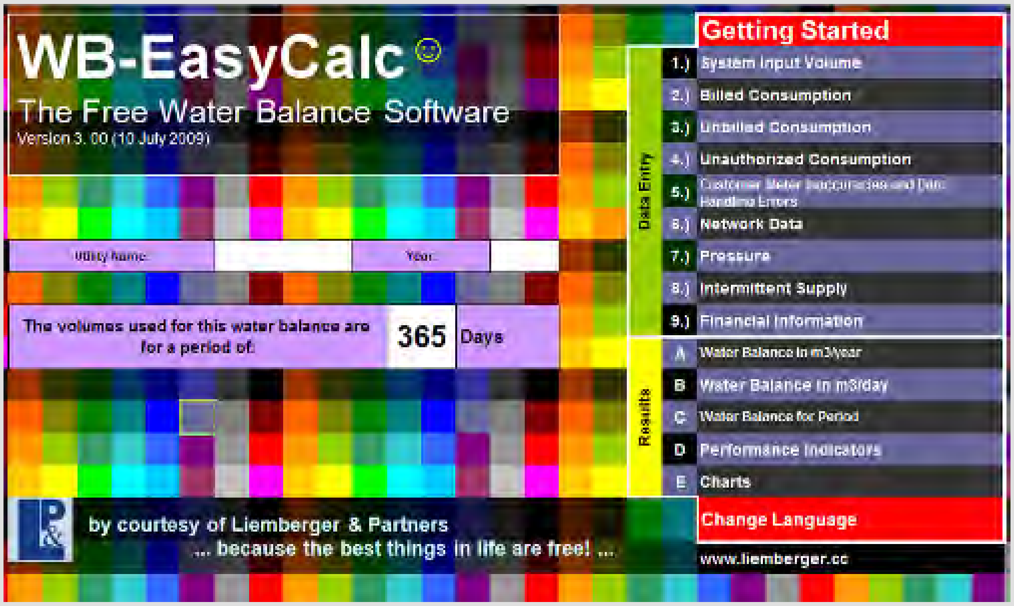
[4] These methodologies are briefly outlined Chapters 6 and 7, and explained in more detail in Losses in Water Distribution Networks.

BOX 2.1: WB-EASYCALC

WB-EasyCalc is one example of a tool to support water balance calculations in addressing NRW. Utility managers can use this spreadsheet-based software, developed by Liemberger and partners and supported by the World Bank Institute (WBI). The picture below shows the homepage of the software for ‚getting started'.



The volumes used for this water balance are for a period of: 365 Days

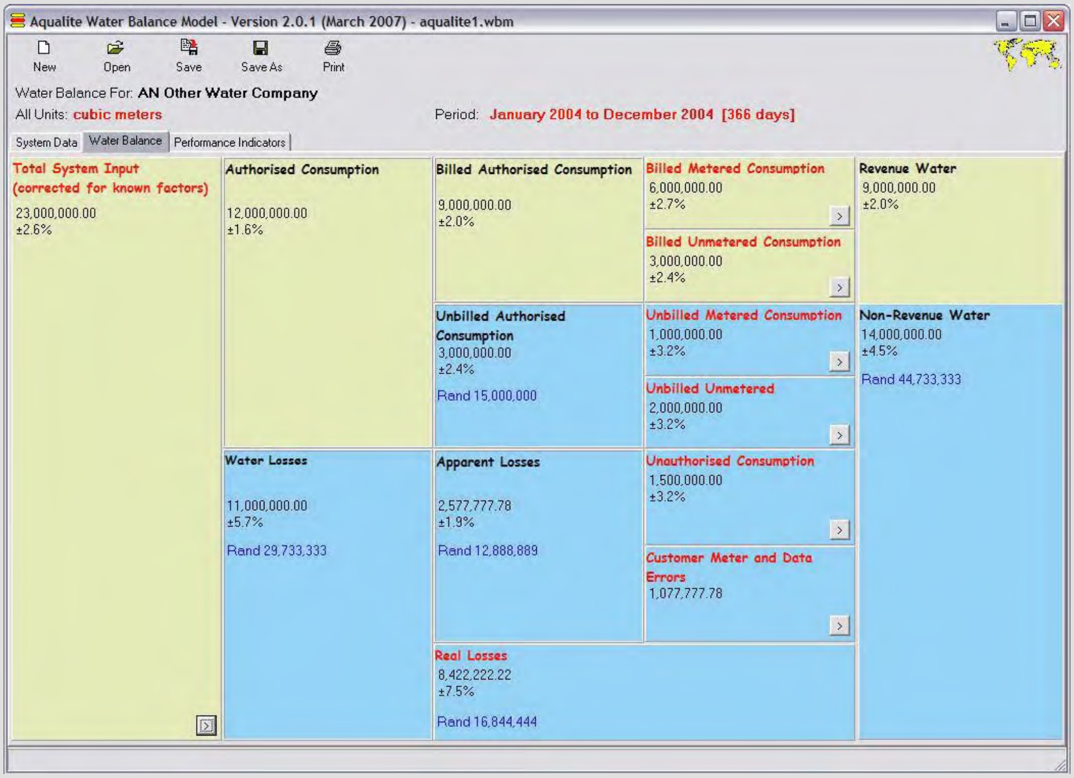
One advantage of EasyCalc is that the software not only asks for physical data, but also for an assessment of the accuracy of those data. For example, when entering the production volume, the user must also estimate the accuracy of these data based on the type and age of production flow meters, if any, and the amount of maintenance carried out on the meter. Using these estimates, the software calculates NRW volume and its various components, in addition to the accuracy of these volumes. For example, EasyCalc may determine that NRW is 21% with an accuracy of +/- 66%— meaning that the actual NRW ranges between 7% and 35%.

WB-EasyCalc is available as a free download at http://www.liemberger.cc/diverse_uploads/WBEasyCalc.xls.

BOX 2.2: AQUALITE

Aqualite is another example of water balance software. It is widely used in South African and other African utilities. The methodologies used in AquaLite also draw strongly on those recommended by IWA, and, like WB-EasyCalc, includes 95% confidence limits. The AquaLite model was developed by Ronnie Mckenzie and can be downloaded from the Water Research Commission (WRC) web site: www.wrc.org.za or obtained from: orders@wrc.org.za or:

Water Research Commission, Private Bag X03, Gezina 0031, South Africa



Water Balance For: **AN Other Water Company**

All Units: cubic meters

Period: January 2004 to December 2004 [366 days]

Total System Input (corrected for known factors)
23,000,000.00
±2.6%

Authorised Consumption
12,000,000.00
±1.6%

Billed Authorised Consumption
9,000,000.00
±2.0%

Billed Metered Consumption
6,000,000.00
±2.7%

Billed Unmetered Consumption
3,000,000.00
±2.4%

Revenue Water
9,000,000.00
±2.0%

Unbilled Authorised Consumption
3,000,000.00
±2.4%
Rand 15,000,000

Unbilled Metered Consumption
1,000,000.00
±3.2%

Unbilled Unmetered
2,000,000.00
±3.2%

Non-Revenue Water
14,000,000.00
±4.5%
Rand 44,733,333

Water Losses
11,000,000.00
±5.7%
Rand 29,733,333

Apparent Losses
2,577,777.78
±1.9%
Rand 12,888,889

Unauthorised Consumption
1,500,000.00
±3.2%

Customer Meter and Data Errors
1,077,777.78

Real Losses
8,422,222.22
±7.5%
Rand 16,844,444

More information on Aqualite can also be obtained from Ronnie Mckenzie, MD, WRP (Pty) Ltd. ronniem@wrp.co.za

2.4 IMPROVING THE ACCURACY OF WATER BALANCE RESULTS

The accuracy of production meters, customer meter reading, and billing are the main factors affecting the NRW volume calculation.

2.4.1 PRODUCTION METER ACCURACY

The accuracy of production flow meters is critical to calculating system NRW. Generally, the number of production flow meters is relatively small, meaning that a greater proportion of the flow is measured by each meter. This means that an error on one of these meters has a great impact on the total production measurement. Different meter types have different accuracies, as shown in Table 2.1.

TABLE 2.1: INDICATIVE EXAMPLES OF METER ACCURACY

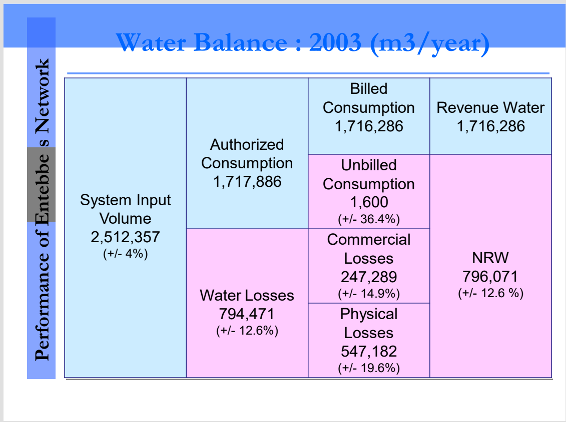
Equipment/Method	Approximate Accuracy Range
Equipment/Method Approximate Accuracy	
Electromagnetic Flow Meters	<0.15 -0.5%
Ultrasonic Flow Meters	0.5 - 1%
Insertion Meters	<2%
Mechanical Meters	1.0 - 2%
Venturi Meter	0.5 - 3%
Weirs in open channels	10 - 50%
Volume calculated with pump curves	10 - 50%

Note: Actual meter accuracy will depend on many factors (like flow profile, calibration, meter installation, maintenance), and has to be verified case by case.

Source: World Bank Institute, 2007.

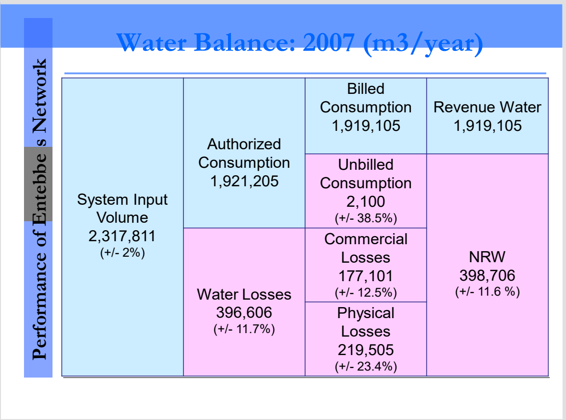
All meter types detailed above must be regularly maintained to ensure their continuing accuracy. Over time these meters can be affected by a number of factors, including water quality, pipe vibration, dirt entering the meter, and electronic malfunction. Utility managers should regularly check the accuracy of both the electronic functionality of the meter, if electronic, and the volumetric accuracy. The electronic functionality can be checked onsite using the meter manufacturer‘s test equipment. The volumetric accuracy can be checked using a second meter, which is generally a portable meter installed just for the test period. Some water utilities opt to install a second meter permanently as a backup in case the first meter fails.

AFRICAN UTILITY EXPERIENCE: USING THE WATER BALANCE TO MEASURE PERFORMANCE OVER TIME



Water Balance : 2003 (m3/year)

System Input Volume 2,512,357 (+/- 4%)	Authorized Consumption 1,717,886	Billed Consumption 1,716,286	Revenue Water 1,716,286
		Unbilled Consumption 1,600 (+/- 36.4%)	NRW 796,071 (+/- 12.6 %)
	Water Losses 794,471 (+/- 12.6%)	Commercial Losses 247,289 (+/- 14.9%)	
		Physical Losses 547,182 (+/- 19.6%)	



Water Balance: 2007 (m3/year)

System Input Volume 2,317,811 (+/- 2%)	Authorized Consumption 1,921,205	Billed Consumption 1,919,105	Revenue Water 1,919,105
		Unbilled Consumption 2,100 (+/- 38.5%)	NRW 398,706 (+/- 11.6 %)
	Water Losses 396,606 (+/- 11.7%)	Commercial Losses 177,101 (+/- 12.5%)	
		Physical Losses 219,505 (+/- 23.4%)	

In Entebbe, one of the 22 towns in Uganda operated by National Water and Sewerage Corporation, the Water Balance was used to demonstrate the improvement in NRW reduction between 2003 and 2007: System Input Volume reduced and Billed Consumption increased—reducing the NRW by almost half.

The illustrations also show the 95% confidence limits around each of the calculated components.

2.4.2 CUSTOMER METER ACCURACY

The accuracy of customer meters is equally important, with the main difference being that there are many more customer meters in operation—and each measures a relatively smaller flow—than production meters. The accuracy of customer metering depends on several factors, including meter type, brand, replacement policy, maintenance, and water quality. The water utility should establish guidelines for all of these factors to ensure accuracy of customer consumption data.

Roof tanks with faulty float valves and aging meters are two sources of meter under-registration.

2.4.3 CUSTOMER BILLING CYCLE

When calculating the NRW value, many water utilities simply subtract customer consumption data from the production meter volume, and then are satisfied with the low result. However, this is often a false measurement of NRW because, unlike with the production meters, which are usually read on the same day of every month, customer meters are read over the full month. Information on the average billing cycle, or the time in days between meter reads, is critical. Utility managers should then factor the total consumption down to get the true consumption volume for the exactly the same time period as the production meter volume measurement.

Addressing the above issues greatly improves the accuracy of the NRW calculation, which utilities will use as the baseline in developing an NRW reduction strategy.

Field verification of the network data is crucial to understanding where water losses originate and setting NRW baseline level.

AFRICAN UTILITY EXPERIENCE: ACCURATE NRW BASELINES

Ouagadougou, capital of Burkina Faso and managed by ONEA, is well performing public utility for the region, with a management emphasis on efficiency. Basic data to construct a water balance is available and accurate:

- Production metering is in place, with electromagnetic meters installed after 2005.
- A customer meter replacement program was completed in 2007.
- Customers are fully metered and there are no individual roof tanks.
- A service contract has resulted in a customer census, a meter workshop, improved collection efficiency and redesign of service connections.
- Commercial losses from illegal connections, meter under-registration, meter tampering and meter reading and data handling errors could be quantified.
- Verification of physical losses was done by carrying out measurements over 24 hours in one large zone.

Key Messages

- NRW is an indicator of water utilities' operating efficiency.
- Ensuring the accuracy of the NRW calculation is essential in understanding the full problem.
- The IWA water balance is an excellent method of breaking down the components of NRW, and tools are available to help utility managers calculate the water balance
- Accurate production and customer metering ensure that the true NRW level is measured
- The average billing cycle must be factored into NRW calculations to ensure that time period used for the consumption volume measurement matches the production meter volume measurement.

3. DEVELOPING A STRATEGY TO REDUCE AND MANAGE NON-REVENUE WATER

The NRW challenge can only be properly understood after NRW and its components are quantified, the appropriate performance indicators calculated, and the lost water volume is translated into its corresponding economic value. Development of the water balance reveals the magnitude of each NRW component. This chapter discusses how to identify the major NRW components and develop a company-wide strategy to reduce targeted components.

3.1 ESTABLISHING THE STRATEGY DEVELOPMENT TEAM

The NRW reduction strategy team ensures that all components of NRW are covered and that the proposed strategy is feasible in terms of physical application and financial requirements. The team should comprise of members from each operational department, including production, distribution, and customer service. It may also include members from the finance, procurement, and human resource departments. Choosing the right members promotes ownership by the utility‘s various departments involved in the strategy‘s implementation, and also ensure consensus by senior management.

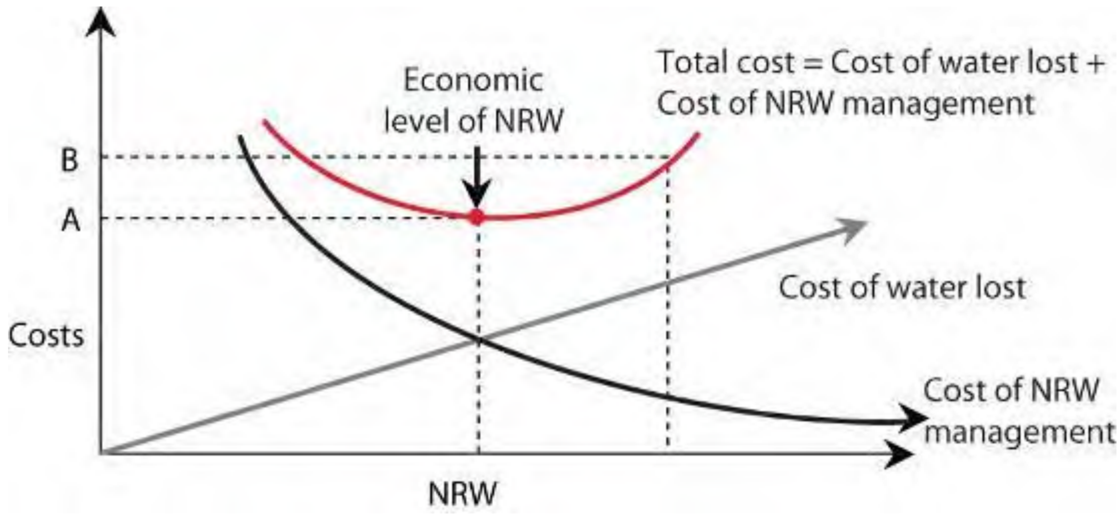
3.2 IMPORTANCE OF SETTING APPROPRIATE NRW REDUCTION TARGETS

The strategy development team should first set a company-wide target for NRW reduction, taking into account the utility‘s other goals or policies that will either complement or conflict with NRW reduction. In addition, water utilities may have an active regulator who will set performance indicators for NRW and other targets. Often, the NRW target is chosen arbitrarily, without any real consideration of cost implications or whether it is achievable. Identifying the economic level of NRW is essential to setting the initial NRW target, and it requires a comparison of the cost of water being lost versus the cost of undertaking NRW reduction activities.

Figure 3.1 highlights how the economic level of NRW is determined. The two components that must be determined are the ***cost of water lost*** and the ***cost of NRW management***:

- The cost of water lost is the value of the water lost through both physical and commercial losses. The volume of physical losses should be multiplied by the variable operational costs, including manpower, chemicals, and electricity. The volume of commercial losses should be multiplied by the average customer tariff. As NRW increases, the cost of water lost increases proportionally.
- The cost of NRW management is the cost of reducing NRW, including staff costs, equipment, transportation, and other factors. As NRW decreases, the cost of NRW management increases.

FIGURE 3.1: IDENTIFYING THE ECONOMIC LEVEL OF NRW



Adding the two cost components together gives the total cost. In Figure 3.1, the intersection of the two component lines coincides with the minimum total cost (cost A), which is the economic level of NRW.

The graph shows that letting NRW increase past the economic level reduces the cost of NRW management, but the total cost (cost B) will rise. Similarly, reducing NRW lower than the economic level of NRW will cost more than the potential savings. However, utility managers may sometimes decide to push NRW below the economic level, for example in areas where raw water is scarce or the image of the country requires low losses. In such cases, the difference between the cost of NRW management and the savings are usually subsidised by the government.

The economic level of NRW constantly changes with shifts in water tariffs, the cost of electricity and chemicals, staff salaries, and equipment supply costs. Managers should assess the economic level of NRW on a yearly basis and adjust the NRW target accordingly to ensure the efficient use of resources.

3.3 PRIORITISING NRW REDUCTION COMPONENTS

Once the utility-wide NRW target is set, utility managers should calculate the proposed volume of water saved by comparing the NRW baseline with the target level. The various components, as detailed in the water balance, are then prioritised according to how the required total reduction can be most cost-effectively achieved. That is, some components may comprise a significant volume, but would not be targeted because of the high cost to achieve reductions in that component. On the other hand, focusing on another component may cost less while reducing the same volume. The water balance table shows the magnitude of NRW components in terms of volume, which utility managers can use to determine the corresponding financial values.

Ensuring customer meter accuracy is just as important as sealing pipe leakages. Fau;ty meters require immediate replacement.

In general, if a physical loss is detected and repaired then the savings will be in terms of a reduction in variable operational costs. When a commercial loss is detected and resolved, then the saving will be an immediate revenue increase and thus is based on the water sales tariff. The water sales tariff is higher than the variable production cost for all profitable water utilities; in some cases, the sales tariff is as high as three or four times the production cost. A smaller volume of commercial loss may have a higher financial value, so if increasing financial resources is the objective, then commercial losses should be prioritised.

AFRICAN UTILITY EXPERIENCE: PROGRAMME TO IMPROVE COMPANY REVENUE

Morogoro Urban Water Supply and Sewerage Authority (MORUWSA), Tanzania, is an independent utility supplying 15000 active customers.

MORUWSA has an impressive record of reducing commercial losses and improving collection efficiency between 1997 (40% efficiency) and 2007 (92% efficiency). How?

- About 80% of the customers are metered.
- Most meters are less than 5 years old but in some cases installation layout is wrong.
- A bonus of TSh 15000 (USD 12) for reporting an illegal connection or bypass.
- An even higher bonus of TSh 100,000 (USD 80) for reporting customer meter theft or vandalizing.
- As a result, Illegal connections are not considered to be a significant problem (100 connections reported in 2006/2007).
- Customer meter bypasses are considered to be the main problem (around 1000 bypasses detected every year).

Where a water utility has a shortage of treated water, and thus some customers receive less than a 24-hour supply or the supply coverage is less than 100%, then a reduction in physical losses would effectively create additional water supply. If increasing water supply is the objective, then prioritising physical losses could enable customers to receive water 24 hours a day, or for new customers to be connected to the supply system.

Table 3.1 shows an analysis of NRW actions according to volume and cost, which provides rational support when deciding how to proceed in NRW planning.

Developing an NRW reduction strategy requires water balance results, appropriate targets, and cost-benefit analyses to determine the return on investments.

TABLE 3.1: VOLUME AND COST ANALYSIS FOR NRW MANAGEMENT ACTIVITIES

		Cost		
		High	**Medium**	**Low**
Volume	**High**	Leakage on mains (P) Leakage on service connections (P)	Unauthorised consumption (C)	Unbilled metered consumption (U)
	Medium	Customer meter replacement (C)	Customer metering inaccuracies and data handling errors (C)	Pressure management (P)
	Low	Reservoir leakage (P)	Unbilled unmetered consumption (U)	Reservoir overflows (P)

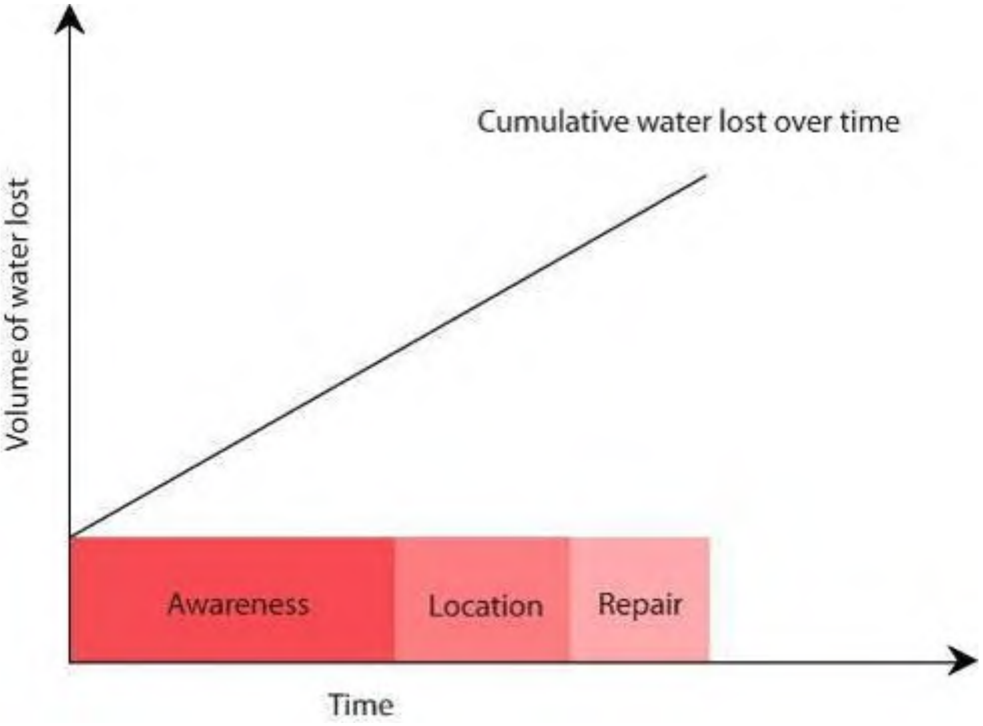
NRW Type: U=Unbilled authorised consumption, C=Commercial losses, P=Physical losses

3.4 BASIC PREMISE OF NRW REDUCTION STRATEGY: AWARENESS, LOCATION, AND REPAIR (ALR)

Once the utility-wide NRW target is set and the different components analysed to prioritise areas for achieving the desired reduction, then individual activities will be identified. The development of the strategy should be based on the concept of Awareness, Location, and Repair, or ALR. This concept states that any loss occurring from leaks, overflows, faulty customer meters, or other sources will have three stages as shown in the diagram below.

- Awareness time—time required for the utility to become aware of the leak.
- Location time—time required to locate the leak.
- Repair time—time required to repair the leak.

FIGURE 3.2: THE EFFECT OF TIME ON THE TOTAL VOLUME LOST



The volume of water lost will continue to increase until the water utility is aware of the problem, locates or pinpoints it, and finally repairs or resolves it. An underground leak could run for several months or even years without anyone being aware that it exists. Therefore, the NRW strategy must ensure that the company reduces its awareness, location, and repair times for all NRW components.

Many losses occur because of poor or limited maintenance, so in addition to reducing ALR, a fourth element of the NRW strategy should be system maintenance. This is critical to maintaining good asset condition and reducing the incidence of new leaks, meter failures, reservoir leaks, and other problems.

Chapters 5, 6, and 7 detail the activities required to shorten the ALR periods. When developing an NRW management strategy, remember that reducing NRW is not a short-term process, especially in aging, large, open, or high pressure systems. The timeframe for implementing each strategy component should be outlined, with some activities possibly spanning years rather than months. NRW strategies spanning between four and seven years are reasonable—any less is ambitious, and any more will not be as cost-effective.

3.5 BUDGET CONSIDERATIONS FOR IMPLEMENTING THE STRATEGY

The development and implementation of activities to achieve the targeted level of NRW incurs a financial cost. With some NRW management strategies lasting years, the overall cost could be quite substantial. A long-term budget that is thoroughly discussed with key stakeholders will ensure that all parties are aware of the costs required and that the strategy is financially viable. Many NRW strategies start off at full speed but often fail due to budget cuts over time.

Managers reviewing the most cost effective and applicable investments to implement water loss reduction activities.

Undertaking pilot projects to demonstrate the effectiveness of the NRW strategy is useful. The pilot should cover a smaller area, be substantial enough to ensure that all components of the NRW strategy are tested, and operate under financial conditions that can be replicated when activities are implemented throughout the entire network. The analysis of the pilot results should be used in the development of the economic level of NRW for the entire system.

The budget should identify the following costs:

- Staffing—Include staff for both direct NRW works (e.g. leakage technicians) and indirect support (e.g. procure
- Equipment—Include equipment installed permanently (e.g. DMA meters) and those used on a day-to-day basis (e.g. leakage detection equipment).
- Vehicles—Include transportation costs, which can become an important issue in maximising the work rate of all staff. Small teams generally cover the entire supply system for undertaking NRW works.
- Works—Include the costs for installing all equipment, such as meters and pressure reducing valves, and also detecting and repair all leaks.

Key Messages

- The NRW reduction strategy team ensures that all components of NRW are covered and that the proposed strategy is feasible in terms of physical application and financial requirements. Choosing the right members promotes ownership by the various utility departments involved in the strategy's implementation, and also ensure consensus by senior management.
- Identifying the economic level of NRW should be the basis for setting the initial utility-wide target for NRW reduction.
- Using the water balance to prioritise components for NRW reduction helps balance the financial and water supply objectives of the NRW strategy.
- The NRW reduction strategy should aim to reduce the awareness, location, and repair (ALR) times in addressing water losses.
- NRW reduction is a long-term process and the strategy may cover a period of 4-7 years. Pilot projects can help water managers understand the full budget required to implement the entire strategy.

A TOOL FOR SETTING NRW TARGETS FOR AFRICAN UTILITIES

A team comprising RTI International (USA)* and colleagues from African utilities are in the process of developing a new analytical tool for NRW target setting, developed specifically for conditions in Africa. The model utilizes many of the concepts presented in this manual, and tools developed by various International Water Association (IWA) NRW Task Force Members. But the new model incorporates additional elements not covered in the Economic Level of Leakage (ELL) approach illustrated in Figure 3.1. These include:

- Commercial losses.
- The annualized cost of water supply capacity expansion.
- Situations where production capacity does not meet demand.

In its current form, the model computes optimal NRW for a given utility, from a modest, commonly known, set of site specific data, and uses default values where specific in-country data are not readily available. Some clear multi-country trends emerge, which provide a simple method to find preliminary estimates of optimal NRW. Therefore, the current model allows individual, regional, or national utility managers and regulators to establish reasonably accurate NRW targets and to optimally allocate resources to NRW management.

More detailed studies and applications are underway in Zambia and Uganda. More studies are planned in collaboration with utilities in Tanzania, Ghana, South Africa and other non-African countries. These efforts should likely yield country specific models and handbooks for general use, and will allow refinement of the general model.

The model provides the optimal levels of NRW, commercial losses and physical losses all in litres / connection / day. It also gives guidelines on optimal meter replacement programs, the optimal period for Active Leakage Control surveys and computes the Economic Infrastructure Leakage Index (see Section 8—Monitoring Performance).

*Wyatt, Alan S., & Romeo, Kyle J. *Application of a Financial Model for Determining Optimal Management of Non-Revenue Water in Developing Countries*. Proceedings of the 3rd ACWUA Best Practice Conference—Non Revenue Water Management in the Arab Region; Rabat, Morocco, January 20-21, 2010. Available from www.iea.ma.

4. RAISING AWARENESS ON THE STRATEGY

Effectively addressing NRW requires a combined effort from management and staff throughout the utility. However, the number of staff with a good knowledge of NRW is usually limited to engineers or others working at an operational level. Everyone, from the Chief Executive Officer to the meter readers and crew, should understand the importance of NRW and how it affects their daily work and the utility. More specifically, the following groups should understand NRW and their role in reducing water losses:

- Top decision-makers, including the Board of Directors, mayors, or political leaders.
- All levels of the utility‘s management and staff.
- The general public, or consumers.

The public‘s perception of NRW is shaped by information presented through the media, which often does not include full explanations of the complex issues involved. During the initial implementation period of the NRW reduction strategy, the public will be greatly affected when water supply is stopped to install meters, repair leaks, or undertake other work. The utility must ensure that the public is aware of the strategy and understands that service interruptions will result in long-term benefits for all.

This chapter describes the roles and responsibilities of each type of stakeholder in implementing the NRW reduction strategy. Outreach programs will help build awareness and consensus regarding the importance of reduction activities and the benefits of reducing NRW.

4.1 GAINING HIGH-LEVEL APPROVAL

Top decision-makers, such as the Board of Directors, the mayor, or other political leaders, are responsible for reviewing and approving the strategy. A general presentation and discussion on NRW will help ensure that they understand the value of minimising NRW. The decision-makers should be informed of the present NRW level, the benefits of reducing NRW, operational activities required to achieve reductions, and the budget required to carry out activities. Lack of approval at the highest levels or inadequate funding support has led to the failure of many NRW strategies.

Securing approval for the NRW reduction strategy from top decision-makers underscores its importance among staff. At the same time, the senior management will be accountable to the decision-makers for achieving results, and will report back on improvements to the strategy and any additional budget requirements.

Awareness can be raised in schools education programmes and at community meetings.

4.2 BUILDING STAFF AWARENESS AND CONSENSUS

The utility‘s staff need to understand NRW and how the NRW reduction programme will improve the organisation. In certain cases, savings from the NRW reduction programme may be shared with the staff through bonuses or other incentives.

All staff, from senior management to the crew, should understand the NRW reduction strategy and their role in achieving the NRW target. Middle managers should participate in briefing sessions to raise their NRW awareness and to provide input to strengthen the strategies. Managers should then brief their operational staff on upcoming activities and changes in policies and practices. Some examples of how individuals in various departments are involved in the strategy‘s implementation are as follows:

AFRICAN UTILITY EXPERIENCE: ENTEBBE’S NRW STRATEGY AND ACTION PLAN

Entebbe has been making reforms and developing a NRW strategy on several fronts since 1999.

Management and Leadership

- Setting priorities.
- Restoring customer confidence in NWSC operations and mobilising public support.
- Giving managers autonomy to take operational decisions.
- Increasing Operations performance accountability and commitment by apportioning operating risk through performance-based pay mechanism.
- Worker involvement to enhance transparency and strategy ownership.

Institutional Strengthening

- Implementing a series of PIP with focus on reducing NRW.
- Introducing incentive based management contracts—with NRW as a parent indicator.
- Regular monitoring & evaluation of performance—checking system.
- Encouraging internal competition between regional utilities.

5 year Action Plan

- Using a participatory approach - with clear time bound objectives & strategies—*(eg reduce NRW from 32% to15% by 2008).*
- Establishing a GIS and carrying out a comprehensive documentation and mapping of the whole network area.
- Sharing experience and information with sister utilities on the challenges and initiatives of NRW reduction.

Pilot Studies

- Setting up three DMAs—with demarcated customer accounts.
- Appointing ‗zonal leaders‘ accountable for zone performance and regular zone performance monitoring.
- Aligning the billing system with the zones for consistent monitoring.

Initiatives to Reduce Physical Losses

- Establishing a 24 hr (standby) leak management unit—*equipped with newly acquired leak detection equipment.*
- In house and external training of staff on effective leak detection, repair & monitoring.
- Establishing a routine programme for finding & locating non-visible leaks—*mainly done at night.*
- Sensitizing and encouraging the public to vigorously report water leaks and bursts—*with a reward for each case reported*
- Repairing identified leaks in < 6hours.
- Computerising the leak reporting register for easy tracking and monitoring.
- Introducing pressure management by installing pressure reducing valves *(14 PRVs installed in high pressure areas.*
- Routine inspection & servicing of valves & fire hydrants.
- Monitoring leak ‗clusters‘ to help planning for mains replacement.
- Developing a medium term investment plan—rehabilitating worn-out segments of the distribution network.

Initiatives to Reduce Commercial Losses

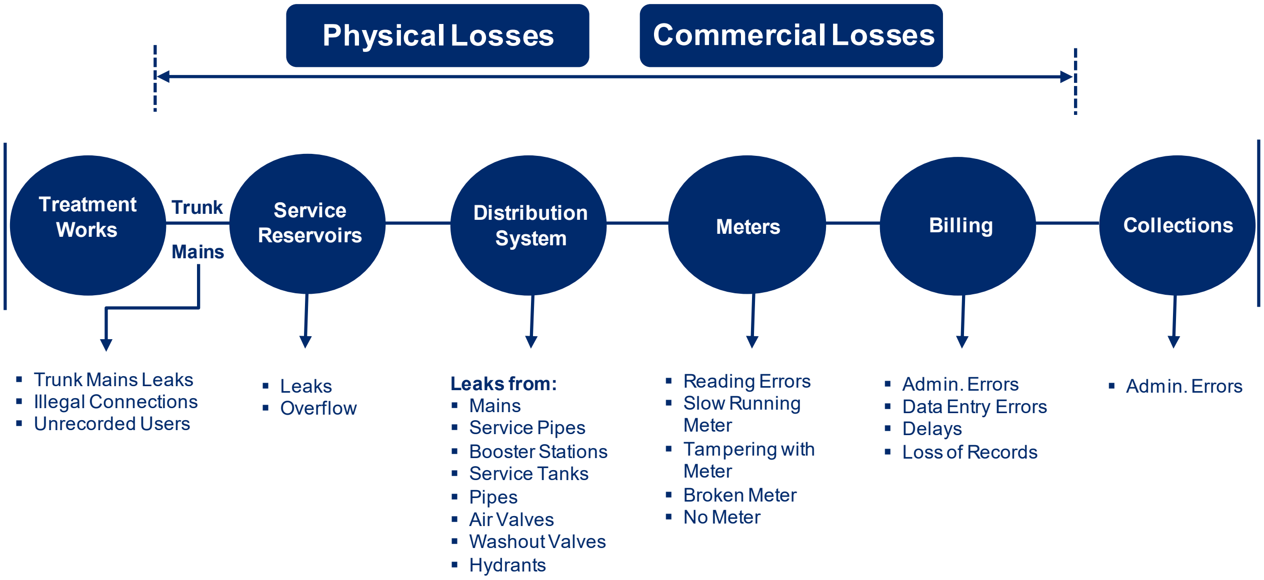
- Carrying out investigations to detect and disconnect illegal connections (declared Monday an ‗illegal connection day‘, investigating cases of suspected illegal connections).
- Working closely with local communities to identify illegal cases.
- Offering incentives/rewards to informers of illegal users and establishing fines/ penalties for illegal connections ($305 + value of 2 years estimated consumption.
- Establishing amnesty programmes to attract back illegal consumers.
- Regular spot checks on large customers and construction sites.
- Spot checks and auditing of meter readings and rotation of meter readers *(every 6 months).*
- Identifying and replacing old and worn out consumer meters with new ones (an ongoing exercise based on the meter age database).
- Universal metering of customer accounts *(all accounts are metered and over 70% of the meters are less 6 years old).*
- Prompt updating of customer database.
- Effective disconnection for non-payment .
- Right sizing of meters - based on the flow—for effective recording, particularly large consumer meters.
- New Connection Policy—NWSC procures and installs all water pipes and fittings and also maintains the service line—ensuring standardization and quality control of pipes & fittings.

It is important to mend reported leaks as quickly as possible.

- Meter readers must provide accurate readings as this will immediately affect the NRW calculation.
- Purchasing officers must complete equipment orders as quickly as possible, since delays in the purchasing process will then hinder these necessary installations and upgrades in the system. As a result, district meter areas (DMAs), which can play a key role in reducing NRW, will not be established in a timely manner.
- Financial officers must not delay payments to suppliers, as this may disrupt future equipment or meter supplies.
- Crew must repair burst pipes as quickly as possible so that water losses and water supply disruptions are minimal. Fast repairs increase the utility‘s efficiency and promote customers‘ willingness to pay their water bill.

FIGURE 4.1: CHART TO HELP STAFF UNDERSTAND NRW COMPONENTS

Typical Losses From A Water Supply System



In certain cases, contractors rather than utility staff will undertake repair works. These contractors should also understand NRW and any new repair standards or practices that are implemented.

Water utility senior managers participating in NRW awareness sessions to understand the causes of water loss.

MALAYSIAN UTILITY EXPERIENCE: NRW AWARENESS PROGRAMME

The NRW management team of Ranhill Water Services, a Malaysian water utility, organised an NRW Strategy Road Show in eight operational districts, with two additional sessions at the headquarters, to ensure that all 1,700 staff members could attend the NRW awareness sessions. After the awareness programme was completed, the Corporate Communication Department conducted a survey to assess staff members‘ understanding of NRW. The results showed that after the Road Show, staff awareness of NRW increased significantly. The Road Show produced other benefits: staff members were more motivated to do their work; planning became more effective; and inter-department communication and communication between managers and crews improved.

4.3 REACHING OUT TO CUSTOMERS

One of the goals of reducing NRW is also to provide better and more efficient services to the public. To accomplish this, the public must also understand how they can help manage NRW by reporting burst pipes, faulty valves, leaks, or other problems that limited utility crews may not detect. The earlier the utility becomes aware of a burst pipe or leak, the faster it will be repaired, thus reducing the losses (see Figure 3.2 in section 3.4 on the relationship between awareness, location, and repair times and water losses).

Engaging customers helps water utilities target water loss sources, such as house connection leakages, water theft, and meter tampering.

Awareness programmes should be organised with a variety of stakeholders from the public, including politicians, community leaders, and household and industrial consumers. Programmes generally focus on basic NRW concepts and how reducing NRW helps ensure that communities receive better water supply and services.

AFRICAN UTILITY EXPERIENCE: COMMUNITY AND EDUCATION AWARENESS CAMPAIGNS

The South African Department of Water Affairs and Forestry (DWAF) is committed to the introduction and enforcement of water conservation and water demand management. The Sebakong/Evaton project was a one-year DWAF initiative, in which several hundred local residents were interviewed to select 50 _Community Liaison Officers‘. These were required to visit every household in the 50 wards that make up the Sebakong/Evaton area, supplying water to 500,000 residents. Numerous posters and pamphlets were designed in several languages. These were distributed throughout the supply area, including all schools, to create an awareness of the value of water, and how it should be used in an efficient and sustainable manner.

After awareness programmes are conducted in each community, all staff should work to ensure that customer confidence in the utility‘s services is maintained. A key element in this is open communication. For example, the public should be able to easily contact the utility to report burst pipes, leakages, or other concerns. The utility should establish a system to receive information or complaints from customers, and then to disseminate it to the relevant operational units so action is taken quickly.

Customers aware of poor service caused by water losses will report defective connections.

Readily visible, easy to remember and free telephone numbers encourage the public to call.

Call centres receive information from the public.

AFRICAN UTILITY EXPERIENCE: CUSTOMER CALL CENTRE

Operating a 24/7 customer call centre with dedicated toll-free lines for customers to report leaks encourages the public to provide information on any problems with the water supply.

In Ouagadougou, Burkina Faso, members of the public are encouraged by the water utility, ONEA, to report visible leaks using a readily visible, easy to remember and free number.

ONEA has 5 permanent repair crews, on shift at the same time as the call centre staff and available to react to leaks quickly.

In 2005, in direct response to call centre leads, the teams repaired 1,090 mains leaks and 3,496 house connections —all repaired within 4 hours from the time of receiving a call.

Key Messages

- Awareness at all levels, from top decision-makers to the end consumer, is important.
- Building the understanding of top-level management on NRW and the budget required to reduce it supports the financial sustainability of the strategy.
- Middle management and staff must understand their roles and responsibilities in reducing NRW, since it requires a long-term, combined effort from all departments in the utility.
- Reaching out to customers helps to increase their awareness of NRW and how reducing water losses will result in improved water supply and quality.

5. UNDERSTANDING COMMERCIAL LOSSES

5.1 DEFINITION OF COMMERCIAL LOSSES

Commercial losses, sometimes called ‗apparent losses‘, include water that is consumed but not paid for by the user. In most cases, water has gone through the meters but is not recorded accurately. In contrast to leaks or reservoir overflows, the lost water is not visible, which leads many water utilities to overlook commercial losses and concentrate instead on physical losses.

Commercial losses can amount to a higher volume of water than physical losses and often have a greater value, since reducing commercial losses increases revenue, whereas physical losses reduce production costs. For any profitable utility, the water tariff will be higher than the variable production cost—sometimes up to four times higher. Thus, even a small volume of commercial loss will have a large financial impact.

An additional benefit in reducing commercial losses is that it can be accomplished quickly and effectively. This chapter reviews the four main elements of commercial losses and presents options to address them.

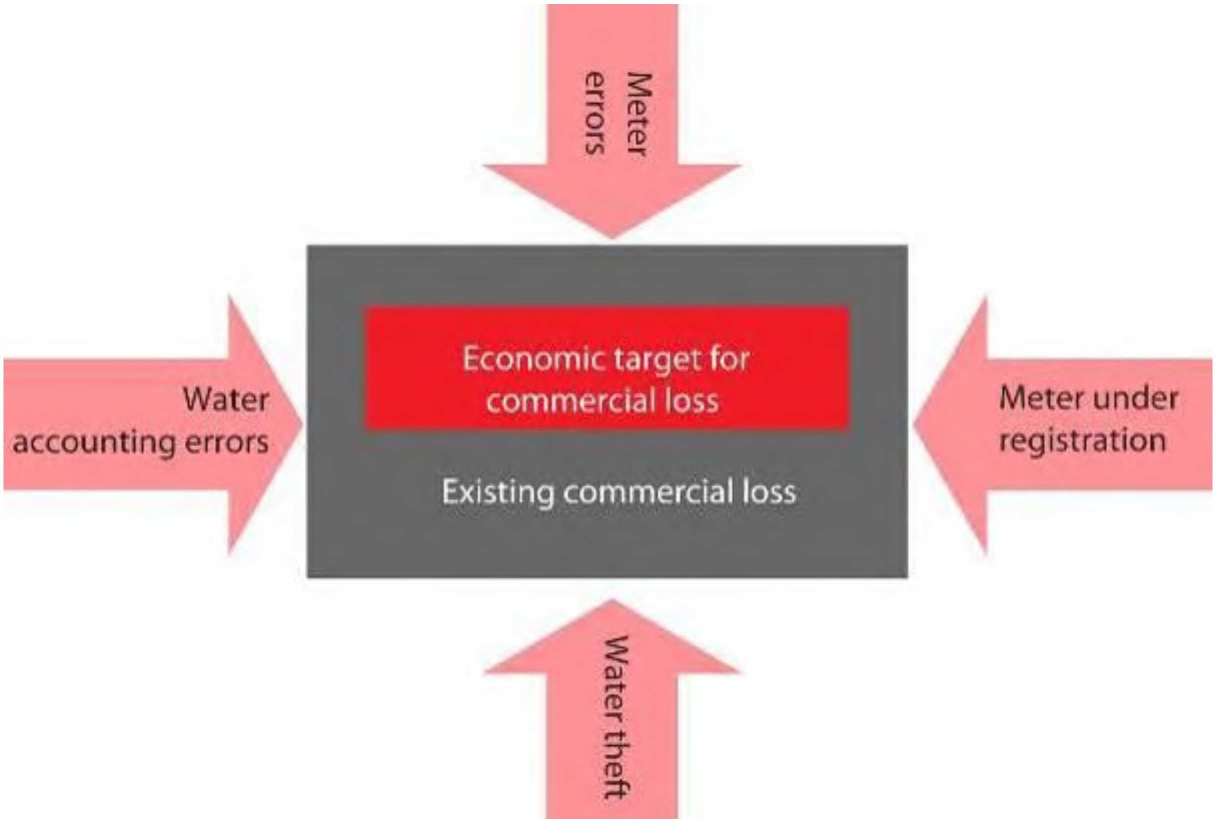
5.2 COMMERCIAL LOSS ELEMENTS AND MANAGEMENT STRATEGIES

Commercial losses can be broken down into four fundamental elements, which are:

- Customer meter inaccuracy.
- Unauthorised consumption.
- Meter reading errors.
- Data handling and accounting errors.

Examples of an illegal bypass around a meter—another form of theft and one of the causes of commercial losses.

FIGURE 5.1: FOUR PILLARS OF COMMERCIAL LOSSES



Water utilities should aim for commercial losses that are no more than 4-6% of authorised consumption. Reducing commercial losses requires a low level of investment with a short payback period, but it needs sustained management commitment, political will, and community support. Utilities should focus on commercial losses in the beginning of an NRW reduction programme since the activities can be undertaken in-house with little effort and the payback is immediate.

Improper meter installation leads to inaccurate data and billing errors. Meter readers in the pictured situation will find it difficult to determine which meter belongs to which property.

5.2.1 HOW TO ADDRESS CUSTOMER METER INACCURACY

Inaccurate meters tend to under-register water consumption—leading to reduced sales and therefore reduced revenue. Only very rarely do meters over-register consumption. Utilities should focus initially on large customers, such as industrial or commercial users, since they consume a larger volume of water and often pay a higher tariff. Using data from accurate meters to bill customers, rather than charging them based on an assumed per capita basis, ensures that customers are charged according to their actual consumption and encourages them to preserve water. The paragraphs below discuss common problems with customer meter accuracies and solutions for utilities.

Installing Meters Properly

Meters should be installed properly according to the manufacturer‘s specifications. For example, some meters require a specific straight length of pipe upstream and downstream of the meter. Therefore a standard meter stand should be designed and constructed onsite. Utilities should purchase the meters on the customers‘ behalf, so that only standard, high quality meters are used. Meters should also be installed where meter readers can easily read them, and where it is easy to identify each property‘s meter. In addition, the management and staff responsible for meter installations should be trained on proper handling of meters.

AFRICAN UTILITY EXPERIENCE: CUSTOMER METERING PROGRAMMES

In **Ouagadougou** customers are fully metered, and, although there are no individual roof tanks customer meter accuracy was seen as a weakness. A service contract was initiated in 2001, resulting in:

- A customer census to establish correct billing records and improved collection efficiency
- A meter workshop to support a regular customer meter sampling and testing program
- A meter replacement program and total customer meter replacement
- Redesign of service connections
- Installation of a modern IT customer management and billing system
- Improved control of metering and corruption at community fountains

In **Entebbe** the utility‘s metering programme included:

- Regular spot checks on large customers and at construction sites
- Spot checks and auditing of meter readings
- Rotation of meter readers (every 6 months)
- Identification and replacement of old and worn out consumer meters with new ones (an-ongoing exercise based on a newly developed meter/age database)
- Universal metering of customer accounts (all accounts are now metered and over 70% of the meters are less 6 yrs old)

Monitoring Water Quality

Poor water quality—resulting from poor raw water, inadequate treatment processes, or dirt infiltration due to pipe shutdowns—may cause sediments to form in the pipes. These sediments can also build up on the internal parts of meters, especially mechanical meters. The build-up in sediment affects the meter‘s accuracy by increasing friction losses, which causes the meter to run more slowly and thus under-register consumption. Utilities must regularly monitor water quality and clean mechanical meters to minimise sediment levels and promote accurate meter measurements.

Sedimentation is a major cause of meter reading inaccuracies.

Monitoring Intermittent Water Supply

Where water supply is intermittent, i.e. the customer receives water only a few hours a day, customer meters will register a certain volume of air when the water supply is first turned on. In addition, the sudden large increase in pressure can damage the meter‘s components. Electronic (fluidic oscillation) and ultrasonic meters are unaffected by air entrainment but are more expensive.

Intermittent supply should be avoided for a number of reasons, including the negative impact on customer meter accuracy. A phased NRW reduction strategy (zone by zone) does help to eliminate intermittent supplies - and the water balance will take account of intermittent supply in the calculation. See Chapter 7 for information on utilising District Meter Areas to implement a 24-hour supply system.

Sizing Meters Properly

Customer meters work within a defined flow range, with the maximum and minimum flows specified by each manufacturer. Large meters will not register low flows when the flow rate is lower than the specified minimum. Therefore, utilities should conduct customer surveys to understand the nature of each customer‘s water demand and their likely consumption. This information helps to determine the proper meter size for households and businesses. For customers with a high demand, checking the flow pattern and the newly installed meter verifies whether the correct meter size is used.

Problems with low flows can occur when a storage tank, with the water flow controlled by a ball or float valve, is installed on the customer‘s premises. These valves operate by slowly closing as the water level in the tank rises, which has the effect of reducing the flow through the meter, often below the minimum flow specification. This problem is compounded even further if the size of the storage tank is large in comparison to the customer‘s consumption because the ball or float valve will never fully open and the flow through the meter will be continually low.

Using the Appropriate Class and Type of Meter

Choosing the appropriate meter helps to ensure the accuracy of customer consumption data. Class B meters are a good choice where water quality is low, as the sediments will not greatly affect the meter. Class D meters are more preferable where roof tanks are used and water quality is good, since they have a lower minimum flow specification and will measure the roof tank inflow more accurately. Class C meters are a suitable compromise in most situations, since they can measure low flows better than Class B meters and are not as expensive as Class D meters.

Common types of meters include positive displacement (PD), multi-jet, single-jet, turbine, and electromagnetic. The most common type of meter for domestic and small commercial installations is the 15 mm and 20 mm PD meter. Single-jet and multi-jet meters are more accurate for small commercial and

AFRICAN UTILITY EXPERIENCE: LARGE CUSTOMER METER REPLACEMENT

The City of Tshwane Metropolitan Municipality, South Africa, carried out an audit of large water users and found examples of unmetered connections at fuel terminals, by-passed fire hydrant meters and un-registered connections. Out of 698 connections audited there were 67 unmetered connections and 156 meters that required replacing. Metering the unmetered connections and replacing malfunctioning meters resulted in extra sales of 17300 m3/month, an increased revenue of USD 206,400/year. The payback on cost of the audit was 17 months.

industrial installations that require 20 mm to 50 mm sizes. Electromagnetic meters are the best choice for sizes 100 mm and above.

Maintaining and Replacing Meters Properly

All meters should be installed above ground and located where they can be audited easily, including by the meter readers during their regular rounds. The utility should replace the meters systematically, beginning with the oldest meters and those in the worst condition. Poor maintenance will not only encourage inaccuracy but may shorten the life span of the meter. A scheduled maintenance and replacement programme should be in place to manage this problem.

Examining meters regularly enables utilities to detect the need for calibration or replacement, and builds trust with customers.

Meter servicing is essential, especially in areas of poor water quality. The accuracy of mechanical meters changes over time as the mechanical bearings wear down, causing friction to increase and thus the meters to under-register. These changes will occur over a number of years, depending on the quality of manufacture. The water utility should regularly test a sample of its customer meters, including a range of meter brands and ages, using a calibrated meter test bench or an *in situ* testing method—comparing volume flow over time against with accurate ‗master meter‘. This testing will determine the optimum age at which customer meters should be replaced.

Checking accuracy of a large customer meter.

One of the proprietary in situ large customer meter testers.

In situ small meter testing with meters in series.

Customer Meter Servicing

It is usually cost-effective to service customer meters 50 mm and above on a 6-month to 1-year frequency, depending on the water quality in the area. In addition, analyses of smaller domestic meters within a District Meter Area (DMA) will reveal if the water quality is affecting the meter accuracy. If so, then the utility should carry out meter servicing for all domestic meters in the DMA.

Addressing Meter Tampering

Although water tariffs in Africa are relatively low, people still sometimes tamper with their meters to lower the measured volume. Customers may insert pins or other objects into the meter to disturb its moving parts. Some try to affect the readings of metal meters by attaching a strong magnet to it. In other cases, customers have boiled plastic meters trying to melt the internal plastic parts.

Most reputable meter manufacturers now produce meters that are very tamper-resistant, with non-metallic parts, strong clear plastic windows, and impenetrable casings. Although these meters may cost a bit more, reduced tampering helps to reduce commercial water losses. For properties with older meters that are not as tamper-resistant, utility managers should conduct customer surveys to assess expected water usage according to the number of household occupants or the nature of businesses in commercial areas. A comparison of expected and actual water use will highlight cases of likely meter tampering.

The customer has tampered with the meter"s moving parts.

5.2.2 UNAUTHORISED CONSUMPTION

Unauthorised consumption includes illegal connections, meter bypassing, illegal use of hydrants, and poor billing collection systems. The following paragraphs describe common problems and possible solutions.

Finding and Reducing Illegal Connections

Illegal connections involve the physical installation of a connection to water distribution pipelines without the knowledge and approval of the water utility. Illegal connections can occur during the installation of a new supply connection, or sometimes the customer‘s supply is cut off after non-payment and the customer cannot afford, or does not want to pay, to be reconnected.

During customer awareness programmes, customers should be encouraged to report illegal connections, and regulations should be in place to penalise the water thieves. Meter readers should also report cases of direct connections without accompanying meters that they see during their rounds.

Water theft can occur from large pipes as well as from household water connections.

Preventing Illegal Connections

Lockable valves help limit illegal connections. The water utility should have the only keys available for the valves. After a customer‘s water supply has been disconnected for non-payment, and reconnection has not been requested within one week, the utility should visit the property to check whether the customer has made an illegal connection.

Tackling Meter Bypassing

Some customers try to reduce their water bills by using a meter bypass, which is an additional pipe installed around the meter. This bypass pipe is often buried and very difficult to detect. This type of unauthorized consumption is usually committed by industrial and commercial premises, where only a small volume of the consumption goes through the meter and the rest through the bypass pipe.

Because large customers tend to steal large volumes of water, the discrepancy will show up when the utility conducts a flow balance analysis. The utility should then undertake customer surveys and leakage step tests to determine where the missing flow occurs.

A sound customer billing consumption management system reduces NRW that is caused by billing and data handling errors.

Preventing Illegal Use of Fire Hydrants

The only legal use of fire hydrants is for fire fighting. However, people can use them illegally to fill tankers (normally at night) or as water supply connections to construction sites. These flows, which are often high flows over a short period of time, can be detected through flow measurements at DMA meters. These high flows are not only incidences of theft of water, but also a detriment to the pipe network and water quality, which affects the service to the customer.

Customer awareness programs should encourage customers to report cases of illegal uses of fire hydrants. Utilities should cooperate with the relevant departments, such as the Road and Transport Department, to identify owners of tankers that steal water, and develop regulations to penalise the water thieves once they are caught.

Actively Checking the Customer Billing System

Sometimes connections are made legally, but the billing department is not notified of the new connection; therefore the customer is never billed. These unregistered customers can be detected during the regular meter reading cycle when diligent meter readers find meters that are not in their reading book. However, this process may not identify all of the errors in the billing system. Conducting a complete customer survey within each DMA, whereby utility representatives visit every property in the DMA—whether or not they are recorded in the billing system—is the best method of comprehensively identifying billing system errors. The survey should include the following information: property address, name of owner, and meter make and number. The representative should also conduct a meter test to ensure that the accurate flow is recorded. A sample of a typical customer survey form can be found in Annex 4.

For metered areas, utilities should focus on large users by encouraging good customer relationships through frequent visits. Checking large customers‘ accounts monthly will help detect anomalies, which may be due to water theft. In areas of suspected high commercial losses, temporary DMAs can be established to analyse flows through standard monitoring activities, such as step testing and flow balancing, to pinpoint problematic areas.

AFRICAN UTILITY EXPERIENCE: METER READING PRACTICES

Entebbe water utility carries out spot checks and audits of meter readings, and rotates meter readers every 6 months.

Avoiding Corrupt Meter Readers

Corrupt meter readers can create a large impact on the monthly billed consumption. The same meter reader who walks the same route for an extended period of time may become familiar with the customers and their monthly billed consumption. Corrupt meter readers will record lower meter readings in exchange for a monetary incentive. To reduce this risk, each meter reader should be assigned to a different meter reading route on a regular basis.

5.2.3 METER READING ERRORS

Errors can be easily introduced through negligence, aging meters, or even corruption during the process of reading the meters and billing customers. Incompetent or inexperienced meter readers may read the meter incorrectly or make simple errors, such as placing a decimal in the wrong place. Dirty dials, faulty meters, and jammed meters can also contribute to meter reading errors. The meter readers should immediately report any observed problems, and the maintenance team should take action to remedy the problem immediately. If remedial action is too slow, meter readers may become demoralised and less inclined to report problems.

These errors are addressed by implementing new systems for meter reading and billing. For example, effective supervision of meter readers, rotating routes, and spot checks will reduce these problems. Meter readers are the frontline of the utility in liaising with customers and their activities have an immediate impact on cash flow. Utilities should therefore invest in capacity building to train and motivate their meter readers.

5.2.4 DATA HANDLING AND ACCOUNTING ERRORS

The typical method of data handling and billing requires a meter reader to visit each property and read the customer meter. The data is then recorded by hand on a form, taken back to the office, given to the billing department, and typed into the billing system. A bill is then printed and mailed to the customer. In this scenario, a variety of errors may occur at the different stages: the meter reader writes down incorrect data; the billing department transfers incorrect data into the billing system; or the bill is sent to the wrong address.

Awareness programmes educate customers on NRW and encourage them to report water thefts.

Spot billing minimizes data handling errors.

A robust billing database is one of the key elements of minimising these errors and should be the initial purchase of any water utility striving to improve its revenues. The latest billing software has built-in analysis functions that can identify potential data handling errors and report them for verification. In addition, billing software will report monthly estimate readings and zero reads, both of which may indicate a problem with the customer‘s meter. Site visits will help identify meters needing replacement.

Training of meter readers promotes diligence, good customer meter maintenance, and decreased meter reading errors. If financially viable, utilities should consider electronic meter-reading devices, which reduce data handling errors to a minimum since all data transfers to the billing system are done electronically.

Key Messages

- For any profitable utility, the water tariff will be higher than the variable production cost—sometimes up to four times higher. Thus, even a small volume of commercial loss will have a large financial impact.
- Commercial losses occur mostly through faulty or tampered meters and through errors committed during meter reading or processing in the billing system.

- Meters are essential tools for measuring water consumption and should be as accurate as possible.
- Coordination from the public and relevant local authorities is required to overcome illegal uses of water.
- Training meter readers, staff, and crews is a continuous process to ensure competent customer service.
- Investing in high quality meters and a robust billing system can result in higher returns.

6. IDENTIFYING PHYSICAL LOSSES

6.1 DEFINITION OF PHYSICAL LOSSES

Water losses occur in all distribution networks, even new ones. Physical losses, sometimes called ‗real losses‘ or ‗leakage‘, includes the total volume of water losses minus commercial losses. However, the water balance process, as described in Section 2.3, indicates that commercial losses are estimated and therefore the resulting leakage volume may be incorrect. Utility managers must therefore verify the results using component analysis (the top-down approach) or physical loss assessment (the bottom-up approach, see Chapter 7 on aggregating night flows in DMAs).

The three main components of physical losses include:

- Leakage from transmission and distribution mains
- Leakage and overflows from the utility‘s reservoirs and storage tanks
- Leakage on service connections up to the customer‘s meter

The first and second types of leakage are usually quite visible to either the public or utility staff, so they are easy to detect and are repaired relatively quickly. The third type is more difficult to detect and can therefore lead to a greater volume of physical losses. This chapter describes these three types of losses and solutions for reducing them.

Catastrophic‟ mains bursts can cause serious damage

6.2 PHYSICAL LOSS ELEMENTS

6.2.1 LEAKAGE FROM TRANSMISSION AND DISTRIBUTION MAINS

Leakages occurring from transmission and distribution mains are usually large events, sometimes catastrophic, causing damage to highway infrastructure and vehicles. The majority of such bursts are usually not very severe although they cause supply disruptions. Because of their size and visibility, the bursts are reported quickly, and are then repaired or shut off soon afterwards.

By using data from repair records, utility managers can calculate the number of leaks on mains repaired during the reporting period (usually 12 months) and estimate an average flow rate of the leaks. This gives the total annual volume of leakage from mains as follows:

Total annual volume of leakage from mains = Number of reported bursts x Average leak flow rate x Average leak duration

If no detailed data are available, utility managers can use approximate flow rates from Table 6.1. Estimates for background losses and excess losses (current undetected leaks on mains) can then be added.

TABLE 6.1: FLOW RATES FOR REPORTED AND UNREPORTED BURSTS

Location of Burst	Flow Rate for Reported Bursts [l/hour/m Pressure]	Flow Rate for Unreported Bursts [l/hour/m pressure]
Mains	240	120
Service Connection	32	32

Source: IWA Water Loss Task Force

Background losses are individual events (small leaks and weeping joints) that flow at rates too low for detection by an active leak detection survey. They are finally detected either by chance or after they have worsened to the point that an active leak detection survey can discover them.

Table 6.2 shows background losses from various components of a network with average infrastructure condition.

TABLE 6.2: CALCULATING BACKGROUND LOSSES

Mains	9.6	Litres per km of mains per day per metre of pressure
Service Connection – main to property boundary	0.6	Litres per service connection per day per metre of pressure
Service Connection – property boundary to customer meter	16.0	Litres per km of service connection per day per metre of pressure

Source: IWA Water Loss Task Force

Excess losses include the water lost from leaks that are not yet detected and repaired under the current leakage control policy

Excess Losses = Physical losses from water balance—known physical loss components

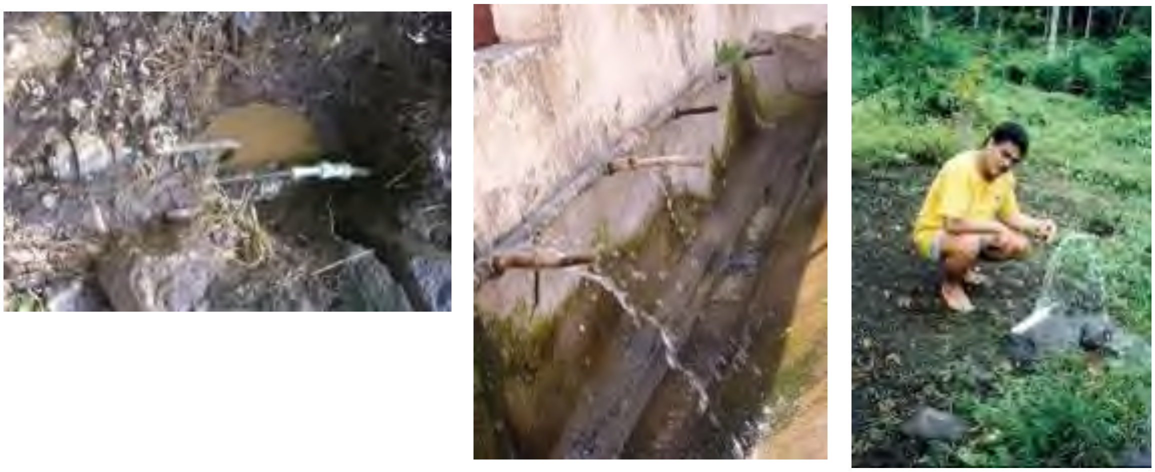
If this equation results in a negative value for excess losses, the assumptions for the physical loss component analysis (e.g. values for leak durations) should be re-checked, and, if necessary, corrected. If the value is still negative after re-checking the assumptions this indicates that faulty data were used in the water balance calculation. For example, utility managers may have underestimated system input or overestimated commercial losses, and all the components should be checked.

6.2.2 LEAKAGE AND OVERFLOWS FROM THE UTILITY'S RESERVOIRS AND STORAGE TANKS

Leakage and overflows from reservoirs and storage tanks are easily quantified. Utility managers should observe overflows then estimate the average duration and flow rate of the events. Most overflows occur at night when demands are low and therefore it is essential to undertake regular nightly observations of each reservoir. These observations can be undertaken either physical or by installing a data logger which will then record reservoir levels automatically at preset intervals.

Leakage from tanks is calculated using a drop test where the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost. However, repairing these leaks is a major operation, requiring draining down the reservoir and planning an alternative supply.

Monitoring reservoir overflows can be done by placing a plastic bottle in the overflow pipe of each reservoir. The bottles are checked once per month - if they have moved outside of the pipe this indicates a possible overflow. Monitoring teams can then undertake further investigations using a pressure (depth) transducer and a data logger.



Typically more difficult to detect, service connection leaks result in significant water losses.

6.2.3 LEAKAGE ON SERVICE CONNECTIONS UP TO THE CUSTOMER’S METER

This type of leakage is usually more difficult to detect and results in the greatest volume of physical losses. Utility managers should calculate the approximate volume of leakage from service connections by deducting the mains leakage and storage tank leakage from the total volume of physical losses.

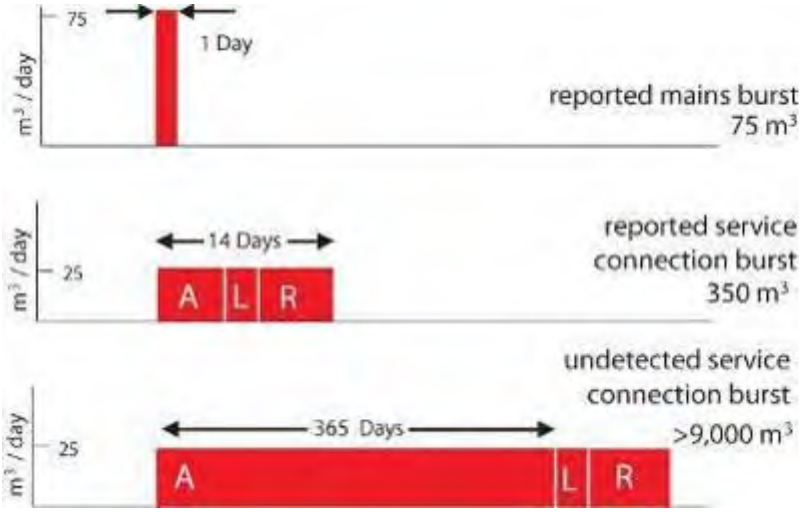
6.3 CHARACTERISTICS OF LEAKAGES

Having defined where leakage can occur in the transmission and distribution network, utility managers should familiarise themselves with the different types of leaks and understand the effect of the leak run time, or ALR, on the total volume of physical losses (see Figure 6.1, and Section 3.3 for a discussion of the ALR concept).

The type and location (e.g. main or service connection) of a burst influences the total run time:

- ***Reported bursts***—Visible and usually quickly reported by the public or observed by water utility staff. They have a short awareness time.
- ***Unreported bursts***—Commonly occur underground and are not visible at the surface. They are usually discovered during leak detection surveys and often have a long awareness time.
- ***Background leakage***—An accumulation of very small leaks that are difficult and not cost-effective to detect and repair individually.

FIGURE 6.1: LEAK RUN TIME AND VOLUME OF WATER LOSS



General conclusions concerning leakage include:

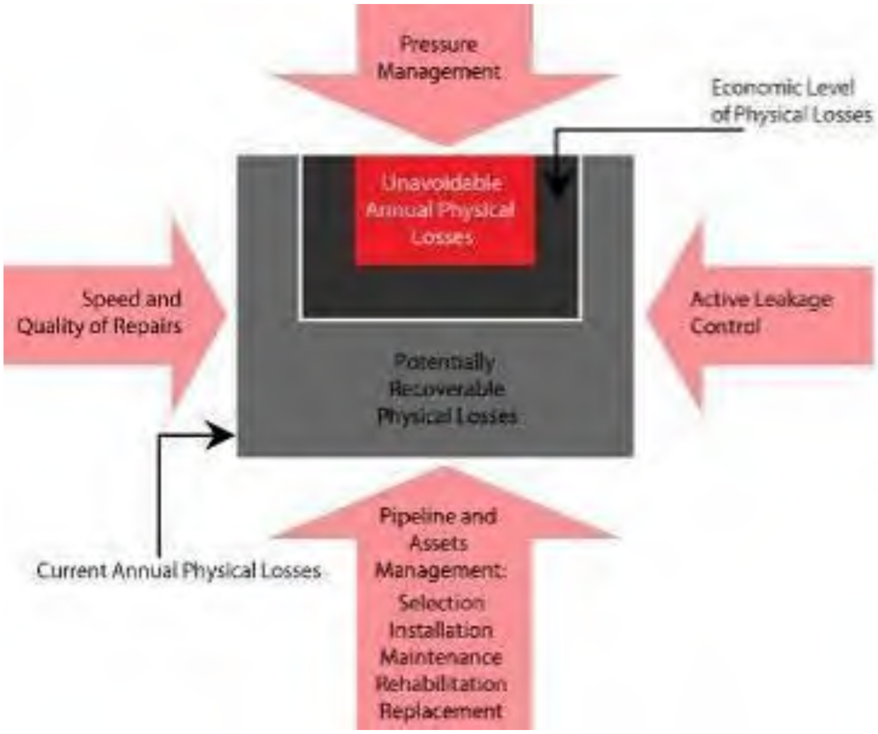
- Most leaks are invisible
- The majority of leaks do not come to the surface
- Managers need to be aware that most leaks are on service connections
- The absence of an active programme to detect invisible leaks is an indication of high levels of leakage

6.4 DEVELOPING A LEAKAGE MANAGEMENT STRATEGY

The four pillars of a leak management strategy include pressure management, repairs, active leakage control, and asset management (Figure 6.2). These factors influence how leakage is managed—and therefore the volume and economic value of leakage—in any utility's distribution network.

The large square represents the **C**urrent **A**nnual Volume of **P**hysical **L**osses (CAPL), which tends to increase as the distribution network ages. But the rate of increase can be constrained by an appropriate combination of the four components of a successful leakage management strategy. The black box represents the **M**inimum **A**chievable **A**nnual **P**hysical **L**osses (MAPL), or the lowest technically achievable volume of physical losses at the current operating pressure. Introducing or strengthening any of the four components will have an effect on the potentially recoverable losses.

FIGURE 6.2: THE FOUR PILLARS OF A SUCCESSFUL LEAKAGE MANAGEMENT STRATEGY

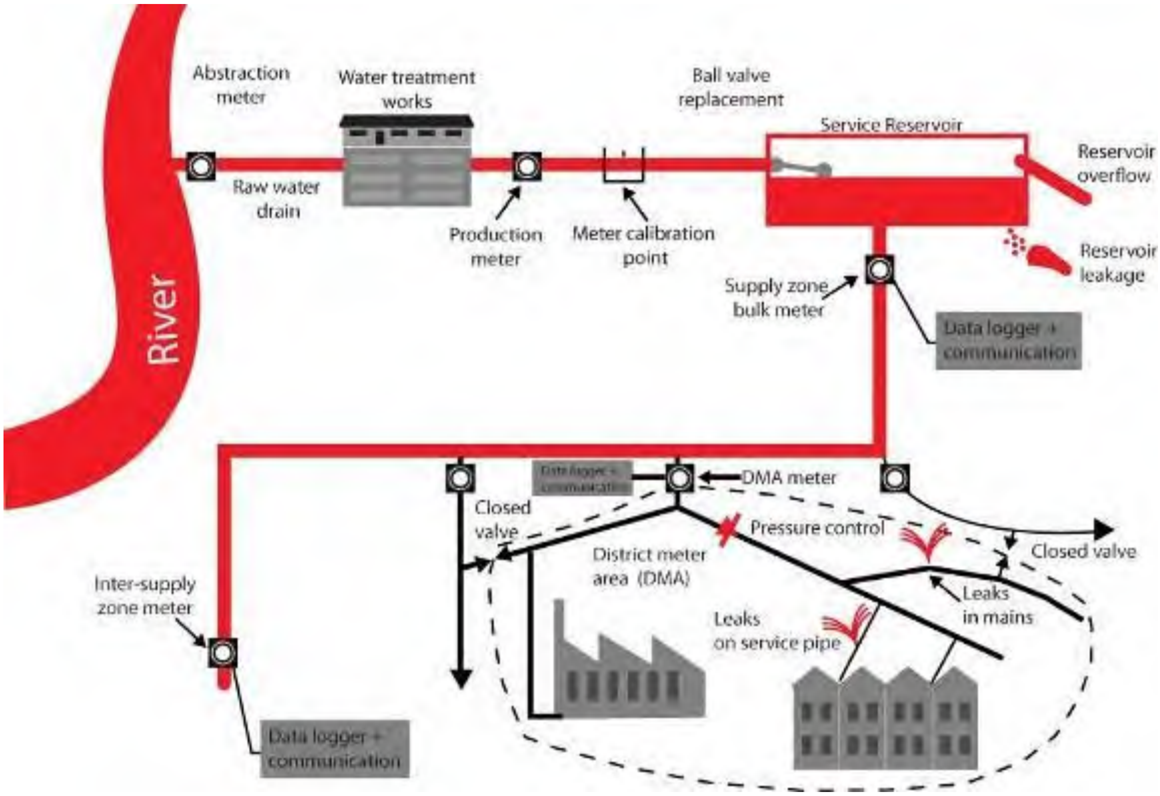


6.4.1 ACTIVE LEAKAGE CONTROL (ALC)

Active leakage control (ALC) is vital to cost-effective and efficient leakage management. The concept of monitoring flows into zones, or district meter areas (DMAs), where bursts and leaks are unreported is now an internationally accepted and well-established technique to determine where leak location activities should be undertaken. The quicker the operator can analyse DMA flow data, the quicker bursts or leaks can be located. This, together with speedy repair, limits the total volume of water lost.

There are many points in a distribution network where leakages can occur and where they are best monitored (Figure 6.3). The DMA concept, and the associated technology and equipment for leakage monitoring, detection, and location, is described in detail in Chapter 7.

FIGURE 6.3: A TYPICAL DISTRIBUTION NETWORK



Flow Metering

Modern flow metering and data capture technologies play a major part in quickly identifying bursts and in estimating the gradual accumulation of smaller leaks. Many water utilities integrate data from DMAs via telemetry into their supervisory control and data acquisition (SCADA) systems. This approach is particularly effective when implemented together with an analysis package that helps the utility manager identify DMAs that requiring leak location work.

Leak Localising, Locating, and Pinpointing

Utility managers need to ensure a detailed process is undertaken to locate leaks:

- Use flow meter data to identify DMAs that contain unreported bursts or an accumulation of leaks
- Narrow down the area of leakage within the DMA
- Pinpoint the exact (or nearly exact) position of the leak.

This process requires reasonable accuracy at each step to avoid high excavation costs and _dry holes‘ (excavations at suspected leak points that reveal no obvious leak). The basic method of detecting and locating a leak is to listen for the noise of the water being released from the pipe under pressure. The effectiveness of this activity is dependent on the system pressure, the size and shape of the leak and the pipe material.

Proper application and maintenance requirements of the equipment needs to be understood.

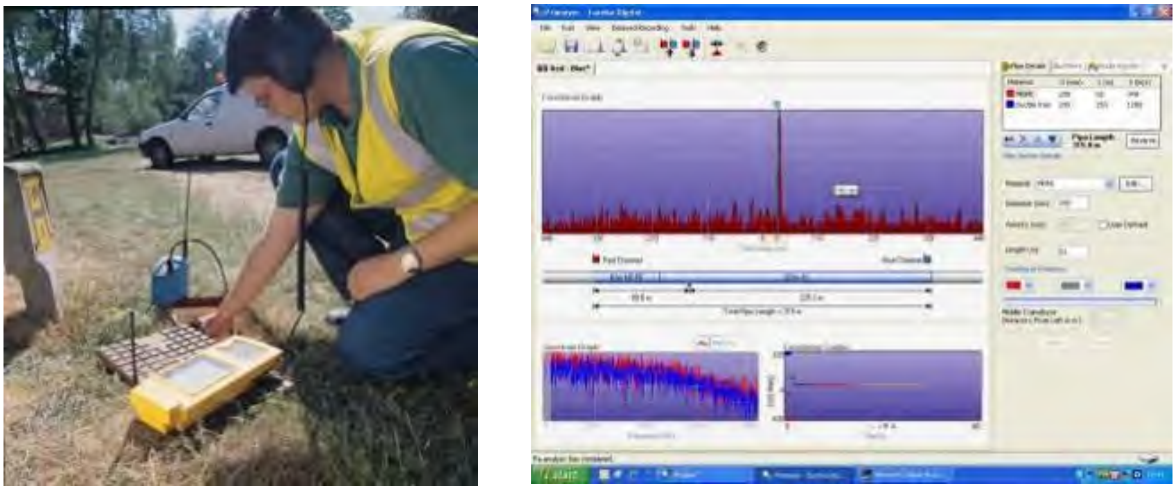
For ensuring accuracy the utility has a wealth of acoustic equipment to choose from to pinpoint leaks and bursts, including noise loggers, leak noise correlators, ground microphones, and sounding sticks. Although these tools are extremely helpful for ALC, utility managers must understand the proper applications and maintenance requirements of each tool to maximise their use.

- ***Noise loggers***—Noise loggers narrow down areas of a DMA that contain suspected bursts or number of leaks. A cluster of loggers, usually 6, 12, or 18, is deployed in the survey area, with each logger placed on a hydrant, meter, or other surface fitting. Noises that are suspected of being caused by leaks can be confirmed, and the leak is located using other location equipment as described below. Some noise logger systems also incorporate data from multiple points to _instantly‘ locate leaks.

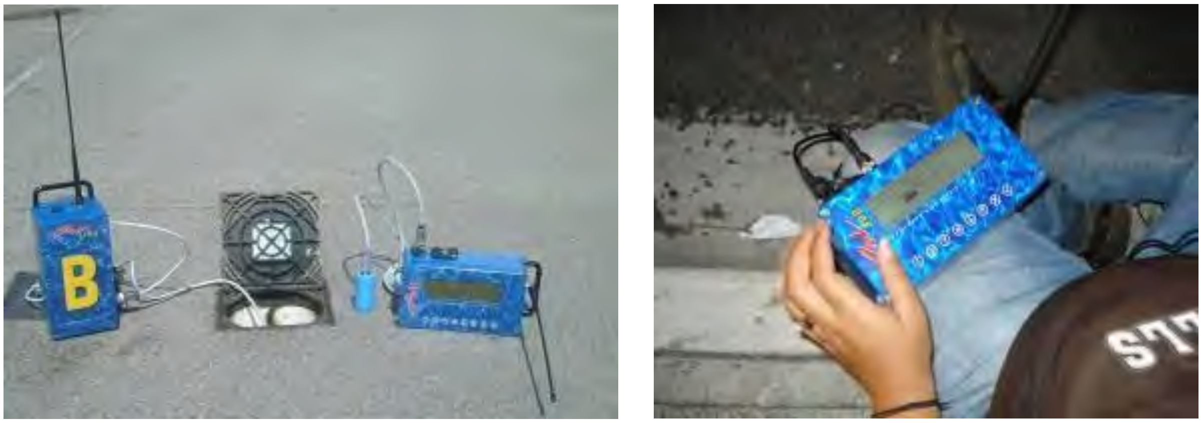
Noise loggers can be deployed on fittings in the network.

- ***Leak noise correlators***—Rather than locating a leak based on the noise level, this instrument uses the velocity of sounds made by the leak as they travel along the pipe wall toward each of two microphones placed on fittings either side of the suspected leak. The effectiveness of this process is dependant on the strength of the leak noise and the sound conductivity of the pipe material. Hydrophones placed in the water column can also enhance the leak sounds in plastic or large pipes and other pipes where the noise conductivity is known to be poor. These hydrophones work by listening to the leak noise travelling through the water, which is a better conductor, than most pipe materials, of sound.

  The latest correlator versions, have the capability of frequency selection and filtering, to quickly locate leaks to within 0.5 metres in most sizes of pipe, provided there are sufficient contact points along the line of the main.

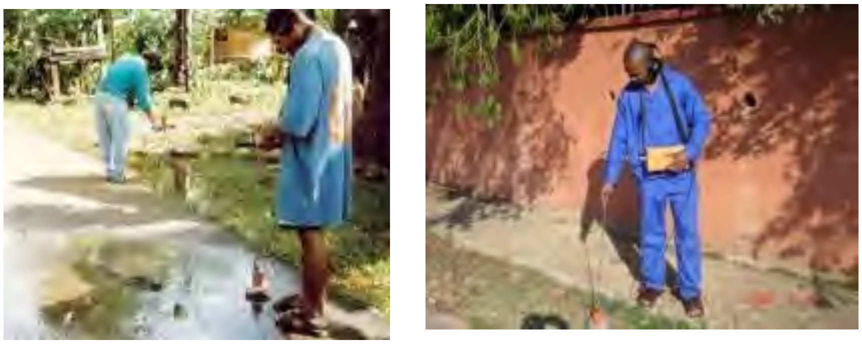


An „advanced" leak noise correlator, showing the correlation peak.



One of the „low-cost" correlators.

Low-cost basic models are also available—these usually have a single channel radio link and fewer functions. Although they are easier to use, and adequate for most situations, they are disadvantaged when correlating over long distances.



Using a ground microphone.

- ***Ground microphones***— The ground microphone electronically amplifies the sound of a leak. It can be assembled for use in either contact or survey mode. Contact mode is for sounding on fittings, similar to an electronic listening stick. Survey mode is for searching for leaks on lengths of pipeline between fittings. The technique involves placing the microphone on the ground at intervals along the line of the pipe and noting changes in sound amplification as the microphone nears the leak position. When a leak is detected by the leak noise loggers or leak noise correlator, the utility manager may use either mode to locate the leak.

- ***Sounding Sticks***—The sounding stick, or ‗stethoscope', is an inexpensive, simple rod made of wood or metal with an ear piece attached to amplify sounds. Utility managers use it to listen to leak sounds on the surface of the highway or on directly exposed pipes and fittings. The sounding stick is a piece of equipment that can be easily made from materials readily available materials, such as a bamboo cane or a reinforcing rod.

  The sounding stick is invariably used to confirm a leak site that is first identified by a correlator, and for checking that a leak has been repaired correctly.

Entry-level equipment—for utilities that are about to embark on active leakage control—could consist of a sounding stick and a ground microphone—and maybe a low-cost correlator. Utilities that are intending to implement a policy of regular leakage monitoring, may wish to add an advanced correlator and a set of acoustic noise loggers.

All of the equipments above will not only detect the noise that a leak makes but also any other noise in the system, such as a pump, tap, air valve, etc, It is therefore important to have a team of experienced leakage detection staff who not only can use the equipment correctly but have the skills to identify leaks correctly.


Using a listening stick.

6.4.2 PRESSURE MANAGEMENT


Low pressure

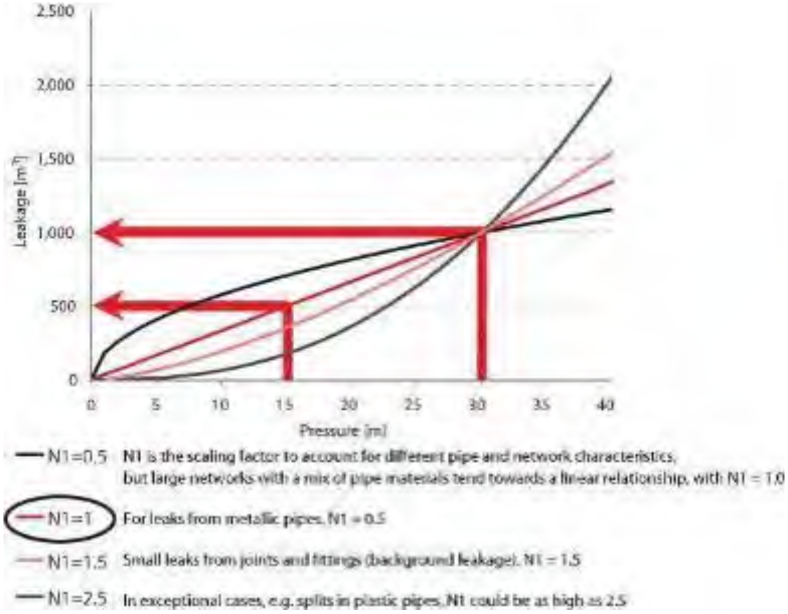
High pressure

Flow rate from the same fractured pipe at low and high pressure.

Pressure management is one of the fundamental elements of a well-developed leakage management strategy. The rate of leakage in water distribution networks is a function of the pressure applied by pumps or by gravity. There is a physical relationship between leakage flow rate and pressure (Figure 6.4), and the frequency of new bursts is also a function of pressure:

- The higher or lower the pressure, the higher or lower the leakage
- The relationship is complex, but utility managers should initially assume a linear relationship (10% less pressure = 10% less leakage)
- Pressure level and pressure cycling strongly influence burst frequency

FIGURE 6.4: PRESSURE/LEAKAGE RELATIONSHIP



N1 is the scaling factor to account for different pipe and network characteristics, but large networks with a mix of pipe materials tend towards a linear relationship, with N1 = 1.0

To assess the suitability of pressure management in a particular system, utilities should first carry out a series of tasks, including:

- Identify potential zones, installation points, and customer issues through a desktop study
- Identify customer types and control limitations through demand analysis
- Gather field measurements of flow and pressure (the latter usually at inlet, average zone point, and critical node points)
- Model potential benefit using specialized models
- Identify correct control valves and control devices
- Model correct control regimes to provide desired results

- Analyse the costs and benefits

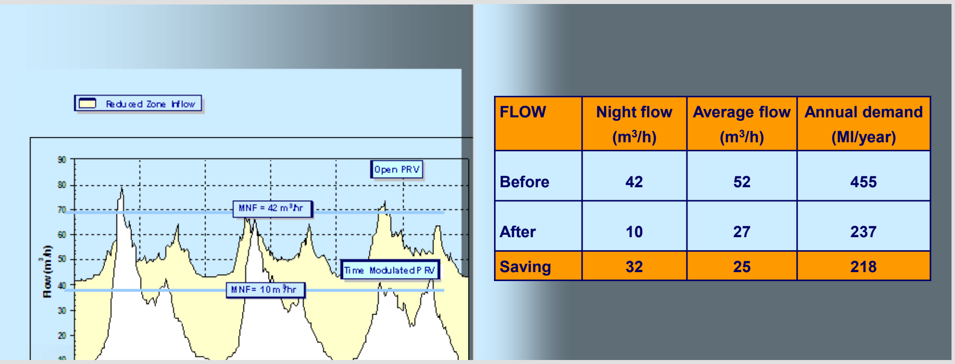
There are a number of methods for reducing pressure in the system, including variable speed pump controllers and break pressure tanks. However the most common and cost effective is the automatic pressure reducing valve or PRV.

PRVs are instruments that are installed at strategic points in the network to reduce or maintain network pressure at a set level. The valve maintains the pre-set downstream pressure regardless of the upstream pressure or flow-rate fluctuations. PRVs are usually sited within a DMA, next to the flow meter, as shown in the photos below. The PRV should be downstream of the meter so that turbulence from the valve does not affect the meter‘s accuracy. It is good practice to install the PRV on a bypass pipe to enable future major maintenance works.

PRVs installed in meter chambers.

AFRICAN UTILITY EXPERIENCE: PRESSURE MANAGEMENT

The City of Tshwane Metropolitan Municipality, South Africa, has 800 pressure reducing valves. The summary of results for Mabopane below show the savings and fast payback from one installation. By reducing night flow from 42 m3/hour to 10m3/hour, the cost saving - at a tariff of 0.5USD/m3—was109 000 USD/year. The installation cost was 25 000USD, giving a payback of less than 3 months.



FLOW	Night flow (m^3/h)	Average flow (m^3/h)	Annual demand (Ml/year)
Before	42	52	455
After	10	27	237
Saving	32	25	218

6.4.3 SPEED AND QUALITY OF REPAIRS

The length of time a leak is allowed to run affects the volume of physical losses, so repairs should be completed as soon as possible once a leak is detected. Repair quality also has an effect on whether the repair is sustained. Key issues to consider when formulating a repair policy include:

- Efficient organisation and procedures from the initial alert through to the repair itself
- Availability of equipment and materials
- Sufficient funding
- Appropriate standards for materials and workmanship
- Committed management and staff
- Good quality of service connections—service connections are often the _weakest link‘

Leak repairs should be fast, efficient and of good quality materials and workmanship.

6.4.4 ASSET MANAGEMENT

Good asset management is a necessity for long-term economic leakage management, and the objective is to tackle leaks in the most cost-effective way. This requires priority setting and decisions on whether to repair, replace, rehabilitate, or leave the assets as they are, while simultaneously implementing pressure management and improving the operation and maintenance programme.

During the decision process, utility managers should ask themselves the following questions:

- If repairing, replacing, or rehabilitating assets, what materials should be used?
- Should pipes be replaced now or later during network extensions to address future demand increases?

AFRICAN UTILITY EXPERIENCE: ASSET MANAGEMENT

The NRW management team in Entebbe, Uganda, has a multi-tiered approach to asset management:

- Pressure management throughout the distribution network by installation of pressure reducing valves
- Routine inspection and servicing of valves and fire hydrants
- Leak _clustering‘ - monitoring the network condition by identifying fragile areas of pipework (frequent breaks and repairs). This helps to plan a replacement policy
- Developing a medium term investment plan—rehabilitating worn-out segments of the water distribution network
  - 12.4 Km of worn out pipes were replaced
  - More than 60% of the network is currently less than 5 years old

Key Messages

- Physical losses include leakage on transmission and distribution mains; leakage and overflows from storage tanks; and leakage on service connections up to the customer meter.
- Leakages from transmission and distribution mains are usually large events so they are reported quickly by the public. They can cause serious damage but are usually repaired quickly. Other types of leakage are more difficult to detect and repair.
- A successful leakage management strategy requires pressure management, active leakage control, pipeline and asset management, and speedy and quality repairs.

Further Reading

Leak Detection Guidance Notes

Developed and published by the IWA Water Loss Task Force, 2007. Available as a free download from the IWA website: www.iwaom.org/wltf

7. UNDERSTANDING DISTRICT METER AREAS

Many water utilities operate their pipe networks as an open system where water is fed from more than one Water Treatment Plant (WTP) into an inter-connected pipe network. Water from each WTP will mix within the network, which continually affects system pressure and water quality. In an open system, NRW can only be calculated for the entire network, which is effectively an average level for the entire system. Thus, determining the exact locations of NRW occurrences—and where NRW reduction activities should take place—can be quite a challenge, especially for large networks.

Generally NRW management in an open system is undertaken in a passive manner where NRW reduction activities are initiated only when the loss becomes visible or is reported. A more effective approach is to move towards Active NRW Management where dedicated teams are established and sent out to look for water losses, such as leaks, reservoir overflows, and illegal connections.

Active NRW Management is only possible using zones, where the system as a whole is divided into a series of smaller sub-systems for which NRW can be calculated individually. These smaller sub-systems, often referred to as District Meter Areas (DMAs) should be hydraulically isolated so that utility managers are able to calculate the volume of water lost within the DMA. When a supply system is divided into smaller, more manageable areas, the utility can better target NRW reduction activities, isolate water quality problems, and better manage overall system pressure to allow for 24/7 water supply throughout the network.

Dividing the open network into smaller, more manageable areas called District Meter Areas (DMAs) enables network operators to manage the system more effectively in terms of pressure control, water quality, and NRW. This chapter describes how utilities should establish DMAs and then use information on flow and pressure to better manage NRW. It also discusses the benefits of using DMAs to improve water quality and supply for customers.

7.1 DMA ESTABLISHMENT CRITERIA AND PROCESS

The design of a series of DMAs is very subjective, and it is unlikely that two utility engineers working on the same network would come up with the same design. The engineer typically uses a set of criteria to create a preliminary DMA design that must be tested either in the field or using a network model.

These criteria include:

- Size of DMA (e.g. number of connections—generally between 1,000 and 2,500)
- Number of valves that must be closed to isolate the DMA
- Number of flow meters to measure inflows and outflows (the fewer meters required, the lower the establishment costs)
- Ground-level variations and thus pressures within the DMA (the flatter the area the more stable the pressures and the easier to establish pressure controls)

- Easily visible topographic features that can serve as boundaries for the DMA, such as rivers, drainage channels, railroads, highways, etc.

To divide a large open system into a series of DMAs, it is essential to close valves to isolate a certain area and install flow meters. This process can affect the system‘s pressures, both within that particular DMA as well as its surrounding areas. The water utility therefore must ensure that the water supply to all customers is not compromised in terms of pressure and supply hours.

BOX 7.1: NETWORK MODELLING

Network modelling is the process of constructing a computer simulation of a pipe network using specialised computer software. Utility managers then verify the simulation by comparing the simulated flows and pressures with real flow and pressure data recorded onsite. Adjustments are made to the model to ensure that the simulated and the real data correlate, thus creating a calibrated hydraulic network model.

Using a calibrated hydraulic network model of the supply system to simulate possible DMA designs will enable analyses of system pressures and flows without affecting supply to customers. However, many water utilities do not have existing calibrated hydraulic network models. Rather than wait for a model to be developed, which can take up to one year or more, a water utility should begin establishing DMAs in network areas that can be easily isolated, i.e. areas with a separate supply zone.

In establishing a DMA, the water utility should limit the number of inflows, which also helps to reduce the cost of flow meter installation. To achieve this, it is necessary to close one or more boundary valves, which must remain shut permanently to ensure that any flow data accurately represents the total inflow for the DMA.

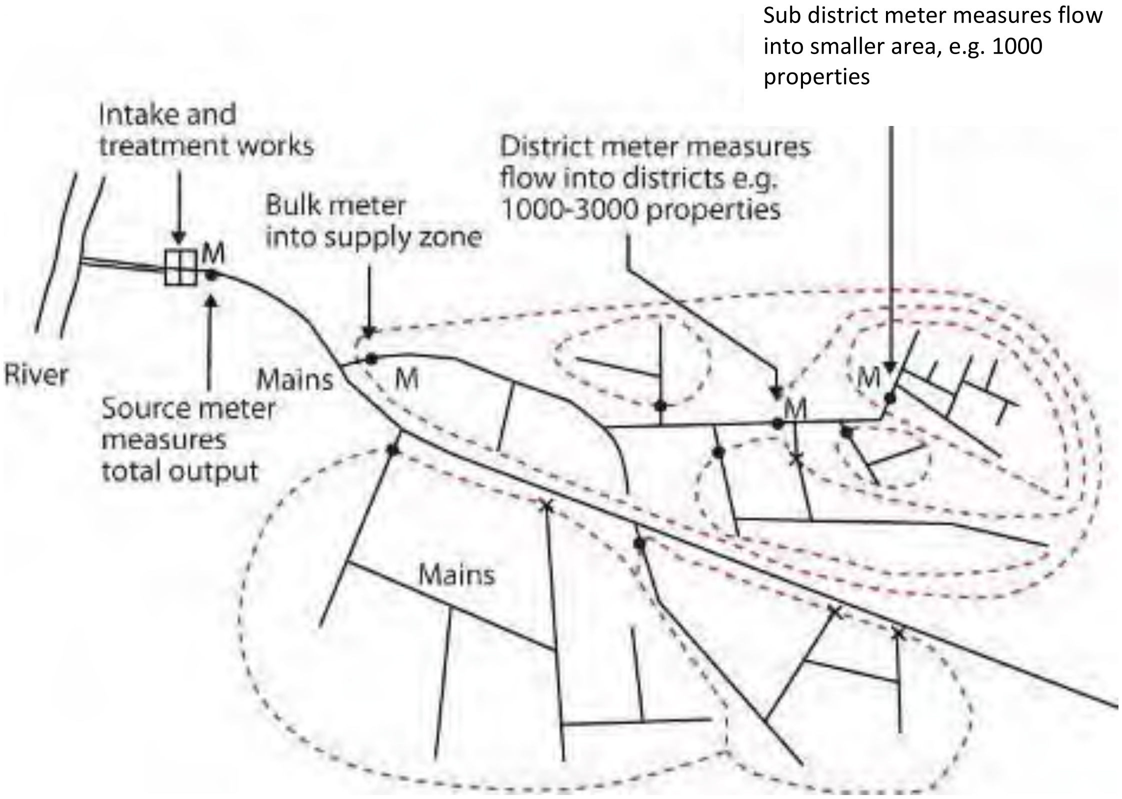
Utility managers will ensure that all pipes into and out of the DMA are either closed or metered by performing an isolation test as follows:

- Close all metered inlets.
- Check whether the water pressure within the DMA drops to zero, since no water should now be able to enter the area.

If the pressure does not drop to zero, then it is likely that another pipe is allowing water into the area and therefore needs to be addressed.

If the budget is limited, the water utility should initially establish larger zones of 5,000 or more connections. It can subsequently subdivide them into DMAs and sub-DMAs of 1,000 or fewer connections for those DMAs with high NRW and long lengths of pipework, as detailed in Figure 7.1.

FIGURE 7.1: TYPICAL DMA LAYOUT



For each DMA, utility managers should develop a detailed operations manual to assist future teams in managing the water supply. The operations manual includes a schematic of the pipe network; location drawings of the flow meters, pressure control valves, and boundary valves; and a copy of the billing database for the DMA. The manual is a working document and operational data should be continually updated, including information on the following:

- Flow and pressure graphs
- Leakage step tests data
- Leak locations
- Illegal connection locations
- Legitimate night flow (LNF) test data
- Pressure T Factor test data

Supply zone schematic showing supply source, DMA meters and boundaries

7.2 USING DMA RESULTS TO REDUCE NRW LEVELS

Once the DMA has been established, it becomes an operational tool for monitoring and managing both of the major components of NRW, physical and commercial losses. The calculation for NRW within a DMA is defined as follows:

DMA NRW = Total DMA Inflow - Total DMA Consumption

After flow meters are installed on all inlets to the DMA, the Total DMA Inflow can be measured using the increase in the totaliser, or the meter counter measuring the volume of water passing through the meter, for the calculation period.

The Total DMA Consumption will depend on the customer meter coverage. If the DMA has a 100% domestic meter coverage, meaning all customers within the DMA have a meter, then the Total DMA Consumption can be calculated through a simple summation of all meter measurements for the calculation period.

If 100% domestic meter coverage does not exist within the DMA, then the Total DMA Consumption can be estimated by using per capita consumption figures. Initially, a survey of all properties within the DMA should be undertaken; this survey may be limited to counting the number of properties and estimating the average number of occupants per property. For a more detailed estimate, surveyors will interview all households and ask how many occupants live within each property.

AFRICAN UTILITY EXPERIENCE: DMA ESTABLISHMENT

The NRW team at Entebbe, Uganda, undertook pilot studies of the distribution network and isolated three discrete DMAs:

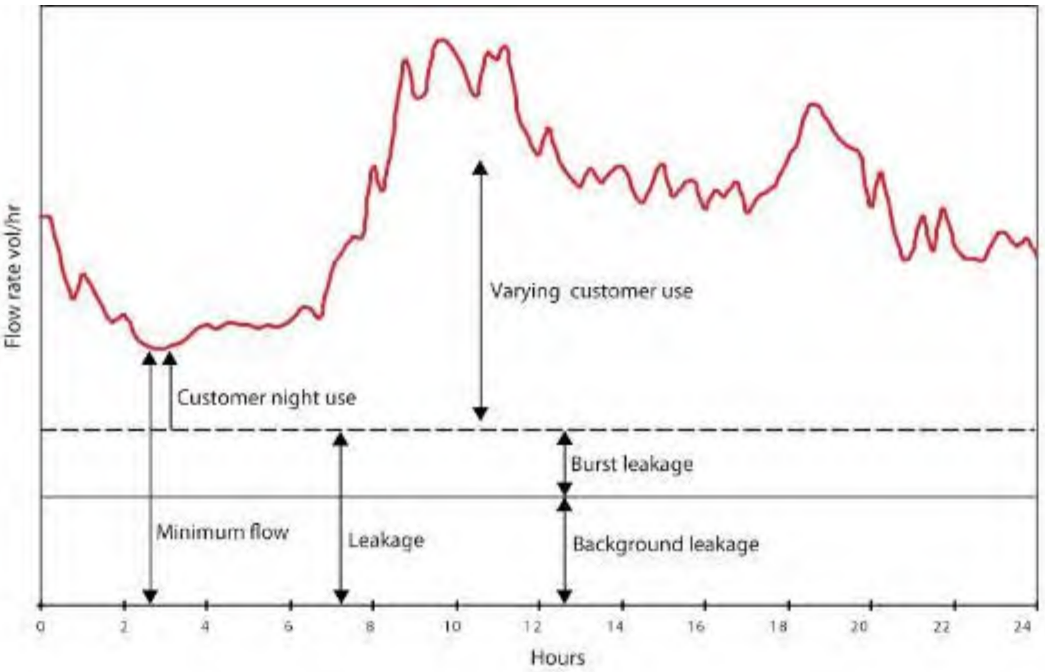
- Each DMA was aligned with the customer billing system - for consistency of monitoring
- A staffing structure was allocated to each DMA—to ensure staff accountability
- DMA leaders were appointed—accountable for the DMA's management and performance
- Targets were set for each DMA—an incentive mechanism was established to drive performance
- Regular DMA performance monitoring was carried out

7.2.1 ESTIMATING PHYSICAL LOSSES

Most DMAs will not contain any reservoirs or trunk mains, so these components are not usually considered when analysing physical losses within a DMA. Physical losses within a DMA are effectively pipe leaks on the main pipes and customer connections. Leakage occurs through holes or cracks in the main pipes or at pipe joints, which will leak water constantly over a 24-hour period. In contrast, leaks from customer connections fluctuate with customer demand throughout the day, with peak demand in the morning and evening, and a minimum demand at night when most customers are asleep and not using water.

Because leakage from the main pipes is continuous, while customer demand is minimal at night, water operators should monitor leakage during the night period. Figure 7.2 shows the flow pattern into a typical DMA with mainly domestic customers.

FIGURE 7.2: TYPICAL 24-HOUR DMA FLOW PROFILE



To estimate the level of leakage in the DMA the operator needs to calculate the system's Net Night Flow (NNF), which is determined by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF).

The MNF is the lowest flow into the DMA over a 24-hour period, which generally occurs at night when most consumers are inactive. This MNF can be measured directly from the data logging device or the flow graph. Although customer demand is minimal at night, water operators still have to account for the small amount of legitimate night flow, i.e. the night-time customer demand, such as toilet flushing, washing machines, etc.

In a system with 100% metering, LNF is calculated by measuring the hourly night flow for all non-domestic demand and a portion (e.g. 10%) of domestic meters within the DMA. The utility will then estimate the total LNF in terms of litres per hour and litres per second.

For systems without 100% customer metering, water operators can approximate LNF based on estimated per capita night consumption. Utility managers should conduct a customer survey of all the properties, both domestic and non-domestic, within the DMA, and then determine the total number of connections per demand group (domestic, industrial, commercial, or others). Based on data from other areas with 100% customer metering, the utility can estimate a night-time flow rate for each demand group and multiply that by the number of connections within the demand group to get the total LNF.

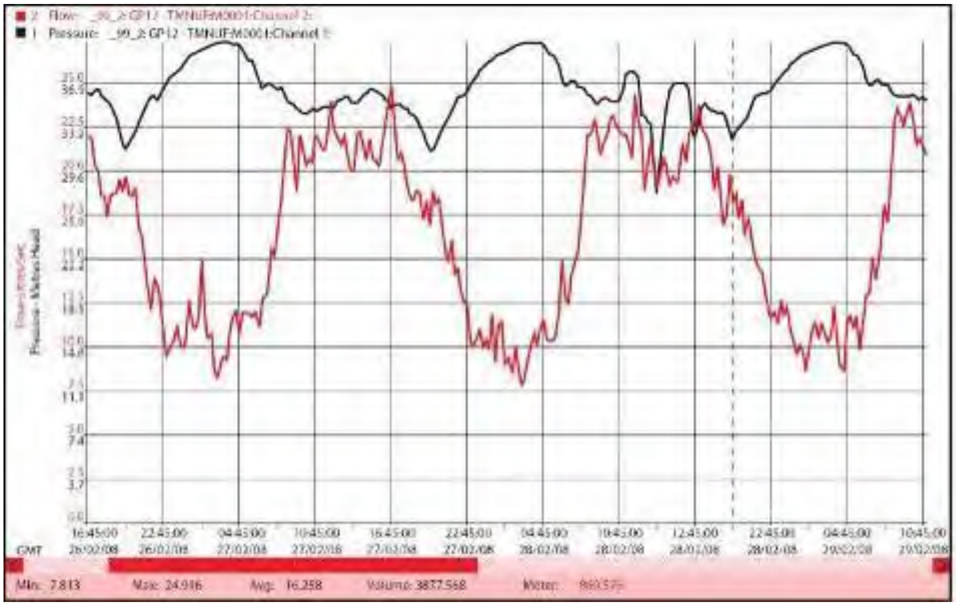
To determine the level of Net Night Flow (NNF) or the portion of night flow directly attribute to leakage, subtract the LNF from the recorded MNF.

$$NNF = MNF - LNF$$

Leakage is proportional to the pressure in the system. Similar to water flows into the DMA, the DMA average pressure will change over a 24-hour period. Pressure is directly proportional to flow due to frictional headlosses within the system, and thus when the DMA has its lowest inflows, the pressure will be at its highest (Figure 7.3). This is because frictional headloss is proportional to velocity, so when flows are low, the velocities in the pipes are also low and less headloss occurs.

Therefore, the NNF or leakage calculated for the minimum night flow period will not be a true representation of leakage across a 24-hour period. Utility managers must also determine a pressure factor, or T Factor, that creates a true average 24-hour leakage value when applied to the NNF. The T Factor is calculated by using a data logger to record pressure over a 24-hour period, and then using those measurements to calculate the average 24-hour pressure. This average 24-hour pressure is compared to the system pressure during the minimum night period and a factor applied.

FIGURE 7.3: DMA FLOW AND PRESSURE RELATIONSHIP OVER A THREE-DAY PERIOD



7.2.2 DETERMINING COMMERCIAL LOSSES

The level of NRW within a DMA can be calculated by subtracting the recorded consumption from the inflow. Section 7.2.1 shows how to determine the leakage level or NNF within each DMA using the minimum night flow. This section discusses how to calculate commercial losses through a simple subtraction of leakage from the NRW, as follows:

Commercial loss = NRW - NNF

Once utility managers identify the DMAs with significantly high commercial losses, they should investigation for faulty meters, tampered meters, and illegal connections. They may also conduct a series of customer surveys of each property within the DMA to verify the property‘s inclusion in the billing database, interview the occupants, and assess the water meter.

7.3 DMA MANAGEMENT APPROACH

Managers walking the line to monitor the DMA.

When a DMA is first established, water utility managers should undertake the initial calculations of NRW, NNF, and commercial losses, and identify the main areas of concern. If the DMA has high leakage or high commercial losses, then NRW reduction activities discussed in Chapters 5 and 6 should be implemented.

When DMAs are first established a baseline NNF target for each DMA should be established. This is done by calculating the NNF from the DMA meter readings before and after a sounding survey and fixing leaks. The survey should be a ‗sweep‘ of the DMA, sounding on every fitting, and all leaks found should be repaired quickly. The second meter reading will give the baseline NNF target for each DMA, so that when NNF rises the leakage team has a baseline level to aim for in each DMA.

Once NRW is reduced to an acceptable level, the operations staff should set up a monitoring regime for DMA inflows. In its simplest form, this consists of a monthly reading of the flow meter totaliser. However, the installation of a data logger to record flows will reveal more detailed data, including the daily NNF, which enables more precise corrections to the system. Eventually, the NNF effectively becomes NRW with minimal levels of commercial loss. The daily NNFs can be plotted on a graph against time, to monitor DMA NRW levels (Figure 7.4).

FIGURE 7.4: NNF AGAINST TIME

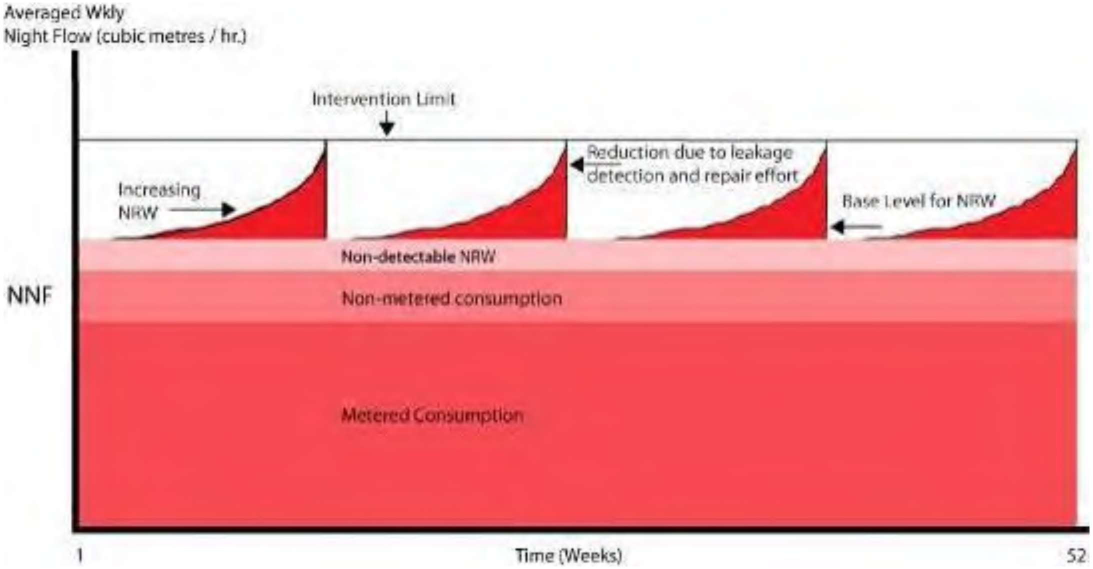
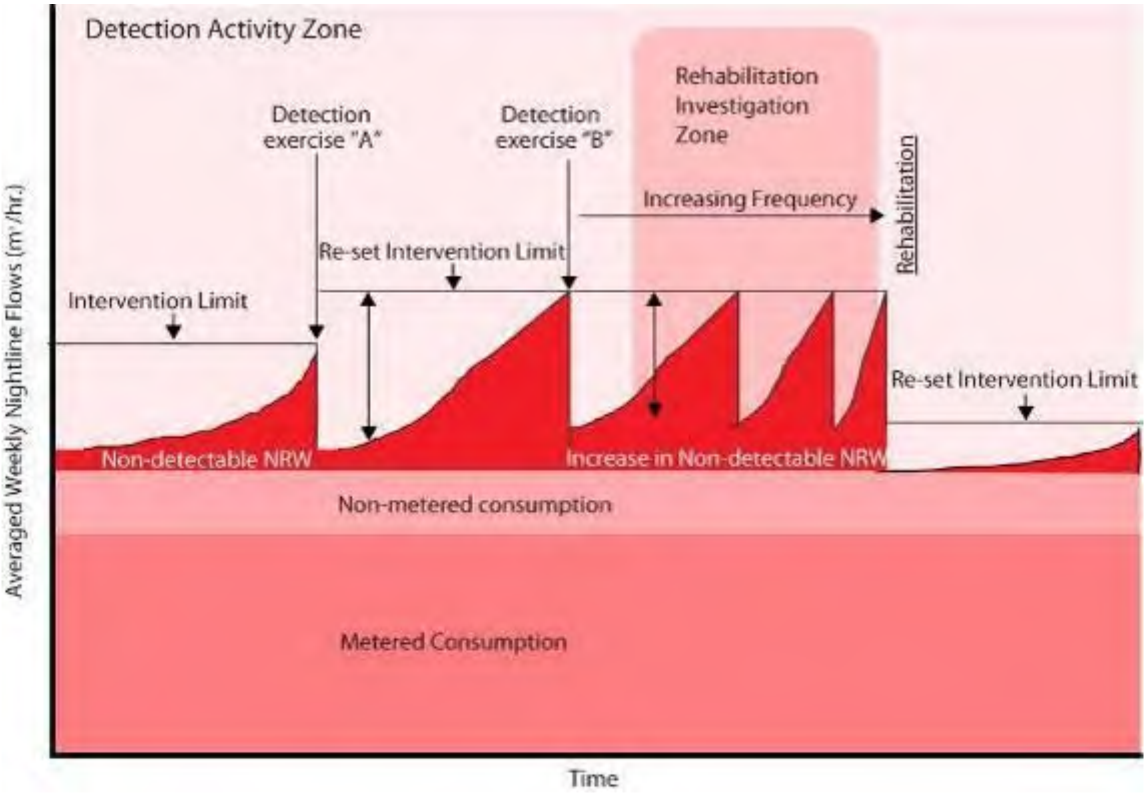


Figure 7.4 shows that the NRW level within the DMA continues to increase, and the rate of increase depends on a number of issues, including pipe network age and condition, system pressures, and the number of illegal connections and tampered meters. For most water utilities, it is inefficient for leakage

detection and customer survey teams to work in the DMA continually. Therefore, the monitoring team should set an intervention limit, or the level at which NRW becomes unacceptable. Once the intervention limit is reached, the teams should be sent in to detect and resolve losses. Generally, once teams have been sent into the DMA, the NRW level can be brought down within two to four weeks. Afterwards, the NRW level should be monitored until the intervention level is reached again. This process is the optimal management cycle of an established DMA.

Water utilities should maintain a record of the time taken for NRW to return to the intervention level. If this time decreases between detection exercises, it indicates that losses within the DMA are occurring more frequently and that the system's assets are deteriorating. For such a case, water utility managers should consider asset rehabilitation such as pipe rehabilitation, relining, or replacement, rather than continual leak detection and repair (Figure 7.5).

FIGURE 7.5: MOVING FROM LEAK DETECTION AND REPAIRS TO PIPE REHABILITATION



Upon completion of asset rehabilitation activities, the level of NRW typically decreases due to fewer leaks, especially underground or previously undetected leaks. Monitoring teams should also detect a much slower increase in the NRW level over time with the much-improved asset condition, and the intervention level should be re-set to a lower level (Figure 7.5).

7.4 ADDITIONAL BENEFITS OF THE DMA

Establishing a series of DMAs not only targets NRW reduction but it also improves asset condition and customer service by:

- Maintaining asset life through pressure management
- Safeguarding water quality
- Enabling continuous water supply

7.4.1 IMPROVED PRESSURE MANAGEMENT

Establishing a DMA and the subsequent reduction in NRW will improve the water pressure within the DMA. As leaks are repaired, the flows within the DMA will decrease and thus the friction headlosses are reduced, which has the effect of increasing DMA system pressures. These increases in pressure will become even more pronounced at night when demands are low and friction headlosses are even lower.

Improved pressure control presents dual benefits of reducing leakages and stabilising system pressures, which increase asset life. Most pipe bursts occur not because of high pressure but rather due to ongoing pressure fluctuations that force the pipe to continually expand and contract, resulting in stress fractures. Installing a pressure control device, such as a pressure reducing valve (PRV), helps to reduce pressure throughout the day, stabilise fluctuations, and reduce stress on pipes.

By design, PRVs reduce pressure to a set level during the day and night-time. A pressure of 30 m is sufficient for most customer demand. However, the pressure in a gravity system can be much higher at night when there is little customer demand. To activate a lower pressure at night and during periods of low demand, and to further reduce leakage levels, water utilities should install a timer device with two set levels—one for daytime when customers need water, and the second for night-time when demand is low. The night-time setting, generally adjusted between 15 m and 20 m pressure, is typically lower than the daytime setting.

7.4.2 SAFEGUARDING WATER QUALITY

Establishing DMAs helps water utilities to prevent water quality deterioration in the distribution network. Closing a number of boundary valves to isolate each DMA, as per standard DMA establishment protocol, reduces the ebb and varying flow of water within the pipe network. As a result, sediments accumulated in the bottom of pipe will be disturbed less, thereby reducing water discolouration. The number of dead-end pipes within the system should be minimised to reduce the number of areas with stagnant water. Where dead-end pipes exist, a regular flushing regime can be implemented to ensure the water is kept fresh.

Water utilities benefit from decreased pipe leaks and repairs as a result of a more stable system pressure. Utilities can better locate pipe leakages that commonly cause infiltration of dirt and potentially contaminated groundwater into the pipes. The need for fewer repairs results in fewer system shutdowns, which in turn keeps sediments undisturbed.

Each DMA should include a water sampling point. Regular sampling and testing will help to identify water quality issues and assist asset rehabilitation teams in identifying pipes that need replacement or repair.

7.4.3 PROVIDING CONTINUOUS (24/7) WATER SUPPLY

In some systems, the water supply is not continuously available to customers 24 hours a day, so they tend to hoard water whenever it is available in case of delays in getting reconnected. As a result, they often store more water than is required for the period of non-supply. When the water supply is reconnected, they then discard the old water and hoard fresh water once again.

Water consumption per capita per day is therefore often much higher in intermittent supply systems compared to continuous supply systems. Converting to a 24-hour supply will result in lower water consumption and lower demand from the water production plant. However, turning the entire network into 24-hour supply remains challenging since the process normally requires five to seven days for the water consumption to decrease to normal (or actual use) levels. During this period, the demand would be so high that the system pressure would be greatly reduced, causing people to continue hoarding water.

DMA principles can be applied to convert from an intermittent to continuous water supply system. First, the water utility should consider installing a small number of DMAs that gradually feed continuous water supply, leading users in those DMAs to adjust to the new system and reduce excessive collection of water. Once consumption stabilises, the inflow volume into the DMAs should decrease within the five to seven day period. The water utility should then undertake leak detection activities and customer surveys to reduce water losses to an acceptable level, creating spare capacity at the production plant. This spare capacity represents additional water that can be supplied to other areas. Once these first DMAs have successfully supplied water continuously and effectively reduced water losses, then the next set of DMAs can be established for conversion to 24-hour supply.

The additional benefit of having 24-hour supply is that the pipe will be constantly pressurised, meaning that infiltration from outside the pipe is minimal. This will ensure that the quality of the water is kept to a premium and that the customer receives water of an acceptable quality.

Key Messages

- Dividing the open network into smaller, more manageable DMAs enables utility managers to manage the system more effectively in terms of pressure control, water quality, and NRW.
- Criteria in establishing DMAs include the size (or number of connections); number of valves that must be closed; number of flow meters; ground-level variations; and visible topographic features that can serve as DMA boundaries.
- Utility managers use the minimum night flow (MNF) and legitimate night flow (LNF) to calculate the net night flow (NNF), along with commercial losses, to determine NRW in a DMA
- Establishing DMAs helps to manage pressure, improve water quality, and enable continuous water supply.

Further Reading

DMA Guidance Notes

Developed and published by the IWA Water Loss Task Force (2007). Available as a free download from the IWA website: www.iwaom.org/wltf.

8. MONITORING PERFORMANCE OF NRW MANAGEMENT

NRW is a measure of a utility‘s efficiency in terms of both operational performance and financial performance. Managers, policymakers, regulatory agencies, and financing institutions use NRW performance indicators (PIs) to rank the utility‘s performance against industry standards and other water utilities. This chapter reviews common performance indicators for physical and commercial losses and briefly describes monitoring programmes.

8.1 CHARACTERISTICS OF PERFORMANCE INDICATORS

Performance indicators help a utility:

- Better understand water losses
- Define and set targets for improvement
- Measure and compare performance
- Develop standards
- Monitor compliance
- Prioritise investments

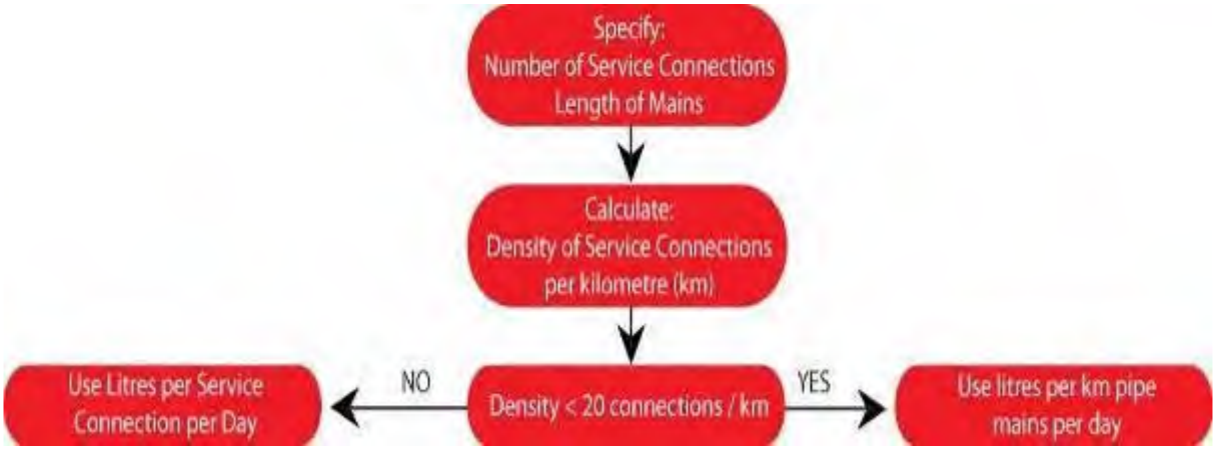
A good NRW PI should be clear and easy to understand and have a rational basis. It should also be easy to calculate using data that the utility gathers regularly. Finally, utilities should include standard performance indicators to measure performance to facilitate comparisons with other utilities. Tools such as decision trees are available for managers to select appropriate performance indicators for their utility‘s needs and operating context (Figure 8.1).

8.2 PERFORMANCE INDICATORS FOR PHYSICAL LOSSES

8.2.1 EXPRESSING NRW AS A PERCENTAGE

NRW has traditionally been expressed as a percentage of input volume. Although this is preferable to setting no targets at all, it is misleading as a PI because it favours utilities with high consumption, low pressure, and intermittent supply. In addition, it does not differentiate between physical losses and commercial losses. Nevertheless, NRW as a percentage of input is sometimes useful for its _shock value‘—a high result can be a spur a utility to initiate a study of the network‘s operational performance and to conduct a water balance calculation. It is also useful as a measure of the utility‘s year-on-year financial performance, as long as the measurement principles are consistent. In that case, it should be expressed as the *value*, not the volume, of water lost.

FIGURE 8.1: IWA DECISION TREE TO SELECT PERFORMANCE INDICATORS



8.2.2 OTHER PERFORMANCE INDICATORS FOR PHYSICAL LOSSES

Appropriate indicators of physical losses include:

- Litres per service connection per day (l/c/d)
- Litres per service connection per day per metre of pressure (l/c/d/m pressure)
- Litres per kilometre of pipeline per day (l/km/d)
- Infrastructure Leakage Index (ILI)

Figure 8.1 shows the Infrastructure Leakage Index (ILI) and other recommended NRW and physical loss performance indicators based on the IWA's *Performance Indicators for Water Supply Services: IWA Manual of Best Practice*.[5] L/c/d gives a more accurate picture than NRW as a percentage of input volume, but taking system pressure into account (l/c/d/m pressure) is an even better indicator. The PIs are categorized by function and level, defined as follows:

- Level 1 (basic): A first layer of indicators that provides a general management overview of the efficiency and effectiveness of the water undertaking.
- Level 2 (intermediate): Additional indicators that provide a better insight than the Level 1 indicators; for users who need to go further in depth.
- Level 3 (detailed): Indicators that provide the greatest amount of specific detail, but are still relevant at the top management level.

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[5] Alegre H., Hirner W., Baptista J.M. and Parena R. (2000) Performance Indicators for Water Supply Services: IWA Manual of Best Practice. ISBN 900222272.

TABLE 8.1: RECOMMENDED INDICATORS FOR PHYSICAL LOSSES AND NRW

Function	Level	Code	Performance Indicator	Comments
Financial: NRW by Volume	1 (Basic)	**Fi 36**	Volume of NRW **[% of System Input Volume]**	Can be calculated from simple water balance, not too meaningful
Operational: Real Losses	1 (Basic)	**Op 24**	**[liters/service connection/day]** or:	Best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems
			[liters/km of mains/day] *(only if service connection density is < 20/km)*	
Operational: Real Losses	2 (Intermed.)	-	**[liters/service connection/day/m pressure]** or:	Easy to calculate Indicator if the ILI is not known yet, useful for comparisons between systems
			[liters/km of mains/day/m pressure] *(only if service connection density is < 20/km)*	
Financial: NRW by cost	3 (Detailed)	**Fi 37**	Value of NRW **[% of annual cost of running system]**	Allows different unit costs for NRW components, good financial indicator
Operational: Real Losses	3 (Detailed)	**Op 25**	**Infrastructure Leakage Index (ILI)**	Ratio of Current Annual Real Losses to Unavoidable Annual Real Losses, most powerful indicator for comparisons between systems

8.2.3 THE INFRASTRUCTURE LEAKAGE INDEX (ILI)

The Infrastructure Leakage Index (ILI) is an excellent indicator of physical losses, one that takes into account how the network is managed. The IWA, which developed the index, and the American Water Works Association (AWWA) Water Loss Control Committee both recommend this indicator. The ILI is particularly useful in networks where NRW is relatively low, for example below 20%. The ILI can then help to identify which areas can be reduced further.

The ILI is a measure of how well a distribution network is managed (i.e. maintained, repaired, and rehabilitated) for the control of physical losses, at the current operating pressure. It is the ratio of **C**urrent **A**nnual Volume of **P**hysical **L**osses (CAPL) to **M**inimum **A**chievable **A**nnual **P**hysical **L**osses (MAPL).

$$ILI = CAPL/MAAPL$$

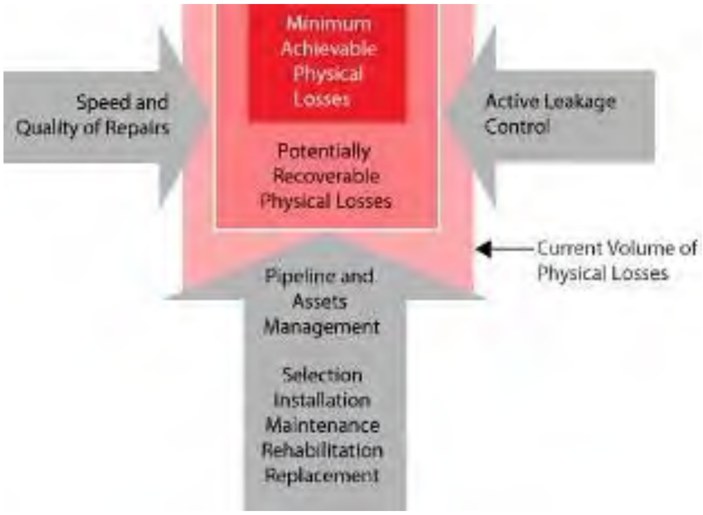
Being a ratio, the ILI has no units and thus facilitates comparisons between utilities and countries that use different measurement units. The complex initial components of the MAAPL formula have been converted to a format using a pre-defined pressure for practical use:

$$MAAPL\ (litres/day) = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P$$

Where Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, property boundary to customer meter (km); and P = average pressure (m).

Figure 8.2 illustrates the ILI concept with the factors that influence leakage management. The large square represents the CAPL, which tends to increase as the distribution networks grow older. This increase, however, can be constrained by a successful leakage management policy. The smallest box represents the MAAPL, or the lowest technically achievable volume of physical losses at the current operating pressure.

FIGURE 8.2: THE ILI CONCEPT



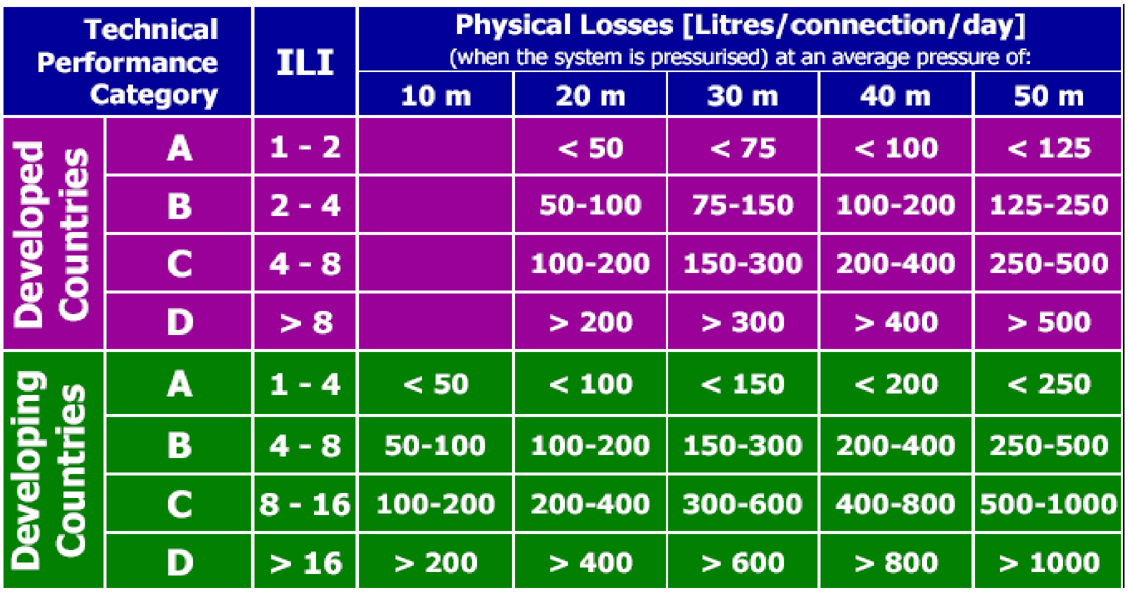
The ratio of the CAPL to MAAPL, or the ILI, is a measure of how well the utility implements the three infrastructure management functions—repairs, pipelines and asset management, and active leakage control. Although a well-managed system can have an ILI of 1.0 (CAPL = MAAPL), the utility may not necessarily aim for this target, since the ILI is a purely technical performance indicator and does not take economic considerations into account.

Calculating the ILI

- **Step 1.** Calculate the MAAPL
- **Step 2.** Calculate the CAPL (e.g. from the Water Balance)
- **Step 3.** Calculate the ILI (CAPL/MAAPL)
- **Step 4.** Adjust for intermittent supply (divide MAAPL by the average number of supply hours per day)
- **Step 5.** Compare ILI with physical loss target matrix (Figure 8.3.)

The physical loss target matrix shows the expected level of ILI and physical losses in l/c/day from utilities in countries at differing levels of network pressure.

TABLE 8.2: PHYSICAL LOSS TARGET MATRIX



Technical Performance Category		ILI	Physical Losses [Litres/connection/day] (when the system is pressurised) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Source: World Bank Institute

Utility managers can use the matrix to guide further network development and improvement:

- Category A—Good. Further loss reduction may be uneconomic and careful analysis needed to identify cost-effective improvements.
- Category B—Potential for marked improvements. Consider pressure management, better active leakage control, and better maintenance.
- Category C—Poor. Tolerable only if water is plentiful and cheap, and even then intensify NRW reduction efforts.
- Category D—Bad. The utility is using resources inefficiently and NRW reduction programmes are imperative.

8.3 PERFORMANCE INDICATORS FOR COMMERCIAL LOSSES

The IWA Water Loss Task Force is also developing a performance indicator for commercial losses similar to the ILI.[6] The indicator uses a base value of 5% of water sales as a reference, and the actual commercial loss value is calculated against this benchmark. This is the Apparent (Commercial) Loss Index (ALI).

$$\textit{Apparent Loss Index (ALI)} = \frac{\textit{Apparent loss value}}{\textit{5\% of water sales}}$$

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[6] Apparent Water Loss Control—The Way Forward. WLTF article, Water 21, April 2008.

A commonly used indicator that expresses commercial losses as a percentage of water supplied is misleading because it does not reflect the true cost of lost revenue. Currently, the best indicator is to measure commercial losses as a percentage of authorised consumption.

8.4 IMPLEMENTING A MONITORING PROGRAM

A water utility embarking on the implementation of an NRW strategy needs to monitor its progress using some or all of the indicators detailed above. Since it is a utility-wide undertaking, an independent team should be established to audit progress. This NRW audit team should not be responsible for any physical activities to reduce NRW, but should be dedicated to auditing all of the departments involved with NRW strategy activities.

Utilities should continuously monitor NRW levels.

The implementation of the NRW strategy is a long-term process, often requiring four to seven years to complete. During this time, staff changes will occur, and the NRW audit team should train all incoming staff on the NRW strategy and its importance to the company.

The NRW audit team should also establish yearly targets for each department using one or more of the indicators, and monitor progress on a monthly progress. The number and type of indicators depends on the department and its activities. For example, the Network Department may be responsible for leakage detection and repair; in this case, the physical loss indicators of litres/connections/day and litres/connections/km can be used.

A monthly NRW strategy progress meeting should include representatives from all departments, with discussions on progress and hindrances. A senior member of the management team should chair the meeting, to stress the importance of the NRW strategy implementation. The head of the NRW audit team will support the chair by providing technical details and progress reports.

Annex 5 contains a ‗self assessment matrix‘ for operators to review the status of tasks at each stage of NRW management. This allows the utility to score its operational efficiency on a range from 1 to 5, and from a basic to a high level of NRW management. The utility can move from a lower to a higher level by introducing improvements to NRW management tasks.

Key Messages

- Utility managers use performance indicators to measure progress in reducing NRW, develop standards, and prioritise investments.
- The best performance indicator for physical losses is the Infrastructure Leakage Index (ILI).
- A commonly used performance indicator for commercial losses is the Apparent Loss Index (ALI). Currently, the best commercial loss indicator is to measure it as a percentage of authorised consumption.
- Utility managers must develop and implement monitoring programs to ensure their NRW targets are being met.

9. BUILDING CAPACITY TO MANAGE NRW THROUGH UTILITY-TO-UTILITY TWINNING PARTNERSHIPS: CASE STUDIES

Reducing and managing NRW remains a challenge for many utilities and service providers, especially those in Africa where dwindling water supply, worsening water quality, and aging infrastructure place additional pressure on tackling water losses and improving operational efficiencies. To overcome these challenges, water service providers worldwide have demonstrated the value of ‗twinning', or focused and sustained exchange between practitioners, in promoting the adoption of improved policies and best practices, and in building human and institutional capacity.

This chapter gives and example of a newly-formed partnership between African utilities, and an example of established twinning partnerships between SE Asian utilities.

BOX 9.1: TWINNING AND WATER OPERATOR PARTNERSHIPS

During the 4th World Water Forum in 2006, the UN Secretary General's Advisory Board on Water and Sanitation announced the Hashimoto Action Plan, calling for the establishment of a platform to launch and coordinate twinning arrangements or Water Operators Partnerships (WOPs) ‗in order to strengthen the capacities of the public water operators that currently provide over 90 per cent of the water and sanitation services and who are key players for attaining the [Millennium Development Goals] on drinking water supply and sanitation.'

9.1 TWINNING APPROACH

9.1.1 FACILITATING LINKAGES

Through twinning, utility managers and staff learn about best practices and gain practical knowledge through peer-to-peer exchanges, specialised on-the-job training, information exchange, technical assistance, peer review, and technology demonstrations from leading utilities. All partners contribute in-kind or in-cash for twinning activities, such as workshop venues, translation services, and local travel.

Practitioners share best practices and new systems to build capacity and realise tangible improvements for managing NRW.

In a twinning arrangement, a utility searching for solutions to operational efficiency constraints is paired with another utility that has proven success in addressing similar challenges and is willing to share its knowledge and innovations. The facilitator searches for potential linkages, matches counterpart institutions, and facilitates the initiation, establishment, and implementation of twinning partnerships.

Both partners have to express their priorities to strengthen their capacities in understanding and addressing NRW. To link both partners with other practitioners the facilitator must conduct an assessment of various utilities that have successfully reduced NRW and then determine their interest in participating in a twinning partnership. Once mentor utility partners are identified detailed discussions between the utilities are held to understand the incentives for all parties to commit to a partnership. Site visits to enable the mentor practitioners to become familiar with the partners‘ operational challenges can also be arranged. Building trust and a working relationship are critical outcomes of the initial introduction.

BOX 9.2: TWINNING PRINCIPLES

- Practitioner-to-practitioner exchange of policies and practical solutions is key.
- Benefits from the twinning partnerships are mutual, but not necessarily equal.
- Twinning partnerships are demand-driven, in line with partner strategies, plans, and interests, and results-oriented, ensuring the adoption of best practices and activities that result in real improvements and tangible outcomes.
- Partners support programmes on a cost-share basis, providing in-kind and funding support for each activity.
- All partnerships operate on a non-profit basis.

9.1.2 UNDERSTANDING PRIORITIES AND SETTING GOALS

To support the partnering approach, the Water and Sanitation Program (WSP) in Africa facilitated a utility self-assessment exercise among selected African water utilities to ascertain their strengths and needs and identify the most promising areas for learning and peer-support under the evolving Water Operators Partnerships (WOPs) platform. The results of the assessment provide a basis for further development of the WOP program in Africa.

The findings, despite the many problems in getting reliable data, broadly confirm the perilous state of the urban water sector in Africa. On average, utilities provide water to only about 65 percent of the population within their respective areas of jurisdiction while sewerage services coverage is only 36 percent. Sewerage coverage generally lags behind water in all regions but it is one of the areas where there is greatest opportunity for collaboration. The findings also show that NRW is a major weakness for most utilities in the sample. In many systems, as much as a third of production is lost due to technical and commercial losses and, on average, utilities in the sample get revenue for only half of the water they produce.

In addition to the NRW challenge, most utilities in the sample are currently struggling to cover even their operating costs. In all regions less than half of the utilities can be considered financially viable and, for many, poor performance on collections seems to be the main problem.

The WOP-Africa programme is managed jointly by the African Water Association (AfWA) and the East and Southern Africa Region-IWA (ESAR-IWA). This is via a three year business plan with major support from the Global WOPs Alliance and the World Bank‘s Water and Sanitation Programme (WSP). The WOP-Africa programme is building on the work of the former Water Utilities Partnership (WUP) in Africa. WOPs apply a strategy of intense and systematic knowledge-sharing (including peer-support) between water operators as a way of bridging the capacity gaps that exists in many countries.

BOX 9.3: BASIC STEPS IN ESTABLISHING TWINNING PARTNERSHIPS

1. Solicitation—Finding the right partners
2. Assessment—Selecting the right match for each utility
3. Initiation—Introducing partners
4. Establishment—Getting started in working together, including understanding priorities and setting goals
5. Implementation—Working together to achieve results
6. Replication—Disseminating best practices through key networks

9.2 TWINNING ACTIVITIES IN AFRICA

Over the last decade more than thirty countries in Africa have been implementing institutional reforms of urban water and sanitation services. Some have been more successful than others but all provide lessons to be shared in the sector. The trend in the sector has been to bring in non-utility consultants to engage with water and sewerage utilities on specific, short-term projects for institutional capacity building. In common with many such projects worldwide these have not usually yielded sustainable solutions. However, selected utility-to-utility exchanges have been promising and provide an opportunity to scale-up these initiatives within a stronger framework.

The WOP-Africa is built on the premise that well-performing utilities will step forward and emerge as leaders and that the needs of the less well-performing utilities will be met in a professional and sustainable manner. This framework for WOP-Africa is a culmination of initial activities facilitated by the Water and Sanitation Programme in Africa (WSP-Africa). This is in response to the need of the utilities in Africa to operationalise the WOP-Africa. The utilities in Africa believe that by working together, making use of the immense experience that exists on the continent and sharing these experiences, WOP-Africa is more likely to realize its vision of an Africa with improved water and sanitation services for all.

9.2.1 WATER OPERATOR PARTNERSHIPS (WOPS)

The development of WOPs in Africa has progressed in stages:

- Inter-utility twinning and capacity building
- ‗Establishment‘ workshops to initiate WOPs
- ‗Building partnerships‘ workshops to identify potential twinning projects

Twinning and capacity building had been carried out between utilities prior to the WOP/AfWA activities. Mentor utilities were:

- SDE Senegal (for most West African countries utilities)
- ONEP Morocco (for most west African countries utilities)
- SODECI Cote d'Ivoire (for most West African counties utilities)
- NWSC Kampala (for most East and Central African utilities
- Rand Water, South Africa (for the southern region)

‗Establishment workshops' to initiate the Water Operator Partnership and potential partnerships in Africa were held at Nairobi, Johannesburg and Cotonou between 2006 and 2008. These workshops led to the creation and launch of WOP Africa for the African continent

Three WOP Africa ‗Building Partnerships' workshops took place over the period July 2007 to October 2008. These began with the Kampala workshop (July 2007) organized by Uganda's NWSC, aimed at utility managers and sector policymakers from Eastern Africa. It was followed by the Dakar workshop (September 2008) gathering utilities from Western & Central Africa including a contingent of senior managers from six Nigerian utilities. The last workshop was directed at utilities from Southern Africa, as well as at a number of Eastern African utilities, and took place in Maseru (November 2008).

Each workshop gathered about 60 to 100 utility managers and representatives from other sectors and partners. All in all, more than 240 utility managers from more than 80 utilities have been exposed to the WOP concept and have participated in its preparation.

9.2.2 THE KIWASCO MODEL

Utility-to-utility partnerships are at the core of the WOP activities, and a first capacity building WOP-Africa is underway between NWSC in Uganda and Kisumu Water and Sewerage Company (KIWASCO) in Kenya.

At a regional workshop held in Kampala in June 2008, a utility self assessment exercise validated and developed a framework for a utility-to-utility partnership. KIWASCO identified NWSC as a corporation from which it would share its best practices based on strengths and weaknesses. A memorandum of understanding was signed on 23rd December 2008 from which areas of cooperation on core utility operations were laid down. Discussions have been held with the Global WOPs Alliance and UN HABITAT regarding the execution of a short term high impact programme with advisory services/technical assistance from the NWSC External Services unit. Funding has been secured and will be channelled through the African Water Association (AfWA). The project began in May 2009.

The partnering project is addressing:

- HR management policies, procedures and tools
- Labour productivity, rewards and incentives
- Operations effectiveness and contractualization
- Reduction of NRW, detection of leaks and other losses

- Customer care, revenue collection and communication strategies

9.3 TWINNING ACTIVITIES IN ASIA

The United States Agency for International Development‘s Environmental Cooperation–Asia (ECO-Asia) programme demonstrates how twinning arrangements helps water utilities meet the challenges of reducing water losses and improving operational efficiencies to support the achievement of the Millennium Development Goals (MDGs) in urban areas. ECO-Asia facilitates linkages between utilities to address specific priority needs, such as NRW management. Utility strengthening through these collaborative arrangements promotes self-reliance and long term sustainability, which in the long run will result in not only improved efficiencies but also expanded service areas and increased revenues.

In 2006-07, ECO-Asia facilitated twinning partnerships between Ranhill Utilities Berhad (Ranhill), a Malaysian utility recognized for effectively reducing and managing NRW, and the Provincial Waterworks Authority (PWA) of Thailand and the Bac Ninh Water Supply and Sewerage Company (WSSC) in Vietnam. The aim was to build their capacities in understanding and tackling NRW. In these twinning arrangements, ECO-Asia promoted the practitioner-to-practitioner exchange of best practices based on Ranhill‘s achievements in reducing NRW in Johor, Malaysia.

After initiating linkages between utility partners, ECO-Asia facilitated the development of a programme of activities involving all partners, where Ranhill—the mentoring utility - would share its best practices for managing NRW. Upon concurring to the joint program, all partners signed an agreement to implement the twinning activities to strengthen capacities and achieve the adoption of best practices for managing water losses at PWA and the Bac Ninh WSSC. ECO-Asia continued to facilitate and monitor the programme implementation to better enable integration of practices and policies.

In the Ranhill-PWA-Bac Ninh WSSC partnerships, activities included a series of classroom and on-the-job training workshops and field practices to enable transfer of practical solutions and best practices. Initially, Ranhill trained senior managers and operations staff to better understand NRW and its impact on a utility‘s finances and operations. Building on this improved awareness, operations staff next learned how to conduct an internationally-recognised water balance to detect key sources of NRW, followed by further hands-on training on approaches to reduce NRW, such as DMA design and establishment. Key PWA and Bac Ninh WSSC managers also visited Ranhill operations in Johor to advance their understanding of field applications of NRW reduction techniques. In all exchanges, Ranhill shared its solutions and practical lessons gained in effectively managing NRW.

9.3.1 THE BAC NINH MODEL

For the Bac Ninh WSSC, the twinning partnership built the capacity of its staff to improve its operations by strengthening the basic understanding of NRW management and introducing various activities needed to lower NRW. Main results from the partnership with Ranhill include:

- Key staff from both technical and non-technical departments improved their understanding of NRW, especially on identifying the major causes of NRW and developing practical

Experts from Ranhill working hand-in-hand with their counterparts in Bac Ninh, Vietnam, to test DMA operations.

- Solutions necessary to manage them, and on performing a water balance as the critical step in developing an NRW management strategy.
- Technical staff members continue to conduct water balances on discrete service areas and are beginning to attribute inconsistent NRW to inadequate billing and collection processes (i.e. commercial losses).
- Technical staff members have incorporated best practices introduced by Ranhill for establishing DMAs, such as ensuring adequate water pressure and closing all boundary valves, to their current procedures and are testing them on a pilot DMA.
- Key engineers worked with Ranhill to revise its current DMA design to enable improved NRW management following training events.
- As part of the pilot DMA activities, the Bac Ninh WSSC purchased and commissioned critical equipment, such as data loggers and a bulk meter to lower NRW levels, with guidance from Ranhill.

9.4 PROMOTING TWINNING PARTNERSHIPS

Twinning partnerships are practitioner-to-practitioner linkages. Linkages are usually water utility partnerships that explore opportunities to twin water service providers, cities, governments, and financing institutions—with the aim of improving and expanding delivery of water supply and sanitation services.

One example of this is the model provided by ECO-Asia to disseminate, replicate, and strengthen the results of such twinning partnerships, ECO-Asia cooperates with regional Asian networks and platforms on knowledge sharing, training, and networking activities. Partner networks include the International Water Association (IWA), Southeast Asian Water Utilities Network (SEAWUN), South Asia Water Utilities Network (SAWUN), ASEAN Environmentally Sustainable Cities Initiative, Association of Development Financing Institutions in Asia and the Pacific, and CityNet. With its partner networks, ECO-Asia will continue to find opportunities to replicate best practices and innovations and to facilitate new twinning arrangements. Inter-regional cooperation is an effective approach to leveraging local capacity and, at the same time, promoting greater understanding and collaboration in a highly diverse region.

In Africa, a workshop for utilities held in Johannesburg on 24-26 April 2007 brought together 96 water utility executives representing 70 water utilities in 30 African countries. The workshop was a follow-up to the 6-8 December 2006 Capacity Building Workshop organized jointly by UN-DESA and UN-HABITAT in Nairobi, Kenya. The idea of Water Operators Partnerships (WOP) was endorsed by the United Nations Secretary-General‘s Advisory Board (UNSGAB) on Water and Sanitation in March 2006 as one of its key programs. It is also part of the Hashimoto Action Plan to be implemented by different key stakeholders in the water and sanitation sector including the UN, international organizations, multi-lateral development banks and governments.

The Water Operators Partnership for Africa (WOP-Africa) will build on the work of the Water Utilities Partnership (WUP) and is part of the Global Water Operators Partnership under the leadership of UN-Habitat. The workshop in Johannesburg was historic in that AfWA and ESAR-IWA, the two Water Associations on the continent, had an unprecedented opportunity to come together and strategize on how best to meet the challenge of improving utility performance and achieving the MDGs in water and sanitation for urban Africa. There are a number of operational details that are yet to be determined, but it is clear that African water utilities are best placed to move forward with this initiative in a participatory and coordinated manner.

Key Messages

- Water service providers worldwide have demonstrated the value of ‗twinning', or focused and sustained exchange between practitioners, in promoting the adoption of improved policies and best practices, and in building human and institutional capacity.
- In a twinning arrangement, a utility searching for solutions to operational efficiency constraints is paired with another utility that has proven success in addressing similar challenges and is willing to share its knowledge and innovations.
- Twinning activities include peer-to-peer exchanges, specialised on-the-job training, information exchange, technical assistance, peer review, and technology demonstrations.
- The twinning model demonstrates how regional collaboration and sharing of best practices among peers benefit all parties involved, although the benefits vary in form and results.
- To disseminate, replicate, and strengthen the results of such twinning partnerships, ECO-Asia cooperates with regional networks and platforms on knowledge sharing, training, and networking activities.

ANNEX 1: GLOSSARY

MANAGERS’ NRW HANDBOOK - GLOSSARY

THE WATER BALANCE

System Input Volume (allow for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorized Consumption	
			Customer Metering Inaccuracies and Data Handling Errors	
		Physical Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility‘s Storage Tanks	
			Leakage on Service Connections up to Point of Customer Use	

WATER BALANCE DEFINITIONS

In the following, all terms used in Figure above are listed in hierarchical order—as one would read the water balance form from left to right. Some of the terms are self-explanatory but are still listed for consistency.

System Input Volume

The volume of treated water input to that part of the water supply system to which the water balance calculation relates.

Authorized Consumption

The volume of metered and/or un-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so by the water supplier, for residential, commercial and industrial purposes. It also includes water exported across operational boundaries.

Authorized consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.

Water Losses

The difference between System Input and Authorized Consumption. Water losses can be considered as a total volume for the whole system, or for partial systems such as transmission or distribution schemes, or individual zones. Water Losses consist of Physical Losses and Commercial Losses (also known as Real Losses and Apparent Losses)

Billed Authorized Consumption

Those components of Authorized Consumption which are billed and produce revenue (also known as Revenue Water). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Unbilled Authorized Consumption

Those components of Authorized Consumption which are legitimate but not billed and therefore do not produce revenue. Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption.

Commercial Losses

Includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorized consumption (theft or illegal use).

Commercial losses are called "Apparent Losses" by the International Water Association and in some countries the misleading term "Non-Technical Losses" is used.

Physical Losses

Physical water losses from the pressurized system and the utility‘s storage tanks, up to the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Physical losses are called "Real Losses" by the International Water Association and in some countries the misleading term "Technical Losses" is used.

Billed Metered Consumption

All metered consumption which is also billed. This includes all groups of customers such as domestic, commercial, industrial or institutional and also includes water transferred across operational boundaries (water exported) which is metered and billed.

Billed Unmetered Consumption

All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering. This component might also include water transferred across operational boundaries (water exported) which is unmetered but billed.

Unbilled Metered Consumption

Metered Consumption which is for any reason unbilled. This might for example include metered consumption by the utility itself or water provided to institutions free of charge, including water transferred across operational boundaries (water exported) which is metered but unbilled.

Unbilled Unmetered Consumption

Any kind of Authorized Consumption which is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well run utility it is a small component which is very often substantially overestimated. Theoretically this might also include water transferred across operational boundaries (water exported) which is unmetered and unbilled—although this is an unlikely case.

Unauthorized Consumption

Any unauthorized use of water. This may include illegal water withdrawal from hydrants (for example for construction purposes), illegal connections, bypasses to consumption meters or meter tampering.

Customer Metering Inaccuracies and Data Handling Errors

Commercial water losses caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.

Leakage on Transmission and/or Distribution Mains

Water lost from leaks and breaks on transmission and distribution pipelines. These might either be small leaks which are still unreported (e.g. leaking joints) or large bursts which were reported and repaired but did obviously leak for a certain period before that.

Leakage and Overflows at Utility's Storage Tanks

Water lost from leaking storage tank structures or overflows of such tanks caused by e.g. operational or technical problems.

Leakage on Service Connections up to point of Customer Metering

Water lost from leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Leakage on service connections might be reported breaks but will predominately be small leaks which do not surface and which run for long periods (often years).

Revenue Water

Those components of Authorized Consumption which are billed and produce revenue (also known as Billed Authorized Consumption). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Non-Revenue Water

Those components of System Input which are not billed and do not produce revenue. Equal to Unbilled Authorized Consumption plus Physical and Commercial Water Losses.

(Unaccounted-for Water)

Because of the widely varying interpretations and definitions of the term ‗Unaccounted for Water', it is strongly recommend that this term be no longer used. It is equivalent to ‗Water Losses' in the Water Balance diagram

UNDERSTANDING LEAKAGE

Background Leakage

Background leakage (also called background losses) are individual events (small leaks and weeps) that will continue to flow, with flow rates too low to be detected by an active leakage control campaign unless either detected by chance or until they gradually worsen to the point that they can be detected. As the term is nearly untranslatable, it is often referred to as "unavoidable losses". The level of background leakage depends on the overall infrastructure condition, the pipe material(s) and the soil. It is furthermore heavily influenced by pressure (N1=1.5 or even higher).

Bursts

Events with flow rates grater than those of background losses and therefore detectable by standard leak detection techniques. Bursts can be visible or hidden.

Reported Bursts

Reported Bursts are visible leaks that are brought to the attention of the water utility by the general public or the water supply organization's own operatives.

Unreported Bursts

Unreported bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties. These breaks go undetected without some form of active leakage control.

Active Leakage Control (ALC)

ALC is the policy a water utility implements if it decides to pro-actively search for hidden leaks. ALC in its most basic form consists of regular sounding (e.g. listening to leak noise on fire hydrants, valves and accessible parts of service connections (e.g. stop cock) with listening sticks or electronic devices.

Leak Duration

The length of time for which a leak runs consists of three separate time components - awareness, location and repair time.

Awareness Time

Awareness Time is the average time from the occurrence of a leak until the water utility becomes aware of its existence. The awareness time is influenced by the type of applied ALC policy.

Location Time

For reported bursts, this is the time it takes for the water utility to investigate the report of a leak or break and to correctly locate its position so that a repair can be carried out. For Unreported bursts, depending on the ALC method used, the location duration may be zero since the burst is detected during the leak detection survey and therefore awareness and location occur simultaneously.

Repair Time

The time it takes the water utility to organize and affect the repair once a leak has been located.

N1 Factor

The N1 Factor is used to calculate pressure/leakage relationships:

Leakage Rate L (Volume/unit time) varies with PressureN1 or L1/L0 = (P1/P0)N1

The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. N1 Factors range between 0.5 (corrosion holes only in metallic systems) and 1.5 with occasional values of up to 2.5. In distribution systems with a mix of pipe materials, N1 values might be in the order of 1 to 1.15. Therefore a linear relationship can be assumed initially until N1 Step Tests are carried out to derive better data.

N1 Step Test

The N1 Step Test is used to determine the N1 value for areas of the distribution network. Inflow to the area as well as pressure at the Average Zone Point are recorded. During the test supply pressure into the area is reduced in a series of steps. This pressure reduction together with the corresponding inflow reduction forms the basis for the calculation of N1.

Pressure Step Test

Equivalent to N1 Step Test.

Average Zone Point (AZP)

The AZP is the point in a certain zone or area of the distribution network which is representative for the average pressure in this particular part of the distribution network.

QUANTIFYING LOSSES

Physical Loss Component Analysis

Determination and quantification of the components of physical losses in order to calculate the expected level of physical losses in a distribution system. The BABE concepts were the first component analysis model.

BABE Concepts

The Bursts And Background Estimates (BABE) concepts were developed by the UK National Leakage Initiative between 1991 and 1993. The concepts were the first to model physical losses objectively, rather than empirically, thus permitting rational planning management and operational control of strategies for their reduction.

Leakage Modeling

Leakage modeling is a methodology to analyze 24h inflow and pressure data of a hydraulically discreet part of the distribution system. Using the N1 pressure:leakage relationship principles and the results of the N1 Step Test the measured inflow can be split into:

- Consumption; and
- Leakage; and further into:
- Background Losses
- Losses from Bursts (= losses which can be recovered)

Equivalent Service Pipe Bursts (ESPBs)

The number of ESPBs is an indication of how many hidden leaks can be expected in a certain part of the distribution network. It is calculated by dividing the volume of excess (or hidden) losses by the volume of water lost through an average service pipe burst.

Hidden Losses (Excess Losses)

Physical loss component analysis is used to determine the part of physical losses which is in "excess" of all other leakage components. The volume of Hidden (Excess) Losses represents the quantity of water lost by "hidden" leaks that are not being detected and repaired with the current leakage control policy.

District Metered Area (DMA)

A discrete zone with a permanent boundary defined by flow meters and/or closed valves.

Night Flow Test (NFT)

Zone inflow and pressure measurement carried out during night hours, usually between 02:00 and 04:00 hours to measure Minimum Night Flow and corresponding Average Zone Night Pressure.

Average Zone Night Pressure (AZNP)

The AZNP is the average pressure during (low consumption) night hours measured at the Average Zone Point.

Minimum Night Flow (MNF)

The Minimum Night Flow (MNF) in urban situations normally occurs during the early morning period, usually between around 02:00 and 04:00 hours. The MNF is the most meaningful piece of data as far as physical loss levels are concerned. During this period, consumption is at a minimum and therefore physical losses are at the maximum percentage of the total flow. The estimation of the physical loss component at Minimum Night Flow is carried out by subtracting an assessed amount of Minimum Night Consumption for each of the customers connected in the zone being studied.

Minimum Night Consumption

Minimum Night Consumption is part of the Minimum Night Flow and is normally composed of three elements:

- Household night use
- Non-household night use
- Exceptional night use

Net Night Flow

Net Night Flow is the difference between Minimum Night Flow and Minimum Night Consumption and is equivalent to Night Leakage

[Net Night Flow] = [Minimum Night Flow] - [Minimum Night Consumption]

PERFORMANCE INDICATORS

Infrastructure Leakage Index (ILI)

The ILI is a measure of how well a distribution network is managed (maintained, repaired, rehabilitated) for the control of real losses, at the current operating pressure. It is the ratio of Current Annual volume of Physical Losses (CAPL) to Minimum Achievable Annual Physical Losses (MAAPL).

$$ILI = CAPL / MAAPL$$

Being a ratio, the ILI has no units and thus it facilitates comparisons between countries that use different measurement units (metric, U.S., or imperial).

Minimum Achievable Annual Physical Losses (MAAPL)

Physical Losses cannot be totally eliminated. The volume of Minimum Achievable Annual Physical Losses represent the lowest technically achievable annual volume of Physical Losses for a well-maintained and well-managed system. The standard equation for calculating MAAPL for individual systems was developed and tested by the IWA Water Losses Task Force. It allows for:

- background leakage—small leaks with flow rates too low for sonic detection if non-visible
- reported leaks and breaks—based on average frequencies, typical flow rates, target average durations
- unreported leaks and breaks—based on average frequencies, typical flow rates, target average durations
- pressure/leakage rate relationships (a linear relationship being assumed)

The MAAPL equation requires data on four key system-specific factors:

- Length of mains (all pipelines except service connections)
- Number of service connections
- Length of service connection between property boundary and customer meter. (Note: this is not the same as the total length of the service connection. Losses on the service connection between the tapping point at the main pipeline are included in the allowance per service connection. The additional allowance for length of connections on private land was included to take the longer leak run-times in situations were visible leaks would not be seen by public into account. In most urban situations, if the

customer meter is inside the building, the length of service connection between property boundary and customer meter is obviously nil.)

- Average operating pressure

Minimum Achievable Annual Physical Losses (MAAPL) is called "Unavoidable Annual Real Losses (UARL)" by the International Water Association.

ANNEX 2: LOCATING AND REDUCING UNAUTHORISED CONSUMPTION

At least once a year, the water utility should:

1. Verify Customer Database

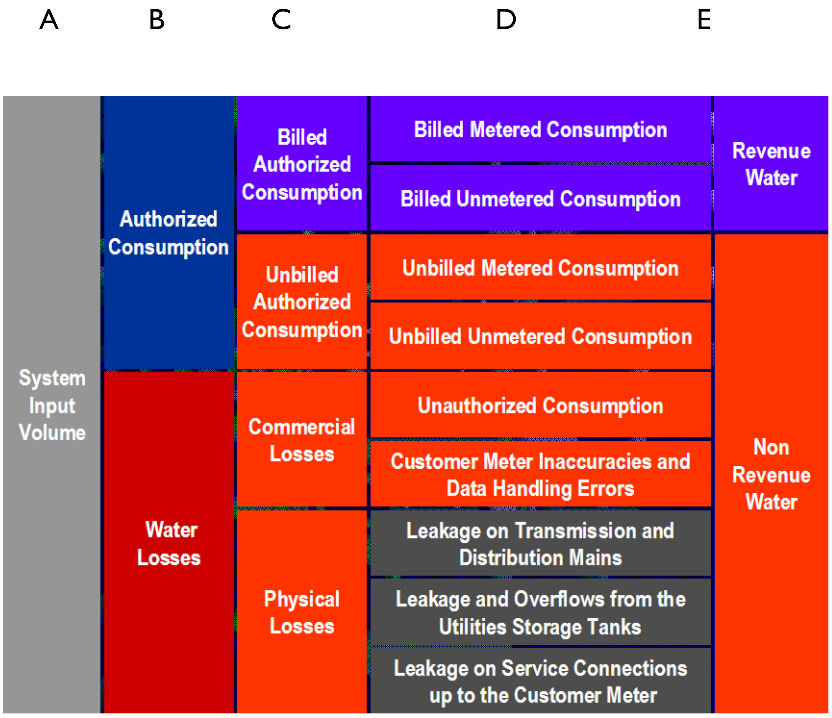
During routine meter reading, direct meter readers to confirm:

- Buildings are connected to and receiving water supply.
- Buildings are recorded in the customer account register.
- Size of the service connection or meter.
- Meter serial number is assigned to the customer account.
- Building classification matches service connection or meter size.

2. Review Policies and Procedures

- Review service connection policies and procedures to make sure they do not encourage illegal connections.
- Simplify connection application procedures.

ANNEX 3: STEPS FOR CALCULATING NRW USING THE IWA WATER BALANCE TABLE



A	B	C	D	E
System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorized Consumption	
			Customer Meter Inaccuracies and Data Handling Errors	
		Physical Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Service Connections up to the Customer Meter	

Water balance results in volumes and consumptions in cubic meters per year.

2.3.1 STEP 1—DETERMINE SYSTEM INPUT VOLUME

Identify sources of input (and export) volume:

- Water supplied to the network from own WTW sources
- Water transferred in from adjacent networks
- Water purchased from bulk suppliers
- Water exported from the network

Ensure meter accuracy:

- Establish meter accuracy from manufacturers‘ manuals (eg +/- 2%)
- Check meter readings using downstream master meter or insertion meter
- Replace or re-calibrate meters as necessary
- Correct System Input Volume for all known errors
- Apply 95% Confidence Limits

If there are any un-metered sources the annual flow should be estimated by using any (or a combination) of the following:

- Temporary flow measurements using portable devices
- Reservoir drop tests
- Analysis of pump curves, pressures and average pumping hours

2.3.2 STEP 2—DETERMINE AUTHORISED CONSUMPTION

Billed Metered Consumption

- Extract consumption of the different consumer categories (e.g. domestic, commercial, industrial) from the utility‘s billing system
- Analyse the data, paying special attention to very large consumers.
- Process the annual billed metered consumption information taken from the billing system to
- allow for meter reading time-lag
- Ensure that the billed metered consumption period used in the audit is consistent with the audit period
- Establish meter accuracy from manufacturers‘ manuals (eg +/- 2%)
- Apply 95% Confidence Limits

Billed Unmetered Consumption

- Extract data from the utility‘s billing system
- Identify and monitor unmetered domestic customers for a certain period, either by the installation of meters on those non-metered connections or by measuring a small area with a number of unmetered customers (the latter avoids customers changing consumption habits)

Unbilled Metered Consumption

- Establish the volume of unbilled metered consumption in a way similar to that for billed metered consumption

Unbilled Unmetered Consumption

Unbilled unmetered consumption, traditionally including water used by the utility for operational purposes, is often seriously overestimated. This might be caused by simplifications (a certain % of total system input) or deliberate overestimates to ‗reduce' water losses. Components of unbilled unmetered consumption should be identified and individually estimated, for example:

- Mains flushing: How many times per month? For how long? How much water?
- Fire fighting: Has there been a big fire? How much water was used?

2.3.3 STEP 3—ESTIMATE COMMERCIAL LOSSES

Unauthorised Consumption

It is difficult to provide general guidelines for estimating unauthorized consumption. There is a wide variation of situations and knowledge of the local situation will be most important to estimate this component. Unauthorised consumption can include:

- Illegal connections
- Misuse of fire hydrants and fire fighting systems
- Vandalised or bypassed consumption meters
- Corrupt practices of meter readers
- Open boundary valves to external distribution systems (unknown export of water).

The estimation of unauthorised consumption is always a difficult task and should at least be done in a transparent, component based way so that the assumptions can be easily checked and/or modified later.

Customer Metering Inaccuracies and Data Handling Errors

The extent of customer meter inaccuracies, namely under- or over-registration, has to be established based on tests of a representative sample of meters. The composition of the sample should reflect the various brands and age groups of domestic meters. Tests are done either at the utility's own test bench, or by specialized contractors. Large customer meters are usually tested on site with a test rig. Based on the results of the accuracy tests, average meter inaccuracy values (as % of metered consumption) will be established for different user groups.

Data handling errors are sometimes a very substantial component of commercial losses. Many billing systems do not reach the expectations of the utilities but problems often remain unrecognised for years. It is possible to detect data handling errors and problems with the billing system by exporting billing data (of say the last 24 months) and analysing it using standard database software.

The detected problems have to be quantified and a best estimate of the annual volume of this component has to be calculated.

2.3.4 STEP 4—CALCULATE PHYSICAL LOSSES

The calculation of real losses in its simplest form is now straightforward:

Physical Losses = Volume of NRW minus Volume of Commercial Losses
This figure is useful for the start of the analysis in order to get a feeling for the expected magnitude of physical losses. However, it always has to be kept in mind that the water balance might have errors—and that the calculated volume of real losses might simply be wrong.

2.3.5 STEP 5—ESTIMATING REAL LOSS COMPONENTS

To accurately split real losses into its components will only be possible with a detailed component analysis. However, a first estimate can be made using a few basic estimates:

Leakage on Transmission and/or Distribution Mains

Bursts on distribution and especially transmission mains are primarily large events—they are visible, reported and normally repaired quickly. By using data from the repair records, the number of leaks on mains repaired during the reporting period (usually 12 months) can be calculated, an average flow rate estimated and the total annual volume of leakage from mains calculated as follows:

NUMBER OF REPORTED BURSTS X AVERAGE LEAK FLOW RATE X AVERAGE LEAK DURATION (SAY 2 DAYS)

A certain provision for background losses and current undetected leaks on mains can then be added.

Leakage and Overflows at Utility's Storage Tanks

Leakage and overflows at storage tanks are usually known and can be quantified. Overflows can be observed and the average duration and flow rate of the events estimated. Leakage of storage tanks can be calculated by making a level drop test with in and outflow valves closed.

Leakage on Service Connections up to Point of Customer Metering

By deducting mains leakage and storage tank leakage from the total volume of real losses, the approximate quantity of service connection leakage can be calculated. This volume of leakage includes reported and repaired service connection leaks as well as hidden (so far unknown) leaks and background losses from service connections.

Step 1: Enter System Input Volume in Column A

Step 2: Enter in Column C: Billed Authorized Consumption

Enter in Column D:

- Billed Water Exported (none exported = 0)
- Billed Metered Consumption
- Billed Un-metered Consumption

Enter in Column E: Revenue Water

(NOTE: Billed Authorized Consumption should equal to the summation of the three Billed components above and. All billed water use is the same as a utility‘s revenue).

Step 3: Calculate the Volume of Non-Revenue Water (E) as:

System Input Volume (A) - Revenue Water (E).

Step 4: Enter in Column D:

- Unbilled Metered Consumption
- Unbilled Un-metered Consumption

Enter in Column C: Total Unbilled Authorized Consumption

Step 5: In Column C: Add volumes of Billed Authorized Consumption and Unbilled Authorized Consumption

Enter sum in Column B (top) as Authorized Consumption

Step 6: Calculate Water Losses (B) = System Input Volume (A) - Authorized Consumption (B)

Step 7: Assess components of Unauthorized Consumption, and Metering Inaccuracies and Data Handling Errors (D) by best means available through field verification in random service area and by estimation.

Add Unauthorized Consumption and Metering Inaccuracies (D)

Enter sum in Commercial Losses (C)

Step 8: Calculate Physical Losses (C) = Water Losses (B) - Commercial Losses (C).

Step 9: Assess components of Physical Losses (D) by best means available in the field and through desk studies (e.g. night flow analysis, burst frequency/flow rate/duration calculations, modeling etc)

Add components of Physical Losses (D)

Cross-check with volume of Physical Losses (C) as derived from Step 8

This approach yields best results when meters are installed and regularly calibrated. Results will remain approximate to the extent that factors are based on estimates.

ANNEX 4: SAMPLE WATER AUDIT CHECKLIST

OBJECTIVES FOR A WATER AUDIT

- To assess whether the water utility is serving its customers effectively, efficiently and equitably;
- To estimate water losses and their sources; and
- To assess how different groups are connected to piped water and to determine how the utility and informal service providers respond to concerns of different groups.

ANALYSIS

The important aspect of the analysis is to reveal:

- The actual coverage of the community with piped water and 24-hour service.
- The official NRW and the use of NRW.
- Unit cost of water from various sources and the numbers who use.
- Unit consumption of water from various sources and the numbers who use.
- The extent of informal water supplies.

USE OF ANALYSIS

The analysis may be used to:

- Reduce water losses.
- Register and assist water vendors.
- Monitor investment and intervention results and gauge impact over time.

SERVICE AREA

1. Population in City
2. Population in Waterworks Service Area
3. Population Served by Waterworks (Direct)
4. Population Served by Waterworks (Bulk Supply / Indirect)
5. Population Served by House Connection

6. Population Served by Shared Connection
7. Population Served by Standpipe or Community Tank
8. Population Served by Waterworks Tanker

SERVICE DELIVERY—METERING

9. Number of Connections Domestic Metered / Not Metered
10. Number of Standpipes / Community Tank Metered / Not Metered
11. Number of Bulk Connections Metered / Not Metered
12. Number of Non-Domestic Connections Metered / Not Metered
13. Number of Sources of Treated Water for Piped Supply Metered / Not Metered
14. Are all master meters accurate? Yes / No
15. Is there any chance of backflow, bypass or double metering of water? Yes / No
16. Number of Waterworks Tankers / Capacity
17. Are all parks, schools, wastewater treatment plants and government buildings metered? Yes / No
18. Are meter readers motivated to find leaks and trained to do so? Yes / No
19. Are slow or stopped meters identified by the billing department? Yes / No
20. Are both system and customer meters regularly tested and properly sized? Yes / No
21. Are authorised unmetered uses estimated and reported? Yes / No

SERVICE DELIVERY—LEVEL OF SERVICE AND OPERATIONS

22. Proportion of House Connections with 24 hour Supply %
23. Percentage of Service Area with 24 Hour Supply %
24. Production Volume (m3/day)
25. Consumption Volume Domestic (m3 / month)
26. Consumption Volume Non-Domestic (m3/ month)
27. Are comparisons made between water produced and water used, on a regular basis?
28. New Connections Installed in last 12 months (Domestic)
29. New Connection Fee and Terms of Payment (Domestic)
30. Average Household Water Consumption Per Month

31. Average Household Water Bill Per Month
32. Number of People Employed by Waterworks
33. Is the public notified via advertising, to report leaks and bursts? Yes / No
34. Are there any unusual pressure drops in any part of the system or isolated complaints about low pressure? Yes / No
35. Are there high flows occurring during periods when flows should be low? Yes / No
36. Are all valves and backflow preventers between pressure zones working properly? Yes / No
37. Is the telemetry available? Yes / No. If yes, is it accurate? Yes / No
38. Are streams and storm channels routinely checked for unusual flows or possible leaks? Yes / No
39. Once estimated, are non-revenue water figure monitored over time? Yes / No
40. Is the volume of non-revenue water increasing? Yes / No

FINANCIAL PARAMETERS

41. Money Billed Per Month for Domestic Customers
42. Money Billed per Month for Non-Domestic Customers
43. Are there any known major errors or are any corrections used in billing records such as wrong multipliers on meters? Yes / No
44. O&M Expenses Power /Staff/ Other Per Annum
45. Operating Ratio Expenses /Total Billings
46. Accounts Receivables in Equivalent Months Billings
47. Annual Capital Expenditure
48. O&M Cost
49. Capital Cost
50. Lifeline Rate for Poor
51. Cross Subsidy Non-Domestic to Domestic
52. Cross Subsidy City to Town
53. Sources of Capital Works Funding (Central Govt, Local Govt, Donors, Other)
54. Average Household Income Per Month

ANNEX 5: SELF ASSESSMENT MATRIX ON NON-REVENUE WATER

SELF ASSESSMENT MATRIX ON NON-REVENUE WATER

	Level / Issues questions	1 Basic	2	3	4	5 High
1	**Water Balance, Flow and Pressure Monitoring, Mapping**					
1.1	**Water Balance**	We do not establish a water balance	We have tried to establish a water balance but gave up since we don't know the split in physical and commercial losses	We establish a water balance following our own format	We establish an annual water balance in accordance with the international form	We establish an annual water balance in accordance with the international form and also use 95% confidence limits to indicate accuracy bands.
1.2	**System Input Metering**	Most of our system input is not metered	Not all, but > 50% of our system input is metered	Our system input is metered but we are not sure about the accuracy of these (partly old) meters	Our system input is metered with mechanical and/or magnetic flow meters that are rarely calibrated	Our system input is metered with magnetic flow meters that are regularly calibrated
1.3	**Pressure Monitoring**	We do not have any pressure recorders installed	We have a few pressure recorders at pumping stations and treatment plants installed	We have a few pressure recorders at pumping stations and treatment plants installed and sporadically measure pressure in the distribution network with pressure gauges	We have a few pressure recorders at pumping station and treatment plants and sporadically measure pressure in the distribution network with pressure loggers	We have permanently installed pressure loggers and continuously monitor pressure in the distribution network

	Level **Issues questions**	**1** **Basic**	**2**	**3**	**4**	**5** **High**
1.4	**Maps/GIS**	We do not have maps at all	The maps we have are not updated	We have started to update our maps	Our maps are updated but do not include GIS	We use GIS based on updated maps
2	**Leak Repair Records**					
2.1	**Leak Repair Records**	We have no records of leak repairs	The only way to know the number of leaks repaired is to look into the customer complaints book	We keep basic leak repair records that only tell us whether the leak was on a main pipe or a service connection	We keep detailed records that indicate location, pipe diameter, material and type of leak as well date of detection and date and duration of repair	We keep detailed records that indicate location, pipe diameter, material and type of leak as well date of detection and date and duration of repair and have linked this to our GIS
3	**Performance Indicators**					
3.1	**Performance Indicators**	The only PI used is % NRW	We have tried to calculate water loss performance indicators	We regularly calculate physical loss performance indicators	We regularly calculate physical and commercial loss performance indicators	We regularly calculate physical and commercial loss performance indicators and publish them in our annual report
4	**Active leakage control**					
4.1	**Active leakage control**	We only repair visible leaks.	We have leak detection equipment but we do not use it.	We do leak detection occasionally if there is a specific problem in an area.	We have started to do regular leak surveys.	We cover the network by leakage survey at least once a year.

	Level Issues questions	1 Basic	2	3	4	5 High
4.2	**District Meter Areas (DMAs)**	We have no DMAs and have no plans to establish DMAs	We have started to establish the first DMAs	The first DMAs are established and we have already the first results	We have several DMAs and check and analyse inflow data sporadically	We have several DMAs and monitor flow and pressure on a regular basis
4.3	**Leak Repair - Distribution Pipes(Repair Time)**	We have no records and therefore don't know how fast our leaks repaired	Our average repair time is more than 7 days	Our average repair time is between 7 and 3 days	Our average repair time is between 3 and 1.5 days	Our average repair time is less than 1.5 days
4.4	**Leak Repair - House Connections**	We have no records and therefore don't know how fast our leaks repaired	Our average repair time is more than 14 days	Our average repair time is between 14 and 7 days	Our average repair time is between 7 and 2 days	Our average repair time is less than 2 days
5	**Customer Metering**					
5.1	**Customer Metering**	We have no customer metering	Only large customers are metered	We have started with universal customer meters but at present not all customers have meters installed	Nearly all of our customers are metered, except public fountains, stand pies and similar.	100% of our customers are metered
5.2	**Customer Meter Replacement and Age**	We have no reliable information on the age of our customer meters	Many of our customer meters are older than 10 years, we have not yet introduced a regular replacement policy	We only change meters if they are obviously not functioning anymore	We have a meter replacement policy but have not been able to change all meters so some of our customer meters are still older than 10 years	We strictly follow our customer meter replacement policy and replace ALL meters every 5 - 7 years

	Level / Issues questions	1 Basic	2	3	4	5 High
5.3	**Customer Meter Class**	All customer meters are class B	All customer meters are Class B and C	All customer meters are class C	All customer meters are Class C and D	All customer meters are class D
5.4	**Customer Database**	Our customer database has not been updated for a long time	We sporadically update our customer database	We are in the process of updating our customer database	We regularly update our customer database by house to house surveys and checks	We have an updated customer data base that is linked to the GIS.
5.5	**Customer Meter Reading**	We have no special system of controlling meter readers	We only rotate meter readers if we are suspicious of inaccuracies	We regularly rotate meter readers	We regularly rotate meter readers and make often spot checks	Our meter readers use handheld meter reading devices
5.6	**Illegal Connections, meter tampering, bypasses**	We have not made any assessment and have no program to deal with water theft	We occasionally detect illegal connections	We occasionally detect illegal connections and other forms of fraud	We have a thorough illegal connection detection program	We have a thorough illegal connection detection program and also try to identify bypasses

N-1 -2

The Manager's Non-Revenue Water Handbook

A Guide to Understanding Water Losses

The Manager's Non-Revenue Water Handbook

A Guide to Understanding Water Losses

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Published July 2008

Ranhill Utilities Berhad and the United States Agency for International Development (USAID) jointly funded the publication of this report. AECOM International Development provided assistance under USAID contract 486-C-00-05-00010-00. The views expressed in this publication do not necessarily reflect the views of Ranhill or USAID.

Contents

List of Figures

List of Tables

List of Boxes

FOREWORD

Most developed countries have a solid infrastructure and established operational practices for managing and controlling non-revenue water (NRW). This is not always the case in developing countries; many are struggling to ensure that customers receive a reasonable supply of safe drinking water, often via a pipe network that is inadequate, with poor record systems and a low level of technical skills and technology. Tariff systems and revenue collection policies often do not reflect the true value of water supplied, which limits the utility's cost recovery and encourages customers to undervalue the service.

Developing countries in Asia face similar challenges in reducing NRW, including aging infrastructure, financial constraints, poor governance, and poor project design. Many utilities in the region, however, can draw on motivated and industrious staff to implement solutions once the challenges of reducing NRW have been identified.

Using some key messages, *The Manager's Non-Revenue Water Handbook* leads the utility manager through the stages of addressing NRW—first, understanding and quantifying NRW, and then developing a strategy to address it.

Chapter 1: examines the scale of NRW, and emphasises the challenges to Asian water utilities. Utility managers and operational staff should be committed to managing NRW as a long-term process that incorporates numerous aspects of water operations. Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. Utilities must end a cycle, known as the 'Vicious Circle', where companies face increased NRW, financial losses, limited investment, and poor service. Instead, utilities should follow the 'Virtuous Circle' that enables them to decrease NRW, improve efficiency, preserve financial resources, and promote strong customer satisfaction and willingness to invest.

Chapter 2: highlights the need to understand and accurately quantify NRW as an indicator of a water utility's operating efficiency. The International Water Association (IWA) water balance is an excellent method for utility managers to break down and identify the key components of NRW. Ensuring the accuracy of data used to calculate the level of NRW is also essential in understanding the full problem. Collecting accurate data from production meters and customer meters helps to measure the true NRW level. In addition, the customer billing cycle must be factored into NRW calculations to ensure that the time period used for the consumption volume measurement matches the production meter volume measurement.

Chapter 3: considers the requirements to develop an NRW reduction strategy. Utilities need to consider establishing an NRW management team to develop a strategy, ensure that all components of NRW are addressed, and verify that the proposed strategy is feasible and practicable in terms of the workload and budget. Choosing the right team members promotes ownership among the various utility departments involved in the strategy's implementation, and also facilitates consensus at the senior management level. As a first step in developing the strategy, the team should set an initial utility-wide target for NRW reduction based on the economic level of NRW. The team can balance the financial and water supply objectives of the strategy using the water balance results, while aiming to shorten the awareness, location, and repair (ALR) times in addressing water losses. The NRW strategy may cover a period of four to seven years. As a result, pilot projects can help utility managers understand the full budget and resources required to implement the entire strategy.

Chapter 4: emphasises the level of awareness required at all levels—from top decision-makers to the end consumer—that is critical for a successful NRW reduction programme. Support from the programme's top-level management, and the budget required, promotes the financial sustainability of the strategy. Middle management and staff must understand their roles and responsibilities in reducing NRW, since it requires a long-term combined effort from all departments in the utility. Also, reaching out to customers helps increase their awareness of NRW and how reducing water losses results in improved water supply and quality.

Chapter 5: addresses commercial losses. Commercial losses represent lost revenue, and even a small volume will have a large financial impact. They occur mostly through tampered meters, aging and improperly maintained meters, unauthorised connections, and administrative errors or even corrupt practices during the meter reading and billing process. Utilities should invest in training for meter readers, staff, and crews, as well as in accurate meters and a robust billing system, which can directly result in higher returns. In addition, collaboration from the public and certain government departments is required to overcome theft and illegal use of water.

Chapter 6: examines physical losses. These include leakage on transmission and distribution mains, leakage and overflows from storage tanks, and leakage on service connections up to the customer meter. Leakages from transmission and distribution mains are usually large events that can cause serious damage, but the public typically reports them rapidly, followed by the utility repair on an emergency basis. Other types of leakage are more difficult to detect and repair. A successful leakage management strategy requires pressure management, active leakage control, pipeline and asset management, and speedy and high-quality repairs.

Chapter 7: deals with zoning. Dividing an open water supply network into smaller, more manageable zones or district meter areas (DMAs) is now internationally accepted best practice. It enables the utility to better understand the network, and to more easily analyse pressure and flows in problem areas. The criteria for establishing DMAs include the size (or number of connections), number of valves that must be closed, number of flow meters, ground-level variations and visible topographic features that can serve as DMA boundaries. Utility managers use the minimum night flow (MNF) and legitimate night flow (LNF) to calculate the net night flow (NNF), along with commercial losses, to determine NRW in a DMA. Establishing DMAs helps to manage pressure, improve water quality, and enable continuous water supply.

Chapter 8: gives an indication of the range of performance indicators (PIs) available to utility managers. PIs are an aid to measuring progress in reducing NRW, developing standards, and prioritising investments. The IWA recommends the Infrastructure Leakage Index (ILI) as the best performance indicator for physical losses. Currently, the best PI for commercial losses is to express them as a percentage of authorised consumption. The IWA is developing another indicator for commercial losses called the Apparent Loss Index (ALI). Utility managers should develop and implement monitoring programs to ensure their NRW targets are being met.

Chapter 9: discusses some options for building capacities for managing NRW through 'twinning' arrangements, or utility-to-utility partnerships, facilitated through the Environmental Cooperation–Asia (ECO-Asia) Programme of the United States Agency for International Development (USAID). Water service providers worldwide have demonstrated the value of twinning, or focused and sustained exchange between practitioners, in promoting the adoption of improved policies and best practices, and in building human and institutional capacity. Twinning partnerships rely on counterpart exchange to help strengthen the capacity of a utility to improve services delivery (such as NRW reduction), expand services or convert to continuous water supply. Effective twinning partnerships are demand driven, address the interests and priorities of partners, results-oriented, and aim at the adoption and replication of best practices and solutions from one partner to another. The ECO-Asia twinning model demonstrates how regional collaboration and sharing of best practices among peers benefit all parties involved, although the benefits vary in form and results.

I am pleased to have been associated with developing *The Manager's Non-Revenue Water Handbook*. NRW is a global problem requiring a management strategy that can be globally applied. Developing such a strategy requires a diagnostic approach to identify the problem, and then to use the available tools to reduce or remove it. Following a step-wise process—asking some basic questions about the utility policies and practices, then undertaking the appropriate tasks to answer them—is the basis of successful strategy development.

As an international consultant, I have worked with many utilities in both developed and developing countries to introduce and implement NRW reduction strategies. I believe that the philosophies, concepts, and recommendations contained in this handbook closely reflect international best practice, particularly those recommended by the IWA and the World Bank Institute. I am pleased to endorse it. If Asian utilities apply the approach recommended in the handbook, they will rapidly benefit from a greater understanding of their networks' performance, and will have an increased knowledge of the tools available to identify and reduce their levels of NRW.

Malcolm Farley
International Water Loss Management Consultant
23 June 2008

1. INTRODUCTION

1.1 BACKGROUND

The global volume of non-revenue water (NRW) or water losses is staggering. Each year more than 32 billion m^3 of treated water are lost through leakage from distribution networks. An additional 16 billion m^3 per year are delivered to customers but not invoiced because of theft, poor metering, or corruption. A conservative estimate of the total annual cost to water utilities worldwide is US$14 billion. In some low-income countries this loss represents 50-60% of water supplied, with a global average estimated at 35%. Saving just half of this amount would supply water to an additional 100 million people without further investment.[1]

Other benefits from reducing NRW include the following:

- Water utilities gain access to a further US$3 billion in self-generated cash flow
- Water utilities reduce illegal connections, thereby creating greater fairness between users
- More efficient and sustainable utilities improves customer service
- New business opportunities creates thousands more jobs

In Asia, many water utilities operate under the jurisdiction of municipal, provincial, or central governments. These utilities often rotate or appoint senior managers and directors with various backgrounds outside the water sector. As a result, senior managers entering these positions have limited knowledge of water supply operations, especially on the vital technical and institutional requirements for effectively managing NRW and water losses. This handbook serves to assist

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[1] Source: World Bank Discussion Paper No. 8, December 2006

senior water utility managers in better understanding the definition, causes, and practical solutions to address NRW, a key performance indicator for a utility's operations. It provides the information that managers need when discussing NRW-related issues with their staff. By design, it is not a hands-on technical guide for engineers to manage NRW, but rather is a reference for senior managers.


By reducing water losses, water utilities have additional supply to expand services to underserved areas.

The United States Agency for International Development (USAID), under the Environmental Cooperation–Asia (ECO-Asia) programme, demonstrates how "twinning" arrangements can help water utilities meet the challenges of NRW management and adjust their operational efficiencies to improve service delivery in urban areas. ECO-Asia is working with a number of successful urban water utilities to develop and implement twinning partnerships with other utilities seeking to enhance their services provision. In 2006-2007, ECO-Asia facilitated twinning partnerships between Ranhill Utilities Berhad (Ranhill), a Malaysian utility recognized for effectively reducing and managing NRW, with the Provincial Waterworks Authority (PWA) of Thailand and the Bac Ninh Water Supply and Sewerage Company (WSSC) in Vietnam. The objective of these partnerships was to strengthen the capacities of PWA and Bac Ninh WSSC to better understand and address NRW. Lessons from Ranhill's experiences and these twinning arrangements have contributed to the development of *The Manager's Non-Revenue Water Handbook*.

1.2 CHALLENGES IN ASIAN WATER UTILITIES

There are areas of plentiful water across Asia, just as there are water-scarce areas, as a result of both regional geography and a country's ability to pay for water. The photos below illustrate the inequity of water availability between countries. Although reducing NRW cannot solve such global contrasts, it can help to improve the quantity and quality of water available in water-scarce areas.


Water abundance improves quality of life


Customers queuing to collect water in water-scarce regions

Not all countries or regions—particularly those in parts of Asia—have the infrastructure and established operational procedures to begin tackling NRW. Many are struggling to ensure that customers receive a reasonable water supply to sustain health and life. Water utility managers in Asia will invariably face greater challenges including the following:

- Rapid urbanization
- Diminishing water supply
- Environmental pollution
- Outdated infrastructure
- Poor operations and maintenance policy, including ineffective record-keeping systems
- Inadequate technical skills and technology
- Greater financial constraints, including an unsuitable tariff structure and/or revenue collection policy
- Political, cultural, and social influences
- A higher incidence of commercial losses, particularly illegal connections

However, Asian utility managers also have a number of strengths they can build on:

- A high work ethic and level of industriousness
- Ability to make do with available resources and materials
- Motivated staff with the potential for developing high technical capacity

These factors all influence the scope for managing losses and demand, and affect the pace of change. At the same time, continued NRW limits the financial resources available to tackle these challenges facing water utilities in Asia. This handbook enables water utility managers in the region to address the limitations, acknowledge the challenges, and make gradual improvements to current policies and practices.

Box 1.1: Why Do Utilities Struggle with NRW Reduction?

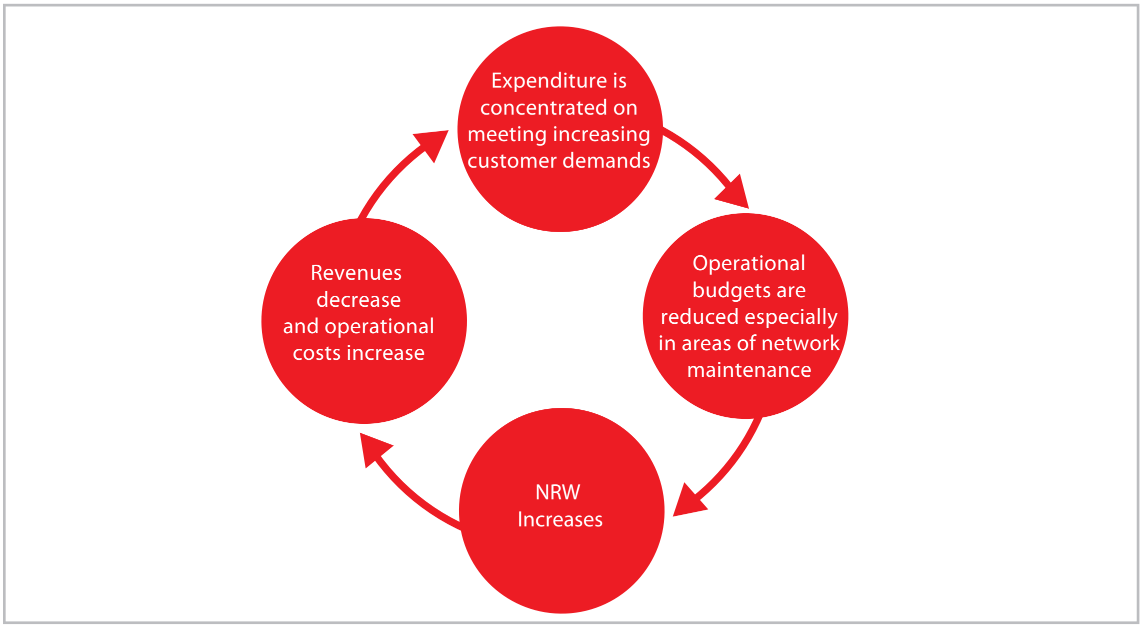
- Not understanding the problem (magnitude, sources, costs)
- Lack of capacity (insufficient trained staff)
- Inadequate funding to replace infrastructure (pipes; meters)
- Lack of management commitment
- Weak enabling environment and performance incentives

Bill Kingdom, Roland Liemberger, Philippe Marin, "The Challenge of Reducing Non-Revenue Water in Developing Countries--How the Private Sector Can Help: A Look at Performance-Based Service Contracting", World Bank, Paper No. 8, Dec 06

1.3 IMPACTS OF NRW: THE VICIOUS AND VIRTUOUS CIRCLES

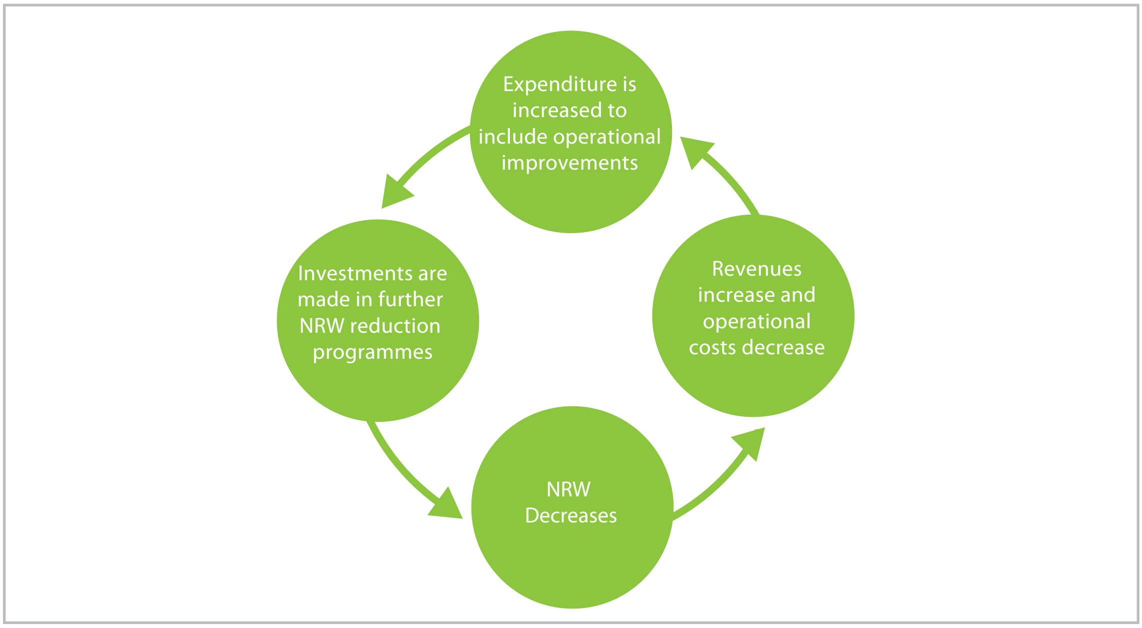
The 'Vicious Circle' of NRW (Figure 1.1) is one of the key reasons for poor company performance and results in both physical and commercial losses (see Chapters 5 and 6). Physical losses, or leakages, divert precious water from reaching customers and increase operating costs. They also result in larger investments than necessary to augment network capacity. Commercial losses, caused by customer meter inaccuracies, poor data handling, and illegal connections, reduce income and thereby financial resource generation.

Figure 1.1: The Vicious NRW Circle



The challenge for water utility managers is to transform the Vicious Circle into the 'Virtuous Circle' (Figure 1.2). In effect, reducing NRW releases new sources of both water and finances. Reducing excessive physical losses results in a greater amount of water available for consumption and postpones the need for investing in new sources. It also lowers operating costs. Similarly, reducing commercial losses generates more revenues.

Figure 1.2: The Virtuous NRW Circle



Replacing aging infrastructure requires financial capacity, which can be gained through NRW reduction

1.4 ADDRESSING NRW

Water utilities anywhere in the world should use a diagnostic approach, followed by the implementation of solutions that are practicable and achievable to reduce NRW. The first step is to learn about the network and operating practices. Typical questions during this process include:

- How much water is being lost?
- Where are losses occurring?
- Why are losses occurring?
- What strategies can be introduced to reduce losses and improve performance?
- How can we maintain the strategy and sustain the achievements gained?[2]

1.4.1 Reasons for failure—and the road to success

Although minimising non-revenue water should be a priority for water utilities, many still struggle to achieve acceptable NRW levels. The reasons NRW strategies fail range from not understanding the magnitude of the problem to a lack of financial or human resource capacity. In addition, utility managers often do not pay enough attention to NRW because of weak internal policies and procedures, which contributes to rising NRW levels.

NRW management is not a one-off activity, but one requiring a long-term commitment and involvement of all water utility departments. Many utility managers do not have access to information on the entire network, which would enable them to fully understand the nature of NRW and its impact on utility operations, its financial health, and customer satisfaction. Underestimating NRW's complexity, and the potential benefits of reducing NRW, often lead to reduction programmes' failure. Successful NRW reduction is not about solving an isolated technical problem, but is instead tied to overall asset management, operations, customer support, financial allocations, and other factors (Figure 1.3).

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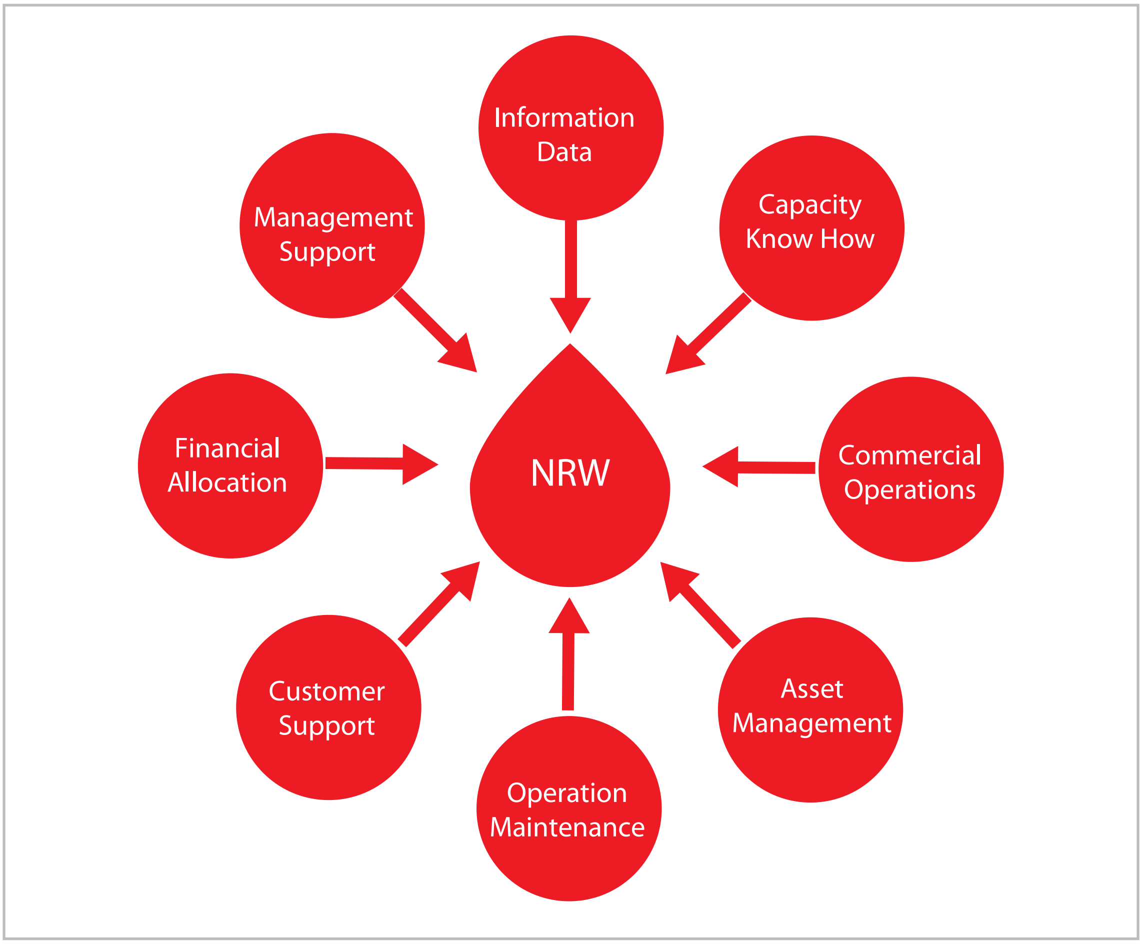
[2] Kingdom, B., R. Liemberger, and P. Marin, 2006. "The Challenge of Reducing Non-Revenue Water in Developing Countries—How the Private Sector Can Help: A Look at Performance-Based Service Contracting", World Bank, Paper No. 8, Dec 2006

Figure 1.3: Reducing NRW is everyone's responsibility



Poor governance also affects NRW reduction. Utility managers often lack the autonomy, accountability, and technical and managerial skills necessary to provide reliable service. The utility's management should also tackle organisational challenges, such as policy barriers, inadequate technical capacity, and aging infrastructure. Finally, poor project design hinders efforts to reduce NRW, particularly underestimating the required budget.

However, utility managers' understanding of the institutional dimension of NRW is growing. In addition, a number of tools are emerging to support sustainable NRW reduction:

- New methodologies that quantify physical and commercial losses more accurately
- More effective technical approaches to manage leakage and reduce system pressure
- New instruments for engaging the private sector, such as performance-based contracts

1.4.2 The Manager's NRW Handbook

The Manager's NRW Handbook is a guide to implementing NRW reduction strategies by addressing each of these issues and designing solutions tailored to the water utility's specific needs. Its approach enables water utility managers to take a fresh look at the NRW problem and the factors influencing it. The handbook provides a starting point for a utility manager to assess NRW, modify operations and infrastructure to address such factors, and implement the required policies and practices. The handbook covers the following issues:

- Calculating the water balance, or how much water enters the network, and the amount that contributes to the utility's revenue water and non-revenue water (Chapter 2)
- Prioritising target NRW components and developing a reduction strategy (Chapter 3)
- Involving stakeholders, including management, operations staff, and the public, to implement the reduction strategy (Chapter 4)
- Addressing commercial losses (Chapter 5)
- Addressing physical losses (Chapter 6)
- Establishing District Meter Areas (DMAs) and using them to manage NRW (Chapter 7)
- Monitoring the utility's NRW management performance (Chapter 8)
- Highlighting a case study where utilities increased capacity and addressed NRW challenges through a twinning partnership arrangement (Chapter 9)

KEY MESSAGES

- Reducing NRW increases both financial resources and the water available to utilities.
- Developing countries in Asia face challenges in reducing NRW, such as aging infrastructure, financial constraints, and poor governance; however water utilities can draw on their motivated and industrious staff as a key strategy to improve NRW.
- The Vicious Circle leads to increasing NRW and financial losses, while the Virtuous Circle leads to decreasing NRW and financial resources.
- Managing NRW is a long-term process that must incorporate numerous aspects of water operations.
- Addressing NRW is the responsibility of managers across the water utility, including finance and administration, production, distribution, customer service, and other departments. *The Manager's NRW Handbook* can help utility managers identify sources of NRW and develop a strategy for reducing them.

2. KNOWING YOUR WATER LOSSES: THE WATER BALANCE

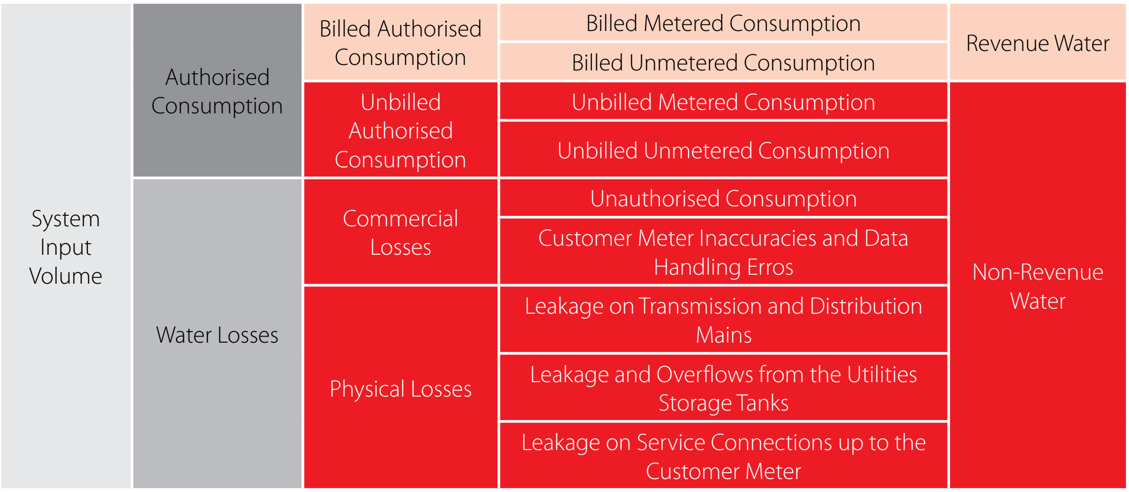
To most water utilities, the level of NRW is a key performance indicator of efficiency. However, most utilities tend to underestimate NRW because of institutional and political pressures, as well as a lack of knowledge to properly determine the NRW level. Reports of low levels of NRW are eagerly accepted by senior managers. However, reported low levels of NRW, whether due to deliberate misinformation or, more likely, a lack of accurate information, will not help the water utility to reduce its costs or increase revenue. Instead, it will mask the real problems affecting the water utility's operating efficiency.

Only by quantifying NRW and its components, calculating appropriate performance indicators, and turning volumes of lost water into monetary values, can the NRW situation be properly understood and the required actions taken. The utility manager now has a powerful tool to support this first step—the water balance calculation. In this chapter we will introduce the water balance concept and also an example of water balance software, WB-EasyCalc. This software assists managers in developing the water balance while also indicating the level of accuracy of the NRW calculation.

2.1 HOW MUCH WATER IS BEING LOST?

The first step in reducing NRW is to develop an understanding of the 'big picture' of the water system, which involves establishing a water balance (also called a 'water audit' in the United States). This process helps utility managers to understand the magnitude, sources, and cost of NRW. The International Water Association (IWA) has developed a standard international water balance structure and terminology that has been adopted by national associations in many countries across the world (Figure 2.1).

Figure 2.1: Water balance showing NRW components



System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Erros	
		Physical Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Service Connections up to the Customer Meter	

Non-revenue water (NRW) is equal to the total amount of water flowing into the water supply network from a water treatment plant (the 'System Input Volume') minus the total amount of water that industrial and domestic consumers are authorised to use (the 'Authorised Consumption').

NRW = System Input Volume - Billed Authorised Consumption

This equation assumes that:

- System input volume has been corrected for any known errors
- The billed metered consumption period for customer billing records are consistent with the System Input Volume period

Utility managers should use the water balance to calculate each component and determine where water losses are occurring, as described in the next sections. They will then prioritise and implement the required policy changes and operational practices.

NRW components cover the entire water utility supply system from the water treatment plant outlet meters to the customer meters, which means that managing NRW is the responsibility of the entire operations department. Water utilities often set up a dedicated 'NRW team', with disappointing results as everyone else in the company leaves NRW management to this team. As discussed in Chapters 3 and 4, an NRW reduction strategy should encompass all staff with each department's responsibilities outlined in detail.

2.2 WATER BALANCE COMPONENTS: WHERE ARE YOUR LOSSES OCCURRING?

Abbreviated definitions of the principal IWA water balance components are outlined in this section (see Annex 1: Glossary for other definitions)[3]:

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[3] See more detailed descriptions of each component and their measurement in the IWA reference manual by Farley, M. and S. Trow, 2003. *Losses in Water Distribution Networks—A Practitioner's Guide to Assessment, Monitoring, and Control.* IWA Publishing: ISBN 1 900222 11 6. http://www.iwapublishing.com/template.cfm?name=isbn1900222116

- **System Input Volume** is the annual volume input to that part of the water supply system.
- **Authorised Consumption** is the annual volume of metered and non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorised to do so (e.g. water used in government offices or fire hydrants). It includes exported water and the leaks and overflows after the point of customer metering.
- **Non-Revenue Water (NRW)** is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of Unbilled Authorised Consumption (usually a minor component of the water balance) and Water Losses.
- **Water Losses** is the difference between System Input Volume and Authorised Consumption. It consists of Commercial Losses and Physical Losses
- **Commercial Losses**, sometimes referred to as 'apparent losses', consist of Unauthorised Consumption and all types of metering inaccuracies
- **Physical Losses**, sometimes referred to as 'real losses', are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

Sometimes even the most basic information, such as system input volume, average pressure, supply time, length of mains, and the number of service connections, is not initially available. The process of calculating each of the water balance components and performance indicators will reveal such deficiencies. The utility management should then take corrective action to close these data gaps and improve data quality. Using incomplete or inaccurate data for the water balance calculation will not produce useful result.

When the entire system input is metered, determining the annual system input volume is a straightforward task. Utility managers must collect meter records regularly and calculate the annual quantities of the individual system inputs. This includes a utility's own sources as well as imported water from bulk suppliers. Ideally the accuracy of the input meters is verified using portable flow measuring devices.

Billed metered consumption includes all of the water consumption that is measured and charged to domestic, commercial, industrial, or institutional customers. It also includes exported water that is measured and charged. The billed metered consumption period used in the calculation should be consistent with the audit period by processing it for time lags (see Section 2.4.3 on 'Customer billing cycles' below). There is generally a lag of up to 30 days between the time when water is consumed and when the meter is read. In addition, NRW managers should determine the general accuracy of various domestic

Water utility managers need to accurately measure water produced from the treatment facility. Total water produced is a key input for the water balance.

and non-domestic consumption meters for a possible 95% confidence limit by taking a sample of existing working meters from various locations and testing them on a standard meter test rig. Independent companies provide testing services if the water utility does not own a meter test rig. If several different customer meter brands are in operation, then the sample selection should include meters from each brand.

Determining the annual billed metered consumption goes hand in hand with detecting billing and data handling errors, information that utilities also require for estimating commercial losses. The volume of unbilled metered consumption should be established using a similar approach to that for billed metered consumption.

Unbilled unmetered consumption is any kind of authorised consumption that is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well-run utility, it is a small component that is very often substantially overestimated. Unbilled unmetered consumption, traditionally including water the utility uses for operational purposes, is often seriously overestimated. This is sometimes caused by simplification (e.g. using a percentage of total system input), or by deliberate overestimates to 'reduce' the amount of NRW.

2.3 KEY STEPS FOR CONDUCTING A WATER BALANCE

The utility manager needs to have certain information about the network to conduct a water balance:

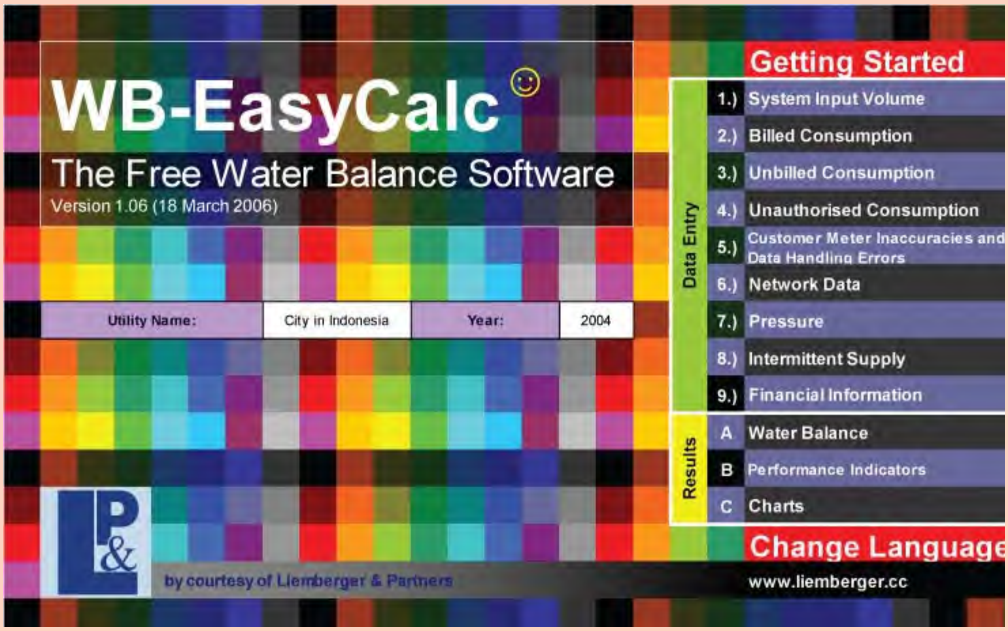
- System input volume
- Billed consumption
- Unbilled consumption
- Unauthorised consumption
- Customer metering inaccuracies and data handling errors
- Network data
- Length of transmission mains, distribution mains and service connections
- Number of registered connections
- Estimated number of illegal connections
- Average pressure
- Historic burst data
- Level of supply service (24-hour, intermittent, etc)

The four basic steps to conduct a water balance are summarised below (see a detailed description in Annex 3: Steps for Calculating NRW Using the IWA Water Balance):

- Step 1. Determine system input volume
- Step 2. Determine authorised consumption
  - Billed—total volume of water billed by the water utility
  - Unbilled—total volume of water provided at no charge

Box 2.1: WB-EasyCalc

WB-EasyCalc is one example of a tool to support water balance calculations in addressing NRW. Utility managers can use this spreadsheet-based software, developed by Liemberger and partners and supported by the World Bank Institute (WBI). The picture below shows the homepage of the software for 'getting started'.



WB-EasyCalc

The Free Water Balance Software

Version 1.06 (18 March 2006)

Utility Name: City in Indonesia
Year: 2004

One advantage of EasyCalc is that the software not only asks for physical data, but also for an assessment of the accuracy of that data. For example, when entering the production volume, the user must also estimate the accuracy of this data based on the type and age of production flow meters, if any, and the amount of maintenance carried out on the meter. Using these estimates, the software calculates NRW volume and its various components, in addition to the accuracy of these volumes. For example, EasyCalc may determine that NRW is 21% with an accuracy of +/- 66%— meaning that the actual NRW ranges between 7% and 35%.

WB-EasyCalc is available as a free download at http://www.liemberger.cc/diverse_uploads/WBEasyCalc.xls.

- Step 3. Estimate commercial losses
  - Theft of water and fraud
  - Meter under-registration
  - Data handling errors
- Step 4. Calculate physical losses
  - Leakage on transmission mains
  - Leakage on distribution mains
  - Leakage from reservoirs and overflows
  - Leakage on customer service connections

Confidence limits of 95% should be applied to all water balance data. These define the boundaries within which utility managers can be 95% sure that the true value for that particular component lies. Although the water balance is an important tool for understanding inflows, consumption, and losses, the general lack of data leads to problems. Data gaps make it difficult to quantify commercial losses and to pinpoint the nature and location of physical losses. However, the water balance can be improved using two other methodologies[4]:

- Component analysis of physical losses (see Chapter 6), using the network information required listed in Table 2.1
- Measurement of leakage, using analyses of night flows into District Meter Areas (DMAs) (see Chapter 7)

2.4 IMPROVING THE ACCURACY OF WATER BALANCE RESULTS

The accuracy of production meters, customer meter reading, and billing are the main factors affecting the NRW volume calculation.

2.4.1 Production meter accuracy

The accuracy of production flow meters is critical to calculating system NRW. Generally, the number of production flow meters is relatively small, meaning that a greater proportion of the flow is measured by each meter. This means that an error on one of these meters has a great impact on the total production measurement. Different meter types have different accuracies, as shown in Table 2.3.

Table 2.1: Indicative examples of meter accuracy

Equipment/Method	Approximate Accuracy Range
Electromagnetic Flow Meters	<0.15 -0.5%
Ultrasonic Flow Meters	0.5 - 1%
Insertion Meters	<2%
Mechanical Meters	1.0 - 2%
Venturi Meter	0.5 - 3%
Meas. Weirs in open channels	10 - 50%
Volume calculated with pump curves	10 - 50%
Note: Actual meter accuracy will depend on many factors (like flow profile, calibration, meter installation, maintenance) and has to be verified case by case	

Source: World Bank Institute, 2007

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[4] These methodologies are briefly outlined Chapters 6 and 7, and explained in more detail in Losses in Water Distribution Networks.

All meter types detailed above must be regularly maintained to ensure their continuing accuracy. Over time these meters can be affected by a number of factors, including water quality, pipe vibration, dirt entering the meter, and electronic malfunction. Utility managers should regularly check the accuracy of both the electronic functionality of the meter, if electronic, and the volumetric accuracy. The electronic functionality can be checked onsite using the meter manufacturer's test equipment. The volumetric accuracy can be checked using a second meter, which is generally a portable meter installed just for the test period. Some water utilities opt to install a second meter permanently as a backup in case the first meter fails.

Ranhill Experience: Production volume measurement

Independent water suppliers operating several water treatment plants in Johor, Malaysia, receive payments depending on the volume of water supplied. Because this volume requires accurate measurement, Ranhill has installed two production meters in series at all independent water supplier outlets to ensure continued accuracy.

2.4.2 Customer meter accuracy

The accuracy of customer meters is equally important, with the main difference being that there are many more customer meters in operation—and each measures a relatively smaller flow—than production meters. The accuracy of customer metering depends on several factors, including meter type, brand, replacement policy, maintenance, and water quality. The water utility should establish guidelines for all of these factors to ensure accuracy of customer consumption data.

Faulty meters require immediate replacement.

2.4.3 Customer billing cycle

When calculating the NRW value, many water utilities simply subtract customer consumption data from the production meter volume, and then are satisfied with the low result. However, this is often a false measurement of NRW because, unlike with the production meters, which are usually read on the same day of every month, customer meters are read over the full month. Information on the average billing cycle, or the time in days between meter reads, is critical. Utility managers should then factor the total consumption down

Field verification of network system data is crucial to understanding where water losses originate and setting NRW baseline level.

to get the true consumption volume for the exact time period as the production meter volume measurement.

Addressing the above issues greatly improves the accuracy of the NRW calculation, which utilities will use as the baseline in developing an NRW reduction strategy.

Ranhill Experience: Accurate NRW baselines

When the water utility in Johor was first privatised in 2000, the initial NRW level was reported as 33%. To verify this baseline level, Ranhill spent two years installing new production meters and replacing 150,000 customer meters. In addition, Ranhill implemented a new customer reading and billing system. These activities improved the data accuracy, resulting in a baseline NRW level of 45%. Although this new reported NRW level was higher, Ranhill now had confidence in its accuracy and could start to develop an NRW reduction strategy.

KEY MESSAGES

- NRW is an indicator of water utilities' operating efficiency.
- Ensuring the accuracy of the NRW calculation is essential in understanding the full problem.
- The IWA standard water balance is an excellent method of breaking down the components of NRW, and tools are available to help utility managers calculate the water balance
- Accurate production and customer metering ensure that the true NRW level is measured
- The average billing cycle must be factored into NRW calculations to ensure that time period used for the consumption volume measurement matches the production meter volume measurement.

3. STRATEGISING TO REDUCE AND MANAGE NON-REVENUE WATER

The NRW challenge can only be properly understood after NRW and its components are quantified, the appropriate performance indicators calculated, and the lost water volume is translated into its corresponding economic value. Development of the water balance reveals the magnitude of each NRW component. This chapter discusses how to identify the major NRW components and develop a company-wide strategy to reduce targeted components.

3.1 ESTABLISHING THE STRATEGY DEVELOPMENT TEAM

The NRW reduction strategy team ensures that all components of NRW are covered and that the proposed strategy is feasible in terms of physical application and financial requirements. The team should comprise of members from each operational department, including production, distribution, and customer service. It may also include members from the finance, procurement, and human resource departments. Choosing the right members promotes ownership by the utility's various departments involved in the strategy's implementation, and also ensure consensus by senior management.

3.2 IMPORTANCE OF SETTING APPROPRIATE NRW REDUCTION TARGETS

The strategy development team should first set a company-wide target for NRW reduction, taking into account the utility's other goals or policies that will either complement or conflict with NRW reduction. In addition, water utilities may have an active regulator who will set performance indicators for NRW and other targets. Often, the NRW target is chosen arbitrarily, without any real consideration of cost implications or whether ivvv t is achievable. Identifying the economic level of NRW is essential to setting the initial NRW target, and it requires a comparison of the cost of water being lost versus the cost of undertaking NRW reduction activities.

Figure 3.1: Identifying the economic level of NRW

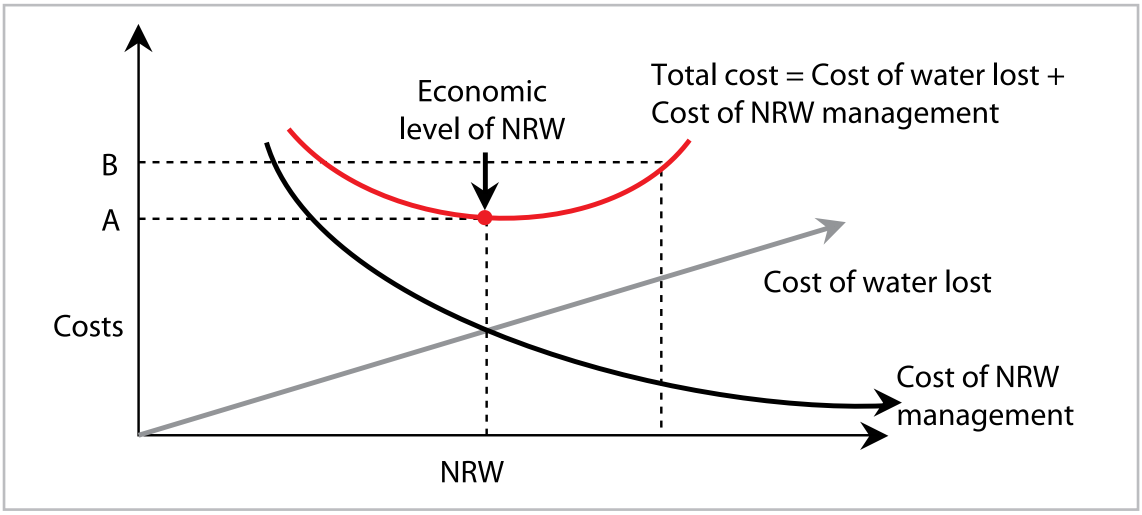


Figure 3.1 highlights how the economic level of NRW is determined. The two components that must be determined are the **cost of water lost** and the **cost of NRW management**:

- The cost of water lost is the value of the water lost through both physical and commercial losses. The volume of physical losses should be multiplied by the variable operational costs, including manpower, chemicals, and electricity. The volume of commercial losses should be multiplied by the average customer tariff. As NRW increases, the cost of water lost increases proportionally.
- The cost of NRW management is the cost of reducing NRW, including staff costs, equipment, transportation, and other factors. As NRW decreases, the cost of NRW management increases.

Adding the two cost components together gives the **total cost**. In Figure 3.1, the intersection of the two component lines coincides with the minimum total cost (cost A), which is the economic level of NRW.

The graph shows that letting NRW increase past the economic level reduces the cost of NRW management, but the total cost for the utility (cost B) will rise. Similarly, reducing NRW lower than the economic level of NRW will cost more than the potential savings. However, utility managers may sometimes decide to push NRW below the economic level, for example in areas where raw water is scarce or the image of the country requires low losses. In such cases, the difference between the cost of NRW management and the savings are usually subsidised by the government.

The economic level of NRW constantly changes with shifts in water tariffs, the cost of electricity and chemicals, staff salaries, and equipment supply costs. Managers should assess the economic level of NRW on a yearly basis and adjust the NRW target accordingly to ensure the efficient use of resources.

3.3 PRIORITISING NRW REDUCTION COMPONENTS

Once the utility-wide NRW target is set, utility managers should calculate the proposed volume of water saved by comparing the NRW baseline with the target level. The various components, as detailed in the water balance, are then prioritised according to how the required total reduction can be most cost-effectively achieved. That is, some components may comprise a significant volume, but would not be targeted because of the high cost to achieve reductions in that component. On the other hand, focusing on another component may cost less while reducing the same volume. The water balance table shows the magnitude of NRW components in terms of volume, which utility managers can use to determine the corresponding financial values.


Ensuring customer meter accuracies is just as important as sealing pipe leakages.

In general, if a physical loss is detected and repaired then the savings will be in terms of a reduction in variable operational costs. When a commercial loss is detected and resolved, then the saving will be an immediate revenue increase and thus is based on the water sales tariff. The water sales tariff is higher than the variable production cost for all profitable water utilities; in some cases, the sales tariff is as high as three or four times the production cost. A smaller volume of commercial loss may have a higher financial value, so if increasing financial resources is the objective, then commercial losses should be prioritised.

Ranhill Experience: Programme to improve company finances

One of the main reasons water services in Johor, Malaysia were privatised was that the government-run utility had been losing money over the previous five years. As soon as Ranhill assumed operations, it implemented a major customer meter replacement plan, installed a new customer billing software package, and introduced spot billing to improve meter reading practices. Within the first year of operation, the company started to realise a profit. Within two years, revenues had increased by 60% due to the programmes that had been implemented.

Developing an NRW reduction strategy requires water balance results, appropriate targets, and cost-benefit analyses to determine the return on investments.

Where a water utility has a shortage of treated water, and thus some customers receive less than a 24-hour supply or the supply coverage is less than 100%, then a reduction in physical losses would effectively create additional water supply. If increasing water supply is the objective, then prioritising physical losses could enable customers to receive water 24 hours a day, or for new customers to be connected to the supply system.

Table 3.1 shows an analysis of NRW actions according to volume and cost, and enables decision-makers to logically proceed with NRW planning.

Table 3.1: Volume and cost analysis for NRW management activities

		Cost		
		High	Medium	Low
Volume	High	Leakage on mains (P) Leakage on service connections (P)	Unauthorised consumption (C)	Unbilled metered consumption (U)
	Medium	Customer meter replacement (C)	Customer metering inaccuracies and data handling errors (C)	Pressure management (P)
	Low	Reservoir leakage (P)	Unbilled unmetered consumption (U)	Reservoir overflows (P)

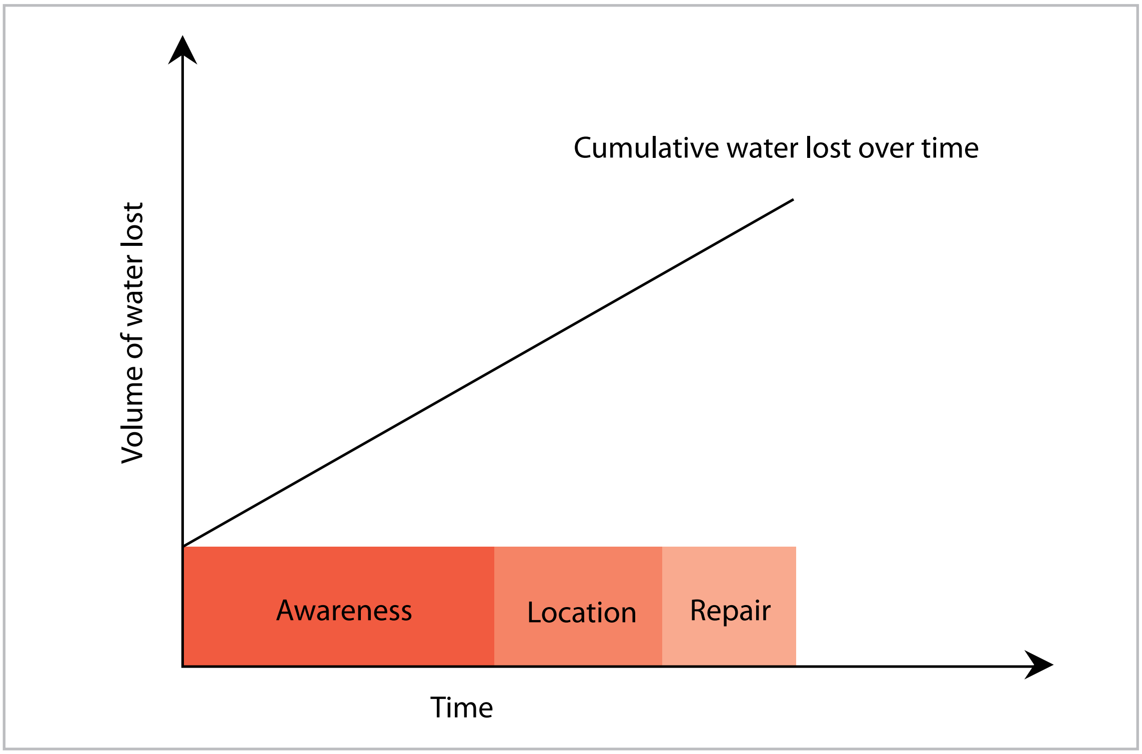
NRW Type: U=Unbilled authorised consumption, C=Commercial losses, P=Physical losses

3.4 BASIC PREMISE OF NRW REDUCTION STRATEGY: AWARENESS, LOCATION, AND REPAIR (ALR)

Once the utility-wide NRW target is set and the different components analysed to prioritise areas for achieving the desired reduction, then individual activities will be identified. The development of the strategy should be based on the concept of Awareness, Location, and Repair, or ALR. This concept states that any loss occurring from leaks, overflows, faulty customer meters, or other sources will have three stages as shown in the diagram below.

- Awareness time—time required for the utility to become aware of the leak
- Location time—time required to locate the leak
- Repair time—time required to repair the leak

Figure 3.2: The effect of time on the total volume lost



The volume of water lost will continue to increase until the water utility is aware of the problem, locates or pinpoints it, and finally repairs or resolves it. An underground leak could run for several months or even years without anyone being aware that it exists. Therefore, the NRW strategy must ensure that the company reduces its awareness, location, and repair times for all NRW components.

Many losses occur because of poor or limited maintenance, so in addition to reducing ALR, a fourth element of the NRW strategy should be system maintenance. This is critical to maintaining good asset condition and reducing the incidence of new leaks, meter failures, reservoir leaks, and other problems.

Chapters 5, 6, and 7 detail the activities required to shorten the ALR periods. When developing an NRW management strategy, remember that reducing NRW is not a short-term process, especially in aging, large, open, or high pressure systems. The timeframe for implementing each strategy component should be outlined, with some activities possibly spanning years rather than months. NRW strategies spanning between four and seven years are reasonable—any less is ambitious, and any more will not be as cost-effective.

3.5 BUDGET CONSIDERATIONS FOR IMPLEMENTING THE STRATEGY

Managers reviewing the most cost effective and applicable investments to implement water loss reduction activities.

The development and implementation of activities to achieve the targeted level of NRW incurs a financial cost. With some NRW management strategies lasting years, the overall cost could be quite substantial. A long-term budget that is thoroughly discussed with key stakeholders will ensure that all parties are aware of the costs required and that the strategy is financially viable. Many NRW strategies start off at full speed but often fail due to budget cuts over time.

Undertaking pilot projects to demonstrate the effectiveness of the NRW strategy is useful. The pilot should cover a smaller area, be substantial enough to ensure that all components of the NRW strategy are tested, and operate under financial conditions that can be replicated when activities are implemented throughout the entire network. The analysis of the pilot results should be used in the development of the economic level of NRW for the entire system.

In preparing a budget, the utility manager needs to identify the following costs:

- Staffing—Include staff for both direct NRW works (e.g. leakage technicians) and indirect support (e.g. procurement staff).
- Equipment—Include equipment installed permanently (e.g. DMA meters) and those used on a day-to-day basis (e.g. leakage detection equipment).
- Vehicles—Include transportation costs, which can become an important issue in maximising the work rate of all staff. Small teams generally cover the entire supply system for undertaking NRW works.
- Works—Include the costs for installing all equipment, such as meters and pressure reducing valves, and also detecting and repair all leaks.

KEY MESSAGES

- The NRW reduction strategy team ensures that all components of NRW are covered and that the proposed strategy is feasible in terms of physical application and financial requirements. Choosing the right members promotes ownership by the various utility departments involved in the strategy's implementation, and also ensure consensus by senior management.
- Identifying the economic level of NRW should be the basis for setting the initial utility-wide target for NRW reduction.
- Using the water balance to prioritise components for NRW reduction helps balance the financial and water supply objectives of the NRW strategy.
- The NRW reduction strategy should aim to shorten the awareness, location, and repair (ALR) times in order to minimise water losses.
- NRW reduction is a long-term process and the strategy may cover a period of four to seven years. Pilot projects can help water managers understand the full budget required to implement the entire strategy.

4. RAISING AWARENESS ON THE STRATEGY

Effectively addressing NRW requires a combined effort from management and staff throughout the utility. However, the number of staff with a good knowledge of NRW is usually limited to engineers or others working at an operational level. Everyone, from the Chief Executive Officer to the meter readers and crew, should understand the importance of NRW and how it affects their daily work and the utility. More specifically, the following groups should understand NRW and their role in reducing water losses:

- Top decision-makers, including the Board of Directors, mayors, or political leaders
- All levels of the utility's management and staff
- The general public, or consumers

The public's perception of NRW is shaped by information presented through the media, which often does not include full explanations of the complex issues involved. During the initial implementation period of the NRW reduction strategy, the public will be greatly affected when water supply is stopped to install meters, repair leaks, or undertake other work. The utility must ensure that the public is aware of the strategy and understands that service interruptions will result in long-term benefits for all.

This chapter describes the roles and responsibilities of each type of stakeholder in implementing the NRW reduction strategy. Outreach programs will help build awareness and consensus regarding the importance of reduction activities and the benefits of reducing NRW.

4.1 GAINING HIGH-LEVEL APPROVAL

Top decision-makers, such as the Board of Directors, the mayor, or other political leaders, are responsible for reviewing and approving the strategy. A general presentation and discussion on NRW will help ensure that they understand the value of minimising NRW. The decision-makers should be informed of the present NRW level, the benefits of reducing NRW, operational activities required to achieve reductions, and the budget required to carry out activities. Lack of approval at the highest levels or inadequate funding support has led to the failure of many NRW strategies.

Ranhill Experience: NRW Strategy and Action Plan

In Johor, Ranhill developed an 'NRW Strategy and Action Plan', which outlines the strategies, initiatives, and activities to reduce NRW. Initial brainstorming sessions drew staff from all levels and all operational departments. The document details policies for each department covering the four areas of awareness, location, repair, and maintenance. When changes or improvements are required, the strategy and action plan are revised and presented to senior management for approval.

Securing approval for the NRW reduction strategy from top decision-makers underscores its importance among staff. At the same time, the senior management will be accountable to the decision-makers for achieving results, and will report back on improvements to the strategy and any additional budget requirements.

4.2 BUILDING STAFF AWARENESS AND CONSENSUS

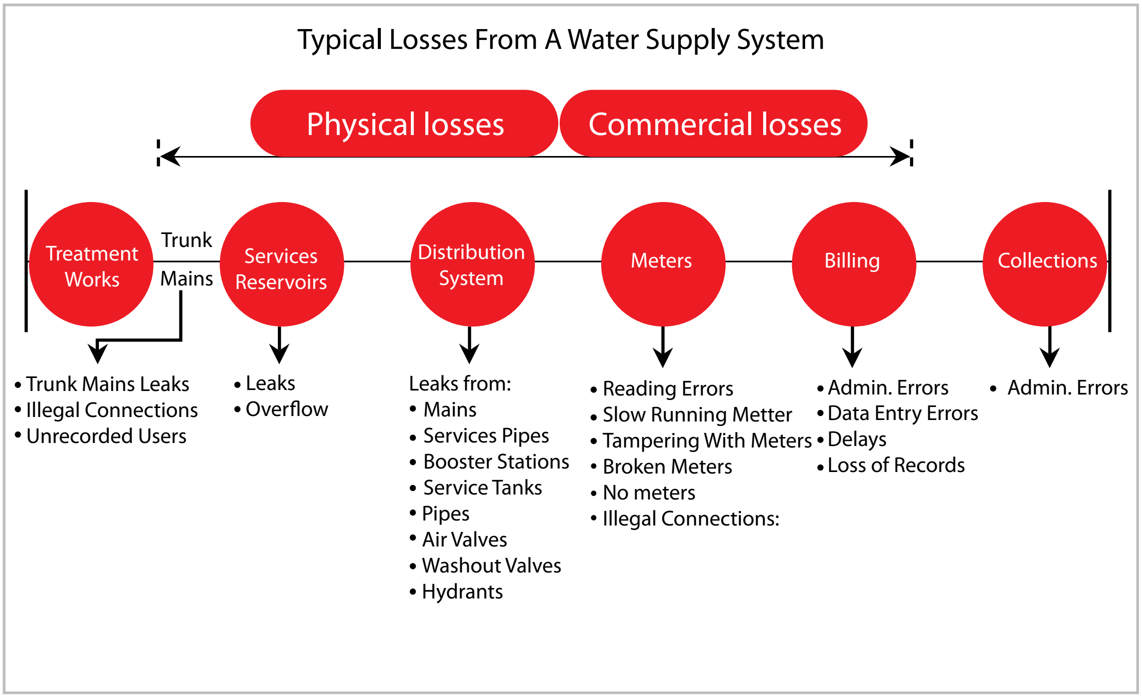
The utility's staff need to understand NRW and how the NRW reduction programme will improve the organisation. In certain cases, savings from the NRW reduction programme may be shared with the staff through bonuses or other incentives.

All staff, from senior management to the crew, should understand the NRW reduction strategy and their role in achieving the NRW target. Middle managers should participate in briefing sessions to raise their NRW awareness and to provide input to strengthen the strategies. Managers should then brief their operational staff on upcoming activities and changes in policies and practices. Some examples of how individuals in various departments are involved in the strategy's implementation include:

- Meter readers must provide accurate readings as this will immediately affect the NRW calculation.
- Purchasing officers must complete equipment orders as quickly as possible, since delays in the purchasing process will then hinder these necessary installations and upgrades in the system. As a result, district meter areas (DMAs), which can play a key role in reducing NRW, will not be established in a timely manner.
- Financial officers must not delay payments to suppliers, as this may disrupt future equipment or meter supplies.

- Crew must repair burst pipes as quickly as possible so that water losses and water supply disruptions are minimal. Fast repairs increase the utility's efficiency and promote customers' willingness to pay their water bill.

Figure 4.1: Chart to help staff understand NRW components



Source: Ranhill

In certain cases, contractors rather than utility staff will undertake repair works. These contractors should also understand NRW and any new repair standards or practices that are implemented.

Water utility senior managers participating in NRW awareness sessions to understand the causes of water loss.

Ranhill Experience: NRW awareness programme

Ranhill's NRW management team organised an NRW Strategy Road Show in eight operational districts, with two additional sessions at the headquarters, to ensure that all 1,700 staff members could attend the NRW awareness sessions. After the awareness programme was completed, the Corporate Communication Department conducted a survey to assess staff members' understanding of NRW. The results showed that after the Road Show, staff awareness of NRW increased significantly. The Road Show produced other benefits: staff members were more motivated to do their work; planning became more effective; and inter-department communication and communication between managers and crews improved.

4.3 REACHING OUT TO CUSTOMERS

Engaging customers helps water utilities target water loss sources, such as house connection leakages, water theft, and meter tampering.

One of the goals of reducing NRW is also to provide better and more efficient services to the public. To accomplish this, the public must also understand how they can help manage NRW by reporting burst pipes, faulty valves, leaks, or other problems that limited utility crews may not detect. The earlier the utility becomes aware of a burst pipe or leak, the faster it will be repaired, thus reducing the losses (see Figure 3.2 in section 3.4 on the relationship between awareness, location, and repair times and water losses).

Awareness programmes should be organised with a variety of stakeholders from the public, including politicians, community leaders, and household and industrial consumers. Programmes generally focus on basic NRW concepts and how reducing NRW helps ensure that communities receive better water supply and services.

Ranhill Experience: Customer awareness

Ranhill organises a programme called 'Mesra Pelanggan' (or 'Engaging the Customer') eight to ten times a year to improve awareness among community leaders and consumers throughout the state of Johor. During the programme, the NRW Department Head explains NRW, its effect on service delivery, and the activities Ranhill is undertaking to tackle NRW. The presentation is followed by a Q&A session. Participants can also browse posters and videos highlighting NRW activities in their communities.

Customers aware of poor service caused by water losses will report defective connections.

Call centre to receive information from the public

After awareness programmes are conducted in each community, all staff should work to ensure that customer confidence in the utility's services is maintained. A key element in this is open communication. For example, the public should be able to easily contact the utility to report burst pipes, leakages, or other concerns. The utility should establish a system to receive information or complaints from customers, and then to disseminate it to the relevant operational units so action is taken quickly.

Ranhill Experience: Customer call centre

Ranhill operates a 24/7 customer call centre with toll-free lines, and it encourages the public to provide information on any problems with the water supply. On average, the call centre receives 550 calls on pipe bursts and 3,600 calls on pipe leakages each month.

KEY MESSAGES

- Awareness at all levels, from top decision-makers to the end consumer, is critical to improving NRW.
- Building the understanding of top-level management on NRW and the budget required to reduce it supports the financial sustainability of the strategy.
- Middle management and staff must understand their roles and responsibilities in reducing NRW, since it requires a long-term, combined effort from all departments in the utility.
- Reaching out to customers helps to increase their awareness of NRW and how reducing water losses will result in improved water supply and quality.


20mm.5m³/h

5. UNDERSTANDING COMMERCIAL LOSSES

5.1 DEFINITION OF COMMERCIAL LOSSES

Commercial losses, sometimes called 'apparent losses', include water that is consumed but not paid for by the user. In most cases, water has passed through the meters but is not recorded accurately. In contrast to leaks or reservoir overflows, the lost water is not visible, which leads many water utilities to overlook commercial losses and concentrate instead on physical losses.

Commercial losses can amount to a higher volume of water than physical losses and often have a greater value, since reducing commercial losses increases revenue, whereas physical losses reduce production costs. For any profitable utility, the water tariff will be higher than the variable production cost—sometimes up to four times higher. Thus, even a small volume of commercial loss will have a large financial impact.

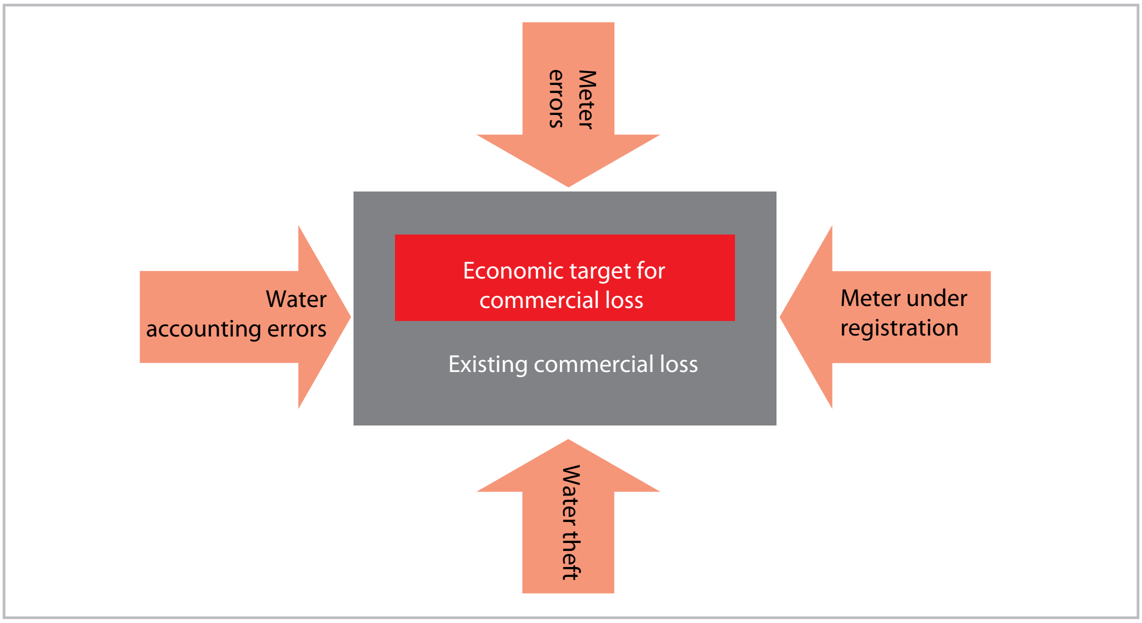
An additional benefit in reducing commercial losses is that it can be accomplished quickly and effectively. This chapter reviews the four main elements of commercial losses and presents options to address them.

5.2 COMMERCIAL LOSS ELEMENTS AND MANAGEMENT STRATEGIES

Commercial losses can be broken down into four fundamental elements, which are:

- Customer meter inaccuracy
- Unauthorised consumption
- Meter reading errors
- Data handling and accounting errors

Figure 5.1: Four pillars of commercial losses



Water utilities should aim for commercial losses that are no more than 4-6% of authorised consumption. Reducing commercial losses requires a low level of investment with a short payback period, but it needs sustained management commitment, political will, and community support. Utilities should focus on commercial losses in the beginning of an NRW reduction programme since the activities can be undertaken in-house with little effort and the payback is immediate.

5.2.1 How to address customer meter inaccuracy

Inaccurate meters tend to under-register water consumption—leading to reduced sales and therefore reduced revenue. Only very rarely do meters over-register consumption. Utilities should focus initially on large customers, such as industrial or commercial users, since they consume a larger volume of water and often pay a higher tariff. Using data from accurate meters to bill customers, rather than charging them based on an assumed per capita basis, ensures that customers are charged according to their actual consumption and encourages them to preserve water. The paragraphs below discuss common problems with customer meter accuracies and solutions for utilities.

Installing meters properly

Meters should be installed properly according to the manufacturer's specifications. For example, some meters require a specific straight length of pipe upstream and downstream of the meter. Therefore a standard meter stand should be designed and constructed onsite. Utilities should purchase the meters on the customers' behalf, so that only standard, high quality meters are used. Meters should also be installed where meter readers can easily read them, and where it is easy to identify each property's meter. In addition, the management and staff responsible for meter installations should be trained on proper handling of meters.

Improper meter installation leads to inaccurate data and billing errors. Meter readers in the pictured situation will find it difficult to determine which meter belongs to which property.

Ranhill Experience: Customer meter standards

Ranhill ensures the quality of its customer meter installations by preparing standard meter stand designs, and then circulating the drawings to all plumbers. Meters are only installed after all of the internal plumbing and meter stands are constructed according to standards. Finally, Ranhill technicians inspect and approve the installations.

Sedimentation is a major cause of meter recording inaccuracies.

Monitoring water quality

Poor water quality—resulting from poor raw water, inadequate treatment processes, or dirt infiltration due to pipe shutdowns—may cause sediments to form in the pipes. These sediments can also build up on the internal parts of meters, especially mechanical meters. The build-up in sediment affects the meter's accuracy by increasing friction losses, which causes the meter to run more slowly and thus under-register consumption. Utilities must regularly monitor water quality and clean mechanical meters to minimise sediment levels and promote accurate meter measurements.

Monitoring intermittent water supply

Where water supply is intermittent, i.e. the customer receives water only a few hours a day, customer meters will register a certain volume of air when the water supply is first turned on. In addition, the sudden large increase in pressure can damage the meter's components. Intermittent supply should be avoided for a number of reasons, including the negative impact on customer meter accuracy. See Chapter 7 for information on utilising District Meter Areas to implement a 24-hour supply system.

Sizing meters properly

Customer meters work within a defined flow range, with the maximum and minimum flows specified by each manufacturer. Large meters will not register low flows when the flow rate is lower than the specified minimum. Therefore, utilities should conduct customer surveys to understand the nature of each customer's water demand and their likely consumption. This information helps to determine the proper meter size for households and businesses. For customers with a high demand, checking the flow pattern and the newly installed meter verifies whether the correct meter size is used.

Problems with low flows can occur when a storage tank, with the water flow controlled by a ball or float valve, is installed on the customer's premises. These valves operate by slowly closing as the water level in the tank rises, which has the effect of reducing the flow through the meter, often below the minimum flow specification. This problem is compounded even further if the size of the storage tank is large in comparison to the customer's consumption because the ball or float valve will never fully open and the flow through the meter will be continually low.

Using the appropriate class and type of meter

Choosing the appropriate meter helps to ensure the accuracy of customer consumption data. Class B meters are a good choice where water quality is low, as the sediments will not greatly affect the meter. Class D meters are more preferable where roof tanks are used and water quality is good, since they have a lower minimum flow specification and will measure the roof tank inflow more accurately. Class C meters are a suitable compromise in most situations, since they can measure low flows better than Class B meters and are not as expensive as Class D meters.

Common types of meters include positive displacement (PD), multi-jet, single-jet, turbine, and electromagnetic. The most common type of meter for domestic and small commercial installations is the 15 mm and 20 mm PD meter. Single-jet and multi-jet meters are more accurate for small commercial and industrial installations that require 20 mm to 50 mm sizes. Electromagnetic meters are the best choice for sizes 100 mm and above.

Ranhill Experience: Large customer meter replacement

In 2007, Ranhill changed 30 large mechanical meters to electromagnetic meters, which increased consumption readings by up to 20% at some locations. Electromagnetic meters have a higher accuracy at both high and low flows, and the flow through the meter is full bore, reducing any headlosses.

Installing an electromagnetic meter with Ranhill's biggest customer in Johor increased the accuracy of readings and led to an 8% increase in their water bill. The payback period for the new meter was only half a month.

Maintaining and replacing meters properly

All meters should be installed above ground and located where they can be audited easily, including by the meter readers during their regular rounds. The utility should replace the meters systematically, beginning with the oldest meters and those in the worst condition. Poor maintenance will not only encourage inaccuracy but may shorten the life span of the meter. A scheduled maintenance and replacement programme should be in place to manage this problem.

Examining meters regularly enables utilities to detect the need for calibration or replacement, and builds trust with customers.

Meter servicing is essential, especially in areas of poor water quality. The accuracy of mechanical meters changes over time as the mechanical bearings wear down, causing friction to increase and thus the meters to under-register. These changes will occur over a number of years, depending on the quality of manufacture. The water utility should regularly test a sample of its customer meters, including a range of meter brands and ages, using a calibrated meter test bench. This testing will determine the optimum age at which customer meters should be replaced.

Ranhill Experience: Customer meter servicing

Ranhill services all customer meters 50 mm and above on a 6-month to 1-year frequency, depending on the water quality in the area. In addition, analyses of smaller domestic meters within a District Meter Area (DMA) will reveal if the water quality is affecting the meter accuracy. If so, then Ranhill carries out meter servicing for all domestic meters in the DMA.

The customer has tampered with the meter's moving parts.

Addressing meter tampering

Although water tariffs in Asia are relatively low, customers still sometimes tamper with their meters to lower the measured volume. Customers may insert pins or other objects into the meter to disturb its moving parts. Some try to affect the readings of metal meters by attaching a strong magnet to it. In other cases, customers have boiled plastic meters trying to melt the internal plastic parts.

Most reputable meter manufacturers now produce meters that are extremely tamper-resistant, with non-metallic parts, strong clear plastic windows, and impenetrable casings. Although these meters may cost a bit more, reduced tampering helps to reduce commercial water losses. For properties with older meters that are not as tamper-resistant, utility managers should conduct customer surveys to assess expected water usage according to the number of household occupants or the nature of businesses in commercial areas. A comparison of expected and actual water use will highlight cases of likely meter tampering.

5.2.2 Unauthorised consumption

Unauthorised consumption includes illegal connections, meter bypassing, illegal use of hydrants, and poor billing collection systems. The following paragraphs describe common problems and possible solutions.

Water theft occurs at large pipes, as well as in household water connections.

Finding and reducing illegal connections

Illegal connections involve the physical installation of a connection to water distribution pipelines without the knowledge and approval of the water utility. Illegal connections can occur during the installation of a new supply connection, or sometimes the customer's supply is cut off after non-payment and the customer cannot afford, or does not want to pay, to be reconnected.

During customer awareness programmes, customers should be encouraged to report illegal connections, and regulations should be in place to penalise the water thieves. Meter readers should also report cases of direct connections without accompanying meters that they see during their rounds.

Ranhill Experience: Preventing illegal connections

Lockable valves help limit illegal connections. The water utility should have the only keys available for the valves. After a customer's water supply has been disconnected for non-payment, and reconnection has not been requested within one week, the utility should visit the property to check whether the customer has made an illegal connection.

Tackling meter bypassing

Some customers try to reduce their water bills by using a meter bypass, which is an additional pipe installed around the meter. This bypass pipe is often buried and very difficult to detect. This type of unauthorised consumption is usually committed by industrial and commercial premises, where only a small volume of the consumption goes through the meter and the rest through the bypass pipe.

Because large customers tend to steal large volumes of water, the discrepancy will show up when the utility conducts a flow balance analysis. The utility should then undertake customer surveys and leakage step tests to determine where the missing flow occurs.

Preventing illegal use of fire hydrants

Although the only legal use of fire hydrants is for fire fighting, some use them illegally to fill tankers (normally at night) or to provide water supply to construction sites. The utility staff can detect these flows, often high volume over a short period of time, through appropriate flow measurements at DMA meters. Such high flows are not only incidences of water theft, but also a detriment to the pipe network and water quality, which affects the service to the customer.

Through customer awareness programs, the utility staff should encourage customers to report cases of illegal uses of fire hydrants. In addition, the utility manager needs to cooperate with relevant local agencies or departments to identify owners of tankers suspected of drawing water illegally and without proper permission. Developing and enforcing regulations to penalise water thieves together with local agencies will also deter unauthorised consumption.

Ranhill Experience: Fire hydrant vandalism

Ranhill charges water losses to those who vandalise fire hydrants, if the public has provided information to accurately identify them, and the Johor Fire Department also charges them for vandalising the hydrant.

Actively checking the customer billing system

Sometimes connections are made legally, but the billing department is not notified of the new connection; therefore, the customer is never billed. These unregistered customers can be detected during the regular meter reading cycle when diligent meter readers find meters that are not in their reading book. However, this process may not identify all of the errors in the billing system.

Actively verifying customer information and water bills minimises administrative errors, a key component of commercial losses.

Conducting a complete customer survey within each DMA, whereby utility representatives visit every property in the DMA—whether or not they are recorded in the billing system—is the best method of comprehensively identifying billing system errors. The survey should include the following information: property address, name of owner, and meter make and number (see samples on enclosed CD). The representative should also conduct a meter test to ensure that the accurate flow is recorded.

For metered areas, utilities should focus on large users by encouraging good customer relationships through frequent visits. Checking large customers' accounts monthly will help detect anomalies, which may be due to water theft. In areas of suspected high commercial losses, temporary DMAs can be established to analyse flows through standard monitoring activities, such as step testing and flow balancing, to pinpoint problematic areas.

Avoiding corrupt meter readers

Corrupt meter readers can significantly impact a utility's monthly billed consumption. For instance, the same meter reader who walks the same route for an extended period of time, thus becoming familiar with the customers and their monthly billed consumption, may collude with those customers to record lower meter readings in exchange for a monetary incentive. To reduce this risk, the utility manager needs to rotate meter readers to different routes on a regular basis.

Ranhill Experience: Meter reading practices

Ranhill's meter readers in Johor are assigned rotating meter reading routes, so that each person reads a particular meter not more than once every four cycles, or approximately every four months.

5.2.3 Meter reading errors

Errors can be easily introduced through negligence, aging meters, or even corruption during the process of reading the meters and billing customers. Incompetent or inexperienced meter readers may read the meter incorrectly or make simple errors, such as placing a decimal in the wrong place. Dirty dials, faulty meters, and jammed meters can also contribute to meter reading errors. The meter readers should immediately report any observed problems, and the maintenance team should take action to remedy the problem immediately. If remedial action is too slow, meter readers may become demoralised and less inclined to report problems.

Because meter readers are the utility's frontline in liaising with customers, their activities have an immediate impact on cash flow. Utility managers should therefore invest in training and motivating their meter readers to record and report information effectively and efficiently. The manager should also establish systems and procedures to prevent meter reading errors by improving its meter reading and billing processes through greater supervision of meter readers, implementation of rotating reading routes, and frequent spot checks.


Spot billing minimises data handling errors.

5.2.4 Data handling and accounting errors

The typical method of data handling and billing requires a meter reader to visit each property and read the customer meter. The data is then recorded by hand on a form, taken back to the office, given to the billing department, and typed into the billing system. A bill is then printed and mailed to the customer. In this scenario, a variety of errors may occur at the different stages: the meter reader writes down incorrect data; the billing department transfers incorrect data into the billing system; or the bill is sent to the wrong address.

A robust billing database is one of the key elements of minimising these errors and should be the initial purchase of any water utility striving to improve its revenues. The latest billing software has built-in analysis functions that can identify potential data handling errors and report them for verification. In addition, billing software will report monthly estimate readings and zero reads, both of which may indicate a problem with the customer's meter. Site visits will help identify meters needing replacement.

Training of meter readers promotes diligence, good customer meter maintenance, and decreased meter reading errors. If financially viable, utilities should consider electronic meter-reading devices, which reduce data handling errors to a minimum since all data transfers to the billing system are done electronically.

KEY MESSAGES

- For any profitable utility, the water tariff will be higher than the variable production cost—sometimes up to four times higher. Thus, even a small volume of commercial loss will have a large financial impact.
- Commercial losses occur mostly through faulty or tampered meters and through errors committed during meter reading or processing in the billing system.
- Meters are essential tools for measuring water consumption and should be as accurate as possible.
- Coordination from the public and relevant local authorities is required to overcome illegal uses of water.
- Training meter readers, staff, and crews is a continuous process to ensure competent customer service.
- Investing in high quality meters and a robust billing system can result in higher returns.

6. UNDERSTANDING PHYSICAL LOSSES

6.1 DEFINITION OF PHYSICAL LOSSES

Water losses occur in all distribution networks, even new ones. Physical losses, sometimes called 'real losses' or 'leakage', includes the total volume of water losses minus commercial losses. However, the water balance process, as described in Section 2.3, indicates that commercial losses are estimated and therefore the resulting leakage volume may be incorrect. Utility managers must therefore verify the results using component analysis (the top-down approach) or physical loss assessment (the bottom-up approach, see Chapter 7 on aggregating night flows in DMAs).

The three main components of physical losses include:

- Leakage from transmission and distribution mains
- Leakage and overflows from the utility's reservoirs and storage tanks
- Leakage on service connections up to the customer's meter

The first and second types of leakage are usually quite visible to either the public or utility staff, so they are easy to detect and are repaired relatively quickly. The third type is more difficult to detect and can therefore lead to a greater volume of physical losses. This chapter describes these three types of losses and solutions for reducing them.

'Catastrophic' mains bursts

6.2 PHYSICAL LOSS ELEMENTS

6.2.1 Leakage from transmission and distribution mains

Leakages occurring from transmission and distribution mains are usually large events, sometimes catastrophic, causing damage to highway infrastructure and vehicles. The majority of such bursts are usually not very severe although they cause supply disruptions. Because of their size and visibility, the bursts are reported quickly, and are then repaired or shut off soon afterwards.

By using data from repair records, utility managers can calculate the number of leaks on mains repaired during the reporting period (usually 12 months) and estimate an average flow rate of the leaks. This gives the total annual volume of leakage from mains as follows:

Total annual volume of leakage from mains = **Number of reported bursts x Average leak flow rate x Average leak duration**

If no detailed data are available, utility managers can use approximate flow rates from Table 6.1.

Table 6.1: Flow rates for reported and unreported bursts

Location of Burst	Flow Rate for Reported Bursts [l/hour/m pressure]	Flow Rate for Unreported Bursts [l/hour/m pressure]
Mains	240	120
Service Connection	32	32

Source: IWA Water Loss Task Force

Utility managers can then add estimates for background losses and excess losses (current undetected leaks). Background losses are individual events (i.e. small leaks and weeping joints) that flow at rates too low for detection by an active leak detection survey. They are finally detected either by chance or after they have worsened to the point that an active leak detection survey can discover them. Table 6.2 shows background losses from various components of the network with average infrastructure condition.

Table 6.2: Calculating background losses

Location of Burst	Litres	Unit of Measure
Mains	9.6	Litres per km of mains per day per metre of pressure
Service Connection – main to property boundary	0.6	Litres per service connection per day per metre of pressure
Service Connection – property boundary to customer meter	16.0	Litres per km of service connection per day per metre of pressure

Source: IWA Water Loss Task Force

Excess losses include the water lost from leaks that are not detected and repaired under the current leakage control policy:

Excess Losses = Physical losses from water balance - known physical loss components

If this equation results in a negative value for excess losses, the assumptions for the physical loss component analysis (e.g. values for leak durations) should be rechecked, and if necessary, corrected. If the value is still negative after rechecking the assumptions, this indicates that faulty data was used in the water balance calculation. For example, utility managers may have underestimated system input or overestimated commercial losses), and all the components should be checked.

6.2.2 Leakage and overflows from the utility's reservoirs and storage tanks

Leakage and overflows from reservoirs and storage tanks are easily quantified. Utility managers should observe overflows then estimate the average duration and flow rate of the events. Most overflows occur at night when demands are low and therefore it is essential to undertake regular nightly observations of each reservoir. These observations can be undertaken either physical or by installing a data logger which will then record reservoir levels automatically at preset intervals.

Leakage from tanks is calculated using a drop test where the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost. However, repairing these leaks is a major operation, requiring draining down the reservoir and planning an alternative supply.

Ranhill Experience: Reservoir monitoring

Ranhill's dedicated reservoir monitoring teams place plastic bottles in the overflow pipes in all 456 of its reservoirs. Teams check the location of these bottles monthly. If bottles are outside of the pipe, indicating a possible overflow, the monitoring teams undertake further investigations using data loggers.

Typically more difficult to detect, service connection leaks result in significant water losses.

6.2.3 Leakage on service connections up to the customer's meter

This type of leakage is usually more difficult to detect and results in the greatest volume of physical losses. Utility managers should calculate the approximate volume of leakage from service connections by deducting the mains leakage and storage tank leakage from the total volume of physical losses.

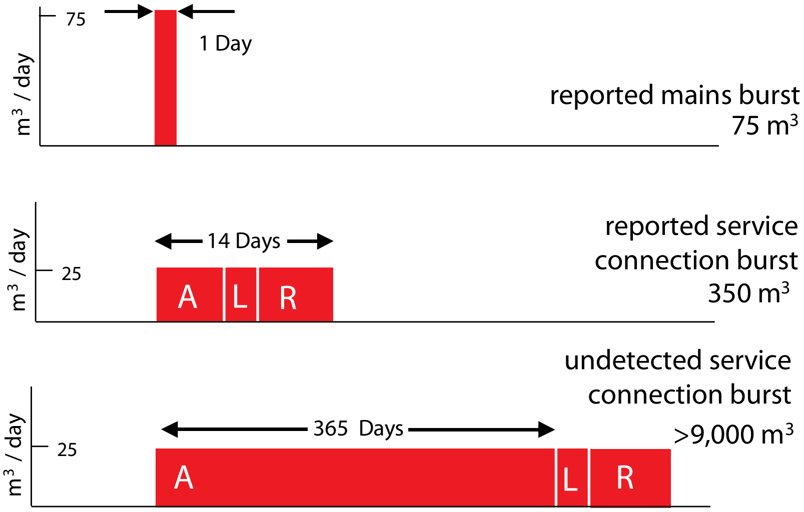
6.3 CHARACTERISTICS OF LEAKAGES

Having defined where leakage can occur in the transmission and distribution network, utility managers should familiarise themselves with the different types of leaks and understand the effect of the leak run time, or ALR, on the total volume of physical losses (see Figure 6.1, and Section 3.3 for a discussion of the ALR concept).

The type and location (e.g. main or service connection) of a burst influences the total run time:

- **Reported bursts**—Visible and usually quickly reported by the public or observed by water utility staff. They have a short awareness time.
- **Unreported bursts**—Commonly occur underground and are not visible at the surface. They are usually discovered during leak detection surveys and often have a long awareness time.
- **Background leakage**—An accumulation of very small leaks that are difficult and not cost-effective to detect and repair individually.

Figure 6.1: Leak run time and volume of water loss



General conclusions concerning leakage include:

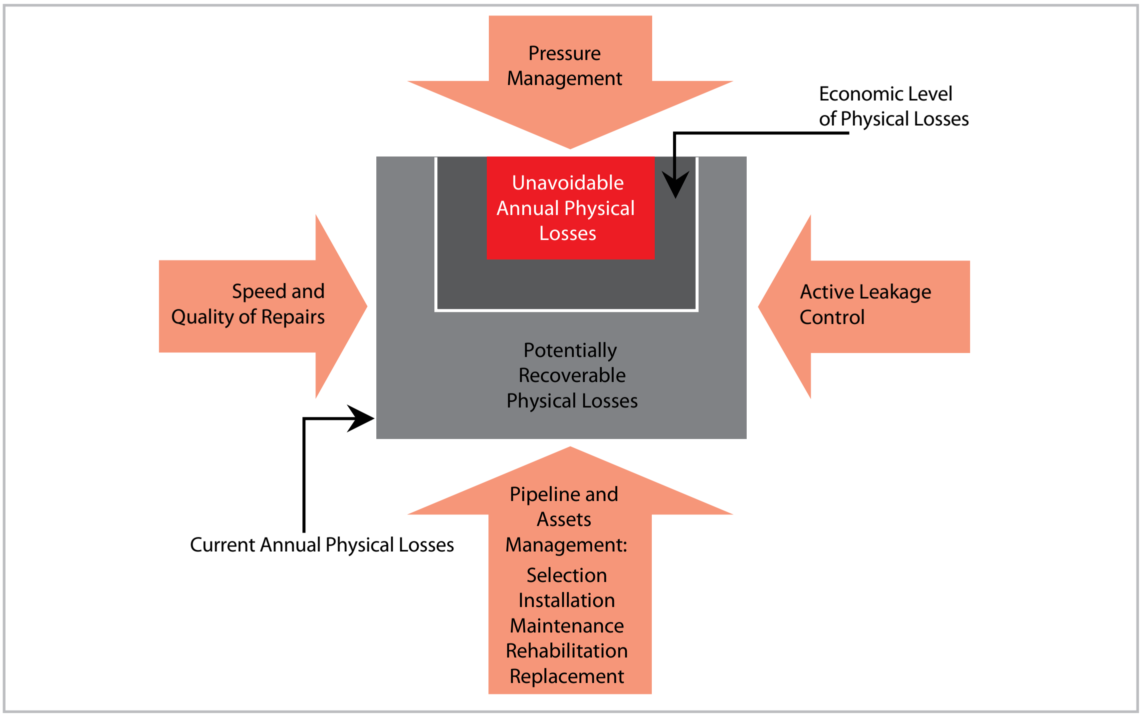
- Most leaks are invisible
- The majority of leaks do not come to the surface
- Managers need to be aware that most leaks are on service connections
- The absence of an active programme to detect invisible leaks is an indication of high levels of leakage

6.4 DEVELOPING A LEAKAGE MANAGEMENT STRATEGY

The four pillars of a leak management strategy include pressure management, repairs, active leakage control, and asset management (Figure 6.2). These factors influence how leakage is managed—and therefore the volume and economic value of leakage—in any utility's distribution network.

The large square represents the **C**urrent **A**nnual Volume of **P**hysical **L**osses (CAPL), which tends to increase as the distribution network ages. But the rate of increase can be constrained by an appropriate combination of the four components of a successful leakage management strategy. The black box represents the **M**inimum **A**chievable **A**nnual **P**hysical **L**osses (MAAPL), or the lowest technically achievable volume of physical losses at the current operating pressure. Introducing or strengthening any of the four components will have an effect on the potentially recoverable losses.

Figure 6.2: The four pillars of a successful leakage management strategy

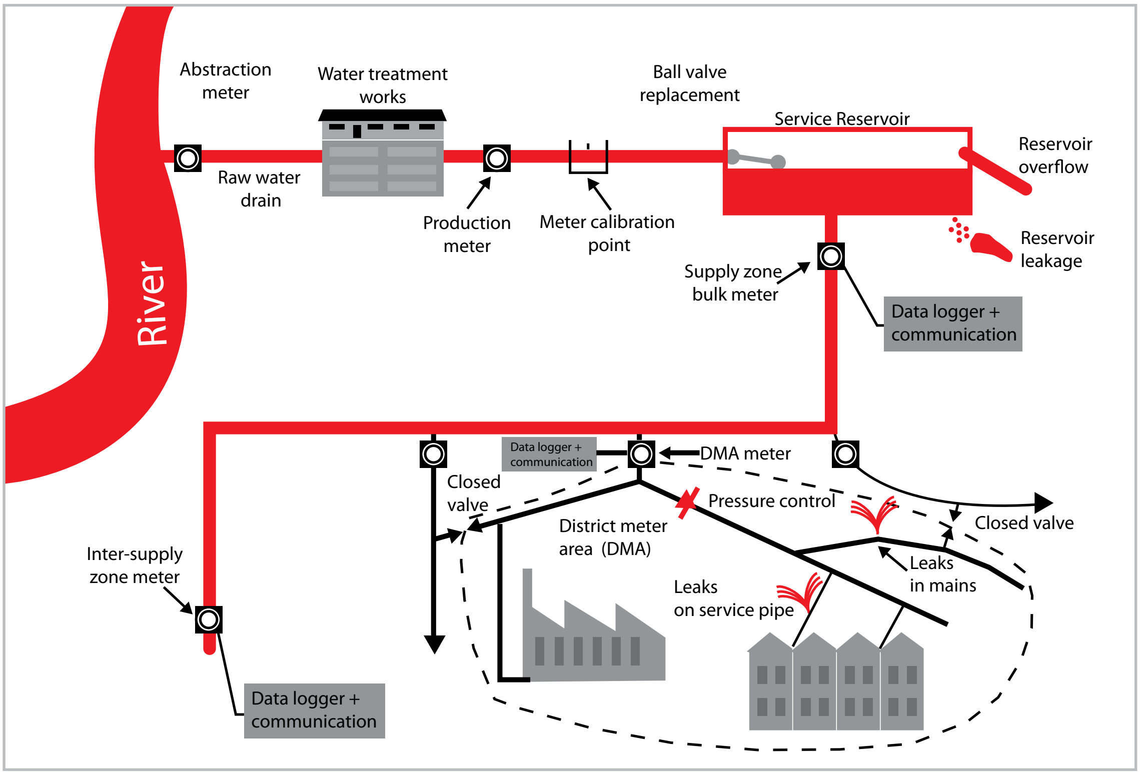


6.4.1 Active leakage control (ALC)

Active leakage control (ALC) is vital to cost-effective and efficient leakage management. The concept of monitoring flows into zones, or district meter areas (DMAs), where bursts and leaks are unreported is now an internationally accepted and well-established technique to determine where leak location activities should be undertaken. The quicker the operator can analyse DMA flow data, the quicker bursts or leaks can be located. This, together with speedy repair, limits the total volume of water lost.

There are many points in a distribution network where leakages can occur and where they are best monitored (Figure 6.3). The DMA concept, and the associated technology and equipment for leakage monitoring, detection, and location, is described in detail in Chapter 7.

Figure 6.3: A typical distribution network



Flow metering

Modern flow metering and data capture technologies play a major part in quickly identifying bursts and in estimating the gradual accumulation of smaller leaks. Many water utilities integrate data from DMAs via telemetry into their supervisory control and data acquisition (SCADA) systems. This approach is particularly effective when implemented together with an analysis package that helps the utility manager identify DMAs that requiring leak location work.

Leak localising, locating, and pinpointing

Utility managers need to ensure a detailed process is undertaken to locate leaks:

- Use flow meter data to identify DMAs that contain unreported bursts or an accumulation of leaks
- Narrow down the area of leakage within the DMA
- Pinpoint the exact (or nearly exact) position of the leak.

This process requires reasonable accuracy at each step to avoid high excavation costs and 'dry holes' (excavations at suspected leak points that reveal no obvious leak). The basic method of detecting and locating a leak is to listen for the noise of the water being released from the pipe under pressure. The effectiveness of this activity is dependent on the system pressure, the size and shape of the leak and the pipe material.

For ensuring accuracy the utility has a wealth of acoustic equipments to pinpoint leaks and bursts, including noise loggers, leak noise correlators, ground microphones, and sounding sticks. Although these tools are extremely helpful for ALC, utility managers must understand the proper applications and maintenance requirements of each tool to maximise their use.

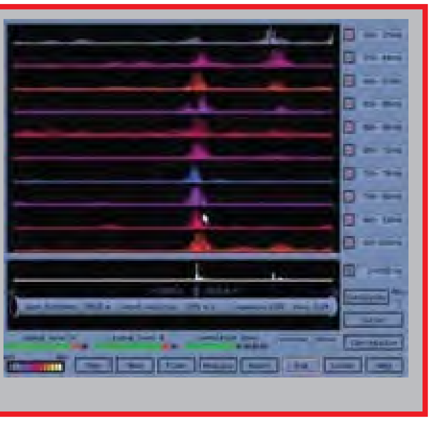
- **Noise loggers**—Noise loggers narrow down areas of a DMA that contain suspected bursts or number of leaks. A cluster of loggers, usually 6, 12, or 18, is deployed in the survey area, with each logger placed on a hydrant, meter, or other surface fitting. Noises that are suspected of being caused by leaks can be confirmed, and the leak is located using other location equipment as described below. Some noise logger systems also incorporate data from multiple points to 'instantly' locate leaks.


Noise logger deployment

- **Leak noise correlators**—Rather than locating a leak based on the noise level, this instrument uses the velocity of sounds made by the leak as they travel along the pipe wall toward each of two microphones placed on fittings either side of the suspected leak. The effectiveness of this process is dependent on the strength of the leak noise and the sound conductivity of the pipe material. Hydrophones placed in the water column can also enhance the leak sounds in plastic or large pipes and other pipes where the noise conductivity is known to be poor. These hydrophones work by listening to the leak noise travelling through the water, which is a better conductor, than most pipe materials, of sound.

  The latest correlator versions, have the capability of frequency selection and filtering, to quickly locate leaks to within 0.5 metres in most sizes of pipe, provided there are sufficient contact points along the line of the main. Low-cost basic models are available, which are adequate for most situations.

- **Ground microphones**—The ground microphone electronically amplifies the sound of a leak. It can be assembled for use in either contact or survey mode. Contact mode is for sounding on



An 'advanced' leak noise correlator, showing correlation peaks at various frequencies

fittings, similar to an electronic listening stick. Survey mode is for searching for leaks on lengths of pipeline between fittings. The technique involves placing the microphone on the ground at intervals along the line of the pipe and noting changes in sound amplification as the microphone nears the leak position. When a leak is detected by the leak noise loggers or leak noise correlator, the utility manager may use either mode to locate the leak.

- **Sounding Sticks**—The sounding stick, or 'stethoscope', is an inexpensive, simple rod made of wood or metal with an ear piece attached to amplify sounds. Utility managers use it to listen to leak sounds on the surface of the highway or on directly exposed pipes and fittings. The sounding stick is invariably used to confirm a leak site that is first identified by a correlator.

Using a sounding stick

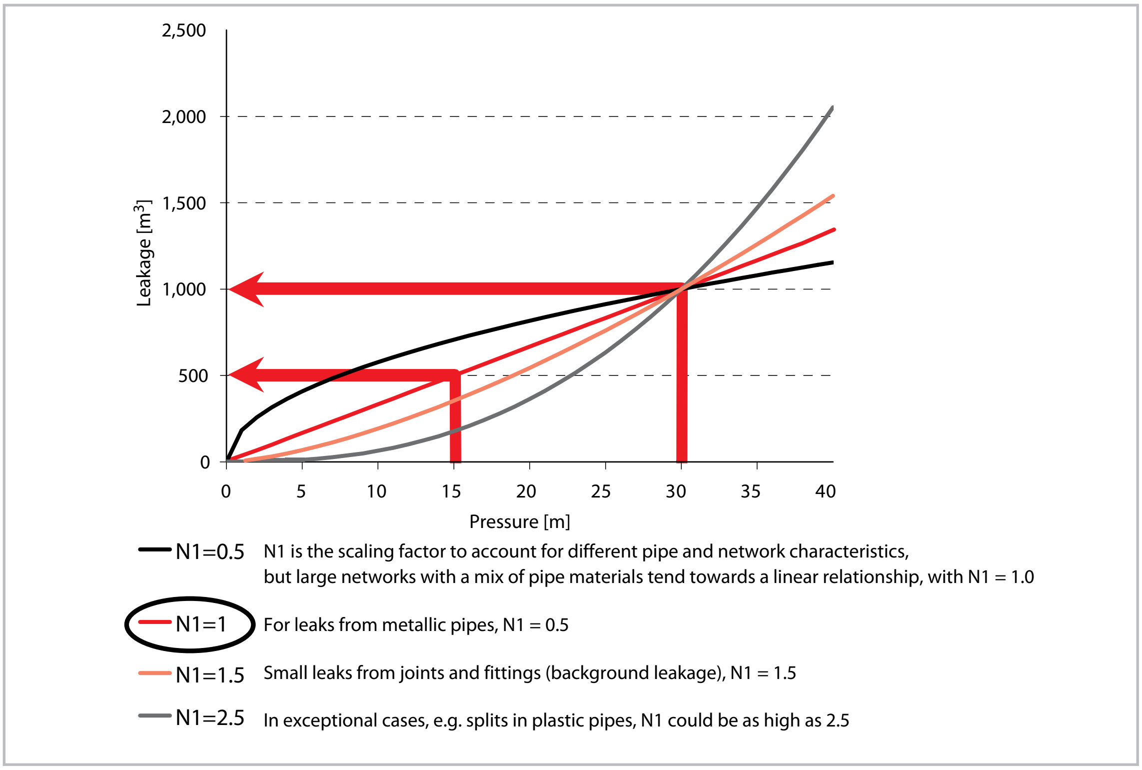
All of the equipments above will not only detect the noise that a leak makes but also any other noise in the system, such as a pump, tap, air valve, etc, It is therefore important to have a team of experienced leakage detection staff who not only can use the equipment correctly but have the skills to identify leaks effectively.

6.4.2 Pressure management

Pressure management is one of the fundamental elements of a well-developed leakage management strategy. The rate of leakage in water distribution networks is a function of the pressure applied by pumps or by gravity. There is a physical relationship between leakage flow rate and pressure (Figure 6.4), and the frequency of new bursts is also a function of pressure:

- The higher or lower the pressure, the higher or lower the leakage
- The relationship is complex, but utility managers should initially assume a linear relationship (10% less pressure = 10% less leakage)
- Pressure level and pressure cycling strongly influence burst frequency

Figure 6.4: Pressure/leakage relationship



Source: World Bank Institute

To assess the suitability of pressure management in a particular system, utilities should first carry out a series of tasks, including:

- Identify potential zones, installation points, and customer issues through a desktop study
- Identify customer types and control limitations through demand analysis
- Gather field measurements of flow and pressure (the latter usually at inlet, average zone point, and critical node points)
- Model potential benefit using specialized models
- Identify correct control valves and control devices
- Model correct control regimes to provide desired results
- Analyse the costs and benefits

There are a number of methods for reducing pressure in the system, including variable speed pump controllers and break pressure tanks. However the most common and cost effective is the automatic pressure reducing valve or PRV.

PRVs are instruments that are installed at strategic points in the network to reduce or maintain network pressure at a set level. The valve maintains the pre-set downstream pressure regardless of

PRVs installed in meter chambers

the upstream pressure or flow-rate fluctuations. PRVs are usually sited within a DMA, next to the flow meter, as shown in the photos below. The PRV should be downstream of the meter so that turbulence from the valve does not affect the meter's accuracy. It is good practice to install the PRV on a bypass pipe to enable future major maintenance works.

Ranhill Experience: Pressure management

Ranhill has installed approximately 200 pressure reducing valves (PRVs), which are distributed throughout 25% of the established DMAs. The PRVs use fixed pressure outlets, but Ranhill is currently investigating the viability of installing timers to reduce pressure further during low demand periods.

6.4.3 Speed and quality of repairs

The length of time a leak is allowed to run affects the volume of physical losses, so repairs should be completed as soon as possible once a leak is detected. Repair quality also has an effect on whether the repair is sustained. Key issues to consider when formulating a repair policy include:

- Efficient organisation and procedures from the initial alert through to the repair itself
- Availability of equipment and materials
- Sufficient funding
- Appropriate standards for materials and workmanship
- Committed management and staffs
- Good quality of service connections—service connections are often the 'weakest link'

6.4.4 Asset management

Asset management is good engineering and business practice, and it includes all aspects of utility management and operations. Good asset management is a necessity for long-term economic leakage management, and the objective is to tackle leaks in the most cost-effective way. This requires priority setting and decisions on whether to repair, replace, rehabilitate, or leave the assets as they are, while simultaneously implementing pressure management and improving the operation and maintenance programme. The critical factors of asset management are:

- Understanding how assets are currently performing
- Collecting data and turning it into useful information for planning
- Good information systems

Particularly relevant to developing an NRW reduction strategy is the aging of the pipe network and making decisions on when to replace or renew the network infrastructure. This requires an understanding of the assets' conditions and deterioration rates. Burst frequency modelling, using data from burst records, helps prioritise pipe rehabilitation, renewal, or replacement. In addition, active leakage control will identify clusters of pipes in the network where bursts and repairs are a continuous occurrence.

When these activities do not lead to reduced leakages, utility managers should undertake a condition assessment programme to decide whether to replace pipes or conduct further repairs. During the decision process, utility managers should ask the following questions:

- If repairing, replacing, or rehabilitating assets, what materials should be used?
- Should pipes be replaced now or later during network extensions to address future demand increases?

Ranhill Experience: Asset replacement

The Johor pipe network has over 10,000 kilometres of aging asbestos cement pipes that need to be replaced. Ranhill identifies pipes for replacement based on the number of bursts per kilometre. In addition, whenever a single DMA has undergone three leak detection activities with no significant reduction in leakage, then the pipework within that DMA is replaced.

KEY MESSAGES

- Physical losses include leakage on transmission and distribution mains; leakage and overflows from storage tanks; and leakage on service connections up to the customer meter.
- Leakages from transmission and distribution mains are usually large events so they are reported quickly by the public. They can cause serious damage unless they are repaired quickly. Less conspicuous types of leakage are more difficult to detect and repair.
- A successful leakage management strategy requires pressure management, active leakage control, pipeline and asset management, and speedy and quality repairs.

7. UNDERSTANDING DISTRICT METER AREAS

Many water utilities operate their pipe networks as an open system where water is fed from more than one Water Treatment Plant (WTP) into an inter-connected pipe network. Water from each WTP will mix within the network, which continually affects system pressure and water quality. In an open system, NRW can only be calculated for the entire network, which is effectively an average level for the entire system. Thus, determining the exact locations of NRW occurrences—and where NRW reduction activities should take place—can be quite a challenge, especially for large networks.

Generally NRW management in an open system is undertaken in a passive manner where NRW reduction activities are initiated only when the loss becomes visible or is reported. A more effective approach is to move towards Active NRW Management where dedicated teams are established and sent out to look for water losses, such as leaks, reservoir overflows, and illegal connections.

Active NRW Management is only possible using zones, where the system as a whole is divided into a series of smaller sub-systems for which NRW can be calculated individually. These smaller sub-systems, often referred to as District Meter Areas (DMAs) should be hydraulically isolated so that utility managers are able to calculate the volume of water lost within the DMA. When a supply system is divided into smaller, more manageable areas, the utility can better target NRW reduction activities, isolate water quality problems, and better manage overall system pressure to allow for 24/7 water supply throughout the network.

Dividing the open network into smaller, more manageable areas called District Meter Areas (DMAs) enables network operators to manage the system more effectively in terms of pressure control, water quality, and NRW. This chapter describes how utilities should establish DMAs and then use information on flow and pressure to better manage NRW. It also discusses the benefits of using DMAs to improve water quality and supply for customers.

7.1 DMA ESTABLISHMENT CRITERIA AND PROCESS

The design of a series of DMAs is very subjective, and it is unlikely that two utility engineers working on the same network would come up with the same design. The engineer typically uses a set of criteria to create a preliminary DMA design that must be tested either in the field or using a network model.

These criteria include:

- Size of DMA (e.g. number of connections—generally between 1,000 and 2,500)
- Number of valves that must be closed to isolate the DMA
- Number of flow meters to measure inflows and outflows (the fewer meters required, the lower the establishment costs)
- Ground-level variations and thus pressures within the DMA (the flatter the area the more stable the pressures and the easier to establish pressure controls)
- Easily visible topographic features that can serve as boundaries for the DMA, such as rivers, drainage channels, railroads, highways, etc.

To divide a large open system into a series of DMAs, it is essential to close valves to isolate a certain area and install flow meters. This process can affect the system's pressures, both within that particular DMA as well as its surrounding areas. The water utility therefore must ensure that the water supply to all customers is not compromised in terms of pressure and supply hours.

Box 7.1: Network Modelling

Network modelling is the process of constructing a computer simulation of a pipe network using specialised computer software. Utility managers then verify the simulation by comparing the simulated flows and pressures with real flow and pressure data recorded onsite. Adjustments are made to the model to ensure that the simulated and the real data correlate, thus creating a calibrated hydraulic network model.

Using a calibrated hydraulic network model of the supply system to simulate possible DMA designs will enable analyses of system pressures and flows without affecting supply to customers. However, many water utilities do not have existing calibrated hydraulic network models. Rather than wait for a model to be developed, which can take up to one year or more, a water utility should begin establishing DMAs in network areas that can be easily isolated, i.e. areas with a separate supply zone.

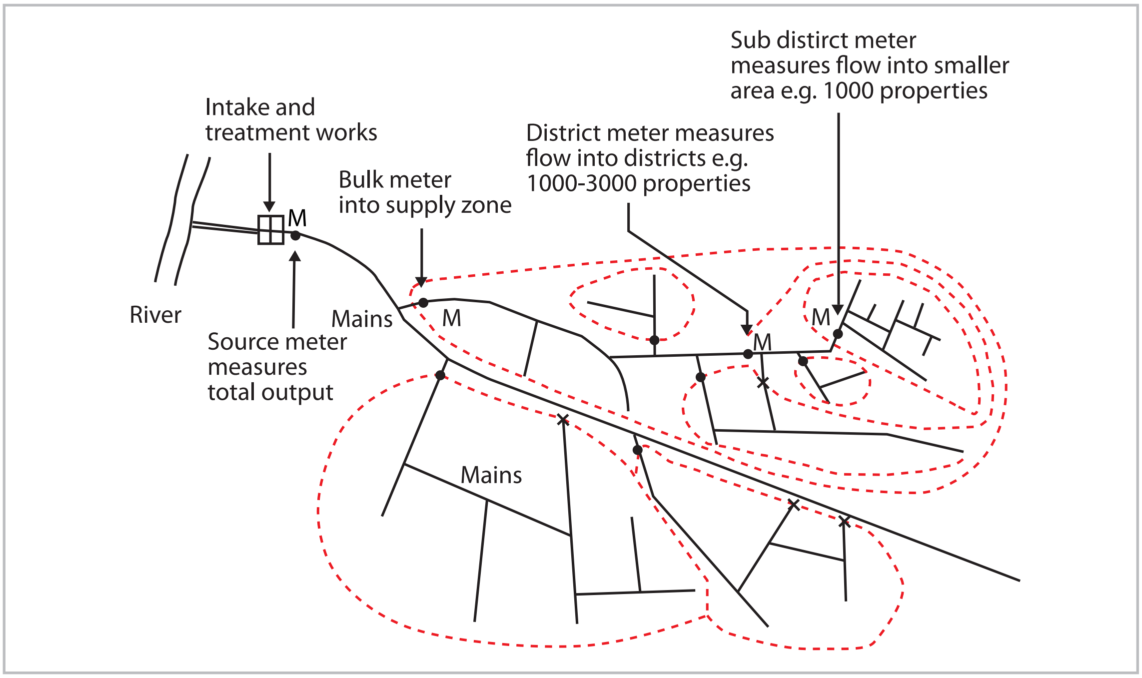
In establishing a DMA, the water utility should limit the number of inflows, which also helps to reduce the cost of flow meter installation. To achieve this, it is necessary to close one or more boundary valves, which must remain shut permanently to ensure that any flow data accurately represents the total inflow for the DMA.

Utility managers will ensure that all pipes into and out of the DMA are either closed or metered by performing an isolation test as follows:

1. Close all metered inlets.
2. Check whether the water pressure within the DMA drops to zero, since no water should now be able to enter the area.

If the pressure does not drop to zero, then it is likely that another pipe is allowing water into the area and therefore needs to be addressed.

Figure 7.1: Typical DMA layout



If the budget is limited, the water utility should initially establish larger zones of 5,000 or more connections. It can subsequently subdivide them into DMAs and sub-DMAs of 1,000 or fewer connections for those DMAs with high NRW and long lengths of pipework, as detailed in Figure 7.1.

For each DMA, utility managers should develop a detailed operations manual to assist future teams in managing the water supply. The operations manual includes a schematic of the pipe network; location drawings of the flow meters, pressure control valves, and boundary valves; and a copy of the billing database for the DMA. The manual is a working document and operational data should be continually updated, including information on the following:

- Flow and pressure graphs
- Leakage step tests data
- Leak locations
- Illegal connection locations

- Legitimate night flow (LNF) test data
- Pressure T Factor test data

7.2 USING DMA RESULTS TO REDUCE NRW LEVELS

Once the DMA has been established, it becomes an operational tool for monitoring and managing both of the major components of NRW, physical and commercial losses. The calculation for NRW within a DMA is defined as follows:

DMA NRW = Total DMA Inflow - Total DMA Consumption

After flow meters are installed on all inlets to the DMA, the Total DMA Inflow can be measured using the increase in the totaliser, or the meter counter measuring the volume of water passing through the meter, for the calculation period.

The Total DMA Consumption will depend on the customer meter coverage. If the DMA has a 100% domestic meter coverage, meaning all customers within the DMA have a meter, then the Total DMA Consumption can be calculated through a simple summation of all meter measurements for the calculation period.

Ranhill Experience: DMA establishment

The supply system in Johor, Malaysia has approximately 865,000 customers. As part of the NRW reduction programme, Ranhill has established 820 DMAs to date with an average of 1,055 customers per DMA. Ranhill has 100% customer meter coverage within its supply system and all customers have been assigned to one of the 820 DMAs. To identify unacceptably high NRW levels, the total DMA consumption and NRW is determined through a simple monthly summation within the billing system database.

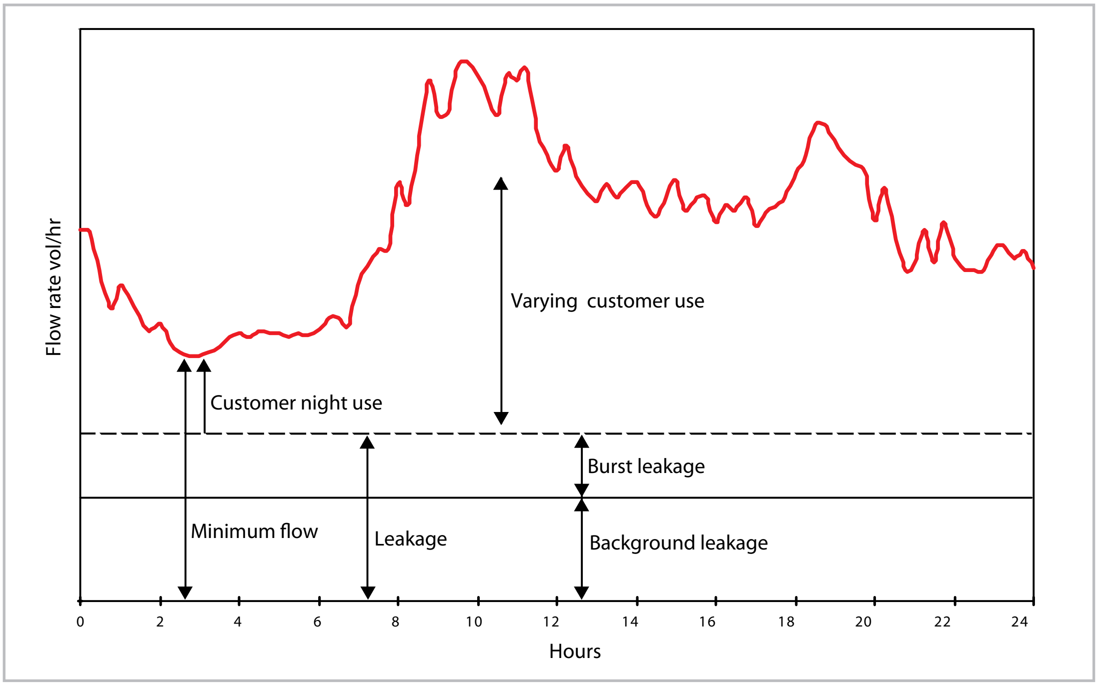
If 100% domestic meter coverage does not exist within the DMA, then the Total DMA Consumption can be estimated by using per capita consumption figures. Initially, a survey of all properties within the DMA should be undertaken; this survey may be limited to counting the number of properties and estimating the average number of occupants per property. For a more detailed estimate, surveyors will interview all households and ask how many occupants live within each property.

7.2.1 Estimating physical losses

Most DMAs will not contain any reservoirs or trunk mains, so these components are not usually considered when analysing physical losses within a DMA. Physical losses within a DMA are effectively pipe leaks on the main pipes and customer connections. Leakage occurs through holes or cracks in the main pipes or at pipe joints, which will leak water constantly over a 24-hour period. In contrast, leaks from customer connections fluctuate with customer demand throughout the day, with peak demand in the morning and evening, and a minimum demand at night when most customers are asleep and not using water.

Because leakage from the main pipes is continuous, while customer demand is minimal at night, water operators should monitor leakage during the night period. Figure 7.2 shows the flow pattern into a typical DMA with mainly domestic customers.

Figure 7.2: Typical 24-hour DMA flow profile



To estimate the level of leakage in the DMA the operator needs to calculate the system's Net Night Flow (NNF), which is determined by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF).

The MNF is the lowest flow into the DMA over a 24-hour period, which generally occurs at night when most consumers are inactive. This MNF can be measured directly from the data logging device or the flow graph. Although customer demand is minimal at night, water operators still have to account for the small amount of legitimate night flow, i.e. the night-time customer demand, such as toilet flushing, washing machines, etc.

In a system with 100% metering, LNF is calculated by measuring the hourly night flow for all non-domestic demand and a portion (e.g. 10%) of domestic meters within the DMA. The utility will then estimate the total LNF in terms of litres per hour and litres per second.

Ranhill Experience: Legitimate Night Flow (LNF)

Ranhill conducts LNF tests within each DMA by measuring the consumption of all non-domestic and 10% of all domestic meters for a two-hour period between 2:00 am and 4:00 am to calculate the average LNF.

For systems without 100% customer metering, water operators can approximate LNF based on estimated per capita night consumption. Utility managers should conduct a customer survey of all the properties, both domestic and non-domestic, within the DMA, and then determine the total number of connections per demand group (domestic, industrial, commercial, or others). Based on data from other areas with 100% customer metering, the utility can estimate a night-time flow rate for each demand group and multiply that by the number of connections within the demand group to get the total LNF.

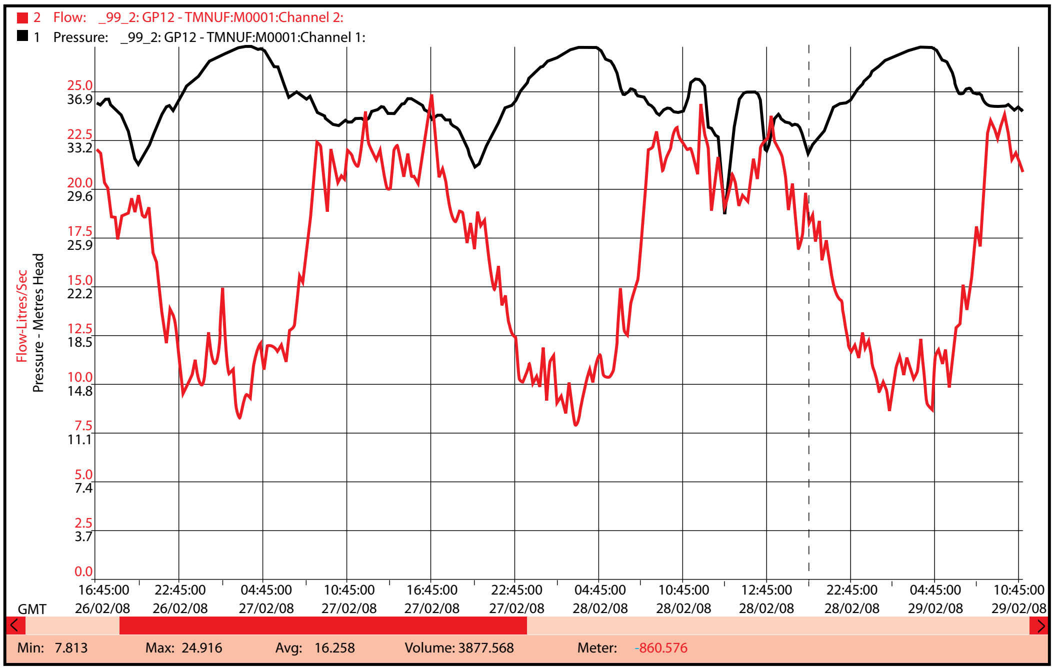
To determine the level of Net Night Flow (NNF) or the portion of night flow directly attribute to leakage, subtract the LNF from the recorded MNF.

NNF = MNF - LNF

Leakage is proportional to the pressure in the system. Similar to water flows into the DMA, the DMA average pressure will change over a 24-hour period. Pressure is directly proportional to flow due to frictional headlosses within the system, and thus when the DMA has its lowest inflows, the pressure will be at its highest (Figure 7.3). This is because frictional headloss is proportional to velocity, so when flows are low, the velocities in the pipes are also low and less headloss occurs.

Therefore, the NNF or leakage calculated for the minimum night flow period will not be a true representation of leakage across a 24-hour period. Utility managers must also determine a pressure factor, or T Factor, that creates a true average 24-hour leakage value when applied to the NNF. The T Factor is calculated by using a data logger to record pressure over a 24-hour period, and then using those measurements to calculate the average 24-hour pressure. This average 24-hour pressure is compared to the system pressure during the minimum night period and a factor applied.

Figure 7.3: DMA flow and pressure relationship over a three-day period



7.2.2 Determining commercial losses

The level of NRW within a DMA can be calculated by subtracting the recorded consumption from the inflow. Section 7.2.1 shows how to determine the leakage level or NNF within each DMA using the minimum night flow. This section discusses how to calculate commercial losses through a simple subtraction of leakage from the NRW, as follows:

Commercial loss = NRW - NNF

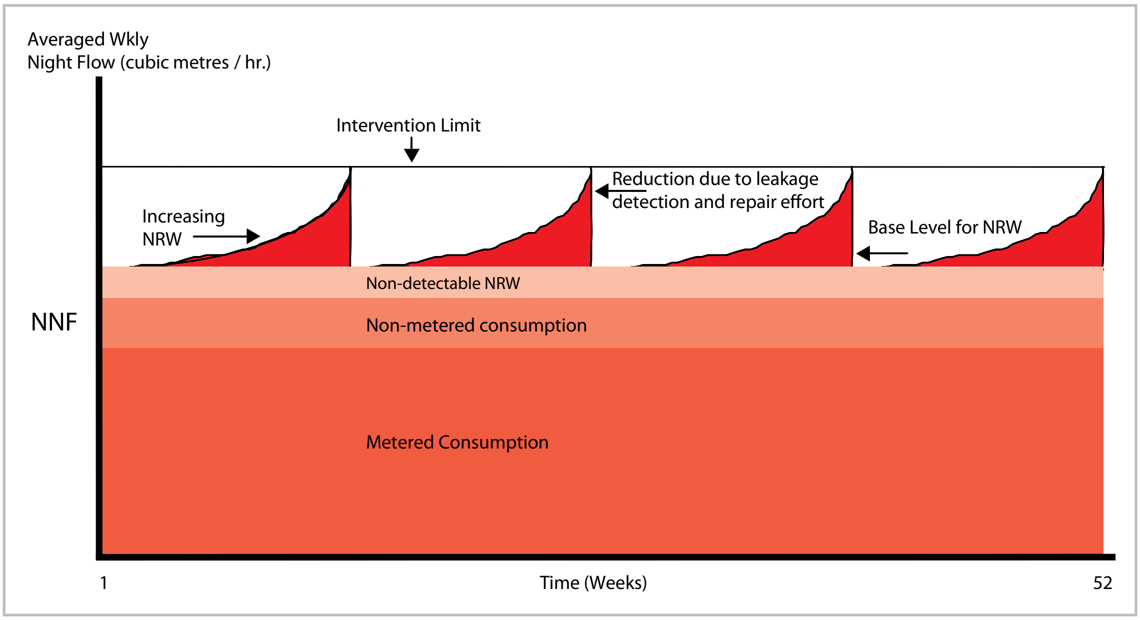
Once utility managers identify the DMAs with significantly high commercial losses, they should investigation for faulty meters, tampered meters, and illegal connections. They may also conduct a series of customer surveys of each property within the DMA to verify the property's inclusion in the billing database, interview the occupants, and assess the water meter.

7.3 DMA MANAGEMENT APPROACH

When a DMA is first established, water utility managers should undertake the initial calculations of NRW, NNF, and commercial losses, and identify the main areas of concern. If the DMA has high leakage or high commercial losses, then NRW reduction activities discussed in Chapters 5 and 6 should be implemented.

Once NRW is reduced to an acceptable level, the operations staff should set up a monitoring regime for DMA inflows. In its simplest form, this consists of a monthly reading of the flow meter totaliser. However, the installation of a data logger to record flows will reveal more detailed data, including the daily NNF, which enables more precise corrections to the system. Eventually, the NNF effectively becomes NRW with minimal levels of commercial loss. The daily NNFs can be plotted on a graph against time, to monitor DMA NRW levels (Figure 7.4).

Figure 7.4: NNF against time

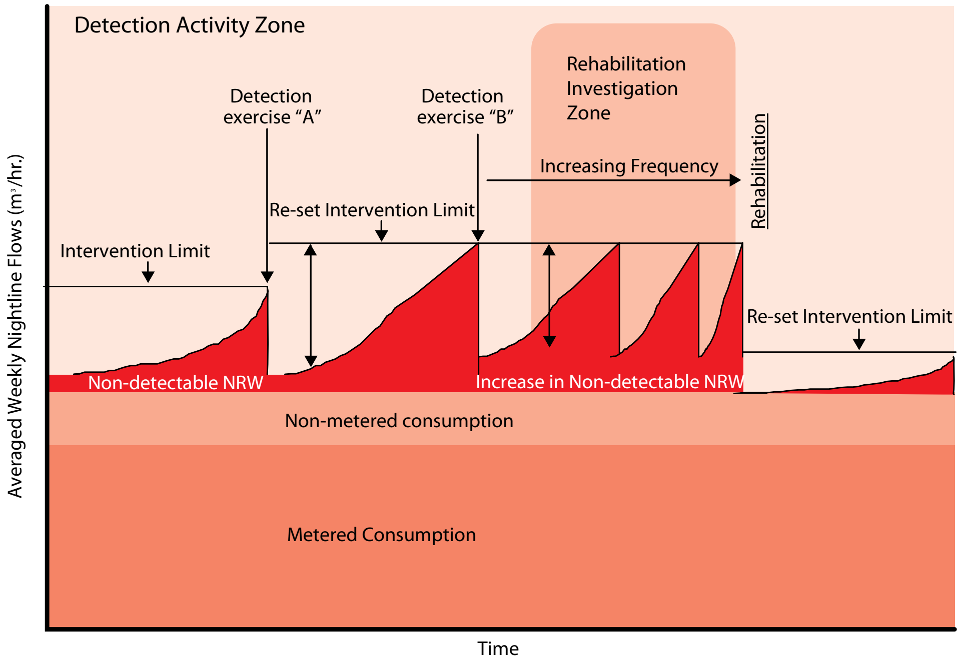


Managers walking the line to monitor the DMA

Figure 7.4 shows that the NRW level within the DMA continues to increase, and the rate of increase depends on a number of issues, including pipe network age and condition, system pressures, and the number of illegal connections and tampered meters. For most water utilities, it is inefficient for leakage detection and customer survey teams to work in the DMA continually. Therefore, the monitoring team should set an intervention limit, or the level at which NRW becomes unacceptable. Once the intervention limit is reached, the teams should be sent in to detect and resolve losses. Generally, once the utility manager deploys teams into the DMA, they can reduce the NRW level within two to four weeks. Afterwards, the manager should ensure that the NRW level is monitored until the intervention level is reached again. This process is the optimal management cycle of an established DMA.

Water utilities should maintain a record of the time taken for NRW to return to the intervention level. If this time decreases between detection exercises, it indicates that losses within the DMA are occurring more frequently and that the system's assets are deteriorating. For such a case, water utility managers should consider asset rehabilitation such as pipe rehabilitation, relining, or replacement, rather than continual leak detection and repair (Figure 7.5).

Figure 7.5: Moving from leak detection and repairs to pipe rehabilitation



Upon completion of asset rehabilitation activities, the level of NRW typically decreases due to fewer leaks, especially underground or previously undetected leaks. Monitoring teams should also detect a much slower increase in the NRW level over time with the much-improved asset condition, and the intervention level should be re-set to a lower level (Figure 7.5).

7.4 ADDITIONAL BENEFITS OF THE DMA

Establishing a series of DMAs not only targets NRW reduction but it also improves asset condition and customer service by:

- Maintaining asset life through pressure management
- Safeguarding water quality
- Enabling continuous water supply

7.4.1 Improved pressure management

Establishing a DMA and the subsequent reduction in NRW will improve the water pressure within the DMA. As leaks are repaired, the flows within the DMA will decrease and thus the friction headlosses are reduced, which has the effect of increasing DMA system pressures. These increases in pressure will become even more pronounced at night when demands are low and friction headlosses are even lower.

Improved pressure control presents dual benefits of reducing leakages and stabilising system pressures, which increase asset life. Most pipe bursts occur not because of high pressure but rather due to ongoing pressure fluctuations that force the pipe to continually expand and contract, resulting in stress fractures. Installing a pressure control device, such as a pressure reducing valve (PRV), helps to reduce pressure throughout the day, stabilise fluctuations, and reduce stress on pipes.

By design, PRVs reduce pressure to a set level during the day and night-time. A pressure of 30 m is sufficient for most customer demand. However, the pressure in a gravity system can be much higher at night when there is little customer demand. To activate a lower pressure at night and during periods of low demand, and to further reduce leakage levels, water utilities should install a timer device with two set levels—one for daytime when customers need water, and the second for night-time when demand is low. The night-time setting, generally adjusted between 15 m and 20 m pressure, is typically lower than the daytime setting,

7.4.2 Safeguarding water quality

Establishing DMAs helps water utilities to prevent water quality deterioration in the distribution network. Closing a number of boundary valves to isolate each DMA, as per standard DMA establishment protocol, reduces the ebb and varying flow of water within the pipe network. As a result, sediments accumulated in the bottom of pipe will be disturbed less, thereby reducing water discolouration.

Water utilities benefit from decreased pipe leaks and repairs as a result of a more stable system pressure. Utilities can better locate pipe leakages that commonly cause infiltration of dirt and potentially contaminated groundwater into the pipes. The need for fewer repairs results in fewer system shutdowns, which in turn keeps sediments undisturbed.

Ranhill Experience: Dead-end pipes

Ranhill ensures that the number of dead-end pipes within the system is minimised to reduce the number of areas with stagnant water. Where dead-end pipes exist, Ranhill implements a regular flushing regime to ensure the water is kept fresh.

Each DMA should include a water sampling point. Regular sampling and testing will help to identify water quality issues and assist asset rehabilitation teams in identifying pipes that need replacement or repair.

7.4.3 Providing continuous (24/7) water supply

In some systems, the water supply is not continuously available to customers 24 hours a day, so they tend to hoard water whenever it is available in case of delays in getting reconnected. As a result, they often store more water than is required for the period of non-supply. When the water supply is reconnected, they then discard the old water and hoard fresh water once again.

Water consumption per capita per day is therefore often much higher in intermittent supply systems compared to continuous supply systems. Converting to a 24-hour supply will result in lower water consumption and lower demand from the water production plant. However, turning the entire network into 24-hour supply remains challenging since the process normally requires five to seven days for the water consumption to decrease to normal (or actual use) levels. During this period, the demand would be so high that the system pressure would be greatly reduced, causing people to continue hoarding water.

DMA principles can be applied to convert from an intermittent to continuous water supply system. First, the water utility should consider installing a small number of DMAs that gradually feed continuous water supply, leading users in those DMAs to adjust to the new system and reduce excessive collection of water. Once consumption stabilises, the inflow volume into the DMAs should decrease within the five to seven day period. The water utility should then undertake leak detection activities and customer surveys to reduce water losses to an acceptable level, creating spare capacity at the production plant. This spare capacity represents additional water that can be supplied to other areas. Once these first DMAs have successfully supplied water continuously and effectively reduced water losses, then the next set of DMAs can be established for conversion to 24-hour supply.

The additional benefit of having 24-hour supply is that the pipe will be constantly pressurised, meaning that infiltration from outside the pipe is minimal. This will ensure that the quality of the water is kept to a premium and that the customer receives water of an acceptable quality.

KEY MESSAGES

- Dividing the open network into smaller, more manageable DMAs enables utility managers to manage the system more effectively in terms of pressure control, water quality, and NRW.
- Criteria in establishing DMAs include the size (or number of connections); number of valves that must be closed; number of flow meters; ground-level variations; and visible topographic features that can serve as DMA boundaries.
- Utility managers use the minimum night flow (MNF) and legitimate night flow (LNF) to calculate the net night flow (NNF), along with commercial losses, to determine NRW in a DMA
- Establishing DMAs helps to manage pressure, improve water quality, and enable continuous water supply.

8. MONITORING PERFORMANCE OF NRW MANAGEMENT

NRW is a measure of a utility's efficiency in terms of both operational performance and financial performance. Managers, policymakers, regulatory agencies, and financing institutions use NRW performance indicators (PIs) to rank the utility's performance against industry standards and other water utilities. This chapter reviews common performance indicators for physical and commercial losses and briefly describes monitoring programmes.

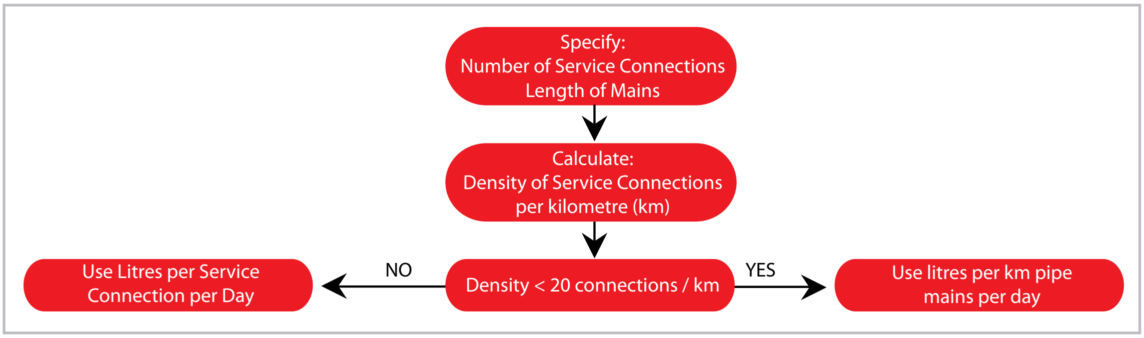
8.1 CHARACTERISTICS OF PERFORMANCE INDICATORS

Performance indicators help a utility:

- Better understand water losses
- Define and set targets for improvement
- Measure and compare performance
- Develop standards
- Monitor compliance
- Prioritise investments

A good NRW PI should be clear and easy to understand and have a rational basis. It should also be easy to calculate using data that the utility gathers regularly. Finally, utilities should include standard performance indicators to measure performance to facilitate comparisons with other utilities. Tools such as decision trees are available for managers to select appropriate performance indicators for their utility's needs and operating context.

Figure 8.1: Decision tree to select performance indicators



Source: Malcolm Farley and Stuart Trow, Losses in Water Distribution Networks, IWA Publishing, 2003

Utility managers can use Figure 8.1 to help choose PIs for their network. For example, in an urban network, where the housing density is usually greater than 20 connections per kilometre of mains, the answer to the question in the middle box in the bottom row would be 'NO' and the PI would be litres/service connection/day. To take account of networks with varying pressures, the utility can enhance the PI by expressing losses in litres per connection per day per metre of pressure (l/conn/day/m).

8.2 PERFORMANCE INDICATORS FOR PHYSICAL LOSSES

8.2.1 Expressing NRW as a percentage

NRW has traditionally been expressed as a percentage of input volume. Although this is preferable to setting no targets at all, it is misleading as a PI because it favours utilities with high consumption, low pressure, and intermittent supply. In addition, it does not differentiate between physical losses and commercial losses. Nevertheless, NRW as a percentage of input is sometimes useful for its 'shock value'—a high result can be a spur a utility to initiate a study of the network's operational performance and to conduct a water balance calculation. It is also useful as a measure of the utility's year-on-year financial performance, as long as the measurement principles are consistent. In that case, it should be expressed as the *value*, not the volume, of water lost.

8.2.2 Other performance indicators for physical losses

Appropriate indicators of physical losses include:

- Litres per service connection per day (l/c/d)
- Litres per service connection per day per metre of pressure (l/c/d/m pressure)
- Litres per kilometre of pipeline per day (l/km/d)
- Infrastructure Leakage Index (ILI)

Table 8.1 shows the Infrastructure Leakage Index (ILI) and other recommended NRW and physical loss performance indicators based on the IWA's *Performance Indicators for Water Supply Services: IWA*

Manual of Best Practice.[5] L/c/d gives a more accurate picture than NRW as a percentage of input volume, but taking system pressure into account (l/c/d/m pressure) is an even better indicator. The PIs are categorized by function and level, defined as follows:

- Level 1 (basic): A first layer of indicators that provides a general management overview of the efficiency and effectiveness of the water undertaking.
- Level 2 (intermediate): Additional indicators that provide a better insight than the Level 1 indicators; for users who need to go further in depth.
- Level 3 (detailed): Indicators that provide the greatest amount of specific detail, but are still relevant at the top management level.

Table 8.1: Recommended indicators for physical losses and NRW

Function	Level	Performance Indicator	Comments
Financial: NRW by Volume	1 (Basic)	Volume of NRW [% of System Input Volume]	Can be calculated from simple water balance not too meaningful
Operational: Physical Losses	1 (Basic)	[Litres/service connection/day or [Litres/km of mains/day] *(only if service connection density is < 20/km)*	Best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems
Operational: Physical Losses	2 (Intermed.)	[Litres/service connection/day/m pressure] or [Litres/km of mains/day/m pressure] *[only if service connection density is < 20/km)*	Easy to calculate indicator if the ILI is not known yet, useful for comparisons between systems
Financial: NRW by cost	3 (Detailed)	Value of NRW [% of annual cost of running system]	Allows different unit costs for NRW component, good financial indicator
Operational: Physical Losses	3 (Detailed)	Infrastructure Leakage Index (ILI)	Ratio of current annual Physical losses to unavidable annual real losses, most powerful indictor for comparisons between systems

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[5] Alegre H., Hirner W., Baptista J.M. and Parena R. (2000) *Performance Indicators for Water Supply Services: IWA Manual of Best Practice*. ISBN 900222272

8.2.3 The Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index (ILI) is an excellent indicator of physical losses, one that takes into account how the network is managed. The IWA, which developed the index, and the American Water Works Association (AWWA) Water Loss Control Committee both recommend this indicator. The ILI is particularly useful in networks where NRW is relatively low, for example below 20%, as the ILI can help to identify which areas can be reduced further.

The ILI is a measure of how well a distribution network is managed (i.e. maintained, repaired, and rehabilitated) for the control of physical losses, at the current operating pressure. It is the ratio of **C**urrent **A**nnual Volume of **P**hysical **L**osses (CAPL) to **M**inimum **A**chievable **A**nnual **P**hysical **L**osses (MAPL).

$$\textbf{ILI = CAPL/MAAPL}$$

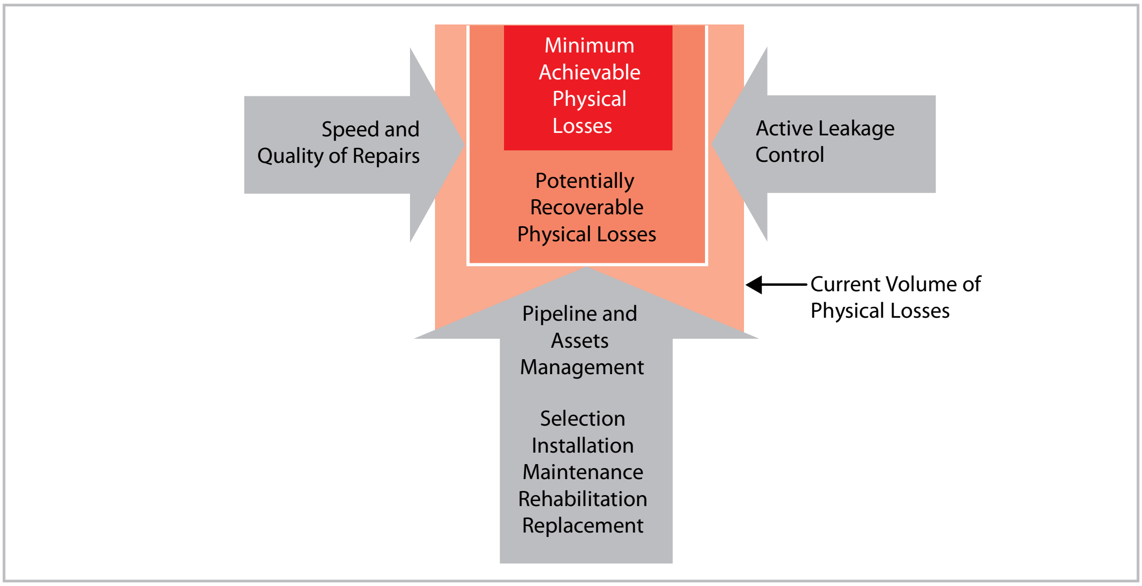
Being a ratio, the ILI has no units and thus facilitates comparisons between utilities and countries that use different measurement units. The complex initial components of the MAAPL formula have been converted to a format using a pre-defined pressure for practical use:

$$\text{MAAPL (litres/day)} = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P$$

Where Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, property boundary to customer meter (km); and P = average pressure (m).

Figure 8.2 illustrates the ILI concept with the factors that influence leakage management. The large square represents the CAPL, which tends to increase as the distribution networks grow older. This increase, however, can be constrained by a successful leakage management policy. The black box represents the MAAPL, or the lowest technically achievable volume of physical losses at the current operating pressure.

Figure 8.2: The ILI Concept



The ratio of the CAPL to MAAPL, or the ILI, is a measure of how well the utility implements the three infrastructure management functions—repairs, pipelines and asset management, and active leakage control. Although a well-managed system can have an ILI of 1.0 (CAPL = MAAPL), the utility may not necessarily aim for this target, since the ILI is a purely technical performance indicator and does not take economic considerations into account.

Calculating the ILI

- **Step 1.** Calculate the MAAPL
- **Step 2.** Calculate the CAPL (e.g. from the Water Balance)
- **Step 3.** Calculate the ILI (CAPL/MAAPL)
- **Step 4.** Adjust for intermittent supply (divide MAAPL by the average number of supply hours per day)
- **Step 5**. Compare ILI with physical loss target matrix (Figure 8.3.)

The physical loss target matrix shows the expected level of ILI and physical losses in l/c/day from utilities in countries at differing levels of network pressure.

Table 8.2: Physical loss target matrix

Technical Performance Category		ILI	Physical Losses [litres/connection/day] (when the system is pressured) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50 - 100	75 - 150	100 - 200	125 - 250
	C	4 - 8		100 - 200	150 - 300	200 - 400	250 - 500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50 - 100	100 - 200	150 - 300	200 - 400	250 - 500
	C	8 - 16	100 - 200	200 - 400	300 - 600	400 - 800	500 - 1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Source: World Bank Institute

Utility managers can use the matrix to guide further network development and improvement:

- Category A—Good. Further loss reduction may be uneconomic and careful analysis needed to identify cost-effective improvements.
- Category B—Potential for marked improvements. Consider pressure management, better active leakage control, and better maintenance.
- Category C—Poor. Tolerable only if water is plentiful and cheap, and even then intensify NRW reduction efforts.

- Category D—Bad. The utility is using resources inefficiently and NRW reduction programmes are imperative.

8.3 PERFORMANCE INDICATORS FOR COMMERCIAL LOSSES

The IWA Water Loss Task Force is also developing a performance indicator for commercial losses similar to the ILI.[6] The indicator uses a base value of 5% of water sales as a reference, and the actual commercial loss value is calculated against this benchmark. This is the Apparent (Commercial) Loss Index (ALI).

Apparent Loss Index (ALI) = Apparent loss value ÷ 5% of water sales

A commonly used indicator that expresses commercial losses as a percentage of water supplied is misleading because it does not reflect the true value of lost revenue. Currently, the best indicator is to measure commercial losses as a percentage of authorised consumption.

8.4 IMPLEMENTING A MONITORING PROGRAM

Utilities should continuously monitor NRW levels

A water utility embarking on the implementation of an NRW strategy needs to monitor its progress using some or all of the indicators detailed above. Since it is a utility-wide undertaking, an independent team should be established to audit progress. This NRW audit team should not be responsible for any physical activities to reduce NRW, but should be dedicated to auditing all of the departments involved with NRW strategy activities.

The implementation of the NRW strategy is a long-term process, often requiring four to seven years to complete. During this time, staff changes will occur, and the NRW audit team should train all incoming staff on the NRW strategy and its importance to the company.

The NRW audit team should also establish yearly targets for each department using one or more of the indicators, and monitor progress on a monthly progress. The number and type of indicators depends on the department and its activities. For example, the Network Department may be responsible for leakage detection and repair; in this case, the physical loss indicators of litres/connections/day and litres/connections/km can be used.

A monthly NRW strategy progress meeting should include representatives from all departments, with discussions on progress and hindrances. A senior member of the management team should chair the meeting, to stress the importance of the NRW strategy implementation. The head of the NRW audit team will support the chair by providing technical details and progress reports.

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[6] 'Apparent Water Loss Control—The Way Forward'. WLTF article, Water 21, April 2008

Ranhill Experience: Monitoring an NRW strategy implementation

Ranhill established an NRW audit team to monitor its NRW strategy implementation. The team monitors each department and external contractors on their monthly progress towards achieving targets set out in the company balance scorecard. This scorecard and the targets are established during the yearly management retreat, ensuring that all departments are involved.

KEY MESSAGES

- Utility managers use performance indicators to measure progress in reducing NRW, develop standards, and prioritise investments.
- The best performance indicator for physical losses is the Infrastructure Leakage Index (ILI).
- A commonly used performance indicator for commercial losses is the Apparent Loss Index (ALI). Currently, the best commercial loss indicator is to measure it as a percentage of authorised consumption.
- Utility managers must establish an independent NRW audit team to monitor progress in the NRW strategy implementation.
- Performance targets should be set on a yearly basis with progress monitored and reported monthly.

9. BUILDING CAPACITY TO MANAGE NRW THROUGH UTILITY-TO-UTILITY TWINNING PARTNERSHIPS: A CASE STUDY

Reducing and managing NRW remains a challenge for many utilities and service providers in Asia, especially those where dwindling water supply, worsening water quality, and aging infrastructure. To overcome these challenges, water service providers have demonstrated the value of 'twinning', or focused and sustained practitioner-to-practitioner exchange in promoting the adoption of improved policies and best practices, and in building human and institutional capacity.

This chapter describes twinning partnerships between Ranhill Utilities Berhad (Ranhill), a Malaysian utility recognised for effectively reducing and managing NRW, with two water utilities in Asia: the Provincial Waterworks Authority (PWA) of Thailand, and the Bac Ninh Water Supply and Sewerage Company (Bac Ninh) in Vietnam. Both twinning partnerships highlight Ranhill best practices, and the value of practitioner-to-practitioner exchange in enabling utilities to address NRW. These twinning partnerships draw on the lessons and best practices detailed in this handbook, and have contributed to the development of this handbook.

The Environmental Cooperation–Asia (ECO-Asia) Water and Sanitation Programme of the United States Agency for International Development provided direct funding and facilitation support for both twinning partnerships with Ranhill. Throughout Asia, ECO-Asia demonstrates how twinning arrangements can help water utilities meet the challenges of reducing water losses and improving operational efficiencies to support the achievement of the Millennium Development Goals (MDGs) in urban areas. ECO-Asia facilitates linkages between utilities to address specific priority needs, such as NRW management. Utility strengthening through these collaborative arrangements promotes self-reliance and long-term sustainability, which in the long run results in not only improved efficiencies but also expanded service areas and increased revenues.

Box 9.1: Twinning and Water Operator Partnerships

During the 4th World Water Forum in 2006, the UN Secretary General's Advisory Board on Water and Sanitation announced the Hashimoto Action Plan, calling for the establishment of a platform to launch and coordinate twinning arrangements or Water Operators Partnerships (WOPs) *'in order to strengthen the capacities of the public water operators that currently provide over 90 per cent of the water and sanitation services and who are key players for attaining the [Millennium Development Goals] on drinking water supply and sanitation.'*

Throughout 2006 and 2007, ECO-Asia facilitated the twinning partnerships between Ranhill and PWA, and between Ranhill and Bac Ninh. The Ranhill-PWA link focused on strengthening PWA's approach to identifying NRW components based on an international best practice employed by Ranhill (see Chapters 2 and 3 of this handbook), raising awareness of NRW management activities among senior decision-makers (Chapter 4), and expanding its knowledge of district meter area (DMA) management (Chapter 7). The Ranhill-Bac Ninh partnership centred on building the capacity of key Bac Ninh staff to comprehend and implement the water balance (Chapter 2), gain basic understanding of NRW components according to Ranhill experiences (Chapters 5 and 6), and specifically to undertake DMA design and piloting efforts per Ranhill best practices (Chapter 7). In these twinning arrangements, ECO-Asia helped facilitate practitioner-to-practitioner exchange of practical solutions and practices applied by Ranhill in Johor, Malaysia, to manage and reduce NRW.

9.1 TWINNING APPROACH

9.1.1 Understanding priorities and facilitating linkages

In a utility-to-utility twinning arrangement, ECO-Asia links a utilities on a range of technical areas, including improving services delivery (such as through enhanced water supply quality or water loss reduction), expanding services to the urban poor, and converting systems to continuous water supply. In a typical twinning arrangement, ECO-Asia identifies a 'mentor' utility with proven success in addressing specific challenges that is willing to share its knowledge and innovations. As the facilitator, ECO-Asia identifies potential linkages, matches counterpart institutions, and facilitates the initiation, establishment, and implementation of twinning partnerships. ECO-Asia establishes partnerships that are mutually beneficial, result in tangible improvements to service delivery, and are relevant to other utilities in Asia.

Practitioners share best practices and new systems to build capacity and realise tangible improvements for managing NRW.

In the case of PWA in Thailand, PWA's top priority was to strengthen its capacity in understanding and managing NRW, especially in managing DMAs. Similarly, Bac Ninh was interested in best practices related to determining and addressing major NRW components and designing, establishing and operating DMAs. To link both partners with a counterpart utility, ECO-Asia identified various utilities in the region that successfully reduced NRW and were interested in a twinning partnership. Of several utilities approached, Ranhill agreed to become the mentor partner for both PWA and Bac Ninh, and was willing to share its best practices and technical expertise. As 'recipient' partners, PWA and Bac Ninh agreed to link with Ranhill.

As a first step for each partnership, the counterpart utilities held detailed discussions to understand the mutual benefits for both twinning partners. ECO-Asia facilitated these discussions and initiated site visits that enabled Ranhill practitioners to become familiar with the operational challenges in each recipient country. Building trust and relationships, as well as understanding of each partner's interests and incentives to twin, were outcomes of the initial introduction.

Box 9.2: Twinning Principles

- Practitioner-to-practitioner exchange forms the basis of twinning partnerships.
- Benefits from the twinning partnerships are mutual, but not necessarily equal.
- Twinning partnerships are demand-driven in line with partner strategies, plans, and interests, and results-oriented, ensuring the adoption of best practices and activities that result in real improvements and tangible outcomes.
- Partners cooperate on a cost-share basis, providing in-kind and funding support
- All partnerships operate on a non-profit basis.

9.1.2 Preparing to implement twinning partnerships that achieve results

After initiation, for each twinning arrangement, ECO-Asia facilitated the development of a joint programme of activities and a work plan that included a series of activities that enabled Ranhill to share targeted best practices based on partner needs. In both cases, partners set milestones and allocated resources to implement the work plan activities. In both arrangements, partners aimed at building current capacities to manage NRW and at adopting best practices for reducing NRW. ECO-Asia facilitated the work plan development process and also committed necessary resources to ensure that the work plan was implemented and results achieved. Upon agreeing to the joint programme, partners in each twinning arrangement signed an agreement committing them to implementing the twinning activities and achieving their expected results.

Box 9.3: Basic Steps in Establishing Effective Twinning Partnerships

1. Identification — Identifying possible partners and understanding their priorities and interests
2. Selection — Selecting the right partners to twin
3. Initiation — Introducing partners
4. Establishment — Getting started in working together and setting goals
5. Implementation — Jointly achieving results
6. Replication — Expanding and replicating twinning partnerships and best practices

9.2 TWINNING ACTIVITIES

Twinning activities typically include peer-to-peer exchanges, specialised classroom and on-the-job training, technical assistance, short internships, peer review of current systems, technology demonstrations, and discussion workshops. In implementing these activities, both partners provide in-kind or cash contributions that support such inputs as workshop costs, translation services, and local travel.

In the Ranhill-PWA partnership, activities included a series of classroom and on-the-job training workshops and field practices that enabled the transfer of practical solutions. Initially, Ranhill trained PWA senior managers and operations staff to better understand NRW and its impact on a utility's finances and operations. Building on this training, operations staff next learned how to conduct an internationally-recognised water balance to detect key sources of NRW, followed by further hands-on training on approaches to reduce NRW, such as DMA design and establishment.

Although twinning activities were similar in the Ranhill-Bac Ninh arrangement, Ranhill provided additional technical assistance for Bac Ninh for the design and establishment DMAs. Ranhill introduced established vendors and suppliers of specific equipment required for setting up and monitoring DMAs. Ranhill also assisted Bac Ninh to properly design and operate a pilot DMA.

Key PWA and Bac Ninh managers also visited Ranhill operations in Johor to advance their understanding of field applications for NRW reduction techniques. During the visit, Ranhill shared its practical lessons and field experience in effectively managing NRW.

ECO-Asia supported and monitored all activities to better enable integration and replication of best practices and solutions from Ranhill to PWA and to Bac Ninh.

9.3 ILLUSTRATIVE RESULTS OF TWINNING PARTNERSHIPS

The ECO-Asia twinning model demonstrates how regional collaboration and sharing of best practices among peers can benefit all parties involved, although the benefits vary in form and results. Ranhill shared key best practices for NRW reduction identified in this handbook with PWA and Bac Ninh during the twinning arrangements.

9.3.1 Provincial Waterworks Authority of Thailand


PWA engineers learning practical approaches implemented by Ranhill to analyse key field data for determining water losses.

PWA noted that the twinning programme enabled its management and staff to adopt new approaches in support of its evolving policies to better manage NRW. Major results from the twinning partnership with Ranhill include:

- Key staff gained practical knowledge for applying an international water balance method using a free water audit software programme translated into Thai, and to use the balance results to systematically address NRW (see Chapters 2 and 3).
- Senior decision-makers gained a basic understanding of the importance of properly identifying NRW components and effectively managing NRW (see Chapter 4).
- Regional training centres integrated several training modules presented by Ranhill for training key operations staff on NRW, and ensuring targeted actions for reducing NRW components. The main modules adapted include conducting a water audit, identifying NRW components, developing NRW management strategies, and understanding DMAs and their management.
- Technical staff responsible for preparing specifications for future DMA establishment contracts incorporated the DMA design criteria, principles, and onsite commissioning procedures introduced by Ranhill (see Chapter 7).
- Several engineers and managers applied hands-on and practical techniques for managing and operating DMAs, including best practices for collecting and analysing DMA data to verify DMA establishment, monitor performance, and maintain target NRW levels in service areas.
- Select engineers utilised simple spreadsheets offered by Ranhill to measure minimum night flow, locate leakages, calculate pressure, and monitor customer meter performance (see Chapter 6 and 7).

> *'Working with Ranhill practitioners through the twinning partnership has really enabled PWA managers and staff to better understand the critical steps and practical approaches required to reduce water losses and manage non-revenue water. We value the peer-to-peer sharing and transfer of information and expertise, which allowed us to access international best practices and apply them on the ground as we strive to improve our operations.'*
>
> *––Vichian Udomratanasilpa, Deputy Governor of Planning and Technical Affairs, PWA*

9.3.2 Bac Ninh Water Supply and Sewerage Company, Vietnam

Experts from Ranhill working hand-in-hand with their counterparts in Bac Ninh, Vietnam, to test DMA operations.

For Bac Ninh, the twinning partnership built the capacity of its staff to improve its operations by strengthening the basic understanding of NRW management and introducing various activities needed to lower NRW. Main results from the partnership with Ranhill include:

- Key staff from both technical and non-technical departments improved their understanding of NRW, especially in identifying the major causes of NRW, developing practical solutions necessary to manage NRW, and performing a water balance as the critical step in developing an NRW management strategy (see Chapters 2-4).
- Technical staff members conducted water balances on discrete service areas and attributed inconsistent NRW to inadequate billing and collection processes, a key source of commercial losses (see Chapter 5).
- Technical staff members incorporated best practices introduced by Ranhill for establishing DMAs, such as ensuring adequate water pressure and closing all boundary valves, to their current procedures and tested them on a pilot DMA (see Chapter 6 and 7).
- Key engineers worked with Ranhill to revise its current DMA design to enable improved NRW management following training events.
- As part of the pilot DMA activities, with guidance from Ranhill, Bac Ninh purchased and commissioned critical equipment, such as data loggers and a bulk meter to lower NRW levels (see Chapter 7).

9.3.3 Ranhill Utilities Berhad, Malaysia

The twinning partnerships with PWA and the Bac Ninh benefited Ranhill in several ways:

- The twinning showcased Ranhill's strengths in water supply services delivery in line with Ranhill's strategic plan to expand its services beyond Malaysia.
- The partnerships provided a platform for Ranhill staff to familiarise themselves with new challenges and the conditions of water supply services and operations outside of Malaysia.
- Ranhill staff networked with water professionals in Thailand and Vietnam, which may lead to downstream commercial opportunities.
- Ranhill added value to its portfolio of activities in Thailand and Vietnam and gained exposure in Asia.

> *'We believe twinning arrangements add value to Ranhill's corporate strategies to position itself as a leading global brand. Twinning helps our staff to understand the challenges and conditions beyond our operations in Malaysia, preparing them for future activities, and allows them to build relations and network with other service providers, creating opportunities for downstream commercial linkages. It also gives us a chance to use our strengths to help others become better at providing water services to their customers while building trust and confidence of our services at the international level.'*
>
> – Ahmad Zahdi Jamil, Chief Executive Officer, Ranhill Utilities Berhad

Box 9.4: Promoting Twinning Partnerships through WaterLinks

To promote twinning, ECO-Asia provides support to WaterLinks (www.waterlinks.org), a regional knowledge hub and platform for facilitating and sustaining partnerships, and sharing information and best practices in Asia.

WaterLinks

KEY MESSAGES

- Water service providers worldwide have demonstrated the value of 'twinning' in promoting the adoption of improved policies and best practices, and in building human and institutional capacity.
- Effective twinning partnerships are demand driven, addressing the interests and priorities of 'recipient' and 'mentor' partners through activities that aim to ensure the adoption and replication of best practices and solutions.
- The twinning model demonstrates how regional collaboration and sharing of best practices among peers can benefit all parties involved, although the benefits vary in form and results.
- Twinning activities typically include peer-to-peer exchanges, specialised classroom and on-the-job training, technical assistance, short internships, peer review of current systems, technology demonstrations, and discussion workshops. In implementing the activities, twinning partners provide in-kind or cash contributions.
- Twinning partnerships leverage counterpart exchange to help strengthen the capacity of utilities in improving services delivery (such as NRW reduction), expanding services and converting to continuous water supply.

ANNEX 1: GLOSSARY

The Water Balance

System Input Volume (allow for known errors)	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Erros	
		Physical Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to the Point Customer Use	

Water Balance Definitions

In the following, all terms used in Figure above are listed in hierarchical order – as one would read the water balance from left to right. Some of the terms are self-explanatory but are still listed for consistency.

System Input Volume

The volume of treated water input to that part of the water supply system to which the water balance calculation relates.

Authorised Consumption

The volume of metered and/or un-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial and industrial purposes. It also includes water exported across operational boundaries.

Authorised consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.

Water Losses

The difference between System Input and Authorised Consumption. Water losses can be considered as a total volume for the whole system, or for partial systems such as transmission or distribution schemes, or individual zones. Water Losses consist of Physical Losses and Commercial Losses (also known as Real Losses and Apparent Losses)

Billed Authorised Consumption

Those components of Authorised Consumption which are billed and produce revenue (also known as Revenue Water). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Unbilled Authorised Consumption

Those components of Authorised Consumption which are legitimate but not billed and therefore do not produce revenue. Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption.

Commercial Losses

Includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorised consumption (theft or illegal use).

Commercial losses are called "Apparent Losses" by the International Water Association and in some countries the misleading term "Non-Technical Losses" is used.

Physical Losses

Physical water losses from the pressurized system and the utility's storage tanks, up to the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Physical losses are called "Real Losses" by the International Water Association and in some countries the misleading term "Technical Losses" is used.

Billed Metered Consumption

All metered consumption which is also billed. This includes all groups of customers such as domestic, commercial, industrial or institutional and also includes water transferred across operational boundaries (water exported) which is metered and billed.

Billed Unmetered Consumtion

All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering. This component might also include water transferred across operational boundaries (water exported) which is unmetered but billed.

Unbilled Metered Consumption

Metered Consumption which is for any reason unbilled. This might for example include metered consumption by the utility itself or water provided to institutions free of charge, including water transferred across operational boundaries (water exported) which is metered but unbilled.

Unbilled Unmetered Consumption

Any kind of Authorised Consumption which is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well run utility it is a small component which is very often substantially overestimated. Theoretically this might also include water transferred across operational boundaries (water exported) which is unmetered and unbilled – although this is an unlikely case.

Unauthorised Consumption

Any unauthorised use of water. This may include illegal water withdrawal from hydrants (for example for construction purposes), illegal connections, bypasses to consumption meters or meter tampering.

Customer Metering Inaccuracies and Data Handling Errors

Commercial water losses caused by customer meter inaccuracies and data handling errors in the meter reading and billing system.

Leakage on Transmission and/or Distribution Mains

Water lost from leaks and breaks on transmission and distribution pipelines. These might either be small leaks which are still unreported (e.g. leaking joints) or large bursts which were reported and repaired but did obviously leak for a certain period before that.

Leakage and Overflows at Utility's Storage Tanks

Water lost from leaking storage tank structures or overflows of such tanks caused by e.g. operational or technical problems.

Leakage on Service Connections up to point of Customer Metering

Water lost from leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property. Leakage on service connections might be reported breaks but will predominately be small leaks which do not surface and which run for long periods (often years).

Revenue Water

Those components of Authorised Consumption which are billed and produce revenue (also known as Billed Authorised Consumption). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Non-Revenue Water

Those components of System Input which are not billed and do not produce revenue. Equal to Unbilled Authorised Consumption plus Physical and Commercial Water Losses.

(Unaccounted-for Water)

Because of the widely varying interpretations and definitions of the term 'Unaccounted for Water', it is strongly recommend that this term be no longer used. It is equivalent to 'Water Losses' in the Water Balance diagram

Understanding Leakage

Background Leakage

Background leakage (also called background losses) are individual events (small leaks and weeps) that will continue to flow, with flow rates too low to be detected by an active leakage control campaign unless either detected by chance or until they gradually worsen to the point that they can be detected. As the term is nearly untranslatable, it is often referred to as "unavoidable losses". The level of background leakage depends on the overall infrastructure condition, the pipe material(s) and the soil. It is furthermore heavily influenced by pressure (N1=1.5 or even higher).

Bursts

Events with flow rates grater than those of background losses and therefore detectable by standard leak detection techniques. Bursts can be visible or hidden.

Reported Bursts

Reported Bursts are visible leaks that are brought to the attention of the water utility by the general public or the water supply organization's own operatives.

Unreported Bursts

Unreported bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties. These breaks go undetected without some form of active leakage control.

Active Leakage Control (ALC)

ALC is the policy a water utility implements if it decides to pro-actively search for hidden leaks. ALC in its most basic form consists of regular sounding (e.g. listening to leak noise on fire hydrants, valves and accessible parts of service connections (e.g. stop cock) with listening sticks or electronic devices.

Leak Duration

The length of time for which a leak runs consists of three separate time components - awareness, location and repair time.

Awareness Time

Awareness Time is the average time from the occurrence of a leak until the water utility becomes aware of its existence. The awareness time is influenced by the type of applied ALC policy.

Location Time

For reported bursts, this is the time it takes for the water utility to investigate the report of a leak or break and to correctly locate its position so that a repair can be carried out. For Unreported bursts, depending on the ALC method used, the location duration may be zero since the burst is detected during the leak detection survey and therefore awareness and location occur simultaneously.

Repair Time

The time it takes the water utility to organize and affect the repair once a leak has been located.

N1 Factor

The N1 Factor is used to calculate pressure/leakage relationships:

Leakage Rate L (Volume/unit time) varies with Pressure^{N1} or $L_1/L_0 = (P_1/P_0)^{N1}$

The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. N1 Factors range between 0.5 (corrosion holes only in metallic systems) and 1.5 with occasional values of up to 2.5. In distribution systems with a mix of pipe materials, N1 values might be in the order of 1 to 1.15. Therefore a linear relationship can be assumed initially until N1 Step Tests are carried out to derive better data.

N1 Step Test

The N1 Step Test is used to determine the N1 value for areas of the distribution network. Inflow to the area as well as pressure at the Average Zone Point are recorded. During the test supply pressure into the area is reduced in a series of steps. This pressure reduction together with the corresponding inflow reduction forms the basis for the calculation of N1.

Pressure Step Test

Equivalent to N^1 Step Test.

Average Zone Point (AZP)

The AZP is the point in a certain zone or area of the distribution network which is representative for the average pressure in this particular part of the distribution network.

Quantifying Losses

Physical Loss Component Analysis

Determination and quantification of the components of physical losses in order to calculate the expected level of physical losses in a distribution system. The BABE concepts were the first component analysis model.

BABE Concepts

The Bursts And Background Estimates (BABE) concepts were developed by the UK National Leakage Initiative between 1991 and 1993. The concepts were the first to model physical losses objectively, rather than empirically, thus permitting rational planning management and operational control of strategies for their reduction.

Leakage Modeling

Leakage modeling is a methodology to analyze 24h inflow and pressure data of a hydraulically discreet part of the distribution system. Using the N1 pressure:leakage relationship principles and the results of the N1 Step Test the measured inflow can be split into:

- Consumption; and
- Leakage; and further into:
- Background Losses
- Losses from Bursts (= losses which can be recovered)

Equivalent Service Pipe Bursts (ESPBs)

The number of ESPBs is an indication of how many hidden leaks can be expected in a certain part of the distribution network. It is calculated by dividing the volume of excess (or hidden) losses by the volume of water lost through an average service pipe burst.

Hidden Losses (Excess Losses)

Physical loss component analysis is used to determine the part of physical losses which is in "excess" of all other leakage components. The volume of Hidden (Excess) Losses represents the quantity of water lost by "hidden" leaks that are not being detected and repaired with the current leakage control policy.

District Metered Area (DMA)

A discrete zone with a permanent boundary defined by flow meters and/or closed valves.

Night Flow Test (NFT)

Zone inflow and pressure measurement carried out during night hours, usually between 02:00 and 04:00 hours to measure Minimum Night Flow and corresponding Average Zone Night Pressure.

Average Zone Night Pressure (AZNP)

The AZNP is the average pressure during (low consumption) night hours measured at the Average Zone Point.

Minimum Night Flow (MNF)

The Minimum Night Flow (MNF) in urban situations normally occurs during the early morning period, usually between around 02:00 and 04:00 hours. The MNF is the most meaningful piece of data as far as physical loss levels are concerned. During this period, consumption is at a minimum and therefore physical losses are at the maximum percentage of the total flow. The estimation of the physical loss component at Minimum Night Flow is carried out by subtracting an assessed amount of Minimum Night Consumption for each of the customers connected in the zone being studied.

Minimum Night Consumption

Minimum Night Consumption is part of the Minimum Night Flow and is normally composed of three elements:

- Household night use
- Non-household night use
- Exceptional night use

Net Night Flow

Net Night Flow is the difference between Minimum Night Flow and Minimum Night Consumption and is equivalent to Night Leakage

[Net Night Flow] = [Minimum Night Flow] - [Minimum Night Consumption]

Performance Indicators

Infrastructure Leakage Index (ILI)

The ILI is a measure of how well a distribution network is managed (maintained, repaired, rehabilitated) for the control of real losses, at the current operating pressure. It is the ratio of Current Annual volume of Physical Losses (CAPL) to Minimum Achievable Annual Physical Losses (MAAPL).

ILI = CAPL / MAAPL

Being a ratio, the ILI has no units and thus it facilitates comparisons between countries that use different measurement units (metric, U.S., or imperial).

Minimum Achievable Annual Physical Losses (MAAPL)

Physical Losses cannot be totally eliminated. The volume of Minimum Achievable Annual Physical Losses represent the lowest technically achievable annual volume of Physical Losses for a well-maintained and well-managed system. The standard equation for calculating MAAPL for individual systems was developed and tested by the IWA Water Losses Task Force. It allows for:

- background leakage – small leaks with flow rates too low for sonic detection if non-visible
- reported leaks and breaks – based on average frequencies, typical flow rates, target average durations
- unreported leaks and breaks – based on average frequencies, typical flow rates, target average durations
- pressure/leakage rate relationships (a linear relationship being assumed)

The MAAPL equation requires data on four key system-specific factors:

- Length of mains (all pipelines except service connections)
- Number of service connections
- Length of service connection between property boundary and customer meter. (Note: this is not the same as the total length of the service connection. Losses on the service connection between the tapping point at the main pipeline are included in the allowance per service connection. The additional allowance for length of connections on private land was included to take the longer leak run-times in situations were visible leaks would not be seen by public into account. In most urban situations, if the customer meter is inside the building, the length of service connection between property boundary and customer meter is obviously nil.)
- Average operating pressure

Minimum Achievable Annual Physical Losses (MAAPL) is called "Unavoidable Annual Real Losses (UARL)" by the International Water Association.

ANNEX 2: STEPS FOR CALCULATING NRW USING THE IWA WATER BALANCE TABLE

A	B	C	D	E
System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Erros	
		Physical Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Service Connections up to the Customer Meter	

Water balance results in volumes and consumptions in cubic meters per year.

Step 1 – Determine System Input Volume

Identify sources of input (and export) volume:

- Water supplied to the network from own WTW sources
- Water transferred in from adjacent networks
- Water purchased from bulk suppliers
- Water exported from the network

Ensure meter accuracy:

- Establish meter accuracy from manufacturers' manuals (eg +/- 2%)
- Check meter readings using downstream master meter or insertion meter
- Replace or re-calibrate meters as necessary
- Correct System Input Volume for all known errors
- Apply 95% Confidence Limits

If there are any un-metered sources the annual flow should be estimated by using any (or a combination) of the following:

- Temporary flow measurements using portable devices
- Reservoir drop tests
- Analysis of pump curves, pressures and average pumping hours

Step 2 – Determine Authorised Consumption

Billed Metered Consumption

- Extract consumption of the different consumer categories (e.g. domestic, commercial, industrial) from the utility's billing system

- Analyse the data, paying special attention to very large consumers.

Process the annual billed metered consumption information taken from the billing system to allow for meter reading time-lag

- Ensure that the billed metered consumption period used in the audit is consistent with the audit period
- Establish meter accuracy from manufacturers' manuals (eg +/- 2%)
- Apply 95% Confidence Limits

Billed Unmetered Consumption

- Extract data from the utility's billing system
- Identify and monitor unmetered domestic customers for a certain period, either by the installation of meters on those non-metered connections or by measuring a small area with a number of unmetered customers (the latter avoids customers changing consumption habits)

Unbilled Metered Consumption

- Establish the volume of unbilled metered consumption in a way similar to that for billed metered consumption

Unbilled Unmetered Consumption

Unbilled unmetered consumption, traditionally including water used by the utility for operational purposes, is often seriously overestimated. This might be caused by simplifications (a certain % of total system input) or deliberate overestimates to 'reduce' water losses. Components of unbilled unmetered consumption should be identified and individually estimated, for example:

- Mains flushing: How many times per month? For how long? How much water?
- Fire fighting: Has there been a big fire? How much water was used?

Step 3 – Estimate Commercial Losses

Unauthorised Consumption

It is difficult to provide general guidelines for estimating unauthorised consumption. There is a wide variation of situations and knowledge of the local situation will be most important to estimate this component. Unauthorised consumption can include:

- Illegal connections
- Misuse of fire hydrants and fire fighting systems
- Vandalised or bypassed consumption meters
- Corrupt practices of meter readers
- Open boundary valves to external distribution systems (unknown export of water).

The estimation of unauthorised consumption is always a difficult task and should at least be done in a transparent, component based way so that the assumptions can be easily checked and/or modified later.

Customer Metering Inaccuracies and Data Handling Errors

The extent of customer meter inaccuracies, namely under- or over-registration, has to be established based on tests of a representative sample of meters. The composition of the sample should reflect the various brands and age groups of domestic meters. Tests are done either at the utility's own test bench, or by specialized contractors. Large customer meters are usually tested on site with a test rig. Based on the results of the accuracy tests, average meter inaccuracy values (as % of metered consumption) will be established for different user groups.

Data handling errors are sometimes a very substantial component of commercial losses. Many billing systems do not reach the expectations of the utilities but problems often remain unrecognised for years. It is possible to detect data handling errors and problems with the billing system by exporting billing data (of say the last 24 months) and analysing it using standard database software.

The detected problems have to be quantified and a best estimate of the annual volume of this component has to be calculated.

Step 4 – Calculate Physical Losses

The calculation of real losses in its simplest form is now straightforward:

Physical Losses = Volume of NRW minus Volume of Commercial Losses

This figure is useful for the start of the analysis in order to get a feeling for the expected magnitude of physical losses. However, it always has to be kept in mind that the water balance might have errors – and that the calculated volume of real losses might simply be wrong.

Step 5 – Estimating Real Loss Components

To accurately split real losses into its components will only be possible with a detailed component analysis. However, a first estimate can be made using a few basic estimates.:

Leakage on Transmission and/or Distribution Mains

Bursts on distribution and especially transmission mains are primarily large events – they are visible, reported and normally repaired quickly. By using data from the repair records, the number of leaks on mains repaired during the reporting period (usually 12 months) can be calculated, an average flow rate estimated and the total annual volume of leakage from mains calculated as follows:

Number of reported bursts x average leak flow rate x average leak duration (say 2 days)

A certain provision for background losses and current undetected leaks on mains can then be added.

Leakage and Overflows at Utility's Storage Tanks

Leakage and overflows at storage tanks are usually known and can be quantified. Overflows can be observed and the average duration and flow rate of the events estimated. Leakage of storage tanks can be calculated by making a level drop test with in and outflow valves closed.

Leakage on Service Connections up to Point of Customer Metering

By deducting mains leakage and storage tank leakage from the total volume of real losses, the approximate quantity of service connection leakage can be calculated. This volume of leakage includes reported and repaired service connection leaks as well as hidden (so far unknown) leaks and background losses from service connections.

Step 1: Enter System Input Volume in Column A

Step 2: Enter in Column C: Billed Authorised Consumption

Enter in Column D:

- Billed Water Exported (none exported = 0)
- Billed Metered Consumption
- Billed Un-metered Consumption

Enter in Column E: Revenue Water

(NOTE: Billed Authorised Consumption should equal to the summation of the three Billed components above and. All billed water use is the same as a utility's revenue).

Step 3: Calculate the Volume of Non-Revenue Water (E) as:

System Input Volume (A) - Revenue Water (E).

Step 4: Enter in Column D:

- Unbilled Metered Consumption
- Unbilled Un-metered Consumption

Enter in Column C: Total Unbilled Authorised Consumption

Step 5: In Column C: Add volumes of Billed Authorised Consumption and Unbilled Authorised Consumption

Enter sum in Column B (top) as Authorised Consumption

Step 6: Calculate Water Losses (B) = System Input Volume (A) - Authorised Consumption (B)

Step 7: Assess components of Unauthorised Consumption, and Metering Inaccuracies and Data Handling Errors (D) by best means available through field verification in random service area and by estimation.

Add Unauthorised Consumption and Metering Inaccuracies (D)

Enter sum in Commercial Losses (C)

Step 8: Calculate Physical Losses (C) = Water Losses (B) - Commercial Losses (C).

Step 9: Assess components of Physical Losses (D) by best means available in the field and through desk studies (e.g. night flow analysis, burst frequency/flow rate/duration calculations, modeling etc)

Add components of Physical Losses (D)

Cross-check with volume of Physical Losses (C) as derived from Step 8

This approach yields best results when meters are installed and regularly calibrated. Results will remain approximate to the extent that factors are based on estimates.

ANNEX 3: SAMPLE WATER AUDIT CHECKLIST

Objectives for a Water Audit:

- To assess whether the waterwork is serving its customers effectively, efficiently and equitably;
- To estimate water losses and their sources; and
- To assess how different groups are connected to piped water and to determine how waterworks and informal service providers respond to concerns of different groups.

Analysis

The important aspect of the analysis is to reveal:

- The actual coverage of the community with piped water and 24-hour service.
- The official NRW and the use of NRW.
- Unit cost of water from various sources and the numbers who use.
- Unit consumption of water from various sources and the numbers who use.
- The extent of informal water supplies.

Use of Analysis

The analysis may be used to:

- Reduce water losses.
- Register and assist water vendors.
- Monitor investment and intervention results and gauge impact over time.

Service Area

1. Population in City
2. Population in Waterwork Service Area
3. Population Served by Waterwork (Direct)
4. Population Served by Waterwork (Bulk Supply / Indirect)
5. Population Served by House Connection
6. Population Served by Shared Connection
7. Population Served by Standpipe or Community Tank
8. Population Served by Waterwork Tanker

Service Delivery – Metering

9. Number of Connections Domestic Metered / Not Metered
10. Number of Standpipes / Community Tank Metered / Not Metered
11. Number of Bulk Connections Metered / Not Metered
12. Number of Non-Domestic Connections Metered / Not Metered
13. Number of Sources of Treated Water for Piped Supply Metered / Not Metered
14. Are all master meters accurate? Yes / No
15. Is there any chance of backflow, bypass or double metering of water? Yes / No
16. Number of Waterwork Tankers / Capacity
17. Are all parks, schools, wastewater treatment plants and government buildings metered? Yes / No
18. Are meter readers motivated to find leaks and trained to do so? Yes / No
19. Are slow or stopped meters identified by the billing department? Yes / No
20. Are both system and customer meters regularly tested and properly sized? Yes / No
21. Are authorised unmetered uses estimated and reported? Yes / No

Service Delivery – Level of Service and Operations

22. Proportion of House Connections with 24 hour Supply %
23. Percentage of Service Area with 24 Hour Supply %
24. Production Volume (m^3 / day)
25. Consumption Volume Domestic (m^3 / month)
26. Consumption Volume Non-Domestic (m^3 / month)
27. Are comparisons made between water produced and water used, on a regular basis?
28. New Connections Installed in last 12 months (Domestic)
29. New Connection Fee and Terms of Payment (Domestic)
30. Average Household Water Consumption Per Month
31. Average Household Water Bill Per Month
32. Number of People Employed by Waterwork
33. Is the public notified via advertising, to report leaks and bursts? Yes / No
34. Are there any unusual pressure drops in any part of the system or isolated complaints about low pressure? Yes / No
35. Are there high flows occurring during periods when flows should be low? Yes / No

36. Are all valves and backflow preventers between pressure zones working properly? Yes / No
37. Is the telemetry available? Yes / No. If yes, is it accurate? Yes / No
38. Are streams and storm channels routinely checked for unusual flows or possible leaks? Yes / No
39. Once estimated, are non-revenue water figure monitored over time? Yes / No
40. Is the volume of non-revenue water increasing? Yes / No

Financial Parameters

41. Money Billed Per Month for Domestic Customers
42. Money Billed per Month for Non-Domestic Customers
43. Are there any known major errors or are any corrections used in billing records such as wrong multipliers on meters? Yes / No
44. O&M Expenses Power / Staff / Other Per Annum
45. Operating Ratio Expenses / Total Billings
46. Accounts Receivables in Equivalent Months Billings
47. Annual Capital Expenditure
48. O&M Cost
49. Capital Cost
50. Lifeline Rate for Poor
51. Cross Subsidy Non-Domestic to Domestic
52. Cross Subsidy City to Town
53. Sources of Capital Works Funding (Central Govt, Local Govt, Donors, Other)
54. Average Household Income Per Month

ANNEX 4: LIST OF CD CONTENTS

1. EasyCALC Water Balance Software
2. International Water Association Leakage (IWA) Detection Guidance Notes
3. IWA District Meter Area (DMA) Guidance Notes
4. Pressure Release Valve Cost Benefit Analysis
5. T Factor Calculation
6. Customer Survey
7. Legitimate Night Flow Calculation
8. Other various forms utility managers can use in reducing water losses

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TOPIC – 1: WASAC STRATEGY TOWARD CUSTOMER-CENTRIC UTILITY

"To enhance further by adopting people-oriented approach"

By Kyowa Consultants, Co., Ltd.

JICA Study Team

CUSTOMER-CENTRIC UTILITY

- Is a motto, addressed in the "Application form for JICA Technical Cooperation" in page 2, as follows;

  "to establish a sustainable and customer –centric utility to deliver an important mandate that touches of all walks of life."

- Seen in a WASAC internet home page, referring to the word "Customer oriented" strategy as one of core mission
- "WASAC Client Charter 2016", further, defines service delivery time in detail to the variety of requests by the customers ;

  -Within 48 hours to respond e-mail by customers

  -Within 5 working days for pipe replacement

They are good examples of customer oriented strategy.

WATER TO ALL THE PEOPLE BY 2018

- How much the actual service coverage rate is attained at Kigali city currently?
- According to the application form to JICA, 83,245 household connections so far installed, supplying water to 1,290,090 population as of April 2015.
- City population is around 1.46 million for 2015 and 2.06 million for 2021 projected as medium rates in the City Master Plan
- WASAC customer data as of July 2016 indicate 83,209 connections installed, including 77,484 domestic customers, 353 public taps, 832 collectives, 2,920 illegal connections and so on.
- Service coverage in Kigali city might be around 70-80% at present.
- How to achieve the target, 100% by 2018?

ATTENTION SHALL BE PAID NOT ONLY TO CUSTOMERS BUT ALSO TO NON-SERVED POPULATION & ILLEGAL WATER USERS!!!!

WHAT'S THE LIVING CONDITION OF THOSE NON-SERVED POPULATION?

- How do they fetch water and what's their water sources? (- especially people who are living within the service area)
- Fetched water are clean and safe?
- People's willingness to connect
- What are major causes affecting people who are reluctant to be WASAC customers?
- Type of connections; yard taps, public taps, or house connections?
- Family size, occupation, etc.

FORMULATION OF CONCEPTUAL WATER SUPPLY SYSTEM DEVELOPMENT PLAN BY WASAC

- WASAC should have a conceptual master plan for a longer period of 20-30 years ahead (water sources, WTPs) at least to establish zoning or MDA of pipe network
- Water supply system development plan should be based on a review of, among other things, the existing water supply conditions, future water requirements, water sources).
- Without water demand forecast by sector or cell, it is hardly attainable to formulate the system development plan.

JICA TEAM'S RECOMMENDATION

- WASAC should provide the Team with the 2012 census data and/or future population projection/water demand forecast by sector, cell and village in Rwanda (for the current and the coming JICA projects)
- WASAC should carry out household surveys at 20 branches, visiting non-served households and illegal water users (willingness to connect, water sources, etc.)
- WASAC shall enhance and register the illegal water users as normal customers through close dialogue with them
- WASAC shall prepare a conceptual long term development plan as early as possible

TOPIC-2: NEEDS OF QUALITY DATA

Customer Data and Drawings

By Kyowa Consultants, Co., Ltd.

JICA Study Team

CUSTOMER DATA AS OF JULY 2016

- Two sources of customer data from GIS and commercial departments
- Although combined into one, there are several data mismatch
- Cross tabulation analysis we made indicates that almost 80% of customer meters/connections have some problems (illegal, meter body, index, screen problems, a lack of sealing, and/or a lack of meter box)
- Merely 20% of customer meters/connections are regarded as normal

STANDARD DRAWINGS OF CUSTOMER METERS/CONNECTIONS

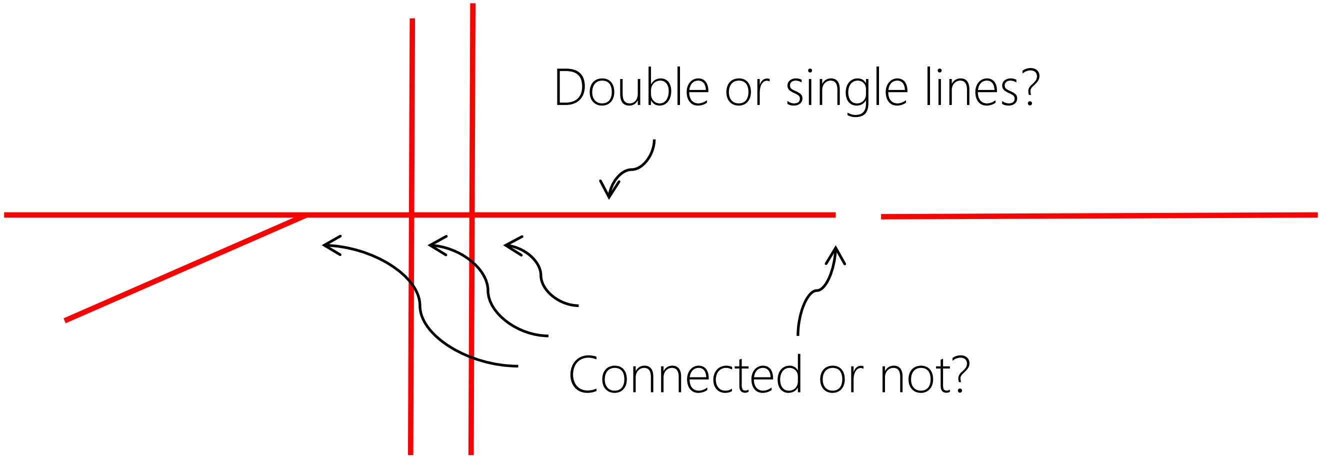
- Meters shall be encased in a meter box or not?
- Meters have a seal to protect human access or not?
- How to deal with old meters? Our study shows 20% of meters installed more than 20 years ago are malfunctioning.
- Are there any standard meter types and brands?
- WASAC has customer registration cards which contain sketches of service connections ? These are precious information, particularly during meter reading.
- Meters are installed in a proper location so that meter readers may easily access?
- Is it necessary to amend the process of reaching decision by customers/WASAC where to install meters?

SURVEY ON CUSTOMER METERS/CONNECTIONS

- To update the customer data and information
- To supplement the missing data
- To carry out on-site meter calibration where required
- To identify malfunctioning meters/connections inconsistent with standard drawings
- To carry out a root cause analysis for improvement
- To prepare bills of quantities for meter replacement
- To prepare budgets (emergency) for meter replacement

DRAWINGS OF PIPELINE NETWORK

- WASAC GIS indicates pipe route and alignment of the existing distribution and transmission pipe network
- Due to a misleading expression of pipeline topology, it is hard to judge whether pipelines are connected or separately installed



- Definitions of primary mains, secondary mains, and tertiary mains are ambiguous
- Distribution or Transmission mains between WTP and Reservoirs?

UPDATE OF PIPELINE DRAWINGS

- Review and validate all pipeline topology in GIS, in cooperation with field staff/engineers concerned who know details of the pipe network
- Excavate test pits to examine pipe conditions and alignment where deemed necessary (500 test pits being excavated under ESRI projects in Kigali)
- Update all GIS data
- All as-built drawings prepared by contractors, if any, shall be incorporated into GIS for easy reference

JICA TEAM' S RECOMMENDATION

- WASAC shall organize a team and carry out the customer survey at all branches, by recognizing importance of data update/renewal, and if not, any hydraulic analyses, asset management, customer management, etc., based on the existing data, may give wrong answer and NRW reduction cannot be achieved accordingly.

  (Furthermore, WASAC' S GIS & SCADA system established may not function as intended)

- As quick win program, WASAC shall replace all malfunctioning meters at all branches in the next several years except those at two pilot areas (Kadobogo and Ruyenzi) where the JICA team is going to undertake similar procedures

TOPIC-3: OUTLINE OF PUBLIC TAPS

What's the existing conditions?

By Kyowa Consultants, Co., Ltd.

JICA Study Team

NUMBER OF PUBLIC TAPS PLANNED IN WASAC 5 YEAR STRATEGIC BUSINESS PLAN (PAGE-7)

	2015/16	**2016/17**	**2017/18**	**2018/19**	**2019/20**
Additional Standpipes connections	200	300	306	200	100
Budget (kRwf)*	710,800	6,397,199	11,122,586	12,125,695	15,285,422

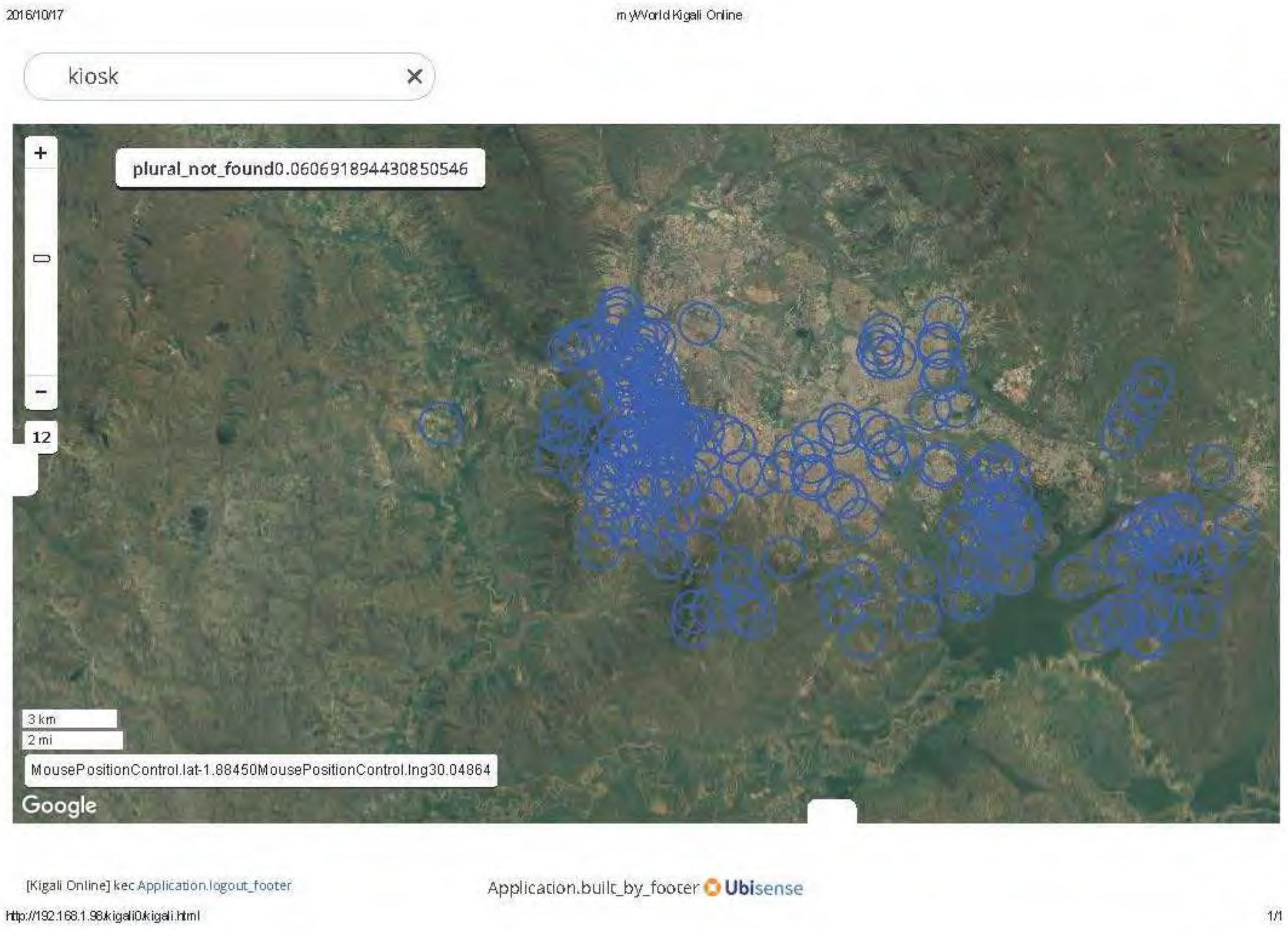
*….The budget also covers costs of additional domestic connections.

OUTLINE OF PUBLIC TAPS ACCORDING TO CUSTOMER DATA AND FIELD RECONNAISSANCE

<Present Conditions>

- There are 353 public taps in Kigali city
- Currently they are operated and maintained by WASAC
- Almost half of the served population fetch water from public taps
- Responding to customers' needs, they are operated intermittently
- Most of public taps are located in the city center and its southern and eastern fringe (see satellite view in next page)

LOCATION MAP OF PUBLIC STANDPIPES



2016/10/17 myWorld Kigali Online

kiosk

[Kigali Online] kec Application.logout_footer

Application.built_by_footer Ubisense

http://192.168.1.98/kigali0/kigali.html 1/1

LIST OF PUBLIC STANDPIPES WITH LESS WATER CONSUMPTION (0M3/MONTH, PAST 4 MONTHS)

Sector	Number of public taps	Number of customers reported	Sector	Number of public taps	Number of customers reported
Gahanga	7	20	Kigarama	1	50
Gatenga	6	40	Kimihurura	1	
Gatsata	2	0	Kimironko	1	
Gisozi	3	253	Kinyinya	3	217
Gitega	3	0	Masaka	9	1157
Jali	1	0	Muyumbu	3	100
Kacyiru	3	20	Niboye	1	9
Kagarama	2	20	Nyakaliro	2	700
Kanombe	6	125	Nyamirambo	5	45
Kicukiro	1		Nyarugunga	1	4
Kigali	2	11	Total	63	2771

NEEDS OF PUBLIC STANDPIPE SURVEY?

- Are there any reports on the existing condition of the public standpipes?
- If available, WASAC shall provide them for the JICA Team to review
- If not available, we think WASAC shall carry out the public standpipe survey
- Does the WASAC 5 year strategic business plan include the work of meter replacement of existing malfunctioning meters?

THE QUESTIONNAIRE SURVEY MAY INCLUDE INQUIRIES REGARDING;

- Number of households being supplied?
- How many times a day, standpipes are in operation?
- How much volume of water does people consume per capita per day in average?
- On-site meter calibration, where required
- Identify malfunctioning meters
- Outline of the malfunctioning meters, including causes, type, year of installation and manufactures, all of which shall be recorded properly

JICA TEAM'S RECOMMENDATIONS

- WASAC shall upgrade GIS maps, taking in the latest information on public standpipes (taps)
- WASAC shall provide the construction plan of the public standpipes with necessary information, i.e., size, location, year of construction, number of customers, etc., for JICA team to review
- WASAC shall carry out the public standpipe survey in case data are not available
- WASAC shall replace all malfunctioning meters with new ones.

TOPIC-4: LARGE CUSTOMERS

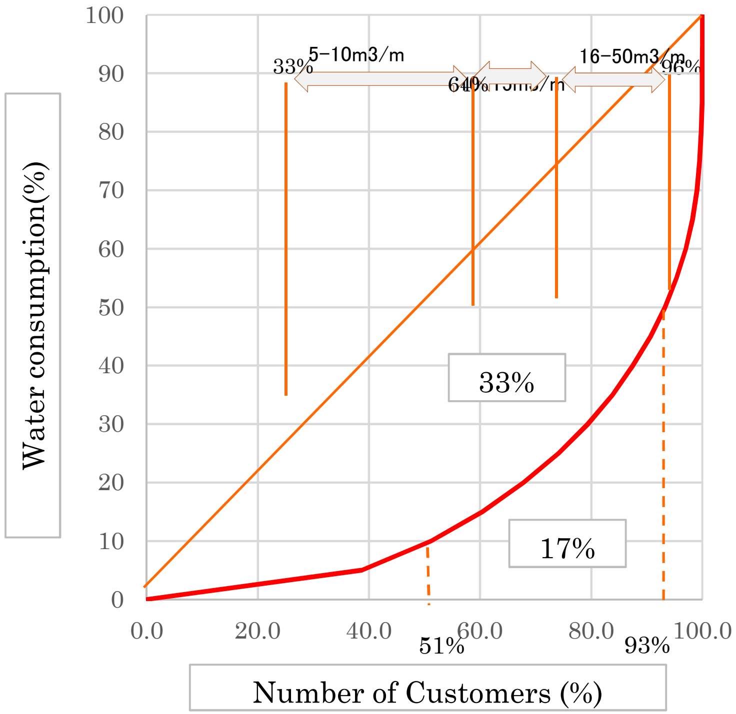
Customer behavior largely affects WASAC

Kyowa Consultants, Co., Ltd.

JICA Study Team

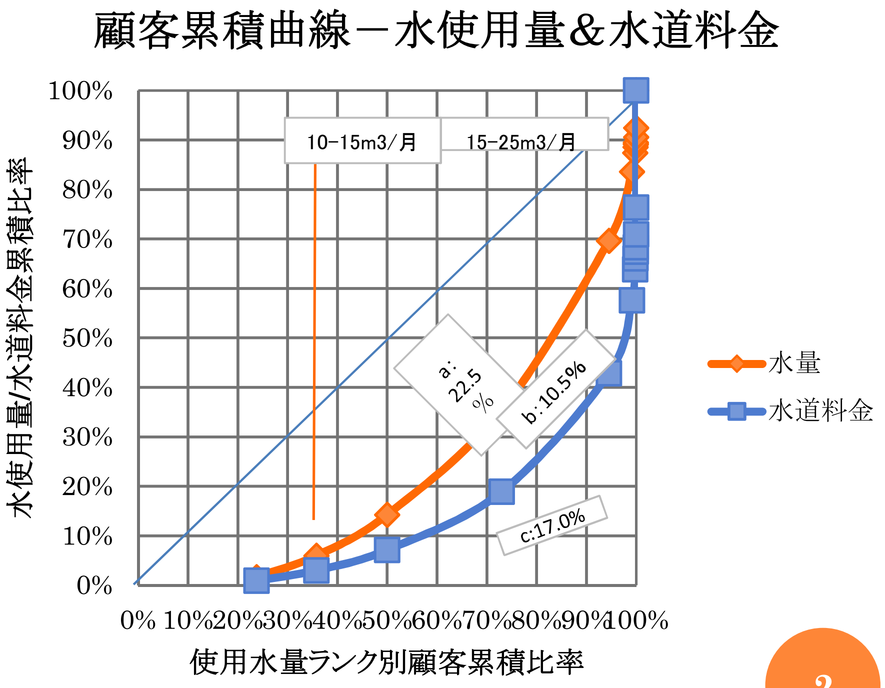
LORENZ CURVE (KIGALI VS. MAKASSAR)

2016/10/21



Kigali city

Makassar, Indonesia



WATER CONSUMPTION BY TOP 10 LARGE CUSTOMERS

sector	cell	customer_type	poc	Jul-16	Jun-16	May-16	Apr-16
Nyarugunga	Kamashashi	Government Institutions	259720003	18,309	14,436	24,144	16,842
Kicukiro	Ngoma	Industry	239160021	14,904	11,121	9,568	14,919
Kimihurura	Rugando	Government Institution	209720028	9,563	8,050	7,037	8,073
Kimihurura	Rugando	Commercial Services	209110012	6,521	7,565	6,630	413
Nyarugenge	Kiyovu	Commercial Services	269110005	5,096	4,193	5,476	5,844
Nyarugunga	Kamashashi	Government Institutions	259720005	4,475	2,600	1,712	2,088
Muhima	Kabeza	Collectivity	249720001	4,203	2,746	3,672	3,383
Nyarugenge	Kiyovu	Commercial Services	269160002	4,094	3,329	3,008	2,719
Nyarugenge	Kiyovu	Government Institutions	269110043	3,981	2,918	3,346	3,297
Remera	Rukiri ii	Government Institution	229720003	3,957	6,760	2,698	3,783

LARGE CUSTOMER'S BEHAVIOR AFFECTS WASAC'S FINANCIAL STANDINGS

- Frequent tariff revision may discourage customers from using WASAC's piped water
- Where groundwater are available, they are likely to shift their water sources from WASAC to boreholes
- This situation would exert negative financial impacts on WASAC

TOWARD INTRODUCTION OF DUAL WATER SUPPLY SYSTEMS FOR PUBLIC AND INDUSTRY?

- If introduced, Rwanda would be the first country in Africa (?)
- This is to support industrial development by supplying half-treated water (usually before filter) with reasonable price
- Needs for water quality differ among customers (water for boiler, cooling, cleaning, process, etc.)
- Customers treat the received water by themselves up to their required quality
- Customers are relieved from heavy burden of water tariff payment

NEEDS OF QUESTIONNAIRE SURVEY

Inquiries may include;

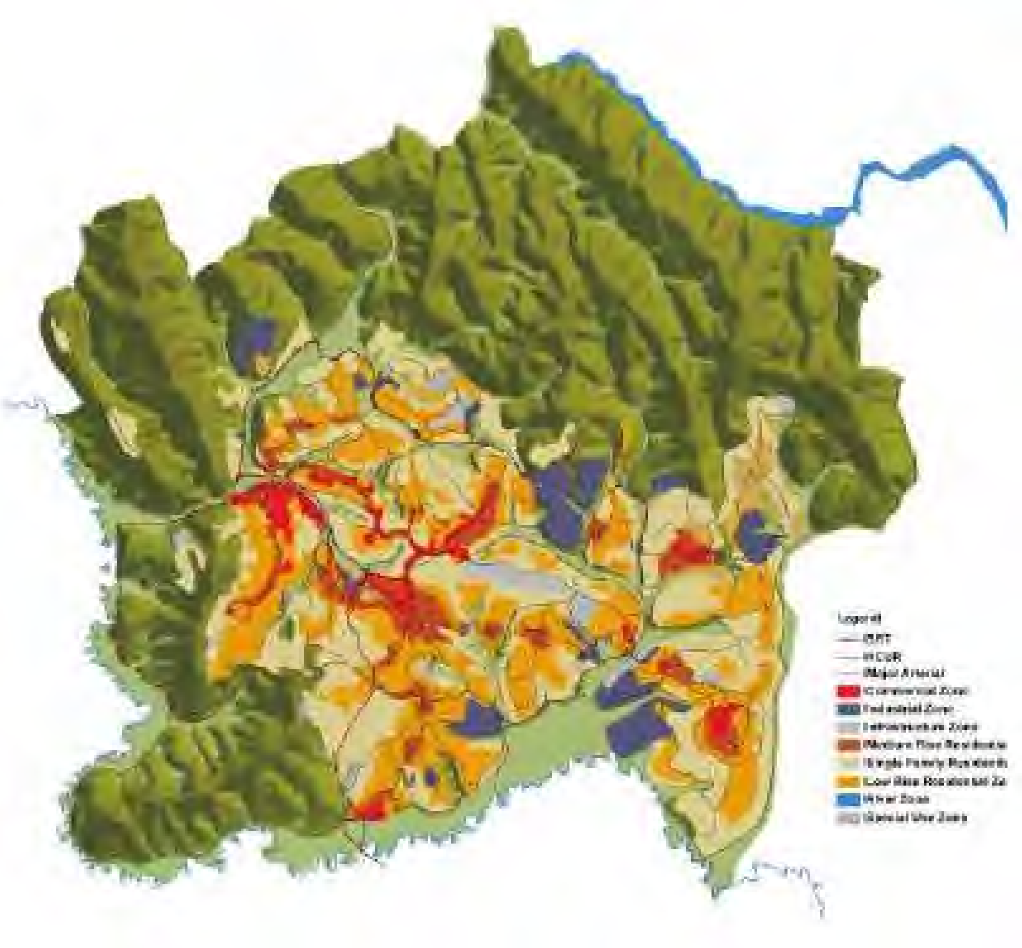
- Companies/shops' particulars, i.e., number of staff, raw materials used, products/commodities, etc.
- Purpose of water usage
- Water quality required
- Wastage disposal and treatment process currently applied and/or future plan
- Current condition of internal water reuse and recycle and/or future plan
- Future plan for expansion
- Future water demand
- Willingness to connect (if industrial water supply system started its operation)
- Any requests to WASAC

JICA TEAM'S RECOMMENDATION

- WASAC shall conduct questionnaire survey visiting the top 100 large customers at least, who consume more than 700m^3/month)
- Based on the survey, WASAC shall analyze customer behavior, water use pattern and forecast future water requirements
- To enhance water saving practice among the customers
- WASAC will carry out study on possible introduction of industrial water supply, when required

<REFERENCE>

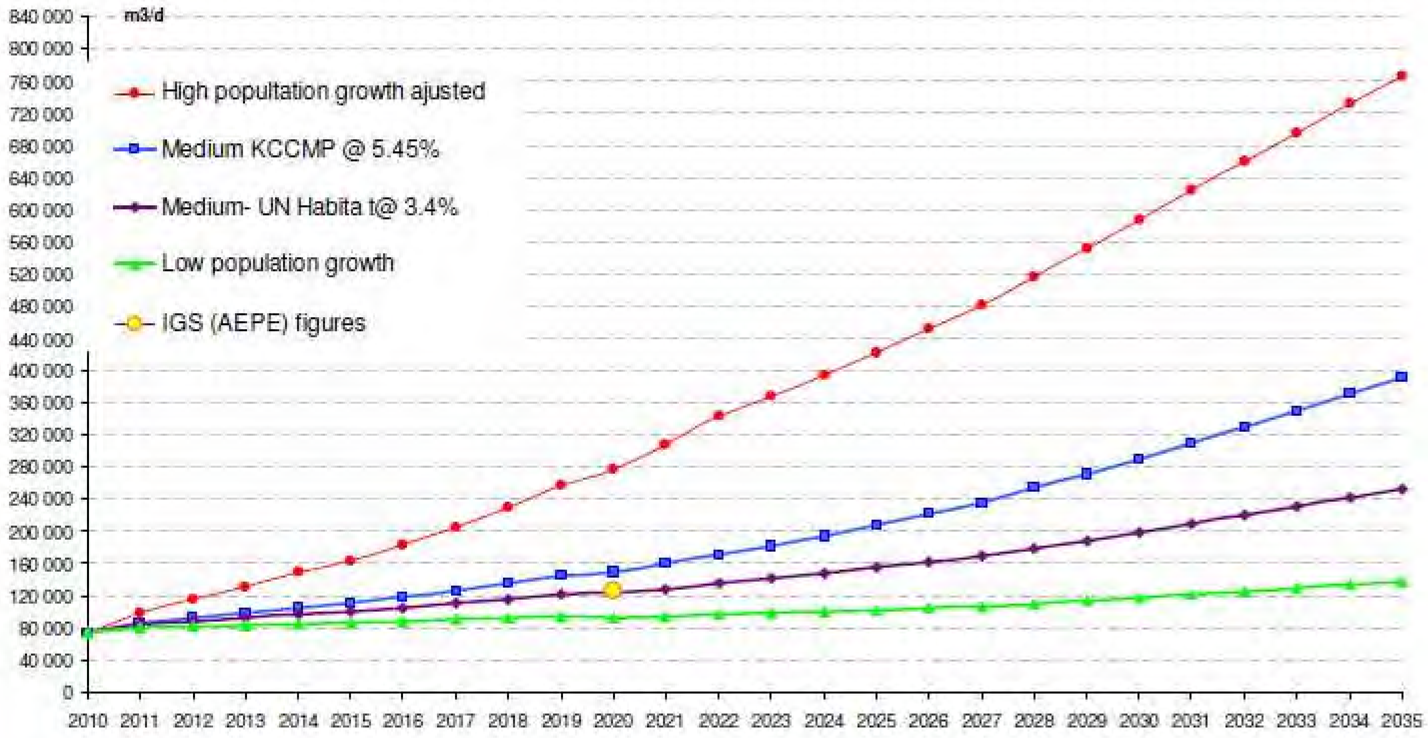
INDUSTRIAL ESTATE PLANNED TO BE LOCATED AT THE OUTSKIRTS, 2040



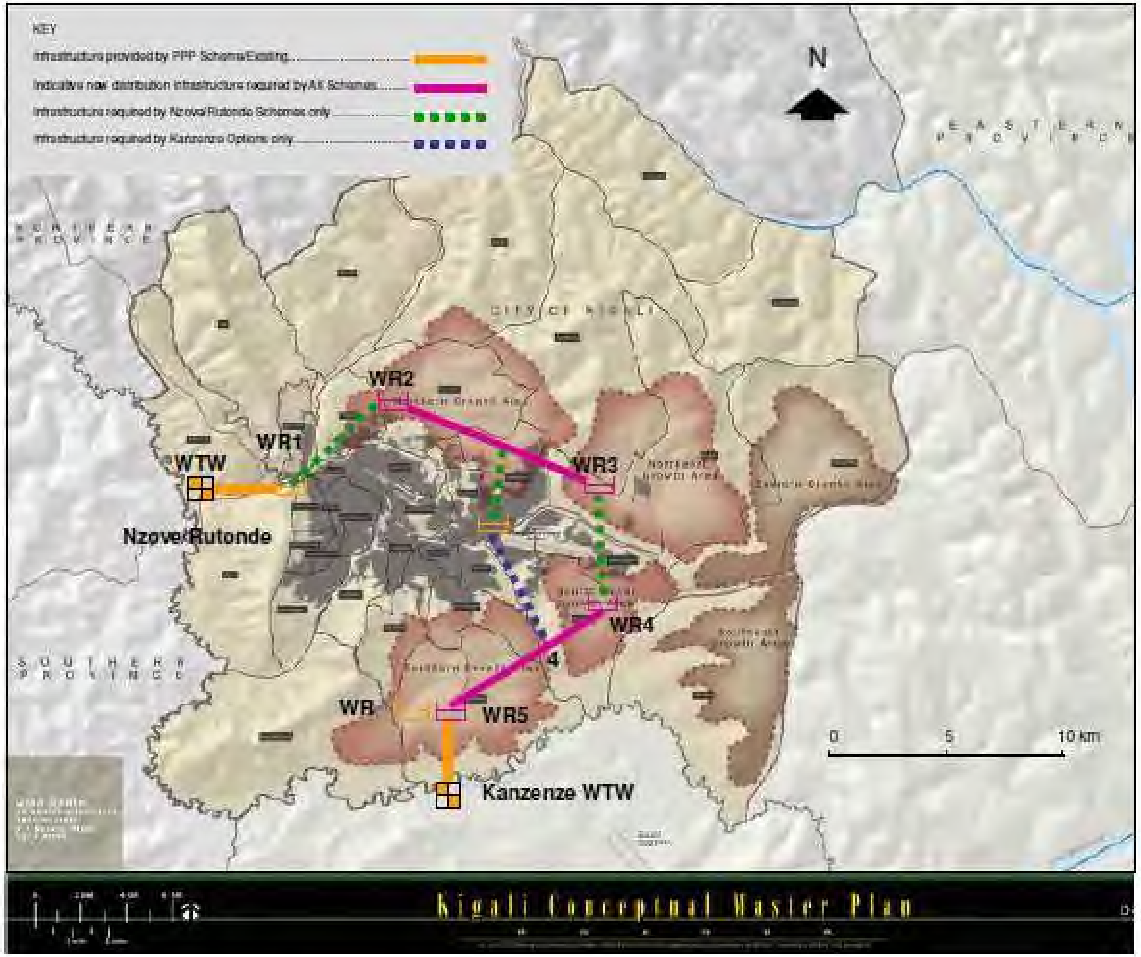
Is it possible to construct industrial water supply system independently to supply north and east industrial estate, while public water supply to city center, commercial zones, and residential zones?

Source: Kigali City Master Plan

WATER DEMAND FORECAST UP TO 2035



CONCEPT OF BULK WATER SUPPLY PLAN



Source: KCCMP

TOPIC-5: ASSET MANAGEMENT

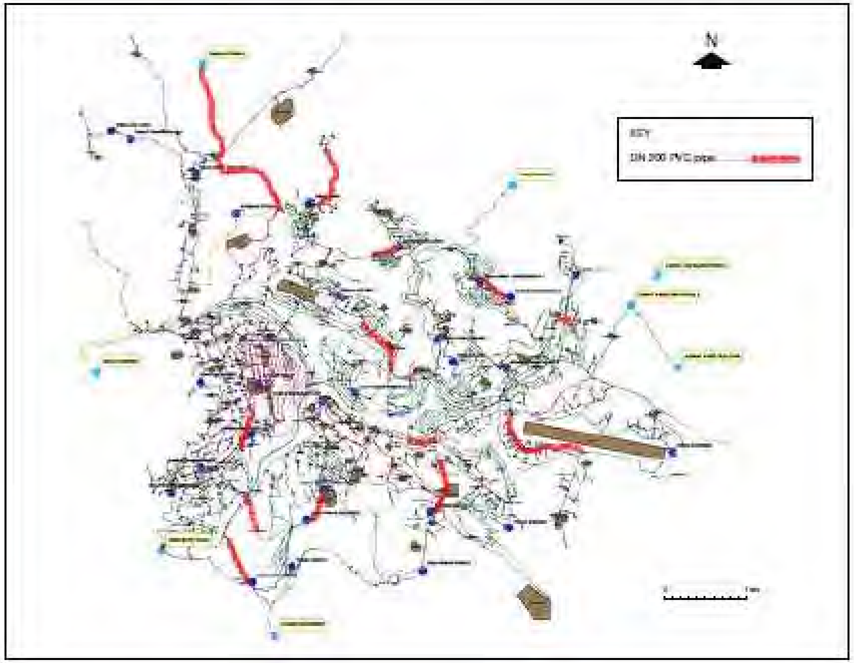
What's the criteria for replacement

Kyowa Consultants Co., Ltd.

JICA Study Team

EXISTING REPORTS PROPOSE PIPE REHABILITATION (1)

<u>Kigali Bulk Water Supply Project Technical Feasibility Report, July 2011</u>, proposes in its page 64, replacement of 200mm PVC with a length of 17.5km in total



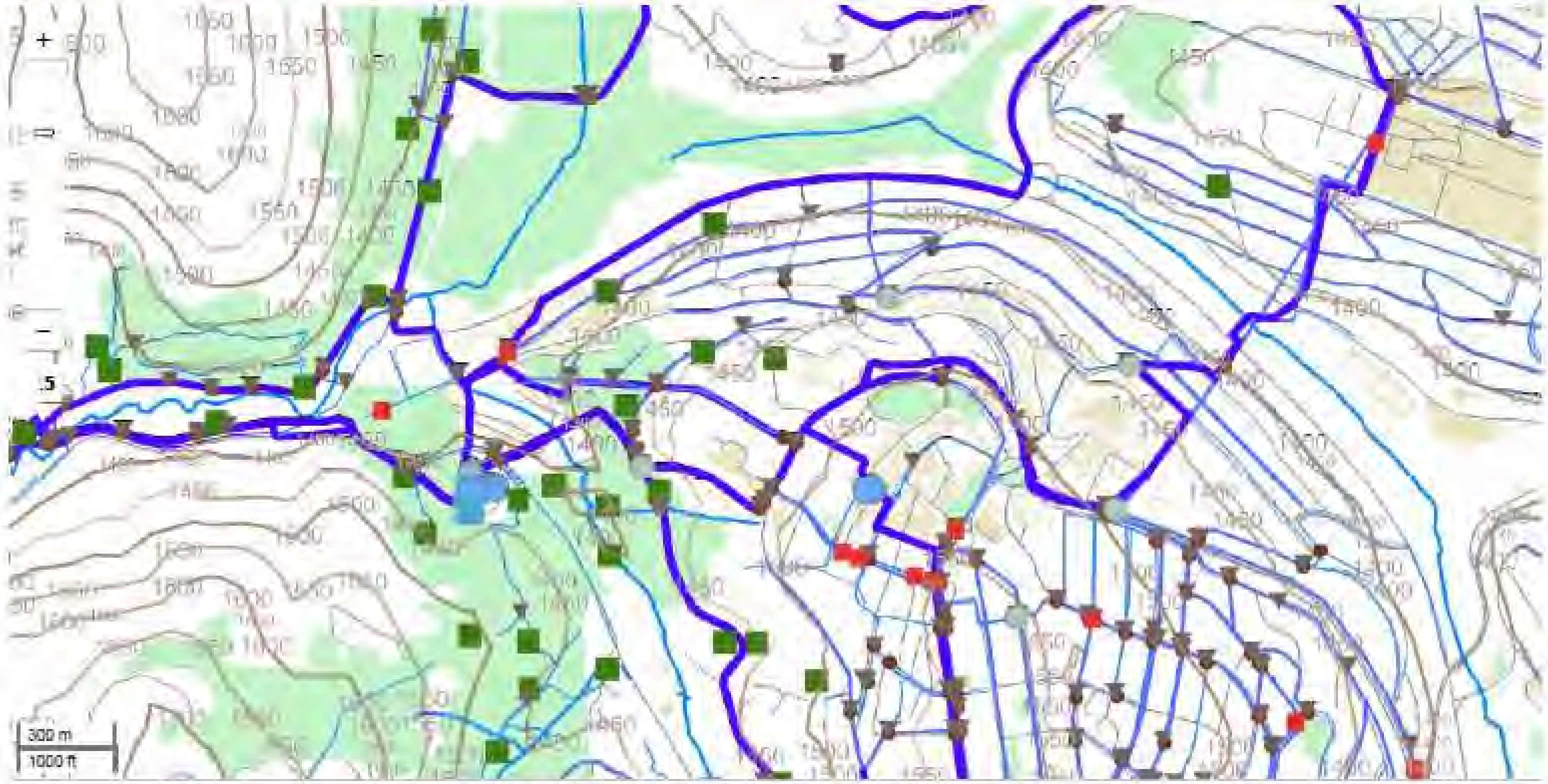
EXISTING REPORTS PROPOSE PIPE REHABILITATION (2)

- WASAC 5 Year Strategic Business Plan, in its page 28, proposes MININFRA budget project (unit: RWF) for rehabilitation reinforcement & extension of Kigali Water Distribution Networks

2015/16	2016/17	2017/2018	2018/2019	2019/2020
6,000,000	9,740,000	9,740,000	9,740,000	9,740,000

- 2015-2016 Action Plan proposes 34km rehabilitation of old pipes, due to frequent leaks

TYPICAL ALIGNMENT OF THE EXISTING PIPE NETWORK

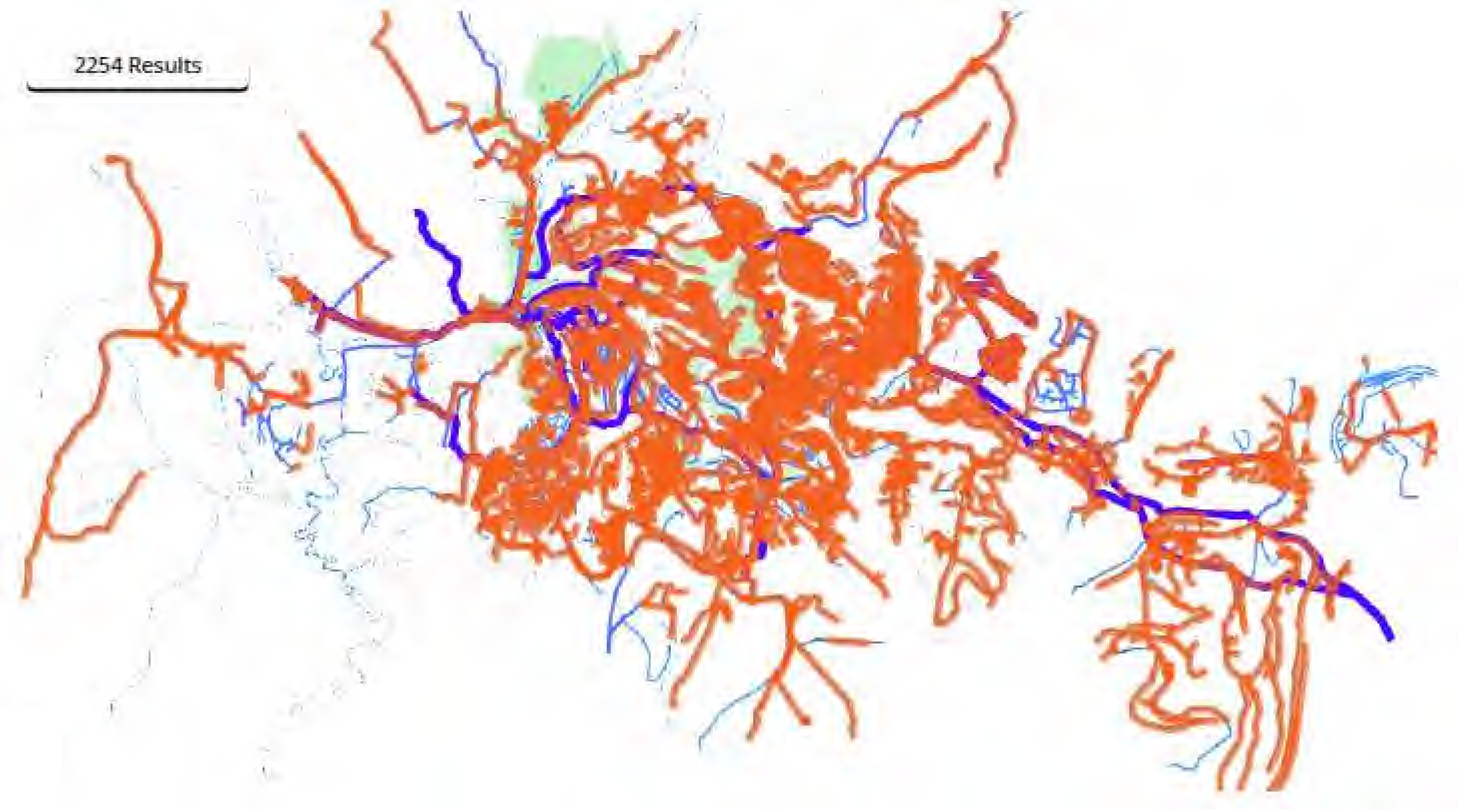


Pipe system is generally well-designed but:
>Because of topography, water pressure may be high in the lower zone
>Distribution branched from transmission mains are seen in the network

TYPICAL PIPE MATERIALS IN KIGALI – DCIP FOR TRANSMISSION AND DISTRIBUTION MAINS

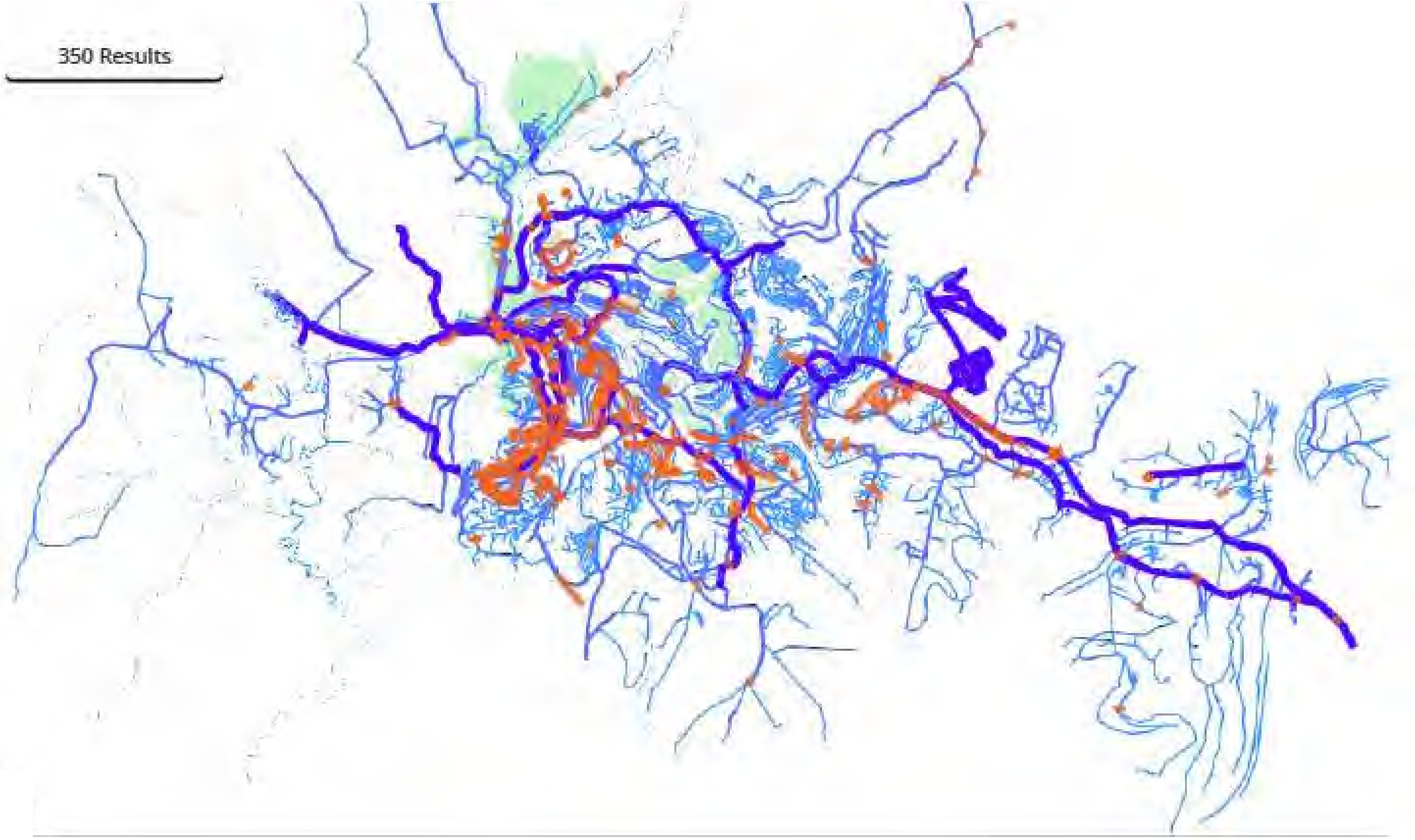
>Total length 42,692m (out of them, 25,496m in dia. 250mm or more)

TYPICAL PIPE MATERIALS IN KIGALI – PVC WIDELY USED FOR DISTRIBUTION MAINS



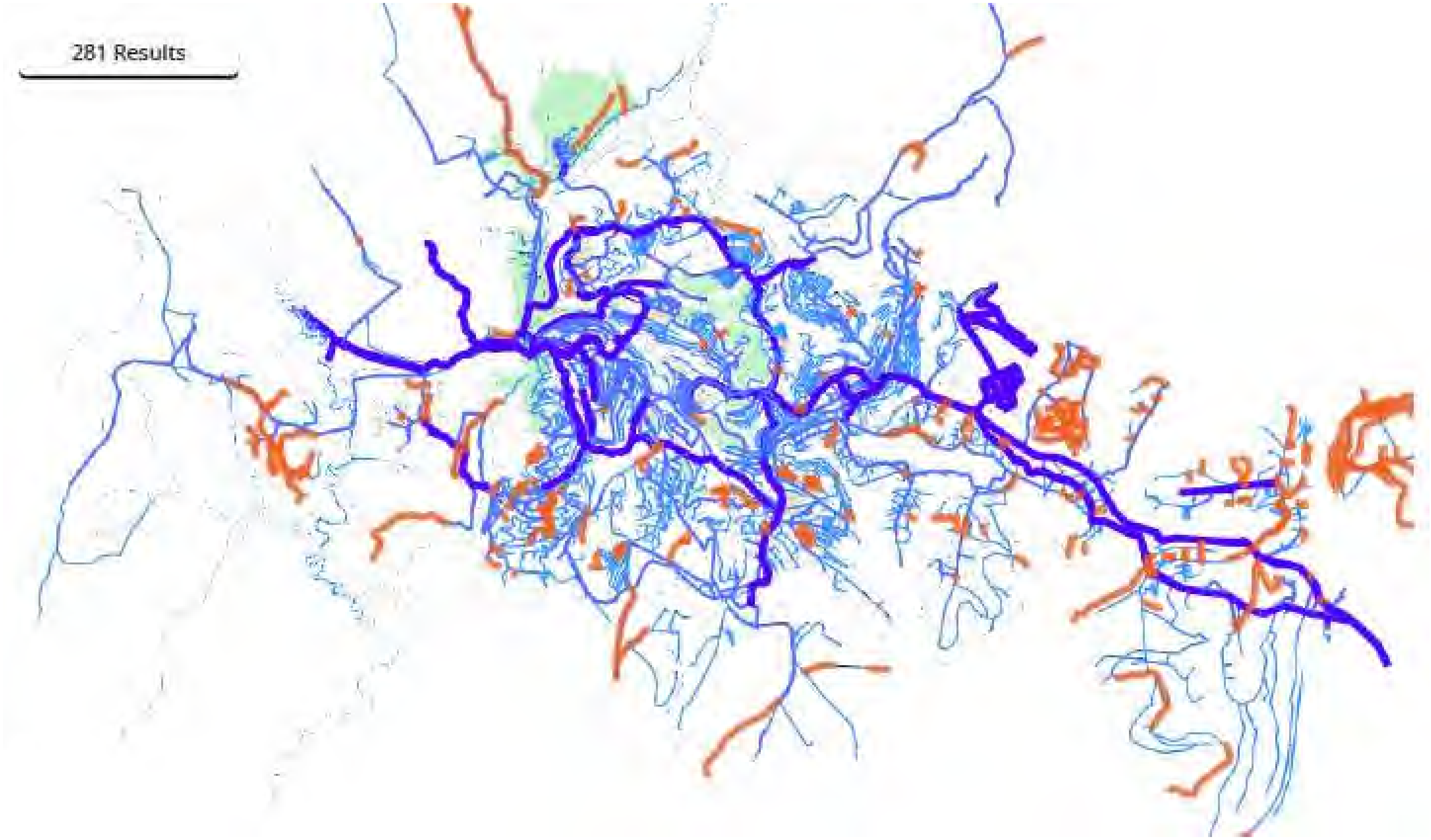
Total length of PVC = 742.7km (out of which 27.5km are 225mm in dia. or more)

TYPICAL PIPE MATERIALS IN KIGALI – GSP BEING REPLACED BY PVC



Total length of GSP = 48.6km, out of which 43.8km are installed before 2002

PHDE PIPES RECENTLY INSTALLED TO EXPAND THE SERVICE AREA



>PDHE pipes with a diameter of 200mm or less total 96.6km

PIPELINE REHABILITATION BECAUSE OF;

- Frequent leaks: leak points, history and frequency
- Pipe characteristic: pipe age, pipe materials, specifications, water pressure, pipe depth installed, capacity of contractors engaged in pipe laying works, etc.
- Vulnerable distribution and transmission mains: frequently affected by an extreme water pressure or water hammer effects induced by sudden power outage
- External conditions: pipeline installed under main roads

GENERAL MEASURES TO REDUCE NRW DURING DESIGN STAGE

<u>Measures (other than pipe repair and replacement)</u>

- <u>Mitigate effects</u> by pump stoppage on pipelines-flywheel devices (?)
- Protect pipelines from the heavy load by adopting "pipe in pipe" method (PVC in SP especially under the road) and from the thrust force by concrete block
- Introduction of <u>3D zoning system</u> to minimize energy loss (AEPE project by SGI?)
- Effective pressure control and management by PRV or BPT (break pressure tanks)
- <u>Review standard drawings</u> (①PVC bends & tees cannot be used where water pressure is high, ②PVC pipes only for tertiary mains/service connections, ③no use of PVC pipes close to gate valves, ④flexible joints and/or sand beds for pipe installation where land subsidence is expected, etc.)

PIPE NETWORK EXPANSION AND REHABILITATION (1)

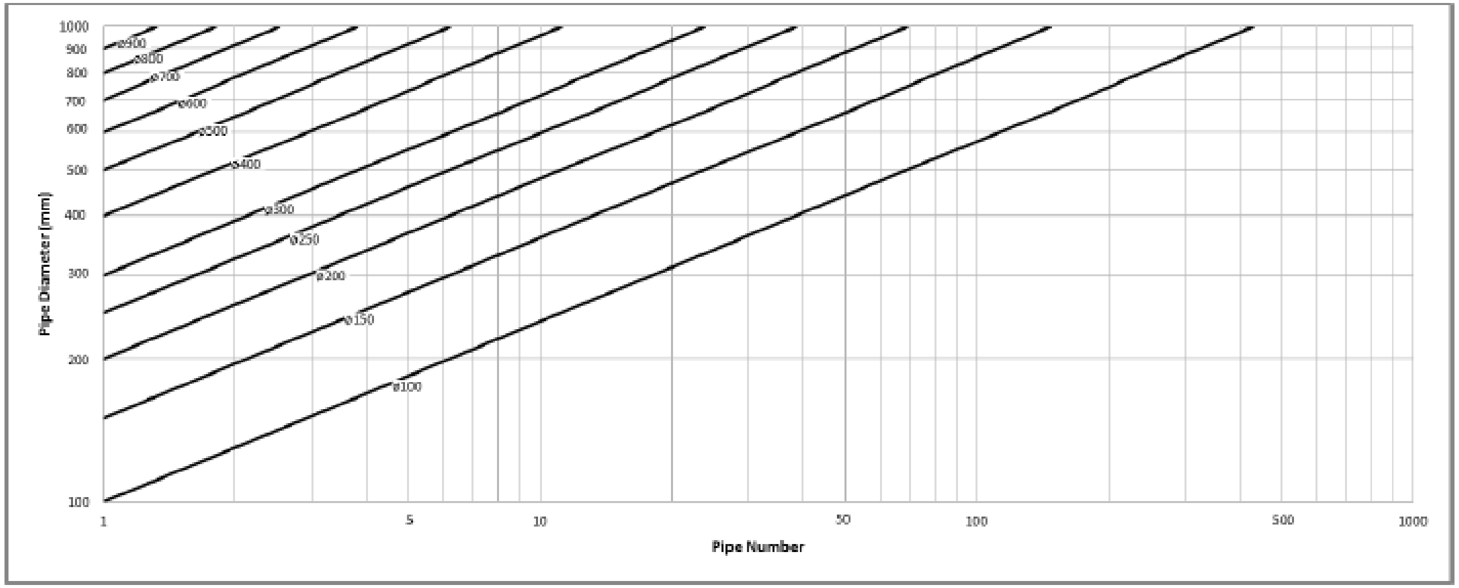
- Expansion and rehabilitation shall be based on future development plan (sources, WTPs, reservoirs, water demand, etc.)
- 3D zoning system to be introduced with DMA (basically four zones- higher zone, lower zone and their extreme cases, each consisting of several DMAs)
- Gate valves, air release valves, and washout valves shall be installed properly on the distribution pipe network

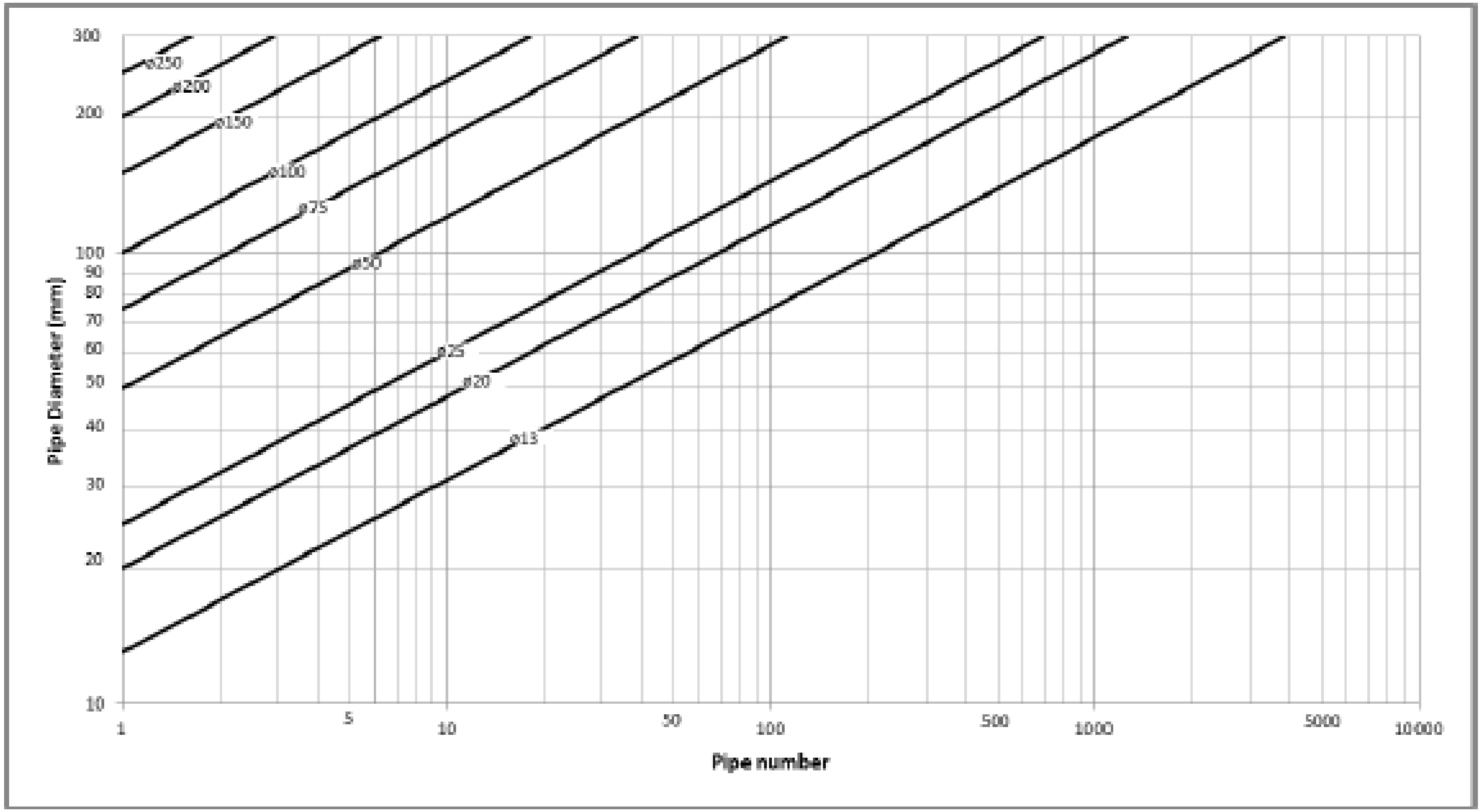
PIPE NETWORK EXPANSION AND REHABILITATION (2)

- Inlets to DMA shall be <u>one or two, not more than three</u>
- Many inlets to DMA may cause operational problems (for flow and pressure control by SCADA in future) and, therefore, may be replaced by <u>pipes hydraulically equivalent</u> (see graphs that follow)
- Introduction of <u>multi-function chambers on the inlets to DMAs</u> (refer to page 16)
- Within the service main network, <u>gate valves</u> shall be installed to ensure continuity of water supply even under emergency (see sample drawing)

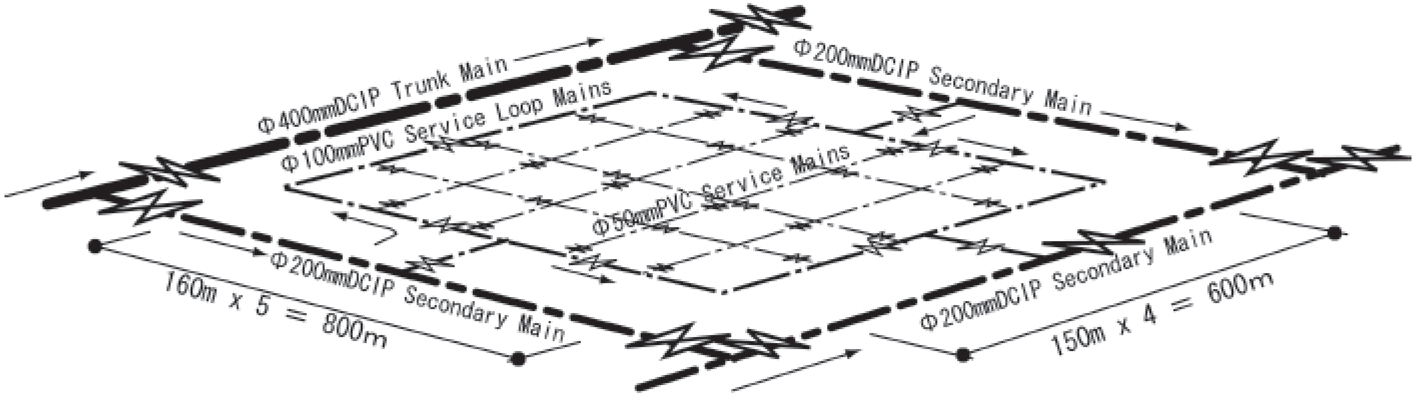
HOW TO REHABILITATE OR REPLACE PIPELINES?

1) Number of pipes hydraulically equivalent, quoted from our technical paper submitted to 2012 IWA conference in Philippines




ø250
ø200
ø150
ø100
ø75
ø50
ø25
ø20
ø13
Pipe Diameter (mm)
300
200
100
90
80
70
60
50
40
30
20
10
1
5
10
50
100
500
1000
5000
10000
Pipe number

SAMPLE DRAWING OF DMA



>Trunk mains only connected with secondary mains, not with service mains
>Customers can get water through service mains, not from secondary mains and trunk mains
>Valves shall be installed properly to isolate the area in the case of emergency

MULTI-FUNCTION CHAMBER

- Flow meter chamber shall have sufficient space for future expansion

With the equipment properly installed, the chamber may multi-function as;

>Meter calibration by installing portable ultra-sonic flow meters
>Flow and pressure control (butterfly valves or pressure reducing valves)
>Washout
>Air release
>Fire hydrant
>Public standpipes, etc.

JICA TEAM'S RECOMMENDATION

- Analyze leak repair history to prioritize pipes/mains for replacement
- Initiate pipeline replacement based on priority after procurement of materials and equipment required
- Large diameter of PVC may not be installed as distribution trunk and limb mains

TOPIC-6: ILLEGAL WATER USERS

Legal or not?

By Kyowa Consultants Co., Ltd.

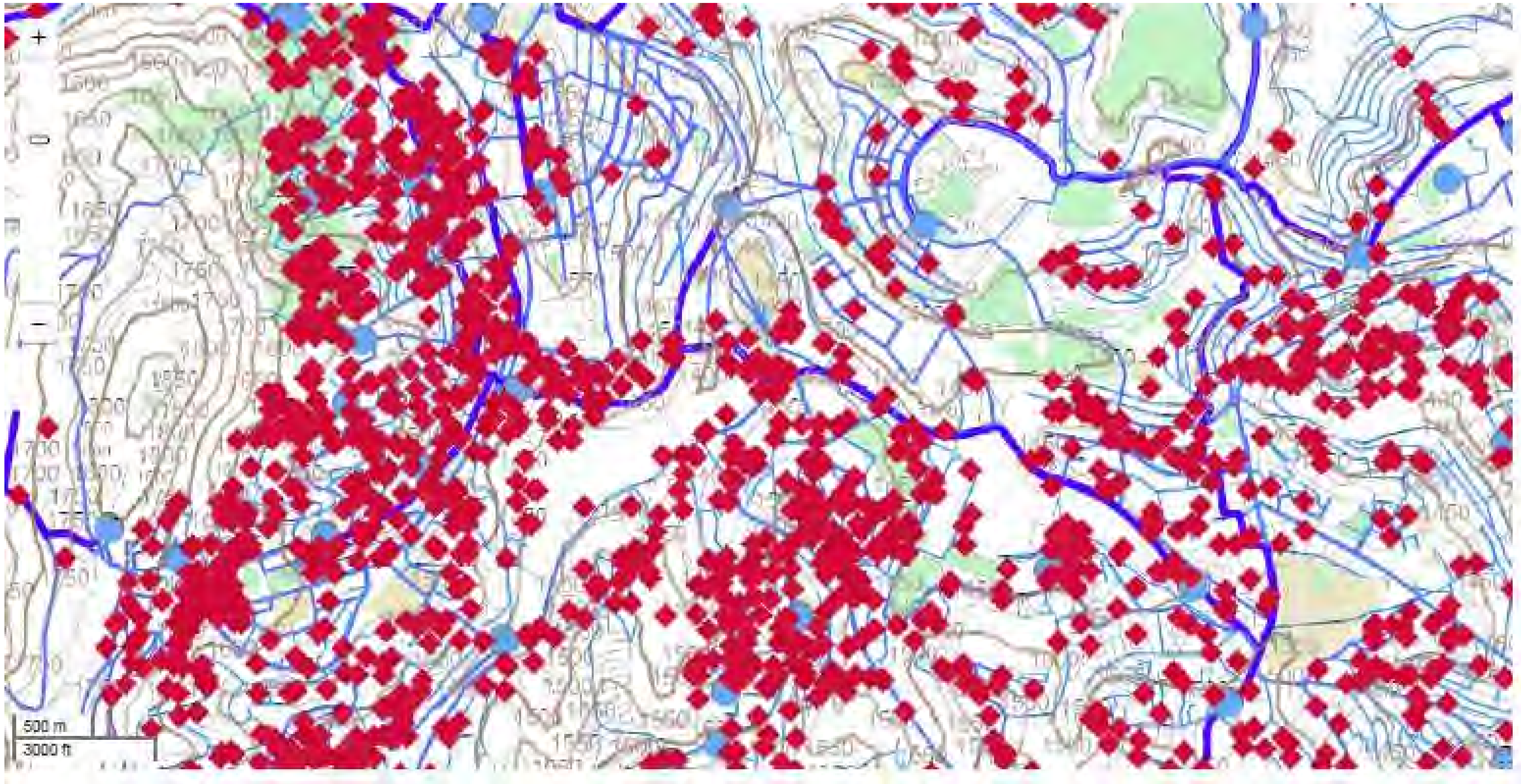
JICA Study Team

ACCORDING TO ACTION PLAN OF NRW UNIT

- 2,400 big and/or illegal customers being surveyed by WASAC at whole branches in 2015-2016
- Similar survey continues in 2016-2017, at around 2,000 big and/or illegal customers

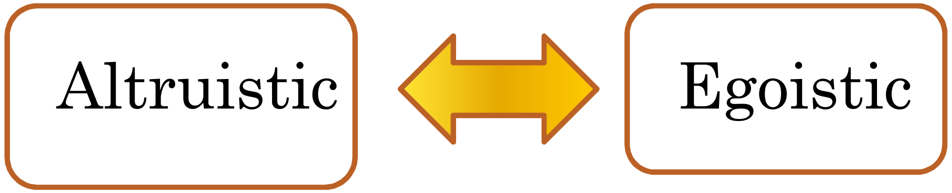
<JICA team's comment on these activities, approaches to big customers and to illegal water users shall be totally different, and dealt with separately>

MANY ILLEGAL WATER USERS?



Customer data suggest around 3,000 illegal water users

VULNERABLE WATER SUPPLY SYSTEM!



Altruistic

Egoistic

All for one!
One for all!

Water supply system facilities can be easily damaged by vandalism/looting when just one egoist exists in the service area

One bad apple spoils the barrel!!!!

One egoist spoils the system!!!!

DIALOGUE WITH ILLEGAL WATER USERS

- They have reasons why they won’t pay for water because of;
  - Meters were not working well
  - Misreading by meter readers
  - A lot of water lost from open taps during night time
  - Failure of flush toilets, showers, roof tanks, etc.
  - Illegal use by neighbors during owner’s absence
  - Water lost due to a sudden in-house leakage
- Some water users, tapping illegally, or using bypass

EVEN ILLEGAL WATER USERS SHALL BE REGARDED AS VALUE

- To keep good relations with the customers are of vital importance for WASAC

Slogan:“Dignifying life”

In close dialogue with them,

- Compromise shall precede all other things
- Based on their comments/opinions, WASAC shall improve customer services
- Punishment shall be avoided as far as possible

Punishment may be a good reason for another emergence of egoists!!

Keep in mind they are precious/probable customers!!

HOW TO COPE WITH ILLEGAL WATER USE DETERMINES WASAC 'S FUTURE

Punishment is not a means of <u>dignifying life</u> but

a means of <u>disqualifying life!</u>

TOPIC-7: SUMMARY - FOR DISCUSSION

What’s your priority measure?

Kyowa Consultants, Co., Ltd.

JICA Study Team

TOPIC -1: WASAC’ S STRATEGY

Proposed measures	Answer
Attention shall be paid not only to customers but also to non-served population	Yes ☐ No ☐ Priority ☐
WASAC should carry out household surveys at 20 branches, visiting non-served households and illegal water users	Yes ☐ No ☐ Priority ☐
WASAC shall register illegal water users as normal customers	Yes ☐ No ☐ Priority ☐
WASAC shall prepare a conceptual long term development plan	Yes ☐ No ☐ Priority ☐

TOPIC-2: NEEDS OF QUALITY DATA

Proposed measures	Answer
Customer survey at all branches	Yes ☐ No ☐ Priority ☐
On-site meter calibration	Yes ☐ No ☐ Priority ☐
Update all customer data	Yes ☐ No ☐ Priority ☐
Prepare budget and meter replacement at all branches	Yes ☐ No ☐ Priority ☐
Update and validate GIS pipe network drawings	Yes ☐ No ☐ Priority ☐
Incorporate as-built drawings, sketches, etc. into GIS	Yes ☐ No ☐ Priority ☐

Topic-3: Outline of Public Taps

Proposed measures	Answer
Carry out the public standpipe survey	Yes ☐ No ☐ Priority ☐
Replace/repair malfunctioning meters	Yes ☐ No ☐ Priority ☐
Upgrade GIS maps (public standpipes)	Yes ☐ No ☐ Priority ☐
Shift the abandoned standpipes to the suburban areas	Yes ☐ No ☐ Priority ☐

TOPIC-4: LARGE CUSTOMERS

Proposed measures	Answer
Study on introduction of industrial water supply systems	Yes ☐ No ☐ Priority ☐
Carry out questionnaire survey (large customers)	Yes ☐ No ☐ Priority ☐
Analyze customer behavior, future water demand, etc.	Yes ☐ No ☐ Priority ☐
Enhance water saving practices	Yes ☐ No ☐ Priority ☐

TOPIC-5: ASSET MANAGEMENT (1)

Proposed measures	Answer
Replace 200mm PVC with new ones based on F/S	Yes ☐ No ☐ Priority ☐
Carry out priority analyses for pipe rehabilitation	Yes ☐ No ☐ Priority ☐
Continue rehabilitation of old pipes (i.e., 34km in 2015/2016) based on priority analyses	Yes ☐ No ☐ Priority ☐
Proper design (1)-water hammer effects, thrust blocks, BPT/PRV,	Yes ☐ No ☐ Priority ☐
Proper design (2)- No large dia. PVC pipes, flexible joints, sand beds, etc.	Yes ☐ No ☐ Priority ☐

:ASSET MANAGEMENT (2)

Proposed measures	Answer
Introduce 3D zoning system	Yes ☐ No ☐ Priority ☐
Inlets to DMA less than 3 in number	Yes ☐ No ☐ Priority ☐
Keep space for expansion as multi-function chambers (DMA’s inlets flow meter chambers)	Yes ☐ No ☐ Priority ☐
Install gate valves properly within service pipe network	Yes ☐ No ☐ Priority ☐
Deal transmission mains separately with distribution mains	Yes ☐ No ☐ Priority ☐
Service connections only from service pipe network, not from trunk/limb mains	Yes ☐ No ☐ Priority ☐

TOPIC-6: ILLEGAL WATER USERS

Proposed measures	Answer
Continue survey on illegal water users	Yes ☐ No ☐ Priority ☐
Keep close dialogue with them	Yes ☐ No ☐ Priority ☐
Punishment shall be minimized as far as possible	Yes ☐ No ☐ Priority ☐

LIST OF REQUESTED DATA

- Population and water demand forecast by the year 2040, by sector and by user category basis
- Future expansion plan of the public standpipes
- Scope of pipe rehabilitation plan (34km)

Appreciate your cooperation!

TOPIC-8: FIVE YEAR NRW REDUCTION PLAN (FRAMEWORK)

"Approach and Procedures"

Kyowa Engineering Consultants, Co., Ltd.

WASAC’s Ongoing Programs

- Five year strategic business plan, 2015
- Five year capacity building plan 2014-2018, September 2014
- 2016-17 Action plan, NRW Unit
- Five year NRW reduction plan (underway in cooperation with JICA)

Framework of 5 year plan

- Ten components: 1) Branch Isolation, 2) All Customers, 3) Public Taps, 4) Large Customers, 5) Leak Repair, 6) Pipe rehabilitation, 7) Pressure management, 8) GIS & SCADA, 9) Public Campaign, and 10) Non-served & Illegal Users
- Phased into three stages: 1) Preparatory Work/Quick Impact, 2) Pilot NRW Reduction, and 3) Routine NRW Reduction
- See Draft Five Year Plan (Framework) attached

WASAC’s Business to Do

Confirm ongoing and newly proposed works

Identify what are further required

Prioritize all proposed works to achieve NRW target

Facilitate and confirm government’ s financial support

Finalize Five Year NRW Reduction Plan

Any contradictions?

Five Year Business Plan & NRW Reduction Plan

Ongoing

Newly proposed
(Topic-1 to 6 + X)

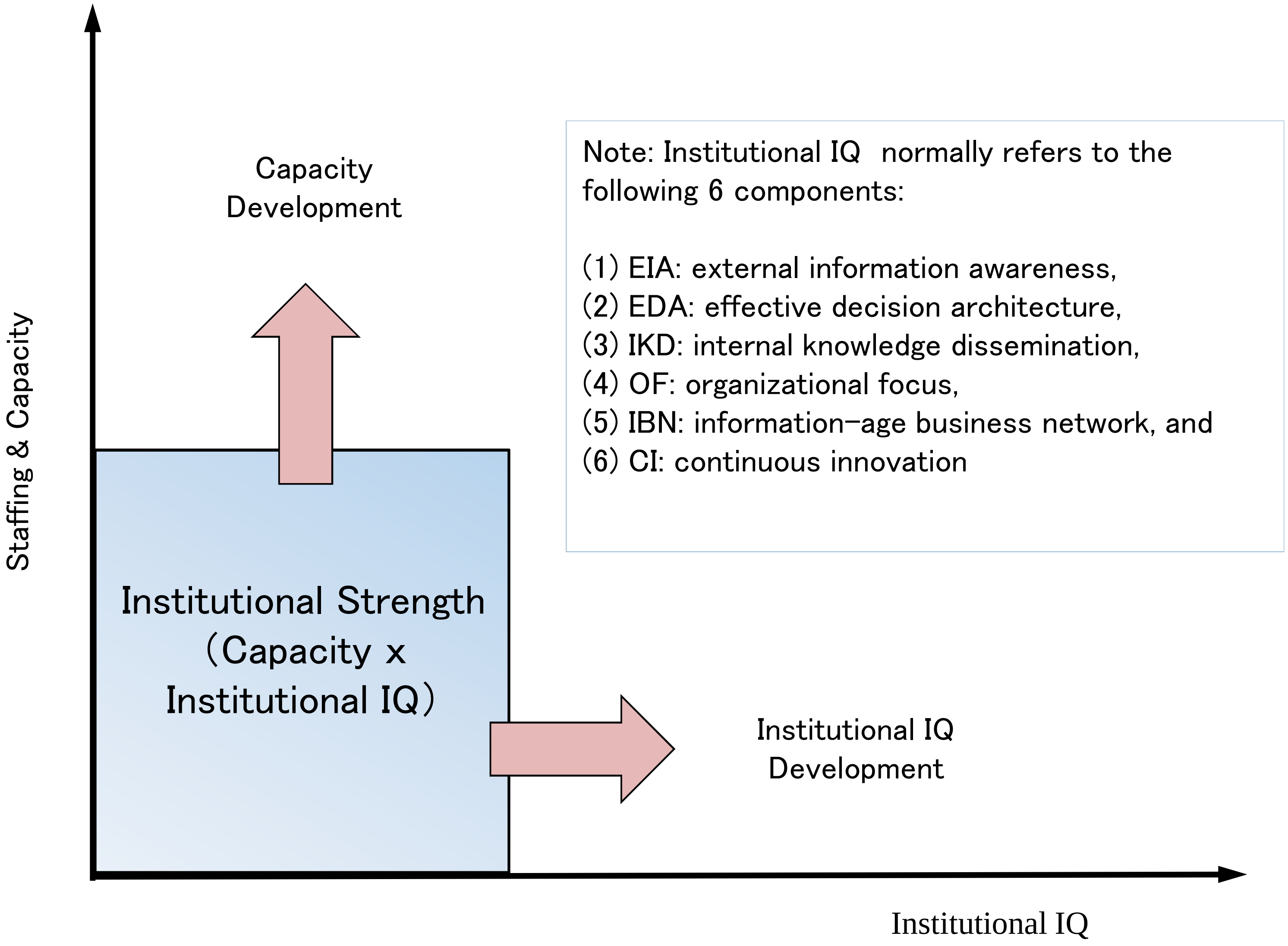
Needs of change (scope, procedures, etc.)

Capacity
(number of staff, level)

Institutional strength
(budget, support, etc.)

What is “institutional strength”?

- Institutional strength is defined as the product of a total capability of members concerned and institutional IQ
- Institutional IQ is a total capability of (1) EIA: external information awareness, (2) EDA: effective decision architecture, (3) IKD: internal knowledge dissemination, (4) OF: organizational focus, (5) IBN: information-age business network, and (6) CI: continuous innovation



Note: Institutional IQ normally refers to the following 6 components:

(1) EIA: external information awareness,
(2) EDA: effective decision architecture,
(3) IKD: internal knowledge dissemination,
(4) OF: organizational focus,
(5) IBN: information-age business network, and
(6) CI: continuous innovation

Capacity Building and Institutional IQ

- Is WASAC's institutional strength is sufficient to implement Five Year NRW Reduction Plan effectively?

  1) Number and capability of additional work force, equipment & tools and budgets required for implementation

  2) Institutional IQ, particularly 3) IKD and 6) CI, to be strengthened

WASAC shall be a main actor!

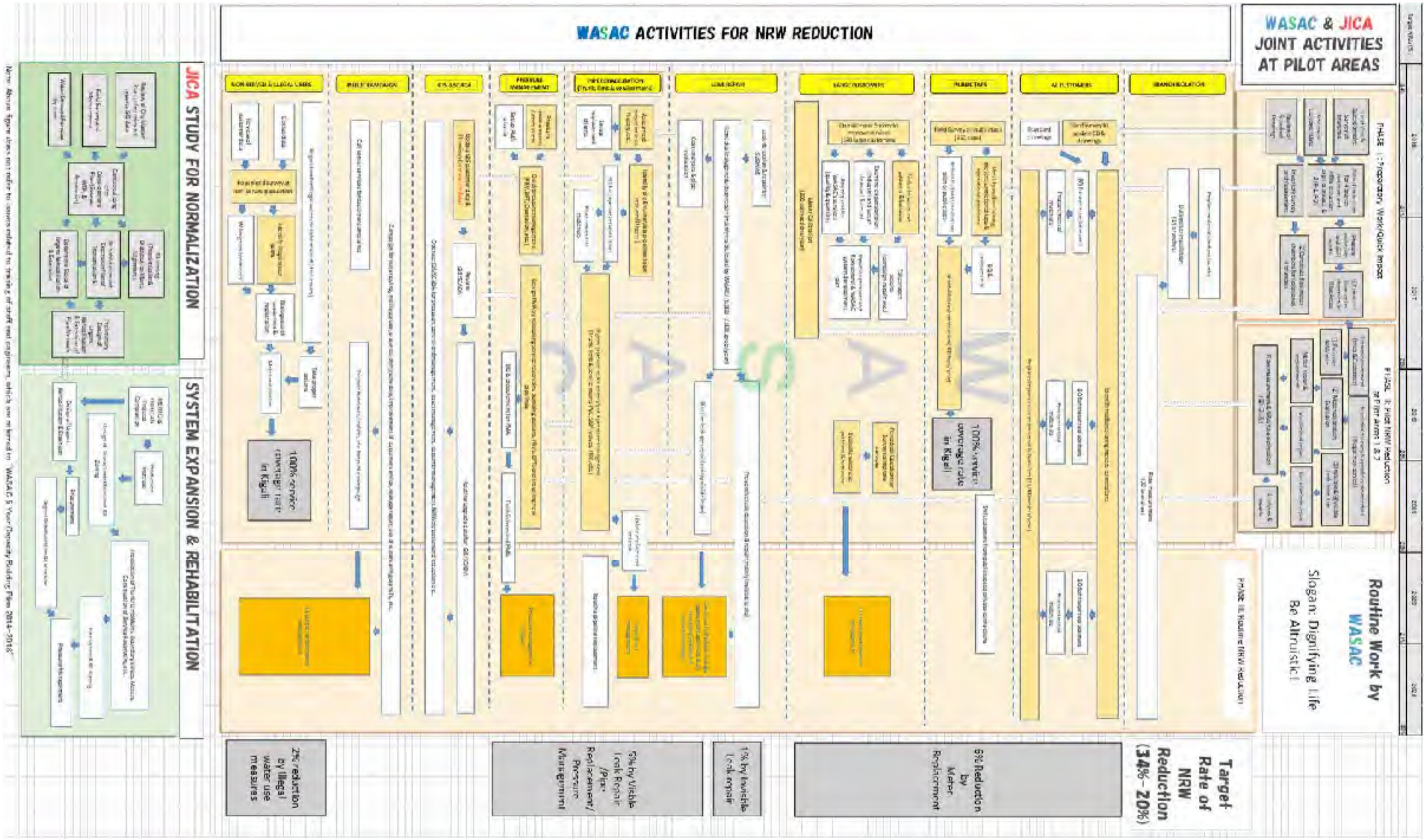
- To attain sustainable development of WASAC, JICA team shall not be a main actor but an assistant
- To formulate the draft Five Year Plan, JICA team is ready to assist, working together

Appreciate your understanding of the above!!!

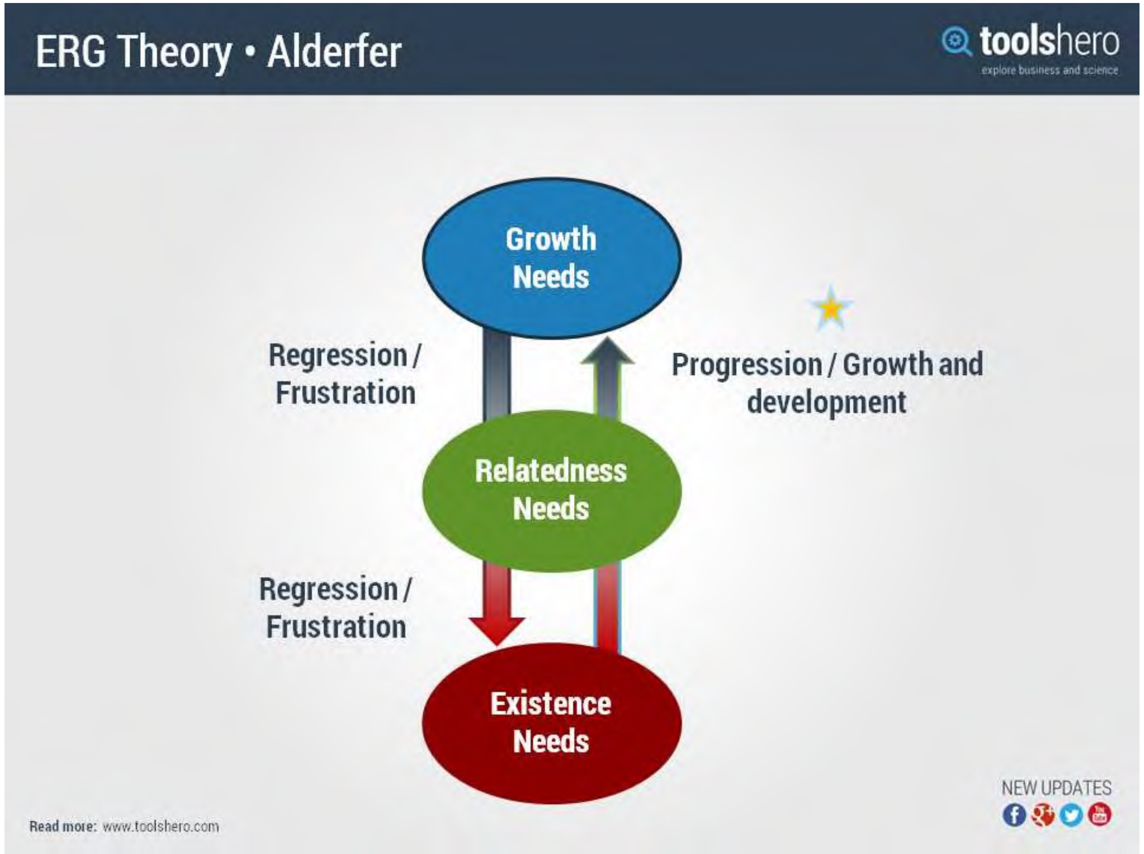
<Reference>

1. Draft Five Year NRW Reduction Plan (Framework)
2. ERG theory

Draft Five Year NRW Reduction Plan (Framework)



1) What is ERG Theory?



Source:

http://www.toolshero.com/effectiveness/erg-theory/

TOPIC-9: "DEVELOPMENT OF WASAC"

2017/2/10

"Development of WASAC"

Kyowa Engineering Consultants, Co., Ltd.

SWOT Analysis is complete

- WASAC 5 Year Strategic Business Plan adopts two line strategy: growth strategy and productivity strategy, addressing four perspectives(Financial, Customer, Internal and Learning & Growth Perspectives)
- From the concept of "Institutional Strength", above business plan is considered perfect.
- Important concept behind the plan touches to R&D, innovation and training center as one of the means of growth strategy

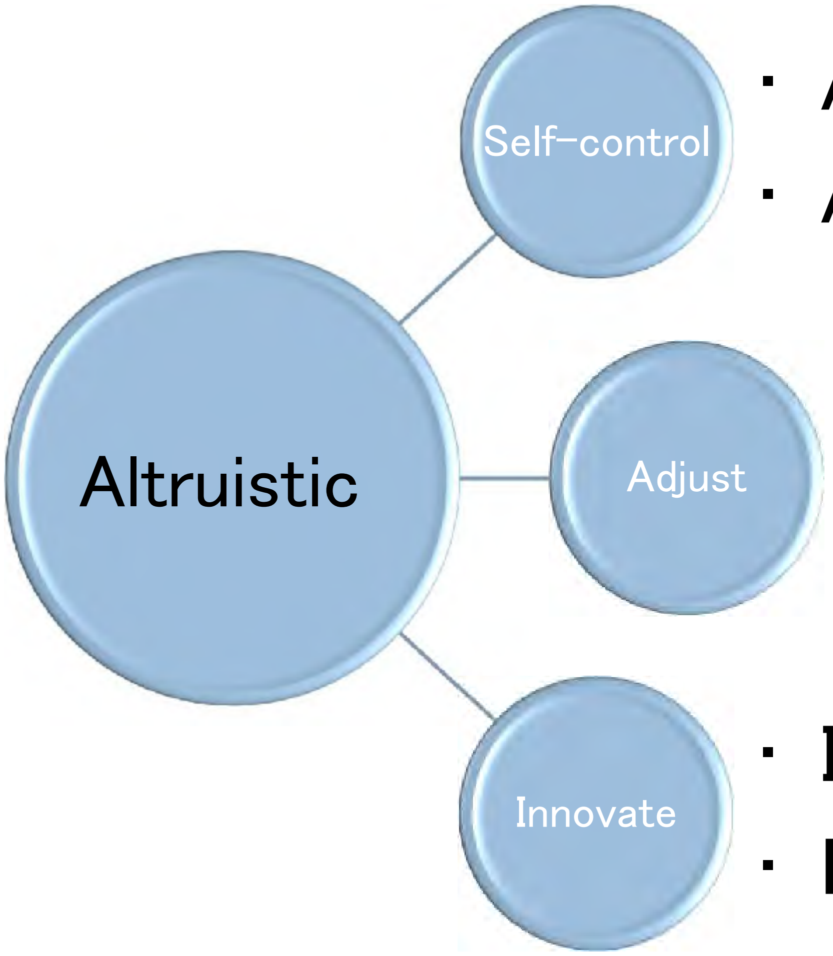
Just have a look at the world!

- There are so much information available in the internet
- What is the difference between advanced and less advanced countries? Germany, Japan, USA, France, UK, China, Korea, etc.
- Just copying is not enough but continuous innovation is a key for development to lead Africa

What is required for Rwanda?

- Altruistic Rwanda people can arrange things and manage themselves for self-control
- This means people can adjust them to their own system
- In the course of the adjustment, however, people may face difficulties and curb them by inventing new means/methods
- So, altruistic people, have a source energy to develop and innovate new system/technology

Altruism is a source of energy



Altruistic

Self-control

- Accept
- Arrange

Adjust

- Own system

Innovate

- Invent
- Develop

Old Chinese philosophy teaches us

Neo-confucianism

- Feudal regime, control and management

Yangmingism

- Modernized society, free innovation

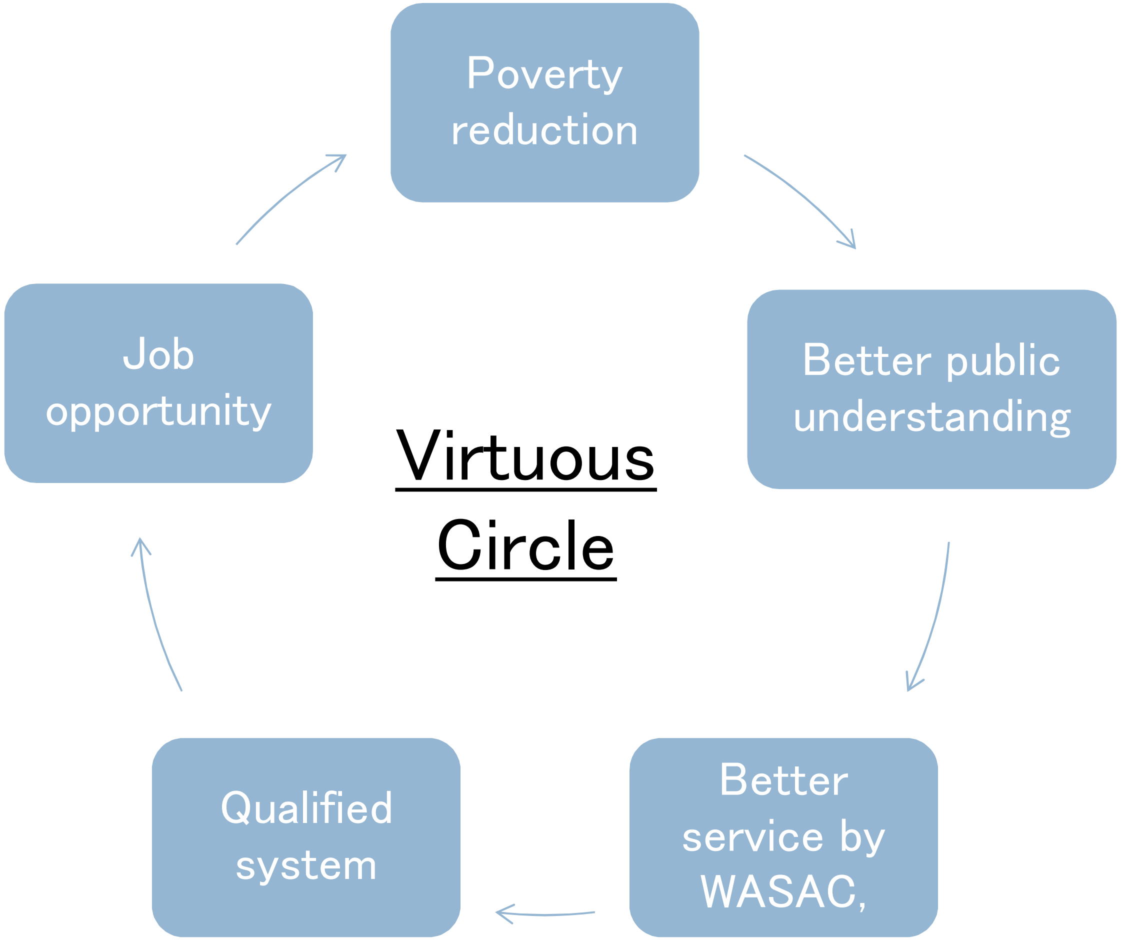
What is a reason why people behave egoistic?

- There might be many reasons; a lack of education, discipline, culture, tradition, policy, etc.
- One of major reasons might be a lack of financial base for existence
- When people are in an extreme poverty, it may be natural that they tend to be egoistic, stealing water, electricity, foods, etc.
- As far as the poverty exists, vulnerable water pipes are easily broken by human access
- To alleviate people from the poverty, how to do?
- Job creation and give them hope!

How to create new jobs?

- Dream and growth
- Qualified system (certificate) of engineers, consultants, suppliers, contractors for pipe laying work, meter installation, meter reading, billing procedures, leakage detection, leak repair, update of customer data/pipeline drawings, etc.
- This civil work society will support WASAC in providing quality service
- Further, this will create new jobs by hiring the poor as daily workers, office supporting staff, etc.

Mutual trust between customers and WASAC



Poverty reduction

Better public understanding

Better service by WASAC,

Qualified system

Job opportunity

<u>Virtuous Circle</u>

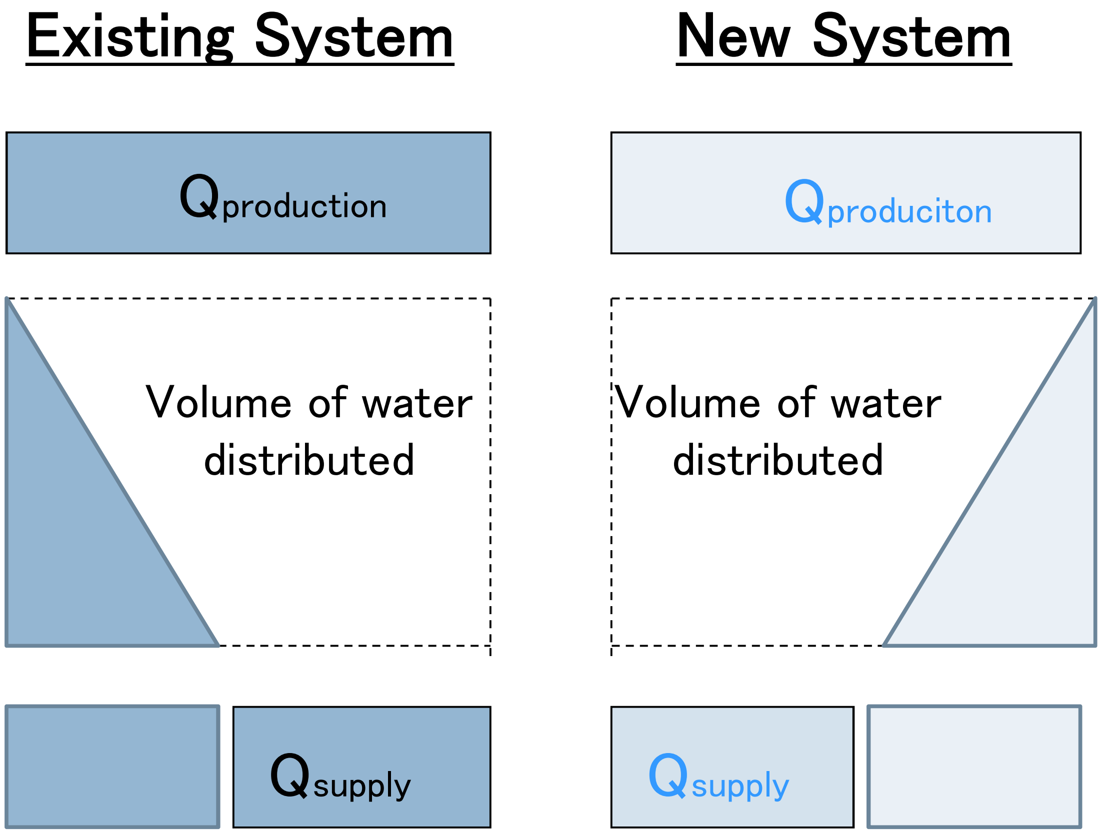
Thank you for attention!

TOPIC-10: REHABILITATION OR EXTENSION

JICA Study Team
Kyowa Engineering Consultants, Co., Ltd.

Which is cost-effective?

- Rehabilitation is more cost-effective than extension
- Rehabilitation for NRW reduction, in general, has double meanings: 1) water loss reduction + water source development (treated water) and 2) increased efficiency for extension (See Fig-1)
- Sample calculation is made hereunder for reference



Fig– 1　Meaning of Water Loss Reduction

Sample Calculation

- ☐ **Supposing that,**

1) water production: 100,000m3/day

2) 40% NRW rate: 20% commercial and 20% physical

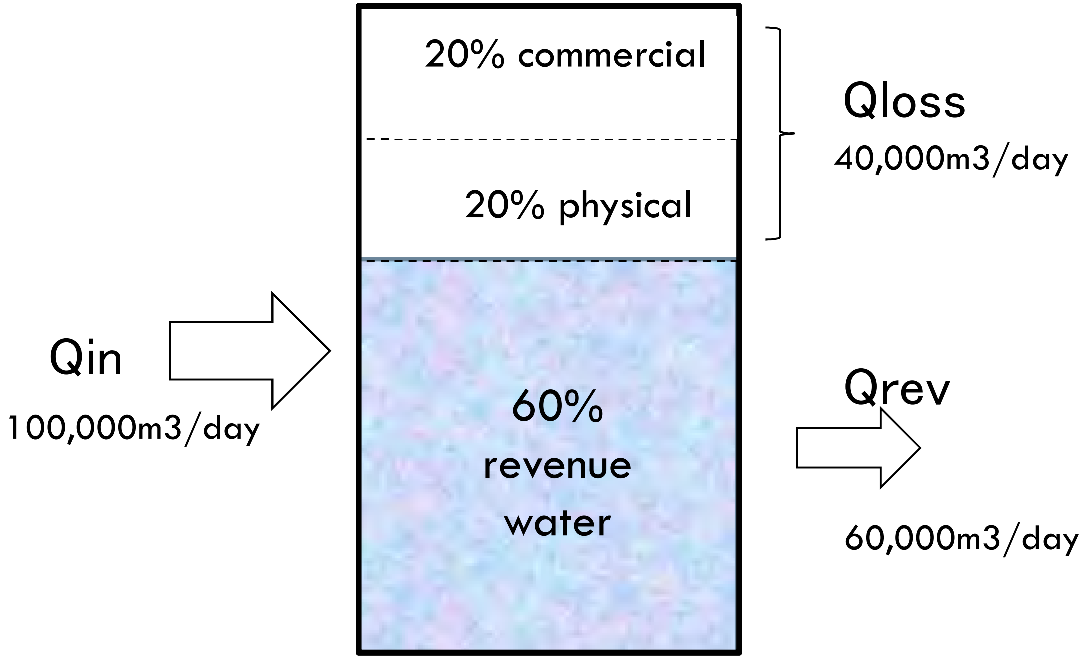
3) total 90,000 customers in Kigali

4) meter replacement cost: 50$/connection

5) all commercial losses (20%) , deriving from malfunctioning meters and illegal status of customers

6) they account for 20% of all customers, namely, 90,000 x 20% = 18,800 customers in number

7) They consume over 100%-150% of average water consumption (e.g., 5 times in Kenya)



<u>Number of customers:</u>
<u>90,000 customers</u>

<u>Number of</u>
<u>malfunctioning meters</u>
<u>(20%): 18,000 meters</u>

Unit cost for rehabilitation

- Rehabilitation to reduce NRW rate from 40% to 20% requires cost for meter replacement, around 900,000$ (=50$ x 18,000 customers)
- Merely 900,000$ of investment can save water of 20,000m3/day (= water production100,000m3 x 20%)
- Unit cost: 45$/m3/day
- (= 900,000$/20,000m3/day)

Unit Cost for WTP Extension

- **Supposing extension of treatment capacity requires around 5million$ for 20,000m3/day**
- **Unit cost: 250$/m3/day**
- **This unit cost is superficial, not true: because 40% of water production is lost as NRW.**
- **Therefore, actual unit cost of extension will be $417/m3/day (=5,000,000/(20,000 x (1-0.4)))**

Comparison of Unit Cost

- Unit cost of rehabilitation shall be dealt with in a same way as extension
- Actual unit cost of rehabilitation:
  900,000/(20,000X (1-0.2)) = 56$/m3
- Comparison of Unit cost:

  Extension Rehabilitation

  417$/m3 >>> 56$/m3

  ; 7.4 times larger

Benefits of rehabilitation

- Water loss reduction by replacing customer meters is considered most cost-effective, if 10-20% NRW can be reduced
- Saved water losses may be supplied to a number of customers as new water source, about 20,000-30,000m3/day, resulting in a revenue increase (more than 20%)
- NRW reduction, further, ensure efficiency in future WTP extension (40% to 20% loss)

Priority to Rehabilitation!!!!!!

- **Unit cost:**

  Extension Rehabilitation

  417$/m3 >>> 56$/m3

- **Increased revenue by 20-30%**

- **An effective decision structure for prioritizing the work**

Thank you for attention!

TOPIC-10:
NRW REDUCTION IN MAKASSAR, INDONESIA

"NRW Reduction"
Kyowa Engineering Consultants, Co., Ltd.

Preliminary Leakage Survey

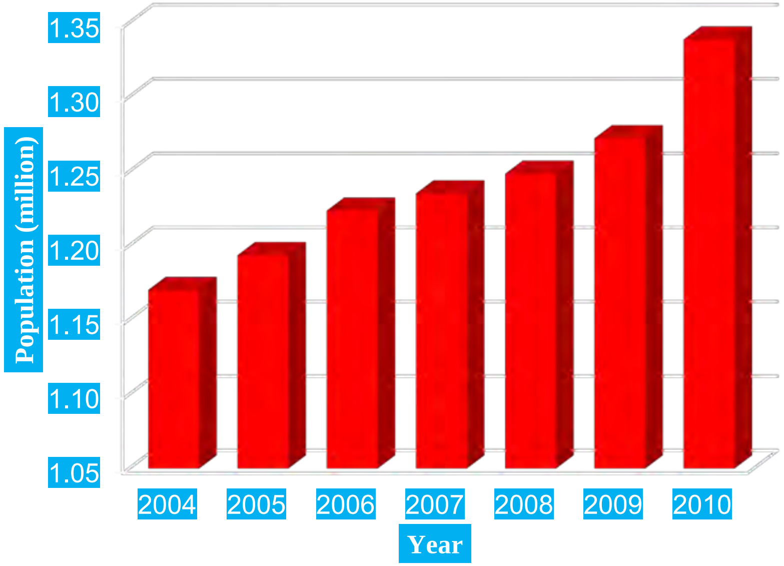
Nine survey blocks in Makassar (tertiary pipes)

BACKGROUND

Central of East Indonesia

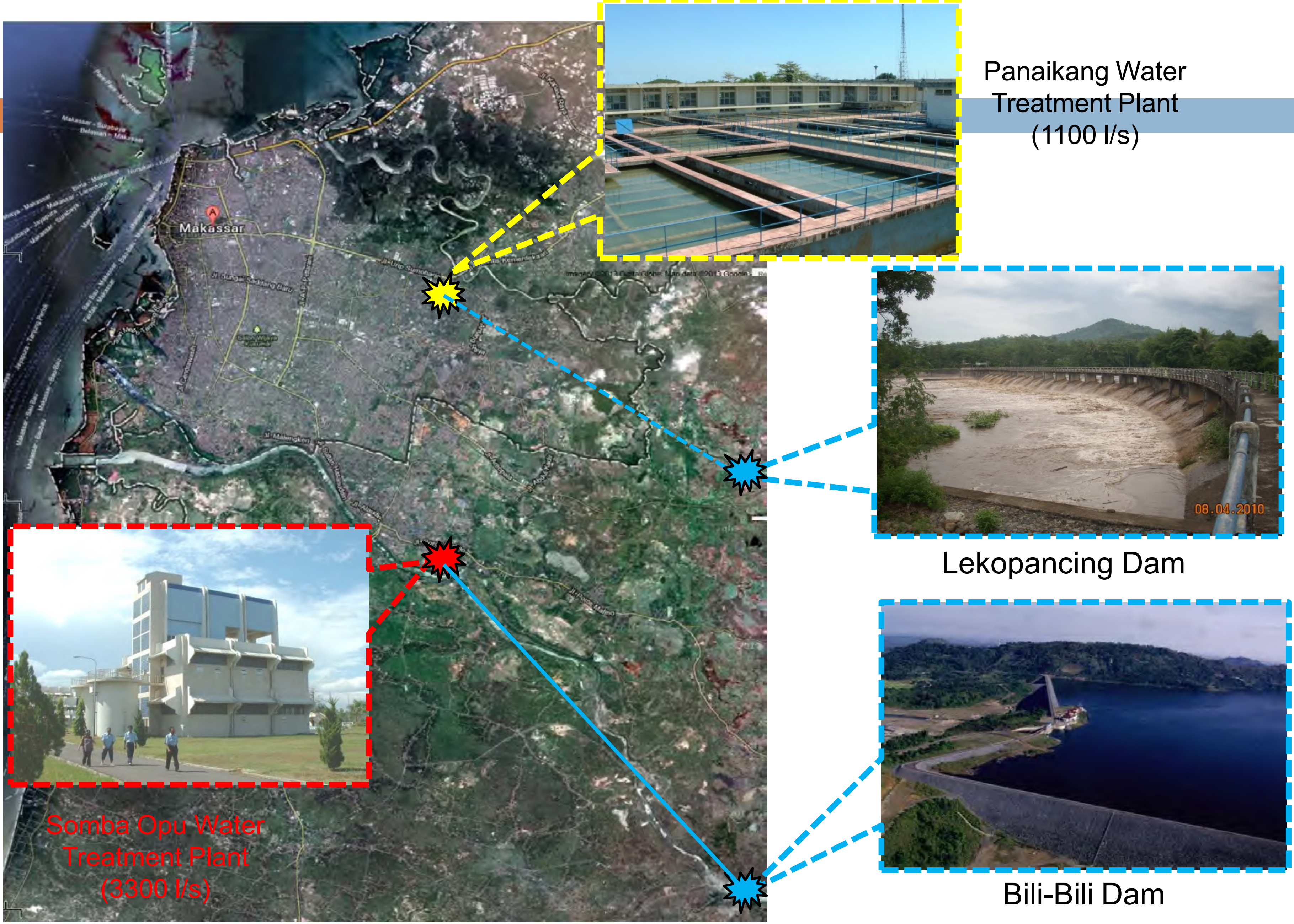
BACKGROUND

Population



2004-2010 (Increasing rate)
- Indonesia = 1,6 % / year
- City of Makassar = 2,4 % / year

EXISTING WATER SUPPLY SYSTEM



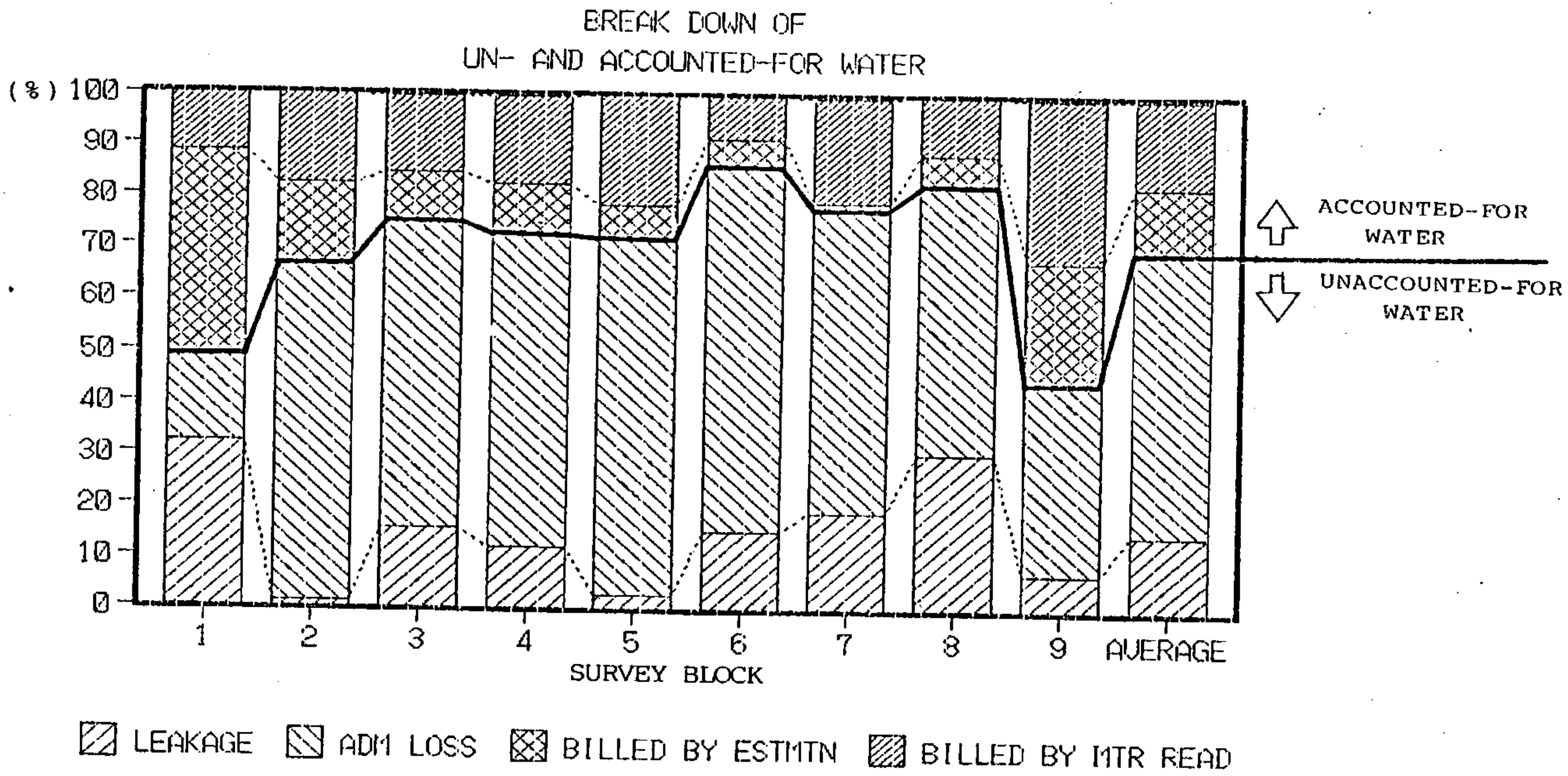
Panaikang Water Treatment Plant (1100 l/s)

Lekopancing Dam

Bili-Bili Dam

Somba Opu Water Treatment Plant (3300 l/s)

Flow measurement at Tertiary Pipes



PRELIMINARY LEAKAGE SURVEY
SUMMARY OF SURVEY RESULTS

	SURVEY BLOCK NO.		1	2	3	4	5	6	7	8	9	AVERAGE
A	PIPE LENGTH	(m)	215.0	423.0	201.3	166.0	486.7	365.7	183.1	249.6	335.8	291.8
B	PIPE DIAMETER	(mm)	50	50	50	50	50	50	50	50	75	52.8
C	PIPE MATERIAL		CIP	CIP	CIP	CIP	CIP	CIP	CIP	PVC	PVC	
D	TOTAL NO. OF HOUSE CONNECTION		29	48	18	17	30	18	22	21	36	26.6
E	NO. OF OPENED HOUSE CONNECTION AT NIGHT		16	25	2	11	5	2.	1	1	0	7.0
F	AVERAGE WATER FLOW FROM OPENED HOUSE CONNECTION AT NIGHT	(l/min)	1.10	0.67	7.90	1.12	6.82	8.37	11.05	8.14	9.80	6.11
G	ESTIMATED CONSUMPTION AT NIGHT	(m3/hr)	1.06	1.00	0.95	0.74	2.05	1.91	0.66	0.49	0.00	0.98
H	MINIMUM NIGHT FLOW AT NIGHT (23:00 - 5:00)	(m3/hr)	1.89	1.08	1.37	1.05	2.13	2.60	1.43	1.98	0.40	1.55
I	ESTIMATED LEAKAGE AT NIGHT	(m3/hr)	0.83	0.08	0.42	0.31	0.08	0.69	0.77	1.49	0.40	0.56
J	AVERAGE PRESSURE AT NIGHT	(m/cm2)	0.86	0.69	3.37	0.93	2.60	5.76	4.65	3.66	6.67	3.24
K	LEAKAGE PER DAY	(m3/day)	14.82	0.78	7.35	4.21	1.56	12.62	11.49	23.34	3.48	8.85
L	TOTAL WATER CONSUMPTION PER DAY	(m3/day)	46.07	71.73	47.77	35.22	64.08	83.97	60.66	76.96	48.77	59.47
M	LEAKAGE RATIO	(%)	32.2	1.1	15.4	12.0	2.4	15.0	18.9	30.3	7.1	14.9
N	PIPE LENGTH PER HOUSE CONNECTION	(m/con.)	7.41	8.81	11.18	9.76	16.22	20.32	8.32	11.89	9.33	11.47
O	HOUSE CONNECTION PER 1 m PIPE LENGTH	(No./m)	0.13	0.11	0.09	0.10	0.06	0.05	0.12	0.08	0.11	0.10

G = E x F
I = H - G
M = (K / L) x 100

	SURVEY BLOCK		1	2	3	4	5	6	7	8	9	AVERAGE
	SEPTEMBER											
A	METERED CONSUMPTION	(m3/month)	195.0	421.0	310.0	177.0	543.0	253.0	428.0	329.0	552.0	356.4
B	ESTIMATED CONSUMPTION	(m3/month)	583.4	350.1	166.2	104.3	127.7	142.1	18.4	140.0	364.9	221.9
C	TOTAL BILLED CONSUMPTION	(m3/month)	778.4	771.1	476.2	281.3	670.7	395.1	446.4	469.0	916.9	578.3
D	BILLED CONSUMPTION PER DAY	(m3/day)	25.9	25.7	15.9	9.4	22.4	13.2	14.9	15.6	30.6	19.3
	OCTOBER											
E	METERED CONSUMPTION	(m3/month)	127.0	347.0	134.0	197.0	316.0	194.0	343.0	215.0	405.0	253.1
F	ESTIMATED CONSUMPTION	(m3/month)	531.4	349.1	116.2	104.3	128.7	142.1	18.4	130.0	330.9	205.7
G	TOTAL BILLED CONSUMPTION	(m3/month)	658.4	696.1	250.2	301.3	444.7	336.1	361.4	345.0	735.9	458.8
H	BILLED CONSUMPTION PER DAY	(m3/day)	21.2	22.5	8.1	9.7	14.3	10.8	11.7	11.1	23.7	14.8
I	AVERAGE BILLED WATER CONSUMPTION PER DAY	(m3/day)	23.6	24.1	12.0	9.5	18.4	12.0	13.3	13.4	27.2	17.0
J	DAILY WATER CONSUMPTION (DATA FROM PRELIMINALY LEAKAGE SURVEY)	(m3/day)	46.1	71.7	47.8	35.2	64.1	84.0	60.7	77.0	48.8	59.5
K	UNACCOUNTED-FOR WATER	(m3/day)	22.5	47.7	35.8	25.7	45.7	72.0	47.4	63.6	21.6	42.4
L	UNACCOUNTED-FOR WATER RATIO	(%)	48.8	66.4	74.9	72.9	71.4	85.7	78.1	82.6	44.3	69.5
M	LEAKAGE RATIO (DATA FROM PRELIMINALY LEAKAGE SURVEY)	(%)	32.2	1.1	15.4	12.0	2.4	15.0	18.9	30.3	7.1	14.9
N	ADMINISTRATIVE LOSS RATIO	(%)	16.6	65.3	59.5	60.9	68.9	70.7	59.2	52.3	37.2	54.5
O	ACCOUNTED-FOR WATER RATIO	(%)	51.2	33.6	25.1	27.1	28.6	14.3	21.9	17.4	55.7	30.5
P	METERED CONSUMPTION RATIO	(%)	11.5	17.6	15.2	17.4	22.0	8.7	20.8	11.6	32.2	17.4
Q	ESTIMATED CONSUMPTION RATIO	(%)	39.7	16.0	9.7	9.7	6.6	5.5	1.0	5.8	23.4	13.0

A : DATA FROM METER BOOK (DSML) OF PDAM
B : DATA FROM METER BOOK (DSML) OF PDAM
C = A + B
D = C / 30
E : DATA FROM METER BOOK (DSML) OF PDAM
F : DATA FROM METER BOOK (DSML) OF PDAM
G = E + F
H = G / 31
✓ I = (D + H) / 2

J : DATA OBTAINED BY MEASUREMENT OF FLOW USING ULTRA SONIC FLOW METER
K = J − I
L = (K / J) x 100
M : RESULT OF PRELIMINALY LEAKAGE SURVEY
N = L − M
O = (I / J) x 100
P = ((((A + E) / 2) / 30.5) / J) x 100
O = ((((B + F) / 2) / 30.5) / J) x 100

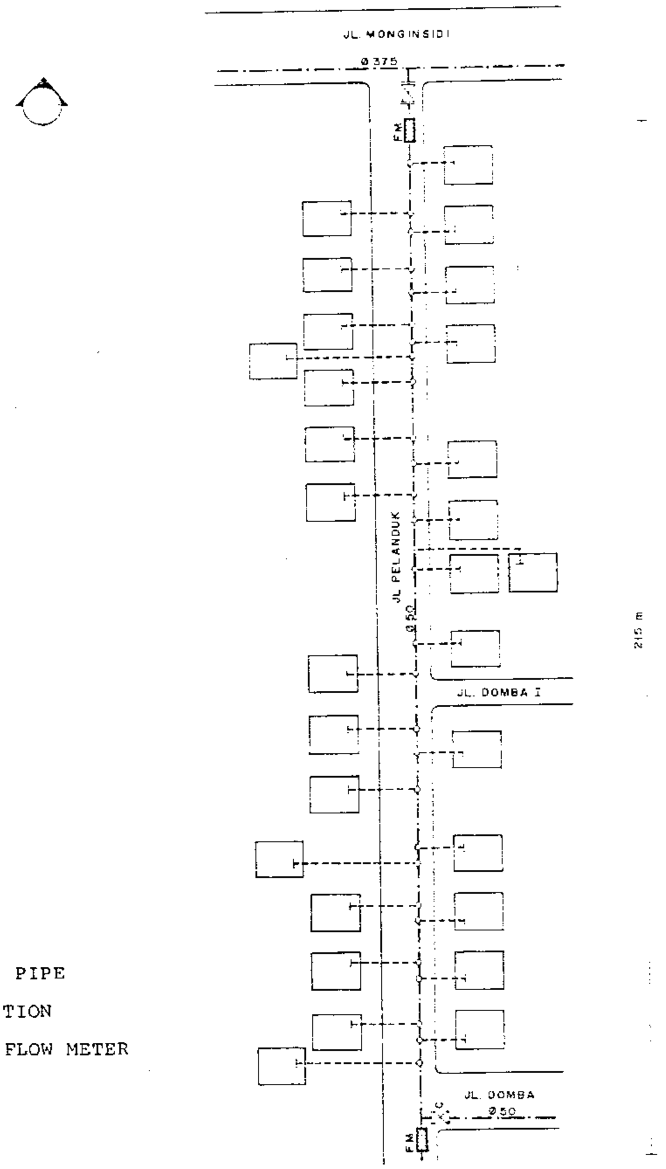
Average UFW and breakdown

- Accounted-for Water: 30.5%
- Unaccounted-for Water: 69.5%

- Metered: 17.4%
- Estimated: 13.0%

- Commercial: 54.5%
- Leakage: 14.9%

- (Commercial+Estimated)/Estimated = **5.2 times**



LEGEND

—·—·—·— : DISTRIBUTION PIPE

-------- : HOUSE CONNECTION

-·-▨-·- FM : ULTRA SONIC FLOW METER

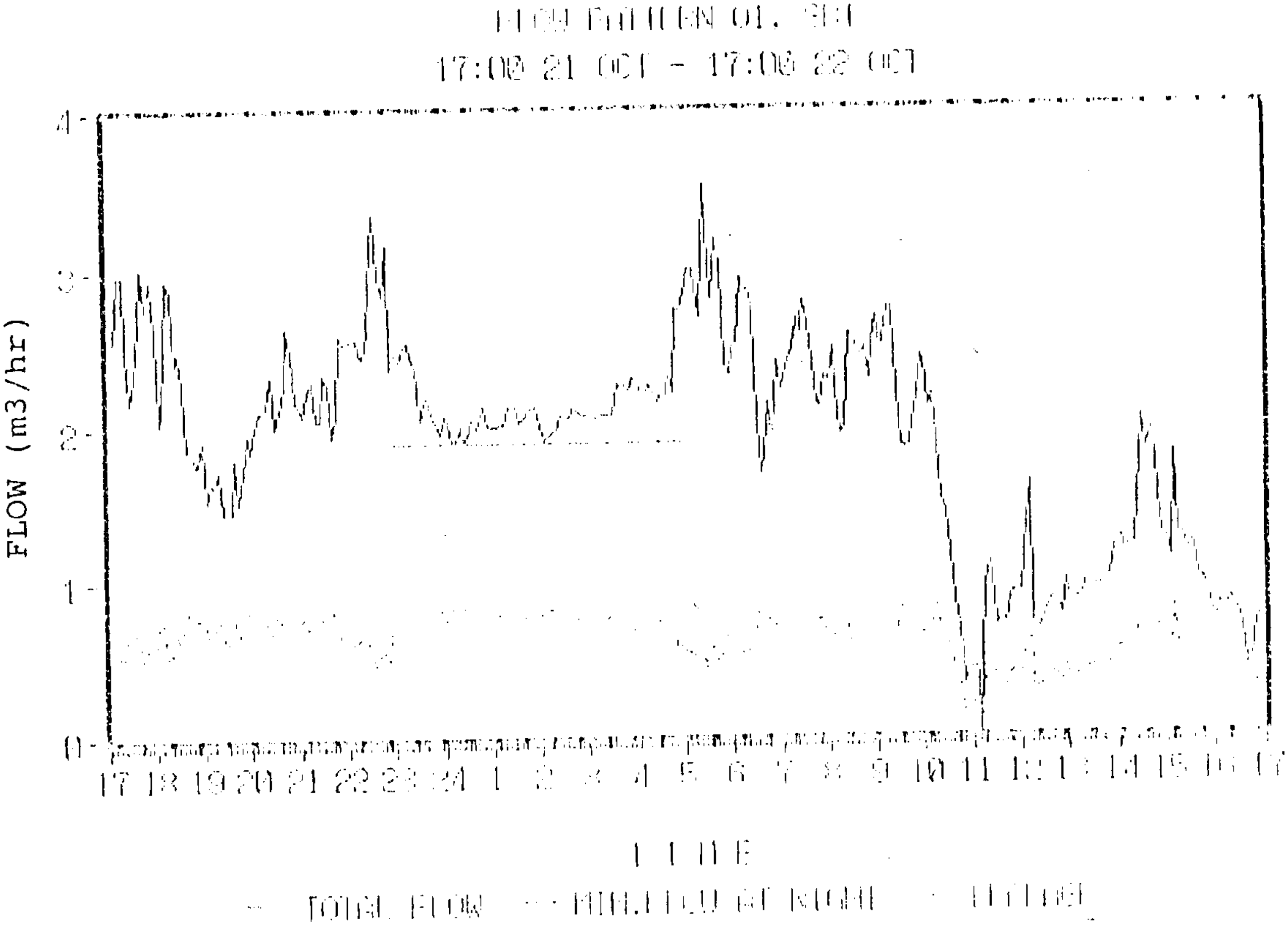
-·-⋈-·- : VALVE

C : CLOSED

TOTAL PIPE LENGTH : 215 m

NUMBER OF HOUSE CONNECTION : 29

UJUNG PANDANG I WATER SUPPLY DEVELOPEMENT PROJECT	SURVEY BLOCK NO.1	FIGURE 1


FLOW PATTERN 01, 3H
17:00 21 OCT - 17:00 22 OCT
FLOW (m3/hr)
0
1
2
3
4
17
18
19
20
21
22
23
24
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
TIME
TOTAL FLOW
MIN.FLOW AT NIGHT
LEAKAGE

Pilot Wastage Control

After leak repair and meter replacement

Table - A5.1 UNACCOUNTED-FOR WATER RATIO BEFORE AND AFTER PWCP

PROJECT AREA	BEFORE PWCP (PLS)				AFTER PWCP			
	TOTAL WATER FLOW INTO PROJECT AREA (m3/day)	BILLED CONSUMPTION BY PDAM (m3/day)	AVERAGE PRESSURE (m)	UNACCOUNTED-FOR WATER RATIO (%)	TOTAL WATER FLOW INTO PROJECT AREA (m3/day)	MEASURED CONSUMPTION BY HOUSE METER (m3/day)	AVERAGE PRESSURE (m)	UNACCOUNTED-FOR WATER RATIO (%)
1	60.7	13.3	1.8	78.1	33.6	31.9	5.0	4.9
3	64.1	18.4	1.7	71.3	38.4	34.4	3.0	10.5
4	48.8	27.2	1.5	44.3	46.3	40.5	2.9	12.5
5	46.1	23.6	1.4	48.8	31.9	28.9	1.8	9.4
8	47.8	12.0	1.7	74.9	22.7	21.6	2.9	4.8
12	77.0	13.4	1.6	82.6	20.2	18.2	1.7	10.0
AVERAGE	57.4	18.0	1.6	66.7	32.2	~~35.1~~ 29.3	2.9	8.7

Table – A5.2 WATER SALES BEFORE AND AFTER PWCP

PROJECT AREA	BEFORE PWCP	AFTER PWCP	INCREASE WATER SALES	
	WATER SALES (m3/month)	WATER SALES (m3/month)	IN QUANTITY (m3/month)	IN PERCENT. (%)
1	710.5	1207.0	496.5	69.9
2	246.5	700.0	453.5	184.0
3	614.0	922.0	308.0	50.2
4	1048.0	2133.0	1085.0	103.5
5	1182.5	1348.0	165.5	14.0
6	982.5	2318.0	1335.5	135.9
7	921.0	1312.0	391.0	42.5
8	531.0	691.0	160.0	30.1
9	358.5	819.0	460.5	128.5
10	910.5	1266.0	355.5	39.0
11	1583.0	3416.0	1833.0	115.8
12	425.5	517.0	91.5	21.5
TOTAL	9513.5	16649.0	7135.5	
AVERAGE				77.9

Table - A5.3 SUMMARY OF LEAKAGE FOUND AND REPAIRED

PROJECT AREA NO. (NO. DAERAH PROYEK)		1	2	3	4	5	6	7	8	9	10	11	12	TOTAL (TOTAL)	AVERAGE (RATA-RATA)
JL. NAME (NAMA JALAN) 1)		M.R.108	KANDEA I	SEMBILAN	MENTIMUN	PELANDUK	KIJANG	DOMBA	GAJAH	LEMBU	ANUANG	ALODRI	CENDERA-	***	***
2)		M.R.108A	KANDEA II	SEMB. I	KANGKUNG							WALANAE	WASIH	***	***
WILAYAH NO. (NO. WILAYAH)		42	71	42	83	17	18	15	17	71	15	17 & 18	10	***	***
TOT. HOUSE CONNECTION (JUMLAH SAMBUNGAN)		37	28	35	49	63	68	49	27	31	65	132	25	609	51
TOT. PIPE LENGTH (PANJANG TOT. PIPA)	(m)	404	297	683	416	616	1112	688	435	367	790	1262	205	7274	606
dia. 50 mm	(m)	404	297	683	50	616	1112	688	435	367	790	1262	205	6910	576
dia. 75 mm	(m)	0	0	0	366	0	0	0	0	0	0	0	0	366	30
NUNDER OF LEAK POINTS (JML TTK KEBOCURAN)		6	1	6	5	6	4	4	5	4	9	11	2	63	5
BY PATROLL (DENGAN PATROLI)		4	1	6	5	4	4	4	5	4	9	10	2	58	5
BY INFORMATION FROM CUSTOMERS (BERDSR.KAN INFO. DARI PELANGGAN)		2	0	0	0	2	0	0	0	0	0	1	0	5	0
ABOVE GROUND (PADA PERMUKAAN TANAH)		4	0	5	2	2	1	1	3	4	7	10	1	40	3
UNDER GROUND (DIBAWAH PERMUKAAN TANAH)		2	1	1	3	4	3	3	2	0	2	1	1	23	2
HOUSE CONNECTION PER LEAK POINT (SAMBUNGAN PER TTK KEBOCORAN)		6	28	6	10	11	17	12	5	8	7	12	13	***	11
PIPE LENGTH PER LEAK POINT (PJG PIPA PER TITIK KEBOCORAN)	(m)	67	297	114	83	103	278	172	87	92	88	115	103	***	133
TOTAL COST FOR LEAK REPAIR * (JML BIY. U/ PERB. KEBOCORAN)	(Rp)	56655	27100	61480	167990	174530	5170	112980	31870	33950	65103	37120	8425	782373	65198
COST PER LEAK POINT * (BIAYA PER TITIK KEBOCURAN)	(Rp)	9443	27100	10247	33598	29088	1293	28245	6374	8488	7234	3375	4213	***	14058
TOTAL MAN-HOUR SPENT ** (JUMLAH JAM KERJA)	(hr)	65	19	52	205	85	117	78	59	39	120	145	36	1019	85
MAN-HOUR PER LEAK POINT ** (JAM KERJA PER TTK KEBOCORAN)	(hr)	11	19	9	41	14	29	20	12	10	13	13	18	***	17

NOTE * : COST FOR MATERIAL USED, EXCLUDING PERSONNEL COST (BIY. U/ KEBUTUHAN MATERIAL, TIDAK TERMASUK BIY. PERSONIL)
** : INCLUDING PATROLL TO FIND LEAKAGE AND REPAIR WORK (TERMASUK PATROLI U/ MENDAPATKAN KEBOCORAN DAN PEK. PERBAIKAN)

Before and After PWCP

- Water consumption: increased from 18.0 to 29.3m^3/month by 63%
- Water sales: increased from Rp.9,513 to Rp.16,649 by 75%
- Water inflow to the areas: decreased from 57.4m^3 to 32.2m^3 by 44%

Lessons learnt from the former projects

- Importance of meter replacement, a key to reduce NRW drastically, cannot be over-emphasized
- Unmetered customers tend to use almost five times much water than normal customers
- Where commercial loss dominates, water inflow rate to the area drops by 40-50% after meter replacement and leak repair

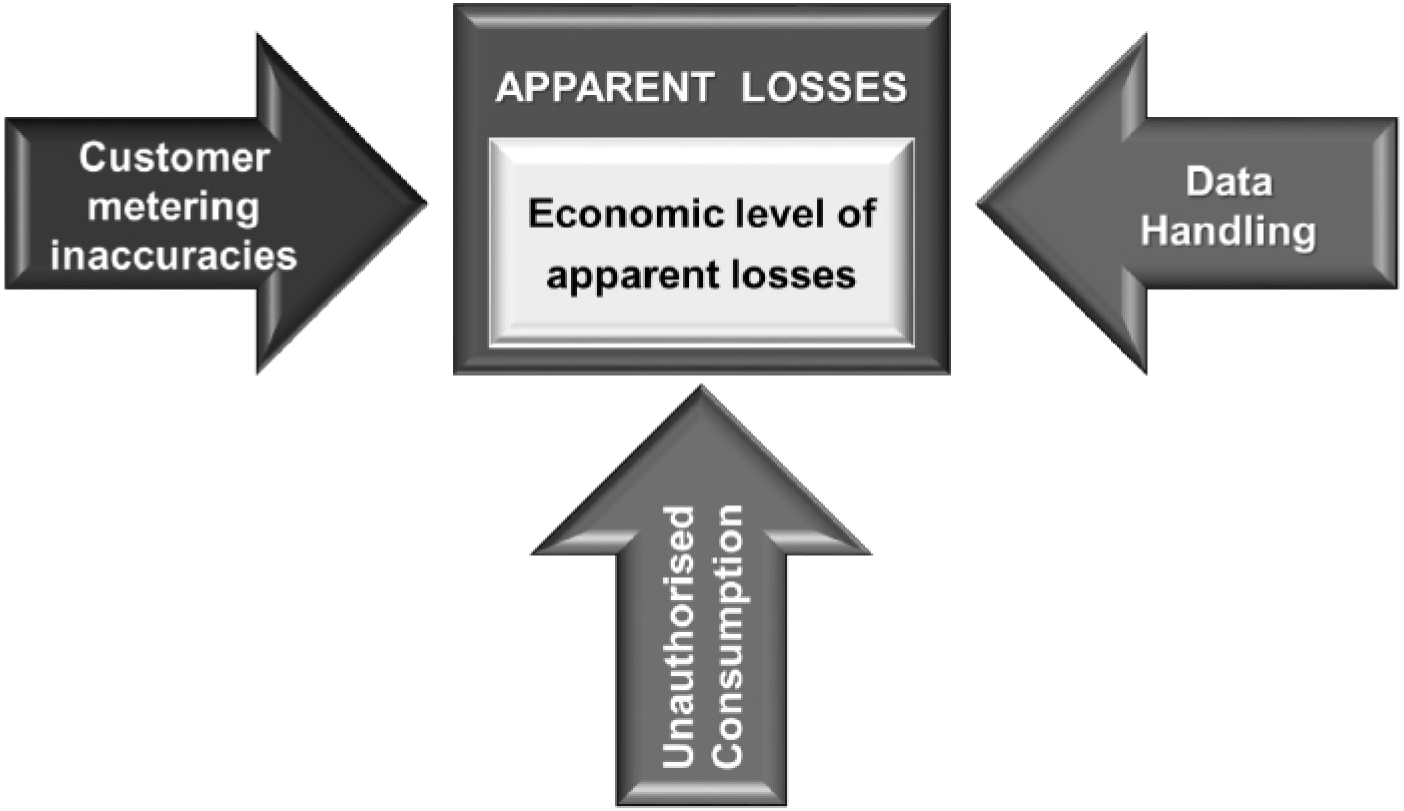
Thank you for attention!

TOPIC-12:
METER (15, 20, 25MM) AND SPECIFICATION

By JICA Engineer

Kyowa Engineering Consultants, Co., Ltd.

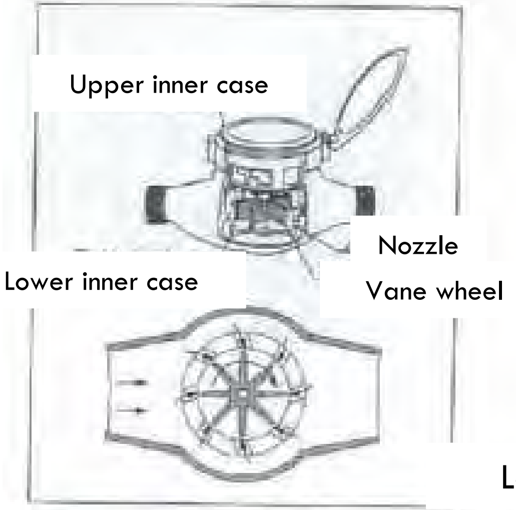
Components of Apparent Losses[1)]

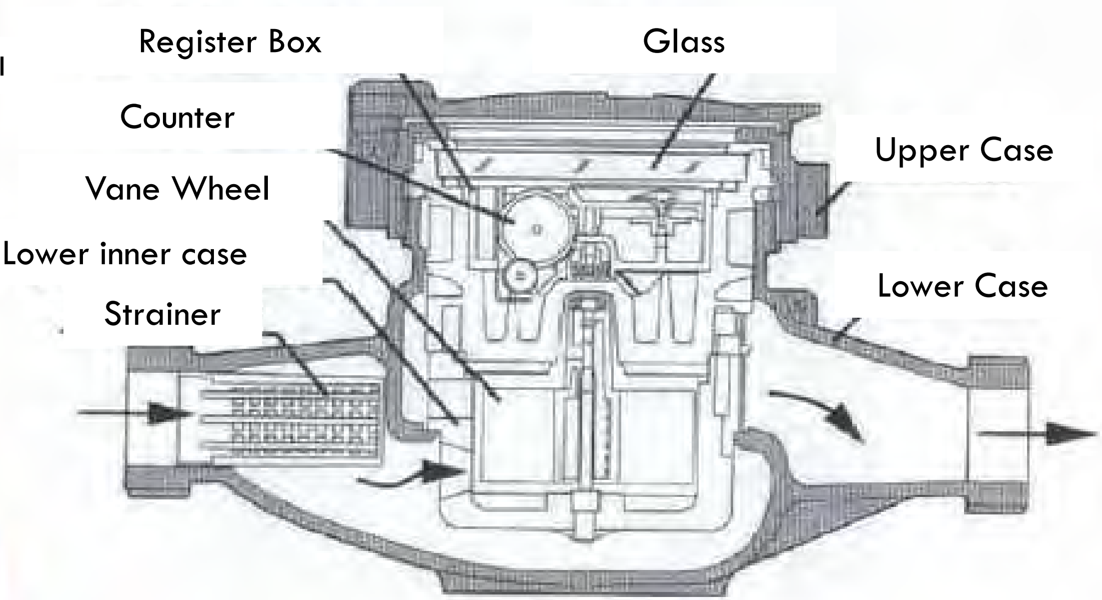


Water meter types

- Inferential type (Velocity type)
- Positive displacement (Volumetric)
- Electromagnetic
- Ultra-sonic
- Waltsman
- Etc.

Vane Wheel Water Meter
– (Dry dial multi-jet)2)





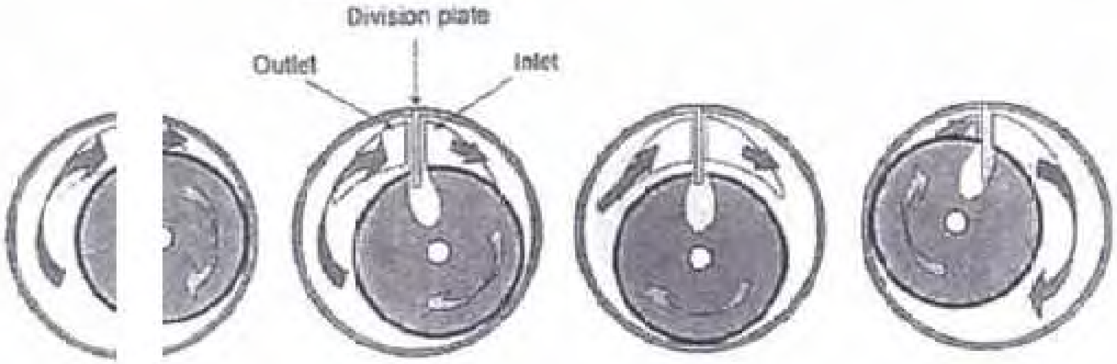
Rotary Piston Water Meter – Positive displacement[2)]

Measuring Chamber

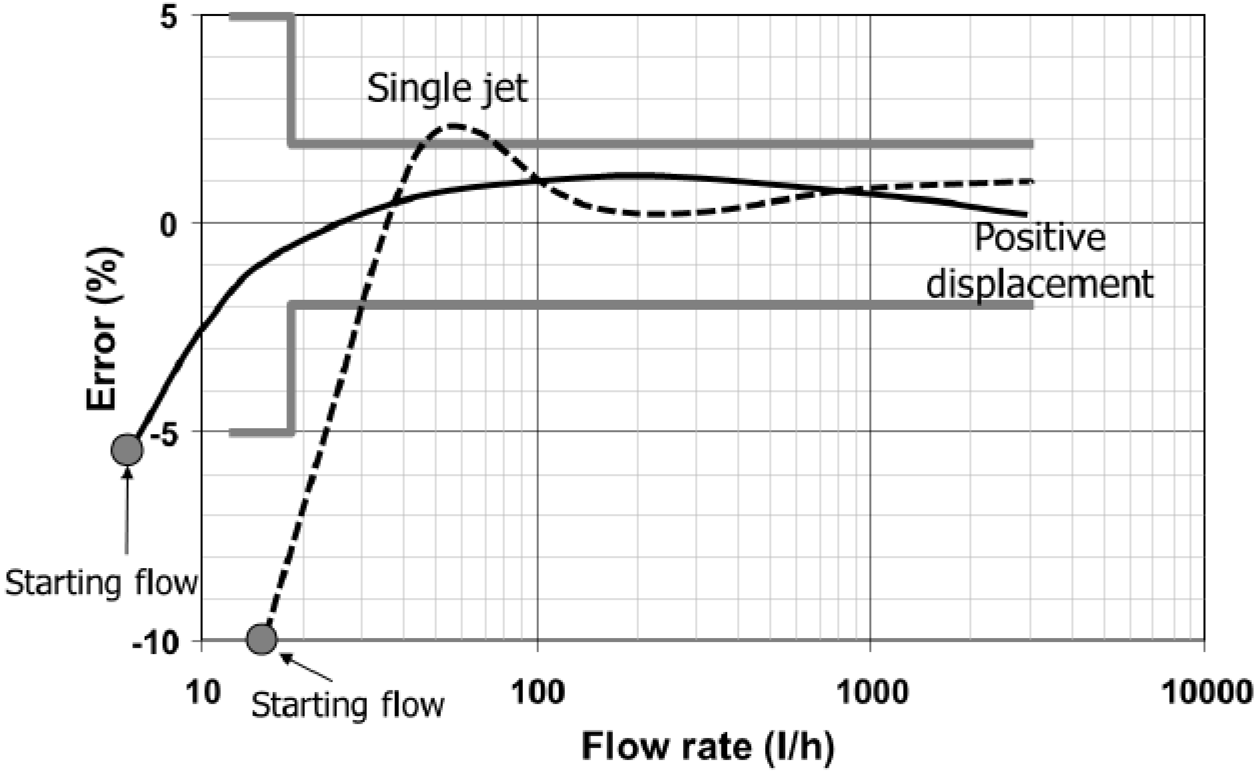
Strainer

Check Valve

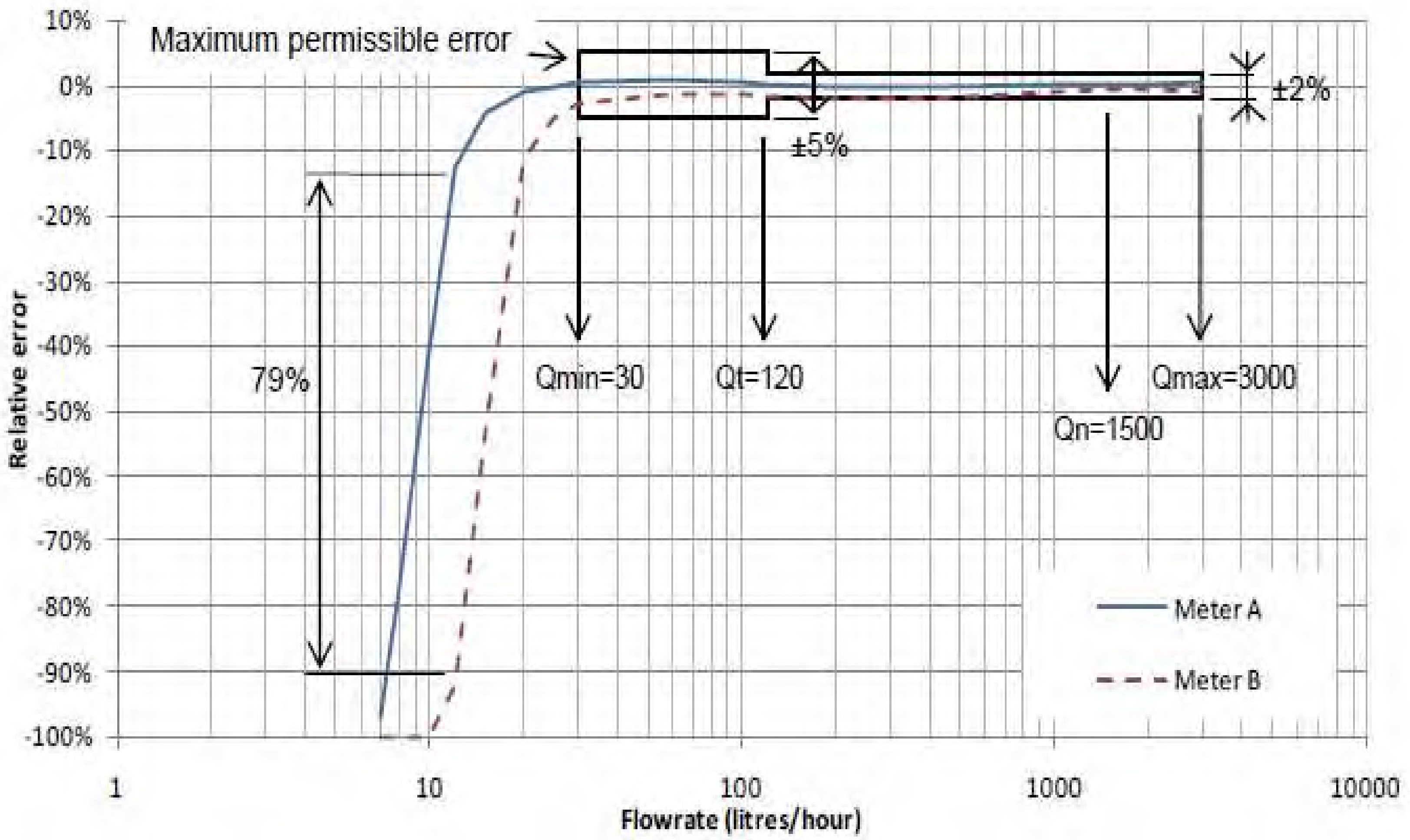
Piston



Positive displacement meters are really durable and accurate? 1)



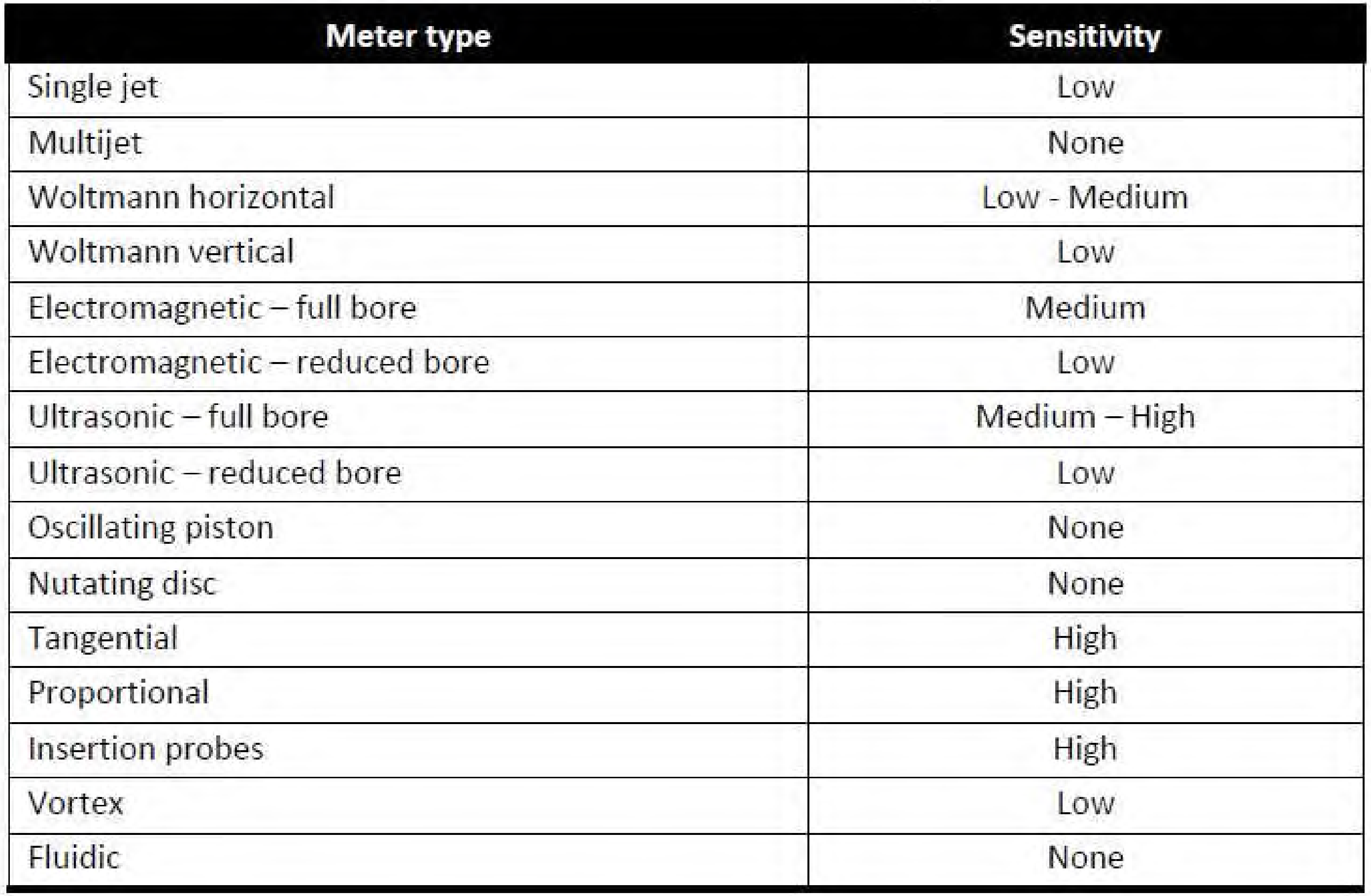
Meter Calibration – previous project in Indonesia, 2009[3)]



Meters wear and tear$^{1)}$

- Moving parts of water meters are subject to wear
- As a general rule, the low flow performance will degrade, causing under-registration
- Changes in meter accuracy at medium and high flow, however, are generally moderate

Flow Distortion Sensitivity[1)]



Meter type	Sensitivity
Single jet	Low
Multijet	None
Woltmann horizontal	Low - Medium
Woltmann vertical	Low
Electromagnetic – full bore	Medium
Electromagnetic – reduced bore	Low
Ultrasonic – full bore	Medium – High
Ultrasonic – reduced bore	Low
Oscillating piston	None
Nutating disc	None
Tangential	High
Proportional	High
Insertion probes	High
Vortex	Low
Fluidic	None

Comparison of Vane Wheel with Rotary Piston Water Meters[1), 2)]

Item	Vane Wheel Type (Dry dial multi-jet)	Rotary Piston-direct reading
Flow rate range	R100	R125
Affects by sand & silt	Not blocked	Easily blocked
Excess flow rate	Magnet coupling needs to design not to slip	Casing sometimes breaks
Durability	Require endurance test in accordance with OIML and ISO. Some manufacturers are not conducting tests	Sometimes doesn't work when restarted after a long term non-operation
Accuracy	Almost similar to piston type within the flow range due to recent technological improvement	Accurate, starting error is close to -20%
Accuracy after years of use	Tends to over-register at the higher range	Error becomes negative after years of use because of scaling
Meter reading	Large register for easy reading	Small register in general
Magnet coupling	Possibly affected by external magnet, but protected in accordance with OIML R49, Part 1- 3	No magnet coupling (use gears for connection)
Orientation (position)	Horizontal installation	Horizontal and vertical installation, depending on type
	When vertically installed, affects accuracy only at low flow rate, less than 100L/h	When misinstalled, affects accuracy at all flow rate

What has changed in ISO4064,1993 and in 2005? 4),5)

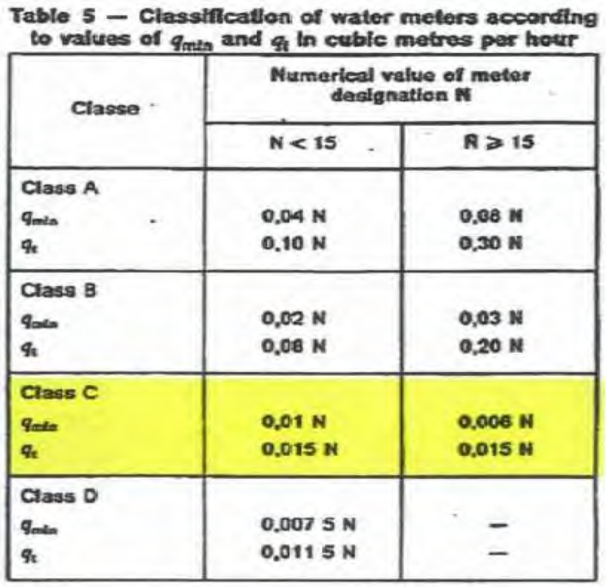
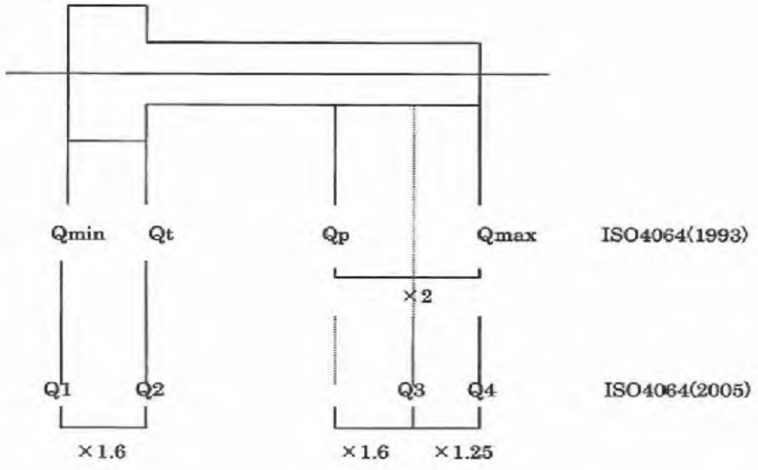
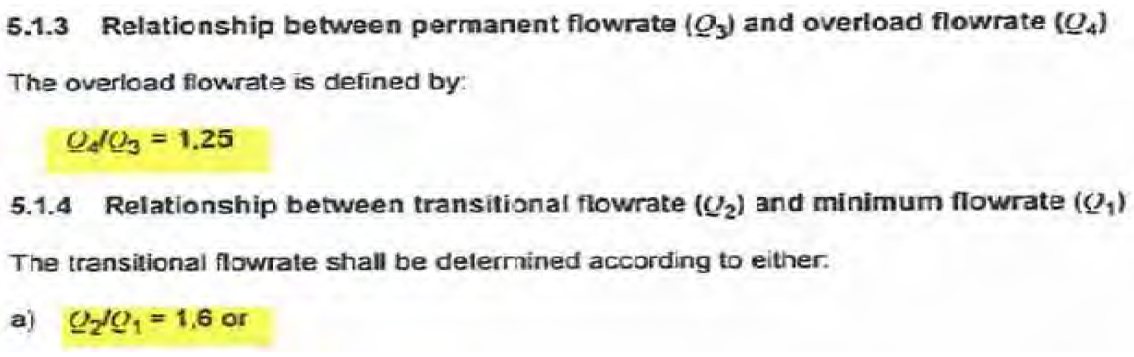


Table 5 — Classification of water meters according to values of q_{min} and q_t in cubic metres per hour

Classe	Numerical value of meter designation N	
	$N < 15$	$R \geqslant 15$
Class A		
q_{min}	0,04 N	0,08 N
q_t	0,10 N	0,30 N
Class B		
q_{min}	0,02 N	0,03 N
q_t	0,08 N	0,20 N
Class C		
q_{min}	0,01 N	0,006 N
q_t	0,015 N	0,015 N
Class D		
q_{min}	0,007 5 N	—
q_t	0,011 5 N	—





5.1.3 Relationship between permanent flowrate (Q_3) and overload flowrate (Q_4)

The overload flowrate is defined by:

$Q_4/Q_3 = 1,25$

5.1.4 Relationship between transitional flowrate (Q_2) and minimum flowrate (Q_1)

The transitional flowrate shall be determined according to either:

a) $Q_2/Q_1 = 1,6$ or

Meter designation and permanent flowrate (Q3)

- Designated according to the permanent flowrate Q3 and ratio of Q3 to the minimum flowrate Q1
- Measuring range (Q3/Q1) will be 80, 100, 125, 160, etc.
- Q4/Q3 = 1.25 and Q2/Q1 = 1.6
- Maximum permissible error in service: twice the maximum permissible errors
- Maximum permissible error, 5% for lower range and 2% for higher range

Consideration for drafting technical specification

- Endurance test
- Meter body made of non-toxic materials free from lead
- Non-reverse flow
- Sample technical specification
- Flow rate(R3)

  15mm- 2.5m3/hour

  20mm- 4.0m3/hour

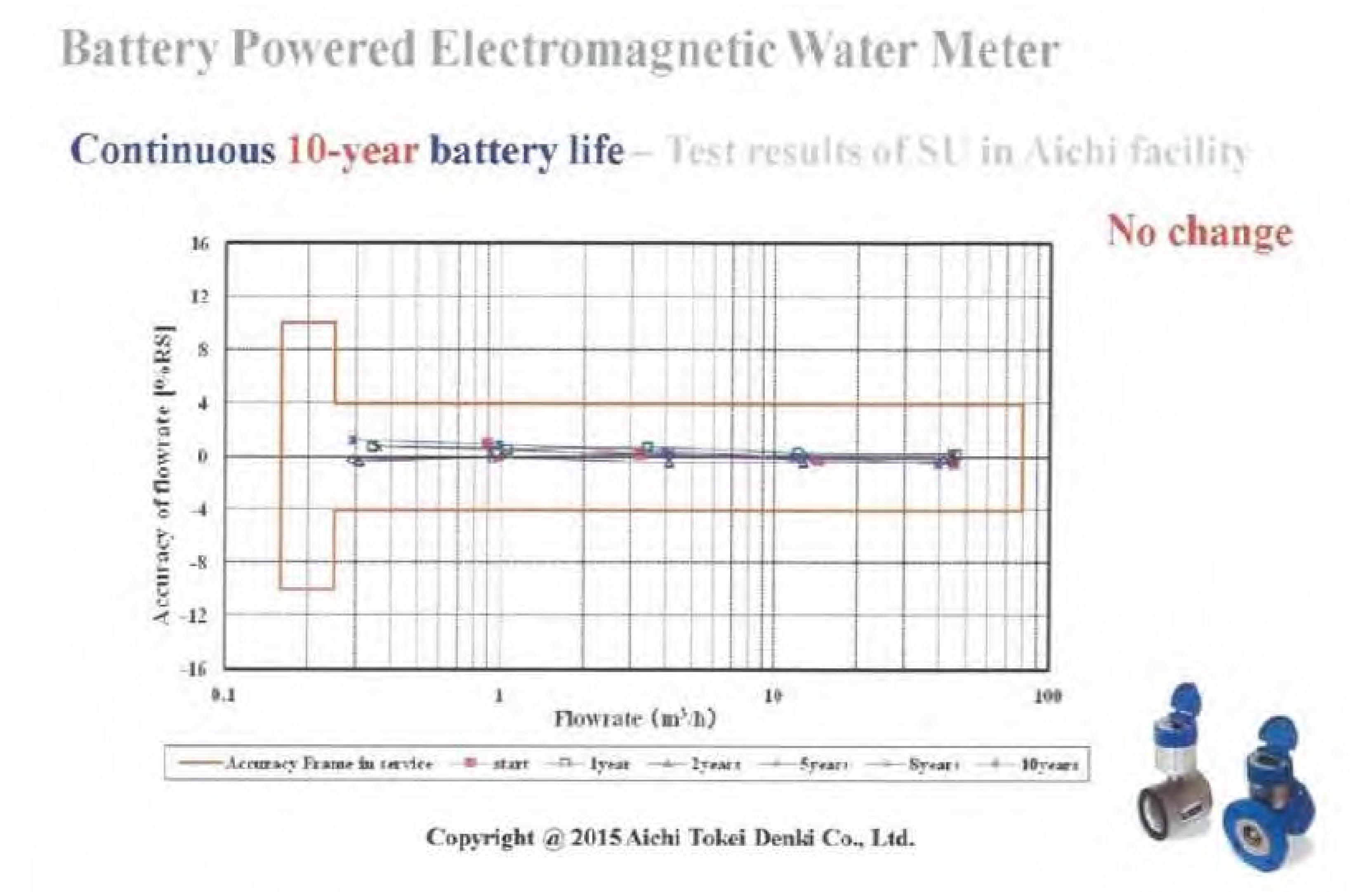
  25mm- 6.3m3/hour

Appendix

1) Flow rate from tap with photos
2) Electromagnetic flow meter
3) Technical Specification

Flow rate from tap with photos$^{2)}$

Note: How long it takes to fill bath tub (200L) give us hints to mind how much water is flowing.



Battery Powered Electromagnetic Water Meter

Continuous 10-year battery life – Test results of SU in Aichi facility

No change

Sample Technical Specification

For Water Meters (15, 20, and 25mm)

1. WATER METERS (15, 20 and 25mm)

Water meters of 15, 20 and 25mm to be procured for the Project shall be of dry dial vane-wheel type and shall be in conformity with ISO 4064-1:2005(E), 4064-2, 4064-3, or JIS B 8570-1:2005, 8570-2:2009 as standard or an equivalent standard as approved by the (name of the Utility).

1.1 TERMS AND DEFINITIONS

Terms and definitions given in this section, shall apply as follows:

1) Flow rate (Q)
   Quotient of the actual volume of water passing through the water meter and the time taken for this volume to pass through the water meter
2) Actual volume (V_a)
   Total volume of water passing through the water meter, disregarding the time taken
3) Indicated volume (V_i)
   Volume of water indicated by meter, corresponding to the actual volume
4) Maximum permissible error (MPE)
   Extreme values of the relative error of indication of the water meter permitted by this part of specification
5) Relative error
   Error of indication divided by the actual volume, expressed as a percentage
6) Error of indication
   Indicated volume minus the actual volume
7) Permanent flow rate (Q_3)
   Highest flow rate under operation at which a water meter is required to operate in a satisfactory manner within the maximum permissible error
8) Overload flow rate (Q_4)
   Highest flow rate at which the water meter is required to operate for a short period of time within the MPE, whilst maintaining its metrological performance when it is subsequently in operation
9) Minimum flow rate (Q_1)
   Lowest flow rate at which the water meter is required to operate within the MPE
10) Transitional flow rate (Q_2)
   Flow rate which occurs between the permanent flow rate, Q3, and minimum flow rate, Q1, that divides the flow rate range into two zones, the "upper zone" and "lower zone", each characterized by its own MPE
11) Minimum admissible working pressure (mAP)
   Minimum pressure that a water meter can withstand permanently for continuous use without deterioration of its metrological performance
12) Maximum admissible working pressure (MAP)
   Maximum pressure that a water meter can withstand permanently for continuous use without deterioration of its metrological performance
13) Pressure loss (Δp)
   Head loss, at a given flow rate caused by the presence of the meter in the pipeline
14) Indicating device
   Part of the meter that displays the measurement results, either continuously or on demand

1.2 METER SIZE AND OVERALL DIMENSIONS

Meter size is characterized by the thread size of the end connections. For each meter size there is a corresponding fixed set of overall dimensions. The dimensions of the meter, as illustrated in Figure 1, shall be in accordance with those listed in Table 1.

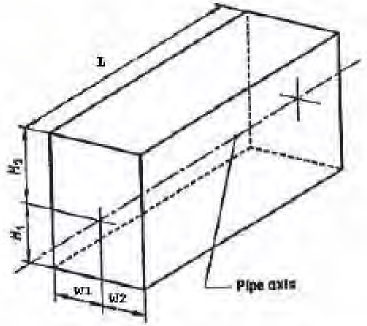


Figure 1 - Meter dimensions

1.3 THREADED CONNECTION

Permissible values of dimensions a and b for threaded connections are given in Table 1. Threads shall comply with ISO 228-1. Figure 2 defines dimensions a and b.

Table 1 – Water meter dimensions(in mm)

Size DN	a_{min}	b_{min}	L^b recommended	L^b alternative	W_1;W_2	H_1	H_2
15	10	12	165	100,110,145,170,175	65	60	220
20	12	14	190	175,195,200	65	60	240
25	12	16	260	175,200,210,225	100	65	260

a DN: nominal size of threaded connections

b Tolerance on length

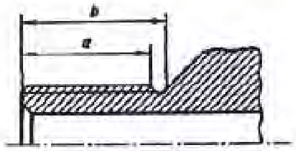


Figure 2 — Thread

Meter shall conform with ISO 4064-1:2005(E), 4064-2, 4064-3, or JIS B 8570-1:2005, 8570-2:2009 as standard or an equivalent standard as approved by Name of the Utility, for velocity, dry, magnetic drive, multi-jet type meters.

1.4 MATERIALS AND CONSTRUCTION OF WATER METERS

The water meter shall be manufactured from materials of adequate strength and durability for the purpose for which the water meter is to be used.

All parts of the water meter in contact with the cold, chlorinated water flowing through it shall be manufactured from materials that are conventionally known to be non-toxic free from lead, non-contaminating and biologically inert.

The complete water meter shall be manufactured from materials that are resistant to internal and external corrosion, or that are protected by a suitable surface treatment.

The water meter indicating devices shall be protected by a transparent window. A cover of suitable type may also be provided as additional protection.

The water meter shall incorporate devices for removal of condensation, where there is a risk of the condensation forming on the underside of the window of the water meter-indicating device.

1.5 ENDURANCE

It shall be demonstrated that the water meter is able to fulfill the appropriate endurance requirements according to the permanent flow rate, Q_3, and the overload flow rate, Q_4, of the meter, simulating service conditions as listed in Table 2.

Table 2 – Endurance Test

Permanent flow rate	Test flow rate	Test water temperature ±5℃	Type of test	Number of interruptions	Duration of pauses	Period of operation at test flow rate	Duration of start-up and rundown
Q3<=16m3/h	Q_3 Q_4	25℃ 25℃	Discontinuous Continuous	100000 -	15s -	15s 100h	$0.15Q_3$ with a minimum of 1s
Q3>16m3/h	Q_3 Q_4	20℃ 20℃	Continuous Continuous	- -	- -	800h 200h	- -

1.6 VERIFICATION MARKS AND PROTECTION DEVICES

A place shall be provided on water meters for the main verification mark, which shall be visible without dismantling the water meter. Such marks include identification:

1) Direction of water flow with an arrow indicating the direction
2) Trade mark and name of manufacturer
3) Manufacturer's serial number of the meter permanently affixed to the meter case
4) Permanent flow rate (Q_3) and the flow ratio (Q_3/Q_1)
5) Stamped with initial "(name of the Utility)".

Further, water meters shall include protection devices that can be sealed so as to ensure that, both before and after correct installation of the water meter, dismantling or modification of the meter and/or its adjustment device or correction device is not possible without damaging these devices.

1.7 INDICATING DEVICES

The indicating device of the water meter shall provide an easily read, reliable and unambiguous visual indication of the indicated volume.

The indicated volume of water shall be expressed in cubic meters. The unit m^3 shall appear on the dial immediately adjacent to the numbered display.

The indicating range of the meter shall conform to the requirements of Table 3.

Table 3 – Indicating range of a water meter

Q3 (m^3/h)	Indicating range (minimum values) (m^3)
Q_3<=6.3	9999
6.3<Q_3<=63	99999

The color black shall be used to indicate the cubic meter and its multiples. The color red shall be used to indicate sub-multiples of a cubic meter.

The value expressed, in cubic meters, for each scale division shall be of the form 10^n, where n is a positive or negative whole number or zero, thereby establishing a system of consecutive decades. Each scale shall be either graduated in values expressed in cubic meters or accompanied by a multiplying factor (x0.001; x0.01; x0.1; x1; x10; x100; x 1,000; etc.)

1.8 METROLOGICAL CHARACTERISTICS

1.8.1 METER DESIGNATION AND PERMANENT FLOW RATE (Q_3)

Water meters are designated according to the permanent flow rate Q_3 in cubic meters per hour and ratio of Q_3 to the minimum flow rate Q_1.

Size DN (mm)	Q_3 (m3/h)
15	2.5
20	4.0
25	6.3

1.8.2 MEASURING RANGE

The measuring range for the flow rate as defined by the ratio, $Q_3/Q_1=100$. The Contractor shall provide information on designated flow rates and the ratio of the water meters procured under the current project.

1.8.3 RELATIONSHIP BETWEEN PERMANENT FLOW RATE (Q_3) AND OVERLOAD FLOW RATE (Q_4)

The overloaded flow rate is defined by:

$$Q_4/Q_3 = 1.25$$

1.8.4 RELATIONSHIP BETWEEN TRANSITIONAL FLOERATE (Q_2) AND MINIMUM FLOWRATE (Q_1)

The transitional flow rate is defined by:

$$Q_2/Q_1 = 1.60$$

1.9 MAXIMUM PERMISSIBLE ERROR LOWER RANGE

The maximum permissible error, positive or negative, on volumes delivered at flow rates between the minimum flow rate (Q_1) and the transitional flow rate (Q_2) is 5 % for water under normal pressure.

1.10 MAXIMUM PERMISSIBLE ERROR UPPER FLOW RANGE

The maximum permissible error, positive or negative, on volumes delivered at flow rates between the transitional flow rate (Q_2) and the overload flow rate (Q_3) is:

- 2% for water having a temperature <= 30 degree centigrade
- 3% for water having a temperature > 30 degree centigrade

1.11 NO REVERSE FLOW

The contractor shall provide water meters which have devices designed to protect reverse flow and avoid any probable risk of contamination and pollution caused from.

1.12 EXTERNAL MAGNETIC INTERFERENCE

If the drive between the metering rotor and the counter is magnetic, then it shall be unaffected by external magnetic interference as specified in 9.4.3 Static Magnetic field, ISO4064-3(2005).

1.13 FLOW TOTALIZATION

The flow meter totalization shall not change when the flow rate is zero.

1.14 ADMISSIBLE WATER PRESSURE

The water pressure shall be measured upstream of the meter inlet for MAP evaluation and downstream of the meter outlet for mAP evaluation.

The minimum admissible pressure, mAP, shall be 30 kPA (0.3 bar).

The meters form maximum admissible pressure classes corresponding to the MAP value of the following ISO series, chosen by the contractor, as shown in Table 4.

Table 4 - Water pressure classes

Class	MAP MPa (bar)	Reference condition MPa (bar)
MAP10	1.0 (10)	0.2 (2)
MAP16	1.6 (16)	0.2 (2)

Note: reference condition shows limits of low pressure.

1.15 WORKING PRESSURE RANGE

Water meters shall operate up to a working pressure range of at least 1 MPa (10bar).

1.16 PERFORMANCE TEST

The Contractor shall submit the results of performance test carried out by manufacturers to the Project Manager of PDAM.

The tests shall be carried out under conditions as follows:

Ambient air temperature: 25 ℃ ± 5 ℃
Ambient relative humidity: 60% ±15%
Ambient atmospheric pressure: 86 kPa to 106 kPa
Water temperature: 25 ℃ ± 5 ℃

Tests shall consider the fact that some influence quantities should have a constant effect on measurement results and not a proportional effect related to the measure volume. The value of the significant fault is related to the measured volume; therefore, in order to be able to compare results obtained in different laboratories it is necessary to perform a test on a volume corresponding to the delivered in one minute at the flow rate, each at 50%Q_1, Q_1, Q_2, Q_3 and Q_4.

1.17 ACCESSORIES

The water meter shall include the following accessories.
1) An internal strainer of at least 18 holes per cm2 near the inflow inlet of the meter.
2) Necessary fittings

Reference

1) Appendix-3 Customer Metering Errors, Guidance Notes on Apparent Losses and Water Loss Reduction Planning, September, 2016
2) Measurement of water flow in fully charged closed conduits-Meters for cold potable water, Aichi Tokei Denki Co., Ltd., April, 2016
3) New Business Model for NRW Reduction Plan, 2011
4) ISO4064 Standard 1993
5) ISO4064-1,-2),-3) International Standard 2005

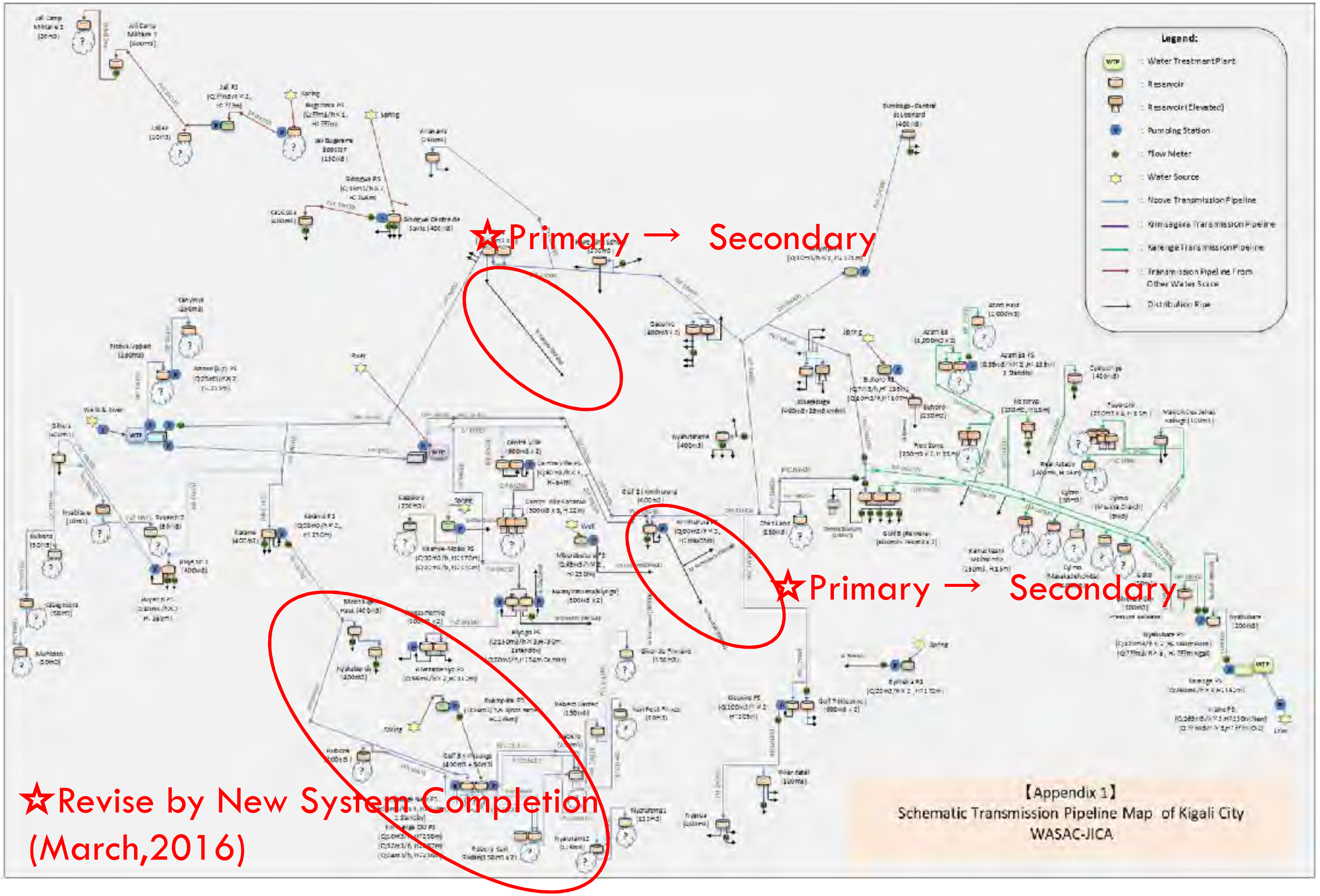
Thanks for your attention!

TOPIC-H1:
HIGH PRESSURE AREA BY BRANCHING FROM TRANSMISSION PIPELINE AND PUMP

"Inventory Survey 1"

Kyowa Engineering Consultants, Co., Ltd.

Schematic Transmission Pipeline Map of Kigali City



☆Primary → Secondary

☆Primary → Secondary

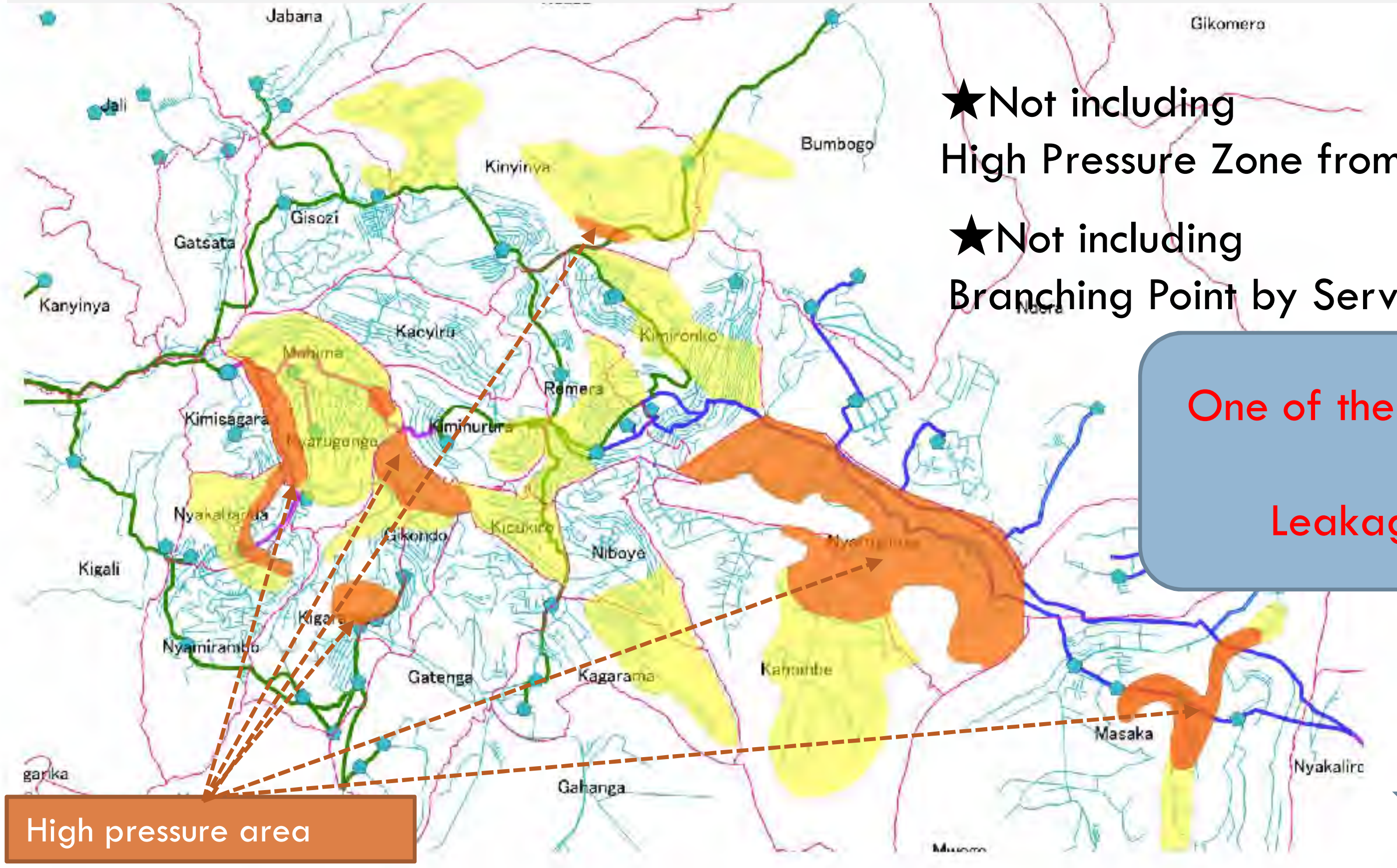
☆Revise by New System Completion (March,2016)

Definition of Pipeline

- **The Transmission Pipeline** means pipes between ○WTP/PS ⇒ Reservoir, and Reservoir/PS ⇒ Reservoir, also including pipes installed at springs and wells of other water sources, as categorized **"Primary Pipeline"** by WASAC.
- **The Distribution Pipeline** means pipes to distribute water to water service area or service block from reservoirs or pumping stations (in peculiar case, distributed from the transmission pipeline by Branch), as categorized **"Secondary Pipeline"** by WASAC.
- **The service piping** means pipes to distribute water to customer from the distribution pipeline (in peculiar case, distributed from the transmission pipeline by Branch), as categorized **"Tertiary Pipe"** by WASAC.

High Pressure Area on Distribution Pipeline

Distribution Area by Branch from Transmission Pipeline and/or by Pump



High pressure area

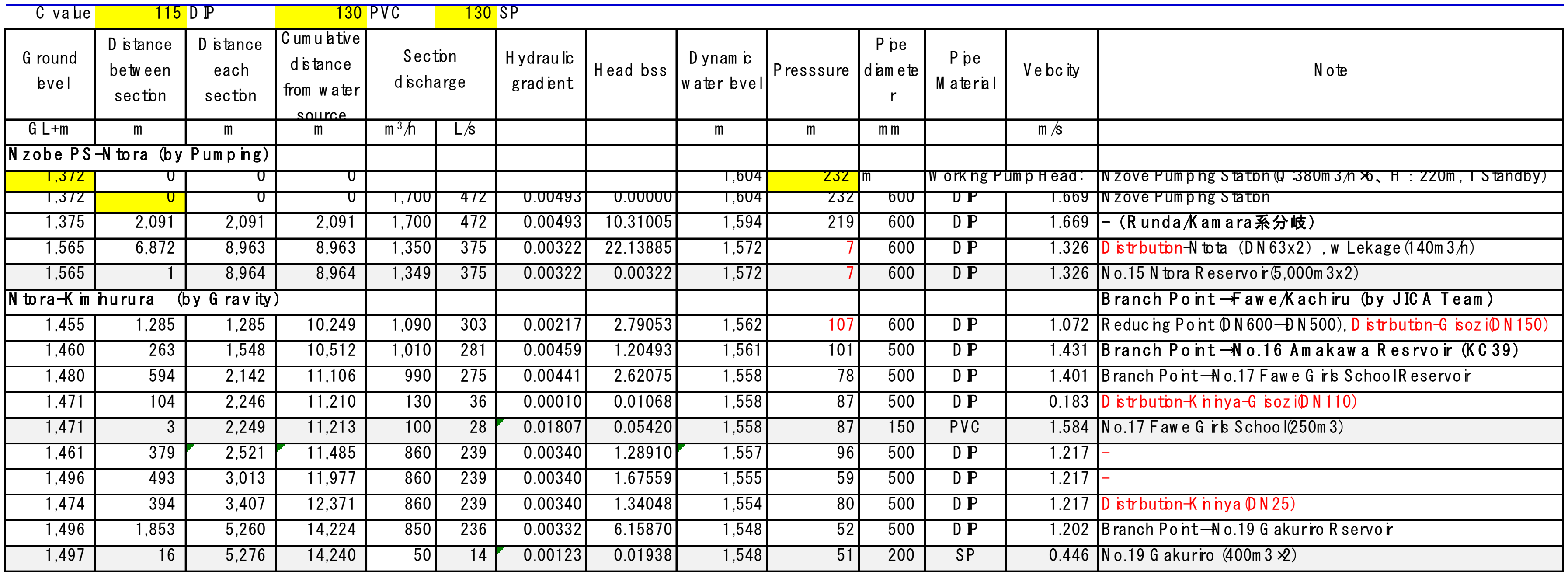
★Not including
High Pressure Zone from Reservoir

★Not including
Branching Point by Service Piping

One of the prioritized area
for
Leakage Reduction

Hydraulic Analysis
for Pressure Calculation 1

Hydraulic Analysis form Nzove PS to Gakuriro Reservor



C value 115 DIP 130 PVC 130 SP

Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Presssure	Pipe diameter	Pipe Material	Velocity	Note
GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s	
Nzobe PS-Ntora (by Pumping)													
1,372	0	0	0					1,604	232	m	Working Pump Head:		Nzove Pumping Station (Q :380m3/h×6、H : 220m, 1 Standby)
1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	**– (Runda/Kamara系分岐)**
1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2) , w Lekage (140m3/h)
1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m3x2)
Ntora-Kimihurura (by Gravity)													**Branch Point→Fawe/Kachiru (by JICA Team)**
1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point→No.16 Amakawa Resrvoir (KC39)**
1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point→No.17 Fawe Girls School Reservoir
1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m3)
1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point→No.19 Gakuriro Rservoir
1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m3×2)

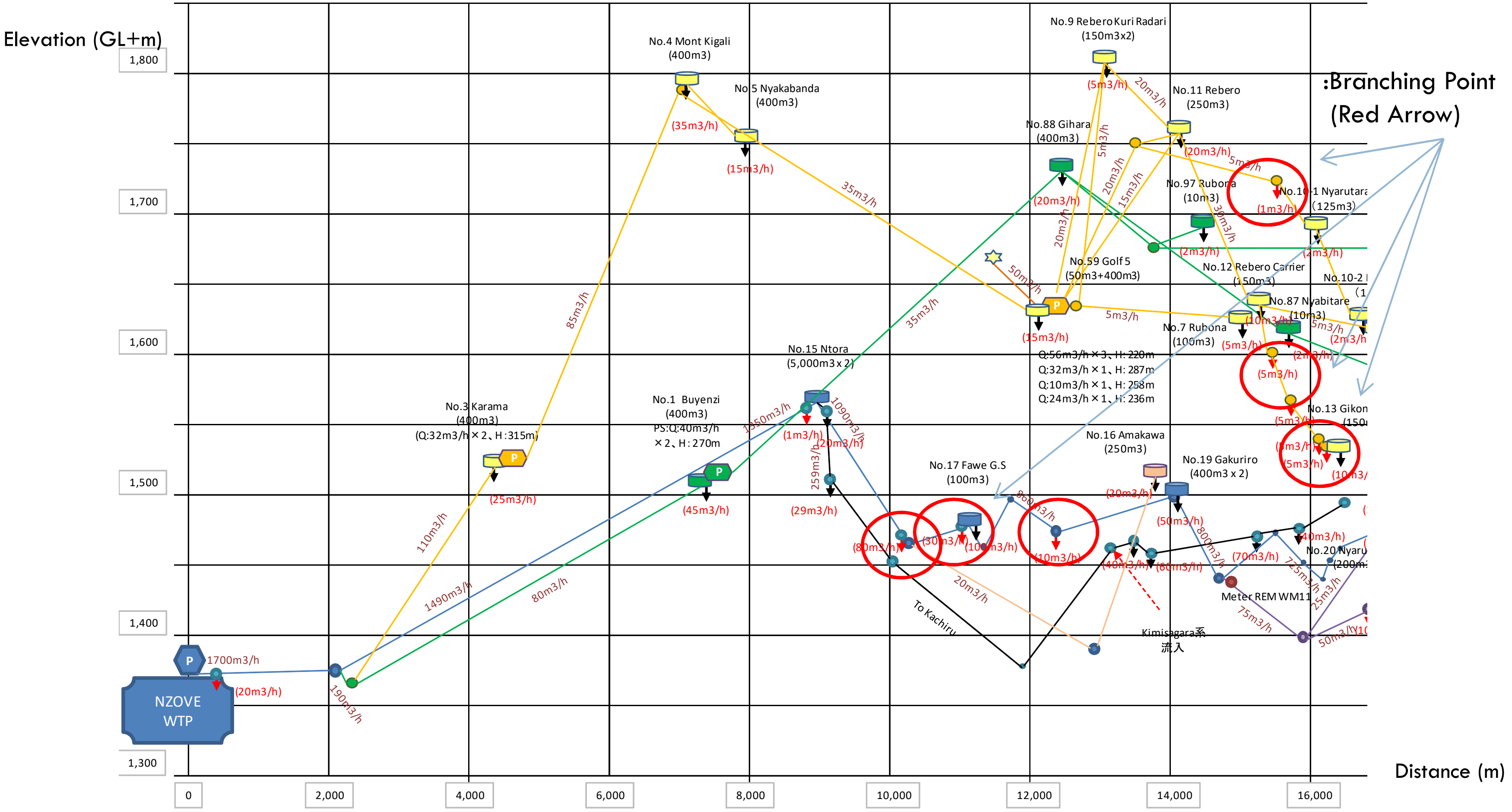
Hydraulic Analysis
for Pressure Calculation 2

Hydraulic Analysis form Kimisagara PS to Biryogo Reservoir

Ground level	Distance between section	Distance each section	Cumulative distance from water	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Presssure	Pipe diameter	Pipe Material	Velocity	Note
m	m	m	m	m^3/h	L/s			m	m	mm		m/s	
Kimisagara Reservoir-Distribution (Gravity)													
1,430													No.14 Kimisagara Reservoir (800m3x3+600m3x4)
1,426	17	17	17	1,000	278	0.00450	0.07560	1,430	4	500	DIP	1.416	Distribution-Ntota（DN300） by Gravity
1,417	22	39	39	960	267	0.00418	0.09354	1,430	13	500	DIP	1.360	Kimisagara PS
Kimihurura/Kwanyiranuma PS (Pumping)													
1,417								1,555	138	m	:Operation Pressure		Kimisagara PS (Q:260m3/h×5、H: 115m)
1,417	1	1	40	960	267	0.00418	0.00418	1,555	138	500	DIP	1.360	**Branch Point →DN300**
DN500→DN250 LINE													
1,436	1,312	1,313	1,352	710	197	0.00238	3.12145	1,552	116	500	DIP	1.003	Reducing Point (DN500→DN250)
DN300 LINE													
1,415	559	559	599	250	69	0.00411	2.29628	1,550	135	300	DIP	0.976	Distribution-(DN90)
1,435	559	560	1,157	243	68	0.00400	2.23509	1,547	112	300	DIP	0.962	Distribution-(DN110)
Confluence/Branch Point → DN500＋DN300 → DN300（Biryogo）＋DN300+DN250													
1,438	119	679	1,276	946	263	0.04887	5.81561	1,542	104	300	DIP	3.721	
													To City with DN250
													To City with DN300
													To Biryogo with DN300
1,426	195	873	1,471	317	88	0.00645	1.25671	1,540	114	300	DIP	1.245	Distribution-(DN110)
1,426	1	875	1,473	310	86	0.00618	0.00865	1,540	114	300	DIP	1.217	Distribution-(DN32)
1,432	523	1,397	1,995	308	86	0.00618	3.22878	1,537	105	300	DIP	1.217	Distribution-(DN32)
1,438	536	1,933	2,531	306	85	0.00605	3.23949	1,534	96	300	DIP	1.203	Distribution-(DN110)
1,454	245	2,178	2,776	299	83	0.00579	1.41946	1,532	78	300	DIP	1.174	Distribution-(DN25)
1,456	127	2,305	2,903	297	83	0.00579	0.73201	1,532	76	300	DIP	1.174	Distribution-(DN110)
1,520	1,031	3,336	3,934	290	81	0.00553	5.70277	1,526	6	300	DIP	1.146	Distribution-(DN160)
1,518	106	3,442	4,040	260	72	0.00445	0.47152	1,525	7	300	DIP	1.019	**No.38 Kwanyiranuma (Biryogo)(600m3x2)+PS**

Branching point on Profile Map of Transmission Pipeline

Profile Map of Nzove Transmission Pipeline with Branching Point



Inventory Survey for Branching Point

- ☐ How many branching points are existing on Transmission Pipeline ?

  -Distribution pipeline →

  Nzove = 23 Branches??
  Kimisagara = 34 Branches??
  Karenge = 8 Branches??

  -Service piping →

  ??? Branches

  by GIS Map

- ☐ Pressure Calculation by Hydraulic Analysis

↓

- ☐ Review for High Pressure Area by Branching

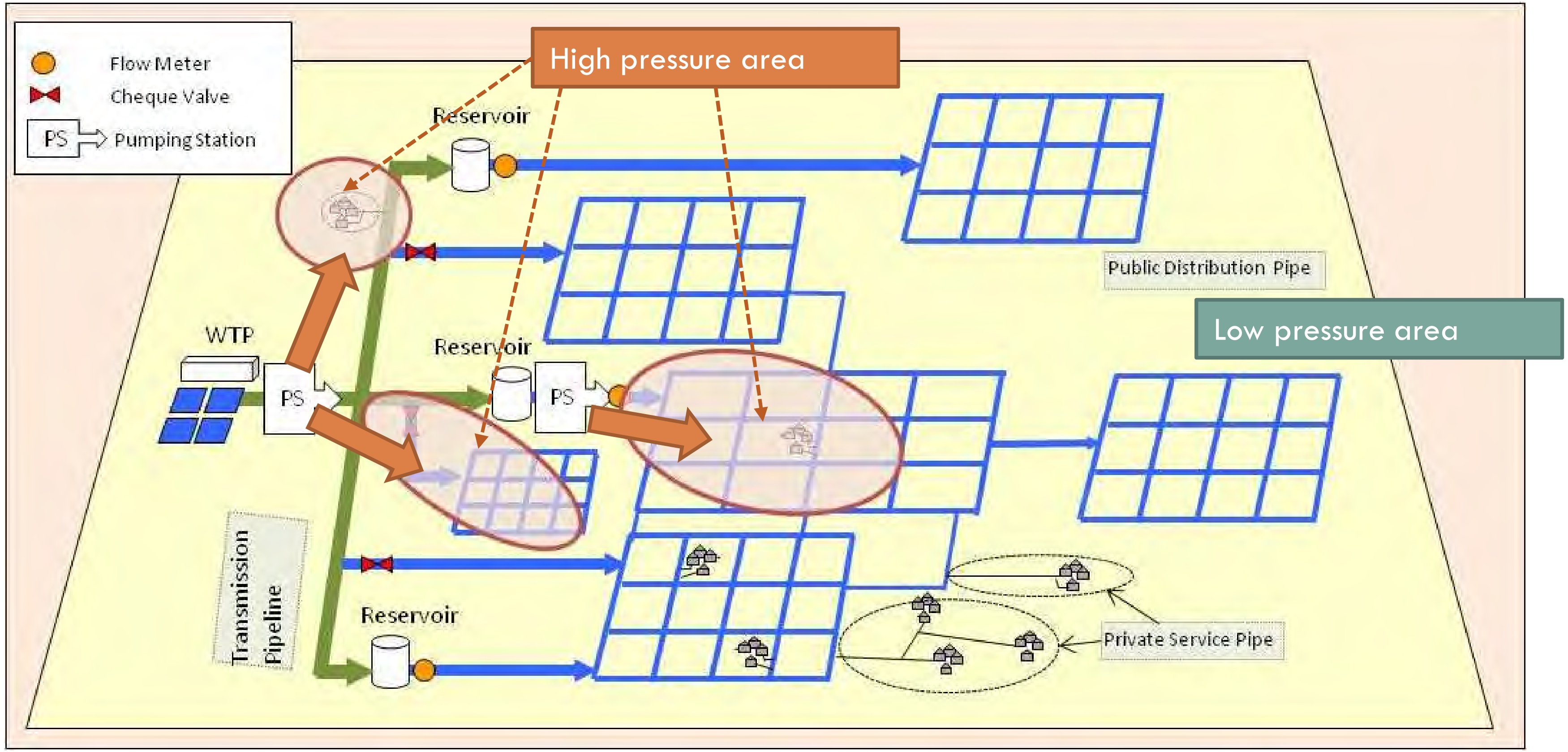
Distribution by Pump

Pumping Station on Kigali Water Network

PUMPING STATION	TOTAL HEAD	PUMPING STATION	TOTAL HEAD
【PS from WTP: 3 PSs】	(m)	【PS on Transmission: 11 PSs】	(m)
Nzove PS	220	Ruyenji PS	269
Kimisagara PS	115	Karama PS	250
Karenge PS	-	Golf5 (Kimisagara) PS	258
【PS from other water source : 7 PSs】		Rwezamenyo PS	112
Rwampara PS	112	Kwanyiranuma (Biryogo) PS	80
Mburabuturo PS	230	Centre Ville PS	64
Buhoro PS	136	Kimihurura PS	65
Jali PS	??	Golf 7 (Kicukiro) PS	205
Kizanye PS	170	Kiyinya PS	371
Byimana PS	172	Azam Ba PS	135
GihogwePS	248	Nyabubare PS	-

High Pressure Distribution Area by Pump

Network Condition of Kigali City



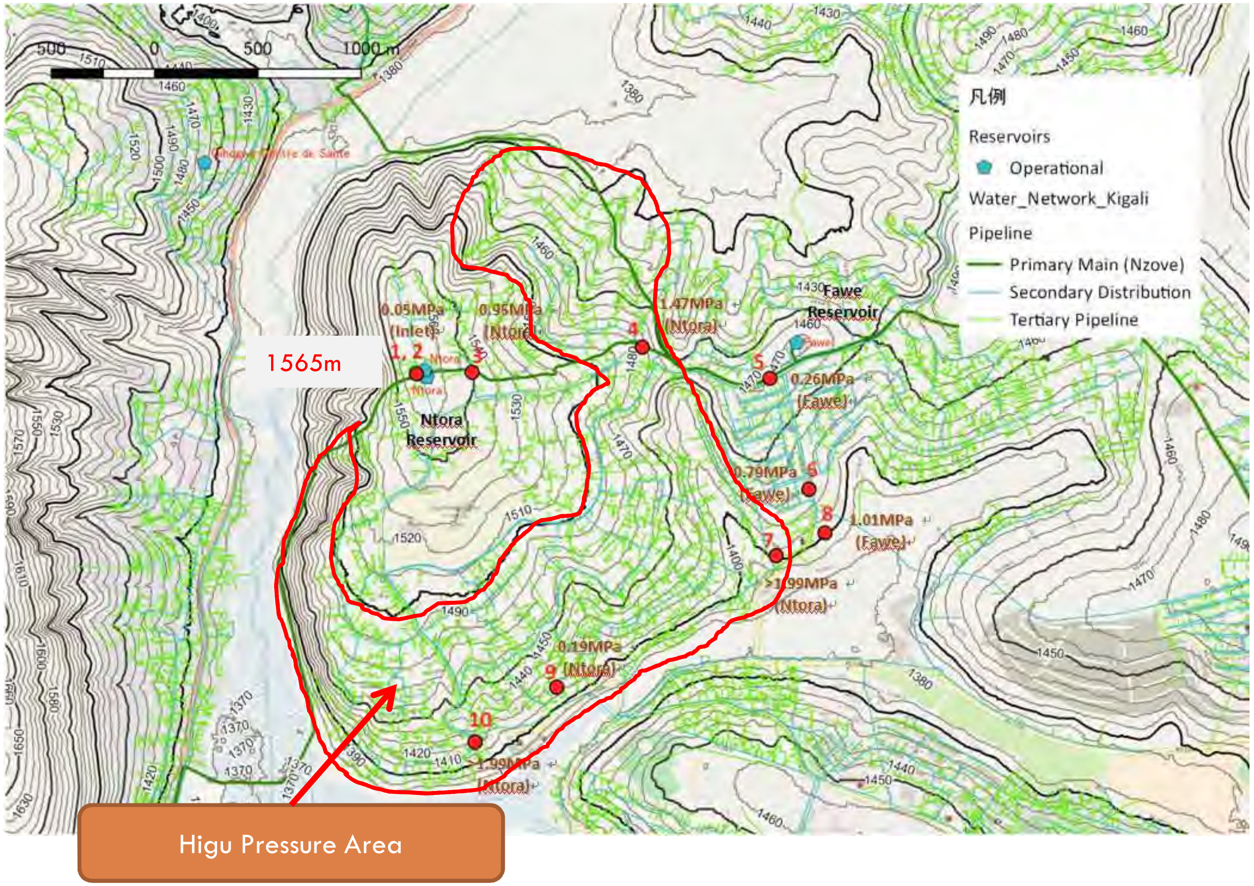
Inventory Survey for Branching Point 2

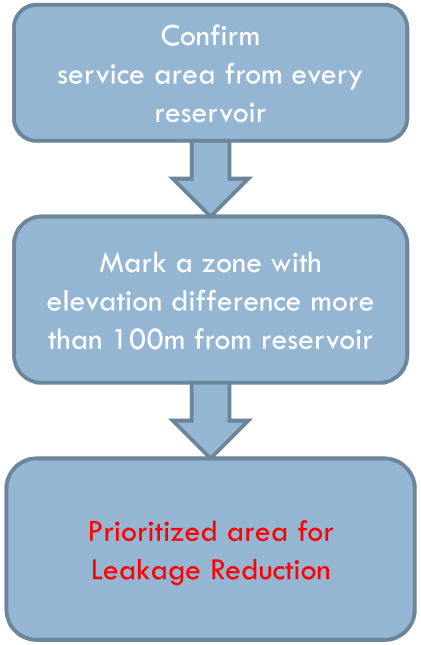
- How many branching points are existing on Distribution Pipeline from Pumping Station
  - -Distribution pipeline
  - -Service piping

  by GIS Map
- Pressure Calculation by Hydraulic Analysis
- Review for High Pressure Area by Pump

Next Step:

- ☐ Next Step: High Pressure Zone by Pressure from Reservoir



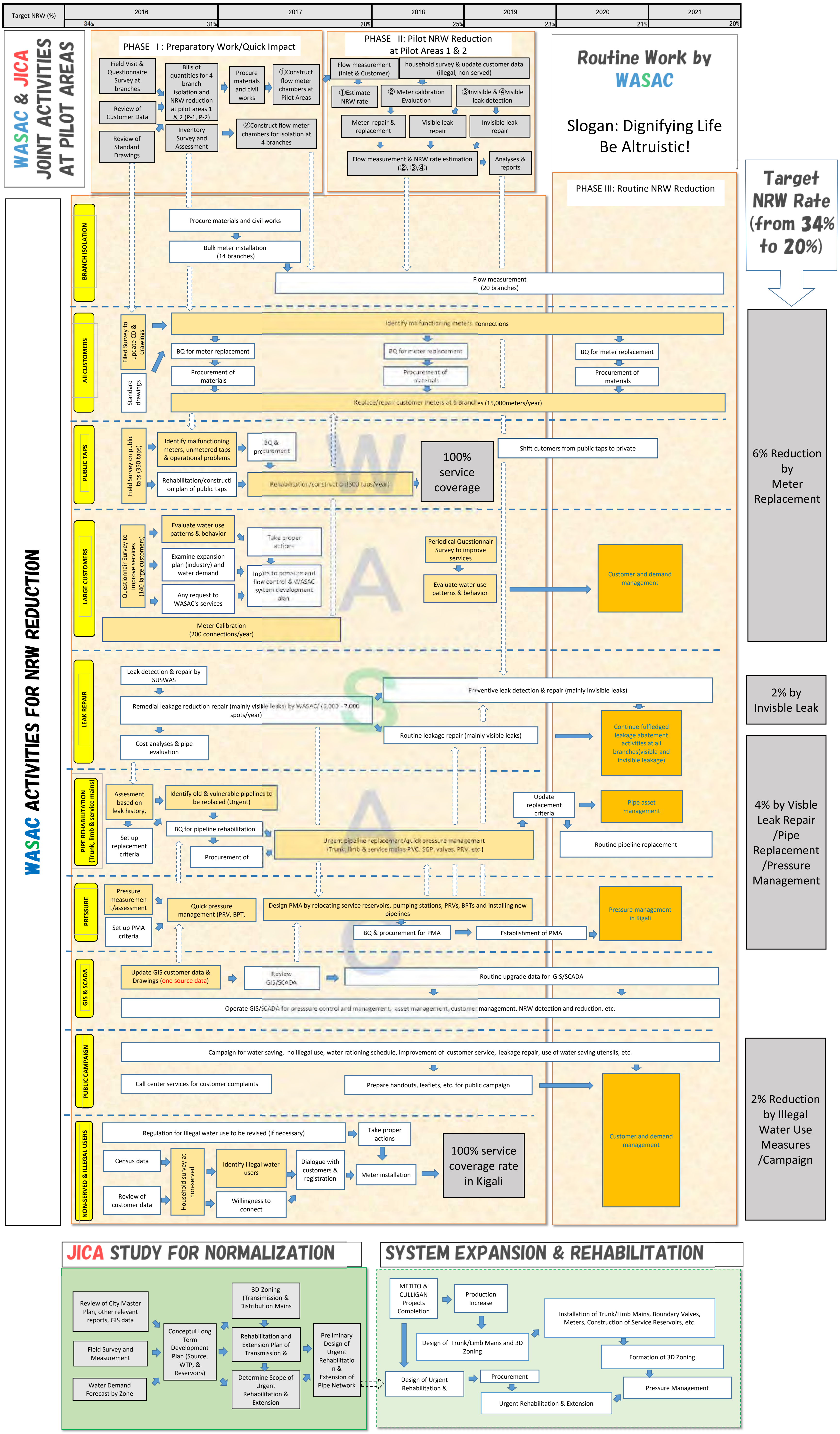


Confirm service area from every reservoir

Mark a zone with elevation difference more than 100m from reservoir

Prioritized area for Leakage Reduction

Measured by JICA Basic Survey Team
13th ,14th December, 2016



Target NRW (%)	2016	2017	2018	2019	2020	2021
34%	31%	28%	25%	23%	21%	20%

WASAC & JICA JOINT ACTIVITIES AT PILOT AREAS

PHASE I : Preparatory Work/Quick Impact

- Field Visit & Questionnaire Survey at branches
- Review of Customer Data
- Review of Standard Drawings
- Bills of quantities for 4 branch isolation and NRW reduction at pilot areas 1 & 2 (P-1, P-2)
- Inventory Survey and Assessment
- Procure materials and civil works
- ①Construct flow meter chambers at Pilot Areas
- ②Construct flow meter chambers for isolation at 4 branches

PHASE II: Pilot NRW Reduction at Pilot Areas 1 & 2

- Flow measurement (Inlet & Customer)
- household survey & update customer data (illegal, non-served)
- ①Estimate NRW rate
- ② Meter calibration Evaluation
- ③Invisible & ④visible leak detection
- Meter repair & replacement
- Visible leak repair
- Invisible leak repair
- Flow measurement & NRW rate estimation (②, ③,④)
- Analyses & reports

Routine Work by WASAC

Slogan: Dignifying Life Be Altruistic!

PHASE III: Routine NRW Reduction

Target NRW Rate (from 34% to 20%)

WASAC ACTIVITIES FOR NRW REDUCTION

BRANCH ISOLATION

- Procure materials and civil works
- Bulk meter installation (14 branches)
- Flow measurement (20 branches)

All CUSTOMERS

- Filed Survey to update CD & drawings
- Standard drawings
- Identify malfunctioning meters, connections
- BQ for meter replacement
- Procurement of materials
- BQ for meter replacement
- Procurement of materials
- BQ for meter replacement
- Procurement of materials
- Replace/repair customer meters at 6 Branches (15,000meters/year)

PUBLIC TAPS

- Field Survey on public taps (350 taps)
- Identify malfunctioning meters, unmetered taps & operational problems
- BQ & procurement
- Rehabilitation/construction plan of public taps
- Rehabilitation/construction(300 taps/year)
- 100% service coverage
- Shift cutomers from public taps to private

LARGE CUSTOMERS

- Questionnair Survey to improve services (140 large customers)
- Evaluate water use patterns & behavior
- Examine expansion plan (industry) and water demand
- Any request to WASAC's services
- Take proper actions
- Inputs to pressure and flow control & WASAC system development plan
- Meter Calibration (200 connections/year)
- Periodical Questionnair Survey to improve services
- Evaluate water use patterns & behavior
- Customer and demand management

6% Reduction by Meter Replacement

LEAK REPAIR

- Leak detection & repair by SUSWAS
- Remedial leakage reduction repair (mainly visible leaks) by WASAC/ (5,000 - 7,000 spots/year)
- Cost analyses & pipe evaluation
- Preventive leak detection & repair (mainly invisible leaks)
- Routine leakage repair (mainly visible leaks)
- Continue fulfledged leakage abatement activities at all branches(visible and invisible leakage)

2% by Invisble Leak

PIPE REHABILITATION (Trunk, limb & service mains)

- Assesment based on leak history,
- Set up replacement criteria
- Identify old & vulnerable pipelines to be replaced (Urgent)
- BQ for pipeline rehabilitation
- Procurement of
- Urgent pipeline replacement/quick pressure management (Trunk, limb & service mains-PVC, SGP, valves, PRV, etc.)
- Update replacement criteria
- Pipe asset management
- Routine pipeline replacement

PRESSURE

- Pressure measurement/assessment
- Set up PMA criteria
- Quick pressure management (PRV, BPT,
- Design PMA by relocating service reservoirs, pumping stations, PRVs, BPTs and installing new pipelines
- BQ & procurement for PMA
- Establishment of PMA
- Pressure management in Kigali

4% by Visble Leak Repair /Pipe Replacement /Pressure Management

GIS & SCADA

- Update GIS customer data & Drawings (one source data)
- Review GIS/SCADA
- Routine upgrade data for GIS/SCADA
- Operate GIS/SCADA for presssure control and management, asset management, customer management, NRW detection and reduction, etc.

PUBLIC CAMPAIGN

- Campaign for water saving, no illegal use, water rationing schedule, improvement of customer service, leakage repair, use of water saving utensils, etc.
- Call center services for customer complaints
- Prepare handouts, leaflets, etc. for public campaign

NON-SERVED & ILLEGAL USERS

- Regulation for Illegal water use to be revised (if necessary)
- Take proper actions
- Census data
- Review of customer data
- Household survey at non-served
- Identify illegal water users
- Willingness to connect
- Dialogue with customers & registration
- Meter installation
- 100% service coverage rate in Kigali
- Customer and demand management

2% Reduction by Illegal Water Use Measures /Campaign

JICA STUDY FOR NORMALIZATION

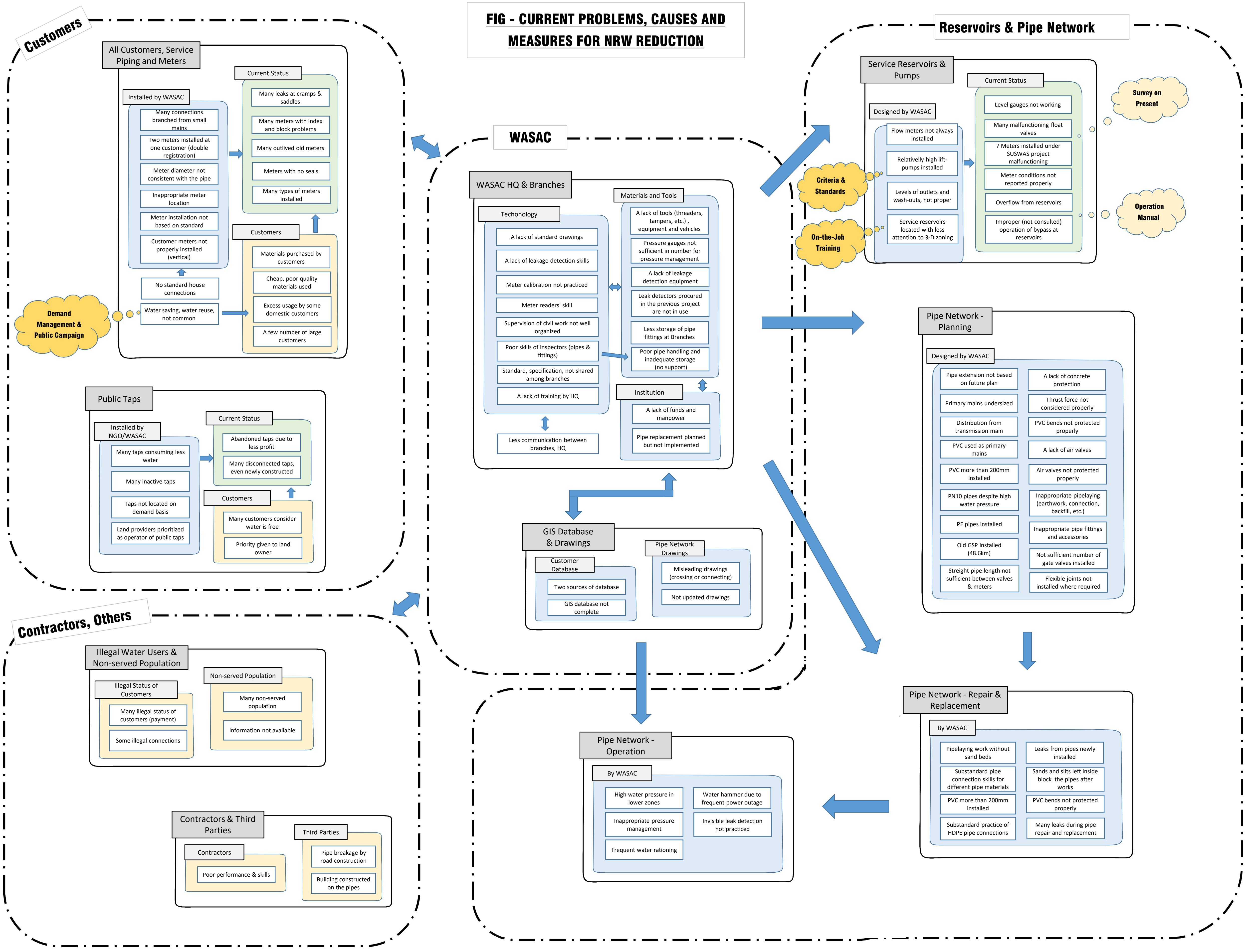
- Review of City Master Plan, other relevant reports, GIS data
- Field Survey and Measurement
- Water Demand Forecast by Zone
- Conceptul Long Term Development Plan (Source, WTP, & Reservoirs)
- 3D-Zoning (Transimission & Distribution Mains
- Rehabilitation and Extension Plan of Transmission &
- Determine Scope of Urgent Rehabilitation & Extension
- Preliminary Design of Urgent Rehabilitation & Extension of Pipe Network

SYSTEM EXPANSION & REHABILITATION

- METITO & CULLIGAN Projects Completion
- Production Increase
- Design of Trunk/Limb Mains and 3D Zoning
- Installation of Trunk/Limb Mains, Boundary Valves, Meters, Construction of Service Reservoirs, etc.
- Formation of 3D Zoning
- Design of Urgent Rehabilitation &
- Procurement
- Urgent Rehabilitation & Extension
- Pressure Management

Note: Above figure does not refer to issues related to training of staff and engineers, which are referred to "WASAC 5 Year Capacity Building Plan 2014–2018".

FIG - CURRENT PROBLEMS, CAUSES AND MEASURES FOR NRW REDUCTION



5 Years Strategic Plan

[redacted]

Non-Revenue Water Reduction

Water and Sanitation Corporation

WASAC Ltd

Table of Contents

1. Introduction

1.1 Background

Rwanda has made impressive progress in extending water supply and sanitation coverage during the past few years under clear political commitment, proper institutional framework and an updated national policy and strategy. While striking results have been achieved in the recent years, considering many years of neglect and the low base from which Rwanda has emerged, water supply services still need improvement to ensure sustainability, availability and affordability to all Rwandans.

Water and Sanitation Services in Rwanda have been delivered under a bundled Energy and Water utility service. The utility has undergone a various changes in the last 15 years - from the initial bundled structure of ELECTROGAZ; to the initial attempt to unbundle the utility into RECO and RWASCO; again, bundled to EWSA; which finally gave birth to WASAC and REG.

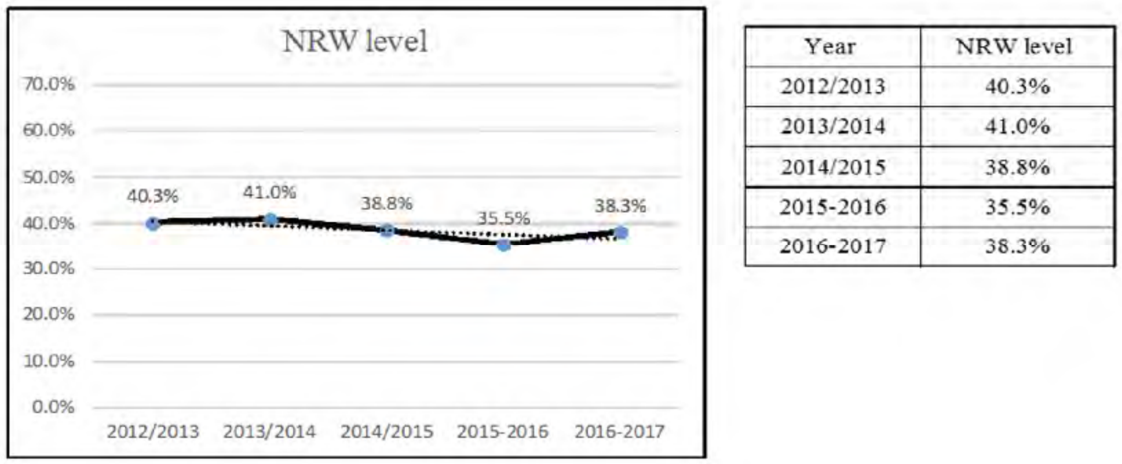
WASAC was established in 2014 as the utility to manage the water and sanitation services in Rwanda and currently focused on the provision of new infrastructure; delivery of efficient and effective services; development of strong human capacity; and meeting key national milestones. WASAC committed to provide quality, reliable and affordable water and sewerage services by establishing a sustainable and customer-oriented utility that would improve the lives of Rwandans.

As many other water utilities across the world, WASAC is still facing a massive challenge of having high ratio of Non-Revenue Water (NRW) at a rate of 35,5 % (2015-2016).NRW is defined as the difference between the volumes of water introduced into the water distribution system and the volumes of water billed. Reducing NRW is critical for financial stability, efficient resource utilization, efficient utility management, enhanced consumer satisfaction and postponement of capital-investment to increase water supply capacity.

There has been great improvement in NRW reduction from the creation of WASAC particularly from the second semester of 2015 (July to November 2015) mainly due to the creation of the NRW unit which is dedicated to monitoring and managing the NRW at the national level and implementing the performance improvement program (PIP) from October 2015.The PIP is focusing on the improvement of key strategic areas including NRW reduction where each branch has a target to achieve according to the overall NRW reduction target of WASAC.

Despite many efforts and strategies currently implemented within WASAC, the level of NRW is still increasing to the level of 38 % (2016-2017).

Therefore, there is a strong need for WASAC to have a consistent and holistic Strategic plan which indicates the clear direction to address progressive NRW.



Year	NRW level
2012/2013	40.3%
2013/2014	41.0%
2014/2015	38.8%
2015-2016	35.5%
2016-2017	38.3%

Figure 1 : NRW trend from 2013- 2017

Table 1 : 2016-2017 NRW rate per branch

ANNUARY (2016 Jul. -2017 June)					
No	Branches	Water Supplied	Water Billed	Difference	NRW
		m3	m3	m3	%
1	KIGALI City	26,902,655	16,723,474	10,085,964	37.5%
2	MUHANGA	888,627	632,579	256,048	28.8%
3	RUBAVU	2,996,017	1,636,568	1,359,606	45.4%
4	MUSANZE	2,393,538	1,594,434	799,296	33.4%
5	RUSIZI	990,791	672,363	318,428	32.1%
6	HUYE	2,074,429	1,203,245	870,816	42.0%
7	NYANZA	595,437	401,255	194,182	32.6%
8	NGOMA	463,982	346,862	117,865	25.4%
9	GICUMBI	567,590	371,376	196,214	34.6%
10	RWAMAGANA	1,977,613	966,024	1,019,754	51.6%
11	NYAMAGABE	554,102	365,764	188,632	34.0%
12	KARONGI	450,962	302,829	148,133	32.8%
13	NYAGATARE	1,812,136	954,465	857,671	47.3%
14	BUGESERA	1,220,017	828,112	391,905	32.1%
15	RUHANGO	325,230	207,646	117,478	36.1%
TOTAL		44,213,124	27,206,996	16,921,989	38.3%

This 5 Year Strategic Plan (5YSP) identifies all components to be tackled, priorities, necessary budget and timeframe in the next 5 years to improve WASAC performance and then ensure financial and commercial viability of the company.

The successful implementation of this 5YSP will require the total investment of around 4.6 Billion Rwf (excluding major CAPEX) to act mainly on Network rehabilitation, billing and metering improvement. However, the budget is not the only obstacle to overcome, the other challenges are related to human resources capacity development, institutional reform, change management, cost optimization and efficiency of the operations.

WASAC's Vision and Mission

Vision: To be the most sustainable Water and Sanitation Utility in Africa, exceeding stakeholder's expectations

Mission: Providing quality, reliable and affordable water and sewerage services through continuous innovations and detailed care to our customers' needs

1.2 5YSP for NRW Reduction guiding documents

Reaching WASAC vision and the ambitious national target (EDPRS III, VISION 2020, 7 years' government program) and the SDG6 dedicated to water and sanitation requires Rwanda to address universal and equitable access to drinking water and sanitation along with issues of quality and supply. There is an urgent need to increase the production to meet the demand and reduce the NRW for the efficient use of produced water and the financial stability of the company.

This 5YSP develops a specific, realistic and integrated strategic plan where all issues related to NRW have been diagnosed, root causes clarified, strategies and specific actions to address the identified issues proposed with estimated budget and timeline.

1.3 Non-revenue water reduction target

To ensure the sustainability of water supply in WASAC Ltd service areas, there is a need to address the current production gap and reduce the NRW at the minimum level. In accordance to the WASAC 5 Years Strategic Business Plan formulated in November 2015, the target is to reduce the NRW rate from 38% to 25% in 2019/2020.

Considering the NRW reduction achievement for the past 2 years compared to the planned target, the timeline must be extended to the year 2022/2023 as presented in the table below

Table 2: Target for NRW reduction for the coming 5 years

Financial year July to June	5 Year Strategic Business Plan	Target value of 5 Year Strategic Business Plan	Implementation Year of 5YSP	Phase of 5YSP	Actual NRW level value %	Proposed New NRW rate
2015/16	Year 1	38%			35.50%	
2016/17	Year 2	32%			38.30%	38.30%
2017/18	Year 3	28%		Preparation		38%
2018/19	Year 4	26%	Year 1	Phase 1		35%
2019/20	Year 5	25%	Year 2	Phase2		32%
2020/21			Year 3			30%
2021/22			Year 4			28%
2022/23			Year 5			25%

The NRW target rate for Kigali city will be confirmed after the implementation of identified NRW reduction activities in pilot areas (kadobogo in kacyiru branch and Runda in Nyarugenge branch) which are being implemented by the joint of WASAC and Japanese experts under the project of NRW reduction with the support of JICA.

2. Methodology and approach

2.1 Procedure for the preparation of the Plan

The Preparation of this 5YSP began in August 2016 and involved the participation of JICA technical cooperation, WASACs directorates, unit, branches and Water treatment plants through interviews, questionnaires, field visits, workshops. The NRW reduction measures currently implemented by WASAC in Kigali and upcountry branches (14 branches outside Kigali) were assessed by consulting different WASAC reports, field visits to assess the network condition, interviews with different WASAC officials, branch managers and Head of water treatment plant.

During the assessment, following steps was conducted in each branch:

1) Questionnaire to 20 Branch Offices and Head Office
2) Water network visit in 20 Branches
3) Reports and Customer Data Base analysis.

Different workshops and seminars were organized to discuss the results of above mentioned topics and propose the countermeasure for each problem identified as presented in the diagram below

Problems identification
↓

Root cause analysis
↓

Proposal of counter measures/strategy
↓

Preparation of Action Plan

2.2 5YSP work Plan

The Work Plan is divided into 2 phases in accordance with the activity content:

a) Phase1: Immediate actions with quick impact (July 2018 to June 2019)

The urgent issues to be addressed have been identified (see table N..) and will be implemented in year one of the implementation of the 5YSP to ensure quick results with available means. These actions will be implemented in parallel with the ones in pilot area of the joint NRW reduction project with JICA (Kacyiru Branch: Kadobogo, Nyarugenge Branch: Ruyenzi) to ensure that the experience gained is being applied in the large scale of WASAC network. Besides Kacyiru and Nyarugenge Branch where the pilot project will be implemented, the same NRW reduction strategies will be applied in other WASAC branches. At the end of this phase, the 5 YSP will be revised for a more concrete one considering the achievements and challenges

b) Phase 2: Routine works (from July 2019 to June 2023)

The NRW reduction routine activities will be implemented based on the experience and technologies acquired in the previous Phase and from the joint NRW reduction project with JICA.

This NRW reduction 5-year Strategic Plan will be updated yearly to a more practical plan based on result of the previous years.

3. Current Situation of NRW Reduction Activities

3.1 Problem Identification

The present conditions and problems extracted as a result of analysis of the basic information are as follows.

a) Insufficient water supply (water shortage)

Most of the WASAC branches have a serious problem of water shortage. The supply gap is mainly due to the current production which is not yet meeting the demand. There is an intermittent supply where water is supplied to areas in daily rotation or only in some hours in the daytime or nighttime. From this situation where water is not supplied continuously, air is mixed into water, hinders correct flow and customer meters measurement. Furthermore, leaks can be detected only if the distribution pipes are filled with water. In addition, When the water supply pipe is broken, sometimes sand and stones may penetrate pipes from leaking point and cause meters blocking. Continuous water supply is an essential condition for the effective implementation of NRW reduction measures.

b) Input volume meter inaccuracy

Although all WASAC water treatment plants and pumping stations are metered, there is still the challenge of ensuring the accuracy of these bulk meters. Some bulk meters are aged, have not been calibrated in so long, inappropriate installation position (close to pumps and bends) and the size of the meters sometimes not appropriate.

There is a need to asses all bulk meter’s condition and proceed for replacement or installation of new meters to ensure the accuracy of the water volume input in WASAC water network.

c) **Meter reading and billing**

Although 100% of WASAC customers have meters, meter reading and billing still needs improvement. Some customers are not billed on monthly basis; others are billed zero consumption while they may have consumed water. Some commercial Field officers do not note down customer indexes and sometimes speculates the consumption. The field inspection by billing inspector to ensure accurate readings is not yet sufficient;

There is not a clear procedure on replacement of customers meters. Ad hoc meter replacement has been done mainly for the blocked meters or from customer complaints.

From the last customer inventory done in Kigali, it has been observed that more than 18 % of Kigali WASAC customers' meters are more than 15 years old, which compromises their accuracy.

Customers' meters have not been tested on site. Only the metering services in Kigali has a test bench. There are a considerable number of meters blocked because of intermittent supply where the service pipe became corroded. Alternatively, sand and other solid particle from leaking pipe can enter and remain suspended in the service pipe due to poor repair work.

The importance of large customers management is recognized. However, insufficient customer consumption analysis has been conducted (only checking of abnormal consumption). Analysis of customer data is extremely required.

Customers who have subscribed to WASAC prepayment system, are billed monthly and after a certain period the adjustment with the real meter readings(consumption) is not done timely.

Some customer meter are not really accessible , sometimes its requires the Commercial Field Officer to move the whole compound or cross buildings to reach the meter . the meter location should not exceed 3m from the fence.

d) Unbilled unmetered authorized consumption

Usually, WASAC estimates the unbilled authorized consumption at 2% of the total water supply in the system (Water for flushing pipes and cleaning reservoirs). Water for firefighting (for fire hydrants which are not yet metered) is not yet included.

e) Water Thefts (Illegal Connections) and Vandalism

In the past two years, about 150 cases of illegal water usage have been confirmed. Many of them have been reported by informers and are from households. The involvement of branch staff to find illegal connections is still low. There is not yet a strong campaign organized to find illegal water users , customers are visited not because of their strange historical consumption trend but on the available information from informers. Public awareness on water theft is not yet sufficient, resulting to an unaware public.

Some WASAC water infrastructures equipment are not protected (manhole not covered) and it has been observed that some people destroy water infrastructure to fetch water or to steal water network equipment.

There is a need to involve local authorities for water infrastructure protection.

Table 3: Number of confirmed illegal connection per branch 2015 -2017

No	Branch	Nbr
1	Bugesera	3
2	Gikondo	7
3	Huye	5
4	Kacyiru	11
5	Kanonbe	8
6	Muhanga	3
7	Musanze	4
8	Ngoma	11
9	Nyagatare	14
10	Nyamirambo	1
11	Nyarugenge	12
12	Remera	14
13	Rubavu	6
14	Ruhango	3
15	Rusizi	1
16	Rwamagana	42
Total		145

f) Planning and Design of water network

The current WASAC water network design condition still presents some substandard which need to be addressed. Basically, all Water distribution pipes should originate from a water distribution tank. In Kigali and other WASAC water network this is not always the case. Some areas are supplied with water directly from a pumping stations or treatment plants. This can be one of the causes of high pressures in supplied areas.

Although, the transmission pipes should be independent pipes that are used for the purpose of transmission between a treatment plant and a distribution tank; the present water network condition has no functional separation among transmission pipes (basically, constant flow rates and continuous transmission) and distribution pipes (change in distribution volumes in time). In this case the establishment of DMA (District Metered Area) and distribution management is quite difficult.

The distribution tank should also adjust differences between transmission and distribution volume. It is necessary to separate transmission and distribution pipes via distribution tanks.

The lack of design of pressure distribution blocks according to altitudes and the direct delivery of water by the pumps from the treatment plants to a distribution tank at the highest altitude cause the pumps to use excessively high transmission pressures (a waste of electric power). Therefore, high distribution pressures are used in the distribution areas with low altitudes and require high pressure resistance pipe materials and promote water leaks (Gatsata case).

Houses and buildings are sometimes built on the ground over transmission and distribution pipes, making the maintenance of those pipes difficult.

g) High Pressure in WASAC water network

High pressure in the network increases the volume of water lost due to leakages and reduce the water network infrastructure lifespan .Sometimes the pressure level exceeds the nominal pressure of installed pipes which lead to frequent pipes leakages and burst (case of Nyarurenzi network). Currently, WASAC does not control and monitor the pressure in its entire water network. Pressure zones (High and low) have not been identified, the acceptable pressure range not yet determined; Pressure measurement is not conducted according to a survey plan and in all the areas. Other challenges include pressure gauge which have not been installed in WASAC network. insufficient pressure reduction measure that have not been implemented in WASAC network and some PRVs (Pressure Reducer Valve) which have been installed with insufficient pressure survey, hydraulic calculation and specific long-term plan of installation and maintenance.

h) Frequent Leaks and burst

An average of 90 leaks per days are being reported and repaired by WASAC branches. The majority of leaks reported are from service connection pipes mainly due to poor quality of pipes fittings or installation works. Nyarugenge, Gikondo, Musanze and Rubavu branches consist of a large number of leaks reported on distribution pipes due to aged pipes.

There have been a number of infrastructure developments across the country mainly for road construction, house construction and the laying of optic fiber which are destroying water infrastructure and leading to leaks and busts. For several of the distribution tanks, the water level gauges are not operational and water level is not properly measured and monitored. On some distribution reservoirs, float valves are not working or not installed. This situation leads to frequent reservoirs overflows.

WASAC does not consist of a trained, dedicated team that monitors active leakages at branch level and leak detection equipment are not sufficient for leak detection. Mainly visible leaks (usually leaking for long periods of time) are reported and repaired. Usually, leaks are reported by the population through call center, via twitter @wasac_rwanda or direct calls to branch staff, this cannot ensure that all leaks have been reported. The response time to pipe repair is still low due to the unavailability of material and logistic issues (means of transport).

The quality of repair is sometimes compromising because of poor standard of material (fittings) and less awareness of staff.

Leak and bust recording, analysis and reporting is not carried out properly, it is still challenging to get all leaks information and details (location, diameter and material) from branches.

Leaks survey are not regularly performed, few minimum night flow measurement have been done in branches because there is a lack of sufficient equipment, number of trained staff and the design of the existing water network (difficulty in identifying a specific area).

i) Asset management

WASAC water network has been mapped but still need correction and adjustment as per build network. The procedure of network update still needs to be revised and disseminated to all GIS users. The current branch structure do not facilitate GIS data update due to lack of staff with expertise. The use of GIS data and network maps is still low due to less awareness and traditional routine habit. New customers connections, network extension and modification in the network should be regularly uploaded on GIS database.

The network maintenance and rehabilitation plan has not been fully implemented mainly due to the budget constraint , the large amount of the company budget is allocated to increase the production and access. Therefore the delay in network rehabilitation and no proper and regular preventive maintenance of water infrastructure resulting some nonfunctional and unreliable water infrastructure.

j) Standard of material and construction water works

Currently, WASAC new customers purchase their own materials for new connection (pipes, fittings and protective equipment) these materials are normally in poor condition and sometimes not compatible to the existing network condition (mixing pipes and fittings made in dissimilar materials).

Although the major part of WASAC water network is well designed , there is still some distribution pipeline which doesn’t not meeting required standard in term of size and the type of material. There are some distribution pipes installed without considering the quality of soil (cause of corrosion). There are also some substandard water works which are done by private contractors mainly due to less involvement and supervision from WASAC staff.

There are a number of trenches that do not respect the standard measurements, which then expose the pipes. Sometimes the connection is not done with proper equipment mainly for pipe cutting and drilling. These are causing water loss as indicated by the daily leakage reports.

Lastly, WASAC is yet to assign a dedicated team for water works inspection mainly for the new connections and leak repaired.

k) Stakeholders management

WASAC started public awareness campaign through local media but still general public is not yet sufficiently involved and aware on NRW which lead some time on delay of report leaks or illegal connection and the protection of the water supply infrastructure. There should be an organized strong awareness campaign on regular basis and direct contact with the population through community works (umuganda) , visit of schools, universities and churches.

There is also less coordination and collaboration with other infrastructures developers (mainly road constructors and telecommunication companies) which lead sometimes to the damage of WASAC water infrastructure and water loss.

l) Staff capacity

There is a certain level of individual capacities which should now be extended at company level. The framework of sharing and expanding knowledge is not ye strong enough. WASAC has quite number of skilled and experienced staff but which is not yet reflected in company performance. There is a need for a strong staff capacity development and knowledge sharing program.

m) Logistics issues

There is no enough material, equipment and means of transport for WASAC operations. These include, to mention but a few;

i) One vehicle for the all activities in each branch

ii) Frequent shortage of materials mainly fittings and small pipes for reparation which lead to poor reparation and delay of leak repairs.

3.2 Assessment of root causes of identified problems

After the problem identification, root causes of each problem have been identified through meetings and workshops with different units and the results are summarized in tables below (Technical, Commercial and Administrative).

Table 4: Root causes of problems

a) Technical

Nr	Problems	causes
A	Production	
1	Intermittent supply (frequent rationing)	• High demand vs production • Delay in investment of production • Rapid urbanization • Limited funds • undersized pipes • Undersized reservoirs capacity • less knowledge of network • network design • Electricity cut off
B	Leaks and Burst	
2	High pressure in the network	• Topography of the ground • Lack of pressure management skills • less knowledge of the network (maps, network information) • Insufficient protective equipment in the network (valves , PRV…) • Network design (PN pipes installed VS service pressure)
3	Time response to leaks repair still low:	• Insufficient logistic facilities (vehicle, tools, etc…) • Ownership, communication, • Insufficient material (mainly fittings for reparation) at the branch level • Few number of Technicians at the branch level • less knowledge of network • less records and analysis of leaks
4	Lack of Leakage survey	• less knowledge on leakage survey (technicians) • insufficient staff and logistics (car and equipment)
5	Lak of Leak detection activities	• less knowledge on leak detection • Insufficient Leak detection equipment • Complexity of the WASAC water network (design, pipes material, ground)
6	Inappropriate pipes installed	• No enough knowledge on pipe choice (Eg , Use of PE pipes instead of HDPE pipes; more than 200mm installed in high pressure zones) . • Not enough material in the store (sometimes pipes installed due to its availability) • Budget constraint • Less management control system for pipe installation

Nr	Problems	causes
7	Leaks and overflows on reservoir	• Insufficient protective equipment and poor maintenance • Insufficient operational and monitoring skills on water network facilities • Some old and leaking reservoirs • Poor Construction of some reservoirs • No clear management of thanks and reservoirs (Responsibility of branch or WTP)
8	Poor Maintenance	• Lack of operational and monitoring skills on water network facilities • Less awareness • Poor maintenance plan (Reactive approach • Insufficient Logistic means (vehicle, tools, ...)
9	Many Leak on service pipes	• Poor quality of materials mainly procured by customers • High pressure in the network • Poor standards for service connection • inappropriate tool for connection (pipe cutting , pipe drilling , pipe welding etc…
10	Poor quality of repairs	• lack of appropriate material, • long process of material requisition • Less knowledge and ownership of technician
11	Under estimation of water loss caused by construction works	• Low of awareness of NRW • Challenge in estimation of water leaking time
12	Many service connections connected to small distribution pipes (Eg 3/4 and 1'' pipe , tertiary with tertiary)	• Insufficient distribution pipelines (extension) • Budget constraint • Less awareness of new connection standard and design • Lack of planning and implementation considering future urbanization • Complexity of existing informal settlement
13	Many leaks at cramps & saddles	• Lack of regular maintenance • Sometimes poor quality of material and work • High pressure in the network
14	Leaks from some pipes newly installed	• Poor quality of work and material • Poor Design/ implementation • Less knowledge
15	Water loss during pipe repair and pipe replacement	• Complexity of network (few sectioning valves) • High pressure in the network • Insufficient logistic and material (sometime not material not available) • Inappropriate tools for connection (pipe cutting, drilling and welding)
16	Surge effect, transient phenomenon, water hammer on pipeline caused by rationing (opening and closing valves	• Interruption of water supply and regular closing and opening valves • Insufficient and some faulty number of protective equipment in the network (air valves, anti-harmer tanks, etc.) High pressure • frequent power cut

Nr	Problems	causes
		• Poor maintenance of protective equipment Unknown and Inaccessible protective equipment (air valves, valves, etc..)
C	Design and mapping	
17	GIS data not updated	• insufficient GIS staff • less awareness of GIS importance • less knowledge of the network (Unknown pipelines) • insufficient equipment (GPS, appropriate computer, etc..)
18	Poor design of water network	• Lack of ownership • Less awareness • Low knowledge on Hydraulic calculation • New projects do not consider long term future demand
19	Different information on customer database from GIS & CMS	• GIS and CMS is still being updated
20	Pressure gauges not sufficient in number for pressure	• Lack of awareness • Less Planning of pressure management
21	high lift-pumps installed	• Less awareness • Budget constraint • Poor design • Complexity of the topography
22	Primary mains undersized	• Less awareness • Budget constraint • Poor planning and design
23	Distribution pipes and service pipes connected directly to transmission main	• Less awareness • Budget constraint • Poor planning and design • Water shortage
24	Flexible joints not installed where required	• Less awareness and knowledge • Budget constraint
D	Standards	
26	Inappropriate material during design /Implementation	• No enough knowledge • Negligence • No study of soil type • Not enough material in the store • Less inspection and control of works
27	Substandard service connection	• No standard procedure manual for new connection • Lack of ownership and induction for new staff • Insufficient distribution pipes
28	poor quality of connection material	• use of cheap material purchased by customers • less control of material purchased by customers
29	Trenching and backfilling sometimes not well done	• procedure manual of works (no formal guidelines) • insufficient Manpower • insufficient knowledge
30	Inappropriate pipe following the region and the quality of soil	• Less awareness and knowledge on soil handling • Soil handling not include procedure manual of works

Nr	Problems	causes
31	Many connections to small size (Eg ¾ as distribution pipes)	- poor planning - budget constraint - informal settlement
32	Substandard materials on local market	- low purchasing power - less control
33	Poor Quality of material(Standards)	- Substandard materials on local market - less ability for pipes testing
34	Not compliance of standard house connections	- Less awareness - Negligence - Less supervisions and inspection of new connection - No certified technicians for new connections
35	Poor quality of materials purchased by customers	- Low purchasing power of customers - Ignorance - Less control and inspection of material purchased by customer
36	Less of on-site work and material standard inspection	- No staff (team) dedicated and trained for work and material inspection
37	Straight pipe length not sufficient between valves & meters	- Less awareness and knowledge - Complexity of existing meter installation
38	Thrust force not considered properly	- Less awareness and knowledge - Negligence
39	Old Galvanized Steel Pipes installed (48.6km)	- Budget constraint
41	Inappropriate pipe fittings and accessories	- Less awareness and knowledge - Negligence - Sometimes fittings not available in stores (procurement plan)
E	Asset management	
44	Aged pipes and less protective equipment (valves, PRV, Air valves, water hammer tanks, etc)	- poor planning and implementation - Irregular maintenance, - budget constraint
45	lack of preventive maintenance plan	- Poor planning, - budget constraint
46	No plan for network Flushing	- Poor planning, - Network design
47	Insufficient valves for network management	- poor plannig , - network design
48	Air pocket caused by lack air valves or not properly installed.	- poor plannig , - network design
49	Less flush of service pipes before the new meter installation	- water shortage - ownership
50	Use of PE pipes instead of HDPE pipes	- No enough knowledge
51	Corrosion of pipes (DCI Pipes, steel pipes…)	- corrosive soil - water quality - choice of material - non internal and external protection coating

Nr	Problems	causes
52	under sized pipes	- poor design and planning, - Rapid urbanization
53	Pipe replacement planned but not fully implemented	- Poor planning - Budget constraint

b) Commercial

Nr	Problems	causes
A	Unauthorized consumption	
1	Illegal water use cases	- wrong attitude from some customers and staff, - Less investigations and enforcement - No compliance of new connection Standard that facilitate customer to remove meters - Inappropriate Meter location - Meter not protected (meter box) - Less customer awareness on water tariff
2	Illegal water use to disconnected customers (inactive connection)	- wrong Attitude, - Poor management of disconnected and inactive customers - Disconnection practices allowing easy illegal water use - Less inspection of disconnected customers
3	Less inspection of customer installation	- Less awareness - Few number of staff at the branch level - Insufficient logistic (cars , motorcycles, etc..)
B	**Billing**	
4	Some Customers not billed	- Negligence of some CFO's - Big number of customers assigned to CFO - Scattered Households in certain areas
5	Many zero consumption	- Lack of water, - Closed customer's compounds, - Blocked and unreadable meters - Illegal water usage - disconnected customers due to unpaid bills - negligence of CFO's
6	Less field inspection by billing Officer and Commercial services staff	- staff mainly focused on revenue collection (less staff involved in meter reading inspection) - less number of staff at the branch level - insufficient logistic (car, motorcycle , etc..)
C	**Data acquisition and analysis**	
7	Error in data acquisition (meter reading)	- less staff ownership, - internet network connection sometimes not available; - Unreadable meters - Human errors - Bad attitude of some staff (CFO's)

Nr	Problems	causes
8	Lack of data analysis (consumption, billing, zero consumption, etc..)	• Less staff ownership • Insufficient knowledge for Data analysis • People in charge are assigned to other tasks (front desk, recovery, etc..) • Less number of staff at the branch level
9	Under estimation of consumption	• Less awareness and knowledge • Blocked meters, unreadable and damaged meters • Negligence
10	Many inactive/abandoned /disconnection public taps and some not located on demand basis	• Increase of house connection in the area • Poor planning • Poor public tap management
11	Non-served population Information not available	• Customer inventory not yet completed for urban towns • Customer inventory not yet started for urban towns
D	**Metering**	
13	Poor implementation of meter installation and replacement policy	• No compliance of meter installation and replacement policy implementation • less knowledge • reactive approach for the replacement
14	Meter inaccuracy	• No planning for customer's meter testing and replacement • Insufficient water meter test bench (onlyKigali) • Use of inappropriate meter size • Aged meters
15	Tampered meters	• wrong attitude and vandalism • less inspection of customer's installation at branch level • meter not sealed
16	Water meter blocked by solid particles	• less flushing after repairs and new connection • Aged and corroded pipes
17	Many aged water meters	• No implementation of policy and standard for meter replacement • Unrespect of meter replacement plan • Less prioritization on meter replacement at branch level • Sometimes lack of meters
18	Customer meter accuracy test not practiced on-site	• Less awareness • No tools for meter on-site testing at branch level • Insufficient logistic (car, motorcycle)
19	Different types of meters installed in our network	• Delay of meters' replacement • Rapid technology development • Different partners bringing meters
21	Meter reading skill (awareness)	• Less commercial field officer induction for the metering
22	Long process for meter test (mainly upcountry)	• Unavailable meter test bench in upcountry branches • Less awareness and knowledge of staff on meter testing

c) Administrative

Nr	Problems	causes
A	**WASAC**	
1	Limited budget for network rehabilitation and maintenance	• limited revenue • low water tariff compare to expenditure • High NRW • Less organization focus on network rehabilitation (priority to increase production) • More attention on production and network extension than rehabilitation and upgrade
2	Less ownership by some WASAC staff	• Less awareness on NRW • Less motivation and bad attitude for some staff
3	Poor knowledge on how to asses NRW component and causes	• Less awareness • Insufficient training • New concept
4	Insufficient logistic means (cars and Motorcycles) and material to ensure quick intervention and repair	• limited budget • Long process and bureaucracy
5	Lack of enough staff at the branch level and at HQ mainly ones dedicated to NRW reduction	• limited budget • Less organization focus on NRW reduction (revenue collection and increase of production) • Insufficient number of staff for NRW reduction
6	Poor analysis and reporting system on NRW	• limited knowledge
7	No enough induction period for new staffs	• Weakness in Human Resource Development • Lack of procedures for training
8	Less supervision and inspection of contractors works	• Negligence • Overloaded staff • Less knowledge on engineering work supervision
9	Poor pipe handling and inadequate storage (no support)	• Less awareness • Less storage facilities (space) in branches
10	Standard, specification of materials and works not shared to the branches	• Less awareness • Less knowledge sharing about standard
11	Lack of appropriate staff training	• Budget constraint and awareness • Lack of implementation of capacity building planning
12	Less communication between branches, HQ	• Poor reporting system • No shared storage for public documents(maps ,procedure manual ,standard and policy)
13	Less storage facilities at Branches level	• No appropriate space for storage at branches • Store management (no dedicated staff for stocks)
B	**CUSTOMERS**	
14	Customer purchasing power	• low income that lead to the purchase of low quality material
15	Customers awareness on NRW still low	• insufficient sensitization
16	Vandalism	• bad attitude • Many customers consider water should be free • Many non-served population (house connection)

Nr	Problems	causes
C	OTHER STAKEHOLDERS	
17	Lack of stakeholder awareness on NRW	• insufficient sensitization
18	Infrastructures development partners not considering the facilities of all parties (utility, partners)	• lack of collaboration among different utilities/stakeholders • negligence
19	Lack of policy and collaboration between road administrator and utility companies	• lack of collaboration among different utilities/stakeholders
20	Very high expectations from many stakeholders	• Rapid development of the country
21	Too Ambitious target which sometimes lead to substandard works	• Rapid development of the country • Budget constraint
22	Unplanned settlement in some area	• financial incapability to implement urbans master plans quickly
23	Poor quality of work done by contractors	• Limited human capacity from contractors • poor supervision
24	Limited human capacity from contractors	• lack of qualified system of contractors • lack of professionalism
25	Pipe damaged by road construction	• No clear policy of collaboration between road administrator , road constructor and utility companies
26	Building constructed on the pipes	• No clear policy of collaboration between urban administrator, construction company and utility companies • Less knowledge of the network • Less consultation from road construction

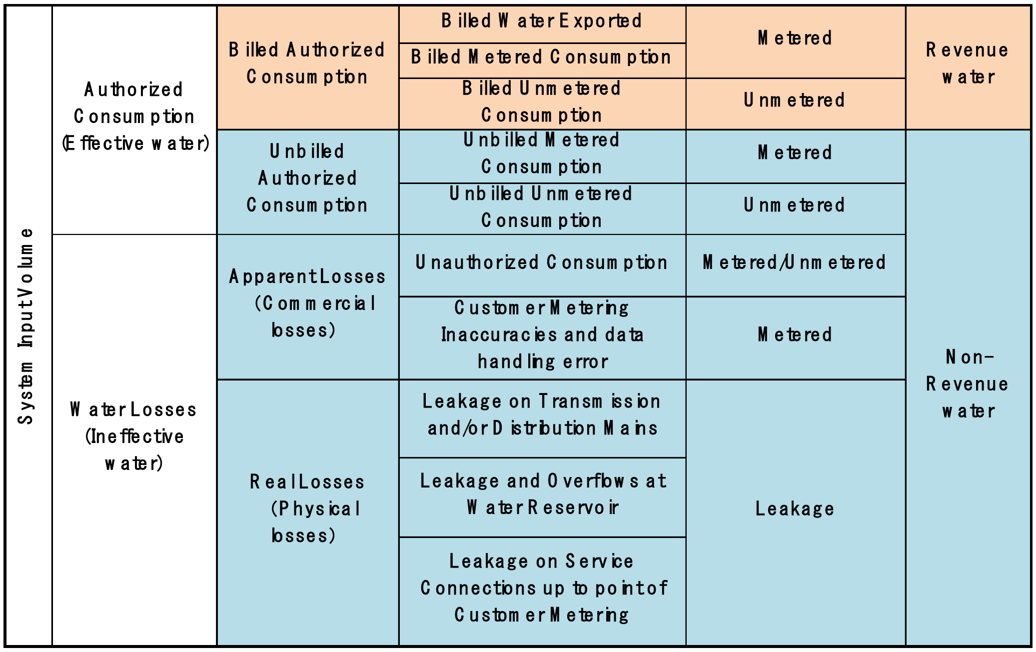
4 Strategic Plan for NRW Reduction

4.1 Reduction measures

From the result of the root causes analysis a series of workshops with different units has been conducted to set up strategies and actions that should be implemented to address the current identified problems.

Reference is made to International Water Association (IWA) water balance table, the proposed 133 specifics actions were classified in 5 main components (water supply system inflow measurement accuracy, commercial losses, Technical losses , unbilled authorized consumption and supportive measures) and grouped in 42 strategies. An order of priority was set gradually based on quick actions with high financial impact; medium term actions which do not require huge investment and long term actions which require huge capital investment and other resources

Table 5: IWA Water Balance Table



System Input Volume	Authorized Consumption (Effective water)	Billed Authorized Consumption	Billed Water Exported	Metered	Revenue water
			Billed Metered Consumption		
			Billed Unmetered Consumption	Unmetered	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Metered	Non-Revenue water
			Unbilled Unmetered Consumption	Unmetered	
	Water Losses (Ineffective water)	Apparent Losses (Commercial losses)	Unauthorized Consumption	Metered/Unmetered	
			Customer Metering Inaccuracies and data handling error	Metered	
		Real Losses (Physical losses)	Leakage on Transmission and/or Distribution Mains	Leakage	
			Leakage and Overflows at Water Reservoir		
			Leakage on Service Connections up to point of Customer Metering		

Table 6 shows the framework of the NRW reduction 5-year Strategic Plan

Table 6: 5Year Strategic Plan for NRW Reduction (see attachment)

Table 7: Responsible Section in WASAC for the Implementation of NRW Reduction Action Plan

Component	Strategy	No*	Responsible Section of WASAC
A. Water supply system inflow measurement accuracy	A1. Volume input metering accuracy	7	WO (Production, Distribution), NRW, CSM (Metering)
	A2. Water production (prevent intermittent supply)	4	UP, WO(Production)
B. Commercial loss	B1. Meter reading and billing	18	DCS, RM(Billing), CSM(Metering), Branches, WO(GIS), DSS(ICT),
	B2. Customers meter management (normal, large and public tap)	7	RM(Billing), CSM(Metering), Branches, WO(GIS), DSS(ICT)
	B3. Illegal Connection	7	NRW (Inspec. & Enforce.), CSM(Metering), RM(Billing), Branches
C. Technical loss	C1. Pressure management	13	WO(GIS, Distribution), NRW(LD&PM), Branches
	C2. Asset Management (Rehabilitation)	10	WO(GIS, Distribution,), CSM(Metering), Branches
	C3. Leaks and burst repair	18	NRW(LD&PM), WO(GIS, Distribution,), Branches, QA(Standard),
D. Unbilled authorized consumption	D. Unbilled authorized consumption	6	RM(Billing), CSM(Metering), Branches, WO(Distribution,)
E. Supportive measures	E1. GIS and CMS database	4	WO(GIS), DSS(ICT), RM, HRM, Branches, NRW
	E2. Planning, design and implementation of works	10	UP, QA(Standard), CSM(Metering), Branches, WO(Distribution), DUWSS
	E3. WASAC NRW management	6	WASAC, DUWSS, UP,NRW, HR
	E4. Stakeholders management	9	WO(Distribution), NRW, WASAC(DUWSS)
	E5. Training	9	WASAC(HR, NRW)
	E6. Institution	3	WASAC(DUWSS,DCS)
	E7. Logistic and quality materials	2	DSS (Admini&Logist.), DUWSS, , Branches
Total		133	

No*: Number of specific actions

4.2 Implementation structure of the Strategic plan

Each specific action was assigned to the responsible departments/units or section as mentioned in the Table7. The Figure 2 shows the responsible departments /units or section.

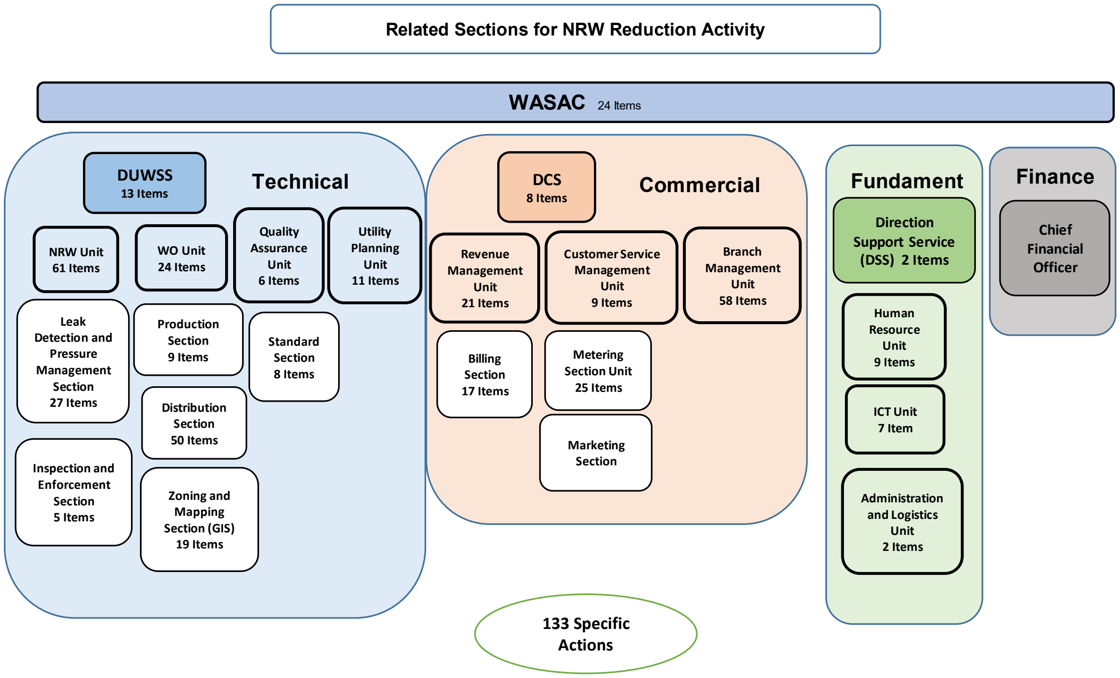


Figure 2: Responsible Department and Units of WASAC HQ

The figure 2 shows that real activities related to NRW reduction will be implemented mainly by 11 Units (NRW, WO, Quality Assurance, Utility Planning, Revenue Management, Customer Service Management, Branch Management, Finance , Human Resource, ICT, Administration and Logistics) wich belong to 4 departements (UWSS, CS, Financial, Support Service). Some unit are directly responsible of the implementation of the strategy and others are responsible of specific actions , see annex No 1. Therefore, the involvement and support of each WASAC staff is strongly recommended. The responsability of implementation of activities can be reviewed or adjusted considering the existing WASAC structure.

a) Implementation team

The DUWSS and Commercial directorates and NRW unit are key for the implementation of this 5YSP. The support services and finance directorate should ensure the full support for the implementation of this 5YSP.

The unit/section and team mentioned for specific actions are directly responsible of their implementation. The NRW unit will be the driving force for the implementation of all planned activities

b) Monitoring Team

The monitoring of the implementation of this 5YSP will be done quarterly with a team appointed by the Senior management. This team should be composed of the staff from DUWSS, DCS, Internal Audit and Branches. The monitoring team leader should be among the WASAC senior managers appointed by the CEO. The NRW unit will work closely with other unit/section to ensure that the activities are being timely implemented, compile and analyze all report to be submitted to the monitoring team. The Monitoring team will scrutinize the summarized report and select the section/ branches to be visited. The monitoring team will appoint the survey team for random on field visit to confirm realizations. At least, one monitoring team member and one staff from NRW units will be in the monitoring survey team. After the monitoring survey, the report will be presented to the Management on quarterly basis

4.3 Implementation and Monitoring Plan

As presented in the annex 1, the implementation and monitoring plan will help to track and assess the 5YSA results and achievements, it will be referred to and updated on regular basis. In addition, this implementation plan will guide the monitoring team on how to collect, analyze and dissemination data both to WASAC management and others stakeholders.

4.4 Budget for the Strategic Plan

For the successful implementation of this strategic plan, a budget of 4.6 billion Rwf has been estimated and should be considered at its approval stage by the WASAC Board of Directors. The phase one implementation has been considered in the approved budget for the Financial Year 2017/2018.

With reference to the detailed plan budget, the breakdown of the estimated budget is summarized in the bellow table

Fiscal Year	Budget (Frw)	Note
2018/2019	780,740,000	Phase one
2019/2020	921,740,000	
2020/2021	941,330,000	
2021/2022	972,981,250	
2022/2023	998,657,331	
Total	4,615,448,581	

This budget does not consider major CAPEX such as huge water network rehabilitation (which is currently under implementation through RSWSSP project) and the complete shift to remote reading metering or prepaid metering system which will be detailed later.

The Non-revenue water reduction in the 5 coming years will allow WASAC to expand and improve service, enhance financial performance and reduce energy consumption. The benefits associated with the NRW reduction from 38% to 25 % in the coming 5 years are various as the volume of water that can be billed will increase by 7.5 million m^3 and an incremental revenue of 11 billion RW on an average tariff of 500 Rwf/m^3 as presented in the table bellow

		2018/2019	**2019/2020**	**2020/2021**	**2021/2022**	**202/223**
System input volume (projection)		48,744,969	51,182,218	53,741,329	56,428,395	59,115,461
NRW ratio	Without NRW reduction	38%	38%	38%	38%	38%
	With NRW reduction	35%	32%	30%	28%	25%
	Difference	3%	6%	8%	10%	13%
Volume saved		1,462,349	3,070,933	4,299,306	5,642,840	7,685,010
Average tariff		500	500	500	500	500
Revenue increment		731,174,535	1,535,466,540	2,149,653,160	2,821,419,750	3,842,504,965

The implementation of this 5YSP involves some routine activities, other with big magnitude and completely new activities. Extra activities, which are not yet being implemented in WASAC will requires the total budget of 2.5 billion in 5 years as detailed in the table below.

Specific actions	Total amount (RWF)	2018/2019	2019/2020	2020/2021	2021/2022	2021/2022	Comments
		1st Year	2nd Year	3rd Year	4th Year	5th Year	
Installation of new meters / Replacement of faulty bulk meters / correction of meters installation based on the result of meter condition analysis	102,500,000	51,250,000	51,250,000				Systematic bulk meters assessment wich will required the replacement of fault or installation of new bulk meters
Procure additional Portable meter test equipment (at least 1 per branch)	120,000,000	120,000,000					Procurement of portable test meters for on site customer meter testing wich is the new activity within WASAC
Replace default and old meters	848,563,947	175,000,000	161,000,000	165,830,000	170,804,900	175,929,047	8000 additional meter replacement compared to the annual meter replacement plan within WASAC
Procure and install one water test bench per province	100,000,000					100,000,000	New activity plan to have at least one test bench in each province for deap customer meter test
Automatic meter reading or prepaid meters for big customers	200,000,000		200,000,000				New activity plan to have remote reading meters/prepaid meters on TOP wasac 200 customers
Procure and install pressure gauges in the network	20,000,000		10,000,000	10,000,000			New activity of installing at least 10 pressure gauges / branch
Implementation of pressure management plan* (PRV, BPT, rearrangement of pumping stations and pipeline network)	164,400,000	33,600,000	30,000,000	33,600,000	33,600,000	33,600,000	Installation of 12 PRV each year in addition of the existing 24 PRV installed yearly by WASAC
Implementation of the maintenance and rehabilitation plan*	775,000,000	155,000,000	155,000,000	155,000,000	155,000,000	155,000,000	Additional budget for water network maintenace and small rehabilitation
Procure and dispatch leak detection equipment to branches	200,000,000			100,000,000	100,000,000		New activity within branches . The leak detection equipment are only being done by HQ team
Exposure visits	15,000,000		7,500,000		7,500,000		Additional exposure visit for WASAC staff
RWF	2,545,463,947	534,850,000	614,750,000	464,430,000	466,904,900	464,529,047	

4.5 Funds mobilization mechanism for the implementation of 5YSP

Currently, the combination of funding sources (Tariff, Taxes) is not sufficient for the implementation of this NRW reduction strategic plan (routine activities and planned new activities). The conventional sources like funding from development partners (JICA, Vitens Evides, etc…) or NGOs through Water Sector Working Group (WSWG) could be one of the options. However, new funding mechanisms could be possible since NRW reduction is profitable for WASAC as mentioned in cost-benefit analysis. Therefore, there is needs to actively seek for new sources such as private partners and commercial banks to secure the budget necessary for the implementation of the 5YSP in timely manner.
In addition, when we consider the CAPEX, more sources will be needed. In this case, government and conventional sources are more realistic to fill the gap.

5 Important Note

As observed above, a specific, realistic and integrated 5YSP for NRW reduction has been developed. it means WASAC is now on the starting point toward the proper NRW management. From this point, WASAC has to take all actions mentioned in the 5YSP which requires 4.6 Billion RWF for coming 5 years. However, WASAC should note that more investment will be needed for NRW reduction, because this amount is not including CAPEX and general expenses.

To ensure the implementation of the 5YSP, yearly PDCA cycle (Plan: Preparation of annual plan, Do: Implementation of each action mentioned in annual plan, Check: Monitoring of the progress, and Act: Update the 5YSP in accordance with the progress and outcome) is quite important. WASAC is required to be always aware of this PDCA cycle and take a steady step forward.

NRW reduction is not the goal for WASAC. It is one of the tools to supply safe drinking water to all continuously. However, without proper NRW management, the goal will not be achieved.

ANNEXES

Annex 1: 5YSP Implementation and Monitoring Plan

Annex 2: Questionare submitted to WASAC branches

1. Problems related to the need for WASAC to take action against the unbilled water consumption

1.1 Problems of water serving activities

Please explain the issues in terms of the management of the water service WASAC through concrete enumerations, according to the examples listed below.

- Inadequate water service volumes in specific regions (Please provide documentation on forecasts of supply and demand, if they exist.)
- Increase in operating costs, management and maintenance of water treatment plants
- Improved low incomes (increase in commercial losses, inadequate service volumes) and management of WASAC

1.2 Issues relating to specific regions and installations

Please summarize in a table the branch offices, service areas and specific facilities under the supervision of WASAC particularly with problems and requiring priority action against the water consumed is not billed (name of branch management, name office, retail facilities, problem areas and content of current activities and measures). Also puting the location site maps, maps of service areas, distribution network maps as well as all the works plans. These maps and plans will serve us to select candidate sites for our study site.

For example, the 4 branch offices below have documented low coverage rate and priority measures against the water consumed is not billed are necessary. Please indicate whether there are specific areas of these branch offices.

Name of management	Office Name	Service rate attested (%)	Name of the region	Details of installations	problematic points	Measures

1.3 Issues related to the implementation of measures against WASAC water unbilled consumption

No		Order	Items	Content problem
1			Details of water service installations : supply, transfer and distribution	
2			Form of the distribution network, the relief of the region	
3			Control of information on existing lines, such as plans of the distribution network	
4			Control of distribution volumes and water supply pressure	
5			Plans and execution studies leaks	
6			Execution of leak repairs	
7			Data management and maintenance of the pipeline network, historic leaks, repairs and renovations	
8			Supply of materials for the repair and renovation of distribution pipes and service pipes, etc.	
9			Check the operation of installations water treatment plants, pumping stations and distribution tanks	
10			Check the operation of installations water treatment plants, pumping stations and distribution tanks	
11			Quality and standard of water meters specifications	
12			Management and maintenance of existing water meters, supply and meters of installations	
13			Installations, equipments and materials for inspection work meters	
14			Verification of consumption and preparation to meters the consumption data	
14			Volumes of water consumed and billed preparation bills	
15			Customer data management, analysis of the volumes used, etc.	
16			Water Assessment unbilled consumption, distribution volumes analysis	
18			Elaboration of annual plans of activities and measures against water not billed consumption	
18			Quality control work for the execution of activities and measures against water not billed consumption	

19			Organizational structure and execution of WASAC system to implement, globally or individually, activities and measures against water not billed consumption	
20			Execution capabilities of agents and implementation capacity of the entire organization WASAC	
21			Budget for the implementation of measures against water not billed consumption	
22			Various	

1.4 Considered problems by WASAC in terms of the implementation of measures against water not billed consumption

Based on the table above, what are the main reasons for the problem of water consumed is not billed for WASAC ? Please enter them in the order in the table in paragraph 1.3. If there is no section for some reason in the table, please register as a supplement.
Please also indicate the items considered necessary to solve and improve the effective implementation of measures against unbilled water consumed by WASAC in the future.

2. Plan of measures against water not billed consumption

2.1 Implementation Plan and request support

Please indicate the concrete implementation plan, strategic plan, medium and long term plans, the annual plan and the financing plan for the measures against non-revenue water consumed of WASAC, developed to address the problems mentioned -above. Please also indicate the related plans as well as the higher level plans considered necessary by WASAC as measures against water consumed is not billed.

Entitled of the execution plan of WASAC	Content of the plan	Situation of execution

Entitled of related plans and higher level plans	Content of the plan	Situation of execution

Please also indicate if support activities are performed by international organizations or by reference to bilateral agreements, or in case of future plans are being formulated, the details of the cooperation and the concrete situation of such activities .

Organization concerned by the request	Items of the request	Situation of activities

3. Flowchart of WASAC, controlled areas and court activities

Please provide the organizational charts of the Directorate General and bracnhes of WASAC, the number of agents, the list of each of the branches offices, their addresses and maps of controlled areas. Please also summarize the desactivités content and the number of officers in each division of the branches and each division of the Department of Production and Operations of the branches. Please mention the divisions responsible for activities relating to measures against unbilled water consumed in the document in Annex 2 of this questionnaire "Divisions WASAC affected by the measures against water consumed unbilled".

4. Situation on budget

Please give us the financial statements (for all years from 2010 to 2015) and Tables of water tariffs.

Does WASAC has developed a financial plan for the implementation of water reduction activities consumed unbilled?

Please show us the documents of the annual financial plan. What problems financially for the implementation of water reduction activities consumed unbilled?

B. Questionnaire submited to WASAC NRW unit

1. Situation of enforcement of measures against water not billed consumption

Please respond concretely to the following questions concerning the activities of measures against non-revenue water consumed currently performed by WASAC.

Please also give us documents such as statements of work and database examples. We would also receive the location site maps, the map of the water distribution area, plans of all structures and plans of the water distribution network, etc., relating to the area 'observation.

1.1 General items

No	Divers questions	YES / No	concrete content
a	Have plans for medium and long term and annual plans of activities were formulated for measures against NRW ? Was a budget he has planned ?		
b	Is there a division responsible measures against the unbilled water consumed and the agents responsible were they appointed ? Composition of this division.		
c	What are the indicators to measure the water consumed is not billed (eg water consumption rate unbilled) ? What concrete targets for these indicators ?		
d	The annual reports of statistics do not indicate a definition of water consumption rate not charged. The evaluation seems to be made from the volumes of water consumed but how rates are determined unbilled water volumes attested ?		
e	The activities of the measures against non-revenue water consumed are they subject to evaluation (for example, financial assessment of the cost-effectiveness) ?		
f	For activities measures against water consumed unbilled, directions of work, procedures, specifications and methods they are raised and standardized of analysis for all divisions and branch offices ? Please indicate which kept manuals and guidelines (list specific title, content).		
g	Content of the work entrusted to subcontractors (eg, inspection and repairs of leaks pose feeder and distribution pipes, installation and replacement of meters, meter verification, investigation of the theft of water, meter readings, distribution of invoices), subcontracting business capacity.		

1.2 Measures against actual losses (physical)

No	Divers questions	yes / No	explanations
a	The division into districts for leakage control or a division into blocks of the area they are controlling the pressure determined in the area of the distribution network ? Is a block subdivision also performed ? If so, what are the criteria for determining the area (area, number of subscribers, etc.) ? Map of the block division of the distribution network.		
b	How is the control of water pressure made within blocks of division of water supply?		

c	Monitor the flow and pressure is it made to the distribution network (purpose, location, frequency) ?		
d	The volume of existing leaks is it measured (night minimum flow) in the block division distribution ?		
e	Are underground leak detection work ? (Periodically / only in case of problems / no)		
f	What methods of surveys, ranking and analysis of the history of leaks repairs ? Please indicate the number of cases of discovering leaks and present the history data leak repairs.		
g	Leakage of water distribution systems seem to be many and what are the measures taken to treat with them?		

1.3 Measures against the apparent (commercial) losses

No	Divers questions	Yes/ No	Explanations
a	What are the principal causes of the apparent losses (water theft, error meters, absence of meter, data processing, etc.)?		
b	Numbers and content of reported thefts. Please provide the data.		
c	Number of flights and illegal modifications meters. Please provide the data.		
d	Orientations for the increased establishment of meter rates.		
e	What are the meter replacement criteria (number of years of use, number of meters, breakdowns, etc.)?		
f	Whether or not meters testers, retail devices, methods and verification criteria		
g	Method of determining the water billed volume in the absence of meter		
h	Treatment method of aggregation of billed water volumes. Please provide data on the volume of water billed (by division of use, division of calculating charged volumes).		
i	Customer data management mode. Please provide an example of a subscriber database.		
j	Methods of managing and monitoring large users customers.		

1.4 Basic information and others

No	Divers questions	Yes / No	Explanations
a	mapping information and treatment method		
b	Treatment of water data unbilled consumption		
c	Plan Renewal Program (Please provide data on this renewal). - Data on the pipes (years of installation, type of pipe, diameter, repair history, etc.) are they		

	treated? - Are the evaluated dilapidated pipes and formulated a plan for renewal? - - Does he really Renewal place?		
d	An analysis of the effects on the management of measures against unbilled water consumed done? By what method?		
e	Outreach activities of the inhabitants in relation to non-revenue water consumed are they implemented? Please indicate their content.		

2. Measures already implemented and their effectiveness

Please list below the concrete steps already taken to reduce the volume of water consumed and not billed indicate their effectiveness (effects).

Content of measures	Effects	Problematic points

2. Detection equipment water leakage in each branch office

Please submit a list of the types and the number of leak detection equipment in each branch office and branch offices as well as their condition.

1) Equipment for measuring flow rate and pressure (ultrasonic flow meters, magnetic flow meters, pressure gauges, data loggers, etc.)

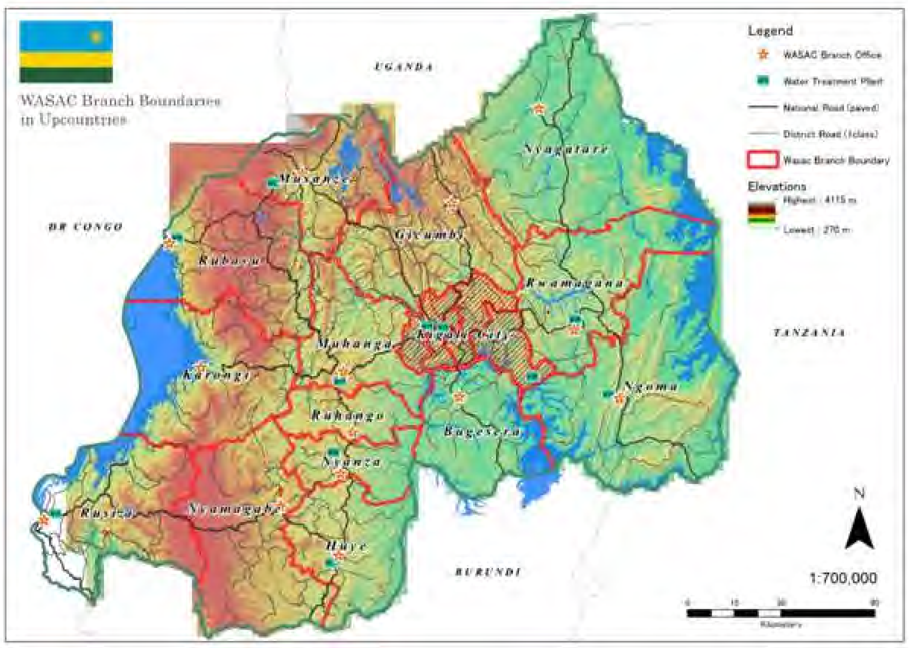
2) leak detection devices (leak detectors, buried pipes sensors, acoustic sensors, etc.)

3) Vehicles for work, others

Device designation	Number	Operating state

Annex 3: Summary of Result from branch questionnaire

Questionnaire survey has conducted for 20 Branch Offices in September 2016 and the answers to the questionnaire are summarized in October 2016. The result was explained for NRW team and discussed it on November 8, 2016.



1. Map

- The pipeline network maps are not prepared and not equipped at most of all branch offices.
- The branch offices do not possess the software of pipeline network maps. They are waiting support of the ESRI project after finish Kigali city.

2. Staffs (Organization)

- About the persons who inspect and manage the NRW reduction in branch, no particular person has not appointed. Among 20 branches, 12 branches answered that WDO and technicians.
- As for the commercial field officer, it is appointed as one in 1,000 customers.
- How is the number of Technician/ Plumber decided at each Branch Offices? Is the present number sufficient for dairy inspection work, installation work of new service connection work, leakage repair work, so on? Is the supporting member for technician such as technical activity, cleanings sufficient?
- At all branch offices, formation of the leakage detection teams is desired.

3. Shortage of water distribution volume

- All three branches visited face to shortage of amounts of distribution water due to shortage of water resource. Therefore, branch offices are supplying water to the water distribution area according to the rotational schedule or taking shifting supply in day and night.

4. Pressure Control

- Geographically, although it is rolling, there is no big vertical interval like Kigali, and there is installation of some pressure reducing valve so that a maximum water pressure is 60 m or less in general, and there are few high pressure parts.
- Generally, branch office is not conscious of lack of his fundamental knowledge on pressure management.
- Construction of DMAs is requested by Branch office in order to conduct pressure management.

5. Commercial Aspect

- About the commercial loss, although the installation rate of customer meter is 100% including public taps, there is no regulation about replacement of meters. Therefore, only stoppage/blocked meters are made replacement. It is not managed about the useful life of meter.
- In Rwamagana branch, 30% of water meters are more than 10 years used without replacement. Only unfunctional meters found by customers or blocked meters by deposits of sand in the meters after repair leaks.
- Supervision on water use situation of big consumer is recognized. In Rwamagana the customers have average consumption per month over 100 m3 during six months are classified as big consumer.
- Data analysis on water use condition of the customers is required.
- Although the numbers of public tap constitute about 3% of the numbers of whole customers, there is much as 13% including livestock combination in Nyagatare.

6. Leakage (Physical Loss)

- Although it is coped with only visible leakage of water on the physical loss, it doesn’t correspond to the invisible underground leakage of water.

- Periodical and premeditated leakage investigation using a set of leakage detection devices and a formation of the trained leakage detection teams are desired.

- The almost case of leakage parts are on water distribution pipe with small diameter and the service connection pipe.

- A regards leakage in different diameters of laid pipes, many leaks are observed in pipes of small sections (DN 63 DN 50 DN 40, DN32, DN25).
- Ruwamagana: 115 leaks per month are many and they are frequently remarkable in the distribution pipes, and several are caused by the damage made by inhabitant's activities and by the variation in pressure between the time missed and resend water.
- The leaks information is reported by customers (17 answers), meter reader: commercial field officers (17 answers) and patrol of staff (9 answers). Dose the reporting by habitant used call centre? What is the concrete content, frequency and the person in charge of the patrol? Has the function of call center at each Branch Office been set up?
- Management of water level and overflow of the reservoir is not sufficient.
- Quick leak repair after the leak discovery is required.

7. Replacement of Aged pipe

- Replacement of the aged pipes and the frequent occurrence pipe of the leakage is required.

8. Service Connection

- Installation of a service connection pipe is performed based on application of new connection, but management of service connection materials and work performance are insufficient so that technical standards are needed.

9. Vandalism

- There are few numbers exposed although there is much vandalism such as an illegal use and water theft. Although a radio, a newspaper are performing the educational campaign about water use, the educational activity in the school is not yet performed.

10. Cooperation with the Authorities Concerned

- It is necessary to perform enough discussion and adjustment with local governments.

Annex 4: Summary report of WASAC branches Visits

In September, 2016 and February and March, 2017, site visit survey was conducted with the members of NRW team to confirm the situation of the WASAC district Branch.

- Site visit survey for three Branch Offices, Ruwamagana, Nagatare and Ngoma, was conducted in September 2016 to confirm existing activities of WASAC branch offices, the situations of facilities, and evaluate it.
- The site visit survey for remaining 11 Branch offices (Musanze, Ruvavu, Gicumbi, Ruhango, Nyanza, Huye, Nyamagabe, Karongi, Rusizi, Bugesera, Muhango) was conducted from the middle of February until the beginning of March.

No.	Province	Branch Office	Day Visit
1	South	NYANZA	2017/2/21
2		HUYE	2017/2/22
3		NYAMAGABE	2017/2/23
4		RUHANGO	2017/2/20
5		MUHANGA	2017/3/8
6	West	KARONGI	2017/2/27
7		RUBAVU	2017/2/15
8		RUSIZI	2017/3/1
9	North	MUSANZE	2017/2/13
10		GICUMBI	2017/2/16
11	East	RWAMAGANA	2016/9/20
12		NYAGATARE	2016/9/21
13		NGOMA	2016/9/22
14		BUGESERA	2017/3/6

No	Province	Kigali City	Day Visit
1	Kigali City	Kacyiru	2016/8/23
2		Gikondo	2016/8/24
3		Nyarugenge	2016/8/30
4		Nyamirambo	2016/8/23
5		Remera	2016/8/23
6		Kanombe	2016/8/23

A. Current Status of the Branches

1. Southern Province

1.1 Nyanza Branch

- The diameter of the distribution pipes is small for the number of customers (quantity of water supplied), so a replacement plan has been prepared.
- The estimate for the replacement plan shows only the pipe diameter, material, and total length, and there no drawings showing where and how the replacement will be carried out (this is the same for all branches).
- It is necessary for WASAC as a whole to review its design, construction, and supervision system.
- Large customers (prisons, universities, schools, hotels) consume about 50% of the quantity of water.
- The existing meters are more than 20 years old.

1.2 Huye Branch

- Most of the distribution pipes and meters are more than 30 years old, and their replacement is necessary.
- Replacement of old pipes with new ones is being carried out, with replacement of the highest priority 1 km being complete. However the plan for replacement of 5 km has been submitted to headquarters, but the budget is not forthcoming.

1.3 Nyamagabe Branch

- Most of the distribution pipes and meters are more than 30 years old, and their replacement is necessary, the same as in Huye Branch.
- Distribution pipes were installed in 1982, so more than 30 years has passed.
- In the past pipes imported from Europe were used so the quality was good, but at present they are being manufactured in China, Uganda, Kenya, Rwanda, etc., and the quality is not very good.
- There are many leaks from PVC, PE, and GIPservice pipes.
- The water gauge in the distribution reservoir is broken, and manned surveillance is being carried out.

1.4 Ruhango Branch

- The PVC transmission pipes have longitudinal cracks, so it is considered that there is a problem with the material. Also water leaks occur at the rate of about 1 per 3 months, so re-installation is urgently required.
- The quantity of water billed varies greatly even though the quantity of water supplied does not vary very much, so there is a great variation in the quantity of non-revenue water.
- In some locations low density polyethylene pipes and galvanized steel distribution pipes are being used.
- There is a large increase in new customers but the distribution pipes cannot be renewed, so in many cases connections are made from narrow distribution pipes.

1.5 Muhanga Branch

- The distribution pipe network is not suitable in terms of diameter, so it is not possible to distribute the design flow rate of the water treatment plant.
- About 300 customers are connected to a 25 mm diameter pipe.
- Generally speaking, the pipe size of the water distribution network is small and there is a plan for replacement. However the budget is not available, so the plan cannot be implemented.
- The oldest meter is 20 years old.
- Many customers do not pay the water charges and 815 of them have been disconnected, but of those about 500 customers do not intend to pay.
- Customers purchase the pipe material, but they purchase the cheapest material, so the quality is poor.
- None of the water distribution reservoirs have flow rate meters to measure the incoming flow rate.

2. Western Province

2.1 Karongi Branch

- The network is more than 50 years old, and it is necessary to implement areplacement plan.
- There are no replacement plan diagrams written on the piping drawings. (This is the same for all branches).
- There is much rock and excavation is difficult, so the transmission pipes are exposed in places.

2.2 Rubavu Branch

- The soil is volcanic soil with high water permeability, so water leaks do not appear on the surface. It is necessary to carry out underground water leak detection using a water leak detector in priority.
- The water distribution pipes were installed a long time ago.
- Water is distributed to an excessive number of customers from small diameter distribution pipes.
- Faulty individual water meters have been replaced, but old meters remain not replaced.
- The quantity of water leak repair materials stored is insufficient. In particular, materials for small diameter pipe joints are procured every time they are needed.
- There are no flow meters for measuring the inflow rate to distribution reservoirs.
- There are no floating valves in the distribution reservoirs, and manned surveillance is being carried out. The water gauges are unusable because of the accumulation of dirt.

2.3 Rusizi Branch

- PVC that is 30-40 years old is in use.
- Also, water is supplied to 300 households from 25 mm diameter water distribution pipes, etc., so it is necessary to prepare a replacement plan based on hydraulic calculations.

3. Northern Province

3.1 Musanze Branch

- The soil is volcanic soil with high water permeability, so water leaks do not appear on the surface. It is necessary to carry out underground water leak detection using a water leak detector in priority.
- Excavation is difficult, so in places pipes are exposed.
- The size of water distribution pipes is small for the quantity of water supplied, with 20 households being supplied from a ¾ inch pipe.
- Low density polyethylene pipes are being used, so the pressure resistance strength is insufficient. It is necessary to replace these low density pipes with high density polyethylene pipes.
- It is considered that there are many leaks in places where there is no change in the daytime and night

time flow rates. Therefore the inflow valves to these areas should be closed, to reduce the quantity of non-revenue water.

- There are GIS maps, but they have not been updated for a long time.
- Air becomes trapped in the pipelines, but the air valves are not automatic, so the air has to be manually vented.
- There are no floating valves in the distribution reservoirs, so valves are operated with manned surveillance.
- There are no flow meters for measuring the incoming flow rates to the distribution reservoirs.

3.2 Gicumbi Branch

- Small diameter distribution pipes using low-density polyethylene (PE32) and galvanized steel needs to be replaced.
- High-lift pumps (40 bar specification) are being used, but this is excessive pressure.
- There are problems with planning, design, construction, and supervision, so the WASAC checking and supervision system is not properly formed.
- The pipe bending prevention for transmission pipes is being carried out on a very smallscale not corresponding to the water pressure. The size specified for flanged ends of gate valves, etc., is too small for the actual pressure.
- Water leaks are caused by road construction. The burial depth is shallow, and the backfill is inappropriate, so it is considered that damage is caused by vehicle loads.

4. Eastern Province

4.1 Rwamagana Branch

- The Branch staff wish to form a non-revenue water reduction team in order to implement measures against non-revenue water.
- Development of the distribution pipe networks commenced in 1986, and almost all is PVC.
- Even though water is supplied 24 hours a day, because the demand is high, during the daytime the water does not reach the most distant parts, although many areas can be supplied with water for 24 hours.
- The branch does not possess piping drawings covering all the areas of the city.
- The locations of water leaks are almost all on smalldiameter water supply connection pipes. No countermeasures are taken against water leaks that cannot be seen.
- Records of water leak repairs are written up in notes.
- Water leaks are notified by meter reading officers(Commercial Field Officers) or the residents.
- Several hours are required between reportsof a water leak and repair. Also, the quantity of water leakage during that time is estimated.

- Most of the materials used for repairs are in storage. Materials and equipment are provided by WASAC Headquarters. If there is no stock at the branch then a procurement request is sent to Headquarters.
- Block Meter refers to a meter with defective operation. A cut in water supply causes water to be drained and air to be accumulated in the raised part of a service pipe, and the pipe dries. In that case, the meter dries and suspended matter within the meter hardens, so it becomes difficult for the meter to rotate.
- When a meter cannot be used, billing is carried out based on the actual amount of usage in the past.
- The diameters of the customer meters are 20 mm, or 25 mm. The rate of installation of meters is 100%.
- For customers with large usage, after reading the meter, inspection is carried out one more time.
- Meters that have exceeded their service life are not well managed. It is necessary to produce standards.
- It is considered that the commercial loss due to non-revenue water is large. It is thought that there are many illegal connections and water is stolen, but only about 5 illegal connections per year are found. Even after discovery it is not possible to strictly enforce the regulations with a legal dispute.

4.2 Nyagatare Branch

- It is not possible to supply water for 24 hours a day.
- There are many leaks in the small diameter pipes.
- There are many acts of vandalism (acts causing damage), in which air valves, drain valves, and manholes are destroyed. It is necessary that there be cooperation with the Local Authority regarding vandalism. Illegal connections (illegal use) are few. The vandalism is reported when it is detected by meter readers, customers, and technicians. It is necessary to raise the awareness of the residents, and cooperation with the local government organizations is also necessary. Use of local media (radio, newspapers, etc.), and discussions with the relevant organizations is required. Awareness activities at schools is carried out by the Sanitary Department, but they have not yet started activities regarding use of water supply.
- Water hammer is caused by insufficient air valves.
- The branch wants to have water leak detectors. It is necessary to newly form a water leak detection team.
- The maximum pressure within the distribution pipe network is 6 bar. There are water leaks within toilets in houses caused by the high pressure.
- There is a problem of turbidity during the rainy season. Customer meters are replaced at 140 locations annually.
- Pipe repair materials are provided by Headquarters upon request from branches. There is no budget at branch level.
- It is considered that commercial losses are greater than technical losses.
- Distribution tank floating valve replacement has been carried out at 8 locations, as part of an annual action plan.
- Normally, drawings cannot be managed at the branch. There are not even prints of the water distribution

area drawings. There is little awareness of active use of water distribution pipe network drawings.

4.3 Ngoma Branch

- The water supply source quantity is always insufficient, so priorities for supply are determined, and rotation of water supply is carried out by operation of valves within the pipe network. Water is stored in tanks in each household, and used in a few days. Water can be supplied to the whole area for 2 days per week.
- Valves are installed on the water distribution pipe network at 25 locations (60 mm to 200 mm), and these are opened and closed every day in order to rotate the water supply. There are no problems with this operation.
- The pipes in which leaks occur are mainly small diameter pipes of 32 mm and less, and service pipes. There are about 18 leaks per month. Leaks occur in large diameter pipes about 2 to 3 times per month. They are detected by meter readers or customers who report them. Causes include (1) heavy traffic vehicles (road construction), (2) high pressure problems, (3) material quality (house connection pipe), the procurement of low-cost materials in the market, and (4) operational problems, so at present contractors are not used, but repairs are carried out directly by WASAC staff. There are no inspections in particular of house connections. There are no standards for inspections.
- The branch does not possess any water leak detectors. At present the branch does not have a water leak detection team, but there are plans to form one. Records of water leak repairs are written up in notes, and some of the repair equipment for leaks is owned by the branch.
- Meters are installed at all supply destinations. Meter replacement is only carried out for faulty meters. The cause of blocked meters is blockage with sand or soil that has entered at the location where a leaking pipe is repaired. The frequency of meter replacements is low, at about 10 to 20 times per month.
- The consumption by large customers is analyzed and checked every month.
- It is considered that there is illegal use, but they have not been found. Information is obtained from meter reading officers (Commercial Field Officers) and residents, but detection is difficult. When detected the supply is cut off, but this causes a dispute.
- Measures for reduction in NRW (Non-Revenue Water) are being tried, and periodic inspection, replacement of old meters, replacement of old pipes, and repair of leaks are carried out at appropriate times.
- Awareness activities for customers are being carried out (in order to recommend use of good quality materials for service pipes), and discussions with the relevant administrative organizations are held.
- Galvanized steel pipes corrode easily, so 3 years ago it was decided to replace them all, and replacement is still in progress. At present about only 5% remain.
- Water flow meters on the outlet side of water distribution tanks are installed only at 2 locations.

- WASAC supplies the meters for water supply connections. The branch pipes are purchased by residents. The diameter of PVC pipes is 25 mm, and meters 20 mm. The pipe connection work is carried out by WASAC. The operation of making a hole for water supply connections at branch saddles is not carried out using a drill, but the hole is formed using a heated reinforcement bar. Pressure tests are not carried out.

4.4 Bugesera（Nyamata) Branch

- It is an urgent task to expand the quantity of water treatment.
- Meters were installed from 2010 onwards, so they are new.
- It is necessary to prepare a water distribution piping plan in accordance with development plans for the International Airport and industrial estate, based on demand forecasting and hydraulic calculations.
- The water supply materials of new customers are evaluated, and if there is a problem with quality the connection is not permitted.
- The Rwanda Standard Board has jurisdiction over the standards for pipes, and imported pipes that comply with the standards are imported. It is also a testing organization, and they carry out witness inspections at factories within the country. This is also carried out by staff from WASAC.
- There are no flow meters for measuring the inflow rate to distribution reservoirs.

5. Kigali

5.1 Kacyiru Branch

- Water is supplied from two directions: water supplied from the Ntora water distribution tank which receives water from Nzove water treatment plant, and water supplied from the Kimisagara water treatment plant. Therefore the water supply status is good, and water can be supplied 24 hours a day, 7 days a week continuously.

5.2 Gikondo Branch

- The sources of water include the Nzove water distribution tank, the Kimisagara water treatment plant, and some groundwater, but it passes through the areas under jurisdiction of Kacyiru Branch and Nyarugenge Branch, for distribution within Gikondo. Therefore the quantity of water within Gikondo is always insufficient, and the water supply status is poor.
- It is expected that the water supply situation will be improved with the new water treatment plant (Kagarama), construction of which is scheduled to be completed in 2017 in the south of Kigali City in a project by Metito. Also, there is a plan for supply of water resulting from the expansion of the Nzove water treatment plant. It is expected that the water supply and distribution status will be improved with the completion of these projects.

- The water supply status is 2 to 3 days a week × 24 hours a day.
- It is said that there is significant theft of water, but detections of illegal connections are about one every 2 to 3 months. There is a system of reward money for detection of illegal connections.
- There are many water leaks. The causes of water leaks are old pipes, and damage to pipes due to road construction or house construction. In most cases, low cost poor quality pipe materials are used for new connections to houses newly constructed or for replacements.
- Water meters remainnot replaced for a long time.

5.3 Nyarugenge Branch

- The sources of water supply are Kimisagara water treatment plant and Nzove water treatment plant. The water treatment plants are close in distance, so the supply conditions are good, and water is supplied 24 hours a day 7 days a week.
- There are many water leaks even though pipe replacement is ongoing. In some cases buried pipes are damaged during road construction or repairs. In some cases houses are constructed above the pipes, so maintenance of the pipelines is difficult.
- There are many water leaks, and in 1 day leaks are repaired at about 20 locations. Also, water leaks sometimes occur at the water distribution tanks at 18 locations. The water leaks are not just from the old network, but there are also leaks from the new areas.
- There are also many leaks in newly connected service pipes. The water leaks can easily occur due to the cheap materials and the construction method carried out by the contractor, because the cost of the water supply connection materials and equipment and construction are borne by the contractor.
- There are also problems with the materials used in the networks delegated from the Local District.

5.4 Nyamirambo Branch

- The sources of the water supply are Kimisagara and Nzove water treatment plants.
- The water supply status has been improved with the completion of Nzove II Plant. At present the water supply status is good, with water being supplied 24 hours a day 7 days a week, except in a part of the area (water supply 2-3 days per week).
- As a result of improvement in the water supply status, there are problems of water leaks caused by high water distribution pressure. The water pressure during the day is 11 to 14 bar, and 7 to 10 water leaks occur per day.Most of the leaks occur in service pipes.
- The pipeline network was installed in the 1960s. The material of the old pipes was galvanized steel, and the material of the new pipes is PVC, but the quality of the new pipes is poor and there are many leaks.
- Almost all the water leaks occur in service pipes.
- There is little theft of water and few illegal connections. There are fines if detected, and, because it is

mainly a residential area there is no major advantage to theft of water, as in commercial or industrial areas.

5.5 Kanombe Branch

- The source of the water supply is Karenge water treatment plant. The status of water supply is poor, with supply 3 days per week × 24 hours per day.

6. Items Common to All Branches

- There are no maps (drawings) indicating the water pressure status of areas within the pipe network that require water pressure management. None of the branches have distribution pipe network map (not even a handwritten one), so there is an extremely poor awareness of the use of drawings.
- There are no drawings showing the pipe materials, diameters, year installed, etc., which is necessary for formulation of plans for replacement of aged pipes and improvement in the pipe network.
- The quantity of water distributed is insufficient due to insufficient supply from the water source in many cases, so water is rotated among areas on a daily basis, and water distribution is carried out separately day and night time.
- Data which is necessary for analysis of the causes of water leaks, such as information on leaks from what location on pipes (bends, joints, the main pipe), and how the leak occurred (splits, holes, separation of joints, corrosion), etc., is not recorded in the water leak repair records. Also, this information is not written onto the piping drawings.
- Regarding physical damage, action is taken only in connection with visible water leaks (detected naturally), but no action is taken in connection with water leaks that cannot be seen that occur underground. It is desirable to form water leak detection teams that carry out water leak surveys using water leak detectors.
- The location of almost all the water leaks is on small diameter water distribution pipes, and water supply connection pipes.
- Water supply pipe connections are carried out when there is an application for a new connection, but there is insufficient control of the materials and construction, and technical standards are necessary.
- There are problems with planning, design, construction, and supervision, and implementation and supervision are being carried out only by a consultant or contractors, so the system of supervision by WASAC has not been established.
- In connection with commercial losses, customer meters have been installed at 100% of subscribers including public water taps, however regulations regarding replacement of meters have not been developed, and only meters that have stopped working are replaced. Meters are not managed based on their service life.

- In the case of customers with large usage, in most cases surveillance is carried out in a thoughtful manner.
- It is said that there are many cases of vandalism such as illegal connections and water thefts, but few are exposed. There are cases where radio and newspapers, etc., are used for awareness activities in connection with use of the water supply, but educational activities at schools are not being carried out yet.
- There are no employees or teams dedicated to activities to reduce non-revenue water.
- There are no vehicles that can be used for dedicated activities to reduce non-revenue water.
- Even where DMAs had been created (and there are branches that have not created a DMA), they are not being operated.
- There are no mechanisms for sharing improvement initiatives between branches. Information is not being exchanged.
- When a pipeline replacement plan is submitted to Headquarters, drawings that form the basis of the plan are not attached. Even when plans are formulated, in most cases, they are not implemented due to budget problems.
- Flow meters for measuring the inflow rate into distribution reservoirs have not been installed, so it is not possible to check the water leaks that occur in service pipes.
- There is no equipment such as water leak detectors, water pressure meters (manometers), etc.

5-Year Strategic Action Plan for NRW Reduction

Gr No.	Components	Sub Gr No.	Countermeasures	Specific actions	Budget	Responsible TEAM for Specific actions					Priority	Necessary Resources	Period	Total amount (RWF)	Implementation Schedule and Estimated Budget																Comments
						Respon-sible UNIT	Action Section/Branch								2017/2018												2018/2019	2019/2020	2020/2021	2021/2022	
															1st Year												2nd Year	3rd Year	4th Year	5th Year	
															Jul	Aug	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June					
A. System Input Volume																															
A1	Volume input metering accuracy	A1.1	Establish the framework to ensure the system volume input accuracy	Inventory of bulk meters (GIS, Esri, Survey)	NRW	NRW	Production	Distribution	-	-	High	NA	already available	-	x																
				Set up a dedicated and experienced team to visit, analyze and report all bulk meters condition (meter age, size, installation, etc..)	NRW	NRW	NRW	Metering	Production	Distribution	High	NA	1 month	-	x																
				Visit, analyze and detailed report of all bulk meters condition	NRW	NRW	NRW	Metering	Production	Distribution	High	Consultant, Staff, Logistics	3 months	2,880,000		960,000	960,000	960,000													JICA expert will be required
				Installation of new meters / Replacement of faulty bulk meters / correcting of meters installation based on the result of meter condition analysis	NRW	NRW	NRW	Metering	Production	Distribution	High	Staff, Bulk meters, Fittings, Logistics	5 months	204,000,000					41,000,000	41,000,000	41,000,000	41,000,000	40,000,000								This amount has been budgeted for the FY2017-2018
				Prepare a plan for bulk meter regular check up for the future.	NRW	NRW	NRW	Metering	Production	Distribution	High	Staff	1 month	-				x													
				Implementation of the plan for bulk meter regular check up for the future.	NRW	NRW	NRW	Metering	Production	Distribution	High		Regular	-					x	x	x	x	x	x	x	x	x	x	x	x	bulk meter check up will be yearly
				Bulk meter reading and analysis	NRW	NRW	NRW	Production	Distribution		High		Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	bulk meter readings should be monthly
A2	Water production (prevent intermittent supply)	A2.1	Increase water production to ensure Continuous supply for proper flow and pressure management	Assessment of water supply gap	UP	UP	UP	-	-	-	High	General expenses	already available	-	x																Increase of the production is very key for NRW reduction activities but this task is currently being implemented using development budget
				Identify project to address the current gap and future demand	UP	UP	UP	-	-	-	High	General expenses	already available	-	x																
				Implement of the identified project (Construction of new WTP, upgrade existing WTP, forwarding infrastructures and the Network)	WO	WO	Production	-	-	-	High	Development budget	on going	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Install backup generators at critical WTP and pumping station (Long term)	WO	WO	Production	-	-	-	Medium	Development budget	2 years	-															x	x	
B. Commercial Losses																															
B1	Meter reading and billing	B.1.1	Ensure correct and 100% customers meter reading	Sensitization of CFO's about the importance of accurate readings through workshops	RM	RM	Billing	Branches	-	-	High	Staff, Logistics	Regular	15,000,000				2,500,000						2,500,000			2,500,000	2,500,000	2,500,000	2,500,000	Twice a year
				Train CFO how to use map in meter reading	RM	RM	Billing	Branches	-	-	High	Staff, Logistics	3 months	720,000					240,000	240,000	240,000										
				Enforce billing supervision at branch level by recruiting billing and revenue collection supervisors	RM	RM	Billing	Branches	-	-	High	General expenses	2 months	-						x	x										
				Regular Random re-reading of customer meters (by the branch management and also the senior management)	RM	RM	Billing	Branches	-	-	High	NA	Continuous	-						x	x	x	x	x	x	x	x	x	x	x	Activity in progress
				Make the business case for outsource meter reading	RM	RM	Billing	Branches	-	-	High	NA	2 months	-						x	x										
		B.1.2	Ensure Customer meter accuracy	Make a plan for Regular meter accuracy test.	CSM	CSM	Metering	Branches	-	-	High		1 month	-						x											
				Implement of the plan for Regular meter accuracy test.	CSM	CSM	Metering	Branches	-	-	High	Staff, Equipment, Logistic	Regular	4,800,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	85,000	1,000,000	1,000,000	1,000,000	1,000,000	Meter test by test bench & portable test meter
				Procure additional Portable meter test equipment (at least 1 per branch)	CSM	CSM	Metering	-	-	-	High	Meter test equipment	6 months	120,000,000		x	120,000,000														Procurement of portable test meters budgeted for FY2017-2018
				Replace default and old meters	CSM	CSM	Metering	Branches	-	-	High	Meters, Staffs, Logistics	continuous	2,108,228,581	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	15,000,000	450,000,000	479,250,000	510,401,250	543,577,331	15000 meters /year
				Procure and install one water test bench per province	CSM	CSM	Metering	-	-	-	Low	Meter test bench	1 year	200,000,000																200,000,000	Estimated 50 Million for 1 meter test bench
		B.1.3	Improve technology and equipment for meter reading and billing	Procure portable bills printers	CSM	DCS	Metering	ICT	-	-	High	Printers and accessories	6 months	92,000,000		x	x	92,000,000													Budgeted for FY2017-2018
				Exposure visit for success stories and adapt if necessary	CSM	DCS	Metering	ICT	-	-	High	Staff, Logistics	1 months	8,000,000							8,000,000										The exposure visit can be organize in the region or other African countries
				Automatic meter reading or prepaid meters for big customers	CSM	DCS	Metering	ICT	-	-	High	Meters, Staffs, Logistics	1 years	200,000,000													200,000,000				
		B.1.4	Monitoring of customer consumption trends	Analysis of customer consumption Database	RM	RM	Billing	Branches	-	-	High	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	monthly analysis should be done
				Plan and visit customer with irregular consumption	RM	RM	Billing	Branches	-	-	High	General expenses	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Analysis of estimated/constant bills	RM	RM	Billing	Branches	-	-	High	General expenses	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Weekly meter reading for big customers (at least 200 big customers)	RM	RM	Billing	Branches	-	-	High	General expenses	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x					Routine activity
				Regular follow up of big customers	RM	RM	Billing	Branches	-	-	High	General expenses	Regular	-													x	x	x	x	After installation of prepaid meters
B2	Customers meter management (normal, larges and public tap)	B2.1	Continue customer mapping and inventory	Complete customer inventory and mapping in Upcountry Branches	RM	RM	Billing	Branches	GIS	ICT	High	Consultant, GIS staff, logistic	6 moths	-	x																On going activity
				Set up and implement a clear customer database update procedures in GIS and CMS	RM	RM	Billing	Branches	GIS	ICT	High	GIS staff	2 moths	-		x	x														
		B2.2	Ensure the quality of meter installation and replacement	Update meter installation and replacement policy	CSM	CSM	Metering	-	-	-	High	NA	2 months	-		x	x														2 months for policy set up and Continuous implementation
				Implement meter replacement according to the replacement policy	CSM	CSM	Metering	Branches	-	-	High		Regular	-			x	x	x	x	x	x	x	x	x	x	x	x	x	x	Routine activity
				Supervision and inspection of meter installation for new connection works	CSM	CSM	Metering	Branches	-	-	High	General expenses	Continuous	-		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	Routine activity
		B2.3	Reinforce public tap management	Public tap inventory and assessment of their condition (meter ,location ,etc..)	RM	RM	Metering	Branches	GIS	-	High	General expenses	2 months	-		x	x														
				Review the existing public tap management procedures	RM	RM	Metering	Branches	-	-	High	NA	1 month	-				x													
B3	Illegal Connection (illegal water use)	B3.1	Prevention of illegal water usage	Raise staff and community awareness through workshops, media show	NRW	NRW	Inspe. & Enforce.	-	-	-	High	Staff, Logistics	Regular	25,000,000						2,500,000						2,500,000	5,000,000	5,000,000	5,000,000	5,000,000	Twice an year workshop/tv show should be organized
				Enhance Incentive for informers (including staff)	NRW	NRW	Inspe. & Enforce.	-	-	-	High	Informers incentives	Continuous	5,800,000	50,000	50,000	50,000	50,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	1,200,000	1,200,000	1,200,000	1,200,000	Assume 2 reported illegal cases per months
				Inspection of suspected customer's and large consumer's connections based on customer data analysis	NRW	NRW	Inspe. & Enforce.	Branches	-	-	High	Staff, Logistics	Regular	13,300,000	125,000	125,000	125,000	125,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	2,700,000	2,700,000	2,700,000	2,700,000	
				Installation of meter protection boxes for suspected customers	CSM	CSM	Metering	Branches	-	-	High	Staff, Logistics	Regular	4,000,000			400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000					
				Complete disconnection of confirmed inactive customers	RM	RM	Billing	Branches	-	-	High	General expenses	continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
		B3.2	Charge fines for confirmed illegal	Disconnection of confirmed illegal cases	RM	RM	Billing	Inspe. & Enforce.	Branches	-	High	Staff, Logistics	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	

			water usage customers	Monitoring of fines payment	***NRW***	***NRW***	*Inspe. & Enforce.*	*Branches*	-	-	High	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
C. Physical Losses																															
C1	Pressure management	C1.1	Determination of high pressure zones	Review, analysis and regular update of existing map of water network, pumping station ,WTP installations, etc..	***WO***	***WO***	*GIS*	-	-	-	High	General expenses	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	There should be hard copy showing the situation before and after changes
				Hydraulic calculation and modeling	***WO***	***WO***	*GIS*	-	-	-	High	General expenses	Regular	-		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Identification, mapping and dissemination of higher pressure zones	***WO***	***WO***	*GIS*	-	-	-	High	GIS staff	1 year	-			x	x	x	x	x	x	x	x	x	x					
		C1.2	Determine the acceptable pressure range in the network and customer tap	Make a survey on the existing pressure in the network and on customer taps	***NRW***	***NRW***	*LD&PM*	-	-	-	High	Staff, Logistics	2 months	3,360,000				1,680,000	1,680,000												
				Propose the acceptable pressure range considering our local conditions	***NRW***	***NRW***	*LD&PM*	*Distribution*	-	-	High	Staff	3 months	-						x	x	x									
		C1.3	High pressure zones survey (from hydraulic analysis)	Identification of place to install pressure gauges ,dataloggers	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	*GIS*	High	Staff, Logistics	3 months	-									x	x	x	x	x				
				Procure and install pressure gauges in the network	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	*GIS*	High	Staff, Pressure gauges, Logistics	2 years	20,000,000													10,000,000	10,000,000			at least 10 gauges / branch
				Follow-up and Analysis of pressure measurement results	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	Staff, Logistics	Continuous	-						x	x	x	x	x	x	x	x	x	x	x	
		C1.4	Proper pressure management	Inventory of existing PRVs, Break Pressure Tanks (BPT)	***WO***	***WO***	*Distribution*	*LD&PM*	*GIS*	-	High		2 months	-	x	x															
				Identification and prioritization of actions to address pressure issues	***NRW***	***NRW***	*LD&PM*	*Distribution*	-	-	High	Staff	3 months	-		x	x	x													
				Set up a plan for pressure management	***NRW***	***NRW***	*LD&PM*	*Distribution*	-	-	High	Staff	3 months	-		x	x	x													
				Implementation of pressure management plan (PRV, BPT, rearrangement of pumping stations and pipeline network)	***NRW***	***NRW***	*LD&PM*	*Distribution*	-	-	High	Staff, Pressure reducer equipment, Logistics	Regular	324,800,000			5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	67,200,000	67,200,000	67,200,000	67,200,000	24 PRV will be installed in year one as planned in the 2017-2018 action plan
				Continuous pressure control	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	Staff, Logistics	Continuous	-			x	x	x	x	x	x	x	x	x	x	x	x	x	x	
C2	Asset Management (Rehabilitation)	C2.1	Asset data management by GIS	Inventory, drawing and mapping of water facilities	***WO***	***WO***	*GIS*	-	-	-	High	Consultant, GIS staff, Logistic	1 year	-	x	x	x	x	x	x	x	x	x	x	x	x					On going activity (Esri project)
				Regular update of GIS data	***WO***	***WO***	*GIS*	-	-	-	High	General expenses	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
		C2.2	Network maintenance and rehabilitation	Inventory of infrastructures to be rehabilitated	***WO***	***WO***	*Distribution*		-	-	High		3 months	-	x	x	x														
				Analysis for optimal use of water infrastructure	***WO***	***WO***	*Distribution*	-	-	-	High	GIS staff, Logistics, GIS software	2 moths	-	x	x															Eg. pipe replacement ,
				Prioritization of areas for rehabilitation	***WO***	***WO***	*Distribution*	-	-	-	High	Staff	Yearly	-		x	x										x	x	x	x	
				Preparation of maintenance and rehabilitation plan	***WO***	***WO***	*Distribution*	-	-	-	High	Staff	Yearly	-		x	x										x	x	x	x	
				Implementation of the maintenance and rehabilitation plan	***WO***	***WO***	*Distribution*	-	-	-	High	Staff, Material, Logistics	Continuous	750,000,000			13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	155,000,000	155,000,000	155,000,000	155,000,000	we referred to the rehabilitation budget allocated to the FY2017-2018
				Monitor and evaluation of the implementation of the maintenance plan	***WO***	***WO***	*Distribution*	-	-	-	High	Staff, Logistics	Continuous	2,400,000						240,000						240,000	480,000	480,000	480,000	480,000	twice a year
		C2.3	Infrastructure protection	Installation of protective facilities (manhole covers , fences …)	***WO***	***WO***	*Distribution*	*Branches*	-	-	Low	Staff, Protective equipment, Logistics	Continuous	15,000,000						1,500,000						1,500,000	3,000,000	3,000,000	3,000,000	3,000,000	mainly installation of air valves
				organize public awareness for infrastructure protection against vandalism	***WO***	***WO***	*Distribution*	*Metering*	*Branches*	-	Low	General expenses	Regular	-							x						x	x	x	x	Once a year
C3	Leaks and burst repair	C3.1	Quick and good quality repairs	Sensitization for leak reporting (meeting , TV show , rewarding informers , etc..)	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	NA	Regular	10,000,000							2,000,000						2,000,000	2,000,000	2,000,000	2,000,000	Once a year
				Daily monitoring of leaks reported and repair (wtsp, LIS)	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	General expenses	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Avail minimum stock at the branch level	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	NA	1 year	-		x	x	x	x	x	x	x	x	x	x	x					availability of material is Continuous process
				Regular inspection of leaks repaired	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	General expenses	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Dissemination of standard for leak repair	***QA***	***QA***	*Standard*	*NRW*	-	-	High	NA	Continuous	-			x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Train staff for leak repair	***NRW***	***NRW***	*LD&PM*	*Branches*	-	-	High	Staff, Logistics	Continuous	15,000,000			3,000,000										3,000,000	3,000,000	3,000,000	3,000,000	once a year
		C3.2	Active leakage control	Make historical analysis of leakages (location, diameter, material etc..)	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Prepare an yearly plan of visible leakage and invisible survey (including reservoir)	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	NA	Regular	-	x												x	x	x	x	
				Implement the yearly plan of visible leakage survey (including reservoir)	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	General expenses	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2160000
				Train staff for leakage survey and leak detection	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	Staff, Logistics, Equipment	Regular	15,000,000			3,000,000										3,000,000	3,000,000	3,000,000	3,000,000	JICA NRW Project
				Procure and dispatch leak detection equipment to branches	***NRW***	***NRW***	*LD&PM*	*Branches*	-	-	High	Leak detection equipment	2 years	400,000,000														200,000,000	200,000,000		Leak detection for branches
				Select critical areas to detect invisible leaks	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	NA	Continuous		x												x	x	x	x	Analysis and survey are required.
				Conduct leak detection activities in all branches and make estimation of water lost through leakages	***NRW***	***NRW***	*LD&PM*	*Distribution*	*Branches*	-	High	Staff, Logistics, Equipment	Continuous	2,160,000	x	x	x	x	x	x							2,160,000	x	x	x	year 1 HQ staff to be trained by JICA . For next years HQ staff will train branches staff
		C3.3	Establish water supply monitoring system (DMA, SCADA ,etc..)	Complete the isolation of Kigali branches	***NRW***	***NRW***	*LD&PM*	*GIS*	*Distribution*	*Branches*	Middle	Staff, Equipment	1 year	-	x	x	x	x	x	x	x	x	x	x	x	x	x				Ongoing activity (JICA NRW Project)
				Creation and management of DMA within branches	***NRW***	***NRW***	*LD&PM*	*GIS*	*Distribution*	*Branches*	Middle	Development budget	Continuous								x	x	x	x	x	x	x	x	x	x	Can be financed by the development budget
				Establish a network monitoring system including reservoirs	***NRW***	***NRW***	*LD&PM*	*GIS*	*Distribution*	*Branches*	Middle	Development budget	5 years	-													x	x	x	x	Can be financed by the development budget
		C3.4	Reporting and recording of leakages	Review and harmonize leaks reporting and repairs format	***NRW***	***NRW***	*LD&PM*	*GIS*	*Distribution*	*Branches*	High	NA	3 months	-	x																
				Daily report of leakages with Location, diameter , materials and so on	***NRW***	***NRW***	*LD&PM*	*GIS*	*Distribution*	*Branches*	High	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	Routine activity
D. Unbilled Authorized Consumption																															
D1	Unbilled metered authorized consumption	D1.1	Ensure proper fire hydrant management	General inventory of all fire hydrants and confirmed if metered and billed	***RM***	***RM***	*Billing*	*Metering*	*Distribution*	*Branches*	High	General expenses	2 months	-	x	x															
				policy establishment for fire hydrants installation and management	***RM***	***RM***	*Billing*	*Metering*	*Distribution*	*Branches*	High	NA	1 month	-			x														
				calculation and analysis of water used by fire hydrants	***RM***	***RM***	*Billing*	*Metering*	*Distribution*	*Branches*	High	NA	Regular	-			x	x	x	x	x	x	x	x	x	x	x	x	x	x	
D2	Unbilled unmetered authorized consumption	D2.1	Have a plan for network and reservoirs flushing	Preparation of network flushing plan	***WO***	***WO***	*Distribution*	*Branches*	-	-	Low	NA	Regular	-	x												x	x	x	x	Every year
				Implementation of the network flushing plan	***WO***	***WO***	*Distribution*	*Branches*	-	-	Low	General expenses	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Estimation of water uses in network flushing , reservoir cleaning	***WO***	***WO***	*Distribution*	*Branches*	-	-	Low	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	Monthly report
E. Fundamental Measures																															
E1	GIS and CMS database	E1.1	link GIS and Customer Management System (CMS)	Harmonize customer data in GIS and CMS	***WO***	***WO***	*GIS*	*ICT*	*RM*	-	High	NA	1 year	-	x	x	x	x	x	x	x	x	x	x	x	x					
				Regular updates of both Systems (GIS, CMS) simultaneously	***WO***	***WO***	*GIS*	*ICT*	*RM*	-	High	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
		E1.2	Avail GIS staff up to branch level	Recruit and affect GIS staff in branches	***HR***	***HR***	*HRM*	-	-	-	Low	General expenses	1 year	-														x			
				Train branch GIS staff	***NRW***	***NRW***	*GIS*	*Branches*	-	-	Low	Staff, Logistics	Continuous	15,000,000						1,500,000						1,500,000	3,000,000	3,000,000	3,000,000	3,000,000	
		E2.1	Develop long term master plan of water network	Prepare a study of WASAC water network master plan	***UP***	***UP***	*UP*	-	-	-	High	Development budget	2 years	-	x	x	x	x	x	x	x	x	x	x	x	x	x				The preparation and elaboration of Kigali water supply and sanitation master
				Elaboration of WASAC water network master plan	***UP***	***UP***	*UP*	-	-	-	High	Development budget	2years	-													x				
				Implementation of the water network master plan	***UP***	***UP***	*UP*	-	-	-	High	Development budget	Continuous	-													x	x	x	x	

E2	Planning, design and implementation of quality works	E2.2	Disseminate existing standard of design and installation of water works	Inventory of all standards and design available	***QA***	***QA***	*Standard*	-	-	-	High	NA	1 month	-		x															
				Procure missing needed standards	***QA***	***QA***	*Standard*	-	-	-	High	General expenses	2 months	-			x	x													
				training and workshop for Dissemination of standards of design and installation	***QA***	***QA***	*Standard*	-	-	-	High	Staff and logistics	1 months	9,000,000					3,000,000										3,000,000	3,000,000	
		E2.3	Ensure the quality of designs and water works	Establish and maintain material specification (meter, pipes, fittings, etc..)	***QA***	***QA***	*Standard*	*Metering*	*Distribution*	*Branches*	High	NA	2 months	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Establish design validation procedures	***QA***	***QA***	*Standard*	-	-	-	High	NA	1 year	-	x	x															
				Set up an inspection team for works standard compliance	***QA***	***DUWSS***	*Standard*	-	-	-	High	NA	1 month	-			x														
				Technician certification for specific works (connection, repair, extension, etc. …)	***HR***	***HR***	*Standard*	*Metering*	*Distribution*	*Branches*	Low	NA	Regular	-													x	x	x	x	Internal certification
E3	WASAC NRW management	E3.1	Customize IWA water balance to WASAC (to clear understand NRW components)	Review the existing water balance used	***NRW***	***NRW***	*NRW*	-	-	-	High	NA	1 month	-						x											JICA expert will help
				Approval of component of the water balance	***NRW***	***NRW***	*NRW*	-	-	-	High	NA	2 months	-						x	x										
		E3.2	Ensure proper NRW management in WASAC	Review WASAC NRW structure	***NRW***	***WASAC***	*NRW*	*HRM*	-	-	High	NA	1 months	-	x							x									JICA expert will propose
				Review WASAC NRW reduction target	***NRW***	***WASAC***	*NRW*	-	-	-	High	NA	Yearly	-	x												x	x	x	x	
				Review the NRW procedure manual	***NRW***	***NRW***	*NRW*	-	-	-	High	NA	1 year	-		x	x	x	x	x											
		E3.3	Mobilize Partners in NRW reduction projects	Identification of different partners intervening in NRW project	***NRW***	***DUWSS***	*NRW*	*UP*	-	-	High	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
E4	Stakeholders management	E4.1	Increase the collaboration with local authorities and other infrastructures development agencies	Organize regular meeting and workshop	***WO***	***WO***	*Distribution*	*NRW*	-	-	Middle	Staff, Logistics	Regular	15,000,000		3,000,000											3,000,000	3,000,000	3,000,000	3,000,000	Once a year
				Prepare and implement MOU with road constructor, Districts and other infrastructures agencies	***WO***	***WO***	*Distribution*	*NRW*	-	-	Middle	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Monitoring of activities	***WO***	***WO***	*Distribution*	*NRW*	-	-	High	NA	Regular	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
		E4.2	Certification of private companies and technicians for specific works (new water works)	Identification ,selection and certification of qualified companies and technicians	***WASAC***	***WASAC***	*DUWSS*	-	-	-	High	NA	Continuous	-													x	x	x	x	From the second year
		E4.3	benchmarking visits in other water utilities	Identification of best practices water utilities companies	***WASAC***	***WASAC***	*DUWSS*	-	-	-	Low	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Preparation of partnership agreement	***WASAC***	***WASAC***	*DUWSS*	-	-	-	Low	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Exposure visits	***WASAC***	***WASAC***	*DUWSS*	-	-	-	Low	Staffs, Logistics	Continuous	15,000,000													7,500,000		7,500,000		Once every two years
		E4.4	Collaboration with research centers and universities	Select research center and universities involved in water sector	***WASAC***	***WASAC***	*DUWSS*	-	-	-	Low	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Prepare and sign partnership agreement	***WASAC***	***WASAC***	*DUWSS*	-	-	-	Low	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
E5	Training	E5.1	Ensure that WASAC have skilled and qualified staff	Assess current staff skill gap (new connection standard , GIS usage, pipe installation, pressure management , etc..)	***WASAC***	***WASAC***	*HR*	-	-	-	High	General expenses	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	JICA experts may support
				Set up appropriate training plan	***WASAC***	***WASAC***	*HR*	-	-	-	High	NA	6 months	-		x	x														
				implement the training plan	***WASAC***	***WASAC***	*HR*	-	-	-	High	General expenses	Continuous	-			x	x	x	x	x	x	x	x	x	x	x	x	x	x	
				Set up an internal knowledge transfers mechanism	***WASAC***	***WASAC***	*HR*	-	-	-	High	NA	6 months	-				x	x	x											
				Monitoring and Evaluation of the change	***WASAC***	***WASAC***	*HR*	-	-	-	High	NA	Continuous	-				x	x	x	x	x	x	x	x	x	x	x	x	x	
		E5.2	Benchmarking of different branches for NRW reduction to enhance NRW performance	Compile and analyze branch NRW report	***WASAC***	***WASAC***	*NRW*	-	-	-	High	NA	Continuous	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	Monthly report
				Set NRW target for Each branch	***WASAC***	***WASAC***	*NRW*	-	-	-	High	NA	2 months	-					x	x											branches NRW targets should be align with company target
				Organize regular meeting with branches	***WASAC***	***WASAC***	*NRW*	-	-	-	High	General expenses	Continuous	-						x						x	x	x	x	x	Quarterly
				Propose incentive measures for NRW reduction	***WASAC***	***WASAC***	*NRW*	-	-	-	High	NA	Continuous	-					x												
E6	Institution	E6.1	Ensure the implementation of the branch new structure	Recruitment of new staff to populate the new structure	***WASAC***	***WASAC***	*DUWSS*	*DCS*	-	-	High	General expenses	6 moths	-							x	x	x	x	x	x					
		E6.2	Reinforce the research and development	Identify area of research and set up the team	***WASAC***	***WASAC***	*DUWSS*	*DCS*	-	-	Low	NA	1 year	-							x	x	x	x	x	x					
		E6.3	Continuous improvement and innovation	Establish the innovation incentive mechanism	***WASAC***	***WASAC***	*DUWSS*	*DCS*	-	-	Low	NA	1 year	-							x	x	x	x	x	x					
E7	Logistic and quality materials	E7.1	Avail enough equipment and logistics (vehicle , motorcycle , tools, protective equipment , etc….)	Inventory of available equipment and logistic facilities at the branch level and determines urgent need	***DSS***	***DSS***	*Admin & Logist*	*DUWSS*	*DCS*	*Branches*	High	NA	3 months	-	x	x	x														
				Procurement of equipment and logistics needed	***DSS***	***DSS***	*Admin & Logist*	*DUWSS*	*DCS*	*Branches*	High	General expenses	2year	-				x	x	x	x	x	x	x	x	x	x				

TOTAL Amount	4,615,448,581	780,740,000	921,740,000	941,330,000	972,981,250	998,657,331	
	US$5,494,582	*US$929,452*	*US$1,097,310*	*US$1,120,631*	*US$1,158,311*	*US$1,188,878*	
WASAC	15,000,000	0	7,500,000	0	7,500,000	0	15,000,000
NRW	1,056,300,000	284,430,000	99,260,000	297,100,000	287,100,000	87,100,000	1,054,990,000
WO	782,400,000	133,480,000	161,480,000	161,480,000	161,480,000	161,480,000	779,400,000
QA	9,000,000	3,000,000	0	0	3,000,000	3,000,000	9,000,000
UP	0	0	0	0	0	0	0
RM	15,720,000	5,720,000	2,500,000	2,500,000	2,500,000	2,500,000	15,720,000
CSM	2,737,028,581	329,670,000	651,000,000	480,250,000	511,401,250	744,577,331	2,716,898,581
Branch	0	0	0	0	0	0	0
HR	0	0	0	0	0	0	0
ICT	0	0	0	0	0	0	0
Ad&Lo	0	0	0	0	0	0	0
	4,615,448,581	756,300,000	921,740,000	941,330,000	972,981,250	998,657,331	4,591,008,581

Responsible Department/ Unit/ Section
Leak detection and pressure management Section: LD&PM
Zoning and mapping Section : GIS
Inspection and Enforcement Section: I&E
Water Production Section: Production
Water Distribution Section: Distribution
Quality Assurance Unit: QA
Utility Planning Unit: UP
Revenue Management Unit: RM
Customer Service Management Unit: CSM
Direction Support Service: DSS
Human Resource Unit: HR
Administration and Logistics Unit: Admi & Logistics

Approach and Methodology

NRW Reduction 5 Year Strategic Action Plan

Root Cause Analysis

- This is effective to have a deep insight and clarify real causes of the current problems
- Based on the analysis, we can propose measures to reduce NRW: Problem-oriented approach

- However, this approach cannot refer to the underlying unknown problems
- It is often the case that the proposed measures are effective but not comprehensive

In our Action Plan, we see below diagram

Problems identification

↓

Root causes analysis

↓

Proposal of counter-measures/strategy

↓

Preparation of Action Plan

- In order to offset adverse facets of the problem-oriented approach, we have applied value chain management at the same time, considering the nature of the NRW reduction
- All people, economy, society, institutions, etc. (stakeholders)
- Behavior and characteristics of these stakeholders has been focused on to clarify critical issues related to NRW

Root cause analysis combined with value chain management?

- A way of building up long-lasting relationship between all stakeholders
- Win-win relationship
- Regard them as ‘value’ or ‘virtue’ who may contribute to NRW reduction directly and indirectly

What is Value Chain Management?

- Keeping in mind stakeholder’s mindset and attitude affects NRW, and
- NRW target cannot be achieved without mutual understanding and trust between WASAC and its stakeholders,

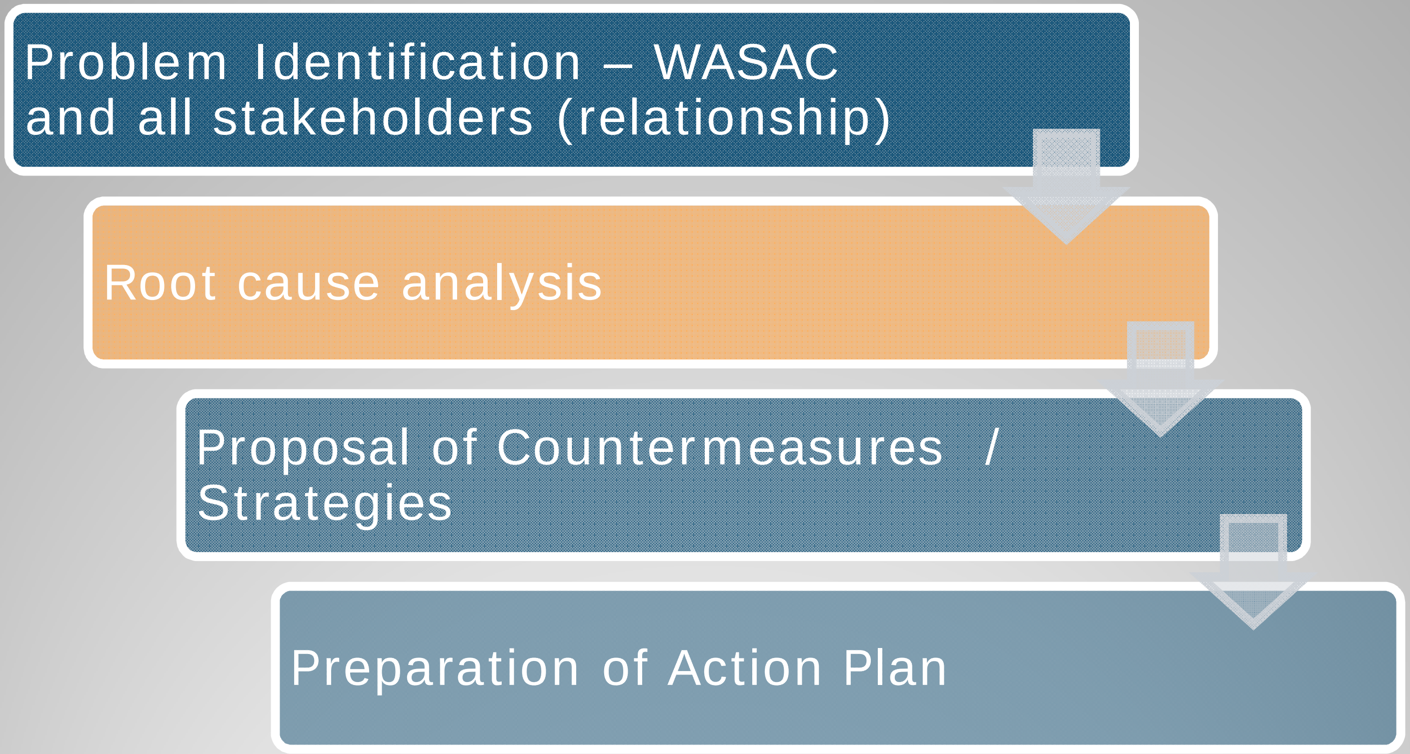
- WASAC shall try to establish the win-win relationship with them
- Not only customers but also non-served population, disconnected customers, utilities, institutions, commerce and industry

- To build up the positive relationship with them, WASAC shall improve its institutional strength in terms of technology, management and administration

How to apply Value Chain Management?

- Root cause analysis and value chain management, which we have actually applied for preparing 5YSAP,
- Deep and comprehensive
- This combined approach does not contradict pro poor policy and sector-wide strategy set forth in 'National Water Supply Policy Implementation Strategy, 2016'
- We have thus identified a variety of measures that enable WASAC to achieve the target NRW rate within the timeframe set up

Our Approach and methodology



Problem Identification – WASAC and all stakeholders (relationship)

Root cause analysis

Proposal of Countermeasures / Strategies

Preparation of Action Plan

Diagram – Approach and Methodology (?)

Thanks for attention

WASAC- NRW REDUCTION
5 YEARS STRATEGIC ACTION PLAN

BAHIGE JB ,

NRW Manager , WASAC ltd

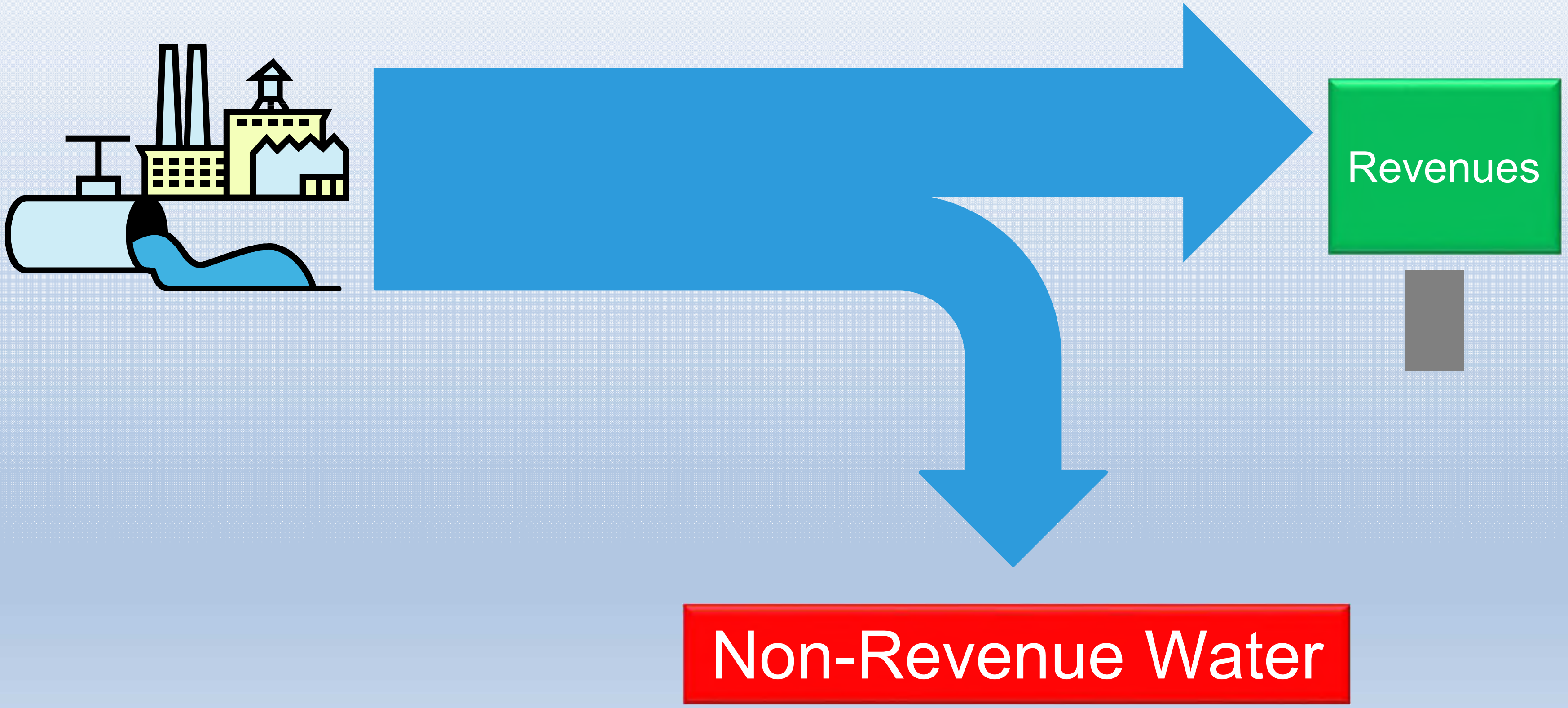
30, 10 2017

Presentation outline

1. NRW definition and Causes
2. IWA Water balance
3. Diagnosis of the Current situation
4. Proposed strategies
5. Detailed action plan
6. Budget

Non-Revenue Water

Non-revenue water (NRW) is the water that has been produced but not billed to the customer



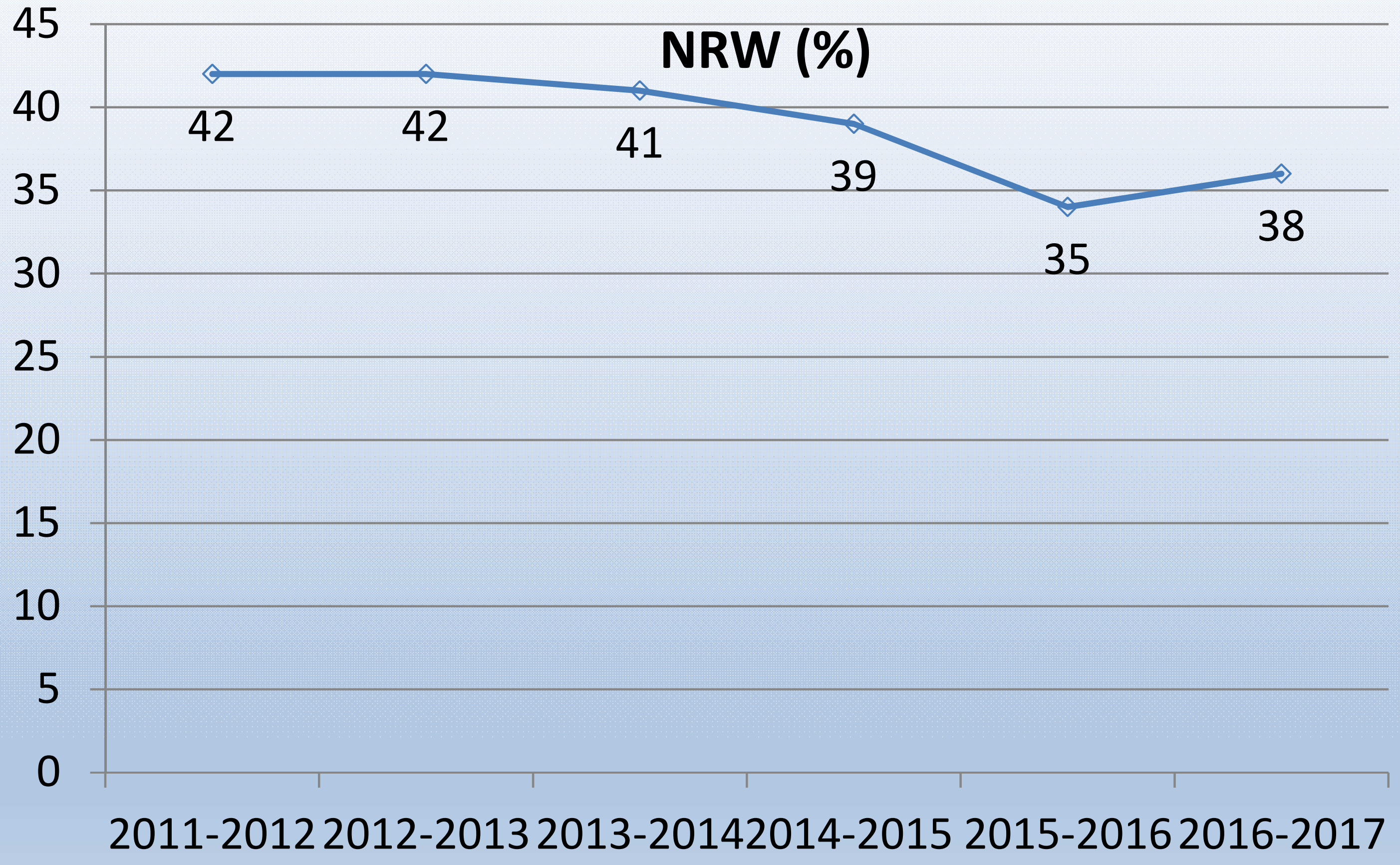
Revenues

Non-Revenue Water

IWA, WATER BALANCE

Supplied Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non Revenue Water
			Unbilled Unmetered Consumption	
	Water loss	Commercial losses	Metering inaccuracies	
			Error in estimation of unmetered consumption	
			Unauthorized consumption	
			Errors linked to the data acquisition processes	
		Technical losses	Leakages on Transmission and Distribution Mains	
			Leakages and Overflows at Storage Tanks	
			Leakages on Service Connections up to point of Customer Meter	

WASAC , NRW trend (2011-2017)



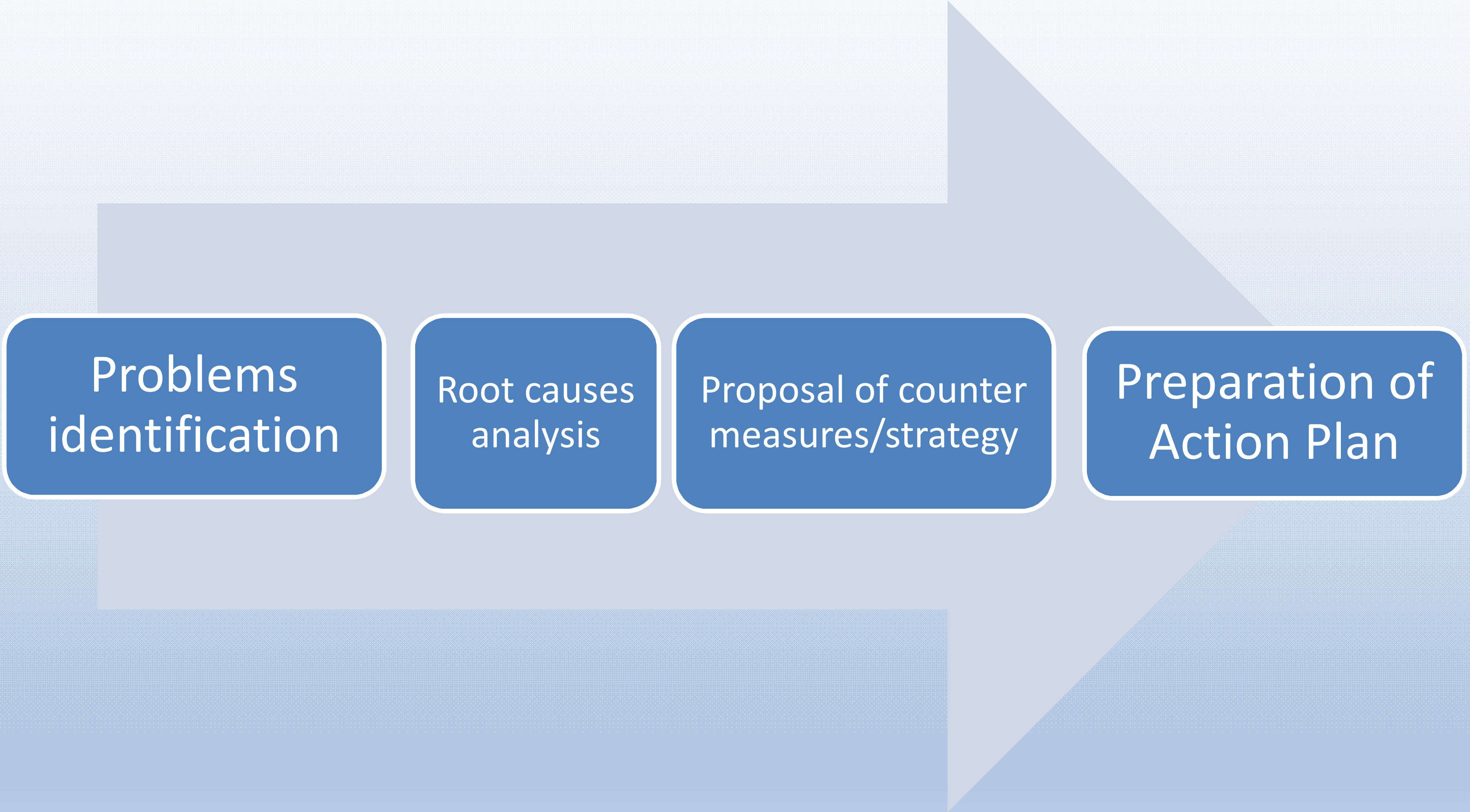
NRW target

Financial year July to June	5 Year Strategic Business Plan	Target value of 5 Year Strategic Business Plan	Implementation Year of 5YSAP	Phase of 5YSAP	Actual NRW level value %	Proposed New NRW rate
2015/16	Year 1	38%			35.5%	
2016/17	Year 2	32%		Preparation	38.3 %	38.3%
2017/18	Year 3	28%	Year 1	Phase 1		35%
2018/19	Year 4	26%	Year 2	Phase2		32%
2019/20	Year 5	25%	Year 3			30%
2020/21			Year 4			28%
2021/22			Year 5			25%

5YSAP OBJECTIVES

- ☐ Holistic planning and implementation of NRW reduction measures
- ☐ “Preventive Action” and not “Reactive” currently
- ☐ Sustainability of activities
- ☐ Clear Mechanism to effectively monitor NRW programs
- ☐ Capacity building
- ☐ NRW reduction

5YSAP – PREPARATION



Problems identification

Root causes analysis

Proposal of counter measures/strategy

Preparation of Action Plan

WASAC
Water & Sanitation Corporation
Dignifying life

Problems Identification (Technical)

Leaks and burst

- Time response to leaks repair still high:
- Insufficient Leak survey and detection activities
- Sometimes Poor quality of repairs and material
- High pressure in the network

Design and mapping

- GIS data not yet completed updated and linked with the billing system
- Design of water network need some improvement

Standard

- Less of on-site work and material standard inspection
- Poor quality of materials purchased by customers
- Sometimes no compliance of standard (house connections, material ,trenching and backfilling

Asset management

- Aged pipes and less protective equipment
- Preventive maintenance plan not fully implemented
- Pipe replacement planned but not fully implemented

Problem Identification (Commercial)

Billing

- Less field inspection by billing Officer and Commercial services staff
- Some Customers not billed

Data acquisition and analysis

- Error in data acquisition (meter reading)
- Insufficient data analysis (consumption, billing, zero consumption, etc..)
- Under estimation of consumption

Metering

- Many aged water meters
- Customer meter accuracy test not practiced on-site
- Water meter blocked by solid particles

unauthorized consumption

- Less inspection of customer installation
- Illegal water use cases
- Illegal water use to disconnected customers (inactive connection)

Problems Identification (ADMISTRATIVE)

WASAC

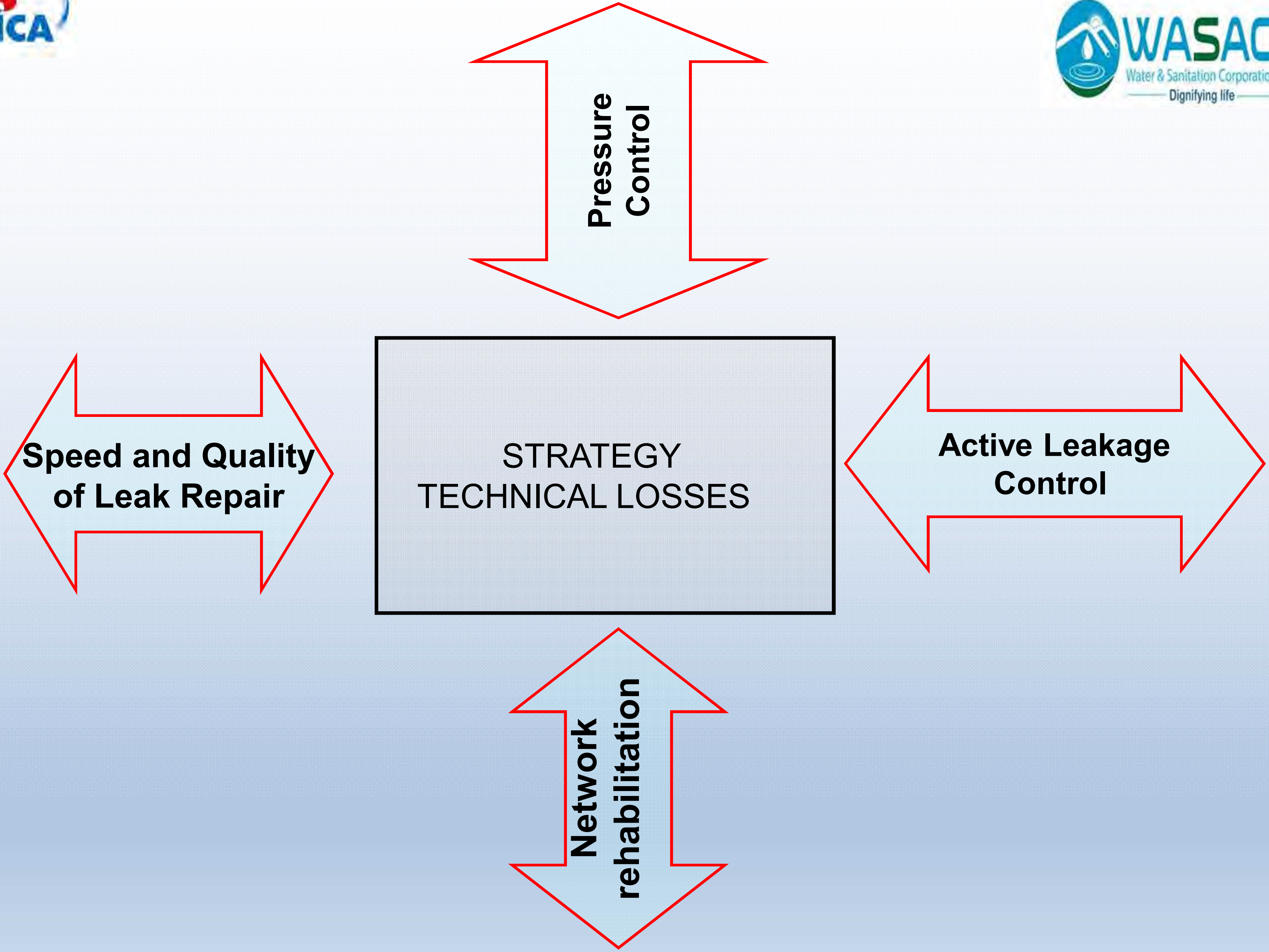
- Budget constraint
- Insufficient logistic means
- Branch structure not really responsive

CUSTOMERS

- Customers awareness on NRW still not sufficient
  - Vandalism
  - Illegal water usage

OTHER STAKEHOLDERS

- Poor quality of work done by some contractors
- Lack of stakeholder awareness on NRW
- Pipe damaged other infrastructures developers (road construction, telecommunication , etc..)



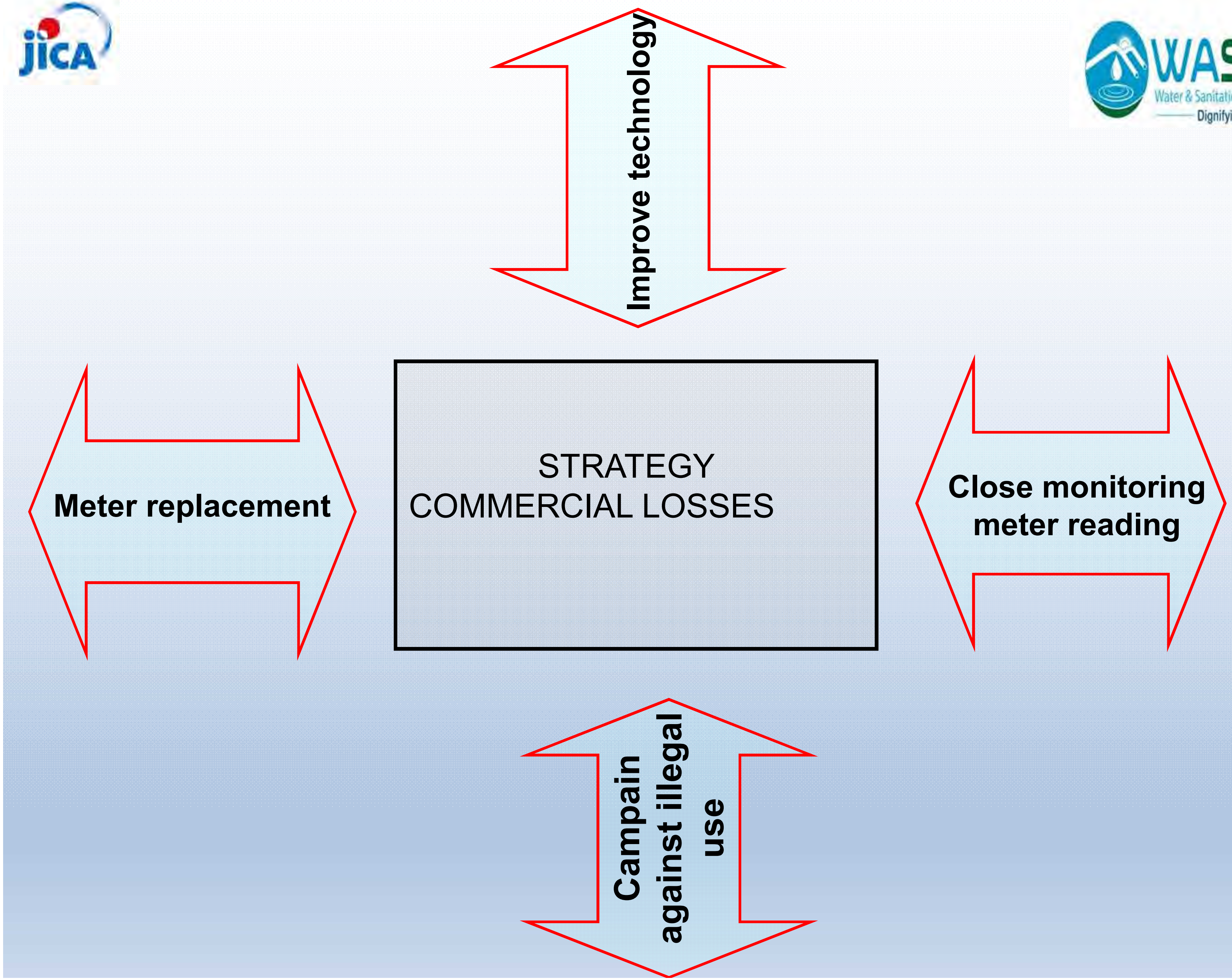
STRATEGY
TECHNICAL LOSSES

Pressure Control

Speed and Quality of Leak Repair

Active Leakage Control

Network rehabilitation



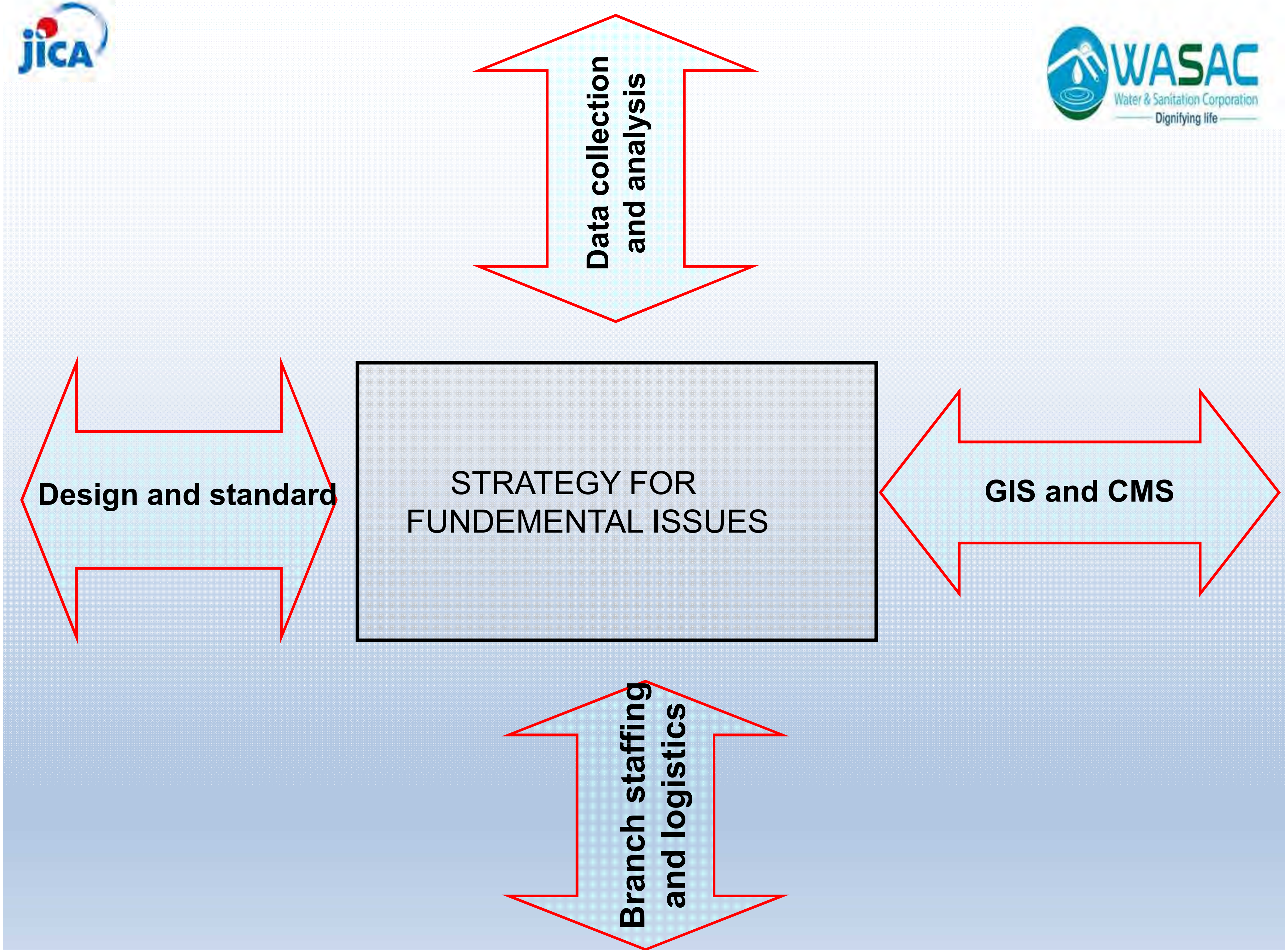
STRATEGY
COMMERCIAL LOSSES

Improve technology

Meter replacement

Close monitoring meter reading

Campaign against illegal use



Data collection and analysis

Design and standard

STRATEGY FOR FUNDEMENTAL ISSUES

GIS and CMS

Branch staffing and logistics

Detailed Action Plan

- Final table 5YSAP 28082017.xlsx
- Implementation Plan for 5YSAP 27102017.xlsx

5YSAP –BUDGET ESTIMATION

Fiscal Year	Estimated Budget	Note
2017/2018	780,740,000	Phase one
2018/2019	921,740,000	
2019/2020	941,330,000	
2020/2021	972,981,250	
2021/2022	998,657,331	
Total	4,615,448,581	

Cost benefit Analysis

		2017/2018	2018/2019	2019/2020	2020/2021	2021/2022
System input volume		46,423,780	48,744,969	51,182,218	53,741,329	56,428,395
NRW ratio	Without NRW reduction	38%	38%	38%	38%	38%
	With NRW reduction	35%	32%	30%	28%	25%
	Difference	3%	6%	8%	10%	13%
Volume saved		1,531,985	3,070,933	4,248,124	5,535,357	7,504,977
Average tariff		500	500	500	500	500
Revenue increment		765,992,500	1,535,466,500	2,124,062,000	2,767,678,500	3,752,488,500

Implementation and monitoring team

- ☐ The DUWSS and Commercial directorates are key for the implementation of this 5YSAP.

- ☐ The support services and finance directorate should ensure the full support for the implementation of this 5YSAP.

- ☐ The unit/section and team mentioned for specifics actions are directly responsible of their implementation.

- ☐ The NRW unit will be the driving force for the implementation of all planned activities
- ☐ The monitoring of the implementation will be done quarterly

Next step

☐ Presentation and the Approval of the 5YSAP by WASAC Management (End October 2017)

☐ Present this 5YSAP to branches staffs (branches visit to present the documents)

☐ Share the document with other stakeholder

☐ Implementation of the 5YSAP and close monitoring

Key Implementation success factors

- Top management involvement and support
- Budget and logistics available
- Change of attitude and mindset
- Close Monitoring
- Strong commitment and engagement from Branches

Thank you

REVISED WORK PLAN (Output 3)

- Procedures, Duration and Specific Activities for NRW Reduction

This work plan is the updated version of the previous plan to summarize approach and procedures for NRW reduction at the selected pilot areas in Kigali city, focusing on time duration, procedures and specific activities required. Minor amendment was made reflecting recent activities and findings by WASAC and JICA Team. Attachment-1 attached hereto is the detailed work schedule for implementing the NRW reduction (Output 3).Attachment-2 exhibits our revised work flow diagram for NRW reduction.

Phase I Activities

1. Organization of an action team and preparatory work for NRW reduction
   (1) Duration: August 15, 2016 to February28, 2016
   (2) Specific activities: selection of pilot areas, field surveys to confirm hydraulic isolation of the pilot areas, analyses of customer database, GIS data review, customer surveys, commercial and physical loss reduction, registration of illegal water users, flow measurement for obtaining NRW rate, cost-benefit analysis, etc. as outlined below.

2. Construction of Pilot Area 1 (KADOBOGO)and Area 2 (RUYENZI) for Isolation
   (1) Duration: December 1, 2016 to June 30, 2017
   (2) Specific activities:
   1) Review of GIS pipeline database,
   2) Field surveys for confirmation of pipeline alignment,
   3) Pressure test at the inlet mains,
   4) Hydraulic separation of the Pilot Area and installation of boundary valves for establishment of subzone areas, and
   5) Construction of flow meter chambers with necessary appurtenances at the inlets of the Pilot Areas, including flow meters, gate valves, flange adapters, manhole cover, and pressure gauges.

Phase II Activities

3. NRW measurement, reduction at the Pilot Areas and additional flow measurement surveys at Kigali whole service area (12 selected tertiary mains)

   (1) Duration: July 1, 2017 to June 30, 2018
   (2) Specific Activities:

1) Organization of survey teams

To carry out NRW reduction in an effective and efficient way, survey teams shall be organized on a timely manner as well as proper procurement of materials, equipment, tools and vehicles required. Tentative schedule, work period, and outline survey teams are summarized in Table below and also given in Attachment-3 Survey Team and Equipment.

Table-1 Survey Team Organization

Work	Baseline NRW Rate 1) Confirm isolation 2) Measure monthly inflow rate 3) Tertiary pipe survey 4) Measure leakage vs pressure	Commercial (Apparent) Loss Reduction 1) Customer survey 2) Survey on non-served households 3) Calibrate meters by test meters and/or test bench 4) Replace meters 5) Data update & analysis 6) NRW rate	Surface (Visible) Leakage Reduction 1) Pipeline survey 2) Leakage repair 3) NRW rate	Invisible (Underground) Leakage Reduction 1) Step test & analysis 2) Leak detection 3) Leak repair 4) Data compilation & analysis	Endline NRW Rate, Analysis & Workshop 1) Flow measurement 2) NRW rate 3) NRW analysis 4) Prepare manuals & propose measures 5) Prepare materials for Workshop 6) Organize/carry out workshop/seminar
Period	2.0 months (continuing from Phase I) July – August 2017	3.5 months Sep – Mid Dec 2017	2.0 month Mid Dec – Mid Feb 2018	2.5 months Mid Feb – April 2018	2.0 months May – Jun 2018
Nos. of Teams	1 team	2 teams each for S & R	2 teams	2 teams	1 team
Technicians	1 + 2	Total S: 1+ 2 + 2	1	1	1 + 3 engineers
Plumbers	1	Total R: 2 + 2	1 + 1	1 + 1	All plumbers for workshop
Workers	1	2 each for S & R	2 + 2	2 + 2	None
Total	5	13 in Total: 7 for S & 6 for R	7	7	4 engineers for analysis & all plumbers for workshop

WASAC branch office and HQ are responsible for the survey teams' organization throughout the project period. Manpower input will be maximized during the period of "Commercial Loss Reduction", requiring 5 technicians, 4 plumbers, and 4 unskilled labors, organized into 4 teams.

2) Confirmation of hydraulic isolation by closing valves

It is important to confirm complete hydraulic isolation of the area. By closing all boundary valves, the isolation of the pilot areas shall be confirmed before initiation of the NRW reduction. Otherwise, the entire activities would be falsely managed resulting in fundamental errors.

3) NRW measurement at Pilot Areas 1 and 2 for 2 months to obtain baseline NRW rate (Actually for 3 months as started from 1 June, and expected to complete by the end of 31 August)

All mechanical flow meters installed on the inlets to Kadobogo and Ruyenzi areas will be monitored for logging at a proper interval (every week/month). Measurement results are compared to metering/billing records obtained in the same period to compute the baseline NRW rate, one of key performance indicators.

4) Three types of NRW Reduction

We plan to demonstrate three types of NRW reduction, a. "Survey Based on JICA SW", b. "Step Test", c. "Tertiary Main Survey". They have their own characteristics as summarized in the table below.

Table-2 Three Types of Survey Method

NRW Reduction	a. Survey Based on JICA SW	b. Step Test	c. Tertiary Main Survey
1. Survey concept/method	By cause	By area (subzone)	By pipe
2. Survey area	Whole pilot area	Whole pilot area	Representative short length of tertiary mains
3. Nature	Full-fledged NRW reduction	Preliminary	Preliminary
4. Data Required	Pipe network and customer and non-served population	Customer information by subzone	Customer information in the survey area
5. Period Required	Long period	Relatively short	Relatively short
6. Materials required	Pipes and meters for replacement	Valves and pipes for isolation	No materials
7. Possible combination	a+b, a+c	a+b	a+c

5) Outline of the tertiary main survey in Kadobogo area (two survey areas) and in Kigali service area (ten survey areas), 12 survey areas in total

As stated above, flow measurement at twelve(12) survey areas selected from whole service area in Kigali, will be carried out to obtain average rate of NRW taking place at tertiary mains and service piping including customer meters. In this procedure, flow rate measurement by ultrasonic flow meters installed on tertiary main inlets for 24 hours will be compared to customers' water consumption obtained by on-site customer meter reading at the survey area. Furthermore, actual physical leakage rate can be obtained, by closing all customers' stop cocks and by gauging the inflow rate at the tertiary main inlets simultaneously. Number of target customers contained in each survey area may be around 30-50.

The baseline NRW rate may contains NRW at all pipe network, while the above rate represents a basis for the average NRW at tertiary mains and service pipelines in Kigali city. The balance between the baseline NRW rate and the above, hence, stands for the average NRW at the remaining primary and secondary mains, consisting of mainly leakage. General feature of the current Kigali Water Supply system, thus, will be identified as rates of NRW, commercial and physical leakage, i.e., key parameters of the Five Year NRW Reduction Plan.

6) Major work for NRW reduction

Work schedule was carefully worked out to reduce NRW effectively as shown in Attachments-1 Work Plan &-2 Work Flow Diagram. Major work contained in these activities includes the following;

Measurement of Baseline NRW Rate

- Confirm isolation of the pilot area and subzones by valve closure
- Tertiary pipe survey and leakage measurement
- Measure inflow and outflow rate to/from the area to obtain baseline NRW rate

Commercial (Apparent) Loss Reduction

- Customer surveys for update of customer database
- Survey on non-served households
- Onsite or in-room calibration of the installed customer meters
- Replace malfunctioning meters by new ones
- Identify Illegal connections and conduct flow measurement of unauthorized consumption
- Register illegal status of water users as normal customers through dialogue and confirmation
- Measure inflow and outflow rate to/from the area

Visible Leakage Reduction

- Pipeline survey to identify visible leakage
- Repair leakage
- Measure inflow and outflow rate to/from the area

Invisible Leakage Reduction

- Preparatory work for step test, including valve installation and relocation of pipelines
- Step test by closing valves
- Analysis of test results to select prioritized areas
- Leakage detection and repair at all subzones to be carried out in order of priority
- Analysis of test results to select prioritized areas

- Leakage detection and repair at prioritized subzones
- Measure inflow and outflow rate to/from the area to obtain breakdown and end-line NRW rate.

4. Preparing materials and holding the workshop and seminar

(1) Duration: May 1, 2018 to 30June 2018

(2) Specific Activities:

1) Review and cost-benefit analysis of NRW reduction

All costs required for reducing commercial (apparent) loss and visible/invisible leakage may include those of civil works for excavation, repair, replacement, and of procurement of meters, fittings, pipes, stop cocks, unions, tools, equipment, vehicles, workers, staff and engineers.

In return, the water loss reduction yields enormous benefit to all aspects of water supply business. Major benefits, above all, are increase in water sales and supply efficiency, reduced O&M costs, and delayed development of water sources due to an increase of the water distribution.

Despite these apparent costs and benefits, it is difficult to quantify them properly as financial, economical, social and environmental values. It is, therefore, considered adequate to compute unit cost of rehabilitation in comparison with unit expansion cost, and/or to compare simply the increase in water sales with the direct costs required for the NRW reduction.

2) Prepare manuals of the NRW reduction procedures and of the equipment

3) Prepare completion report

4) Carry out workshop and seminar to share information with institution and agencies concerned

5. Construction of Pilot Area 2 (RUYENZI)

(1) Duration: (To be determined)

(2) Specific Activities: same as Pilot Area 1

6. NRW measurement and reduction at the Pilot Area 2

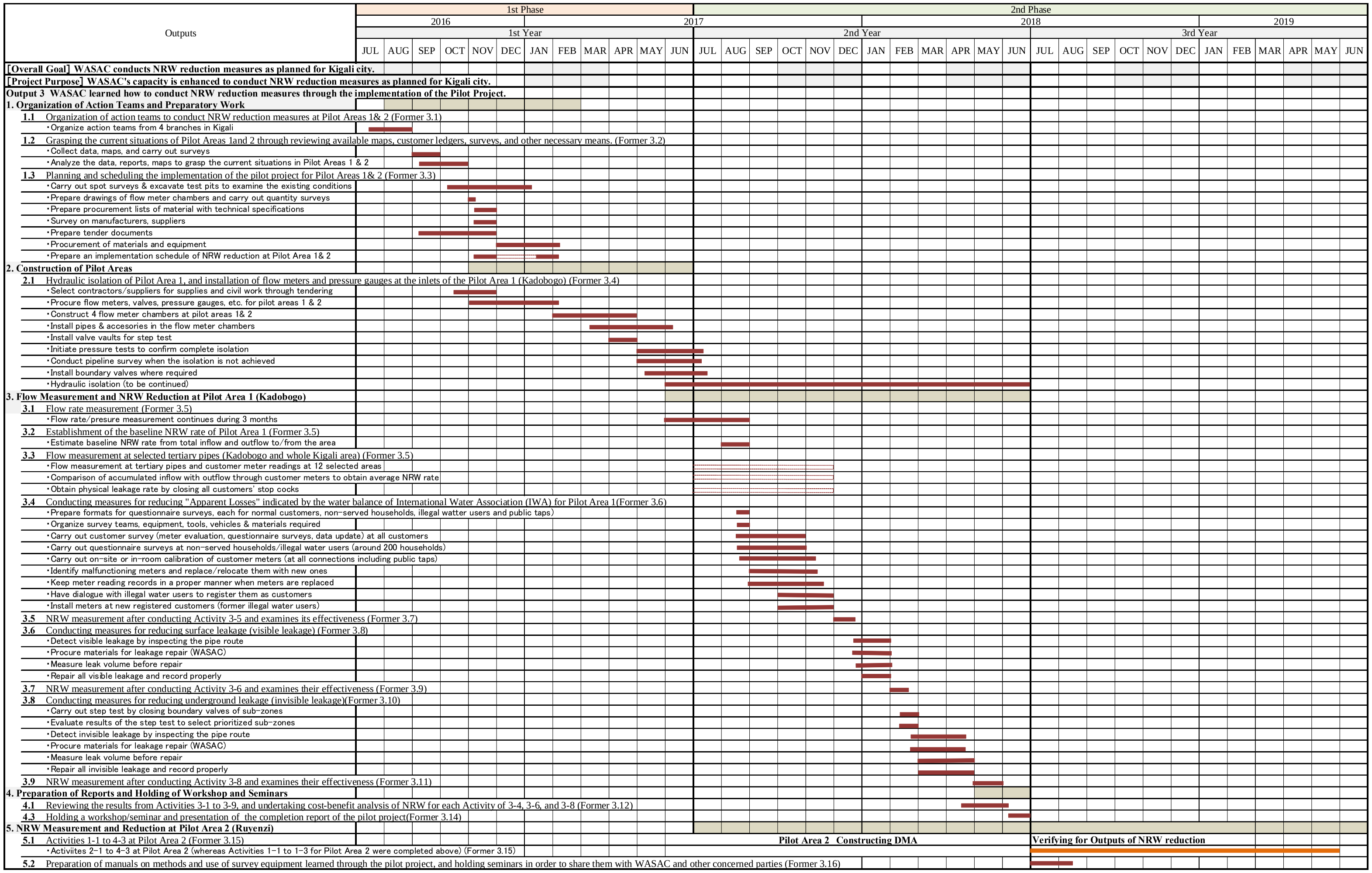
(1) Duration:(To be determined)

(2) Specific Activities: same as Pilot Area 1

7. Preparing and holding the workshop and seminar
    (1) Duration: (To be determined)
    (2) Specific Activities: same as Pilot Area 1

Attachment-1 Work Plan for Implementing the Project

(Output 3)



[Overall Goal] WASAC conducts NRW reduction measures as planned for Kigali city.

[Project Purpose] WASAC's capacity is enhanced to conduct NRW reduction measures as planned for Kigali city.

Output 3 WASAC learned how to conduct NRW reduction measures through the implementation of the Pilot Project.

1. Organization of Action Teams and Preparatory Work

1.1 Organization of action teams to conduct NRW reduction measures at Pilot Areas 1& 2 (Former 3.1)
- Organize action teams from 4 branches in Kigali

1.2 Grasping the current situations of Pilot Areas 1and 2 through reviewing available maps, customer ledgers, surveys, and other necessary means. (Former 3.2)
- Collect data, maps, and carry out surveys
- Analyze the data, reports, maps to grasp the current situations in Pilot Areas 1 & 2

1.3 Planning and scheduling the implementation of the pilot project for Pilot Areas 1& 2 (Former 3.3)
- Carry out spot surveys & excavate test pits to examine the existing conditions
- Prepare drawings of flow meter chambers and carry out quantity surveys
- Prepare procurement lists of material with technical specifications
- Survey on manufacturers, suppliers
- Prepare tender documents
- Procurement of materials and equipment
- Prepare an implementation schedule of NRW reduction at Pilot Area 1& 2

2. Construction of Pilot Areas

2.1 Hydraulic isolation of Pilot Area 1, and installation of flow meters and pressure gauges at the inlets of the Pilot Area 1 (Kadobogo) (Former 3.4)
- Select contractors/suppliers for supplies and civil work through tendering
- Procure flow meters, valves, pressure gauges, etc. for pilot areas 1 & 2
- Construct 4 flow meter chambers at pilot areas 1& 2
- Install pipes & accesories in the flow meter chambers
- Install valve vaults for step test
- Initiate pressure tests to confirm complete isolation
- Conduct pipeline survey when the isolation is not achieved
- Install boundary valves where required
- Hydraulic isolation (to be continued)

3. Flow Measurement and NRW Reduction at Pilot Area 1 (Kadobogo)

3.1 Flow rate measurement (Former 3.5)
- Flow rate/presure measurement continues during 3 months

3.2 Establishment of the baseline NRW rate of Pilot Area 1 (Former 3.5)
- Estimate baseline NRW rate from total inflow and outflow to/from the area

3.3 Flow measurement at selected tertiary pipes (Kadobogo and whole Kigali area) (Former 3.5)
- Flow measurement at tertiary pipes and customer meter readings at 12 selected areas
- Comparison of accumulated inflow with outflow through customer meters to obtain average NRW rate
- Obtain physical leakage rate by closing all customers' stop cocks

3.4 Conducting measures for reducing "Apparent Losses" indicated by the water balance of International Water Association (IWA) for Pilot Area 1(Former 3.6)
- Prepare formats for questionnaire surveys, each for normal customers, non-served households, illegal watter users and public taps)
- Organize survey teams, equipment, tools, vehicles & materials required
- Carry out customer survey (meter evaluation, questionnaire surveys, data update) at all customers
- Carry out questionnaire surveys at non-served households/illegal water users (around 200 households)
- Carry out on-site or in-room calibration of customer meters (at all connections including public taps)
- Identify malfunctioning meters and replace/relocate them with new ones
- Keep meter reading records in a proper manner when meters are replaced
- Have dialogue with illegal water users to register them as customers
- Install meters at new registered customers (former illegal water users)

3.5 NRW measurement after conducting Activity 3-5 and examines its effectiveness (Former 3.7)

3.6 Conducting measures for reducing surface leakage (visible leakage) (Former 3.8)
- Detect visible leakage by inspecting the pipe route
- Procure materials for leakage repair (WASAC)
- Measure leak volume before repair
- Repair all visible leakage and record properly

3.7 NRW measurement after conducting Activity 3-6 and examines their effectiveness (Former 3.9)

3.8 Conducting measures for reducing underground leakage (invisible leakage)(Former 3.10)
- Carry out step test by closing boundary valves of sub-zones
- Evaluate results of the step test to select prioritized sub-zones
- Detect invisible leakage by inspecting the pipe route
- Procure materials for leakage repair (WASAC)
- Measure leak volume before repair
- Repair all invisible leakage and record properly

3.9 NRW measurement after conducting Activity 3-8 and examines their effectiveness (Former 3.11)

4. Preparation of Reports and Holding of Workshop and Seminars

4.1 Reviewing the results from Activities 3-1 to 3-9, and undertaking cost-benefit analysis of NRW for each Activity of 3-4, 3-6, and 3-8 (Former 3.12)

4.3 Holding a workshop/seminar and presentation of the completion report of the pilot project(Former 3.14)

5. NRW Measurement and Reduction at Pilot Area 2 (Ruyenzi)

5.1 Activities 1-1 to 4-3 at Pilot Area 2 (Former 3.15)
- Activiites 2-1 to 4-3 at Pilot Area 2 (whereas Activities 1-1 to 1-3 for Pilot Area 2 were completed above) (Former 3.15)

5.2 Preparation of manuals on methods and use of survey equipment learned through the pilot project, and holding seminars in order to share them with WASAC and other concerned parties (Former 3.16)

Attachment-2 Work Flow Diagram for NRW Reduction

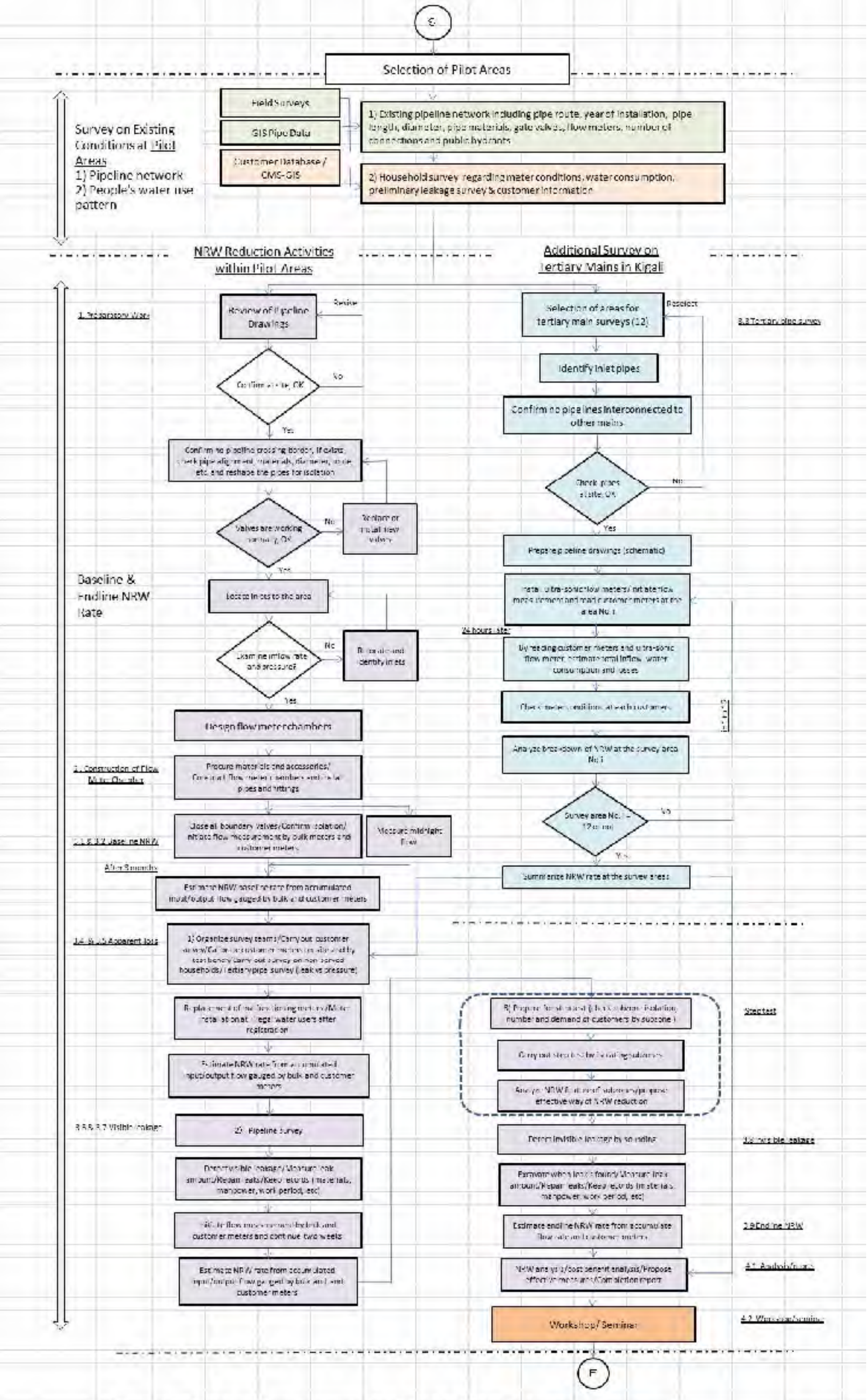
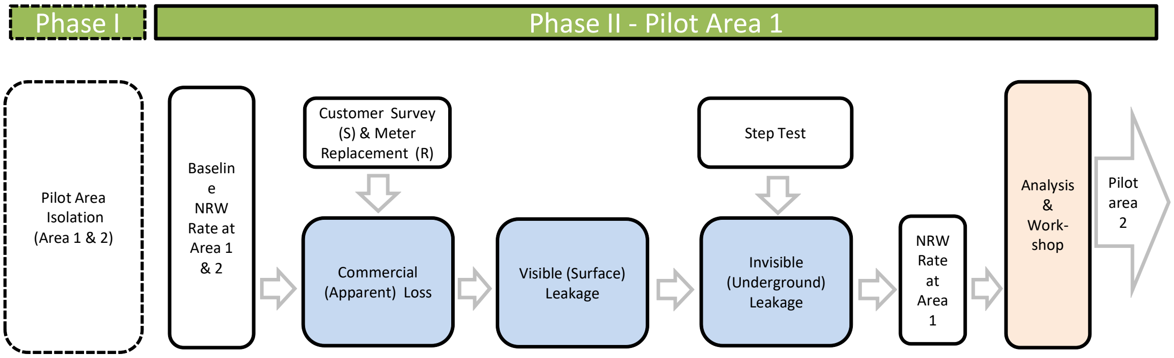


Figure-A2 Workflow Diagram for Pilot NRW Reduction Activities

Attachment-3 Survey Team and Equipment



Work	1) Confirm isolation 2) Measure monthly inflow rate 3) Tertiary pipe survey 4) Measure leakage vs pressure	1) Customer survey 2) Survey on non-served households 3) Calibrate meters by test meters and/or test bench 4) Replace meters 5) Data update & analysis 6) NRW rate	1) Pipeline survey 2) Leakage repair 3) NRW rate	1) Step test 2) Leak detection 3) Leak repair 4) Data compilation & analysis	1) Flow measurement 2) NRW rate 3) NRW analysis 4) Prepare manuals & propose measures 5) Prepare materials for Workshop 6) Organize/carry out workshop/seminar
Period	2.0 months (continued from Phase I) July – August 2017	3.5 months Sep – Mid Dec 2017	2.0 month Mid Dec – Mid Feb 2018	2.5 months Mid Feb – April 2018	2.0 months May – Jun 2018
Nos. of Teams	1 team	2 teams each for S & R	2 teams	2 teams	1 team
Technicians	1 + 2	Total S: 1+ 2 + 2	1	1	1 + 3 engineers
Plumbers	1	Total R: 2 + 2	1 + 1	1 + 1	All plumbers for workshop
Workers	1	2 each for S & R	2 + 2	2 + 2	None
Total	5	13 in Total: 7 for S & 6 for R	7	7	4 engineers for analysis & all plumbers for workshop
Tools & Equipment	Ultrasonic flow meter: one set	Test meters: 3 sets GPS: 2 sets Cameras: 2sets Pressure gauges: 2 sets Othert tools: pipe cutters, threaders, wrench, etc.	Tools: pipe cutters, threaders, wrench, etc. GPS: 2 sets Buckets: 2sets Cameras: 2 sets	Tools: pipe cutters, threaders, wrench, etc. GPS: 2 sets Buckets: 2sets Cameras: 2 sets	None
Materials	None	PVC, PHDE, GSP pipes, unions, meters, cocks, sealing materials, etc.	PVC, PHDE, GSP pipes, unions, valves, etc.	PVC, PHDE, GSP pipes, unions, valves, etc.	None
Vehicles	2	3 (1 for S & 2 for R)	2	2	None
Products	1) NRW rate 2) Relation between pressure and leakage	1) Breakdown commercial loss 2) Defective meter characteristics 3) NRW rate	1) Breakdown visible leakage (cost, materials, manpower) 2) NRW rate	1) Breakdown invisible leakage (cost, materials, manpower) 2) NRW rate	1) NRW evaluation report 2) Cost benefit analysis 3) Reduction manuals 4) Proosal for pressure control 5) Evaluation report of trainees
Remark	- Isolation to be confirmed by valve closure	-Survey on non-served households may focus on their water sources and willingness to connect	-	-If invisible leakage were not found by normal detection, detailed step tests would be carried out.	-Training/seminar will be carried out before workshop

Figure-A3 Survey Team and Equipment for NRW Reduction at Pilot Area 1

Outputs	1st Phase												2nd Phase																							
	2016						2017												2018												2019					
	1st Year												2nd Year												3rd Year											
	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
[Overall Goal] WASAC conducts NRW reduction measures as planned for Kigali city.																																				
[Project Purpose] WASAC's capacity is enhanced to conduct NRW reduction measures as planned for Kigali city.																																				
Output 3 WASAC learned how to conduct NRW reduction measures through the implementation of the Pilot Project.																																				
1. Organization of Action Teams and Preparatory Work		▨	▨	▨	▨	▨	▨	▨																												
1.1 Organization of action teams to conduct NRW reduction measures at Pilot Areas 1& 2 (Former 3.1)																																				
･Organize action teams from 4 branches in Kigali	■	■																																		
1.2 Grasping the current situations of Pilot Areas 1and 2 through reviewing available maps, customer ledgers, surveys, and other necessary means. (Former 3.2)																																				
･Collect data, maps, and carry out surveys			■																																	
･Analyze the data, reports, maps to grasp the current situations in Pilot Areas 1 & 2			■	■																																
1.3 Planning and scheduling the implementation of the pilot project for Pilot Areas 1& 2 (Former 3.3)																																				
･Carry out spot surveys & excavate test pits to examine the existing conditions				■	■	■	■																													
･Prepare drawings of flow meter chambers and carry out quantity surveys					■																															
･Prepare procurement lists of material with technical specifications					■																															
･Survey on manufacturers, suppliers					■																															
･Prepare tender documents			■	■	■																															
･Procurement of materials and equipment						■	■	■																												
･Prepare an implementation schedule of NRW reduction at Pilot Area 1& 2					■	┈	■	■																												
2. Construction of Pilot Areas					▨	▨	▨	▨	▨	▨	▨	▨																								
2.1 Hydraulic isolation of Pilot Area 1, and installation of flow meters and pressure gauges at the inlets of the Pilot Area 1 (Kadobogo) (Former 3.4)																																				
･Select contractors/suppliers for supplies and civil work through tendering				■	■																															
･Procure flow meters, valves, pressure gauges, etc. for pilot areas 1 & 2					■	■	■	■																												
･Construct 4 flow meter chambers at pilot areas 1& 2								■	■	■																										
･Install pipes & accesories in the flow meter chambers									■	■	■	■																								
･Install valve vaults for step test										■																										
･Initiate pressure tests to confirm complete isolation											■	■	■																							
･Conduct pipeline survey when the isolation is not achieved											■	■	■																							
･Install boundary valves where required											■	■	■																							
･Hydraulic isolation (to be continued)												■	■	■	■	■	■	■	■	■	■	■	■	■												
3. Flow Measurement and NRW Reduction at Pilot Area 1 (Kadobogo)												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
3.1 Flow rate measurement (Former 3.5)																																				
･Flow rate/presure measurement continues during 3 months												■	■	■																						
3.2 Establishment of the baseline NRW rate of Pilot Area 1 (Former 3.5)																																				
･Estimate baseline NRW rate from total inflow and outflow to/from the area														■																						
3.3 Flow measurement at selected tertiary pipes (Kadobogo and whole Kigali area) (Former 3.5)																																				
･Flow measurement at tertiary pipes and customer meter readings at 12 selected areas													┈	┈	┈	┈	┈	┈																		
･Comparison of accumulated inflow with outflow through customer meters to obtain average NRW rate													┈	┈	┈	┈	┈	┈																		
･Obtain physical leakage rate by closing all customers' stop cocks													┈	┈	┈	┈	┈	┈																		
3.4 Conducting measures for reducing "Apparent Losses" indicated by the water balance of International Water Association (IWA) for Pilot Area 1(Former 3.6)																																				
･Prepare formats for questionnaire surveys, each for normal customers, non-served households, illegal watter users and public taps														■																						
･Organize survey teams, equipment, tools, vehicles & materials required														■																						
･Carry out customer survey (meter evaluation, questionnaire surveys, data update) at all customers														■	■	■																				
･Carry out questionnaire surveys at non-served households/illegal water users (around 200 households)														■	■	■																				
･Carry out on-site or in-room calibration of customer meters (at all connections including public taps)														■	■	■	■																			
･Identify malfunctioning meters and replace/relocate them with new ones															■	■	■																			
･Keep meter reading records in a proper manner when meters are replaced															■	■	■																			
･Have dialogue with illegal water users to register them as customers																■	■																			
･Install meters at new registered customers (former illegal water users)																■	■																			
3.5 NRW measurement after conducting Activity 3-5 and examines its effectiveness (Former 3.7)																		■																		
3.6 Conducting measures for reducing surface leakage (visible leakage) (Former 3.8)																																				
･Detect visible leakage by inspecting the pipe route																		■	■																	
･Procure materials for leakage repair (WASAC)																		■	■																	
･Measure leak volume before repair																		■	■																	
･Repair all visible leakage and record properly																			■																	
3.7 NRW measurement after conducting Activity 3-6 and examines their effectiveness (Former 3.9)																				■																
3.8 Conducting measures for reducing underground leakage (invisible leakage)(Former 3.10)																																				
･Carry out step test by closing boundary valves of sub-zones																				■																
･Evaluate results of the step test to select prioritized sub-zones																				■																
･Detect invisible leakage by inspecting the pipe route																				■	■	■														
･Procure materials for leakage repair (WASAC)																				■	■	■														
･Measure leak volume before repair																					■	■														
･Repair all invisible leakage and record properly																					■	■														
3.9 NRW measurement after conducting Activity 3-8 and examines their effectiveness (Former 3.11)																							■													
4. Preparation of Reports and Holding of Workshop and Seminars																							▨	▨												
4.1 Reviewing the results from Activities 3-1 to 3-9, and undertaking cost-benefit analysis of NRW for each Activity of 3-4, 3-6, and 3-8 (Former 3.12)																							■													
4.3 Holding a workshop/seminar and presentation of the completion report of the pilot project(Former 3.14)																								■												
5. NRW Measurement and Reduction at Pilot Area 2 (Ruyenzi)													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
5.1 Activities 1-1 to 4-3 at Pilot Area 2 (Former 3.15)																		**Pilot Area 2 Constructing DMA**							**Verifying for Outputs of NRW reduction**											
･Activiites 2-1 to 4-3 at Pilot Area 2 (whereas Activities 1-1 to 1-3 for Pilot Area 2 were completed above) (Former 3.15)																									🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
5.2 Preparation of manuals on methods and use of survey equipment learned through the pilot project, and holding seminars in order to share them with WASAC and other concerned parties (Former 3.16)																									■	■										

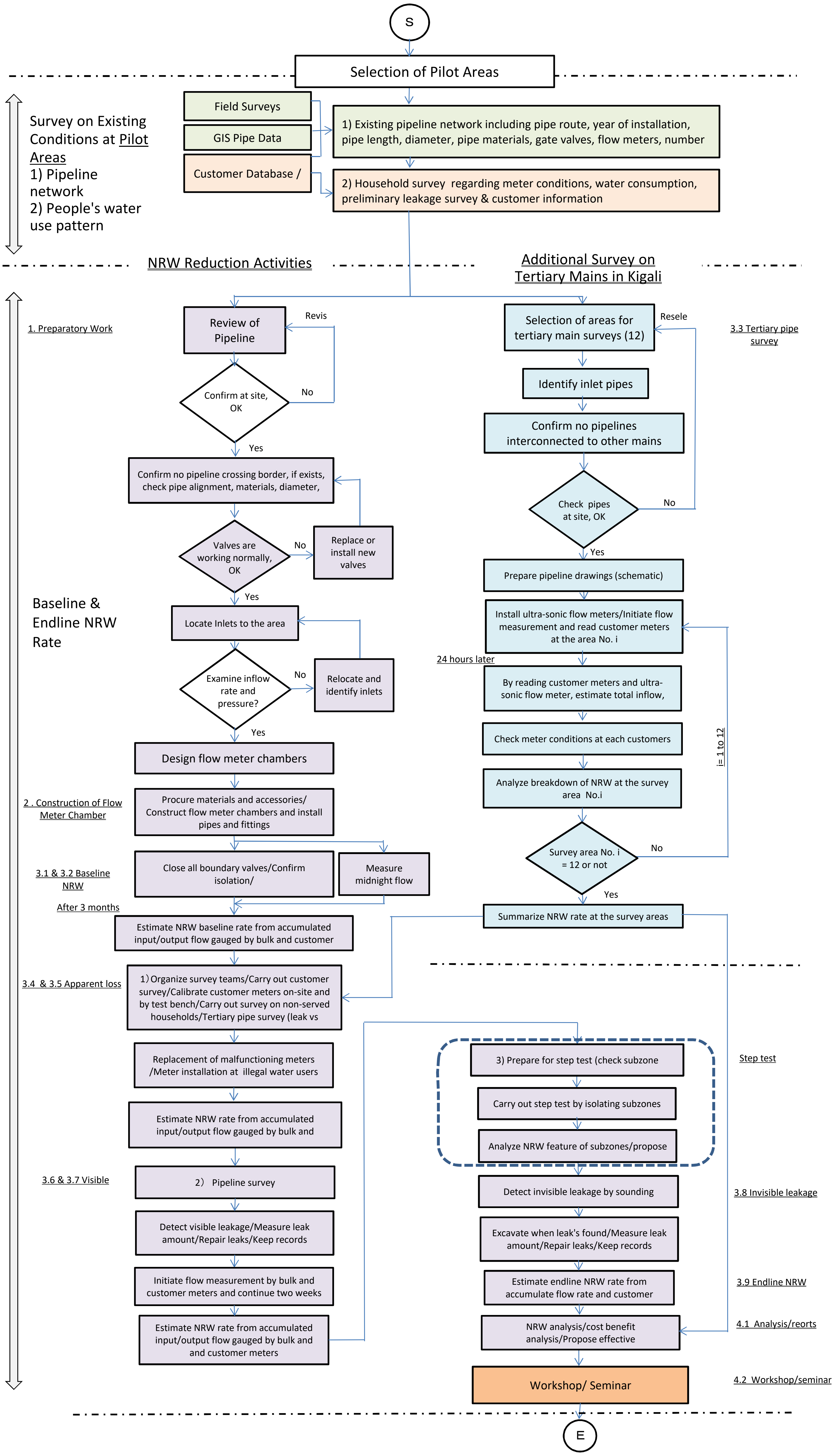
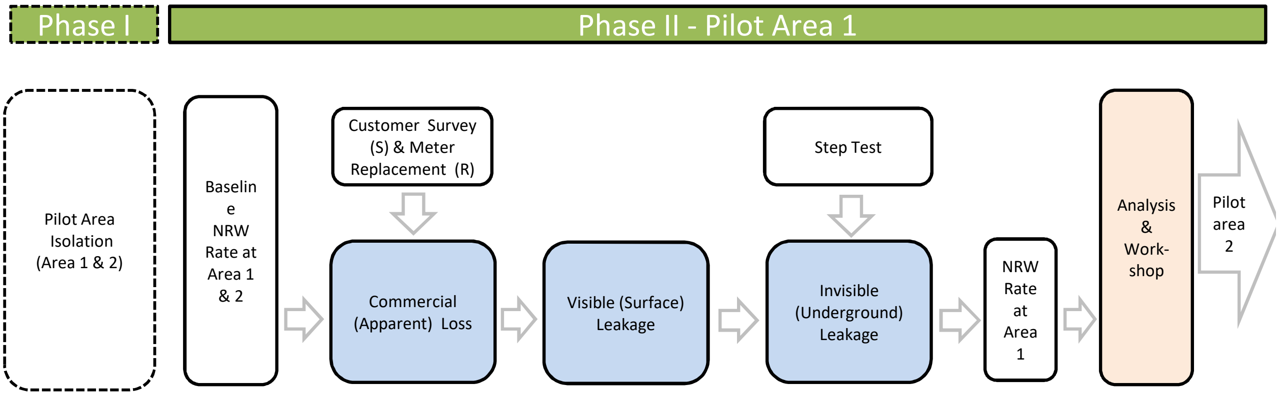


Figure-A2 Workflow Diagram for Pilot NRW Reduction Activities



Work	1) Confirm isolation 2) Measure monthly inflow rate 3) Tertiary pipe survey 4) Measure leakage vs pressure	1) Customer survey 2) Survey on non–served households 3) Calibrate meters by test meters and/or test bench 4) Replace meters 5) Data update & analysis 6) NRW rate	1) Pipeline survey 2) Leakage repair 3) NRW rate	1) Step test 2) Leak detection 3) Leak repair 4) Data compilation & analysis	1) Flow measurement 2) NRW rate 3) NRW analysis 4) Prepare manuals & propose measures 5) Prepare materials for Workshop 6) Organize/carry out workshop/seminar
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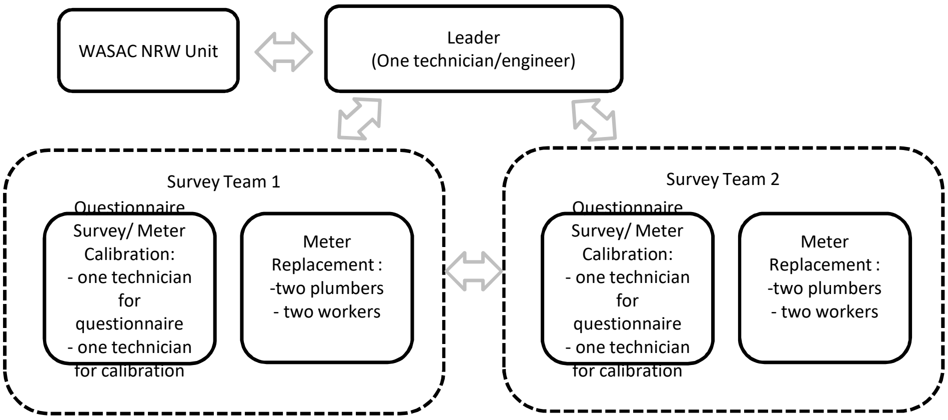
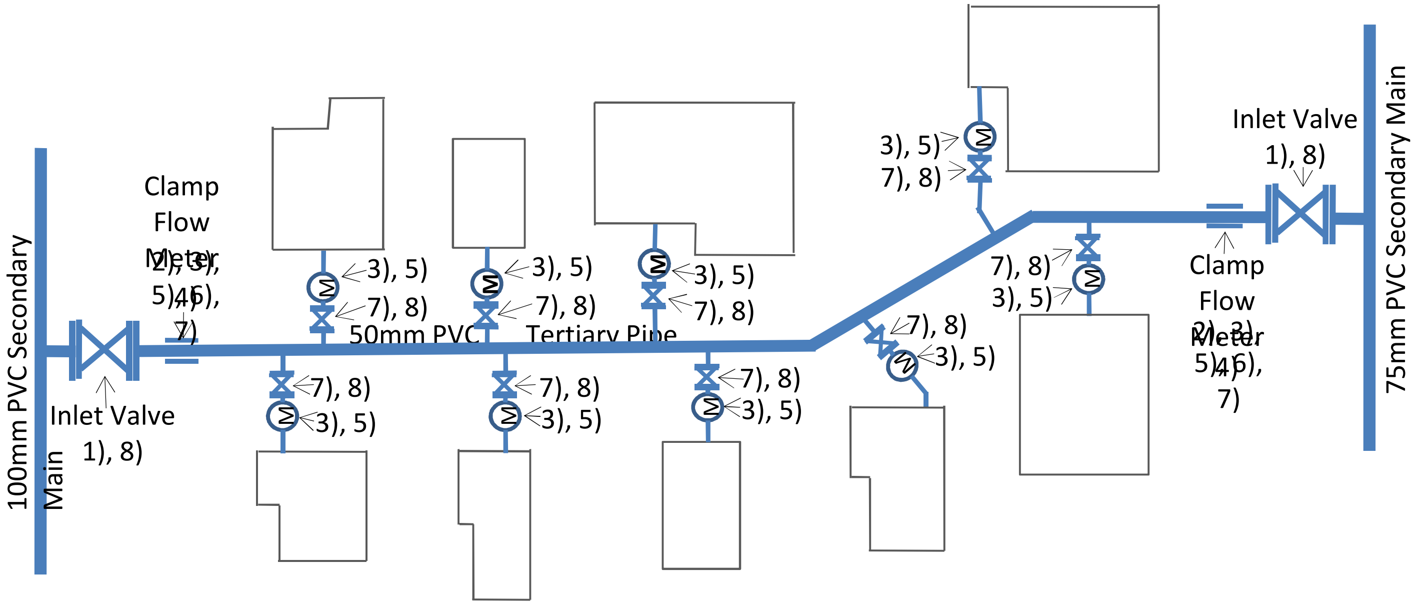
Technicians	1 + 2	Total S: 1+ 2 + 2	1	1	1 + 3 engineers
Plumbers	1	Total R: 2 + 2	1 + 1	1 + 1	All plumbers for workshop
Workers	1	2 each for S & R	2 + 2	2 + 2	None
Total	5	13 in Total: 7 for S & 6 for R	7	7	4 engineers for analysis & all plumbers for workshop
Tools & Equipment	Ultrasonic flow meter: one set	Test meters: 3 sets GPS: 2 sets Cameras: 2sets Pressure gauges: 2 sets Othert tools: pipe cutters, threaders, wrench, etc.	Tools: pipe cutters, threaders, wrench, etc. GPS: 2 sets Buckets: 2sets Cameras: 2 sets	Tools: pipe cutters, threaders, wrench, etc. GPS: 2 sets Buckets: 2sets Cameras: 2 sets	None
Materials	None	PVC, PHDE, GSP pipes, unions, meters, cocks, sealing materials, etc.	PVC, PHDE, GSP pipes, unions, valves, etc.	PVC, PHDE, GSP pipes, unions, valves, etc.	None
Vehicles	2	3 (1 for S & 2 for R)	2	2	None
Products	1) NRW rate 2) Relation between pressure and leakage	1) Breakdown commercial loss 2) Defective meter characteristics 3) NRW rate	1) Breakdown visible leakage (cost, materials, manpower) 2) NRW rate	1) Breakdown invisible leakage (cost, materials, manpower) 2) NRW rate	1) NRW evaluation report 2) Cost benefit analysis 3) Reduction manuals 4) Proosal for pressure control 5) Evaluation report of trainees
Remark	– Isolation to be confirmed by valve closure	–Survey on non–served households may focus on their water sources and willingness to connect	–	–If invisible leakage were not found by normal detection, detailed step tests would be carried out.	–Training/seminar will be carried out before workshop

Figure–A3 Survey Team and Equipment for NRW Reduction at Pilot Area 1

Work	Baseline NRW Rate 1) Confirm isolation 2) Measure monthly inflow rate 3) Tertiary pipe survey 4) Measure leakage vs pressure	Commercial (Apparent) Loss Reduction 1) Customer survey 2) Survey on non-served households 3) Calibrate meters by test meters and/or test bench 4) Replace meters 5) Data update & analysis 6) NRW rate	Surface (Visible) Leakage Reduction 1) Pipeline survey 2) Leakage repair 3) NRW rate	Invisible (Underground) Leakage Reduction 1) Step test & analysis 2) Leak detection 3) Leak repair 4) Data compilation & analysis	Endline NRW Rate, Analysis & Workshop 1) Flow measurement 2) NRW rate 3) NRW analysis 4) Prepare manuals & propose measures 5) Prepare materials for Workshop 6) Organize/carry out workshop/seminar
Period	2.0 months (continuing from Phase I) July – August 2017	3.5 months Sep – Mid Dec 2017	2.0 month Mid Dec – Mid Feb 2018	2.5 months Mid Feb – April 2018	2.0 months May – Jun 2018
Nos. of Teams	1 team	2 teams each for S & R	2 teams	2 teams	1 team
Technicians	1 + 2	Total S: 1+ 2 + 2	1	1	1 + 3 engineers
Plumbers	1	Total R: 2 + 2	1 + 1	1 + 1	All plumbers for workshop
Workers	1	2 each for S & R	2 + 2	2 + 2	None
Total	5	13 in Total: 7 for S & 6 for R	7	7	4 engineers for analysis & all plumbers for workshop





Note:
1) Hydraulic isolation by boundary valves' closure
2) Install ultra-sone (clamp) flow meters
3) Starat measurement
4) Record reading by ultra-sonic flow meters at one hour interval
5) After 24 hours, read all meters
6) Estimate NRW rate
7) Measure leakage by stopcock closure
8) Measure leakage by stepwise closure of inlet valves to obtain relationship between pressure and leakage

Commercial (Apparent) Loss Reduction
<Methodology and Procedures>

1) Customer data format

Prior to initiation of a customer survey in the pilot area concerned, WASAC shall confirm how to update the customer data. Items of customer data tentatively selected are as follows:

a. Customer particulars: POC, Latitude, Longitude, Altitude, User category, Family name, First name, Phone number, Occupation, Number of family members, Metered or not, Water tank and Tank capacity, Disconnected (tentatively or permanently), Village, Cell, Sector, District, Province, and DMA No.

b. Meters: Manufacturer, Year of manufacture, Serial number, Meter type, Working or not (Condition: normal, blocked, unclear screen, vandalized, and others), Meter sealing, Pipe diameter, Meter diameter, Meter box, and Meter location (sketch)

c. Water consumption: Last reading, Monthly water consumption (past 12 months).

2) Review of data and drawings

Make a review of all previous reports, drawings and customer data related to water supply conditions of the pilot area. Monthly water consumption of each customer, water tanks, reservoirs, complaints, leakage repair records and meter conditions, in particular, will provide a general view of customers' behavior, water consumption pattern, connection status and pipeline conditions, which may be key inputs to prepare detailed work schedule.

3) Questionnaire Survey

Prepare questionnaire format for customer survey, non-served households and public tap surveys.

a. Customer survey will focus on water use purpose (washing, bathing, drinking, cooking, gardening, etc.), other water sources if any, income level, and requests to WASAC as well as items a. and b. listed above

b. Questionnaire survey of non-served households shall also focus on their address, family name, first name, occupation, family size, their main water sources, income level, willingness to pay for water, requests to WASAC, etc.

c. Public tap survey is to know the present conditions, including those of installed meters, name of operators/owners and phone number, number of households serviced (beneficiaries), average water tariff, location (Latitude, Longitude, Altitude), POC, disconnected (tentatively or permanently), Village, Cell, Sector, District, Province, DMA No. When public taps are not functioning, it is considered crucial to know major reason why they are not in operation(ex. delayed payment, number of customers, water shortage, etc.).

4) Team organization

Work out the detailed work schedule and organize two (2)survey teams, each consisting of 2 sub-teams, one for questionnaire survey/meter calibration and the other for meter replacement. Under a Leader's mandate, these two teams deployed separately, shall cooperate and work together as shown on Figure below.

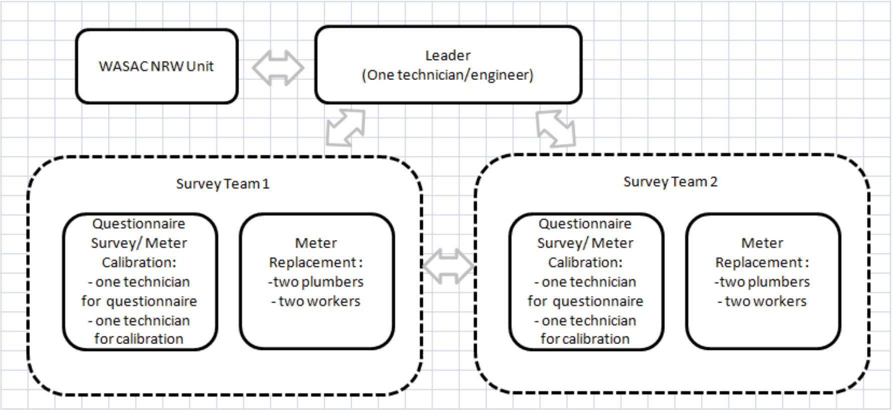


Figure - Team Organization

5) Meter calibration

When the survey team applies on-site meter calibration by portable test meters, measurement at minimum flow rate (Q1), transitional flow rate (Q2) and permanent flow rate (Q3) defined in ISO 4064-1 to 3 shall be a minimum requirement to confirm meter accuracy. When in-room calibration by test benches is applied, scope and procedures of the performance test shall comply completely with ISO standard. In this case, measurement flow rate generally applied are at 50%Q1, Q1, Q2, Q3 and Q4.

Meters shall be within the maximum permissible error (MPE) defined in ISO standard. If not, they should be regarded malfunctioning and replaced by new ones.

6) Demonstrate survey activities at the pilot area for orientation

Before starting the survey, all team members shall fully understand what and how they are going to do for reducing commercial (apparent) losses. It is, therefore, of vital importance to carry out technology transfer to upgrade their skills and keep consistency in their performance. To this end, NRW unit and the Leader shall conduct demonstration at the pilot area for orientation that may continue for one week at least.

7) Initiate the survey at the pilot area

Pilot areas shall be split into two, where each sub-team works separately under direction of the Leader. Areas/pipelines where to initiate and in which order shall be determined carefully with a view to work efficiency, water pressure and flow direction. All data and information obtained in the course of the surveys are recorded properly including their daily work activities, performance, problems found, lessons learnt, tools, equipment used, materials used, etc.

8) The leader shall take necessary actions for procurement of required equipment, tools, vehicles and materials in timely manner and be responsible for their performance giving proper direction and controlling all activities.

9) After completion of the survey above, the team shall measure inflow rate to the pilot area for continuing several weeks, preferably one month. The total inflow and water

consumption by the customers will give NRW rate of the pilot area. In comparison with the baseline NRW rate, the leader will evaluate effects of commercial (apparent) loss reduction.

10) The leader shall report the outcome of their activities to NRW unit and JICA team at the weekly meeting held at WASAC HQ.

11) WASAC NRW unit shall be responsible for analyzing the questionnaire surveys including those of customer survey, non-served households and public tap survey. WASAC CMD shall be also responsible for providing customer data required for analysis (monthly payment, water consumption, etc.) and giving proper advice and suggestion.

Visible (Surface) Leakage Reduction

<Methodology and Procedures>

1) Make a review of all leak repair records of the pilot area and their causes to clarify leak pattern and places where the leakage used to take place. Under normal conditions, visible leaks are usually found on the weakest points of pipelines like tees, bends, flanges, unions, valves, inlets and outlets of the structure (ex. meter chambers, tanks, reservoirs, pipe bridges, etc.), where unexpected land subsidence takes place.

2) In the course of the customer survey undertaken for "Commercial Loss Reduction", visible leaks may be found on the customer connections, especially on stopcocks, meters and unions. When the leaks are found, the sub-team for meter replacement shall gauge how much water are being lost per minute and shall repair them immediately for recording leak amount, their causes, water pressure, location, materials used, time spent for repair, any water losses during repair, etc.

3) WASAC shall exert continued efforts for organizing the survey team for visible leakage reduction. The designated team leader shall carry out orientation to the team members for better understanding of the survey method and procedures.

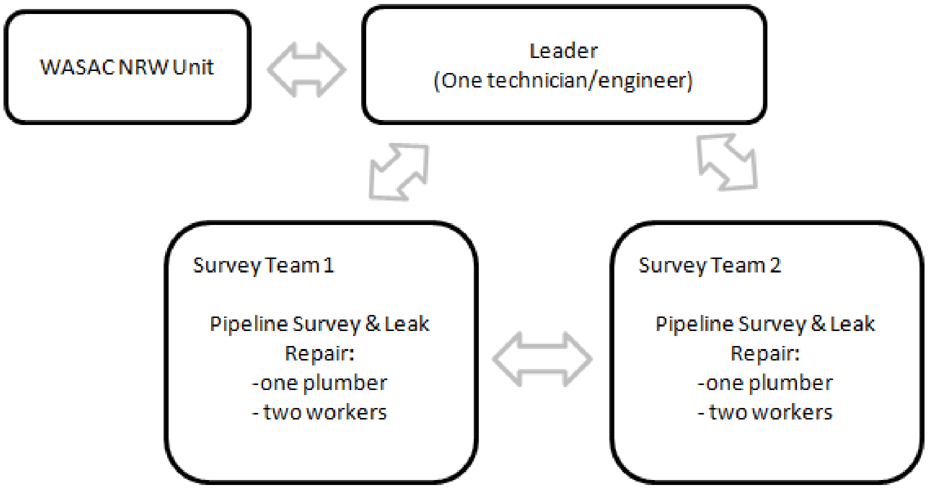


Figure- Team Organization for Visible Leakage Reduction

4) The survey team shall carry out pipeline survey by walking on foot along the pipelines located within the pilot area concerned. The team shall pay particular attention to those installed in the area of swamps and valleys where the normal routine work by WASAC used to lack full monitoring and maintenance.

5) When leaks are found, the team shall repair immediately and record them in a proper format as stated above. Procurement of materials, tools and equipment required for repair shall be under responsibility of the leader.

6) After completion of the visible leak repair in the pilot area, the team shall measure inflow rate to the pilot area for continuing several weeks, preferably one month. The

total inflow and water consumption by the customers will give NRW rate of the pilot area. In comparison with the NRW rate measured after "Commercial Loss Survey", the leader will evaluate effects of visible leakage reduction.

7) The leader shall report the outcome of their activities to NRW unit and JICA team at the weekly meeting held at WASAC HQ.

Invisible (Underground) Leakage Reduction
<Methodology and Procedures>

1) Make a review of all leak repair records of the pilot area and their causes to clarify typical leak pattern and leak points in a similar way as given in "Visible (Surface) Leakage Reduction".

2) In the course of the preparatory survey for leakage detection in April - May 2017, the survey team headed by Japanese Expert accompanied by WASAC engineers and staff has detected invisible leaks at some customer connections. In parallel to the leak detection, he demonstrated how to handle equipment and acoustic bars with an aim to technology transfer to them. Despite insufficiency in terms of period and frequency, this preparatory survey will be beneficial to an efficient leakage detection planned to be carried out in April - June 2018.

3) WASAC shall organize the survey team for invisible leakage reduction. It may be appropriate that the previous team members organized for Visible Leakage Reduction continue to be assigned as they are familiar to the similar kind of leak detection.

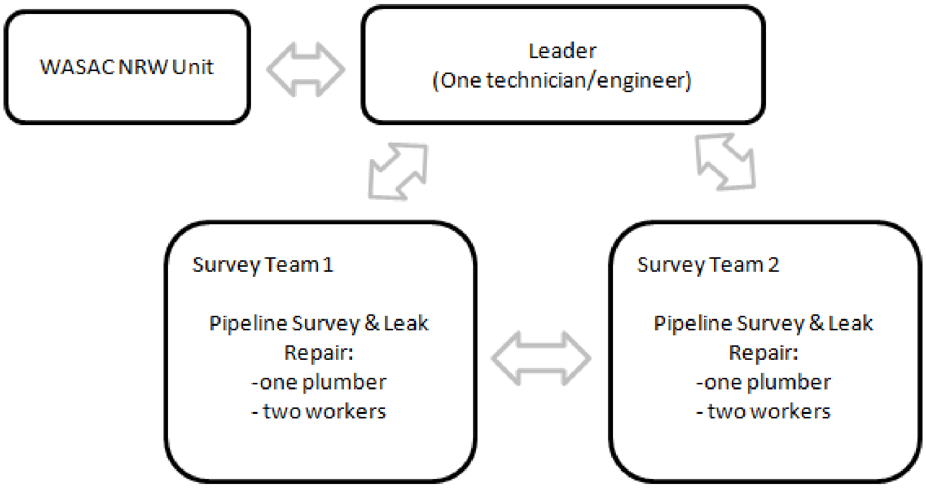


Figure- Team Organization for Invisible Leakage Reduction

4) The designated team leader shall give orientation to the team members for better understanding of the survey method and procedures. Procurement of materials, tools and equipment required for repair shall be under responsibility of the leader.

5) The survey team shall detect visible leakage by walking on foot along all the pipelines installed within the pilot area concerned. Weak pipelines identified in the leak repair review shall be a main target for leak detection. Particular attention shall be paid to those installed in low lands where water pressure may exceed the allowable working pressure of the pipes and fittings.

6) When the leaks are found, the survey team shall gauge how much water are being

lost per minute and shall repair them immediately for recording leak amount, their causes, water pressure, location, pipe materials and diameter, materials used, time spent for repair, any water losses during repair, etc.

7) After completion of the invisible leakage reduction in the pilot area, the team shall measure inflow rate to the pilot area for continuing one month. The total inflow and water consumption by the customers will give NRW rate of the pilot area. In comparison with the baseline NRW rate and those measured after "Commercial Loss Reduction" and "Visible Leakage Reduction", the leader will evaluate effects of visible leakage reduction and summarize the breakdown the leakage rate.

8) The leader shall report the outcome of their activities to NRW unit and JICA team at the weekly meeting held at WASAC HQ.

Tertiary Pipe and Connection Survey

<Methodology and Procedures>

I. Preparatory Work

1) Each WASAC branch office shall select several representative pilot areas to obtain an average NRW rate at the tertiary mains and service connections, taking into consideration the following,

- Inlet tertiary mains to the pilot area shall be one or two in number, on which gate/sluice valves are being installed,
- Confirm the areas are completely isolated by closing the boundary valves,
- Each pilot area shall contain an appropriate number of customers ranging from minimum 30 to maximum 100 to ensure a certain level of accuracy,
- The area shall be representative in terms of pipe diameter, materials, year of installation, contractors involved, number of connections, pipe alignment, water pressure, etc., and
- When no valves on tertiary mains are found, the branch office shall take a proper action to achieve hydraulic isolation of the areas.

2) Number of the pilot areas shall be determined properly based on aims and goals of the survey.

3) Organize the survey team consisting of one engineer, several number of meter readers, workers and security guards. Review customer consumption data in advance to identify possible illegal water users.

4) Carry out preliminary survey of the tertiary pipes and customer meters in the pilot area to examine whether they are working or not properly and whether visible leakages are taking place. Record POC of all customers at the site for confirmation and conduct spot pipe-surveys by excavation where required. Conduct questionnaire surveys of non-served households regarding their major water sources, household characteristics and willingness to connect, when deemed necessary. Prepare a sketch of the pipeline, diameter, length of pipe installed, customer residences, boundaries, meter conditions, valves, branched pipes, etc.

II. Survey Procedures

1) Reconfirm, prior to initiation of the survey, the hydraulic isolation of the pilot survey area.

2) Confirming valves on the inlets open, install ultrasonic flow meters and pressure gauges on all inlets to the area, providing a proper energy source and vigilance for 24 hour measurement.

3) Start measurement by the flow meters at daytime or nighttime when water consumption by the customers falls minimum, reading at the same time all customer meters for recording initial values.

4) Keep records of inflow rate and pressure of the inlets at one hour interval.

5) During the survey period (24 hours), the value registered by the customer meters will increase accordingly by customers' water consumption. Read again all meters to obtain

water consumption by the customers in the area after 24 hours. When meters are malfunctioning, estimate water consumption based on WASAC formula generally applied.

6) Estimate NRW rate of the area from the balance of all customers' water consumption and the inflow rate.

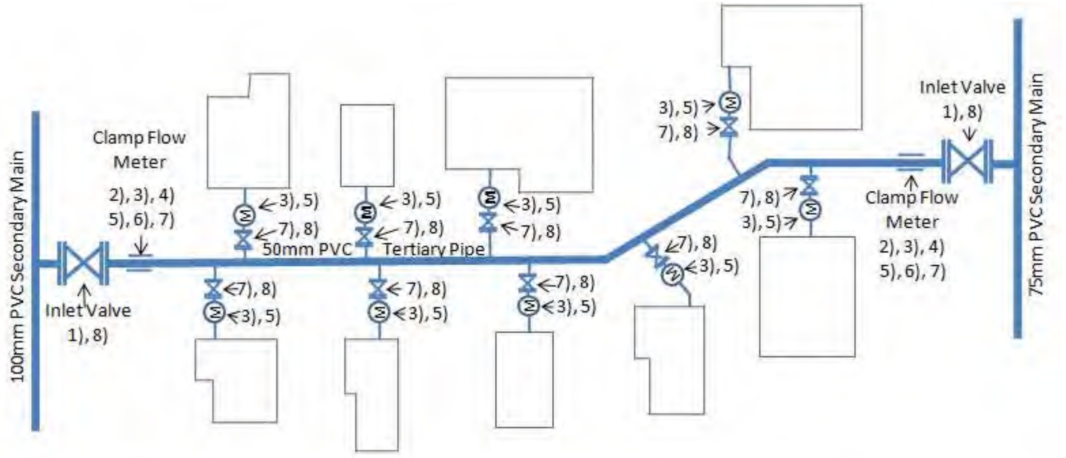
7) After measurement, it may be proper procedures to close all stopcocks of the customers and measure inflow rate for ten minutes to obtain possible physical leakage.

8) Furthermore, when inlet valves are located, gradual valve closure may give relationship between leakage vs pressure. This may be precious information on how to conduct pressure management of the distribution pipe network effectively.

9) Continue the survey at the remaining pilot areas and record all data properly.

10) Analyze NRW and its breakdown at the pilot areas and compare them with total NRW rate in Kigali, to obtain an average breakdown of physical (Primary/Secondary Mains and Tertiary Mains/Connections) and commercial loss (meter under-registration and assumption error) in Kigali city.

Figure- Procedures for Tertiary Pipe & Connection Survey



Note:
1) Hydraulic isolation by boundary valves' closure
2) Install ultra-sone (clamp) flow meters
3) Start measurement
4) Record reading by ultra-sonic flow meters at one hour interval
5) After 24 hours, read all meters
6) Estimate NRW rate
7) Measure leakage by stopcock closure
8) Measure leakage by stepwise closure of inlet valves to obtain relationship between pressure and leakage

WASAC

GIS Procedure Guide

Data Update and Management for
Water Network and Customer Information

27th October 2016

JICA NRW Project

Document Title

WASAC GIS Procedure Guide
Data Update and Management for Water Network and Customer Information (1st Edition)

Acknowledgement

This document was written for WASAC - JICA Technical Cooperation Project for “Strengthening Non-Revenue Water Control in Kigali City Water Network” which has been supported by Japan International Cooperation Agency (JICA).

In particular, this document is written for WASAC GIS team (Zoning and Mapping Services in WASAC Headquarter), and Water Distribution Officers and Technicians in WASAC Branch Offices

JICA GIS expert of the project had implemented trainings and discussions which targeted on “GIS data update and management for water network and customer information” for / with WASAC GIS team from August to November 2016. This document was created as one of the outcomes through our discussions during the term; and this mainly aims to enable all persons who are related to GIS operation in WASAC to review the overall procedure and their own responsibilities of GIS data update and management. Furthermore, it will provide some ideas and future visions of utilization of GIS in the waterworks organization.

The fundamental environment related to GIS in the organization and the country will be changing day by day; therefore this document must be revised by WASAC GIS team reflecting the latest situation. I strongly hope that all the people who are related to GIS operation and management in WASAC will read this document and learn the importance of GIS and how to utilize it taking their own responsibilities for the operation and management.

9th November 2016

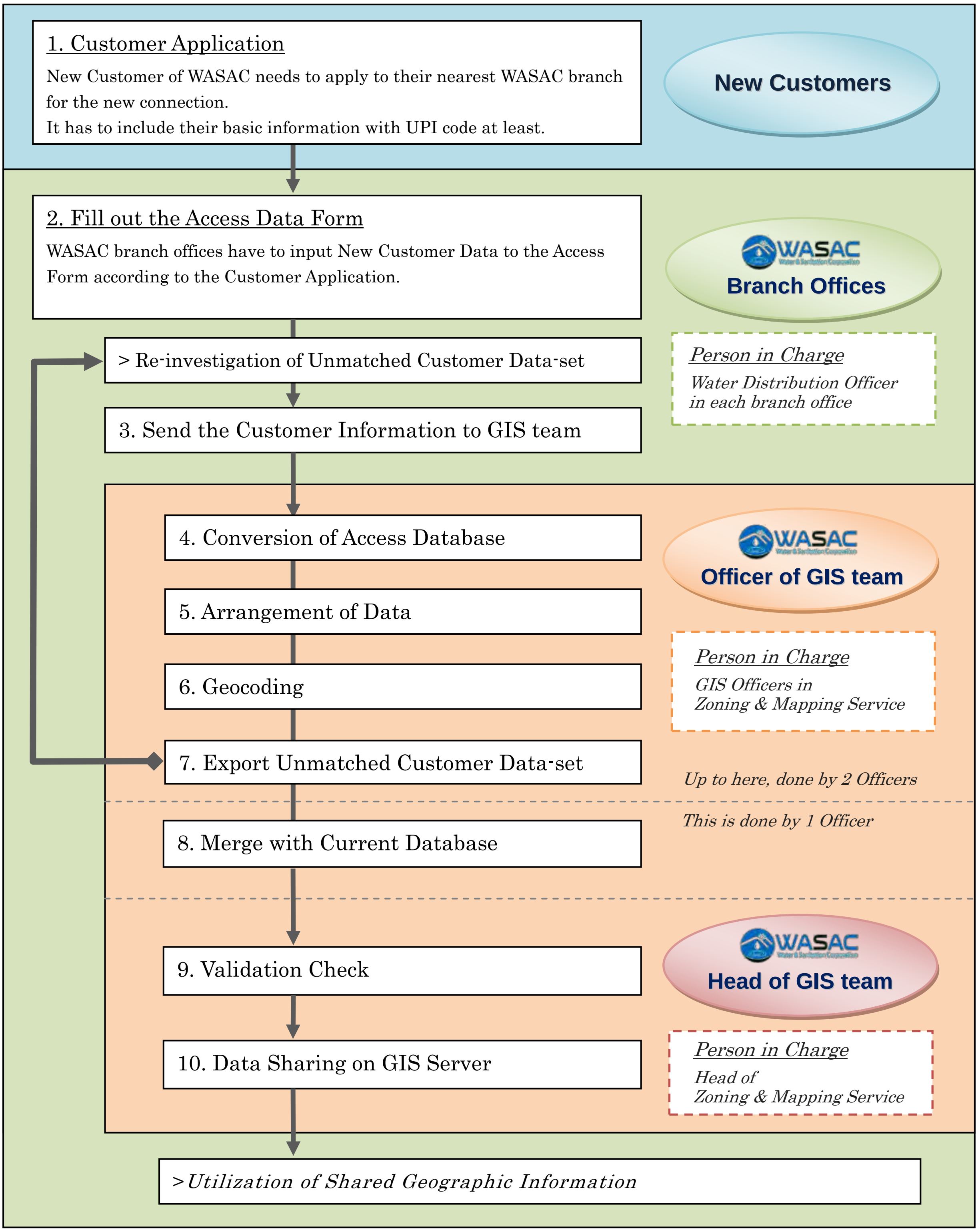
Eita Horishita
GIS expert, JICA
Strengthening Non-Revenue Water Control in Kigali City Water Network

Table of Contents

I. Procedures for GIS Customer Data Update

1. Work-Flow of GIS Customer Data Update

Current Work-Flow: Only target on 6 branches in Kigali City



1. Customer Application

New Customer of WASAC needs to apply to their nearest WASAC branch for the new connection.
It has to include their basic information with UPI code at least.

New Customers

2. Fill out the Access Data Form

WASAC branch offices have to input New Customer Data to the Access Form according to the Customer Application.

WASAC Branch Offices

> Re-investigation of Unmatched Customer Data-set

3. Send the Customer Information to GIS team

Person in Charge
Water Distribution Officer in each branch office

4. Conversion of Access Database

5. Arrangement of Data

6. Geocoding

7. Export Unmatched Customer Data-set

WASAC Officer of GIS team

Person in Charge
GIS Officers in Zoning & Mapping Service

Up to here, done by 2 Officers

8. Merge with Current Database

This is done by 1 Officer

9. Validation Check

10. Data Sharing on GIS Server

WASAC Head of GIS team

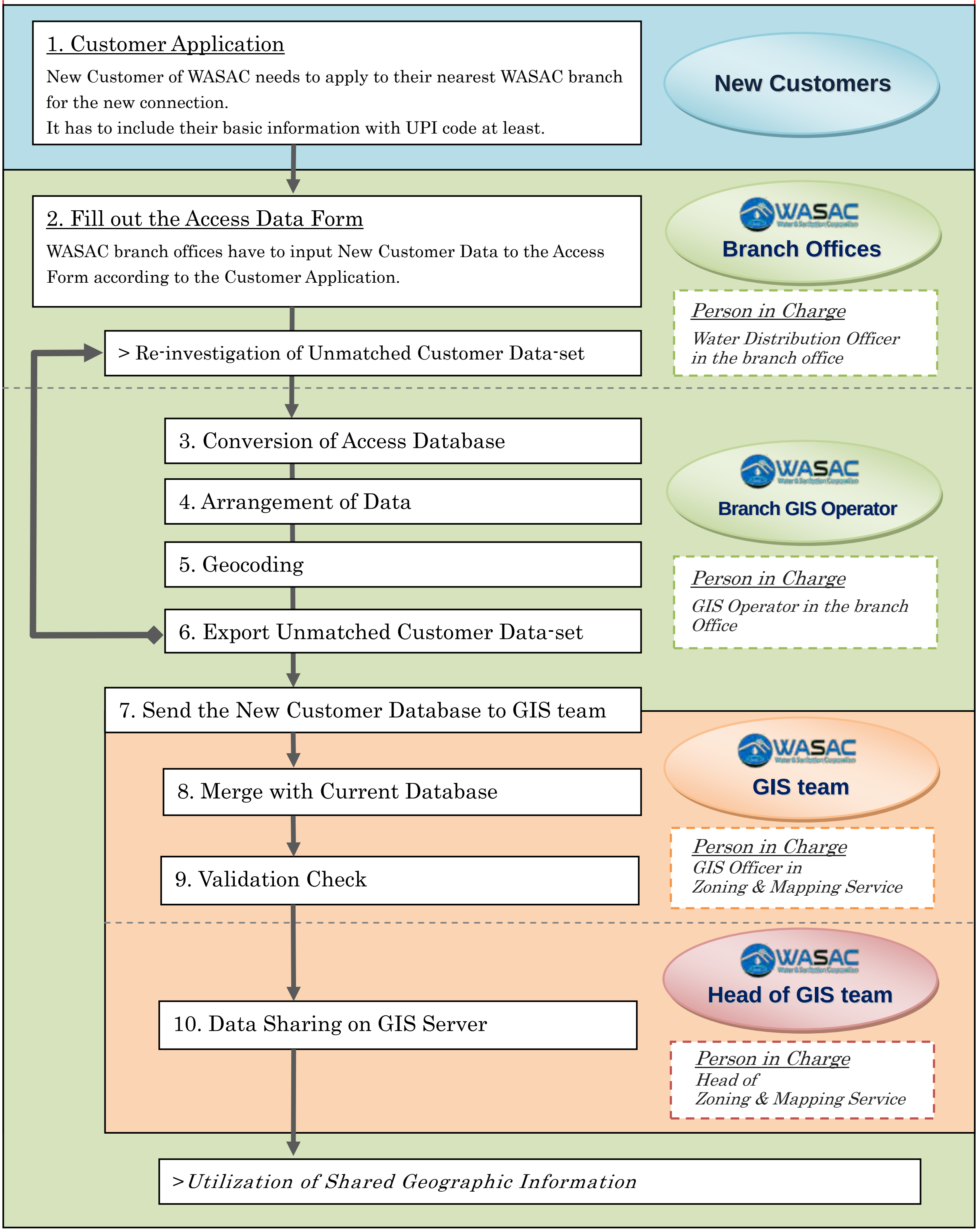
Person in Charge
Head of Zoning & Mapping Service

> *Utilization of Shared Geographic Information*

Future Work-Flow: will target on all 20 branches in Rwanda

Since it would be over-capacity for GIS team to handle GIS data update for all 20 branches in WASAC, this future work-flow plans to have each branch implement the duty operating ArcGIS by themselves.

It will require at least 3 conditions: Installation of ArcGIS on their computers; Fast Internet Connection; Training by GIS team.



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Person in Charge
Water Distribution Officer in the branch office

3. Conversion of Access Database

4. Arrangement of Data

5. Geocoding

6. Export Unmatched Customer Data-set

WASAC Branch GIS Operator

Person in Charge
GIS Operator in the branch Office

7. Send the New Customer Database to GIS team

8. Merge with Current Database

9. Validation Check

WASAC GIS team

Person in Charge
GIS Officer in Zoning & Mapping Service

10. Data Sharing on GIS Server

WASAC Head of GIS team

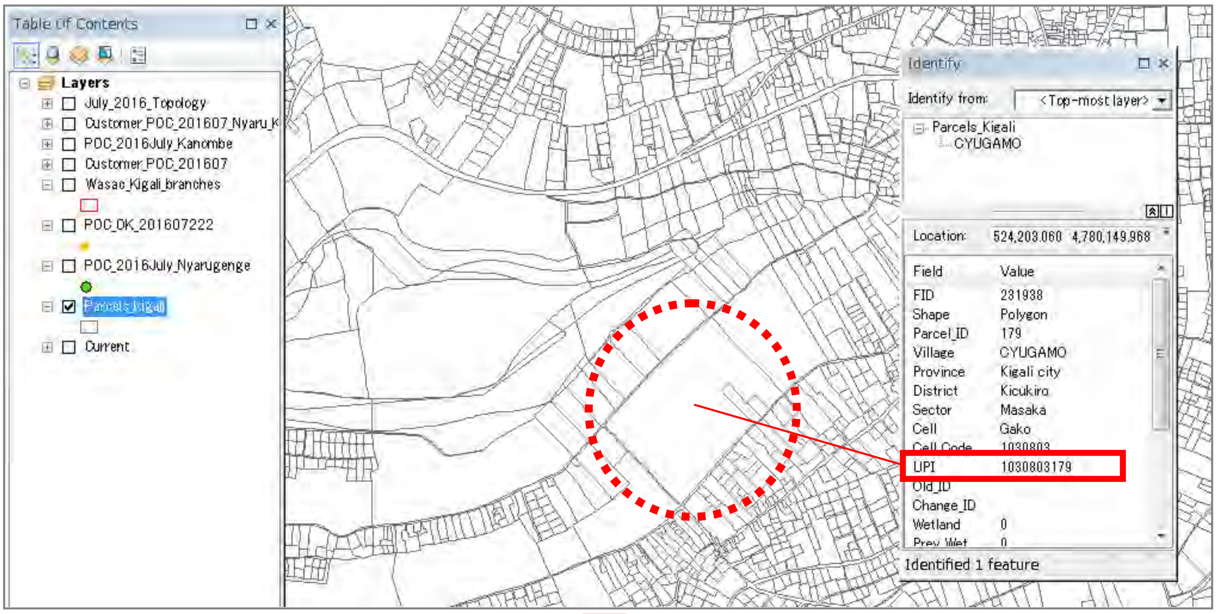
Person in Charge
Head of Zoning & Mapping Service

\> *Utilization of Shared Geographic Information*

2. WASAC GIS team

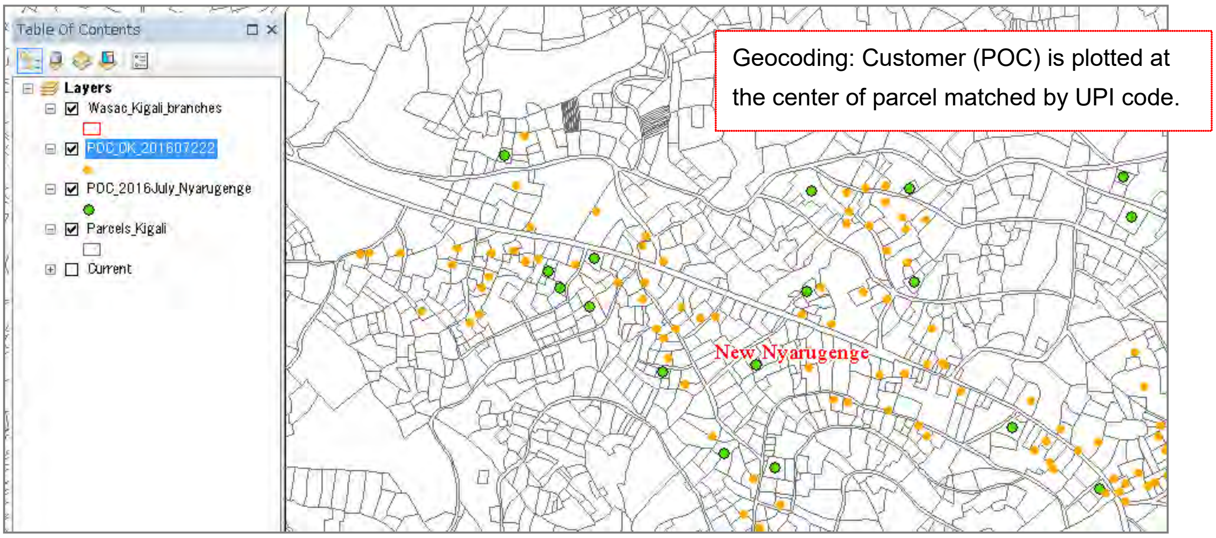
UPI Code: In the current work-flow, GIS team uses Parcel data with UPI code for Geocoding, and which must be the same data in the Customer Application.

- ➢ Please keep updating UPI Parcel Data. It is desirable that GIS team update the Parcel data and its Address Locator **Once in 3 months** at least.



Location: 524,203.060 4,780,149.968

Field	Value
FID	231938
Shape	Polygon
Parcel_ID	179
Village	CYUGAMO
Province	Kigali city
District	Kicukiro
Sector	Masaka
Cell	Gako
Cell Code	1030803
UPI	1030803179
Old_ID	
Change_ID	
Wetland	0
Prev_Wet	0



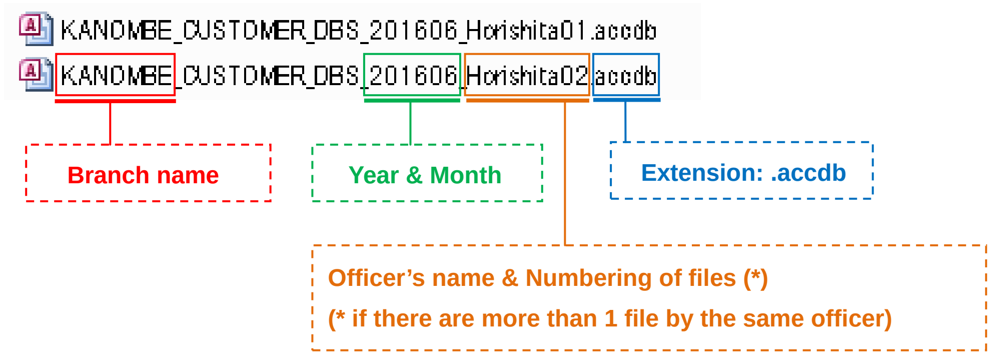
Geocoding: Customer (POC) is plotted at the center of parcel matched by UPI code.

- ➢ New Customer Data-set is created monthly by GIS Officers or Operators; and GIS Officer merges New & Old Data-sets. Head of GIS team is responsible for Validation Check.

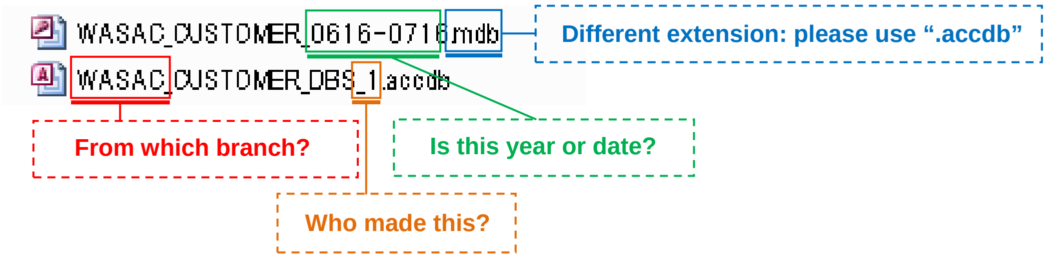
3. WASAC Branch Office: Fill out the Access Data Form

- **File name**: please follow this [*Good example*] shown below.

Good example



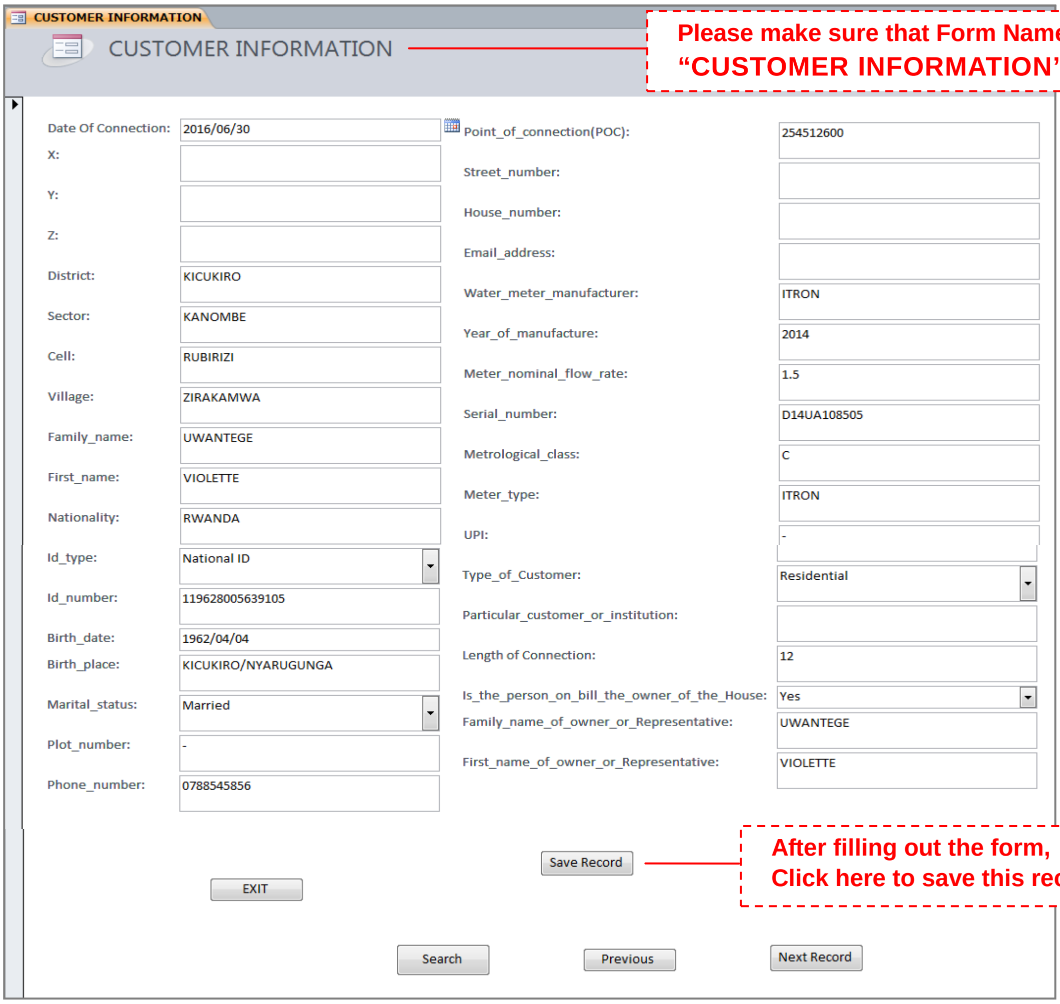
Bad example



- **UPI Code**: Please make sure to use the up-to-date information of UPI corresponding to GIS team. If there is no UPI code for the customer, please fill in the form of XY coordinates.

- **Access Database**: **PLEASE USE FIXED FORM from GIS team** shown as next page.
  - In case that you do not have the fixed form or you do not know how to use it, please ask to GIS team in WASAC Headquarter.

Data Form: you need to input this according to customer's application



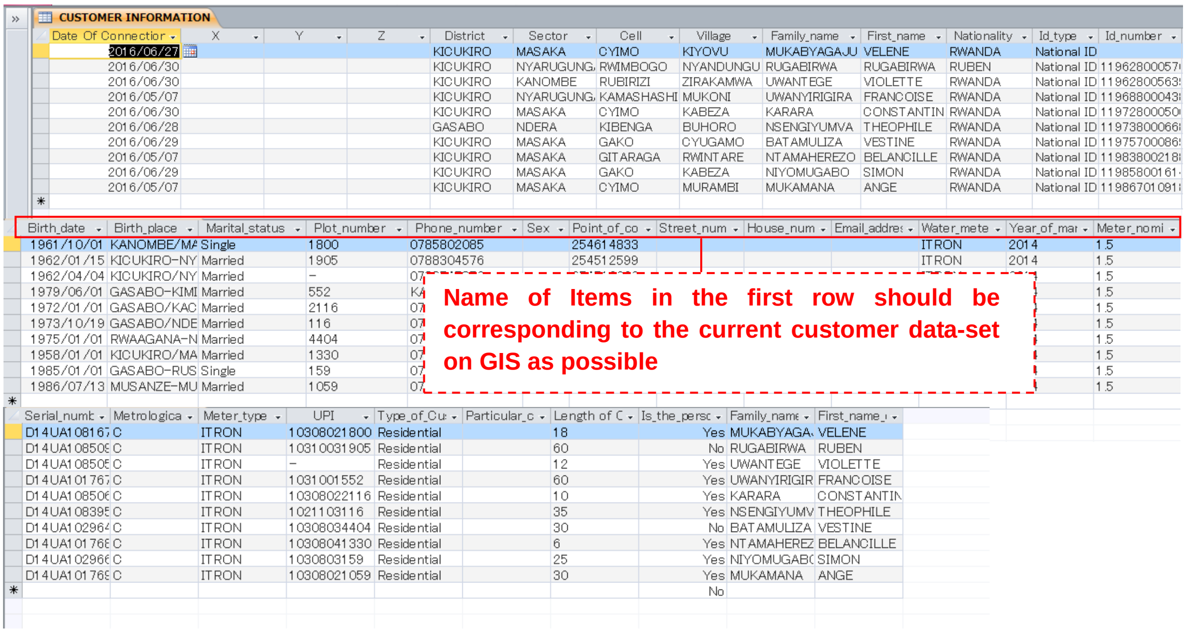
Please make sure that Form Name is "CUSTOMER INFORMATION"

Date Of Connection: 2016/06/30
X:
Y:
Z:
District: KICUKIRO
Sector: KANOMBE
Cell: RUBIRIZI
Village: ZIRAKAMWA
Family_name: UWANTEGE
First_name: VIOLETTE
Nationality: RWANDA
Id_type: National ID
Id_number: 119628005639105
Birth_date: 1962/04/04
Birth_place: KICUKIRO/NYARUGUNGA
Marital_status: Married
Plot_number: -
Phone_number: 0788545856

Point_of_connection(POC): 254512600
Street_number:
House_number:
Email_address:
Water_meter_manufacturer: ITRON
Year_of_manufacture: 2014
Meter_nominal_flow_rate: 1.5
Serial_number: D14UA108505
Metrological_class: C
Meter_type: ITRON
UPI: -
Type_of_Customer: Residential
Particular_customer_or_institution:
Length of Connection: 12
Is_the_person_on_bill_the_owner_of_the_House: Yes
Family_name_of_owner_or_Representative: UWANTEGE
First_name_of_owner_or_Representative: VIOLETTE

After filling out the form,
Click here to save this record.

Data Table: automatically listed when you saved records from the Data Form



Date Of Connectior	X	Y	Z	District	Sector	Cell	Village	Family_name	First_name	Nationality	Id_type	Id_number
2016/06/27				KICUKIRO	MASAKA	CYIMO	KIYOVU	MUKABYAGAJU	VELENE	RWANDA	National ID	
2016/06/30				KICUKIRO	NYARUGUNG/	RWIMBOGO	NYANDUNGU	RUGABIRWA	RUGABIRWA	RUBEN	National ID	11962800057
2016/06/30				KICUKIRO	KANOMBE	RUBIRIZI	ZIRAKAMWA	UWANTEGE	VIOLETTE	RWANDA	National ID	11962800563
2016/05/07				KICUKIRO	NYARUGUNG/	KAMASHASHI	MUKONI	UWANYIRIGIRA	FRANCOISE	RWANDA	National ID	11968800043
2016/06/30				KICUKIRO	MASAKA	CYIMO	KABEZA	KARARA	CONSTANTIN	RWANDA	National ID	11972800050
2016/06/28				GASABO	NDERA	KIBENGA	BUHORO	NSENGIYUMVA	THEOPHILE	RWANDA	National ID	11973800066
2016/06/29				KICUKIRO	MASAKA	GAKO	CYUGAMO	BATAMULIZA	VESTINE	RWANDA	National ID	11975700086
2016/05/07				KICUKIRO	MASAKA	GITARAGA	RWINTARE	NTAMAHEREZO	BELANCILLE	RWANDA	National ID	11983800218
2016/06/29				KICUKIRO	MASAKA	GAKO	KABEZA	NIYOMUGABO	SIMON	RWANDA	National ID	11985800161
2016/05/07				KICUKIRO	MASAKA	CYIMO	MURAMBI	MUKAMANA	ANGE	RWANDA	National ID	11986701091

Birth_date	Birth_place	Marital_status	Plot_number	Phone_number	Sex	Point_of_co	Street_num	House_num	Email_addres	Water_mete	Year_of_mar	Meter_nomi
1961/10/01	KANOMBE/MA	Single	1800	0785802085		254614833				ITRON	2014	1.5
1962/01/15	KICUKIRO-NY	Married	1905	0788304576		254512599				ITRON	2014	1.5
1962/04/04	KICUKIRO/NY	Married	–	07								1.5
1979/06/01	GASABO-KIMI	Married	552	KA								1.5
1972/01/01	GASABO/KAC	Married	2116	07								1.5
1973/10/19	GASABO/NDE	Married	116	07								1.5
1975/01/01	RWAAGANA-N	Married	4404	07								1.5
1958/01/01	KICUKIRO/MA	Married	1330	07								1.5
1985/01/01	GASABO-RUS	Single	159	07								1.5
1986/07/13	MUSANZE-MU	Married	1059	07								1.5

Name of Items in the first row should be corresponding to the current customer data-set on GIS as possible

Serial_numb	Metrologica	Meter_type	UPI	Type_of_Cu	Particular_c	Length of C	Is_the_persc	Family_name	First_name_
D14UA108167	C	ITRON	10308021800	Residential		18	Yes	MUKABYAGA	VELENE
D14UA108509	C	ITRON	10310031905	Residential		60	No	RUGABIRWA	RUBEN
D14UA108505	C	ITRON	–	Residential		12	Yes	UWANTEGE	VIOLETTE
D14UA101767	C	ITRON	1031001552	Residential		60	Yes	UWANYIRIGIR	FRANCOISE
D14UA108506	C	ITRON	10308022116	Residential		10	Yes	KARARA	CONSTANTIN
D14UA108395	C	ITRON	1021103116	Residential		35	Yes	NSENGIYUMV	THEOPHILE
D14UA102964	C	ITRON	10308034404	Residential		30	No	BATAMULIZA	VESTINE
D14UA101768	C	ITRON	10308041330	Residential		6	Yes	NTAMAHEREZ	BELANCILLE
D14UA102966	C	ITRON	1030803159	Residential		25	Yes	NIYOMUGAB(	SIMON
D14UA101769	C	ITRON	10308021059	Residential		30	Yes	MUKAMANA	ANGE
							No		

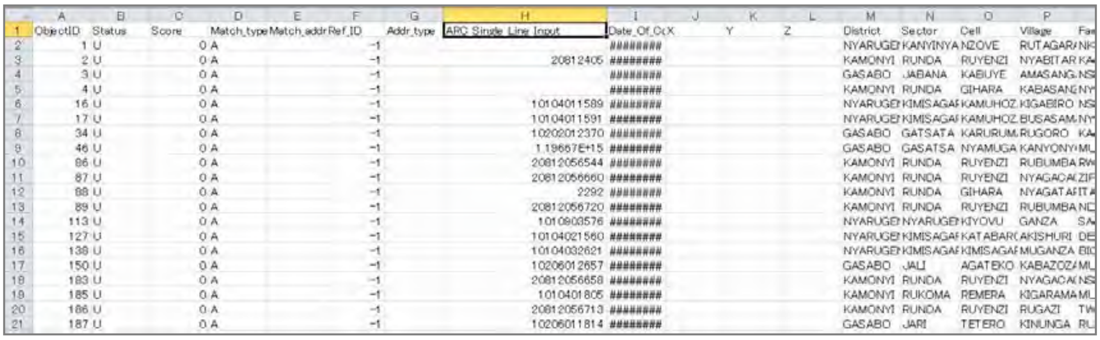
4. WASAC Branch Office: Re-investigation of Unmatched Data-set

Records unmatched by UPI code are listed in CSV data-table, and sent to each branch from WASAC GIS team.

File name (Sample)

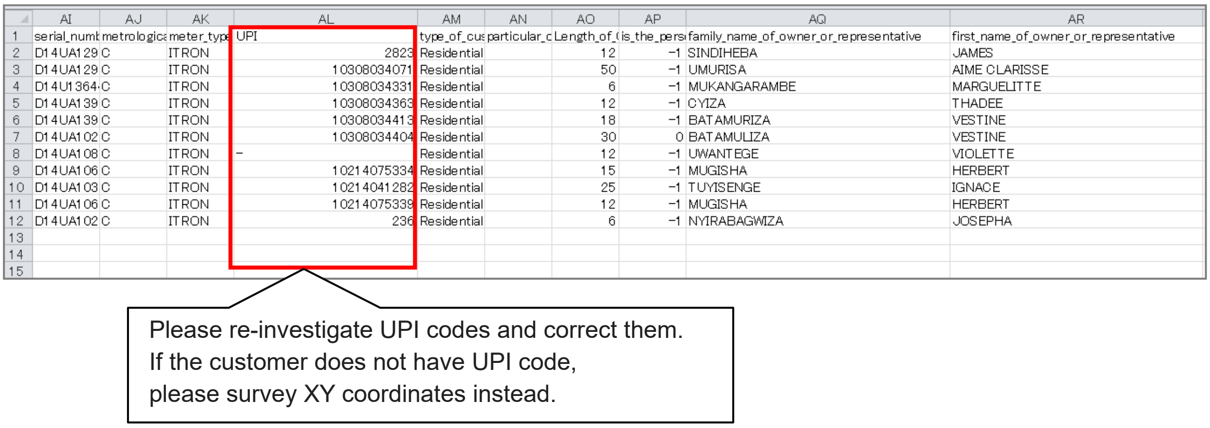
Unmatched_2016July_Nyarugenge.csv

CSV data-table (Sample)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	ObjectID	Status	Score	Match_type	Match_addr	Ref_ID	Addr_type	ARC Single Line Input	Date_Of_C(	X	Y	Z	District	Sector	Cell	Village	Fa
2	1	U	0	A		-1			########				NYARUGE	KANYINYA	NZOVE	RUTAGAR	NK
3	2	U	0	A		-1		20812405	########				KAMONYI	RUNDA	RUYENZI	NYABITAR	KA
4	3	U	0	A		-1			########				GASABO	JABANA	KABUYE	AMASANG.	NS
5	4	U	0	A		-1			########				KAMONYI	RUNDA	GIHARA	KABASANG	NY
6	16	U	0	A		-1		10104011589	########				NYARUGE	KIMISAGA	KAMUHOZ.	KIGABIRO	NS
7	17	U	0	A		-1		10104011591	########				NYARUGE	KIMISAGA	KAMUHOZ.	BUSASAM.	NY
8	34	U	0	A		-1		10202012370	########				GASABO	GATSATA	KARURUM.	RUGORO	KA
9	46	U	0	A		-1		1.19667E+15	########				GASABO	GASATSA	NYAMUGA	KANYONYI	MU
10	86	U	0	A		-1		20812056544	########				KAMONYI	RUNDA	RUYENZI	RUBUMBA	RW
11	87	U	0	A		-1		20812056660	########				KAMONYI	RUNDA	RUYENZI	NYAGACA(	ZIF
12	88	U	0	A		-1		2292	########				KAMONYI	RUNDA	GIHARA	NYAGATAF	IT A
13	89	U	0	A		-1		20812056720	########				KAMONYI	RUNDA	RUYENZI	RUBUMBA	NC
14	113	U	0	A		-1		1010803576	########				NYARUGE	NYARUGE	KIYOVU	GANZA	SA
15	127	U	0	A		-1		10104021560	########				NYARUGE	KIMISAGA	KATABAR(	AKISHURI	DE
16	138	U	0	A		-1		10104032621	########				NYARUGE	KIMISAGA	KIMISAGA	MUGANZA	BIC
17	150	U	0	A		-1		10206012657	########				GASABO	JALI	AGATEKO	KABAZOZ	MU
18	183	U	0	A		-1		20812056658	########				KAMONYI	RUNDA	RUYENZI	NYAGACA(	NS
19	185	U	0	A		-1		1010401805	########				KAMONYI	RUKOMA	REMERA	KIGARAMA	MU
20	186	U	0	A		-1		20812056713	########				KAMONYI	RUNDA	RUYENZI	RUGAZI	TW
21	187	U	0	A		-1		10206011814	########				GASABO	JARI	TETERO	KINUNGA	RU

- ➢ Please re-investigate correct UPI code for each unmatched customer; and return the data-table to WASAC GIS team.



	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
1	serial_numb	metrologica	meter_type	UPI	type_of_cus	particular_c	Length_of_(	is_the_pers	family_name_of_owner_or_representative	first_name_of_owner_or_representative
2	D14UA129	C	ITRON	2823	Residential		12	-1	SINDIHEBA	JAMES
3	D14UA129	C	ITRON	10308034071	Residential		50	-1	UMURISA	AIME CLARISSE
4	D14U1364	C	ITRON	10308034331	Residential		6	-1	MUKANGARAMBE	MARGUELITTE
5	D14UA139	C	ITRON	10308034363	Residential		12	-1	CYIZA	THADEE
6	D14UA139	C	ITRON	10308034413	Residential		18	-1	BATAMURIZA	VESTINE
7	D14UA102	C	ITRON	10308034404	Residential		30	0	BATAMULIZA	VESTINE
8	D14UA108	C	ITRON	-	Residential		12	-1	UWANTEGE	VIOLETTE
9	D14UA106	C	ITRON	10214075334	Residential		15	-1	MUGISHA	HERBERT
10	D14UA103	C	ITRON	10214041282	Residential		25	-1	TUYISENGE	IGNACE
11	D14UA106	C	ITRON	10214075339	Residential		12	-1	MUGISHA	HERBERT
12	D14UA102	C	ITRON	236	Residential		6	-1	NYIRABAGWIZA	JOSEPHA
13										
14										
15										

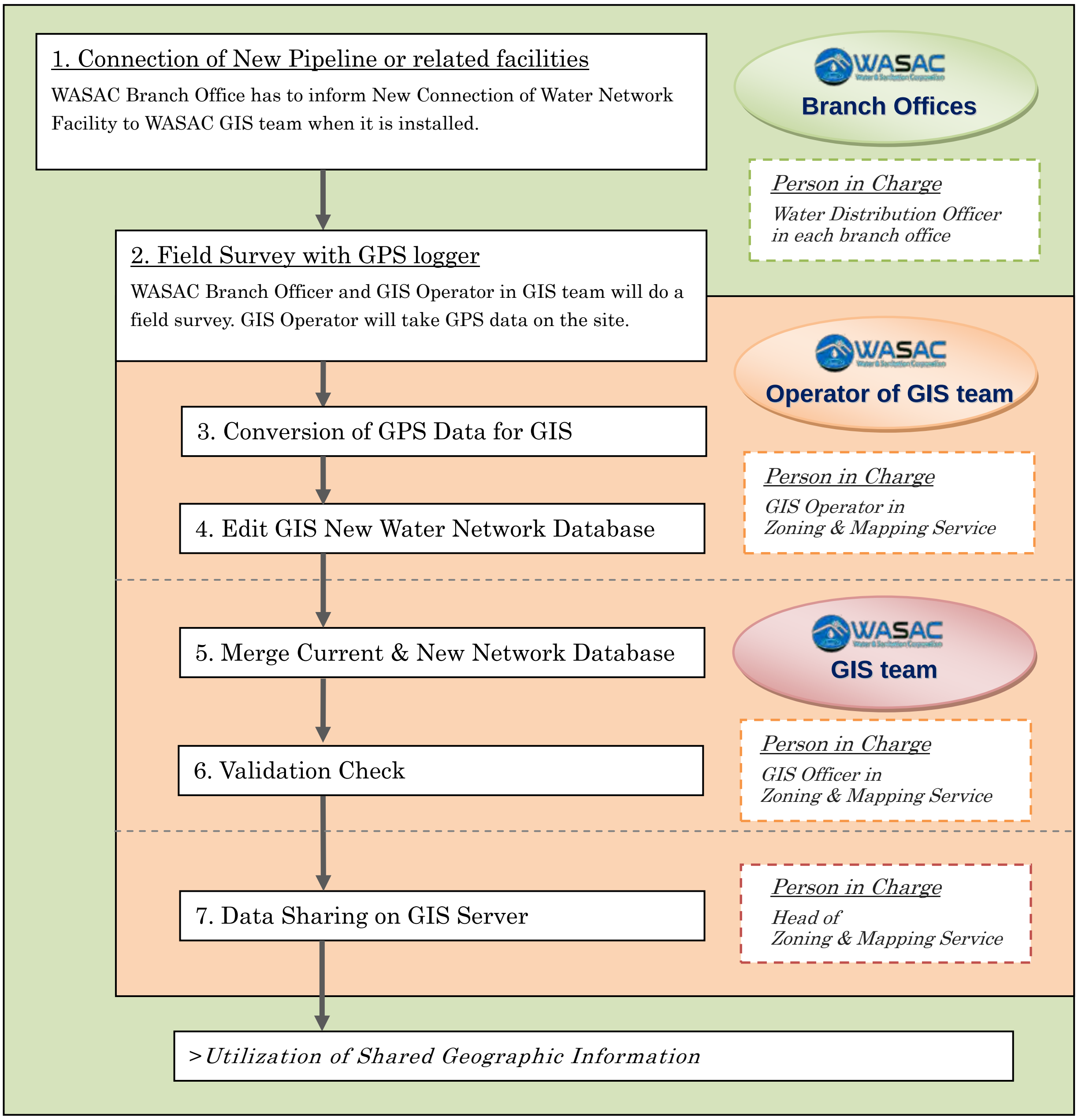
Please re-investigate UPI codes and correct them.
If the customer does not have UPI code,
please survey XY coordinates instead.

- ➢ If UPI code in the unmatched record is correct, Parcel data that GIS team has might have been outdated. Then please inform that issue to GIS team; and GIS team must update Parcel data.

II. Procedures for GIS Water Network Data Update

1. Work-Flow of GIS Water Network Data Update

Current Work-Flow: Only targets on 6 branches in Kigali City



1. Connection of New Pipeline or related facilities

WASAC Branch Office has to inform New Connection of Water Network Facility to WASAC GIS team when it is installed.

2. Field Survey with GPS logger

WASAC Branch Officer and GIS Operator in GIS team will do a field survey. GIS Operator will take GPS data on the site.

3. Conversion of GPS Data for GIS

4. Edit GIS New Water Network Database

5. Merge Current & New Network Database

6. Validation Check

7. Data Sharing on GIS Server

> *Utilization of Shared Geographic Information*

Branch Offices

Person in Charge
Water Distribution Officer in each branch office

Operator of GIS team

Person in Charge
GIS Operator in Zoning & Mapping Service

GIS team

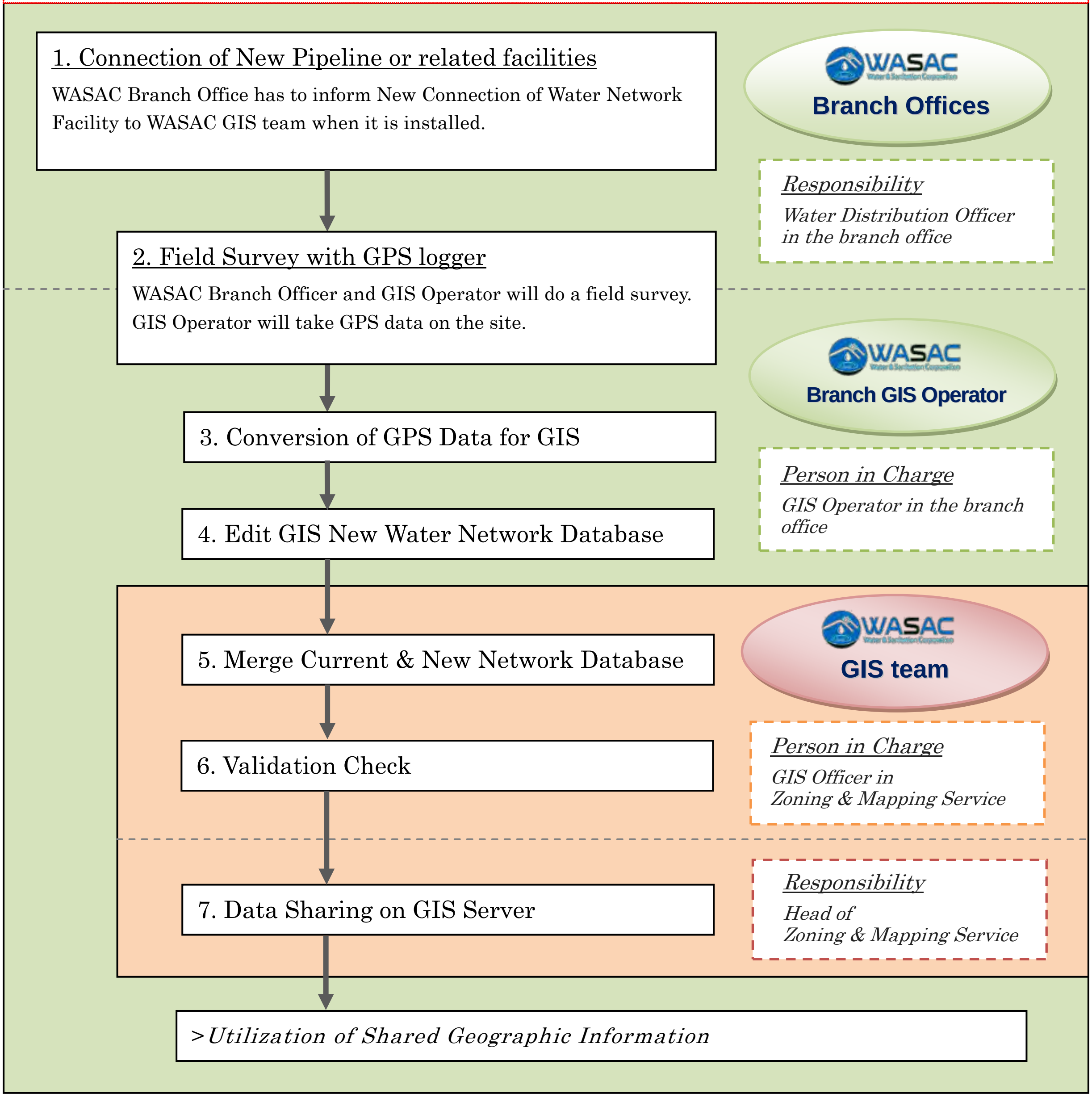
Person in Charge
GIS Officer in Zoning & Mapping Service

Person in Charge
Head of Zoning & Mapping Service

Future Work-Flow: will target on all 20 branches in Rwanda

Since it would be over-capacity for GIS team to handle GIS data update for all 20 branches in WASAC, this future work-flow plans to have each branch implement the duty operating ArcGIS by themselves.

It will require at least 3 conditions: Installation of ArcGIS on their computers; Fast Internet Connection; Training by GIS team.



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WASAC Branch Offices

Responsibility
Water Distribution Officer in the branch office

WASAC Branch GIS Operator

Person in Charge
GIS Operator in the branch office

WASAC GIS team

Person in Charge
GIS Officer in Zoning & Mapping Service

Responsibility
Head of Zoning & Mapping Service

2. WASAC Branch Office & GIS team: Field Survey

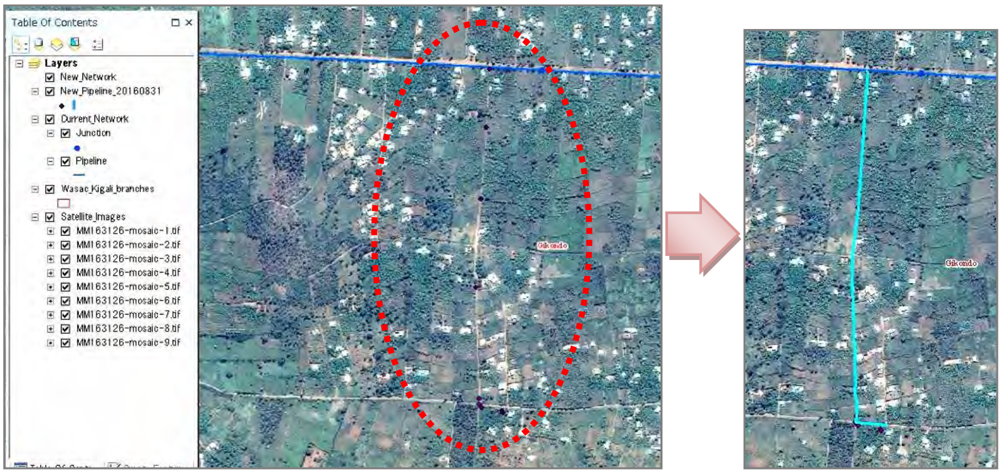
After the installation of new pipeline or the other facilities, WASAC Branch Office has to inform it to GIS team; and then GIS team will bring GPS logger to the field in order to capture coordinates of the location.

- WASAC GIS team and Branch Officers are sharing information for Network Update on an application of their phones so as them to make it timely.

WhatsApp Group for Network Update

- Field Survey is implemented by GIS Operator and Branch Officer. GIS Operator brings GPS Logger and Field-map for the survey.

- GPS data is converted to GIS data by GIS Operator, and data-sets of the water network are updated. **New Water Network Data-set is created monthly** by GIS Operator; and GIS Officer merges New & Current Data-sets and validates it.



III. Utilization of GIS in WASAC

1. Data Sharing Methods

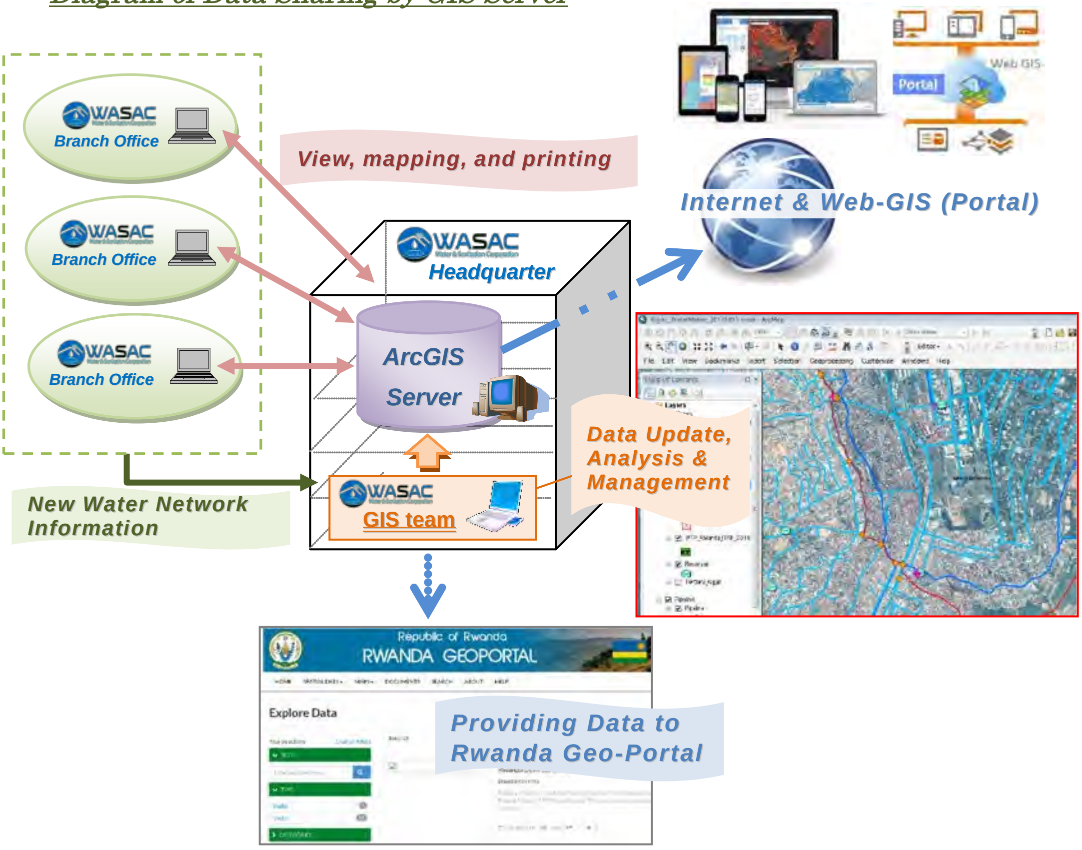
The most important factors for advancing utilization of GIS are ***Data Sharing*** and ***Continuous Update of Data***.

Data Sharing Methods are various: if the organization has high-speed network connection in Local Area Network (LAN) and the Internet, then sharing through [GIS Server] would be the best way. On the other hand, if network connection is slow in speed, you would better to copy all the data-sets or output maps by hand to hand. In that case, you may share the map exporting to PDF, or using Free-Software such as QGIS.

ArcGIS Server

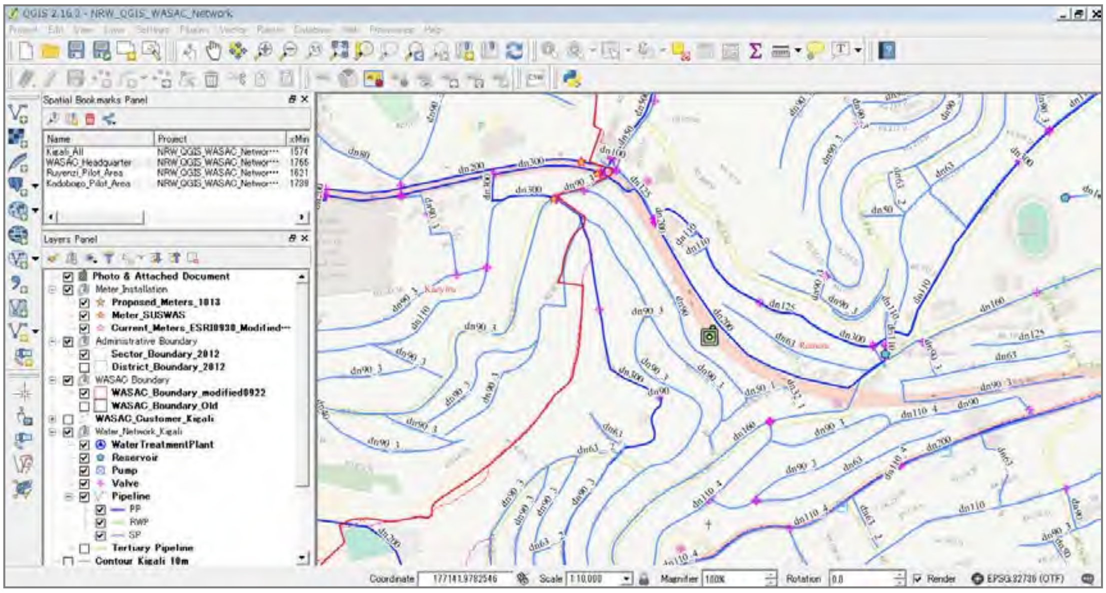
WASAC GIS team plans to introduce ArcGIS Server in order to share the GIS data throughout the organization (as of October 2016). ArcGIS is one of the most popular GIS software that has various kinds of powerful analysis tools and layout flexibilities. With this, the organization is able to maximize GIS usefulness for its business.

- *Diagram of Data Sharing by GIS Server*



QGIS

QGIS is one of the most popular free-GIS software. What you need to do is to install the software on your computer and copy the GIS data-set. Software license is free of charge and the internet connection is not required for its installation and operation.

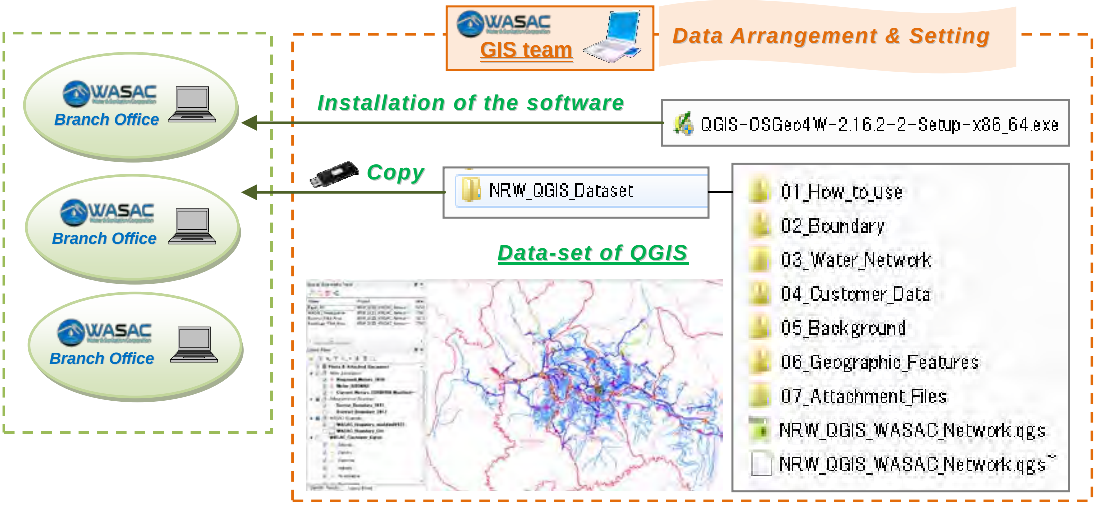


This software enables you:

- To view all GIS data-set and the information that GIS team has.
- To edit GIS feature data-set
- To run some basic spatial analyses

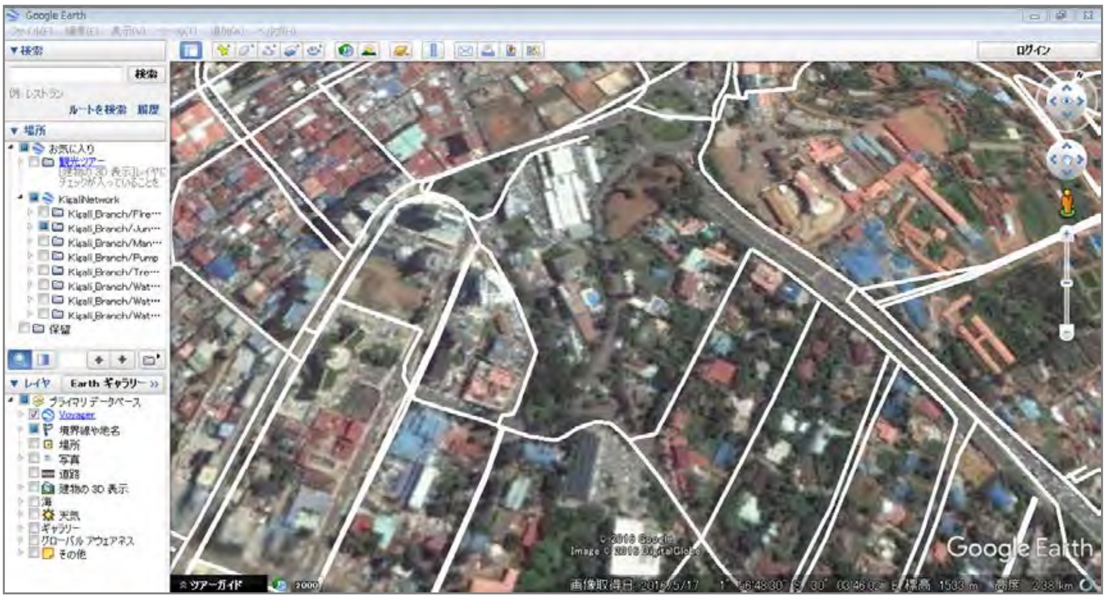
In order to share the information, all folders in the data-set must be copied to your computer. In addition, you need to install QGIS software.

➢ ***Diagram of Data Sharing by QGIS***



Google Earth

Google Earth is a virtual globe and mapping system developed by Google. It displays satellite images as base-map allowing users to see geographic features easily. Users are able to add some GIS data onto the map using KML file format.



Comparison of Software

	ArcGIS Server	QGIS	Google Earth
Software Category	GIS Server	GIS Editor/Viewer	Map Viewer
Editing tools	Powerful	Possible	Limited
Spatial Analysis	Powerful	Possible	Limited
Cost	Expensive	Free	Free
Feature data type	Shape/GeoDatabase	Shape	KML
Data Sharing Method	Network connection to the server	Copy data-sets (by hand / File Storage)	Copy data-sets (by hand / Google Drive)
Internet Connection	Required (for Server connection)	Not required (as far as sharing by hand)	Sometimes required (to read base-map)
Interface	Skill required	Partly skill required	User Friendly
Setting difficulty	Skill required	Skill required	User Friendly

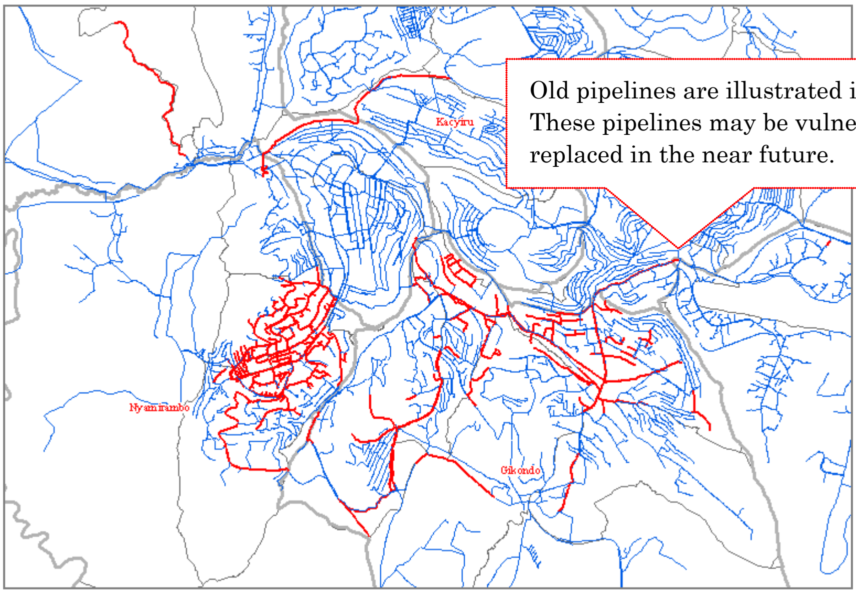
2. Examples of GIS Analyses in Water Network Management

It has been widely recognized that GIS takes essential roles in Planning for Water Network and Asset Management.

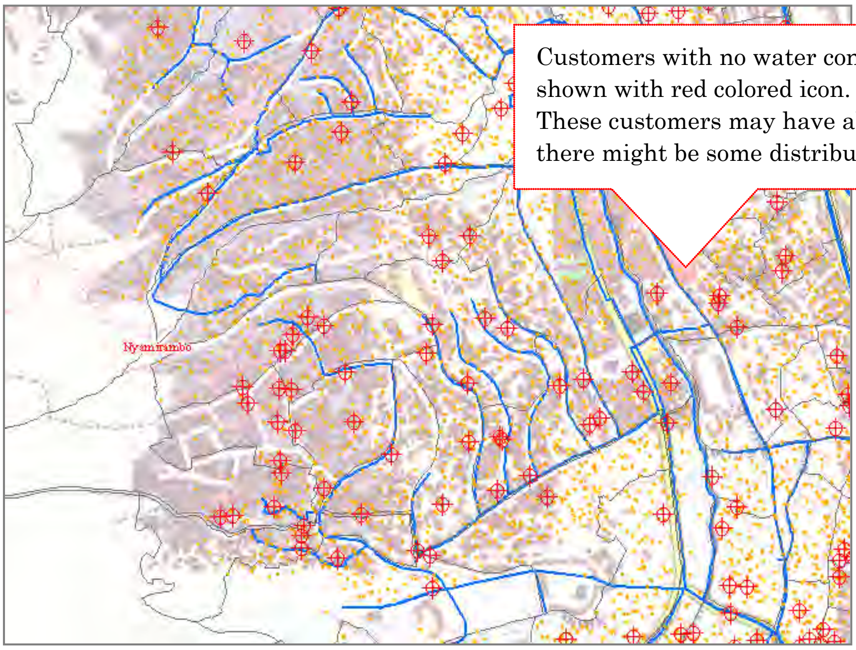
Asset Management by GIS Data Visualization

Analysis based on GIS data often reveals many facts on a map. For example, old pipelines are easily identified by different color in a sight; and it can be used for the pipeline renewal plan.

Distribution of Customers related to Water Consumption data shows lower / higher consumption areas; and it may identify inactive customers and some trends of water usage in the area.



Old pipelines are illustrated in red colored line. These pipelines may be vulnerable and should be replaced in the near future.

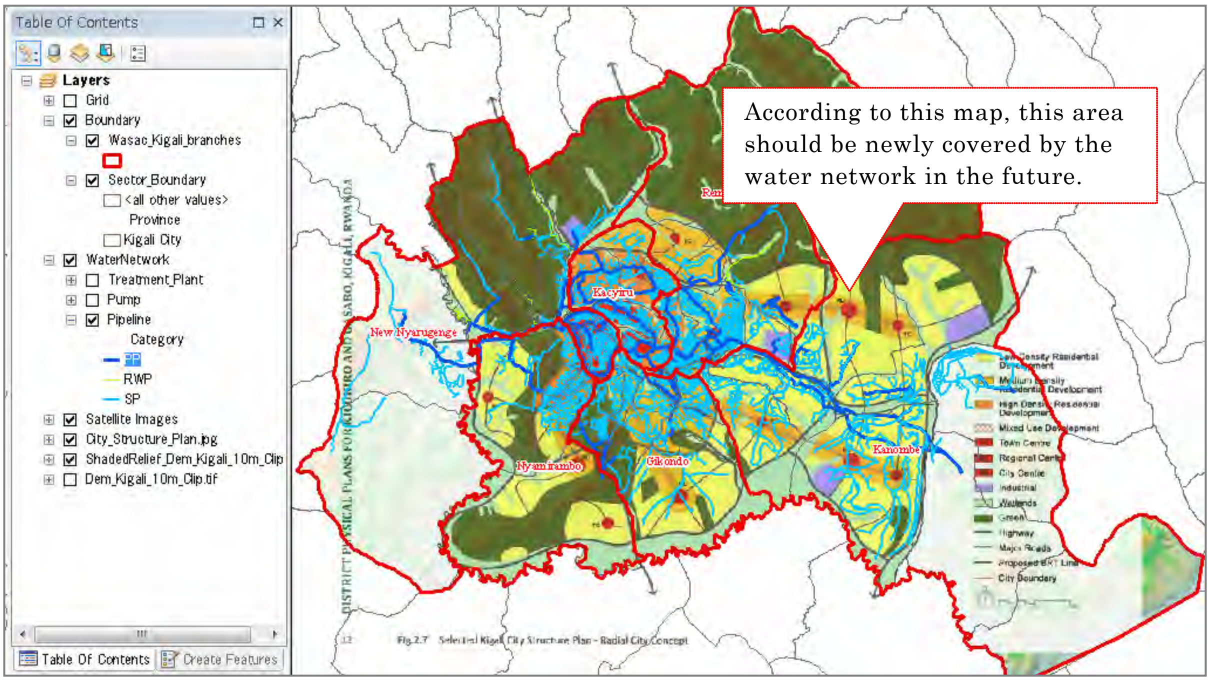


Customers with no water consumption are shown with red colored icon.
These customers may have already moved; or there might be some distribution problems.

Future Planning by Mapping Overlay

Master-Plans and Diagrams from the other department may provide robust rationales for your plan when your GIS data is overlaid with those maps & diagrams.

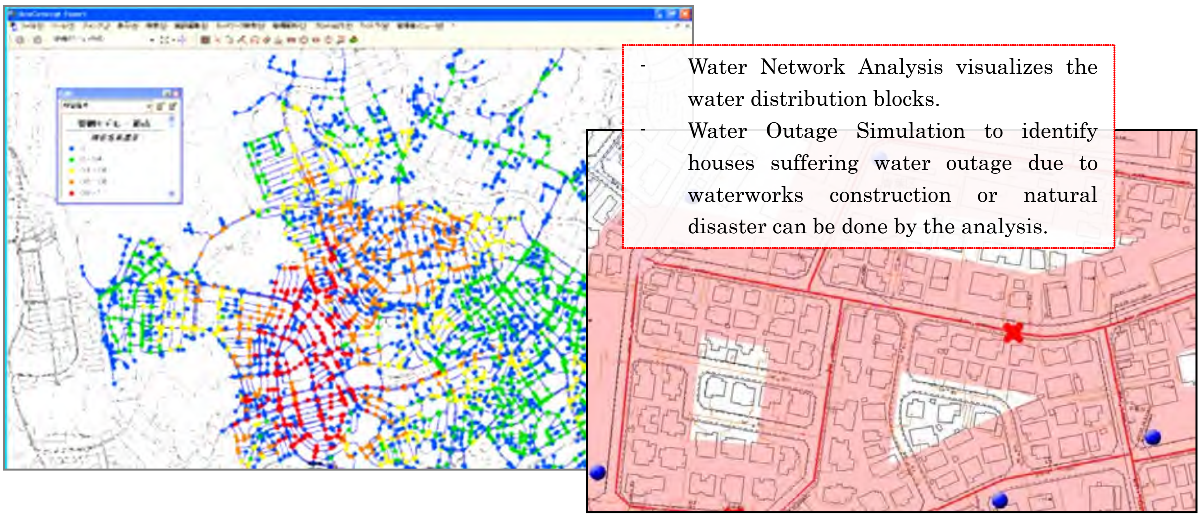
➢ Example: Kigali City Structure Plan (Kigali City Master Plan Report 2013) with Water Network data



According to this map, this area should be newly covered by the water network in the future.

Water Outage Simulation by Water Network Analysis

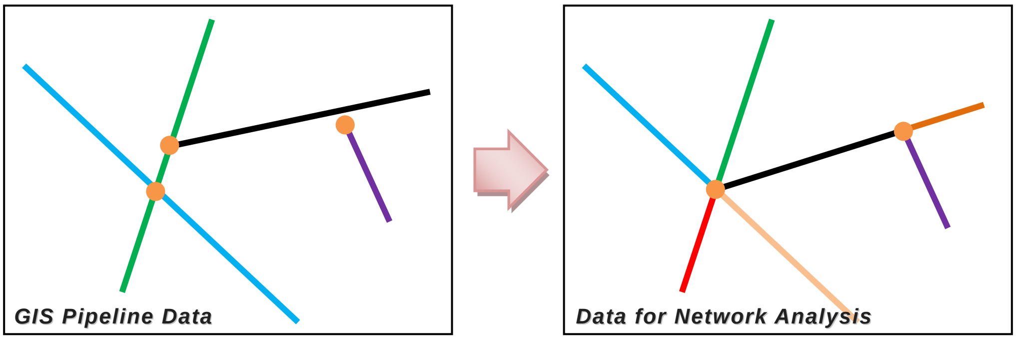
Analysis of Water Network enables you to do convincing and prompt decision making. For example: detection of high-water-pressure zones; identifying blocks of water distribution so as to calculate the area of suspension of the water supply due to waterworks construction.



- Water Network Analysis visualizes the water distribution blocks.
- Water Outage Simulation to identify houses suffering water outage due to waterworks construction or natural disaster can be done by the analysis.

Before implementing Water Network Analysis, **You Need to Simplify GIS data**. This modification may be done by using specific software (so-called Water-GIS).

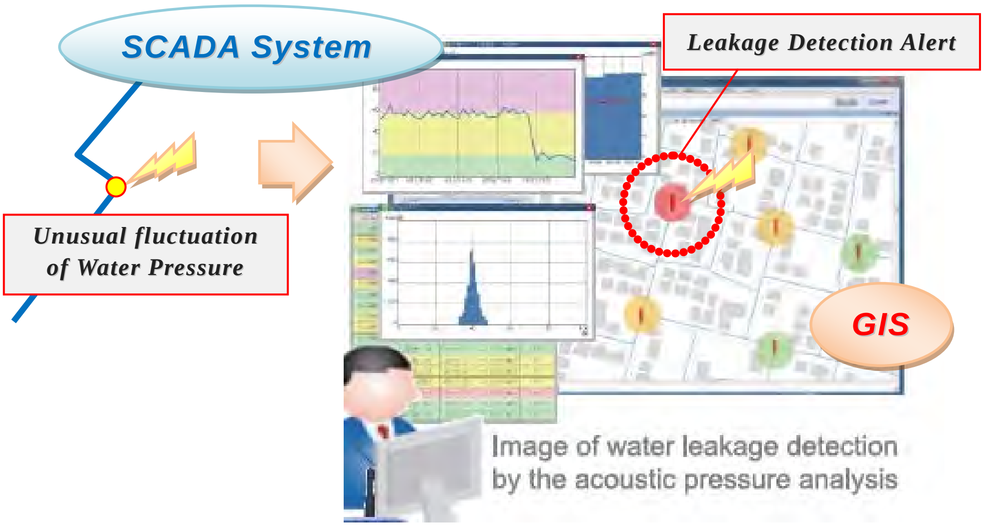
- *Example of GIS data modification for Water Network Analysis*



Water Leakage Detection by the Pressure Analysis

SCADA system will send the current data of Water Network to the server so as you to monitor the information at the time. If information of Water Pressure at the meter is sent and updated on GIS, then Water Leakage can be detected by seeing its trend and fluctuation.

Although GIS software may not have the real-time synchronization with SCADA, it is still possible to update the data manually and run the analysis.

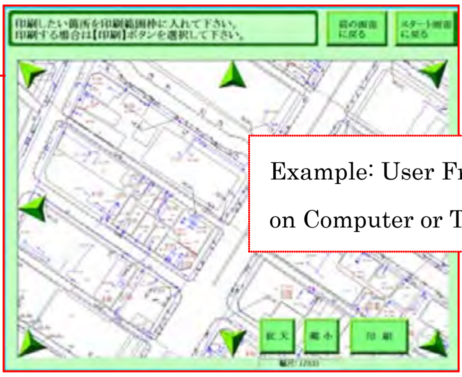


3. Improvement of Customer Services

Mapping System for the Customer Service Counter

In many government municipal offices, GIS Map Viewer is installed at the Customer Service Counter. It provides plenty of mapping information to visitors, and which is operated by visitors or by operators in the office.

For example, it shows inventory of the water network; location of water network facilities for new road or new building constructions; the information where the water network construction affects residents of the area; map printing service; however private information should be limited to show.

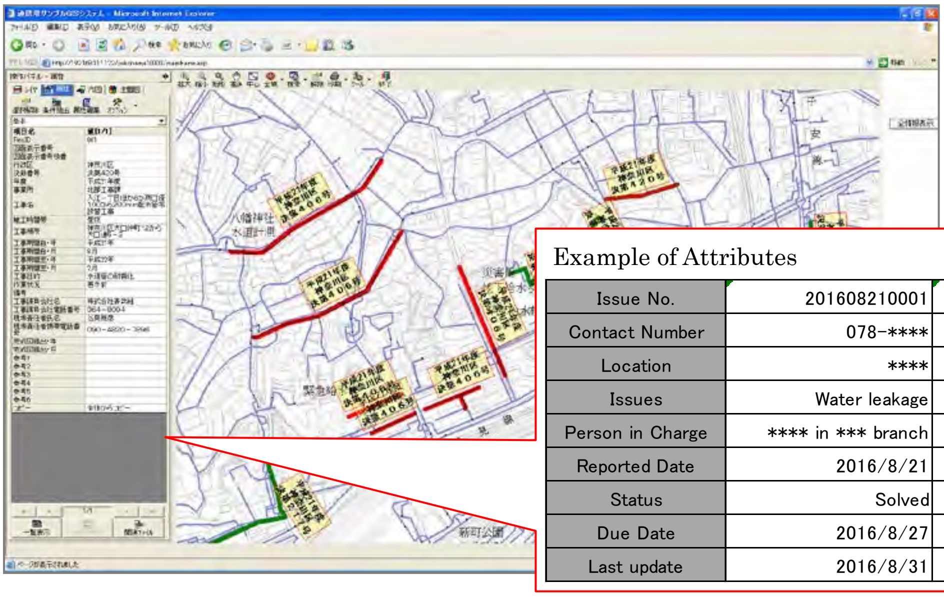


印刷したい箇所を印刷範囲枠に入れて下さい。
印刷する場合は【印刷】ボタンを選択して下さい。

Example: User Friendly GIS Viewer installed on Computer or Tablet at the Services Counter.

Management of Customer's Inquiry & Claim

Customer's inquiries and claims are plotted on GIS by operators and promptly shared among officers in the organization. The attributes of inquiry may contain a person in responsible and the status of progress, so that the organization can manage customer's demands or requests properly without confusion.



Example of Attributes

Issue No.	201608210001	201608250029
Contact Number	078-****	073-****
Location	****	****
Issues	Water leakage	Public tap was broken
Person in Charge	**** in *** branch	**** in *** branch
Reported Date	2016/8/21	2016/8/25
Status	Solved	To be surveyed
Due Date	2016/8/27	2016/9/30
Last update	2016/8/31	2016/8/31

WASAC GIS Procedure Guide
Data Update and Management for Water Network and Customer Information

1st Edition on 9th November 2016

JICA Project for Strengthening Non-Revenue Water Control in Kigali City Water Network [GIS]

WASAC

GIS Operation Manual

Data Update and Management for
Water Network and Customer Information

2016 October

JICA NRW Project

Document Title

WASAC GIS Operation Manual
Data Update and Management for Water Network and Customer Information (1st Edition)

Acknowledgement

This document was written for WASAC - JICA Technical Cooperation Project for "Strengthening Non-Revenue Water Control in Kigali City Water Network" (NRW Project) which has been supported by Japan International Cooperation Agency (JICA).

In particular, this document is written for WASAC GIS team (Zoning and Mapping Services in WASAC Headquarter), and any other officers who are responsible for GIS data update.

JICA GIS expert of the project had implemented trainings and discussions which targeted on "GIS data update and management for water network and customer information" for / with WASAC GIS team from August to November 2016. This document was created as one of the outcomes through our trainings and discussions during the term; and this mainly aims to enable all persons who are related to GIS operation in WASAC to learn and review detailed software operations in order to implement GIS data update and appropriate management.

The fundamental environment related to GIS in the organization and the country will be changing day by day; therefore this document must be revised by WASAC GIS team reflecting the latest situation. I strongly hope that all the people who operate GIS data update in WASAC will read this document and continuously update the GIS data in order to advance the utilization.

9th November 2016

Eita Horishita
GIS expert, JICA
Strengthening Non-Revenue Water Control in Kigali City Water Network

Table of Contents

I. Water Network Data Update

Workflow for Customer Data Update on GIS is as below.

i. Field Survey with GPS logger

Field Officer of the branch office / GIS team needs to acquire GPS data to investigate exact location of the new network.

ii. Create Monthly New Network database

GIS Operator creates Geodatabase on ArcGIS for New Network data-sets in the month.

iii. Conversion of GPS data on ArcGIS

GPS data from the Field Officer is converted to GIS data by GIS Officer in GIS team.

iv. Edit the Monthly New Network data on GIS

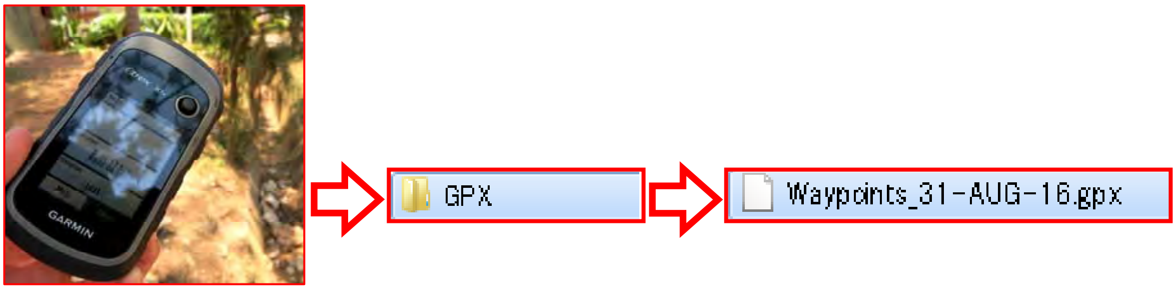
GIS Operator draws New Pipeline and the other network data, and input Attribute information on them.

v. Merge New & Current GIS database and make Validation Check

The New Network Data-sets in the month will be handed over to GIS Officer. GIS Officer merges New and Current network data-set, and makes validation check.

1. Preparation: Aquire the GPX data from the field survey

➢ After the Field Survey with GPS logger, you will connect it with your computer and copy the tracks/waypoints data.

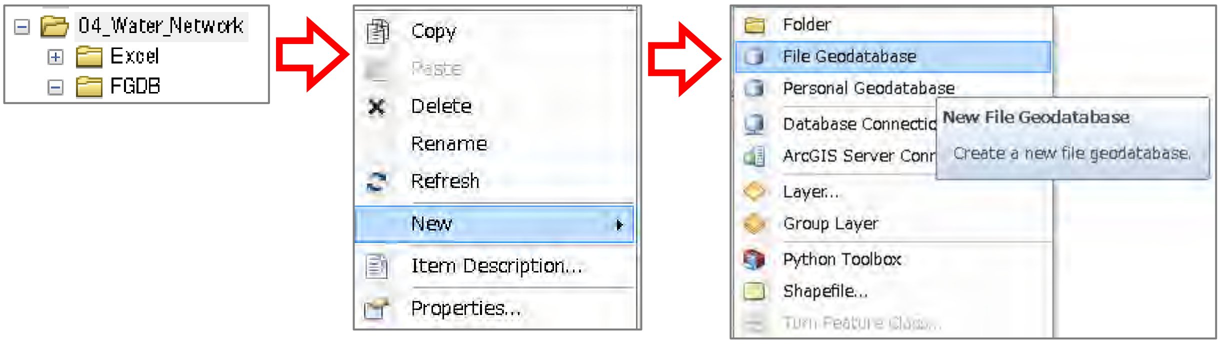


2. Preparation: Create Monthly Geodatabase on ArcCatalog

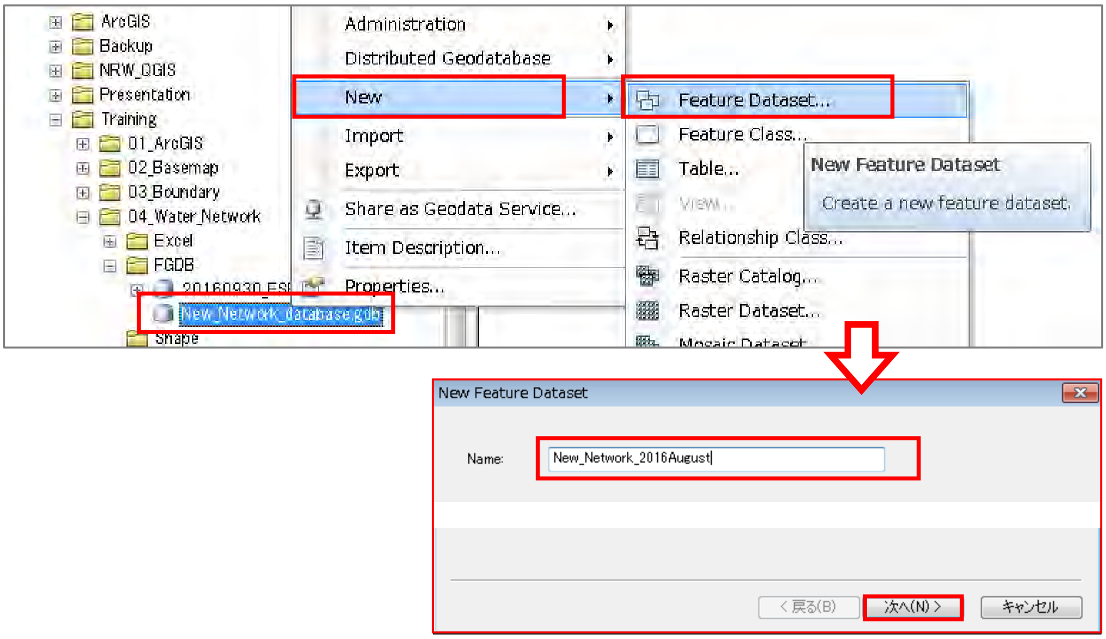
➢ As a preparation for Water Network Update, firstly you need to create FileGeodatabase , Feature Data-set, and Feature Class. Feature Data-set should be created MONTHLY.

❗ Please make sure that GIS Operator would create these Geodatabase and Data-set in an appropriate folder with explicit file names for Feature Class.

- In the ArcCatalog, Right Click the folder and [New > File Geodatabase]



- Create New Feature Data-set: Right Click on the File Geodatabase, and [New > Feature Dataset]. Put appropriate name like "New_Network_2016August".



Name: New_Network_2016August

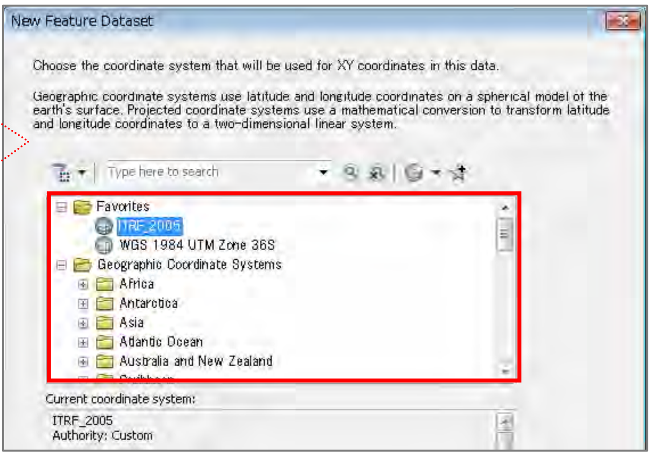
- In the next dialog, select appropriate Coordinate System (ITRF2005, Custom)

It is recommended to save the Coordinate System in "Favorites".

<u>Custom Parameter of ITRF2005</u>

ITRF_2005
Authority: Custom

Projection: Transverse_Mercator
False_Easting: 500000.0
False_Northing: 5000000.0
Central_Meridian: 30.0
Scale_Factor: 0.9999
Latitude_Of_Origin: 0.0
Linear Unit: Meter (1.0)

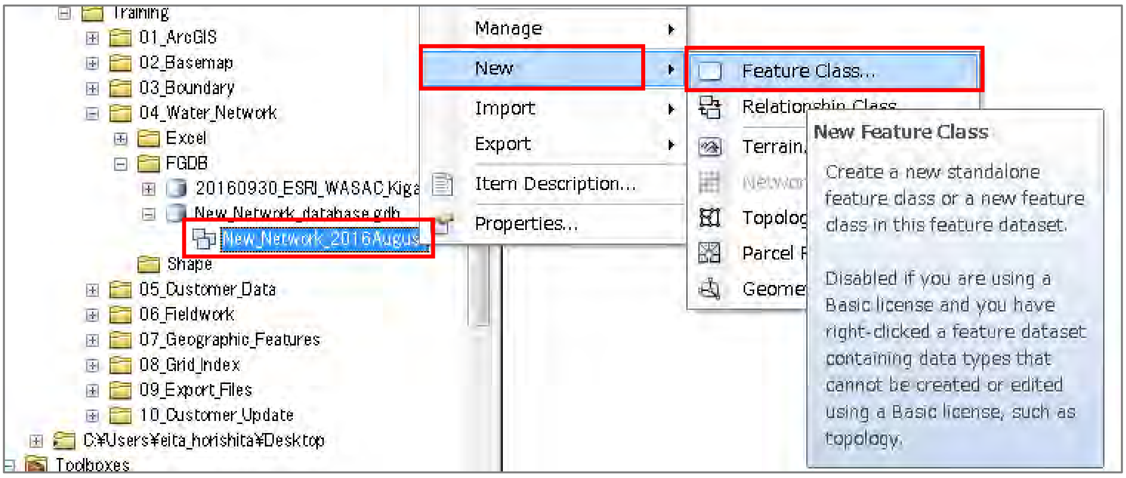


Choose the coordinate system that will be used for XY coordinates in this data.

Geographic coordinate systems use latitude and longitude coordinates on a spherical model of the earth's surface. Projected coordinate systems use a mathematical conversion to transform latitude and longitude coordinates to a two-dimensional linear system.

Current coordinate system:
ITRF_2005
Authority: Custom

- After creating Feature Dataset, please create Feature Class for Monthly Network Update. Right Click on the Feature Dataset, and [New > Feature Class]

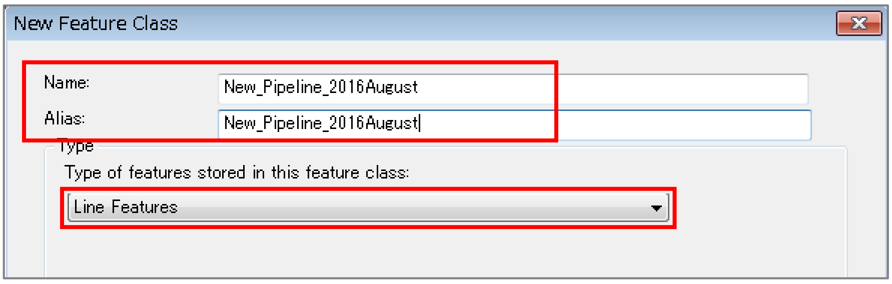


New Feature Class

Create a new standalone feature class or a new feature class in this feature dataset.

Disabled if you are using a Basic license and you have right-clicked a feature dataset containing data types that cannot be created or edited using a Basic license, such as topology.

- In the [New Feature Class] dialog, please type appropriate Name like “New_Pipleline_2016August”
- Please select the appropriate feature type: if it is [Pipeline] data, the feature type is [Line Features].


New Feature Class

Name: New_Pipeline_2016August

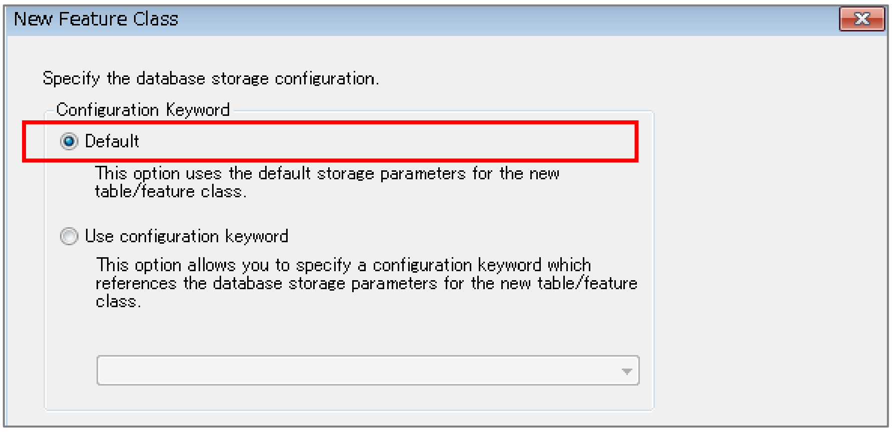
Alias: New_Pipeline_2016August

Type

Type of features stored in this feature class:

Line Features

- In the next dialog, please keep it as “Default” setting and go to next.


New Feature Class

Specify the database storage configuration.

Configuration Keyword

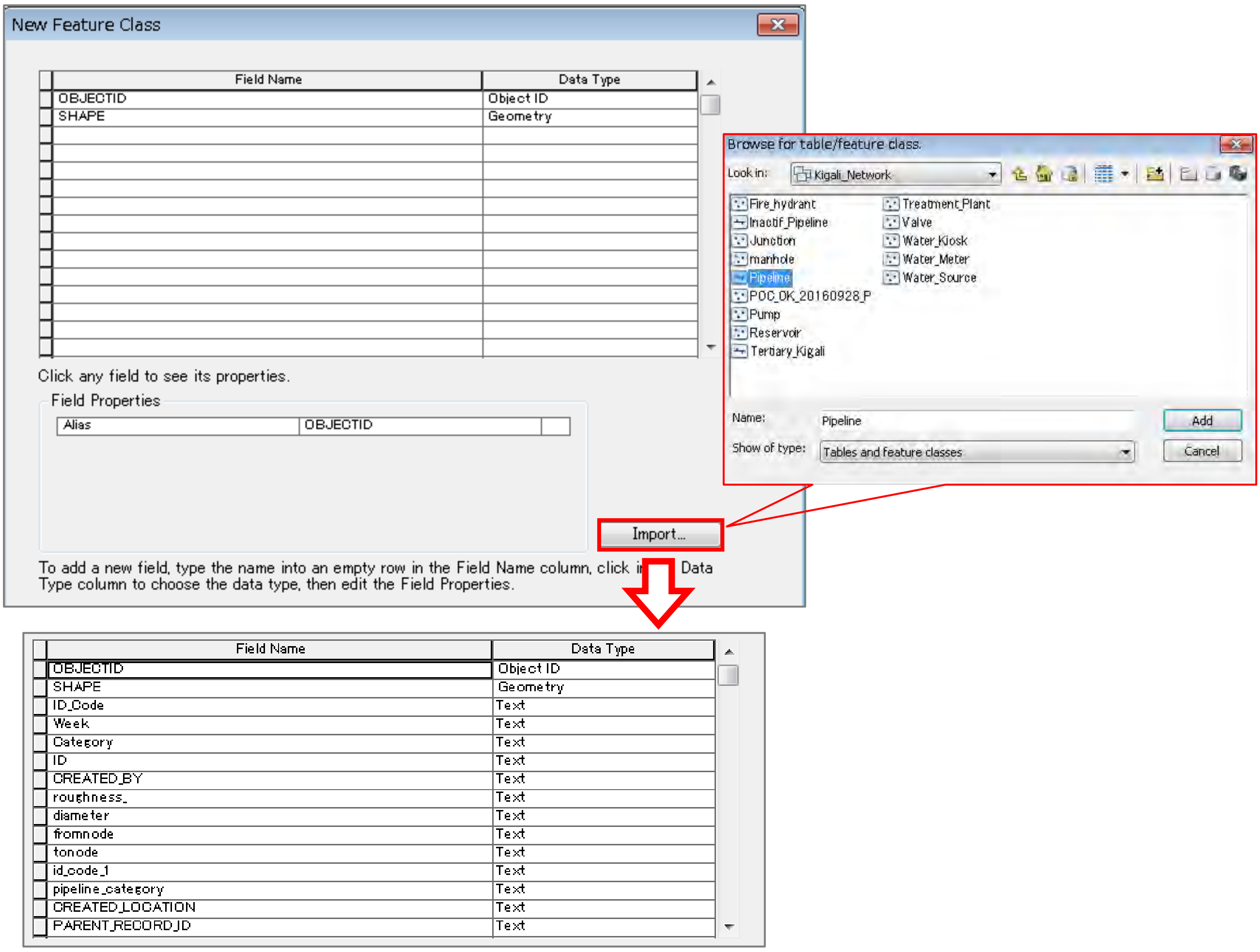
● Default

This option uses the default storage parameters for the new table/feature class.

○ Use configuration keyword

This option allows you to specify a configuration keyword which references the database storage parameters for the new table/feature class.

- In the next dialog, please click [Import] in order to import the Attribute Field name from the Current Network database.



Field Name	Data Type
OBJECTID	Object ID
SHAPE	Geometry

Click any field to see its properties.

Field Properties

Alias	OBJECTID

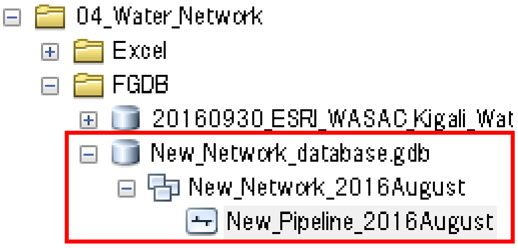
Name: Pipeline

Show of type: Tables and feature classes

To add a new field, type the name into an empty row in the Field Name column, click in the Data Type column to choose the data type, then edit the Field Properties.

Field Name	Data Type
OBJECTID	Object ID
SHAPE	Geometry
ID_Code	Text
Week	Text
Category	Text
ID	Text
CREATED_BY	Text
roughness_	Text
diameter	Text
fromnode	Text
tonode	Text
id_code_1	Text
pipeline_category	Text
CREATED_LOCATION	Text
PARENT_RECORD_ID	Text

- Click "Finish", and then New Feature Class for Monthly Data Update is created.

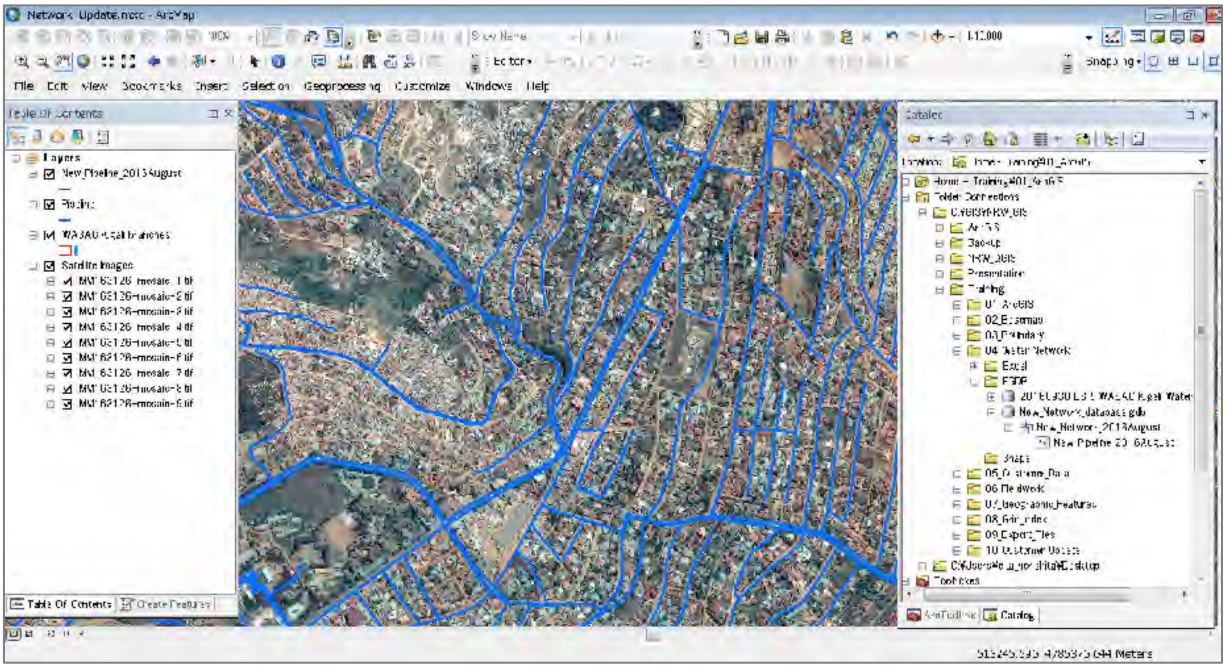


New Network (Pipelines, Meters, and so on) Data in the month will be edited in the same Feature Data-set in Geodatabase.

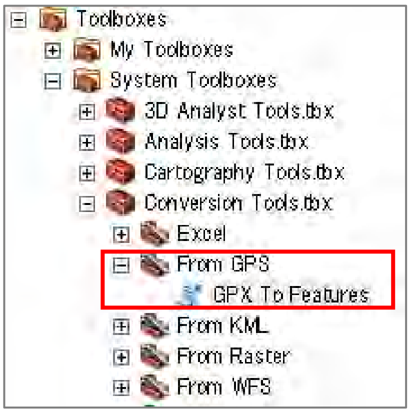
3. Conversion of GPX file

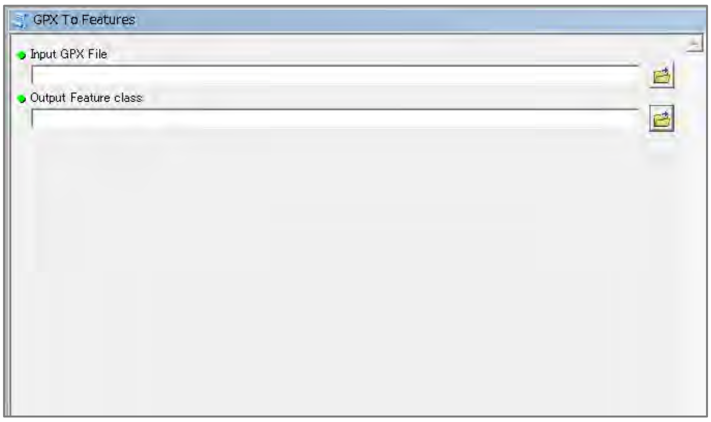
- For your workspace on ArcMap, insert the current network data and background maps such as Satellite Images and Boundary data on your ArcMap.

  As shown below, you should change symbol colors in order to make the features clear to see. In addition, creating Layer Group is also recommended for easy operation.

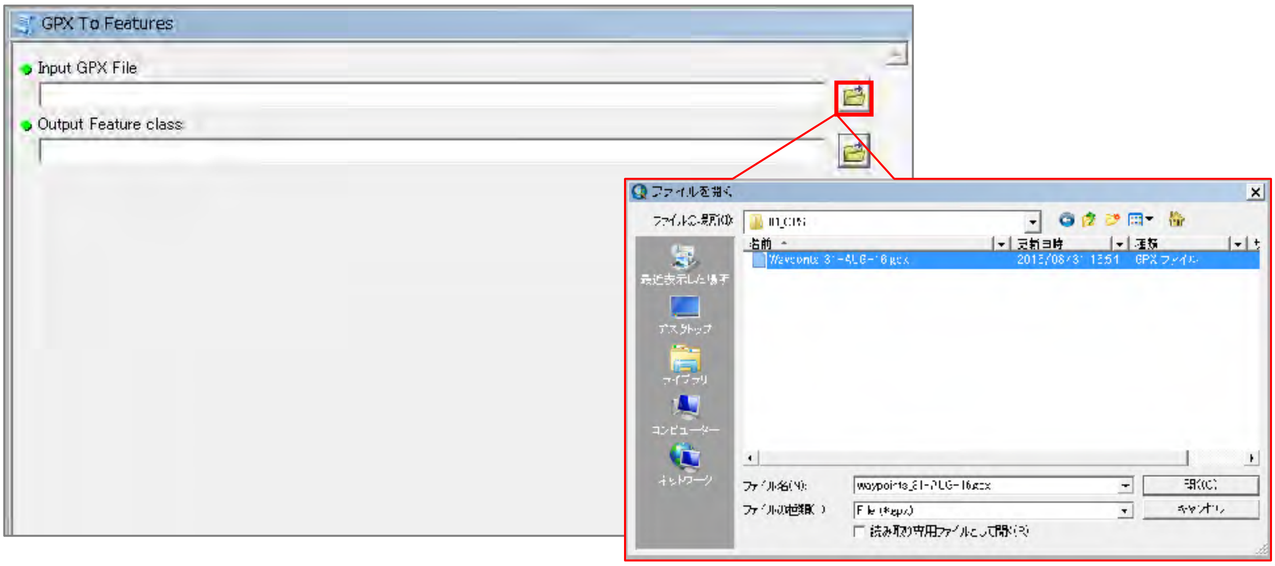


- Data from GPS has extension named ".gpx". In order to insert the data on ArcMap, you need to convert it to Shape file.
  - Select the Conversion Tool from ArcToolbox:
    [ArcToolbox > Conversion Tools > From GPS > GPX to Features]

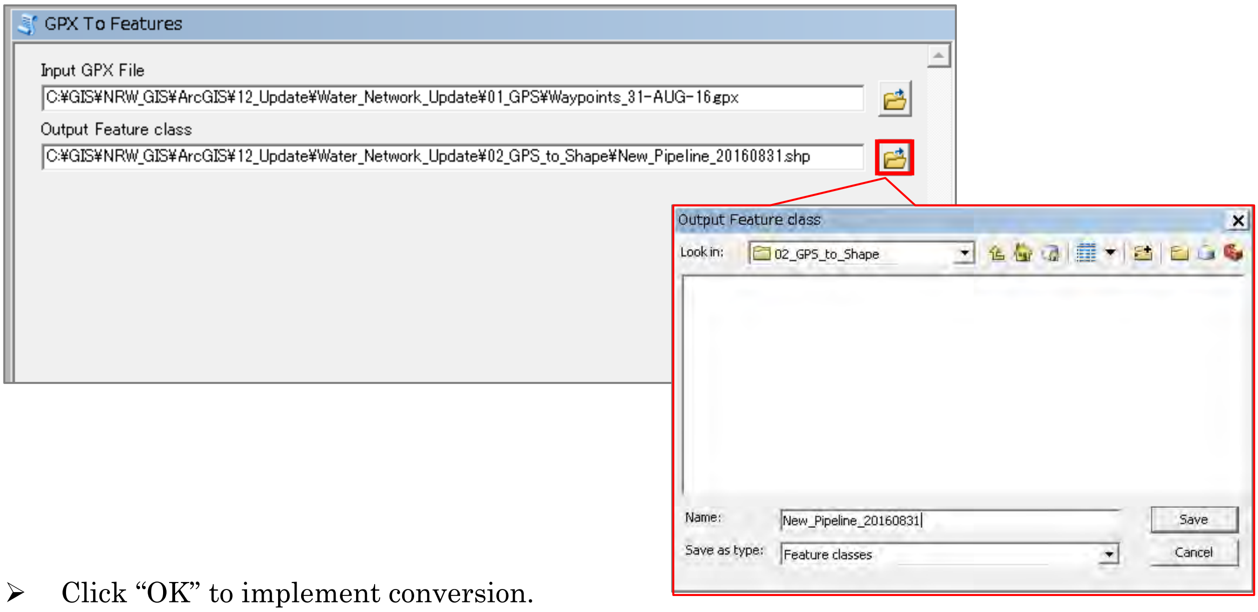




- Select GPX file that you want to convert.



- Select Output Feature Class:
  - Please set the appropriate folder that you can easily find out. Please put simple and explicit name like: New_Pipeline_Gahanga_20160831



Input GPX File: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Water_Network_Update¥01_GPS¥Waypoints_31-AUG-16.gpx

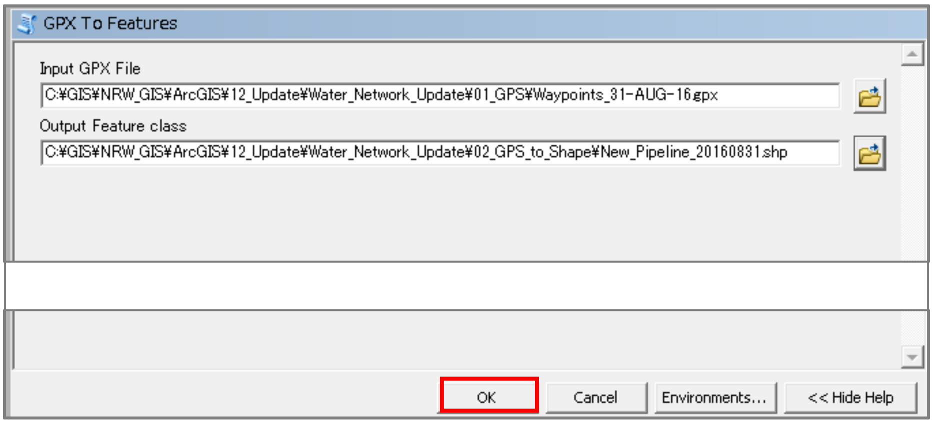
Output Feature class: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Water_Network_Update¥02_GPS_to_Shape¥New_Pipeline_20160831.shp

Look in: 02_GPS_to_Shape

Name: New_Pipeline_20160831

Save as type: Feature classes

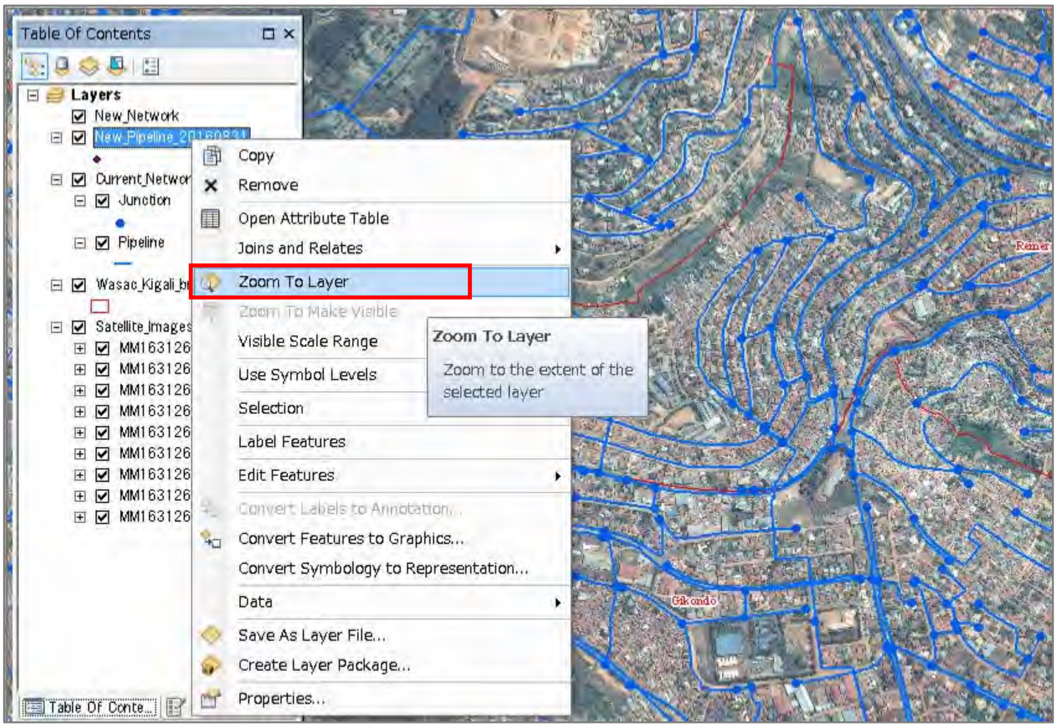
- Click “OK” to implement conversion.



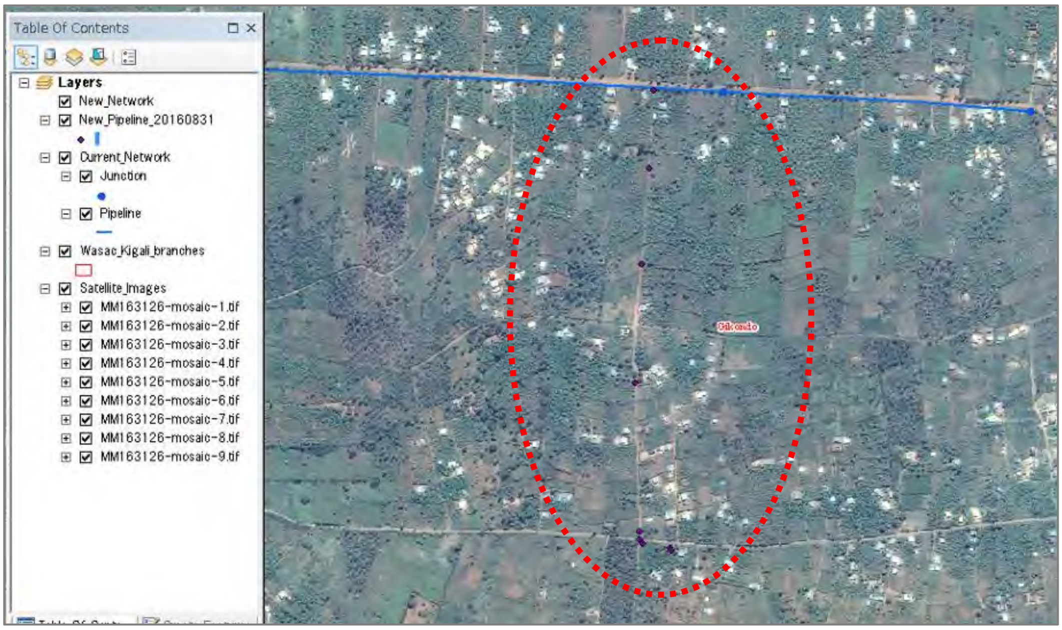
Input GPX File: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Water_Network_Update¥01_GPS¥Waypoints_31-AUG-16.gpx

Output Feature class: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Water_Network_Update¥02_GPS_to_Shape¥New_Pipeline_20160831.shp

- If the conversion is successfully done, created Shape file is automatically inserted on ArcMap.
  - Please Right Click on the layer and select "Zoom to Layer"; and then converted data is displayed in the center of the map.



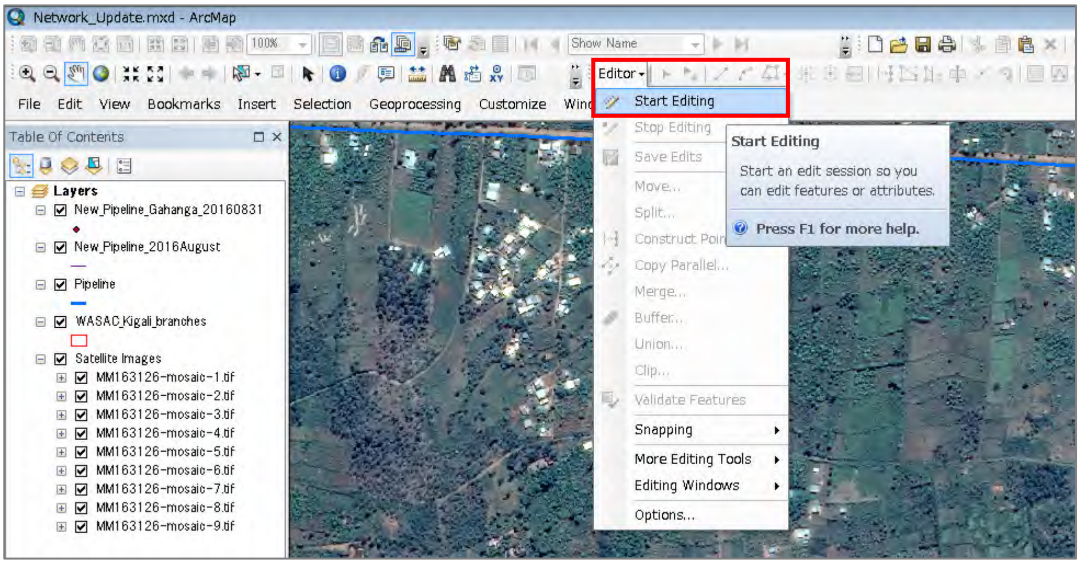
Zoom to the extent of the selected layer



4. Edit the New Water Network

GPX data is converted as Point features. It is possible to convert from Point to Line feature as a new Pipeline; however it is not recommended in terms of accuracy because GPS may have a gap in few meters. It would be better to be used for location reference, and **New Water Network data should be edited manually**.

- To Edit a layer, select [Start Editing] from [Editor].

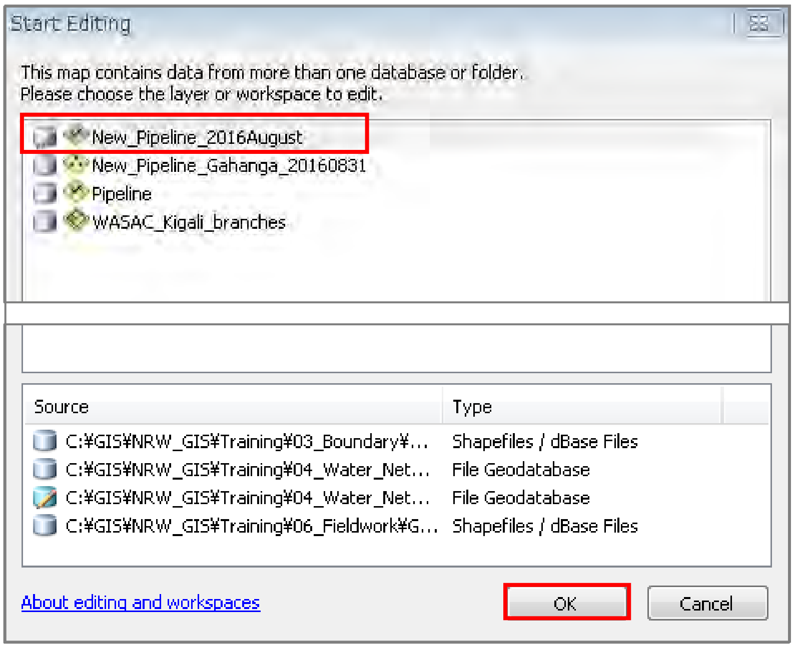


Start Editing

Start an edit session so you can edit features or attributes.

Press F1 for more help.

- In the Dialog of [Start Editing], select the New Network data; and Click OK.

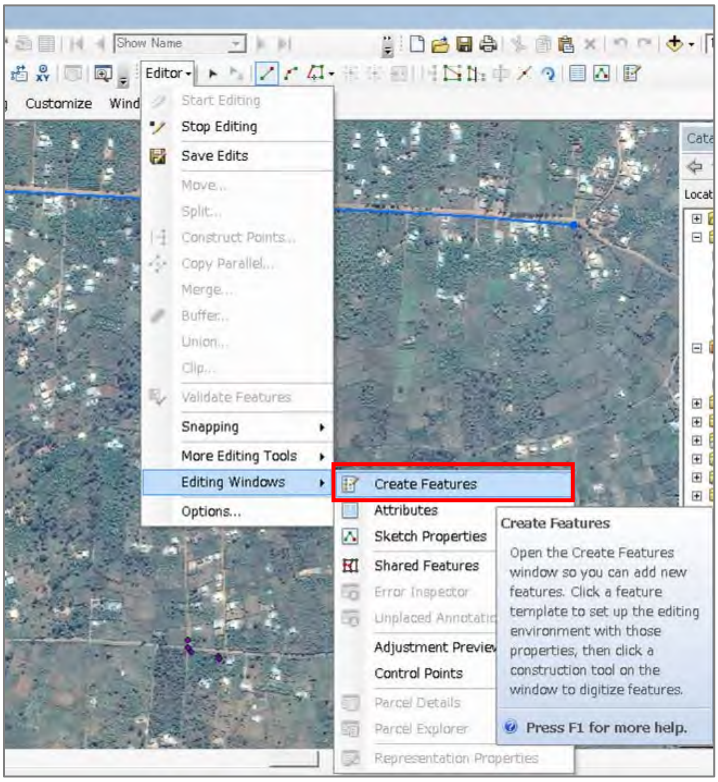


This map contains data from more than one database or folder. Please choose the layer or workspace to edit.

New_Pipeline_2016August
New_Pipeline_Gahanga_20160831
Pipeline
WASAC_Kigali_branches

Source	Type
C:¥GIS¥NRW_GIS¥Training¥03_Boundary¥...	Shapefiles / dBase Files
C:¥GIS¥NRW_GIS¥Training¥04_Water_Net...	File Geodatabase
C:¥GIS¥NRW_GIS¥Training¥04_Water_Net...	File Geodatabase
C:¥GIS¥NRW_GIS¥Training¥06_Fieldwork¥G...	Shapefiles / dBase Files

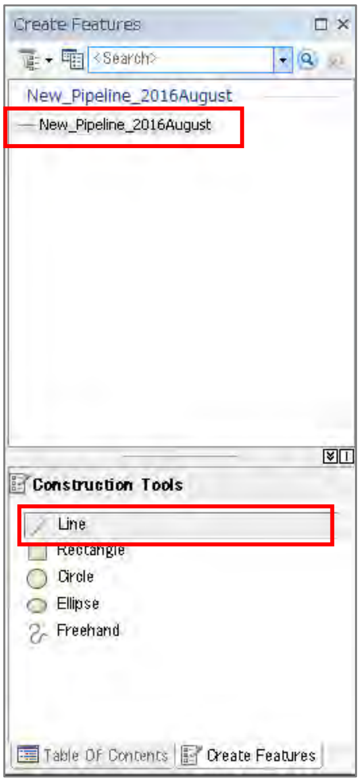
- Please turn on the [Create Features] Window for easy editing if it is not displayed.
  - In the “Create Features” Window, please select “Pipeline” layer and “Line” in Construction Tools.



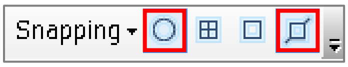
Create Features

Open the Create Features window so you can add new features. Click a feature template to set up the editing environment with those properties, then click a construction tool on the window to digitize features.

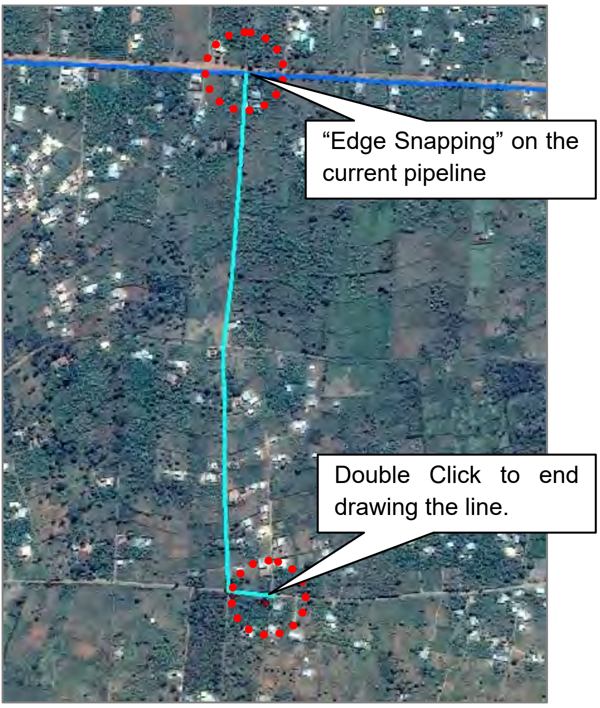
Press F1 for more help.



- ➢ Do not forget to set Snapping. In this case, “Point Snapping” and “Edge Snapping” are recommended.



- ➢ Snapping the Current Pipeline and seeing Satellite Images, draw new pipeline manually. Double Click to finish drawing when it comes to the end point.

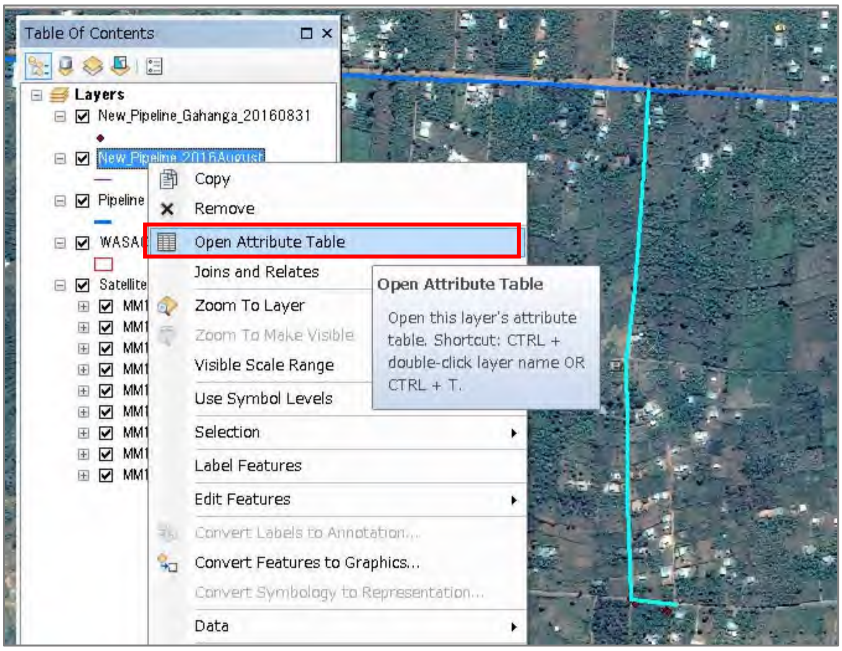


“Edge Snapping” on the current pipeline

Double Click to end drawing the line.

➢ After drawing, you need to edit the Attribute Table.

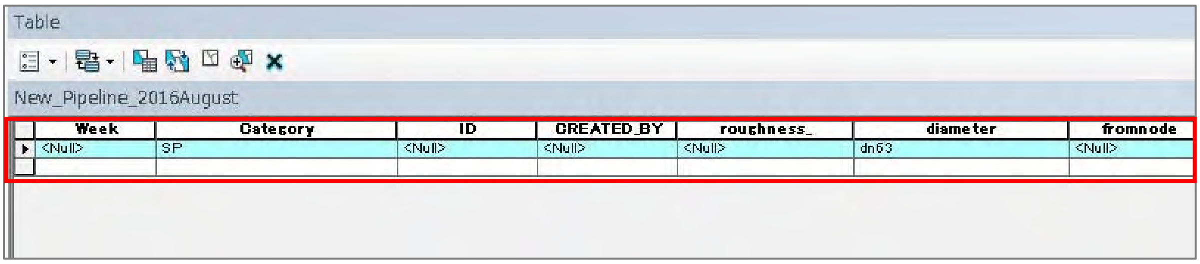
- Right Click on Pipeline layer in Table of Contents and select [Open Attribute Table].



Open Attribute Table

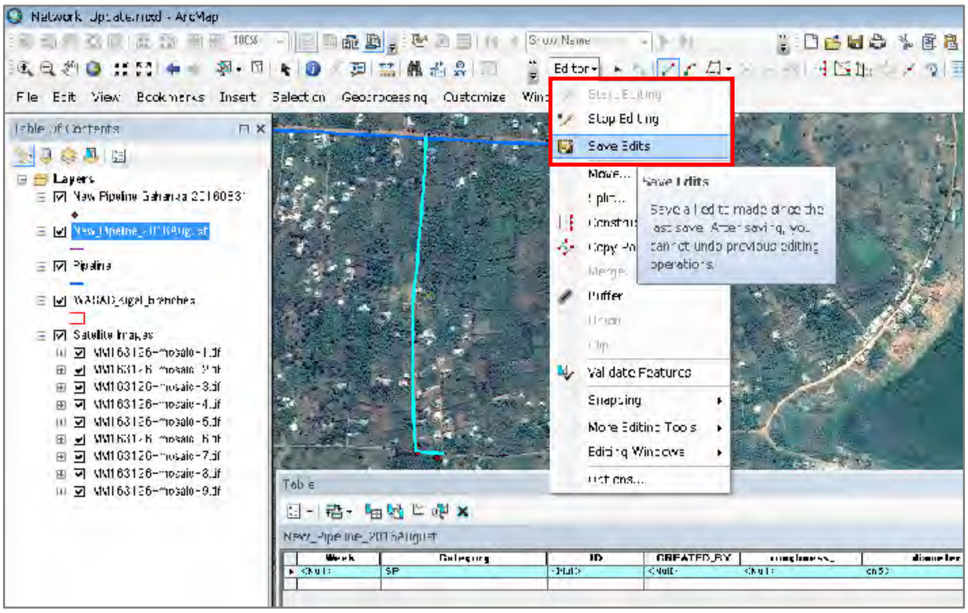
Open this layer's attribute table. Shortcut: CTRL + double-click layer name OR CTRL + T.

- Edit Attributes of the new pipeline.



Week	Category	ID	CREATED_BY	roughness_	diameter	fromnode
<Null>	SP	<Null>	<Null>	<Null>	dn63	<Null>

- When you completed update, select “Save Edits”; and “Stop Editing” to finish editing.



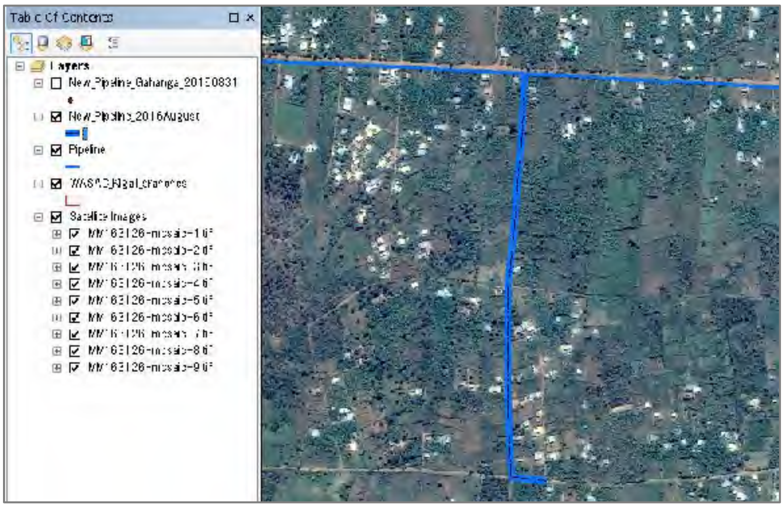
Save Edits

Save all edits made since the last save. After saving, you cannot undo previous editing operations.

Week	Category	ID	CREATED_BY	roughness_	diameter
<Null>	SP	<Null>	<Null>	<Null>	dn63

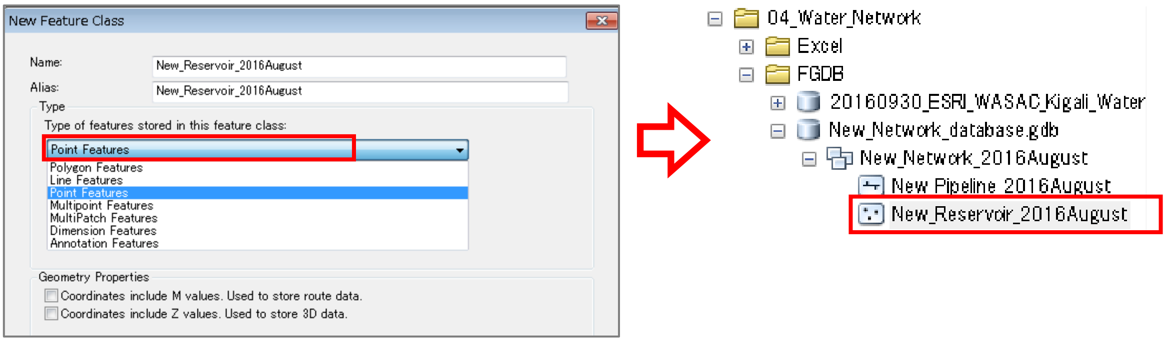
- Pipeline data is successfully updated.

  Please make sure that Pipelines, Junctions, and the other Network features are topologically connected.



If you need to edit point features such as Pumps, Meters, or Reservoirs:

- Create "Point" Feature Class under the Feature Dataset of "New Network". Please make sure in the [New Feature Class] dialog that Feature Type is "Point Features"


New Feature Class

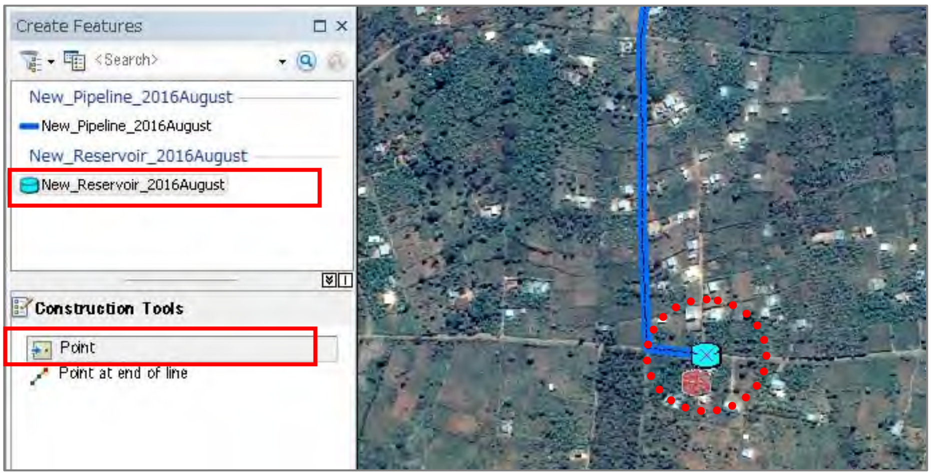
Name: New_Reservoir_2016August

Alias: New_Reservoir_2016August

Type

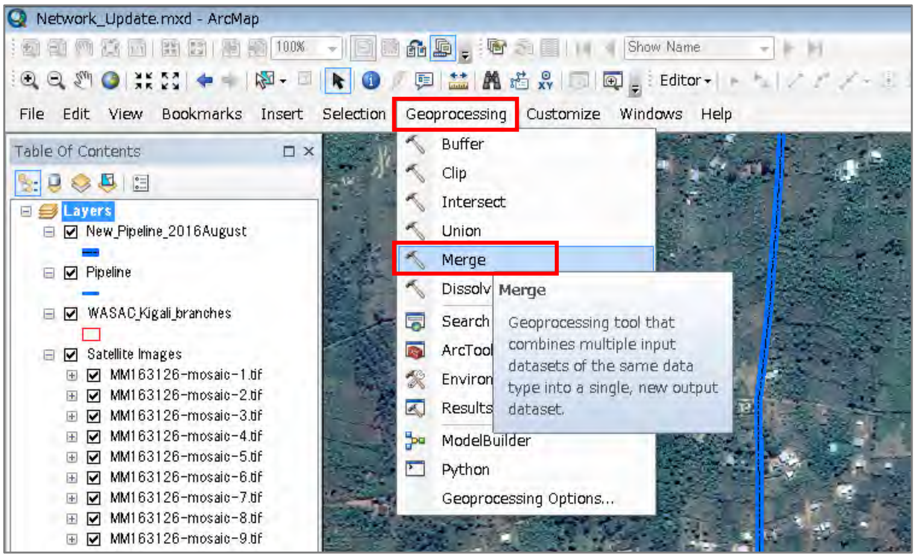
Type of features stored in this feature class: Point Features

- In the "Create Features" Window, please select the feature layer that you want to edit; and "Point" in Construction Tools. The other steps are same as above.



5. Merge New and Current Network Database

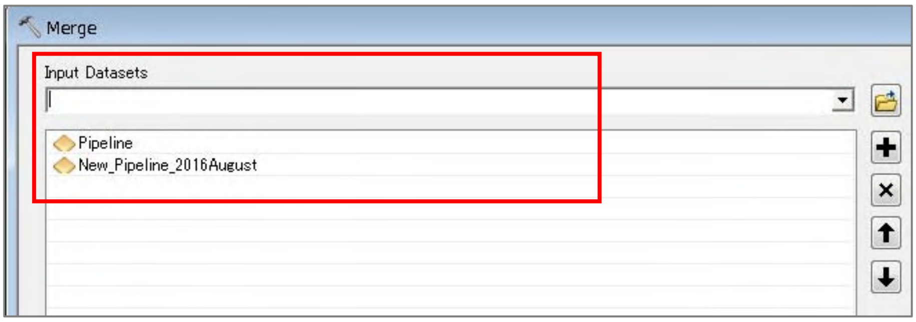
- GIS Officer in GIS team merges the New Network Database with the Current Database. [Geoprocessing > Merge]



Merge

Geoprocessing tool that combines multiple input datasets of the same data type into a single, new output dataset.

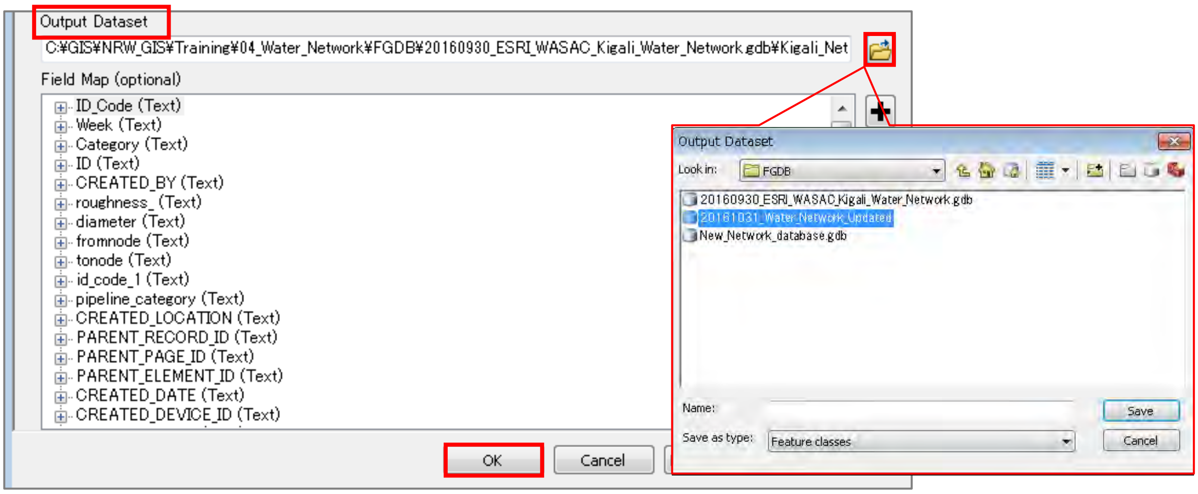
- In the [Merge] dialog, select the Current Dataset and the New Dataset for Input Datasets. This example shows the case of Pipeline.



Input Datasets

Pipeline
New_Pipeline_2016August

- For Output Dataset, Please select appropriate Geodatabase and Feature Data-Set name like "Water_Network_Updated_20160831". Click "OK", and merge is implemented.



Output Dataset

C:¥GIS¥NRW_GIS¥Training¥04_Water_Network¥FGDB¥20160930_ESRI_WASAC_Kigali_Water_Network.gdb¥Kigali_Net

Field Map (optional)

ID_Code (Text)
Week (Text)
Category (Text)
ID (Text)
CREATED_BY (Text)
roughness_ (Text)
diameter (Text)
fromnode (Text)
tonode (Text)
id_code_1 (Text)
pipeline_category (Text)
CREATED_LOCATION (Text)
PARENT_RECORD_ID (Text)
PARENT_PAGE_ID (Text)
PARENT_ELEMENT_ID (Text)
CREATED_DATE (Text)
CREATED_DEVICE_ID (Text)

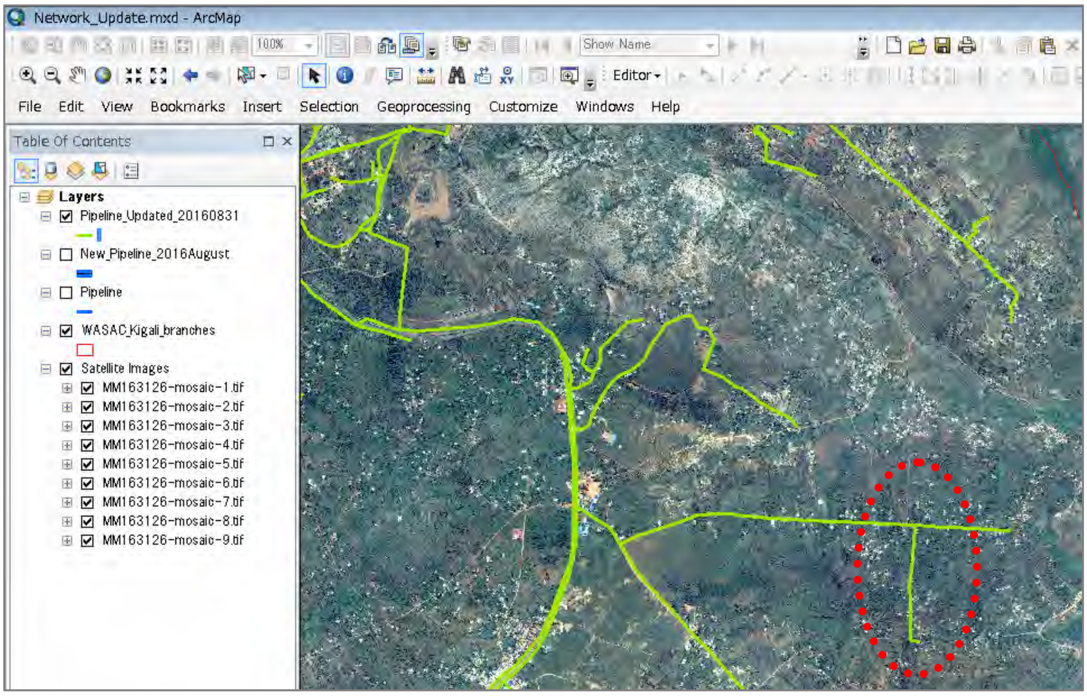
Output Dataset

Look in: FGDB

20160930_ESRI_WASAC_Kigali_Water_Network.gdb
20161031_Water_Network_Updated
New_Network_database.gdb

Name:
Save as type: Feature classes

- When Merge is completed, the merged network data is added on the map. Please check the topological connection and the attribute information of the newly edited features.



- Check-Sheet for Customer Data Update must be recorded after each updating stage.

No.	Description	Person in Charge	201607
1	Create Monthly Geodatabase and Feature Dataset for Updated Network	(GIS Operator)	✓
2	Edit New Water Network Features	(GIS Operator)	✓
3	Merge New & Current Network Database	(GIS Officer)	✓
4	Validation Check	(GIS Officer)	✓

II. Customer Data Update

Workflow for Customer Data Update on GIS is as below.

i. Collecting New Customer Information

Collect New Customer Information from the branch offices. In general, it is created on Microsoft Access Database. GIS Officer in WASAC collects the database every month.

ii. Conversion of database

Convert each Access Database into Excel Worksheet. If Access database files are more than one, you need to combine them into one Excel data-table.

iii. Arrangement of the table for Geocoding

Arrange names of items in the first column of the Excel Worksheet in correspondence with the current customer database on Geodatabase.

iv. Geocoding

Implement Geocoding for Excel table with Address Locator using UPI code. Unmatched dataset should be listed and returned to each branch for re-investigation.

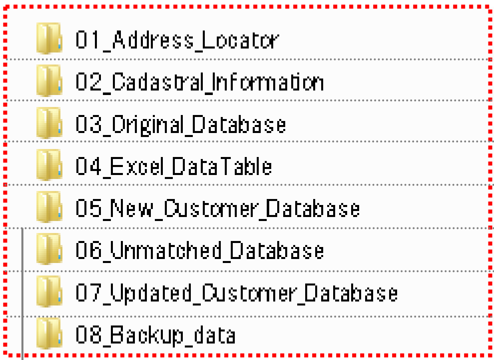
v. Merge New & Current Datasets

Merge New Customer Dataset with the Current Dataset.

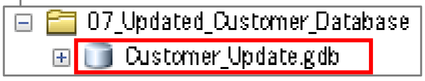
vi. Validation Check

Validate the result using Topology or any other approaches. Do not forget to fill the check-sheet of Customer Update.

1. Preparation: Folder Structure



01_Address_Locator	Contains Address Locator which is used for Geocoding
02_Cadastral_Information	Contains Cadastral Data with UPI code such as "Parcels"
03_Original_Database	Contains Access database collected from each branch
04_Excel_DataTable	Contains Excel Table which is converted from Access
05_New_Customer_Database	Contains FileGeodatabase of New Customers after Geocoding
06_Unmatched_Database	Contains lists of Unmatched Customer after Geocoding
07_Updated_Customer_Database	Contains FileGeodatabase merged by new & old dataset
08_Backup_data	



07_Updated_Customer_Database
Customer_Update.gdb

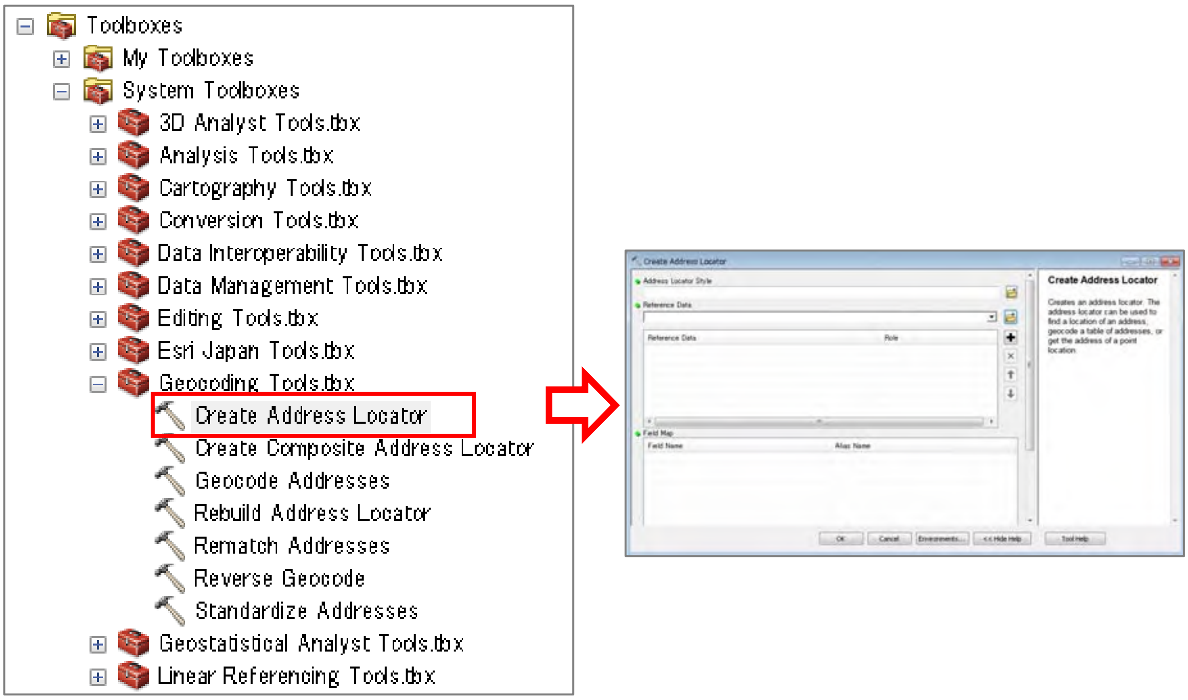
In the preparation, please create FileGeodatabase in folders of [05] & [07] if not existed.

2. Preparation: Create Address Locator

In case that you do not have Address Locator in your folder, you need to create it at first. If you already have it, please go to the next chapter.

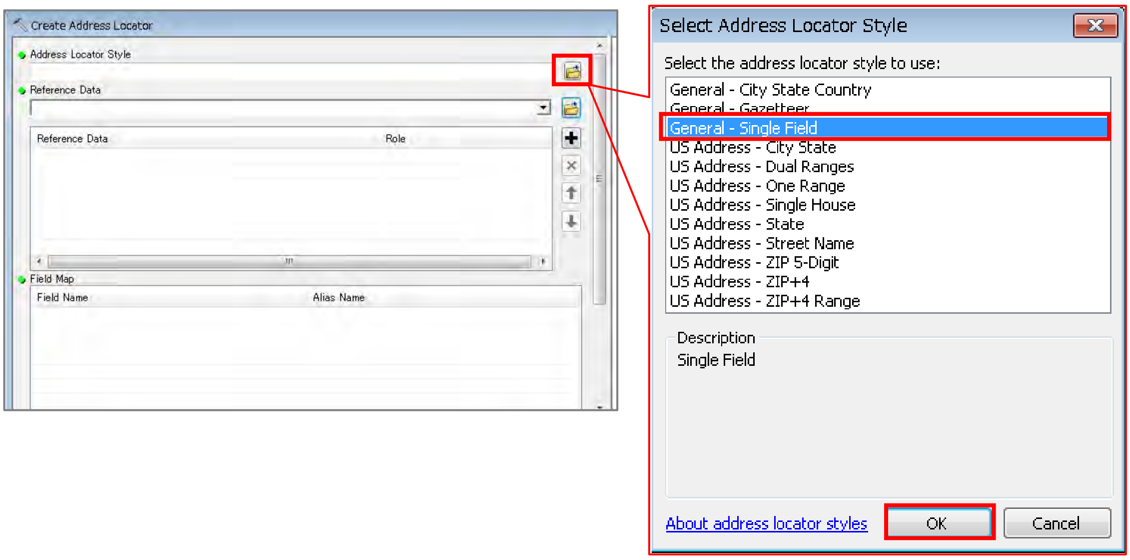
- Open “Create Address Locator” Dialog on your ArcMap

  [ArcToolbox > Geocoding Tools > Create Address Locator]

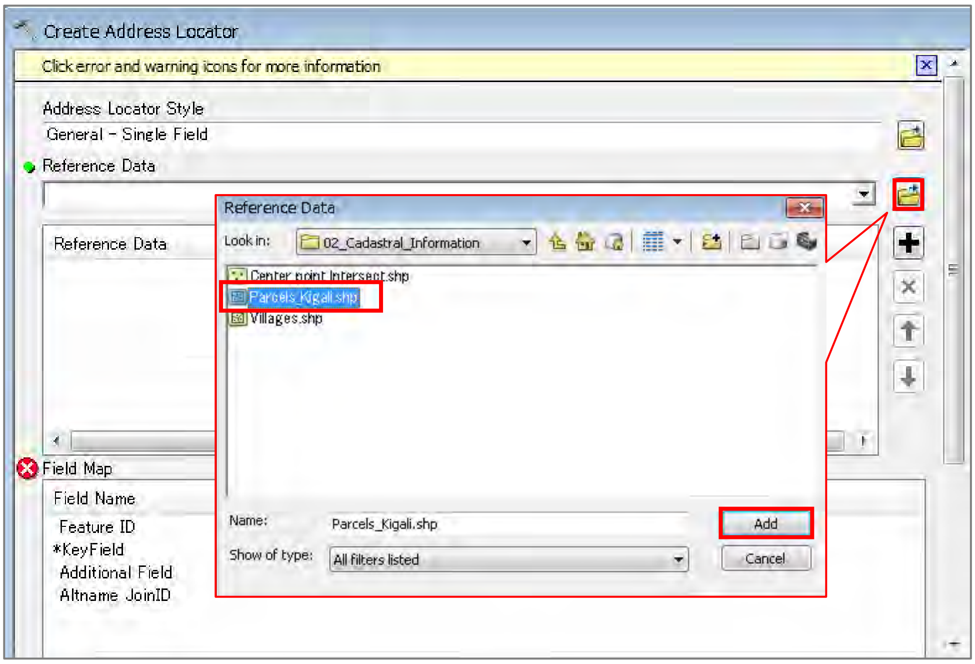


- Set the dialog box as following:

  - Address Locator Style: General – Single Field



- Reference Data: [02_Cadastral_Information¥Parcels_Kigali.shp]
  (❗ Caution: Referenced data must be Polygon data)



Create Address Locator

Click error and warning icons for more information

Address Locator Style: General - Single Field

Reference Data

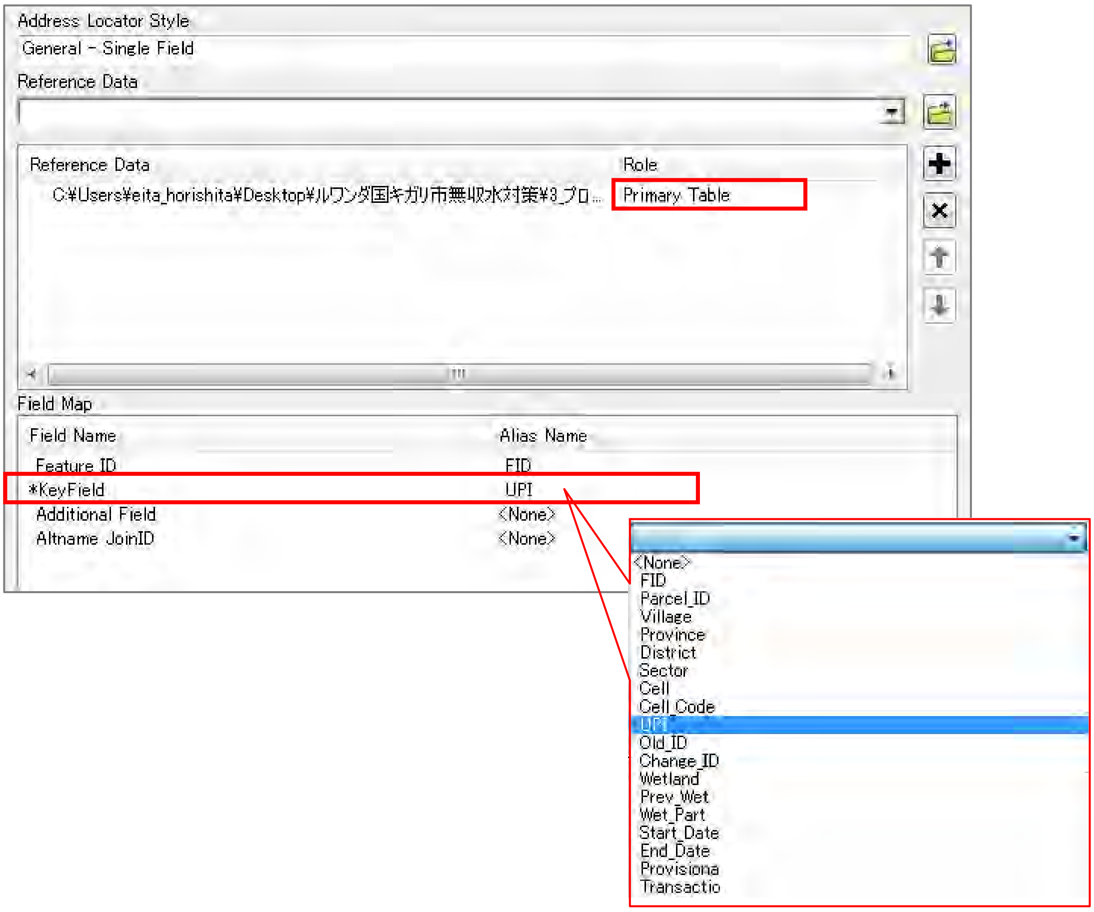
Look in: 02_Cadastral_Information

Center point Intersect.shp
Parcels_Kigali.shp
Villages.shp

Name: Parcels_Kigali.shp

Show of type: All filters listed

- Please select “Primary Table” in “Role”, and “UPI” for “KeyField” from pulldown



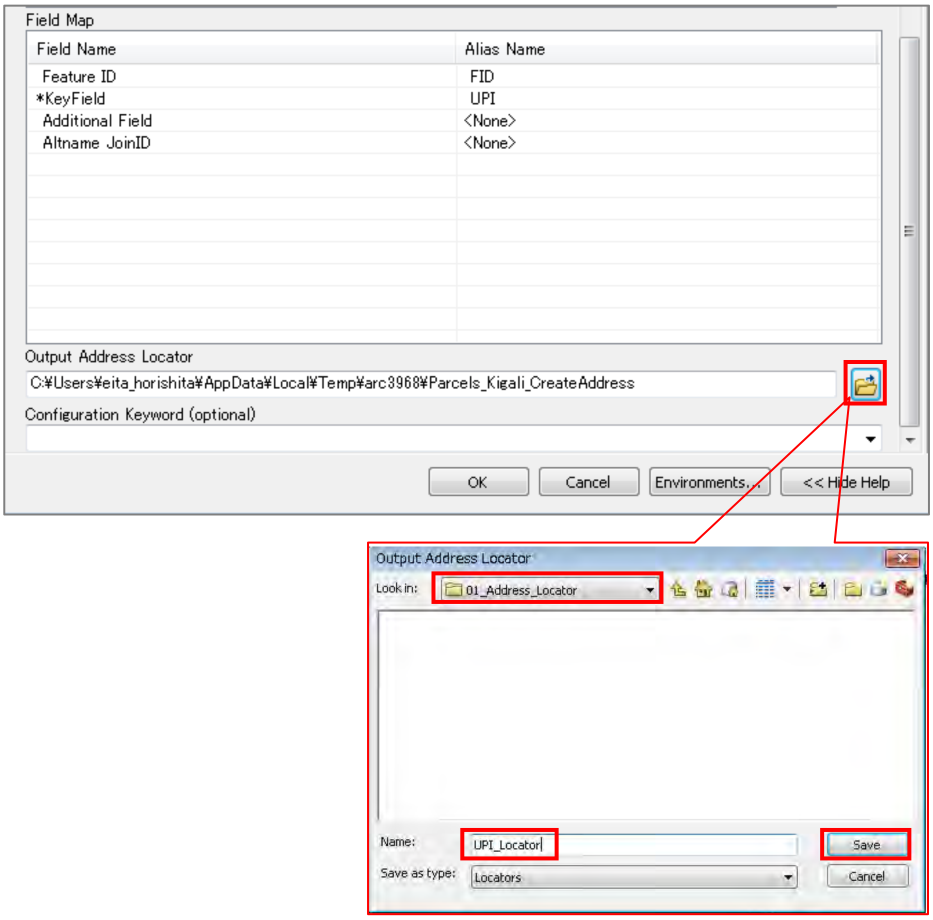
Address Locator Style: General - Single Field

Reference Data	Role
C:¥Users¥eita_horishita¥Desktop¥ルワンダ国キガリ市無収水対策¥3_プロ...	Primary Table

Field Map

Field Name	Alias Name
Feature ID	FID
*KeyField	UPI
Additional Field	<None>
Altname JoinID	<None>

- Select Output folder of Address Locator as
  Folder: [¥01_Address_Locator]
  Name: [UPI_Locator]



Field Map

Field Name	Alias Name
Feature ID	FID
*KeyField	UPI
Additional Field	<None>
Altname JoinID	<None>

Output Address Locator: C:¥Users¥eita_horishita¥AppData¥Local¥Temp¥arc3968¥Parcels_Kigali_CreateAddress

Configuration Keyword (optional)

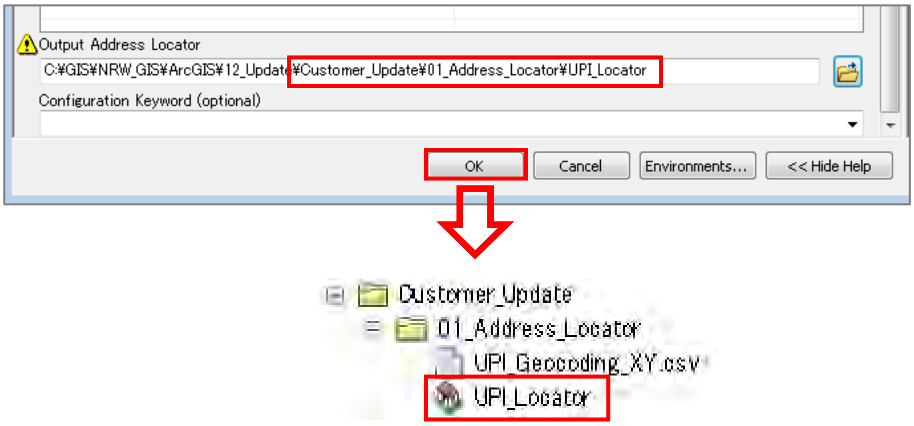
Output Address Locator

Look in: 01_Address_Locator

Name: UPI_Locator

Save as type: Locators

- Click [OK], and Address Locator will be successfully created.



Output Address Locator: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥01_Address_Locator¥UPI_Locator

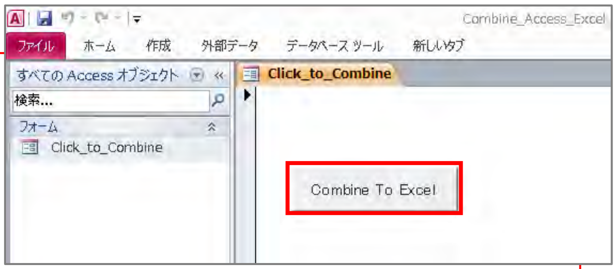
Configuration Keyword (optional)

3. Access: Convert Access Database to Excel Worksheet

WASAC branch offices create database of newly connected customers by Microsoft Access. It has UPI code which is related to Cadastral database, however no XY coordinates; therefore you are not able to import it to GIS directory (As of October 2016).

This Chapter 3 and 4 will introduce how to convert Access Database to Excel, and combine them into an Excel Worksheet as preparation processes for Geocoding mentioned in Chapter 5.

If you have lots of separated Access files to be converted, I recommend creating Macro or VBA Script for the task. I introduce an example of VBA Script which enables you to combine lots of Access files in a folder into an Excel Worksheet by a single click.



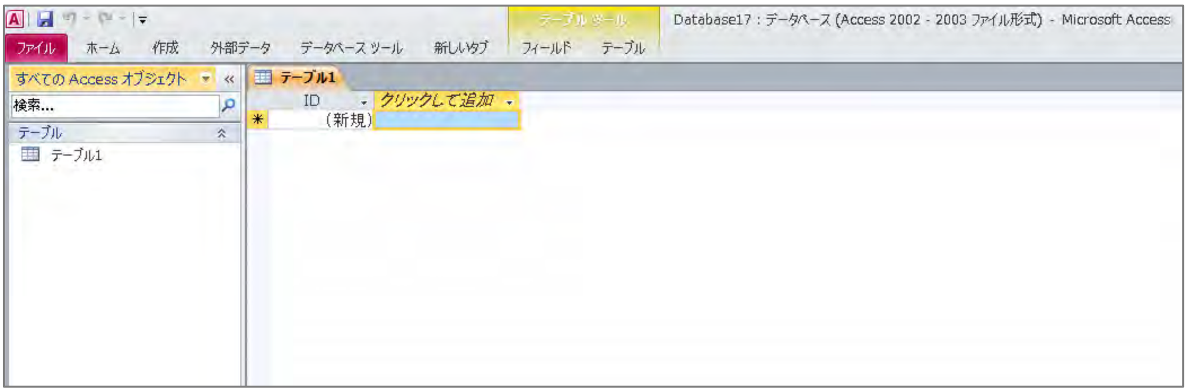
```
Private Sub Combine_Click()
    Dim db As DAO.Database
    Dim rs As DAO.Recordset
    Dim rscnt As DAO.Recordset
    Dim strFile As String
    Dim strSQL As String
    Dim Wb As Object
    Dim xlsx As Object
    Dim idx1 As Long
    Dim idx2 As Long

    Set xlsx = CreateObject("Excel.Application")
    Set Wb = xlsx.Workbooks.Add()

    strFile = Dir(CurrentProject.Path & "¥Files" & "¥" & "*.accdb", vbNormal)
    idx1 = 2

    Do While strFile <> ""
        Set db = DBEngine.Workspaces(0).OpenDatabase(CurrentProject.Path & "¥Files" & "¥" & strFile)
        Set rs = db.OpenRecordset("CUSTOMER INFORMATION")
        strSQL = "select Count(*) As RecCount from [CUSTOMER INFORMATION]"
        Set rscnt = db.OpenRecordset(strSQL)
        idx2 = rscnt![RecCount]

        If rs.RecordCount > 0 Then
            Wb.Worksheets(1).Cells(idx1, 1).CopyFromRecordset Data:=rs
            idx1 = idx1 + idx2
        End If

        rs.Close: Set rs = Nothing
        db.Close: Set db = Nothing
        strFile = Dir()
    Loop

    xlsx.Visible = True
    xlsx.UserControl = True

    MsgBox ("Export Completed.")
End Sub
```

An Example of VBA:

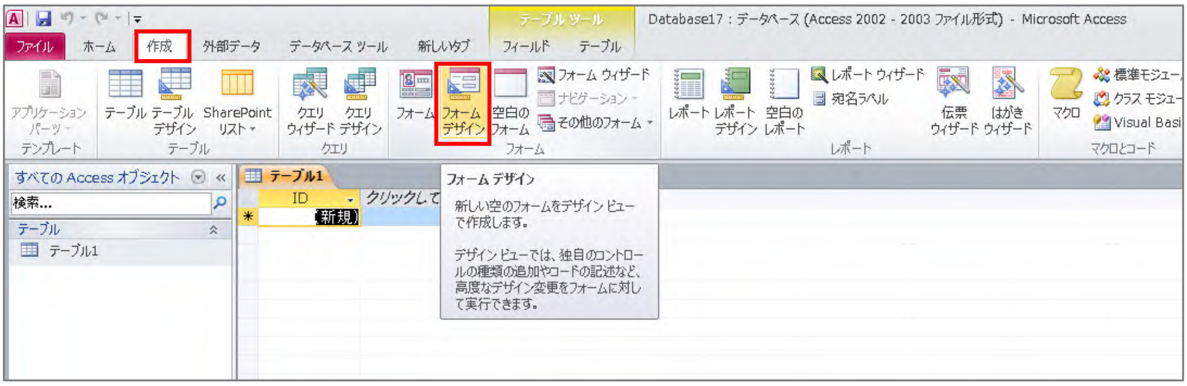
- Combine all Access Database files in a folder named [Folders] under the current folder.
- Name of Data Form in Access Database must be named [CUSTOMER INFORMATION]
- The first column of the output Excel file will be blank for inserting Items (mentioned in the latter part of Chapter 4).

- How to set-up this VBA on Access file:

  - Open New Blank Access file



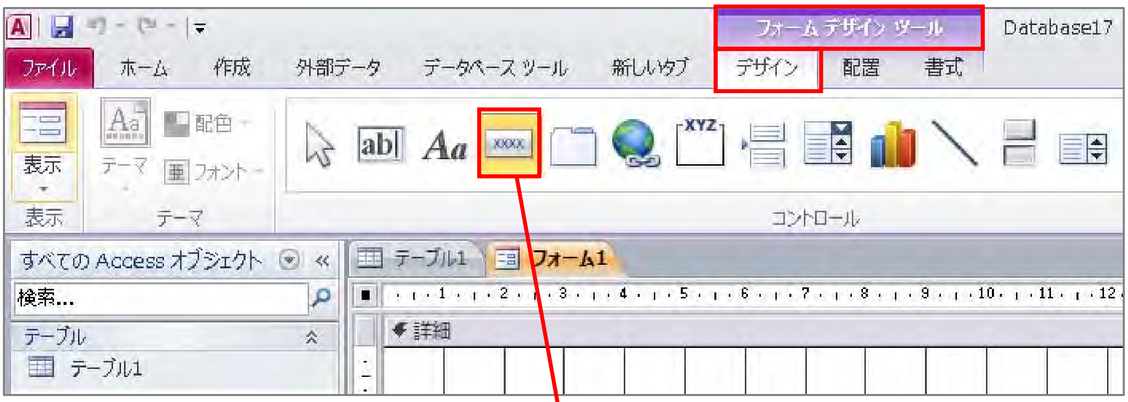
  - Select [Form Design] in [Creation] Tab,



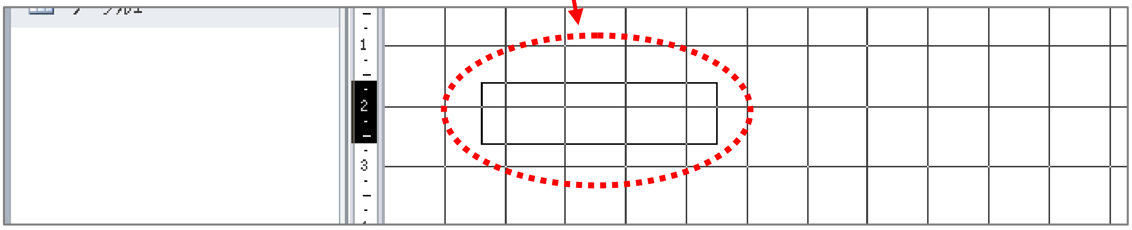
新しい空のフォームをデザイン ビューで作成します。

デザイン ビューでは、独自のコントロールの種類の追加やコードの記述など、高度なデザイン変更をフォームに対して実行できます。

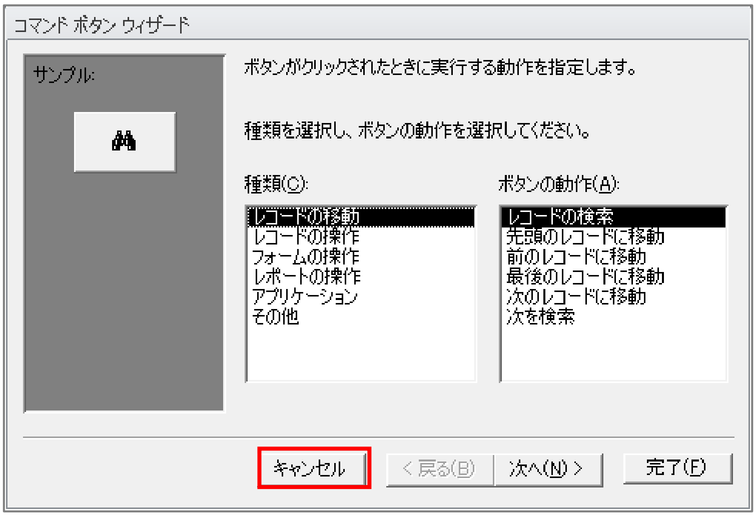
  - Select [Button] Contorl in [Form Design Tool > Design]



  - Draw Button by drag



- If the “Command Button Wizard” is shown up, please click “Cancel” and close the wizard.

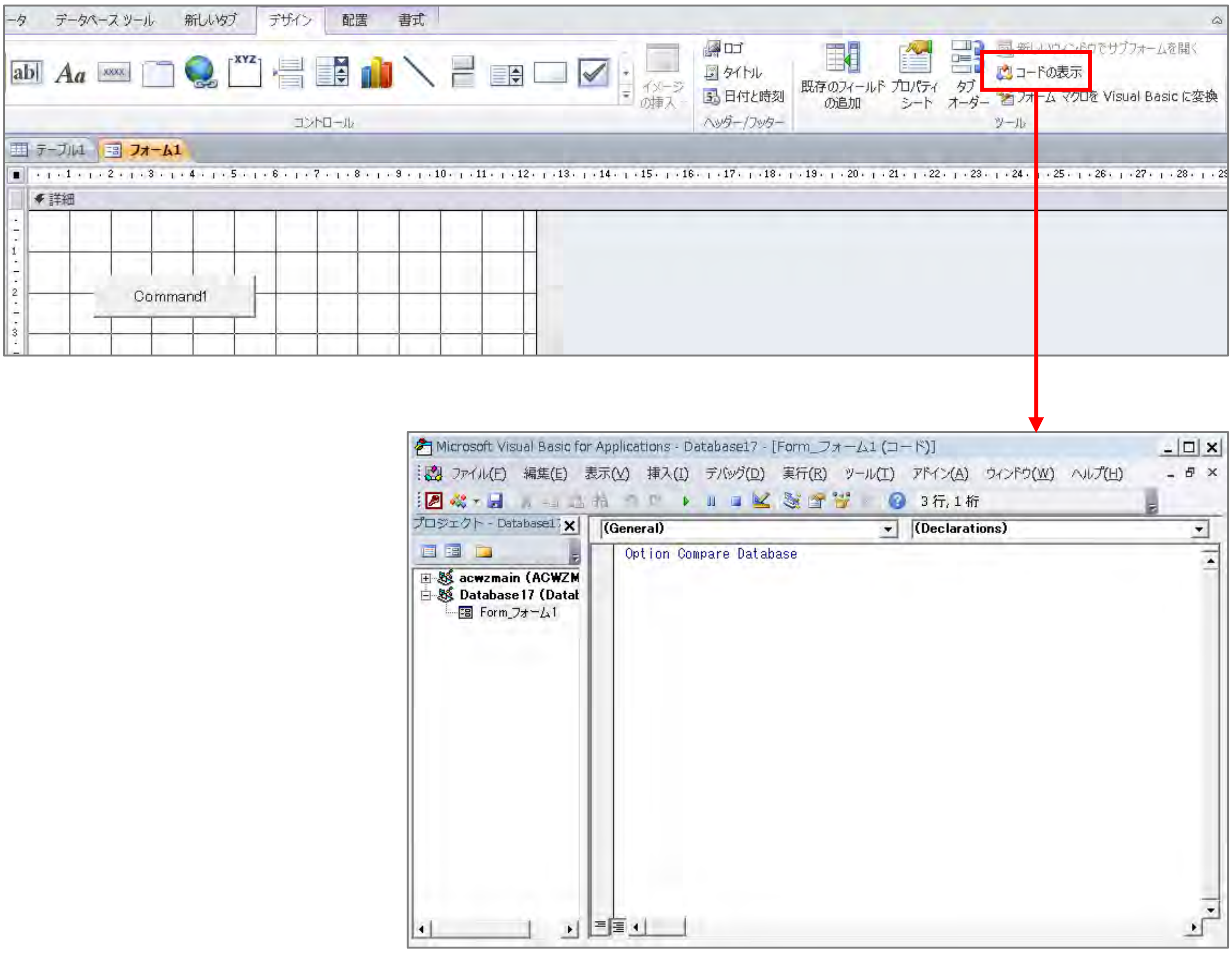


コマンド ボタン ウィザード

ボタンがクリックされたときに実行する動作を指定します。

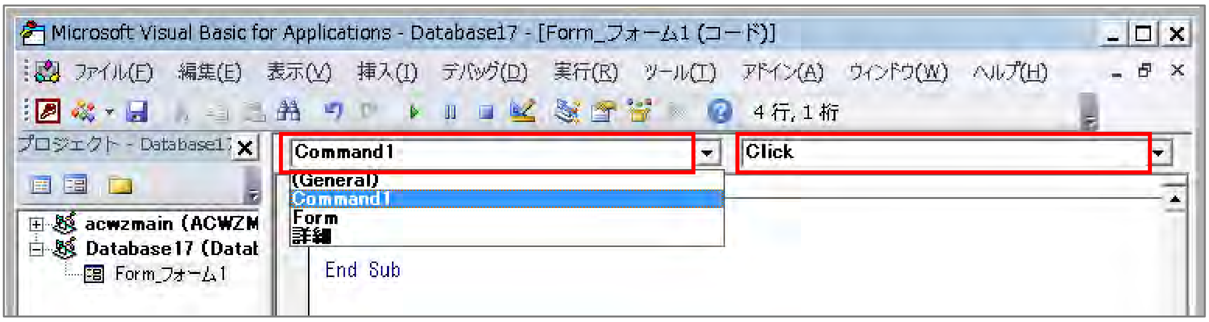
種類を選択し、ボタンの動作を選択してください。

- Click “Display Code”; then Editor of Visual Basic for Application is opened.



```
Option Compare Database
```

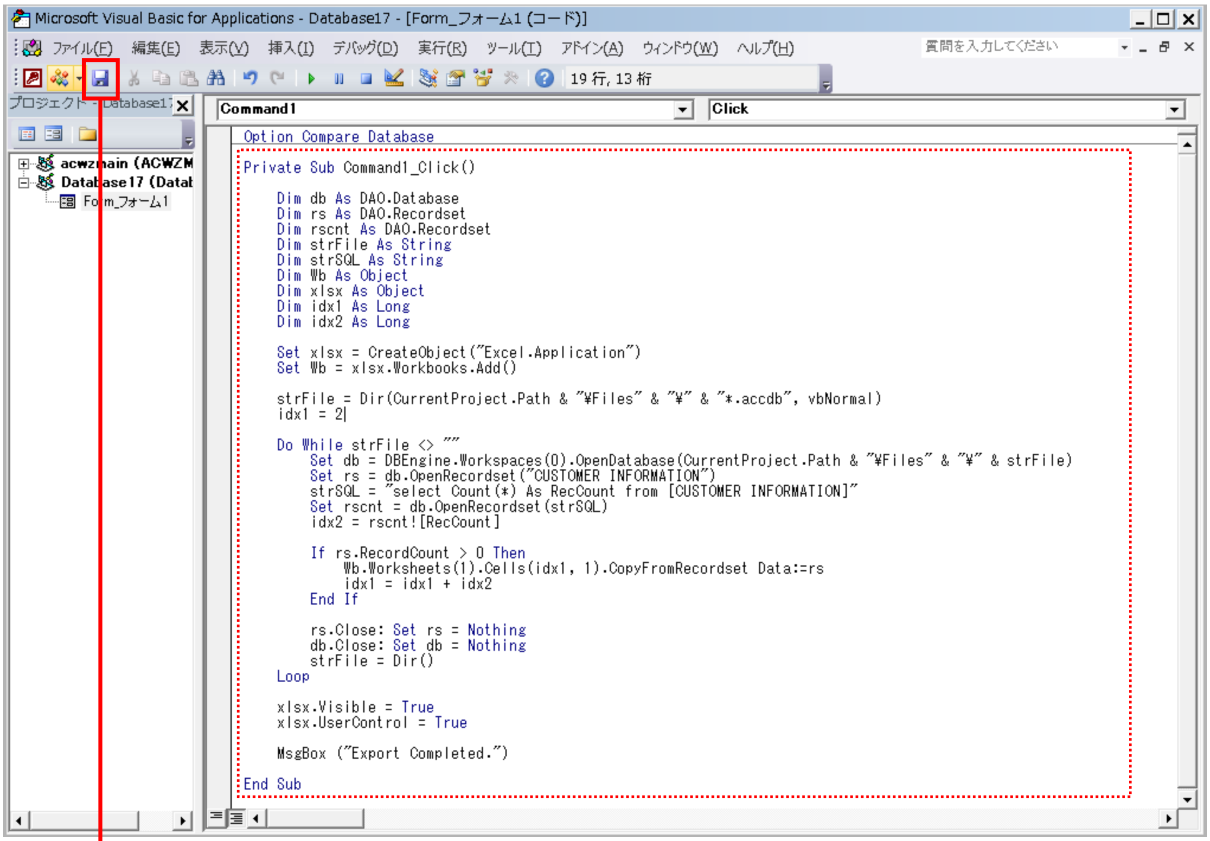
- Choose the name of Command and Action as below.



Microsoft Visual Basic for Applications - Database17 - [Form_フォーム1 (コード)]

Command1 | Click

- Type the VBA between "Private Sub Command_Click()" and "End Sub".
- Save edit.

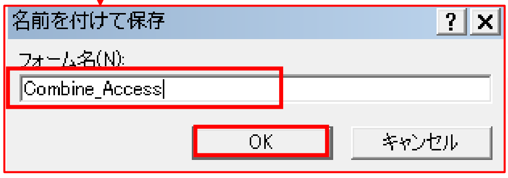


Microsoft Visual Basic for Applications - Database17 - [Form_フォーム1 (コード)]

Command1 | Click

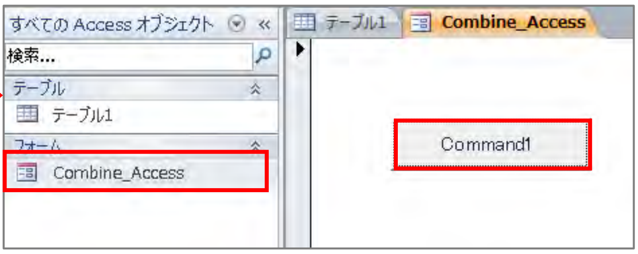
```
Option Compare Database

Private Sub Command1_Click()

    Dim db As DAO.Database
    Dim rs As DAO.Recordset
    Dim rscnt As DAO.Recordset
    Dim strFile As String
    Dim strSQL As String
    Dim Wb As Object
    Dim xlsx As Object
    Dim idx1 As Long
    Dim idx2 As Long

    Set xlsx = CreateObject("Excel.Application")
    Set Wb = xlsx.Workbooks.Add()

    strFile = Dir(CurrentProject.Path & "¥Files" & "¥" & "*.accdb", vbNormal)
    idx1 = 2

    Do While strFile <> ""
        Set db = DBEngine.Workspaces(0).OpenDatabase(CurrentProject.Path & "¥Files" & "¥" & strFile)
        Set rs = db.OpenRecordset("CUSTOMER INFORMATION")
        strSQL = "select Count(*) As RecCount from [CUSTOMER INFORMATION]"
        Set rscnt = db.OpenRecordset(strSQL)
        idx2 = rscnt![RecCount]

        If rs.RecordCount > 0 Then
            Wb.Worksheets(1).Cells(idx1, 1).CopyFromRecordset Data:=rs
            idx1 = idx1 + idx2
        End If

        rs.Close: Set rs = Nothing
        db.Close: Set db = Nothing
        strFile = Dir()
    Loop

    xlsx.Visible = True
    xlsx.UserControl = True

    MsgBox ("Export Completed.")

End Sub
```

- Name this form to save it; and then you can run this VBA script by clicking the button.

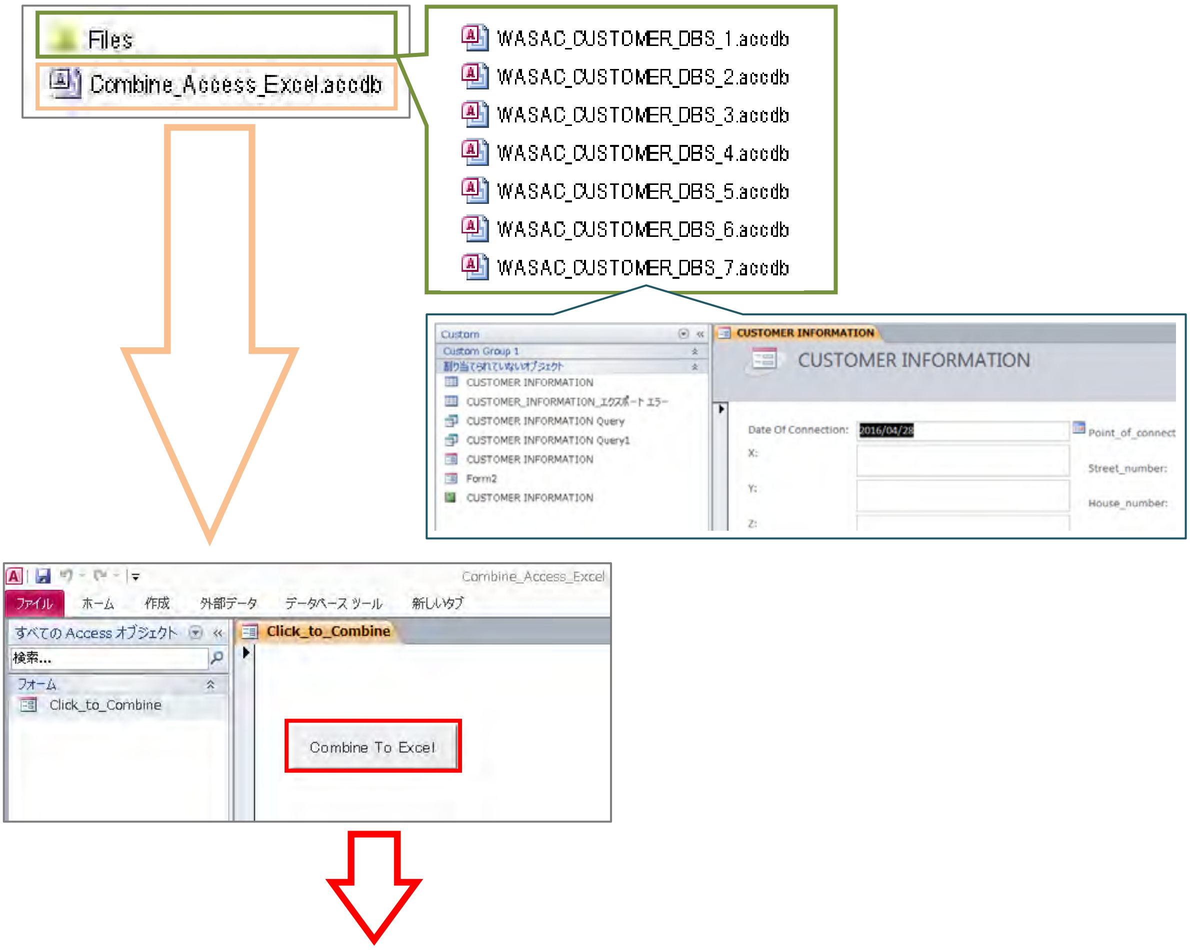


名前を付けて保存

フォーム名(N): Combine_Access

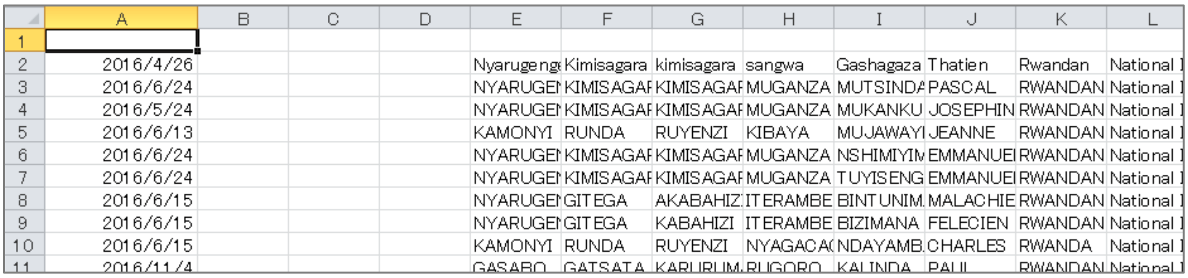


- Folder Structure for the example of this VBA script:



Date Of Connection: 2016/04/28

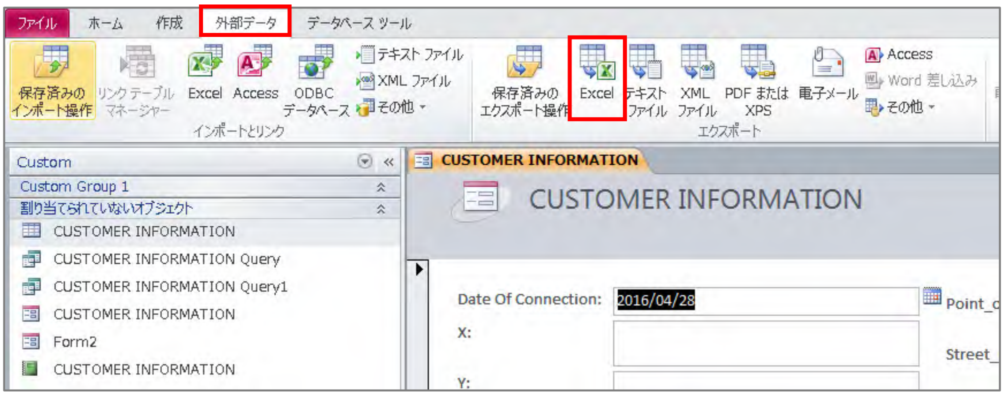
> Sheet1: Combined data-table



	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	2016/4/26				Nyarugeng	Kimisagara	kimisagara	sangwa	Gashagaza	Thatien	Rwandan	National
3	2016/6/24				NYARUGE	KIMISAGA	KIMISAGA	MUGANZA	MUTSINDA	PASCAL	RWANDAN	National
4	2016/5/24				NYARUGE	KIMISAGA	KIMISAGA	MUGANZA	MUKANKU	JOSEPHIN	RWANDAN	National
5	2016/6/13				KAMONYI	RUNDA	RUYENZI	KIBAYA	MUJAWAYI	JEANNE	RWANDAN	National
6	2016/6/24				NYARUGE	KIMISAGA	KIMISAGA	MUGANZA	NSHIMIYIM	EMMANUE	RWANDAN	National
7	2016/6/24				NYARUGE	KIMISAGA	KIMISAGA	MUGANZA	TUYISENG	EMMANUE	RWANDAN	National
8	2016/6/15				NYARUGE	GITEGA	AKABAHIZ	ITERAMBE	BINTUNIM.	MALACHIE	RWANDAN	National
9	2016/6/15				NYARUGE	GITEGA	KABAHIZI	ITERAMBE	BIZIMANA	FELECIEN	RWANDAN	National
10	2016/6/15				KAMONYI	RUNDA	RUYENZI	NYAGACA	NDAYAMB.	CHARLES	RWANDA	National
11	2016/11/4				GASABO	GATSATA	KARURUM.	RUGORO	KALINDA	PAUL	RWANDAN	National

- ➢ If you have successfully combined Access Database into An Excel Worksheet, please jump to the latter part of Chapter 4: Arrange name of the items.

- ➢ If you need to convert Access files to Excel manually, please follow this instruction:
  - Open the Access Database and Click [Excel] button in the [External Data] tab.



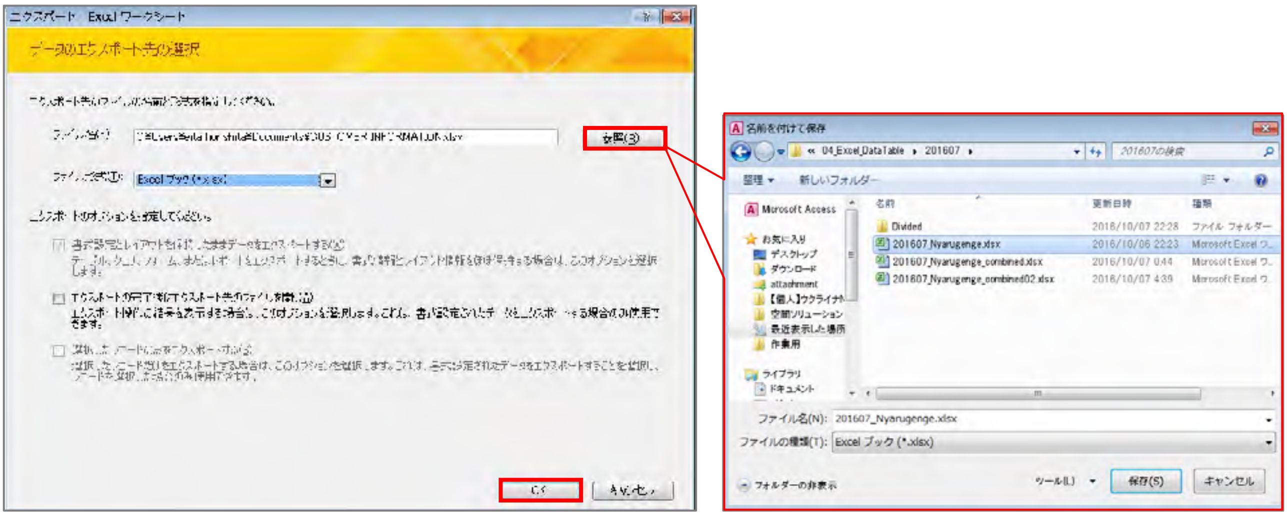
Date Of Connection: 2016/04/28

X:

Y:

  - Select the following folder to save exported Excel file: [04_Excel_DataTable]

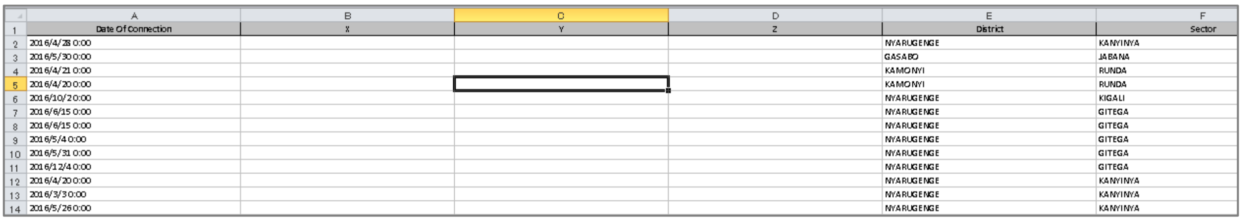
(✱ Name of Excel file should be simple and explicit like “201607_Nyarugenge”.)



ファイル名(N): 201607_Nyarugenge.xlsx

ファイルの種類(T): Excel ブック (*.xlsx)

  - Close the dialog, and check the Excel file that you exported.

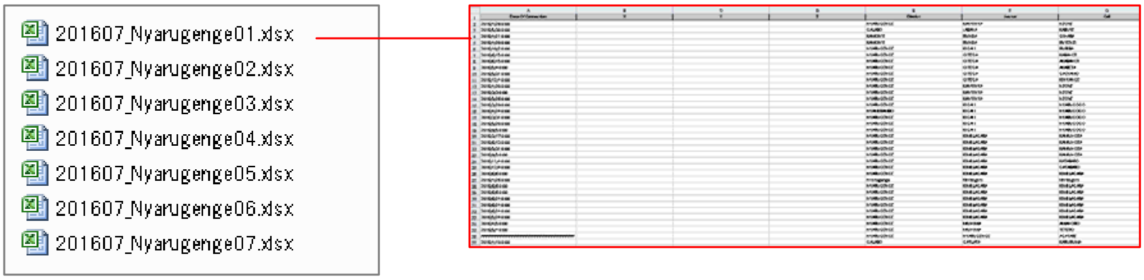


	A	B	C	D	E	F
1	Date Of Connection	X	Y	Z	District	Sector
2	2016/4/28 0:00				NYARUGENGE	KANYINYA
3	2016/5/30 0:00				GASABO	JABANA
4	2016/4/21 0:00				KAMONYI	RUNDA
5	2016/4/20 0:00				KAMONYI	RUNDA
6	2016/10/2 0:00				NYARUGENGE	KIGALI
7	2016/6/15 0:00				NYARUGENGE	GITEGA
8	2016/6/15 0:00				NYARUGENGE	GITEGA
9	2016/5/4 0:00				NYARUGENGE	GITEGA
10	2016/5/31 0:00				NYARUGENGE	GITEGA
11	2016/12/4 0:00				NYARUGENGE	GITEGA
12	2016/4/20 0:00				NYARUGENGE	KANYINYA
13	2016/3/3 0:00				NYARUGENGE	KANYINYA
14	2016/5/26 0:00				NYARUGENGE	KANYINYA

4. Excel: Combine all Excel worksheets and arrange the items

If the exported Excel files are more than one, you have to combine them into one Excel data-table.

- In order to combine all worksheets into one, the simplest method would be Copy & Paste.

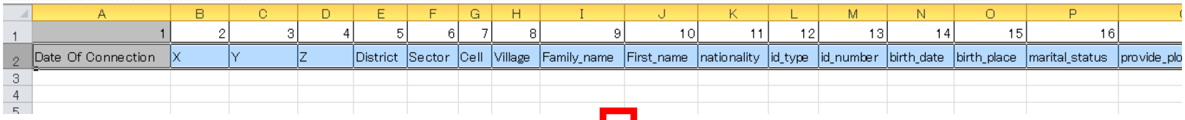


201607_Nyarugenge01.xlsx
201607_Nyarugenge02.xlsx
201607_Nyarugenge03.xlsx
201607_Nyarugenge04.xlsx
201607_Nyarugenge05.xlsx
201607_Nyarugenge06.xlsx
201607_Nyarugenge07.xlsx

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	2016/4/28 0:00				NYARUGENGE	KANYINYA	NZOVE	RUTAGARAII	NKURUNZIZA	PAUL	RWANDAN	National ID	1195280000117078	#########	NYARUGENGE	Single	1402
2	2016/5/30 0:00				GASABO	JABANA	KABUYE	AMASANGANO	NSEGIYUMVA	JEAN PIERRE	RWANDAN	National ID	1198280199251036	#########	RUSIZI	Married	863
3	2016/4/21 0:00				KAMONYI	RUNDA	GIHARA	KABASANZA	NYIRAMANA	FORTUNEE	RWANDAN	National ID	1197270002036142	#########	NYARUGENGE	Single	3053
4	2016/4/20 0:00				KAMONYI	RUNDA	RUYENZI	NYABITARE	KAREMANGINGO	GONZALVE	RWANDAN	Passport	145859	#########	KAMONYI	Married	405
5	2016/10/2 0:00				NYARUGENGE	KIGALI	RURIBA	MISIBYA	URARIJORO	ABDU	RWANDA	National ID	1194780000086097	#########	NYARUGENGE	Married	82
6	2016/6/15 0:00				NYARUGENGE	GITEGA	KABAHIZI	ITERAMBERE	BIZIMANA	FELECIEN	RWANDAN	National ID	1196200000007097	#########	NYARUGENGE	Married	0698
7	2016/6/15 0:00				NYARUGENGE	GITEGA	AKABAHIZI	ITERAMBERE	BINTUNIMANA	MALACHIE	RWANDAN	National ID	119728000015007	#########	NYARUGENGE	Married	689

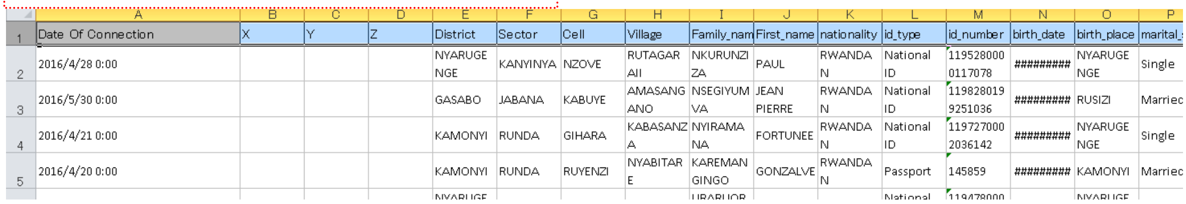
- Arrange name of items in Excel table in order to correspond with the existing customer database on GIS.
  - It is recommended to prepare Correspondence Table such as follows: [04_Excel_DataTable¥POC_AttField_Correspond.xlsx], and Copy & Paste it on a combined Excel table.

Correspondence Table which has same names of items with Attributes of the Customer data on Geodatabase



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	Date Of Connection	X	Y	Z	District	Sector	Cell	Village	Family_name	First_name	nationality	id_type	id_number	birth_date	birth_place	marital_status
3																
4																

Copy & Paste it on the first column of combined Excel table



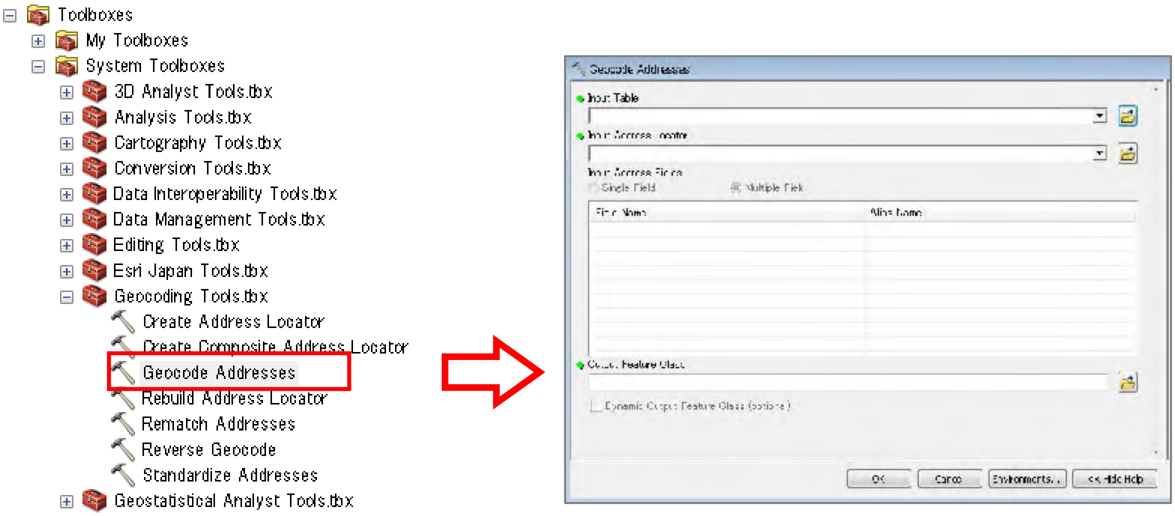
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Date Of Connection	X	Y	Z	District	Sector	Cell	Village	Family_nam	First_name	nationality	id_type	id_number	birth_date	birth_place	marital_
2	2016/4/28 0:00				NYARUGENGE	KANYINYA	NZOVE	RUTAGARAII	NKURUNZIZA	PAUL	RWANDAN	National ID	1195280000117078	#########	NYARUGENGE	Single
3	2016/5/30 0:00				GASABO	JABANA	KABUYE	AMASANGANO	NSEGIYUMVA	JEAN PIERRE	RWANDAN	National ID	1198280199251036	#########	RUSIZI	Marriec
4	2016/4/21 0:00				KAMONYI	RUNDA	GIHARA	KABASANZA	NYIRAMANA	FORTUNEE	RWANDAN	National ID	1197270002036142	#########	NYARUGENGE	Single
5	2016/4/20 0:00				KAMONYI	RUNDA	RUYENZI	NYABITARE	KAREMANGINGO	GONZALVE	RWANDAN	Passport	145859	#########	KAMONYI	Marriec

5. ArcGIS: Geocoding

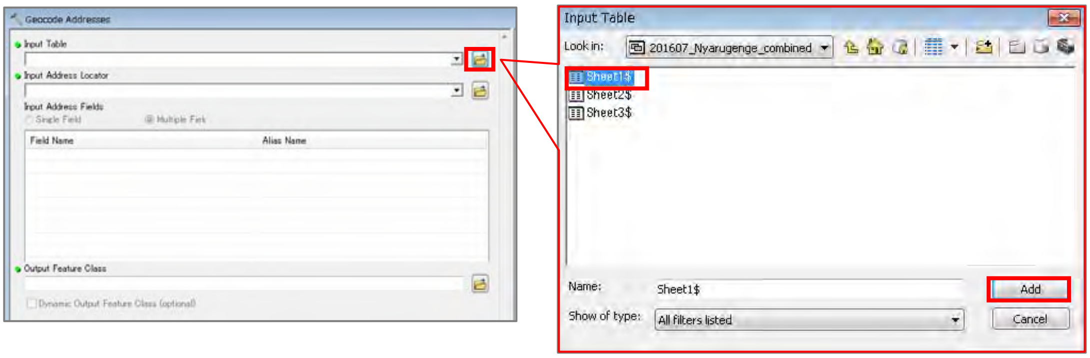
Implement Geocoding on ArcGIS. Customer information listed in the Excel Workbook has UPI Code; and it is referenced in the location matching.

- Open ArcToolbox on ArcGIS, and select “Geocoding Addresses”.

  [ArcToolbox > Geocoding > Geocode Addresses]

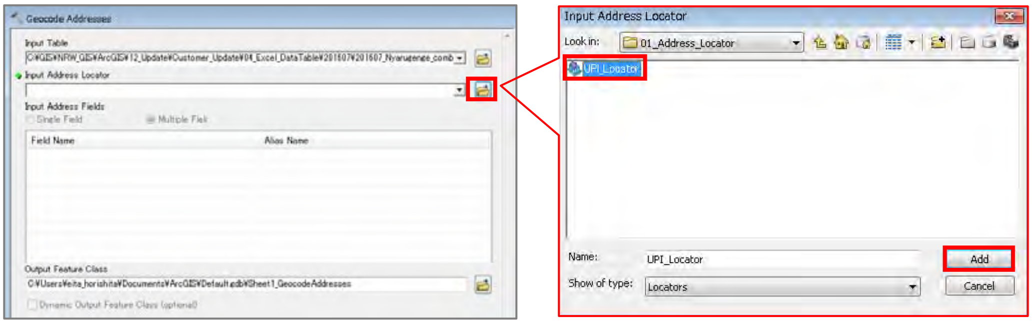


- Set the dialog as following:
  - For “Input Table”, choose the Excel worksheet of customer data-table that you have created in Chapter 4.



Name: Sheet1$

  - Choose Address Locator from the folder [01_Address_Locator]. (If not, please refer to Chapter 2)

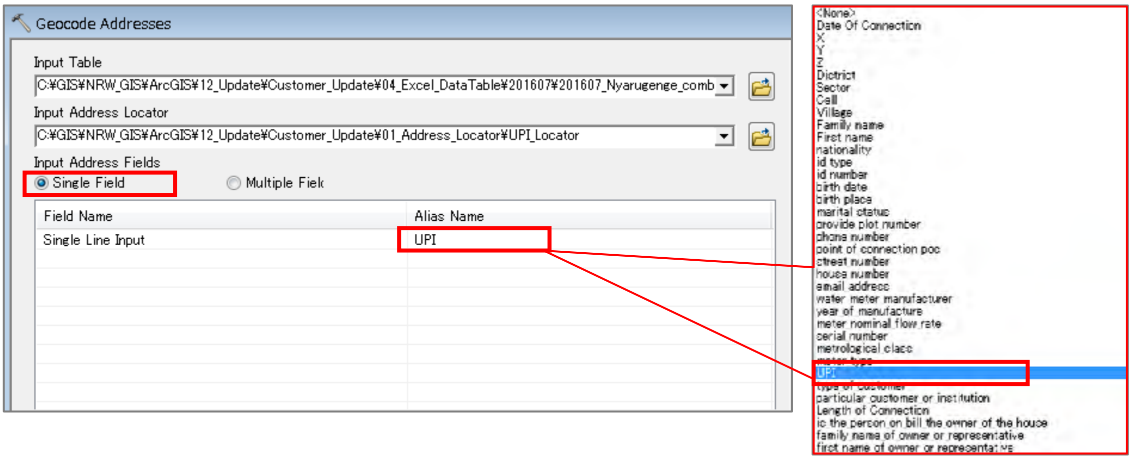


Input Table: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥04_Excel_DataTable¥201607¥201607_Nyarugenge_comb

Output Feature Class: C:¥Users¥eita_horishita¥Documents¥ArcGIS¥Default.gdb¥Sheet1_GeocodeAddresses

Name: UPI_Locator

- Check “Single Field” in [Input Address Fields], and choose “UPI” in [Alias Name].


Geocode Addresses

Input Table
C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥04_Excel_DataTable¥201607¥201607_Nyarugenge_comb

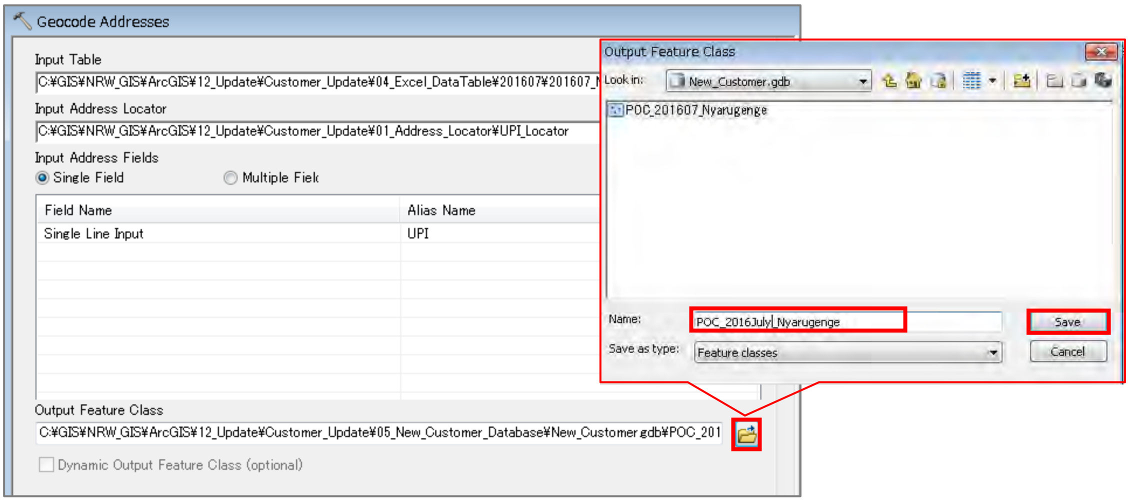
Input Address Locator
C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥01_Address_Locator¥UPI_Locator

Input Address Fields
● Single Field ○ Multiple Fiel

Field Name	Alias Name
Single Line Input	UPI

- Choose Folder and Geodatabase for Output Feature Class as [05_New_Customer_Database¥New_Customer.gdb]. (Caution: The Output Feature Class should be Geodatabase and not Shapefile. If there is no Geodatabase created in [05_New_Customer_Database], please refer to Chapter 1.)

- Put simple and explicit name for Output Feature Class like “POC_2016July_Nyarugenge”.


Geocode Addresses

Input Table
C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥04_Excel_DataTable¥201607¥201607_N

Input Address Locator
C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥01_Address_Locator¥UPI_Locator

Input Address Fields
● Single Field ○ Multiple Fiel

Field Name	Alias Name
Single Line Input	UPI

Output Feature Class
C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥05_New_Customer_Database¥New_Customer.gdb¥POC_201

☐ Dynamic Output Feature Class (optional)

Output Feature Class

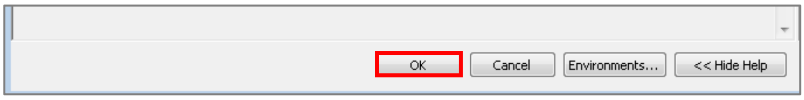
Look in: New_Customer.gdb

POC_201607_Nyarugenge

Name: POC_2016July_Nyarugenge

Save as type: Feature classes

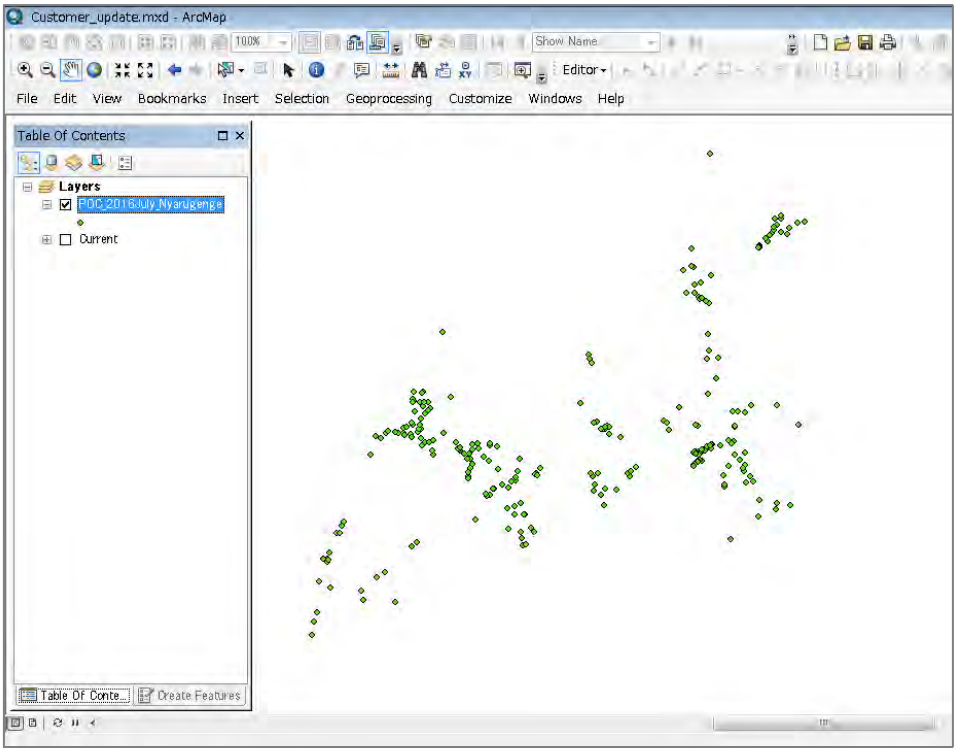
- Click “OK”; then Geocoding is implemented.



- When Geocoding is succeeded, the result is added on the ArcMap.

  ❗ If Geocoding is failed, please review the check-points as below to avoid errors:

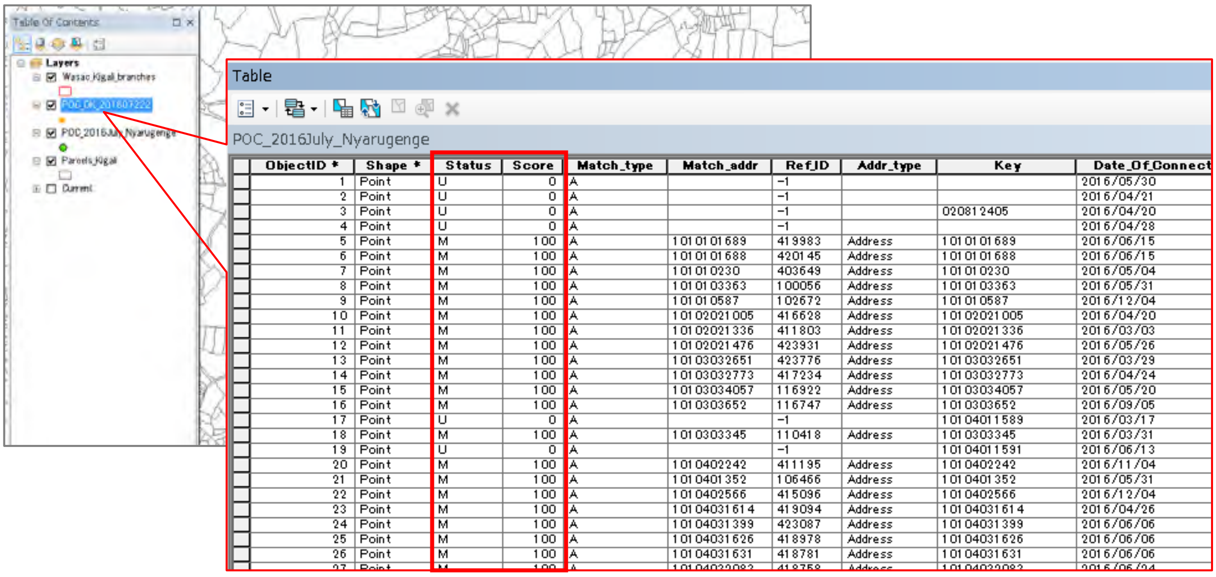
  - Please make sure that Excel file used for Geocoding is not opened.
  - Name of the feature class in Geodatabase must not start by numbers, and must not include "." "(space)", and "-". You can use "_" (underbars) instead.



- In order to check the location of new customers, add some layers such as WASAC branch boundary, the current customer database, and Parcels.

6. ArcGIS: Create a list for Unmatched Customer data

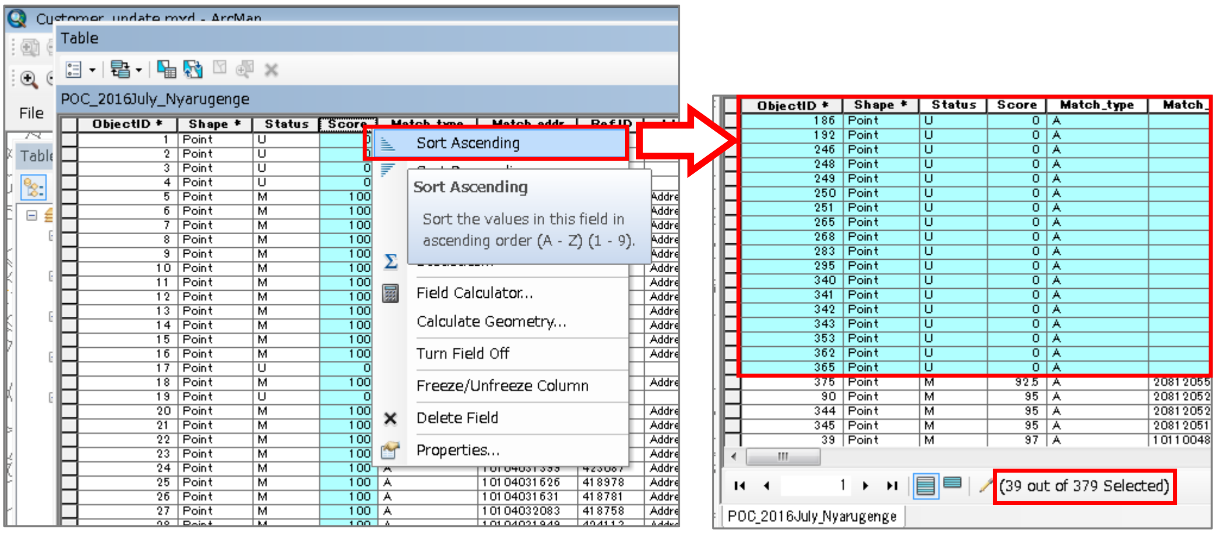
- ➢ Open Attribute table of POC New Customer Layer, and check “Status” and “Score”.
  - Status: “M” means matched, “U” means Unmatched.
  - Score: It shows the matching level. Score 100 means perfectly matched, and lower score means lower matching level. Score 0 means unmatched.



POC_2016July_Nyarugenge

ObjectID *	Shape *	Status	Score	Match_type	Match_addr	Ref_ID	Addr_type	Key	Date_Of_Connect
1	Point	U	0	A		-1			2016/05/30
2	Point	U	0	A		-1			2016/04/21
3	Point	U	0	A		-1		0208124405	2016/04/20
4	Point	U	0	A		-1			2016/04/28
5	Point	M	100	A	1010101689	419983	Address	1010101689	2016/06/15
6	Point	M	100	A	1010101688	420145	Address	1010101688	2016/06/15
7	Point	M	100	A	101010230	403649	Address	101010230	2016/05/04
8	Point	M	100	A	1010103363	100056	Address	1010103363	2016/05/31
9	Point	M	100	A	101010587	102672	Address	101010587	2016/12/04
10	Point	M	100	A	10102021005	416628	Address	10102021005	2016/04/20
11	Point	M	100	A	10102021336	411803	Address	10102021336	2016/03/03
12	Point	M	100	A	10102021476	423931	Address	10102021476	2016/05/26
13	Point	M	100	A	10103032651	423776	Address	10103032651	2016/03/29
14	Point	M	100	A	10103032773	417234	Address	10103032773	2016/04/24
15	Point	M	100	A	10103034057	116922	Address	10103034057	2016/05/20
16	Point	M	100	A	1010303652	116747	Address	1010303652	2016/09/05
17	Point	U	0	A		-1		10104011589	2016/03/17
18	Point	M	100	A	1010303345	110418	Address	1010303345	2016/03/31
19	Point	U	0	A		-1		10104011591	2016/06/13
20	Point	M	100	A	1010402242	411195	Address	1010402242	2016/11/04
21	Point	M	100	A	1010401352	106466	Address	1010401352	2016/05/31
22	Point	M	100	A	1010402566	415096	Address	1010402566	2016/12/04
23	Point	M	100	A	10104031614	419094	Address	10104031614	2016/04/26
24	Point	M	100	A	10104031399	423087	Address	10104031399	2016/06/06
25	Point	M	100	A	10104031626	418978	Address	10104031626	2016/06/06
26	Point	M	100	A	10104031631	418781	Address	10104031631	2016/06/06

- ➢ Sort the “Score” attribute field in Ascending, and select all the Unmatched Records.



Sort Ascending

Sort the values in this field in ascending order (A - Z) (1 - 9).

POC_2016July_Nyarugenge

ObjectID *	Shape *	Status	Score
1	Point	U	
2	Point	U	
3	Point	U	0
4	Point	U	0
5	Point	M	100
6	Point	M	100
7	Point	M	100
8	Point	M	100
9	Point	M	100
10	Point	M	100
11	Point	M	100
12	Point	M	100
13	Point	M	100
14	Point	M	100
15	Point	M	100
16	Point	M	100
17	Point	U	0
18	Point	M	100
19	Point	U	0
20	Point	M	100
21	Point	M	100
22	Point	M	100
23	Point	M	100
24	Point	M	100
25	Point	M	100
26	Point	M	100
27	Point	M	100

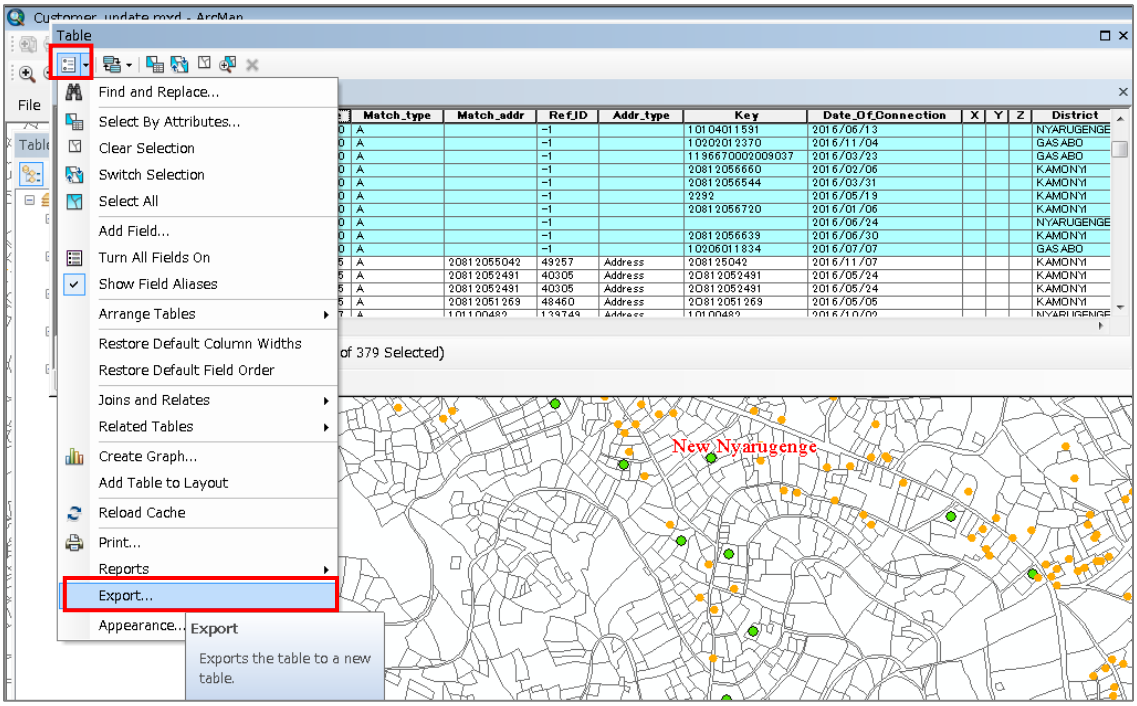
ObjectID *	Shape *	Status	Score	Match_type	Match_
186	Point	U	0	A	
192	Point	U	0	A	
246	Point	U	0	A	
248	Point	U	0	A	
249	Point	U	0	A	
250	Point	U	0	A	
251	Point	U	0	A	
265	Point	U	0	A	
268	Point	U	0	A	
283	Point	U	0	A	
295	Point	U	0	A	
340	Point	U	0	A	
341	Point	U	0	A	
342	Point	U	0	A	
343	Point	U	0	A	
353	Point	U	0	A	
362	Point	U	0	A	
365	Point	U	0	A	
375	Point	M	92.5	A	20812055
90	Point	M	95	A	20812052
344	Point	M	95	A	20812052
345	Point	M	95	A	20812051
39	Point	M	97	A	10110048

(39 out of 379 Selected)

POC_2016July_Nyarugenge

Please discuss the criteria of “Unmatched” for re-investigation: Should only Unmatched records (Scored “0”) be re-investigated, or should records scored under 50 be included?

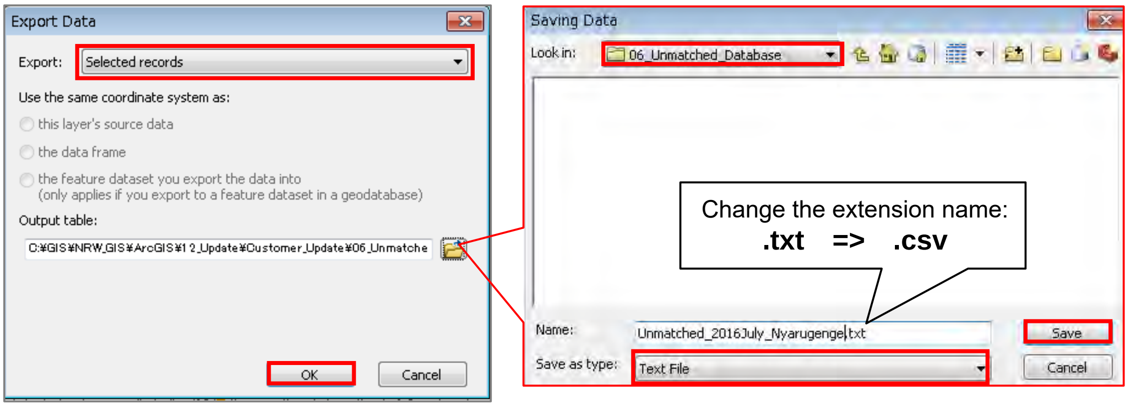
- Export Unmatched Customer Record as data-table.
  - Keep selecting Unmatched Data-set, and select [Export] from the Attribute table menu.



Match_type	Match_addr	Ref_ID	Addr_type	Key	Date_Of_Connection	X	Y	Z	District
A		-1		1010401 1591	2016/06/13				NYARUGENGE
A		-1		10202012370	2016/11/04				GASABO
A		-1		1196670002009037	2016/03/23				GASABO
A		-1		20812056660	2016/02/06				KAMONYI
A		-1		20812056544	2016/03/31				KAMONYI
A		-1		2292	2016/05/19				KAMONYI
A		-1		20812056720	2016/01/06				KAMONYI
A		-1			2016/06/24				NYARUGENGE
A		-1		20812056639	2016/06/30				KAMONYI
A		-1		10206011834	2016/07/07				GASABO
A	20812055042	49257	Address	2081 25042	2016/11/07				KAMONYI
A	20812052491	40305	Address	20812052491	2016/05/24				KAMONYI
A	20812052491	40305	Address	20812052491	2016/05/24				KAMONYI
A	20812051269	48460	Address	20812051269	2016/05/05				KAMONYI

of 379 Selected)

  - In the Export Dialog, please make sure only “Selected records” is targeted, and choose Saving folder for Output table to [06_Unmatched_Database]
  - Choose “Text File” in the pulldown of [Save as type]. Change the extension name from “.txt” to “.csv”



Export: Selected records

Output table: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥06_Unmatche

Look in: 06_Unmatched_Database

Change the extension name:
.txt => .csv

Name: Unmatched_2016July_Nyarugenge.txt

Save as type: Text File

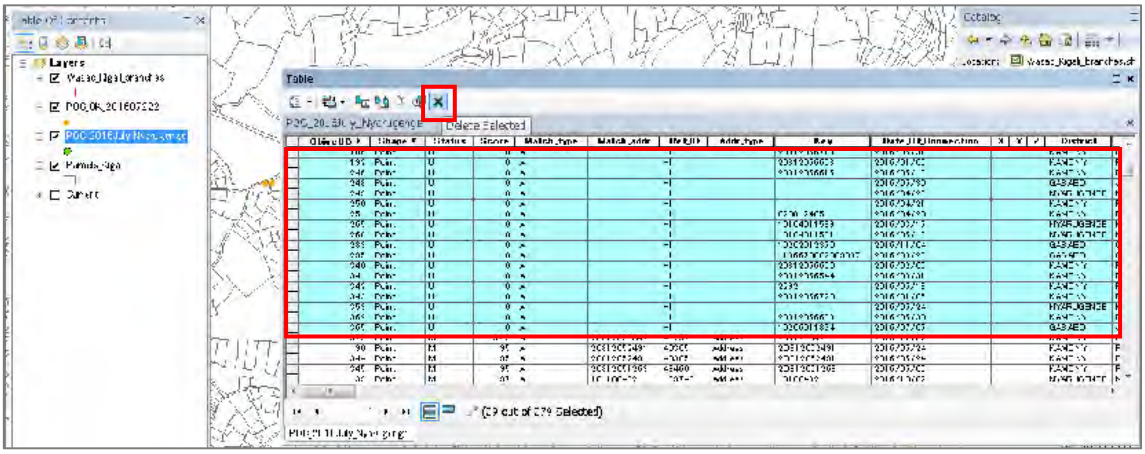
- Click “OK”,

Click “No” when you are asked to add the table on the current map.

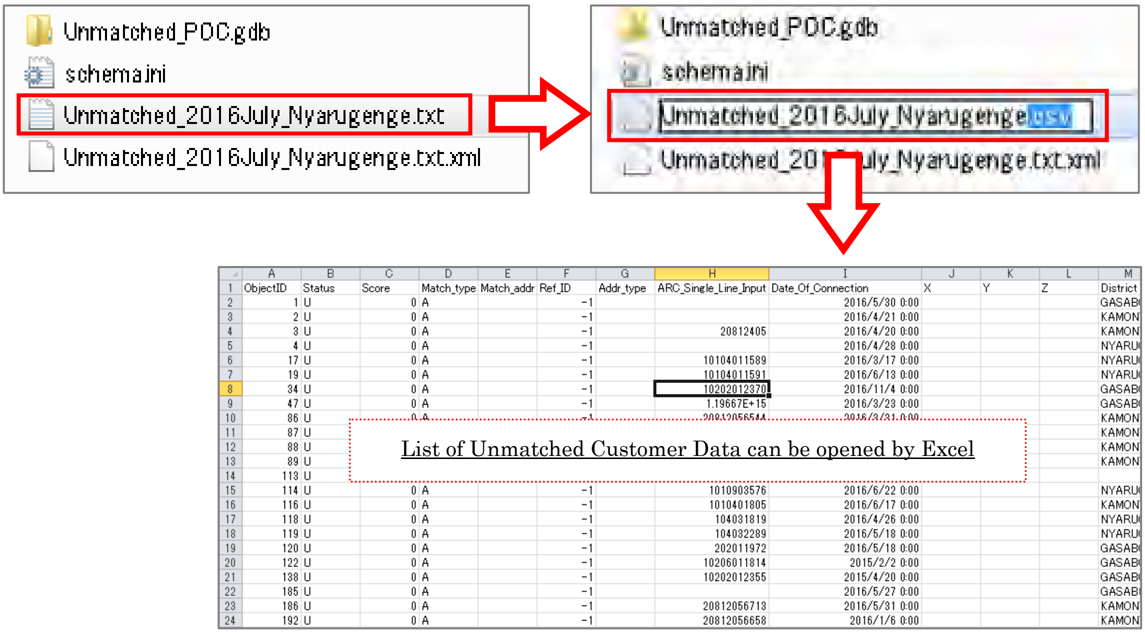
Do you want to add the new table to the current map?

- After exporting the list of unmatched records, delete the unmatched data from GIS data.

  ✱ In order to delete the selected records, you need to [Start Editing].



- If you did not change the extension name of the file from ".txt" to ".csv", go to folder [06_Unmatched_Database], and change the extension of the file that you exported. "CSV" file can be opened in Excel, and which shows the Unmatched Customers.


Unmatched_POC.gdb
schema.ini
Unmatched_2016July_Nyarugenge.txt
Unmatched_2016July_Nyarugenge.txt.xml

Unmatched_POC.gdb
schema.ini
Unmatched_2016July_Nyarugenge.csv
Unmatched_2016July_Nyarugenge.txt.xml

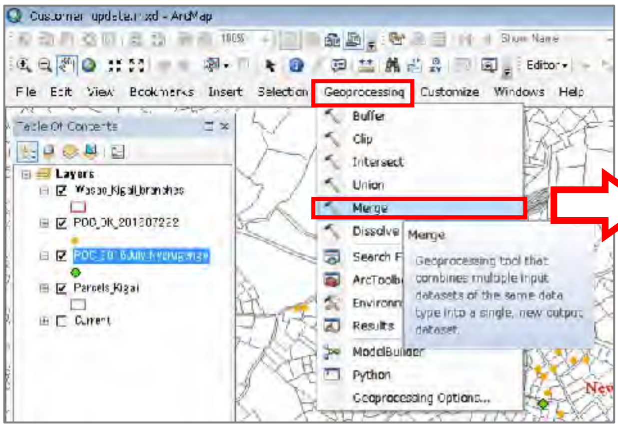
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	ObjectID	Status	Score	Match_type	Match_addr	Ref_ID	Addr_type	ARC_Single_Line_Input	Date_Of_Connection	X	Y	Z	District
2	1	U	0	A		-1			2016/5/30 0:00				GASAB
3	2	U	0	A		-1			2016/4/21 0:00				KAMON
4	3	U	0	A		-1		20812405	2016/4/20 0:00				KAMON
5	4	U	0	A		-1			2016/4/28 0:00				NYARU
6	17	U	0	A		-1		10104011589	2016/3/17 0:00				NYARU
7	19	U	0	A		-1		10104011591	2016/6/13 0:00				NYARU
8	34	U	0	A		-1		10202012370	2016/11/4 0:00				GASAB
9	47	U	0	A		-1		1.19667E+15	2016/3/23 0:00				GASAB
10	86	U	0	A		-1		20812056544	2016/3/31 0:00				KAMON
11	87	U											KAMON
12	88	U											KAMON
13	89	U											KAMON
14	113	U											
15	114	U	0	A		-1		1010903576	2016/6/22 0:00				NYARU
16	116	U	0	A		-1		1010401805	2016/6/17 0:00				KAMON
17	118	U	0	A		-1		104031819	2016/4/26 0:00				NYARU
18	119	U	0	A		-1		104032289	2016/5/18 0:00				NYARU
19	120	U	0	A		-1		202011972	2016/5/18 0:00				GASAB
20	122	U	0	A		-1		10206011814	2015/2/2 0:00				GASAB
21	138	U	0	A		-1		10202012355	2015/4/20 0:00				GASAB
22	185	U	0	A		-1			2016/5/27 0:00				GASAB
23	186	U	0	A		-1		20812056713	2016/5/31 0:00				KAMON
24	192	U	0	A		-1		20812056658	2016/1/6 0:00				KAMON

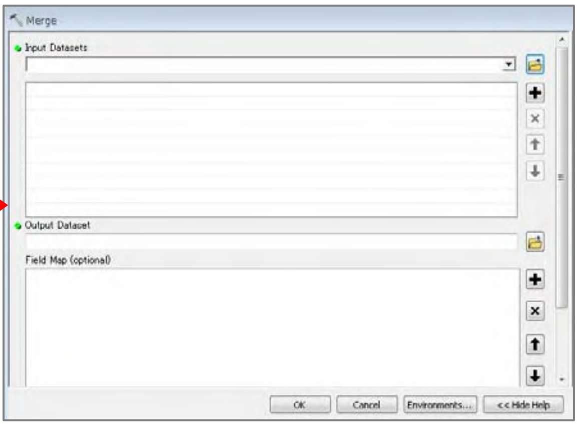
List of Unmatched Customer Data can be opened by Excel

- This CSV data will be sent to each branch for re-investigation of the location coordinates or UPI.

7. ArcGIS: Merge New & Current Customer Database

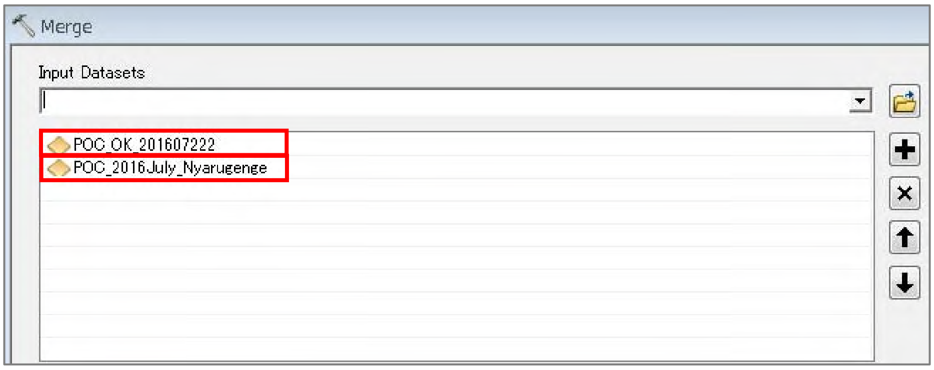
- [Geoprocessing > Merge] Open Merge Dialog-box.





- Set Merge Dialog-box as follows:
  - For [Input Datasets], please select the Current POC dataset, and New POC dataset respectively.

Please make sure to **Select Current POC Dataset at First**; and new dataset after that. Then Attribute Field of Output data will be based on the current dataset.



Input Datasets

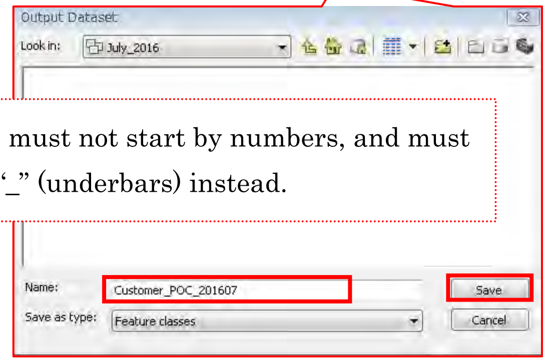
POC_OK_201607222

POC_2016July_Nyarugenge

  - Choose the folder and Geodatabase for Output dataset: [07_Updated_Customer_Database¥Customer_Update.gdb]

Output Dataset

C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥07_Updated_Customer_Database¥Customer_Update.gdb¥Ju



Look in: July_2016

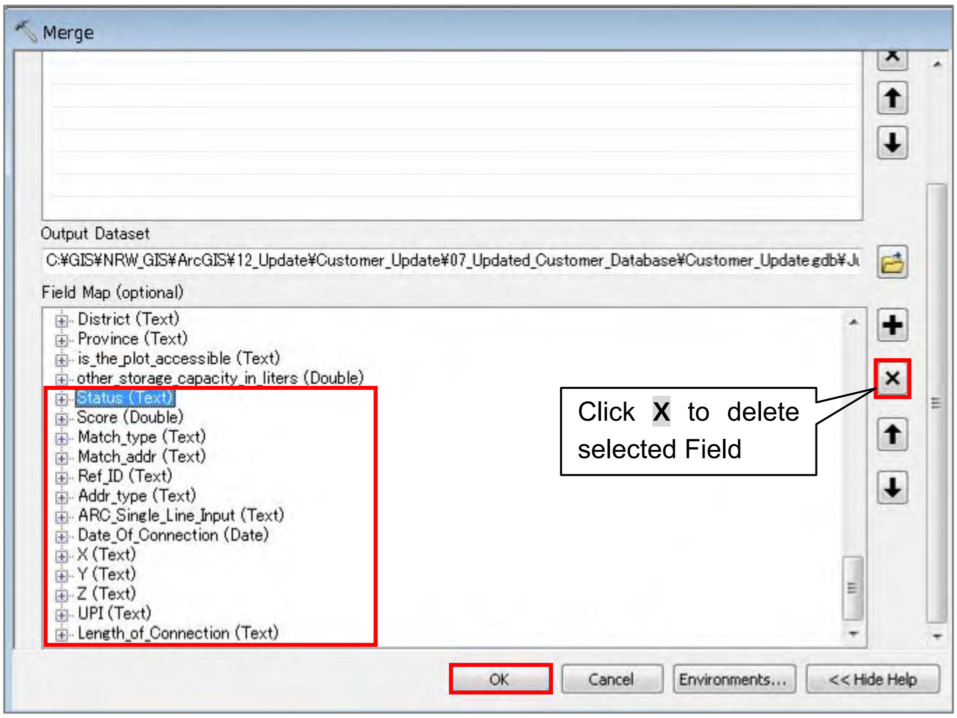
Name: Customer_POC_201607

Save as type: Feature classes

Name of the feature class in Geodatabase must not start by numbers, and must not include "." "(space)", and "-". You can use "_" (underbars) instead.

- Delete unnecessary attribute fields in the Field Map.

  Please discuss appropriate attribute field for the Customer Database. If it is based on the current database (as of October 2016), “Status”, “Score”, … , “UPI”, and “Length of Connection” should be deleted.



Output Dataset

C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥07_Updated_Customer_Database¥Customer_Update.gdb¥Ju

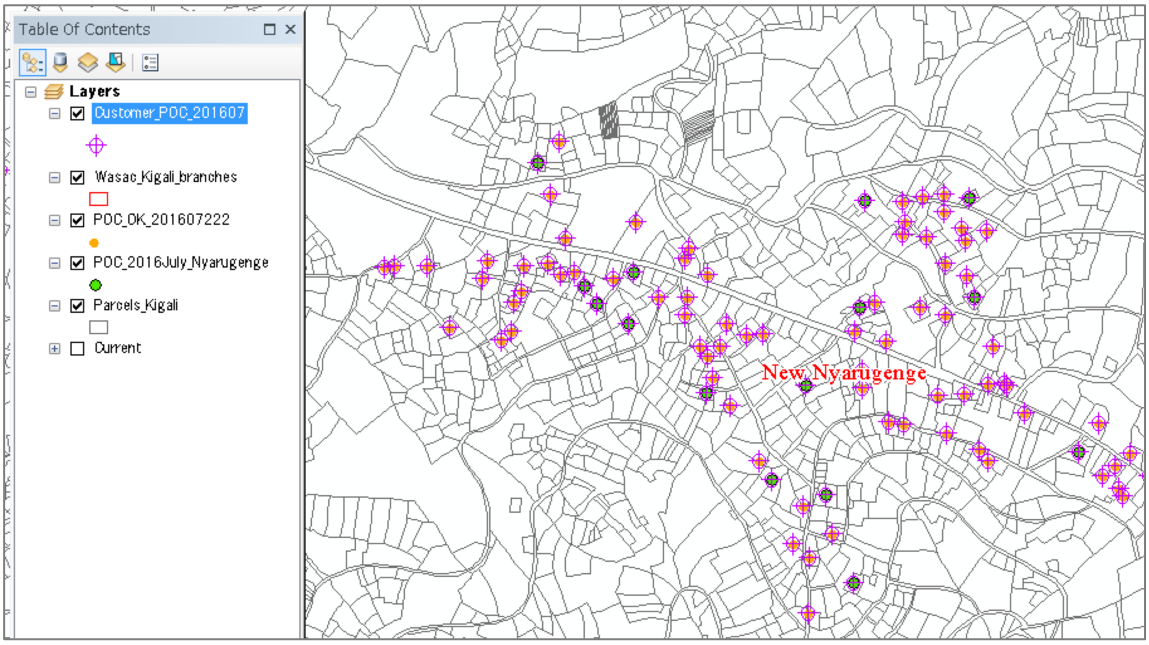
Field Map (optional)

District (Text)
Province (Text)
is_the_plot_accessible (Text)
other_storage_capacity_in_liters (Double)
Status (Text)
Score (Double)
Match_type (Text)
Match_addr (Text)
Ref_ID (Text)
Addr_type (Text)
ARC_Single_Line_Input (Text)
Date_Of_Connection (Date)
X (Text)
Y (Text)
Z (Text)
UPI (Text)
Length_of_Connection (Text)

Click X to delete selected Field

➢ Click [OK], and then Merge is implemented.

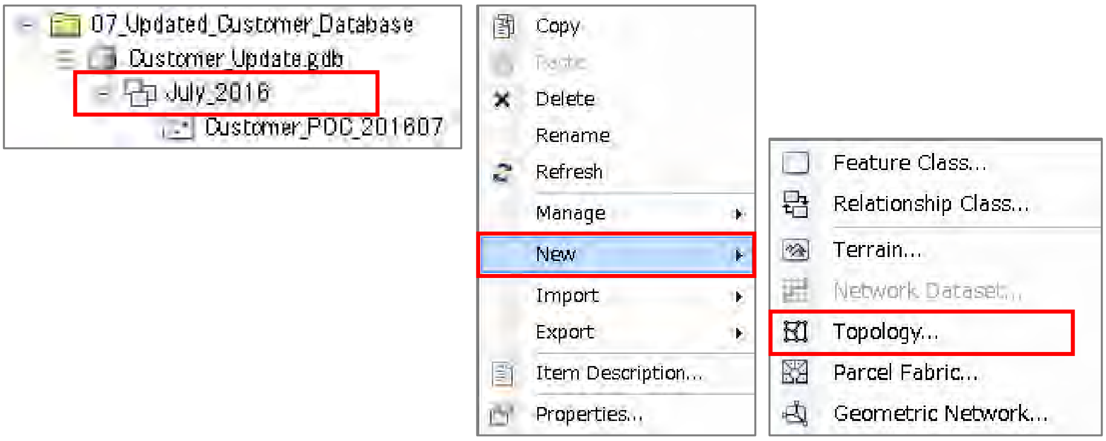
- When Merge is successfully done, the result is added on the ArcMap.
- An error will occur when a blank record exists in the Attribute Field of number type such as “Double”. Please check if there is a blank in the New Customer Database.



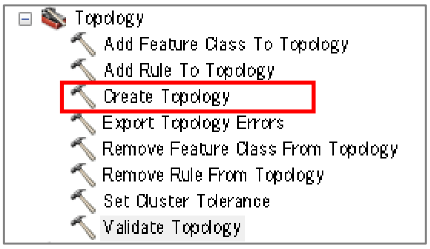
8. Validation Check by Topology Rules

Validation of the Data-base should be checked by Head of GIS team. There would be several approaches in order to check inappropriate data-set: This chapter will introduce the "Topology Validation" on ArcGIS in order to find out points that are overlapped by the other points, and which means that those points are double-counted or plotted at the same place.

- ➢ Create Topology from ArcCatalog or ArcToolbox as shown below. Topology can be created only in the Geodatabase Feature Dataset.
  - [ArcCatalog: 07_Updated_Customer_Database] Right Click on the GDB Dataset.

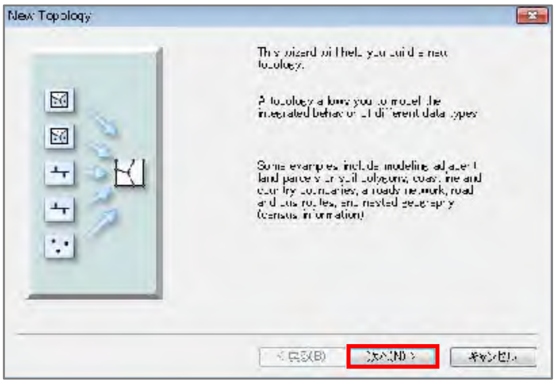


  - [ArcToolbox > Topology > Create Topology]

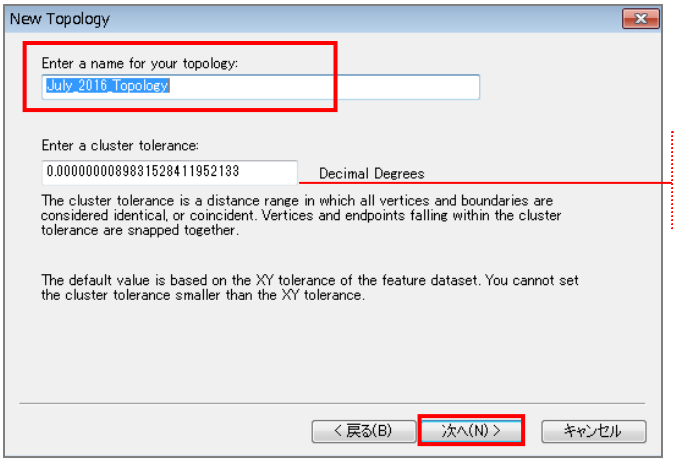


Topology must be in the same Feature Dataset with the Customer Dataset that will be validated. If you do not have Feature Dataset or Geodatabase in the folder, please create it by Right Click on the Folder or Geodatabase.

- ➢ Wizard for "New Topology" is opened. Click "Next".



- In the next wizard, enter a name of Topology. Please put simple and explicit name on it like: POC_July_2016_Topology
- Click “Next” to go forward.



New Topology

Enter a name for your topology: July_2016_Topology

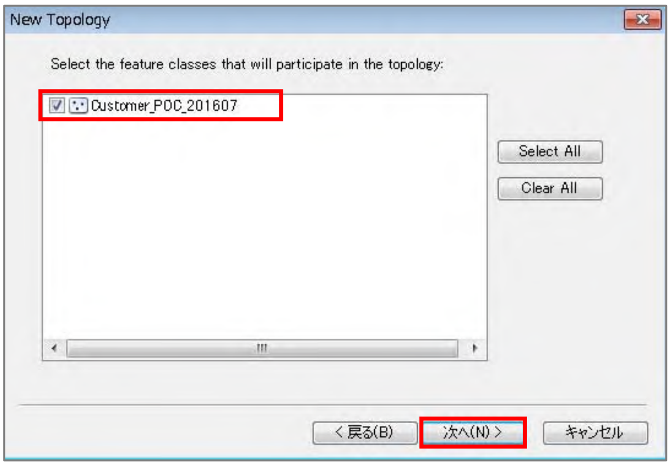
Enter a cluster tolerance: 0.0000000089831528411952133 Decimal Degrees

The cluster tolerance is a distance range in which all vertices and boundaries are considered identical, or coincident. Vertices and endpoints falling within the cluster tolerance are snapped together.

The default value is based on the XY tolerance of the feature dataset. You cannot set the cluster tolerance smaller than the XY tolerance.

You can ignore a cluster tolerance if the default value is set on it.

- In the next wizard, please select the Customer_POC feature class that is validated.
  If you cannot find the feature class in this wizard, please check the Feature Dataset. The feature class and Topology must be in the same Feature Dataset in Geodatabase.

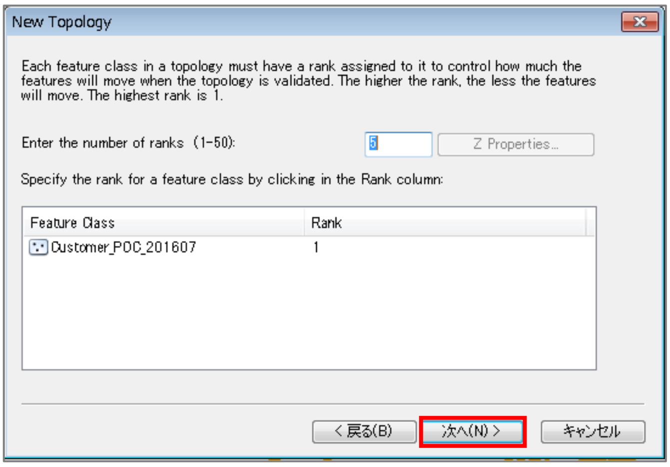


New Topology

Select the feature classes that will participate in the topology:

☑ Customer_POC_201607

- The next wizard sets the priority, and you can ignore this when you implement validation using only one feature. Keep it as default, and Click “Next”.



New Topology

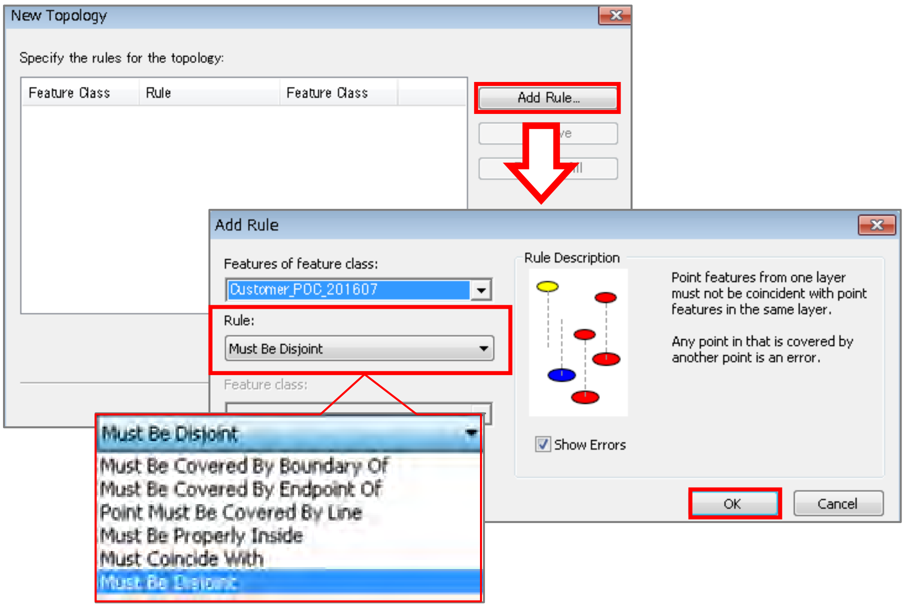
Each feature class in a topology must have a rank assigned to it to control how much the features will move when the topology is validated. The higher the rank, the less the features will move. The highest rank is 1.

Enter the number of ranks (1-50): 5

Specify the rank for a feature class by clicking in the Rank column:

Feature Class	Rank
Customer_POC_201607	1

- In the next wizard, click “Add Rule”, and select “Must Be Disjoint” for [Rule].



Features of feature class: Customer_POC_201607

Rule: Must Be Disjoint

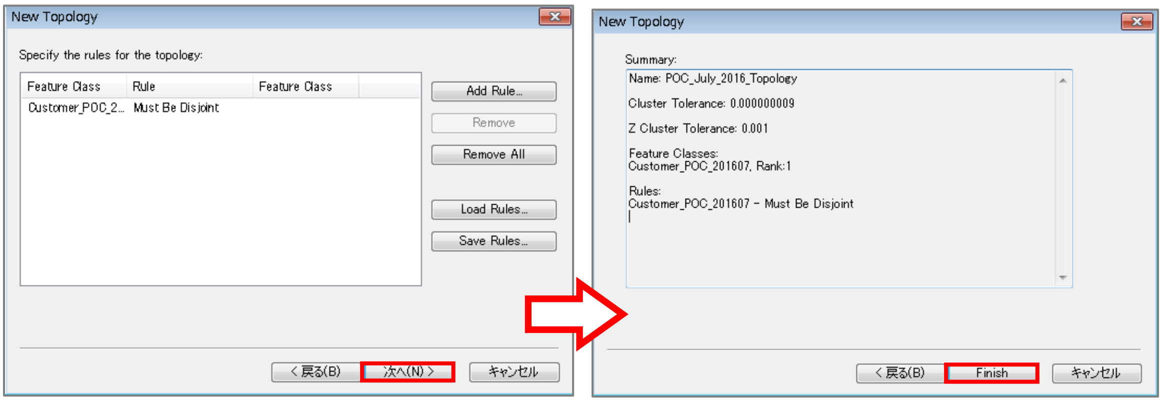
Feature class:

Point features from one layer must not be coincident with point features in the same layer.

Any point in that is covered by another point is an error.

☑ Show Errors

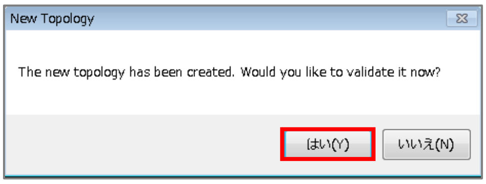
- Click “Next” after added the Rule.
- Confirmation is asked. Click “Finish”.



Feature Class	Rule	Feature Class
Customer_POC_2...	Must Be Disjoint	

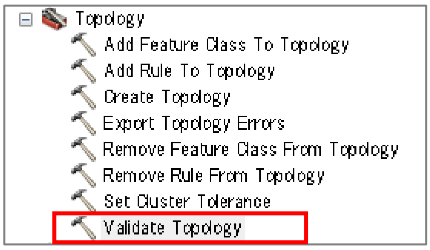
Summary:
Name: POC_July_2016_Topology
Cluster Tolerance: 0.000000009
Z Cluster Tolerance: 0.001
Feature Classes:
Customer_POC_201607, Rank:1
Rules:
Customer_POC_201607 - Must Be Disjoint

- When Topology is successfully created, you will be asked to validate it now or later. Click “Yes”.

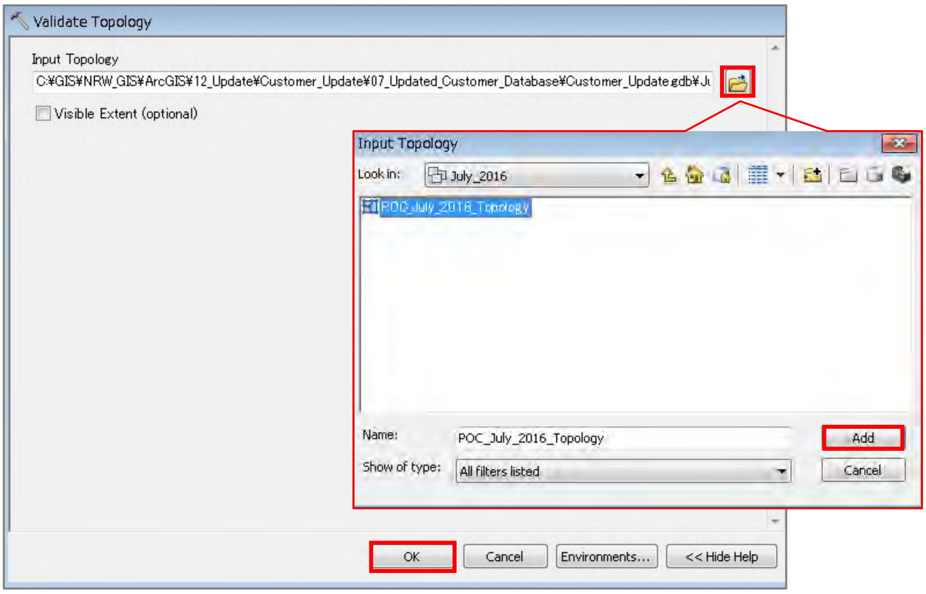


The new topology has been created. Would you like to validate it now?

➢ To implement Validation using Topology that you created, please go to: [ArcToolbox > Topology > Validate Topology]



- In the “Validate Topology” Dialog, please select Topology that you have created.



Validate Topology

Input Topology: C:¥GIS¥NRW_GIS¥ArcGIS¥12_Update¥Customer_Update¥07_Updated_Customer_Database¥Customer_Update.gdb¥Ju

☐ Visible Extent (optional)

Input Topology

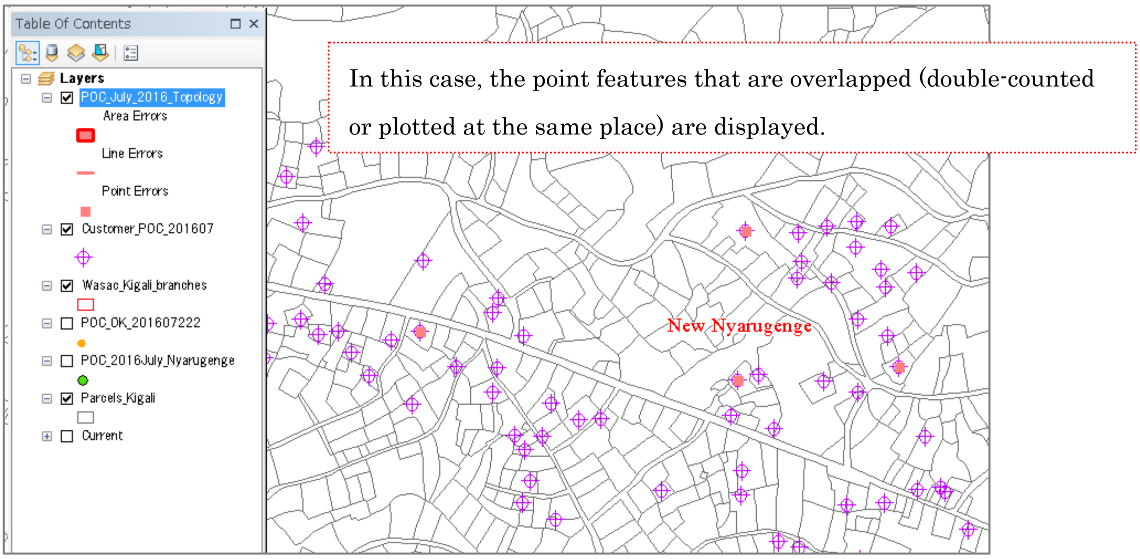
Look in: July_2016

POC_July_2016_Topology

Name: POC_July_2016_Topology

Show of type: All filters listed

- Click “OK”. If Validation is successfully implemented, the errors (the features that are not following the rule) are displayed.



In this case, the point features that are overlapped (double-counted or plotted at the same place) are displayed.

Table Of Contents

- Layers
  - ☑ POC_July_2016_Topology
    - Area Errors 🟥
    - Line Errors
    - Point Errors
  - ☑ Customer_POC_201607
  - ☑ Wasac_Kigali_branches
  - ☐ POC_OK_201607222
  - ☐ POC_2016July_Nyarugenge
  - ☑ Parcels_Kigali
  - ☐ Current

Topology Validation is only to display features that are not following your “Rule” as errors. These features are NOT automatically moved or deleted.

- You need to check the features that are displayed as errors, and edit them properly.
  - Double-counted POC customer: must be deleted
  - POC customers plotted at the same place: must be moved to the right place with detailed information referencing Satellite Images.

When two customers have same UPI code, both customers are plotted at the same place by Geocoding: at the center of UPI parcels. You need to move them manually.

This chapter introduced a simple method of Topology Validation. There are many options for Topology on ArcGIS that you can try. Created Topology can be edited from ArcToolbox or Property of Topology in ArcCatalog (from Right Click Menu).

- In addition to this, you may look through or find all the mistaken record (but not found as errors) manually on ArcGIS or Excel.

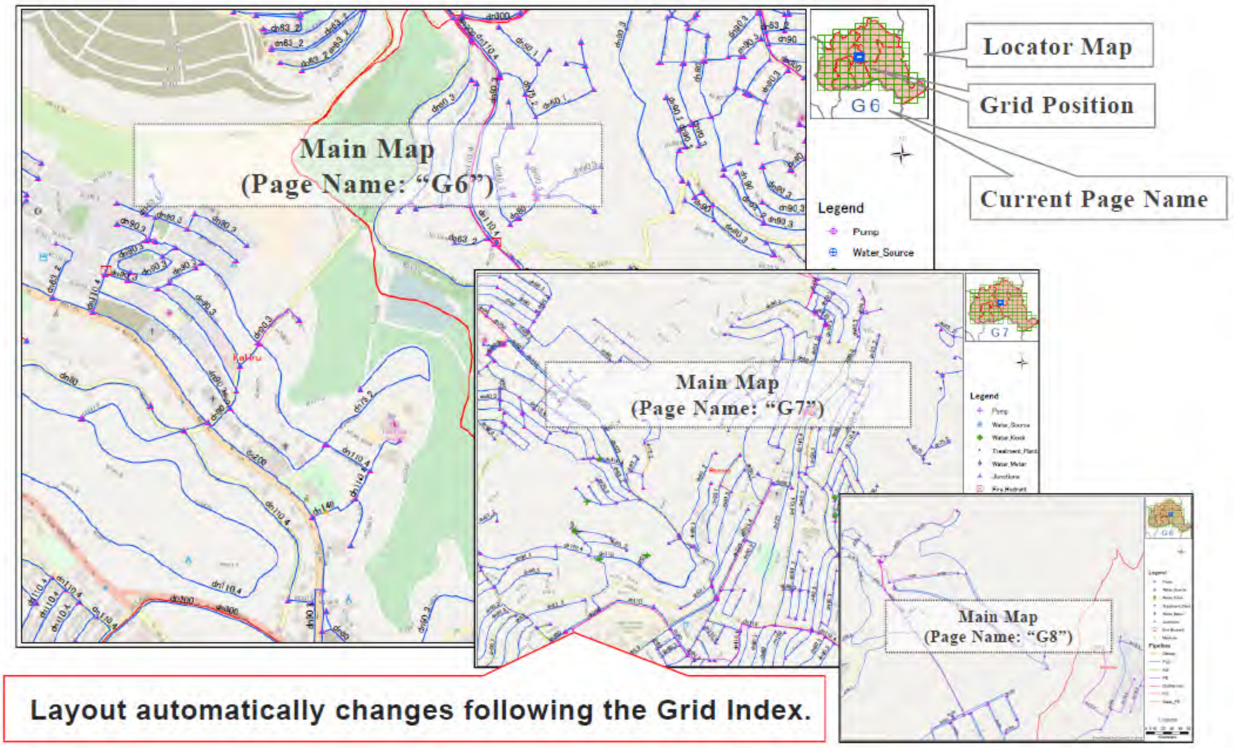
- Check-Sheet for Customer Data Update must be recorded after each updating stage.

No.	Description	Person in Charge	201607
1	Acquire New Customer Database from Branches	(GIS Officer)	✓
2	Export the Database to Excel Worksheet	(GIS Officer)	✓
3	Combine all Excel Worksheets in the month and arranged Field Items	(GIS Officer)	✓
4	Geocoding	(GIS Officer)	✓
5	Export Unmatched Data to Table	(GIS Officer)	✓
6	Merge New & Current Database	(GIS Officer)	✓
7	Validation Check	(Head of GIS team)	✓

III. Data Driven Page Layout

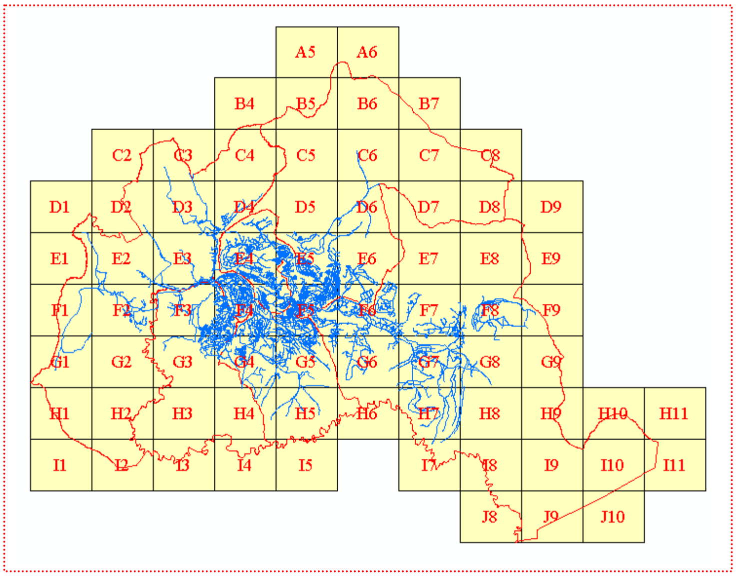
1. Introduction and Sample

Data Driven is one of the tools on ArcToolbox that enables to create Series of Pages in one ArcGIS (.mxd) file.

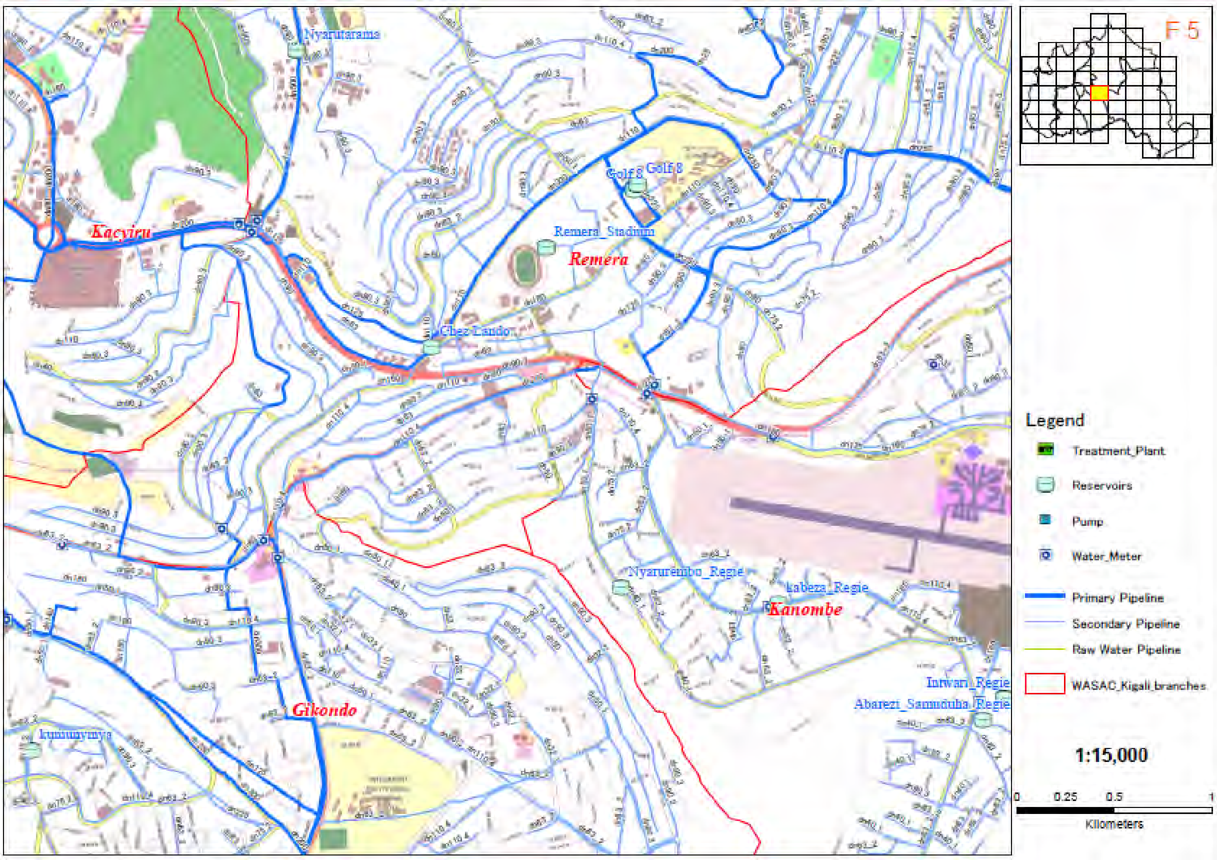


- ➢ This example shows how to create Index Grid covering Kigali City and Layout with Data Driven Page (73 Pages, 5000m * 4200m per 1 page, Scale 1:15,000).

- ***Index Grid :***

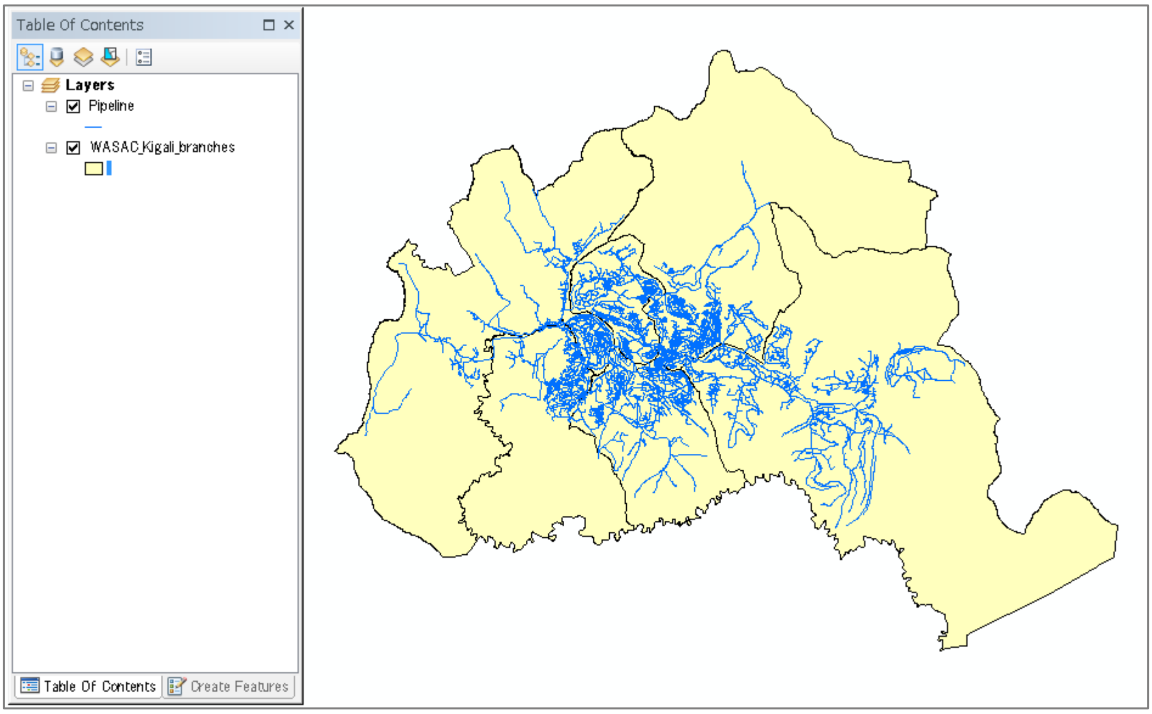


- The Sample Layout that will be created in this example.

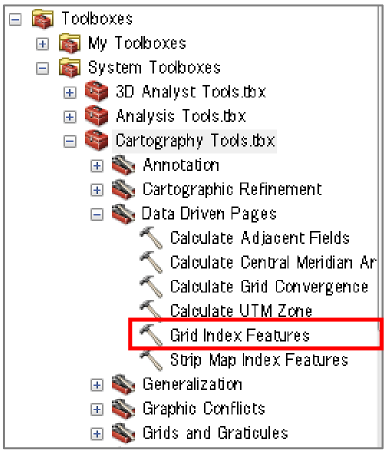


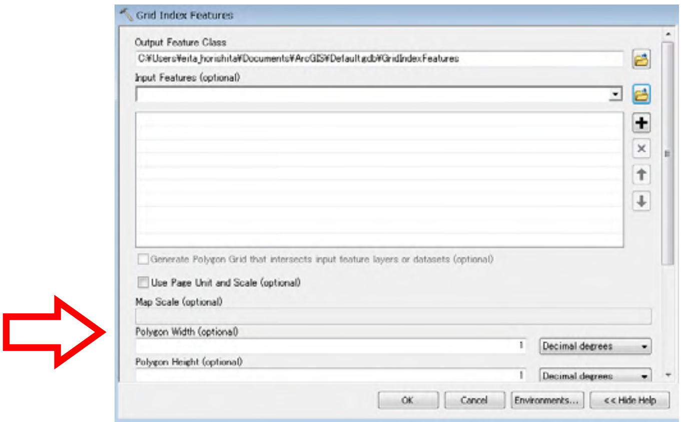
2. Create Index Grid

➢ Add [Pipeline] data and [WASAC Kigali Branch Boundary] data on your ArcMap



- [ArcToolbox > Cartography Tools > Data Driven Pages > Grid Index Features]




Grid Index Features

Output Feature Class: C:¥Users¥eita_horishita¥Documents¥ArcGIS¥Default.gdb¥GridIndexFeatures

Input Features (optional)

☐ Generate Polygon Grid that intersects input feature layers or datasets (optional)

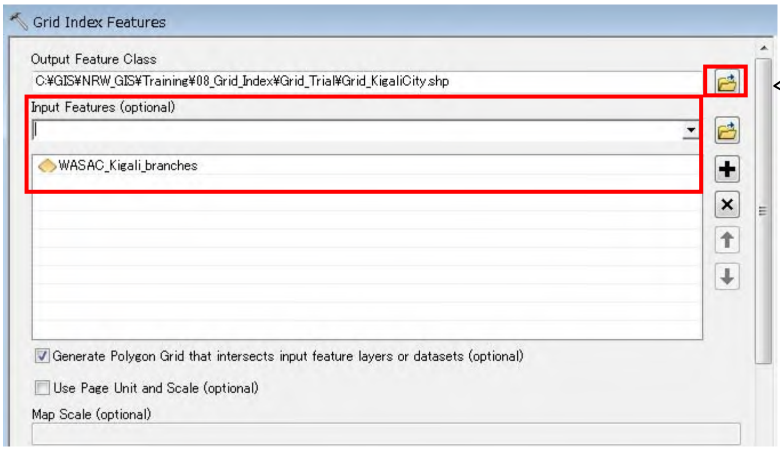
☐ Use Page Unit and Scale (optional)

Map Scale (optional)

Polygon Width (optional): 1 Decimal degrees

Polygon Height (optional): 1 Decimal degrees

- Choose the appropriate folder and filename for Output Feature Class. Please select WASAC Kigali Branch Boundary for Input Features.


Grid Index Features

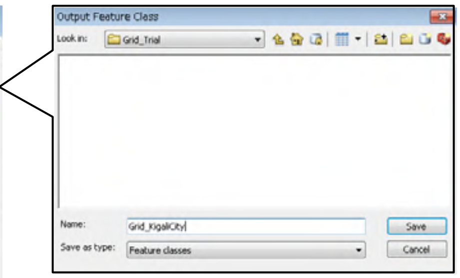
Output Feature Class: C:¥GIS¥NRW_GIS¥Training¥08_Grid_Index¥Grid_Trial¥Grid_KigaliCity.shp

Input Features (optional): WASAC_Kigali_branches

☑ Generate Polygon Grid that intersects input feature layers or datasets (optional)

☐ Use Page Unit and Scale (optional)

Map Scale (optional)


Output Feature Class

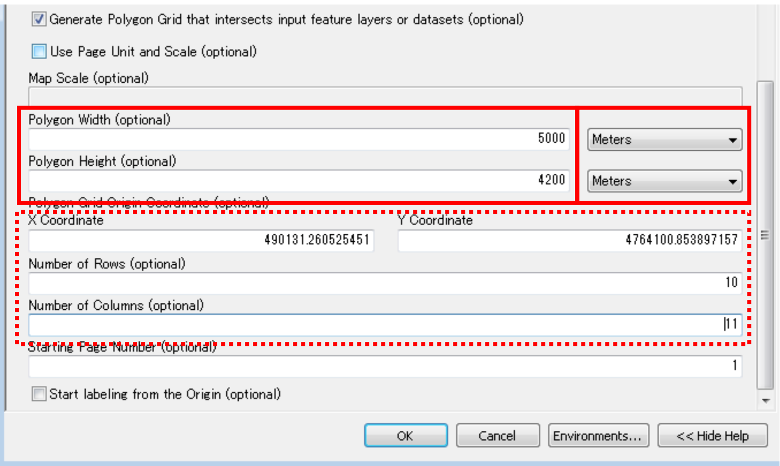
Look in: Grid_Trial

Name: Grid_KigaliCity

Save as type: Feature classes

- Set Polygon Width and Height for a Grid. In this case, Width is “5000”, and Height is “4200”. Please make sure that unit is “Meters”.

If you selected Input Features (optional), then XY Coordinates and Numbers of Rows and Columns are automatically calculated. It is possible to set these numbers manually by yourself.


☑ Generate Polygon Grid that intersects input feature layers or datasets (optional)

☐ Use Page Unit and Scale (optional)

Map Scale (optional)

Polygon Width (optional): 5000 Meters

Polygon Height (optional): 4200 Meters

Polygon Grid Origin Coordinate (optional)

X Coordinate: 490131.260525451

Y Coordinate: 4764100.853897157

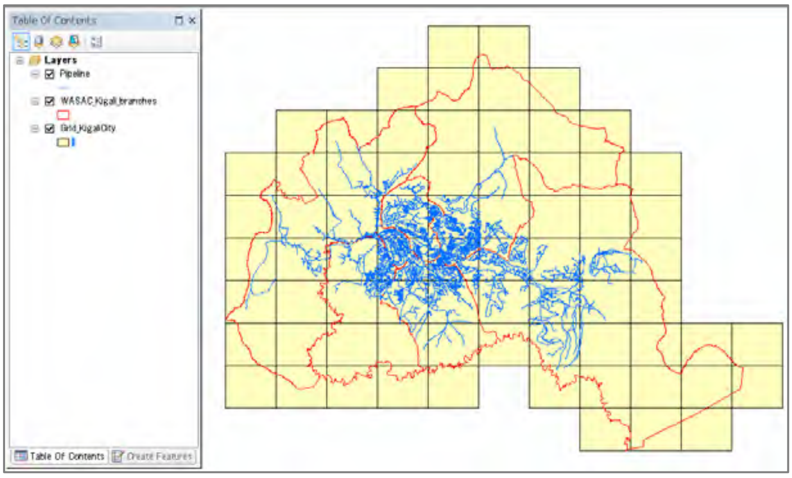
Number of Rows (optional): 10

Number of Columns (optional): 11

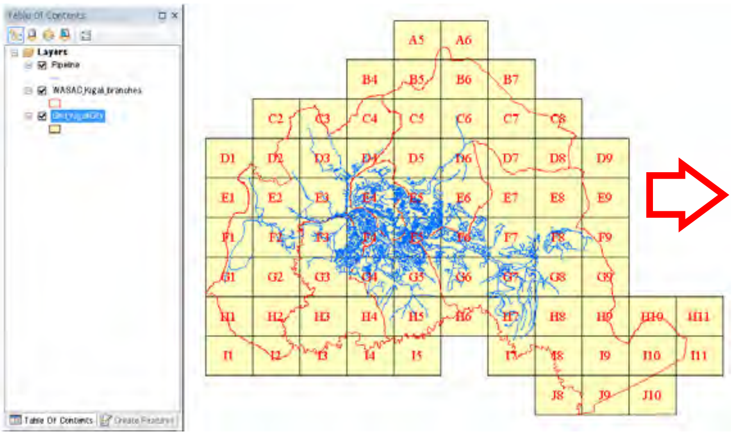
Starting Page Number (optional): 1

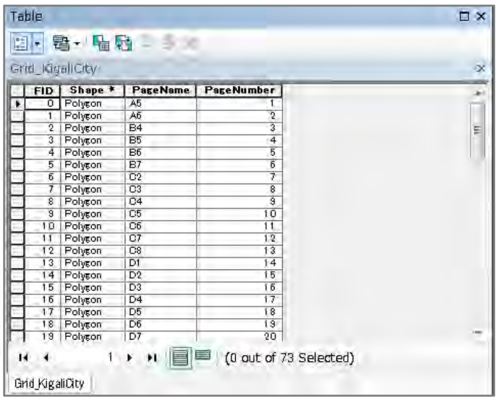
☐ Start labeling from the Origin (optional)

- Click “OK”, and then Index Grid is generated.



Grid Index feature has Page Number and Page Name in its Attribute Table.



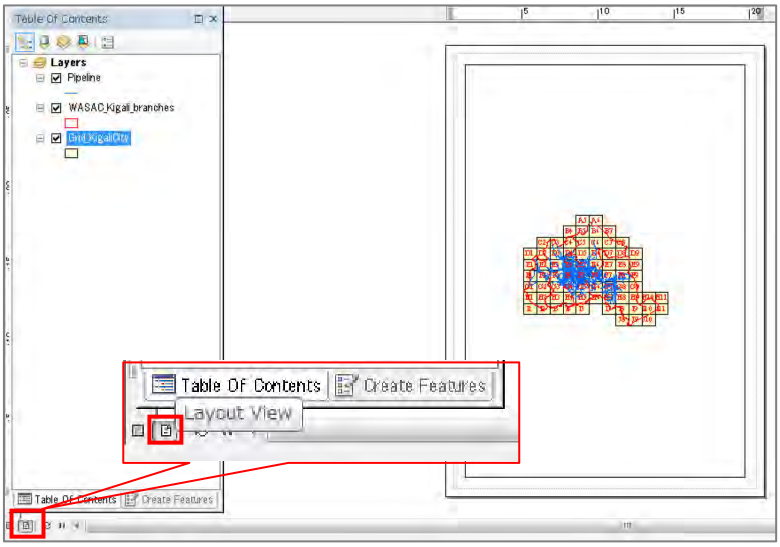


FID	Shape *	PageName	PageNumber
0	Polygon	A5	1
1	Polygon	A6	2
2	Polygon	B4	3
3	Polygon	B5	4
4	Polygon	B6	5
5	Polygon	B7	6
6	Polygon	C2	7
7	Polygon	C3	8
8	Polygon	C4	9
9	Polygon	C5	10
10	Polygon	C6	11
11	Polygon	C7	12
12	Polygon	C8	13
13	Polygon	D1	14
14	Polygon	D2	15
15	Polygon	D3	16
16	Polygon	D4	17
17	Polygon	D5	18
18	Polygon	D6	19
19	Polygon	D7	20

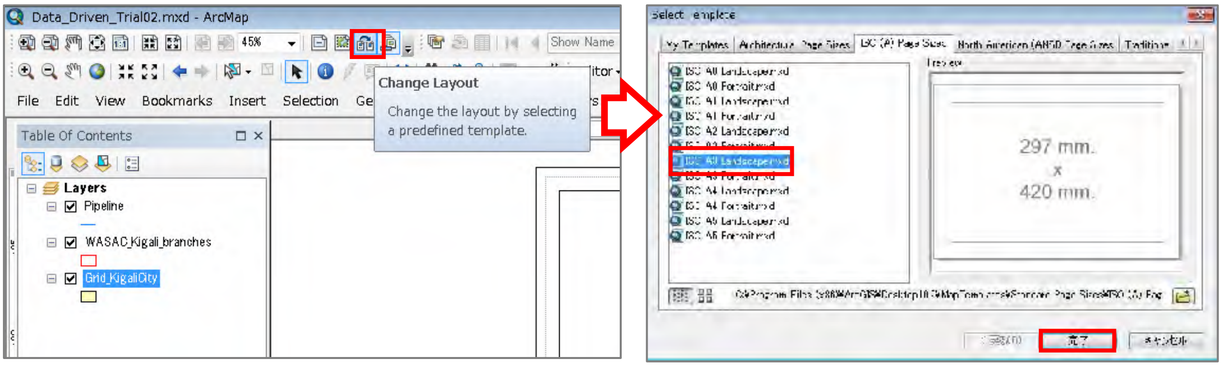
(0 out of 73 Selected)

3. Layout Setting

- To the next step, please go to Layout View.

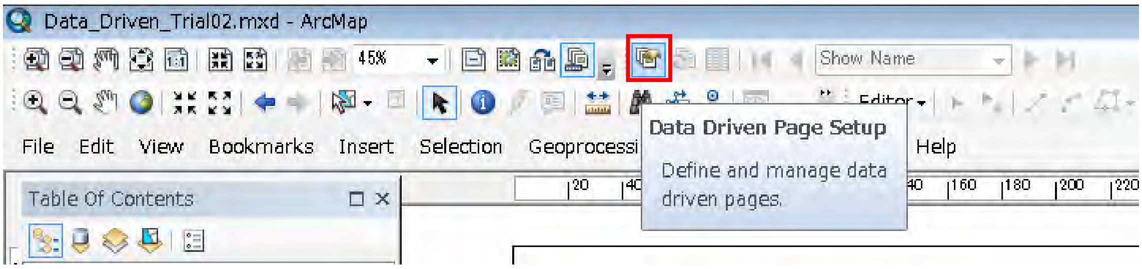


➢ In the Layout View, Please click "Change Layout" to change the layout size. In this case, select ISO A3 size, Landscape.

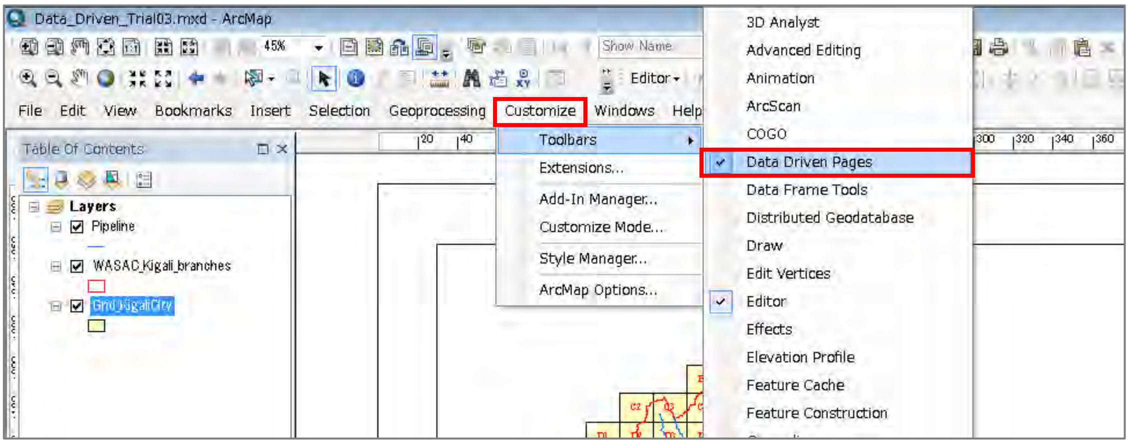


4. Data Driven Page Setup

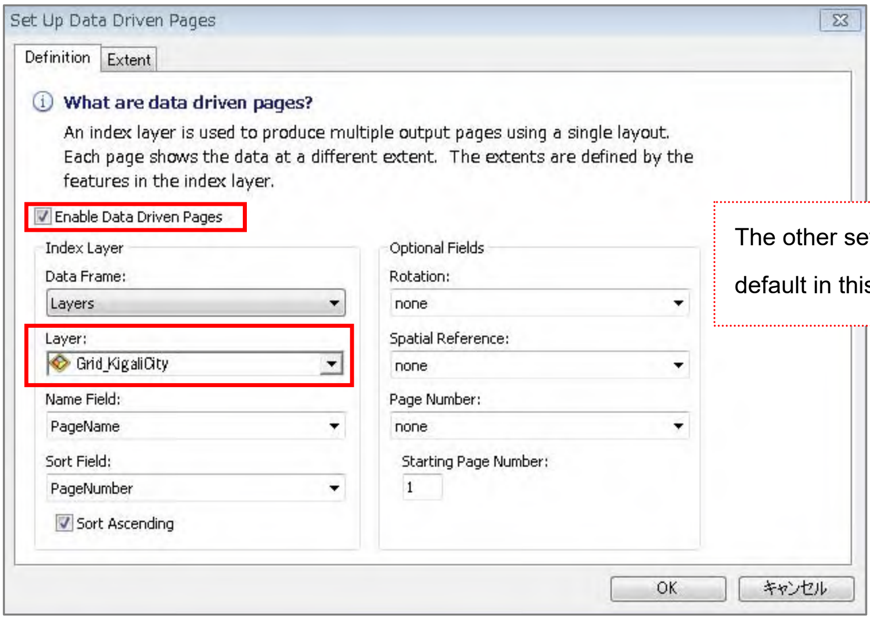
➢ Next, click [Data Driven Page Setup].



If you cannot find the icon, [Data Driven Page Set Up] is shown from [Customize > Toolbars > Data Driven Pages]



➢ In the [Set Up Data Driven Pages] Dialog, please check [Enable Data Driven Pages]. After that, please select the Grid Index Layer that you have created in [Layer].



Set Up Data Driven Pages

Definition | Extent

What are data driven pages?

An index layer is used to produce multiple output pages using a single layout. Each page shows the data at a different extent. The extents are defined by the features in the index layer.

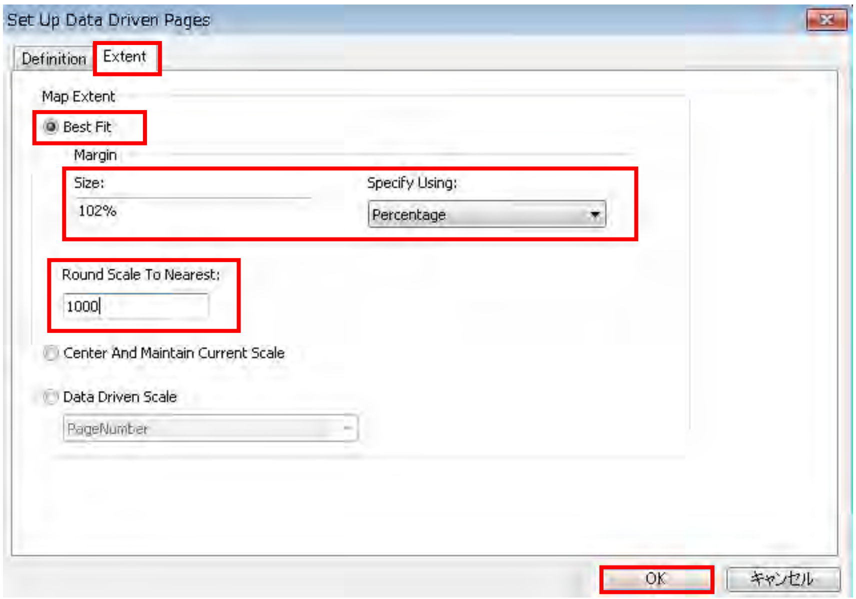
☑ Enable Data Driven Pages

Index Layer
Data Frame: Layers
Layer: Grid_KigaliCity
Name Field: PageName
Sort Field: PageNumber
☑ Sort Ascending

Optional Fields
Rotation: none
Spatial Reference: none
Page Number: none
Starting Page Number: 1

The other settings are kept as default in this example.

- In the [Extent] tab, you can set-up margin and scales of pages generated by Data Driven. In this example, select [Best Fit], [Margin Size: 102 %], [Round Scale To Nearest: 1000].

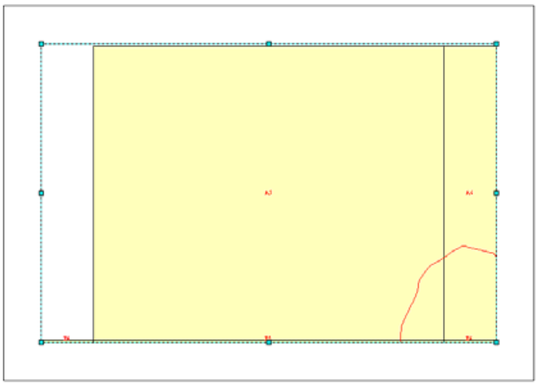


Set Up Data Driven Pages

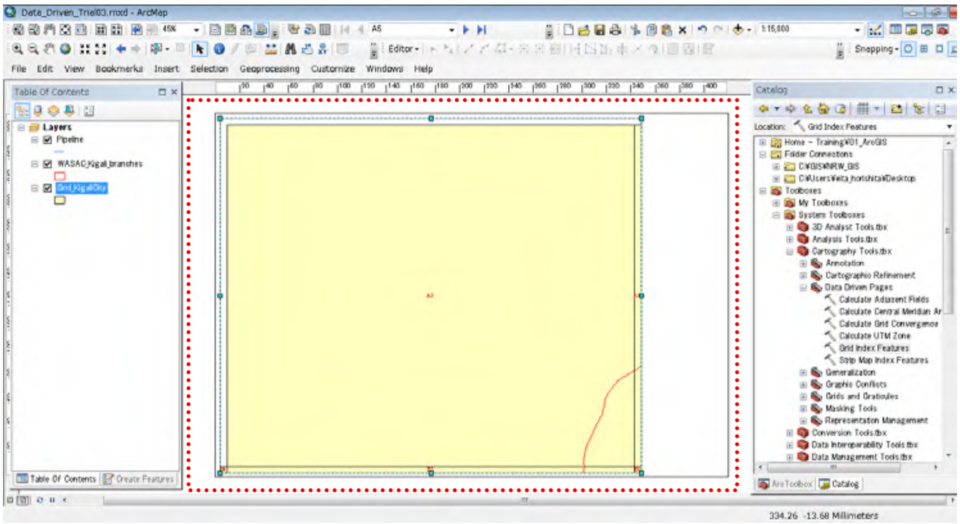
Definition | Extent

Map Extent
● Best Fit
Margin
Size: 102%
Specify Using: Percentage
Round Scale To Nearest: 1000
○ Center And Maintain Current Scale
○ Data Driven Scale
PageNumber

- Click OK, and then Data Driven Pages are generated.

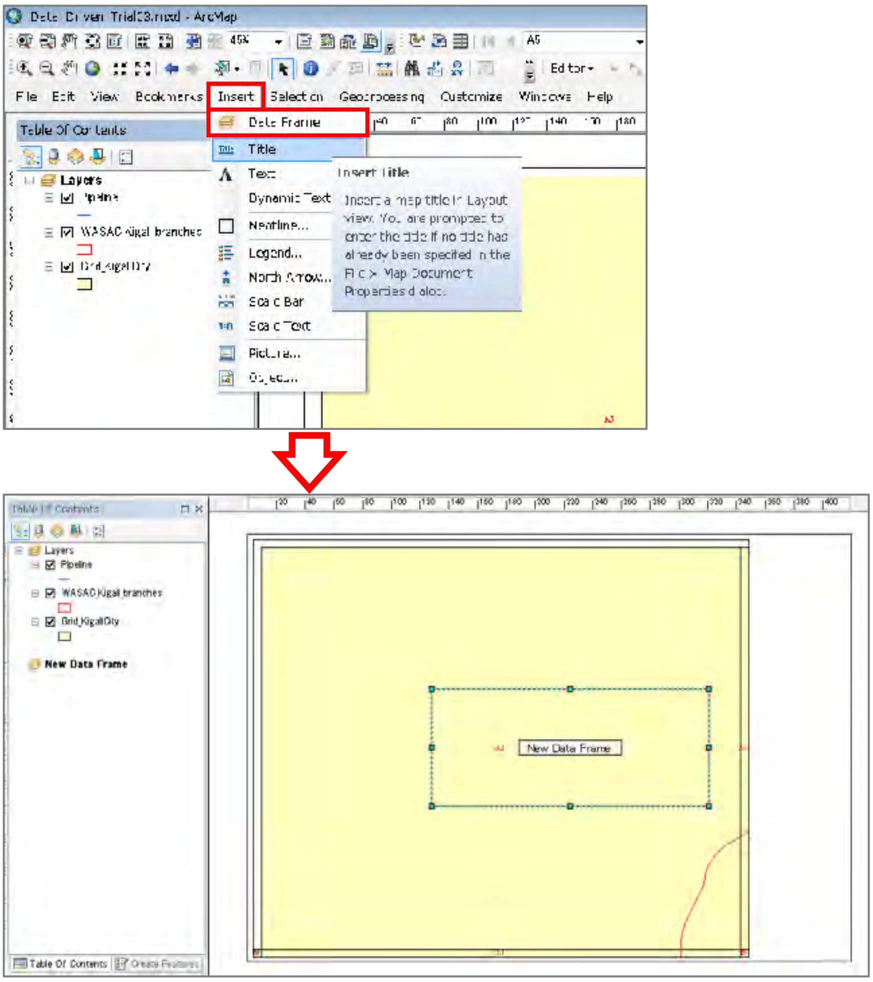


- ➢ Please adjust the Data Frame as below for this example.



5. Create Locator Map

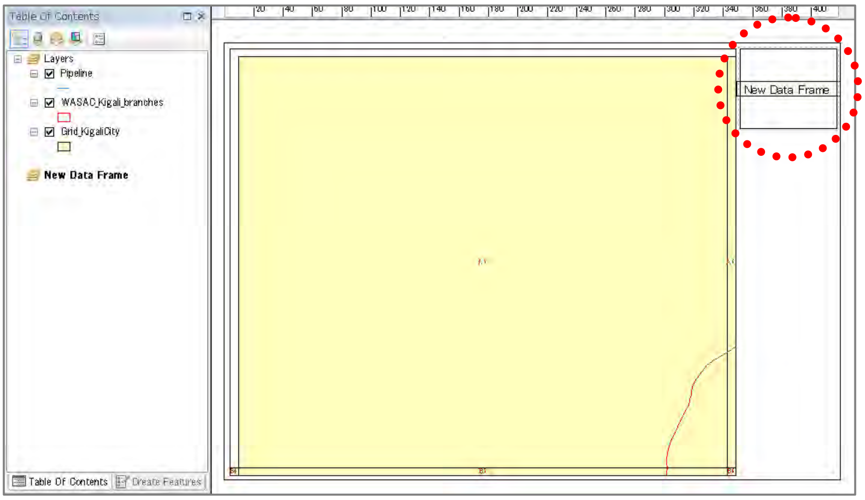
- ➢ Insert another Data Frame in Layout View. [Insert > Data Frame]



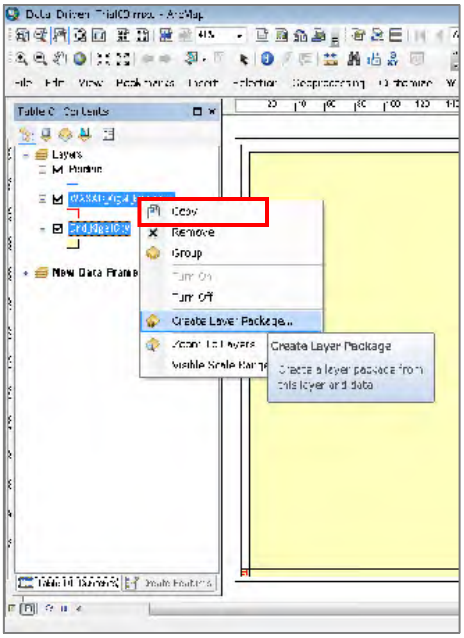
Insert Title

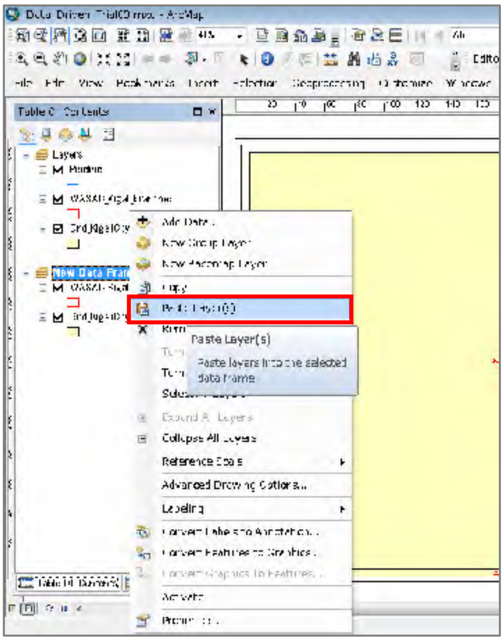
Insert a map title in Layout view. You are prompted to enter the title if no title has already been specified in the File > Map Document Properties dialog.

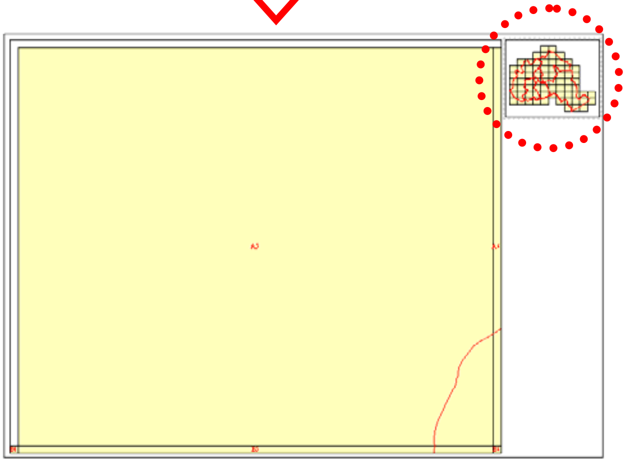
- Please adjust the New Data Frame on the corner shown as below.



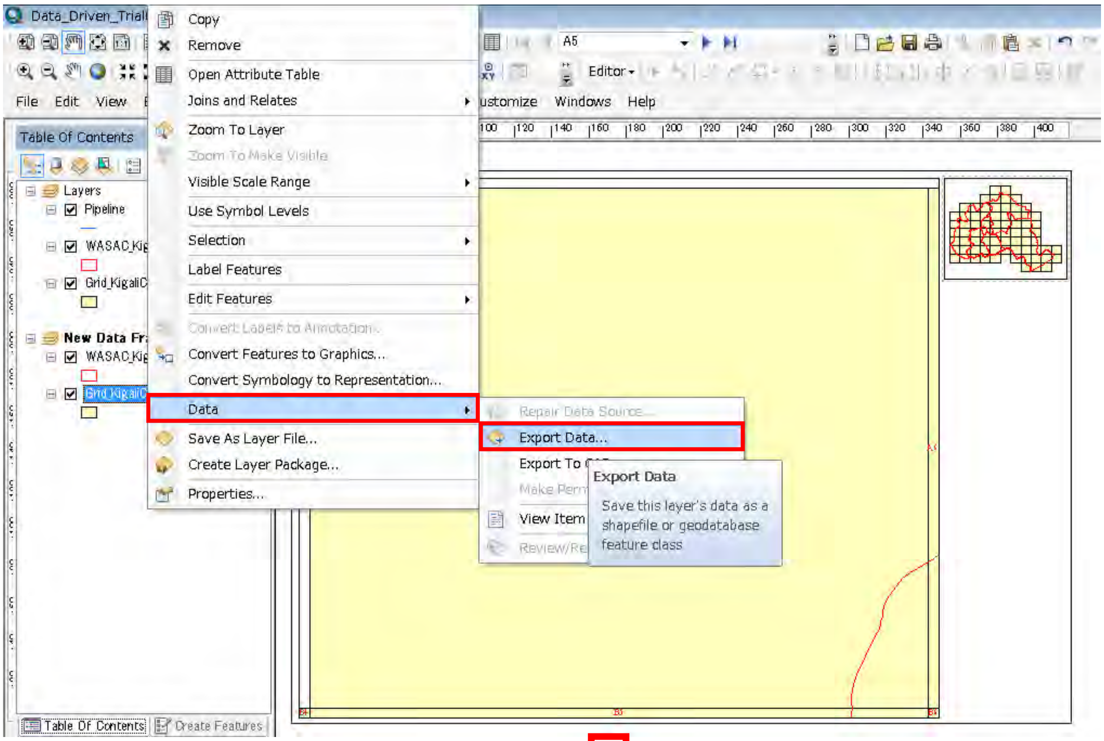
- Right Click on the layers and Copy [WASAC Kigali Branch Boundary] and the Index Grid, and [Paste Layer(s)] on the New Data Frame.





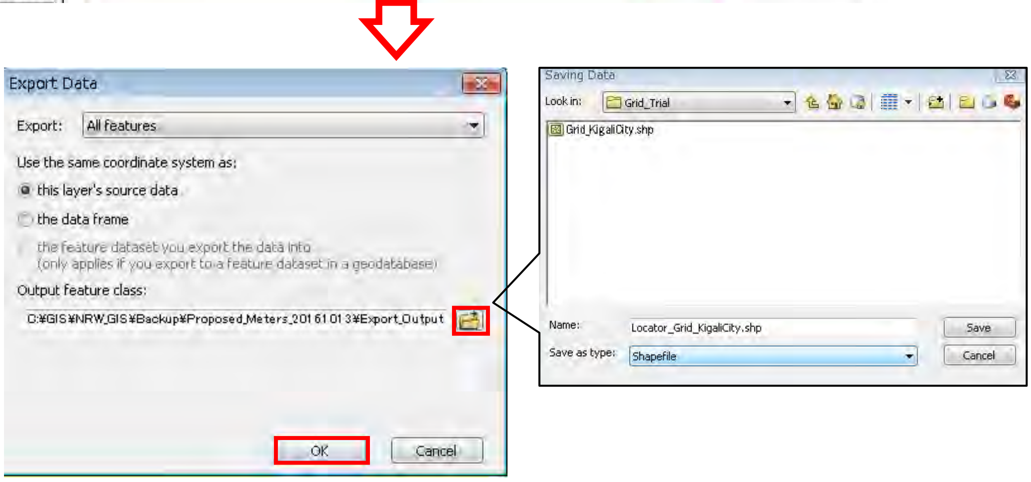


- Right Click on the Grid Index Layer in the New Data Frame, and Export Data.



Export Data

Save this layer's data as a shapefile or geodatabase feature class



Export: All features

Use the same coordinate system as:

● this layer's source data

○ the data frame

○ the feature dataset you export the data into (only applies if you export to a feature dataset in a geodatabase)

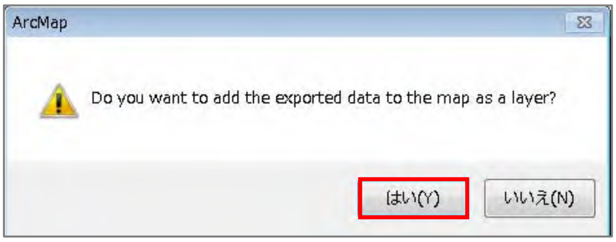
Output feature class:

C:¥GIS¥NRW_GIS¥Backup¥Proposed_Meters_20161013¥Export_Output

Name: Locator_Grid_KigaliCity.shp

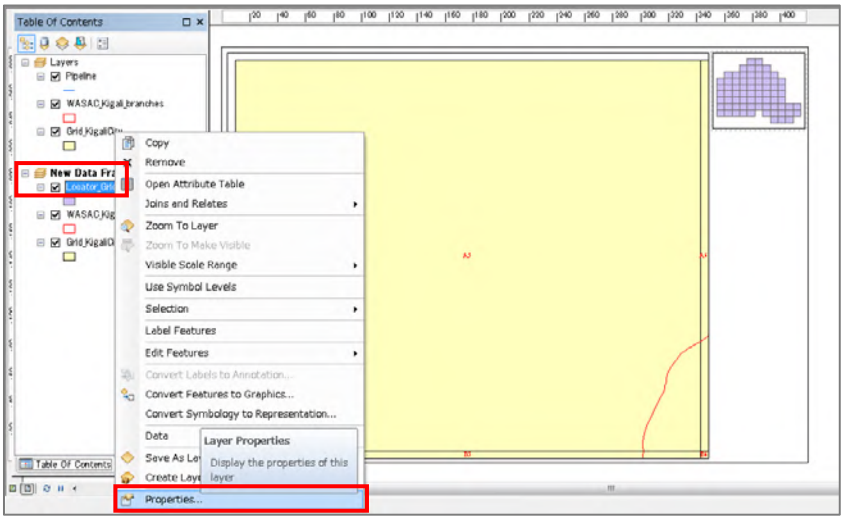
Save as type: Shapefile

- Click "Yes" to add the exported data to the map in the New Data Frame.



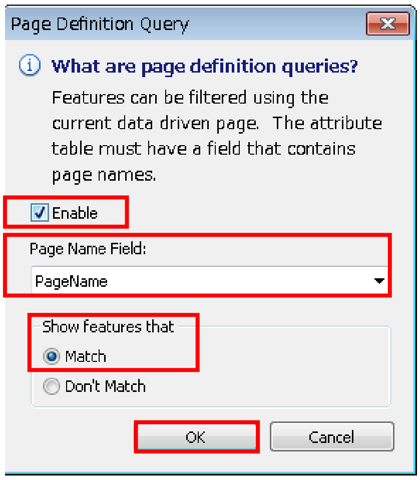
Do you want to add the exported data to the map as a layer?

- ➢ Right Click the exported Grid data, and click [Proporties]



- ➢ In the Layer Property Dialog, go to [Definition Query] tab, and click [Page Definition]

- ➢ In the Page Definition Query Dialog, check [Enable], and Page Name Field is [PageName], and Show features that [Match].


Page Definition Query

What are page definition queries?

Features can be filtered using the current data driven page. The attribute table must have a field that contains page names.

☑ Enable

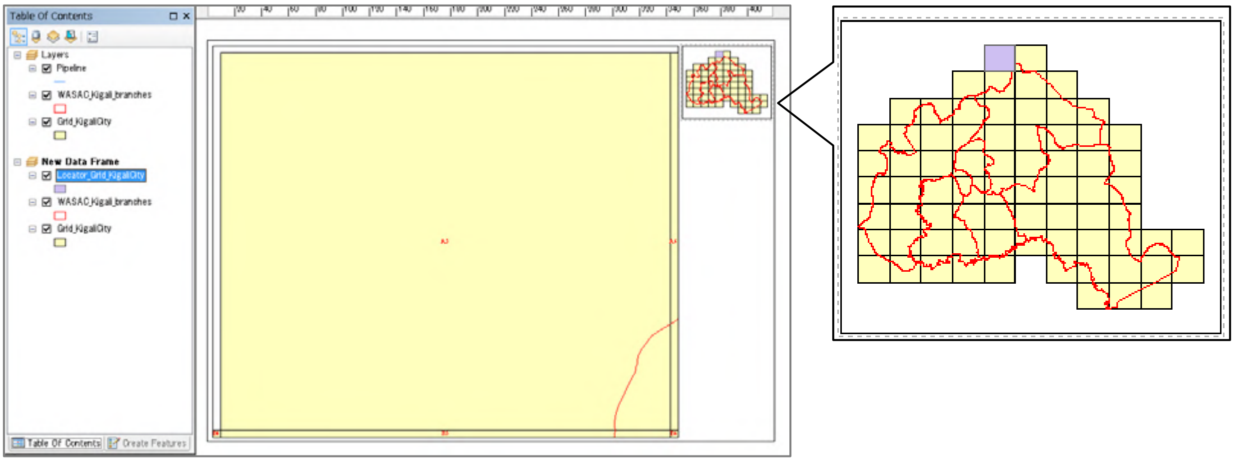
Page Name Field: PageName

Show features that

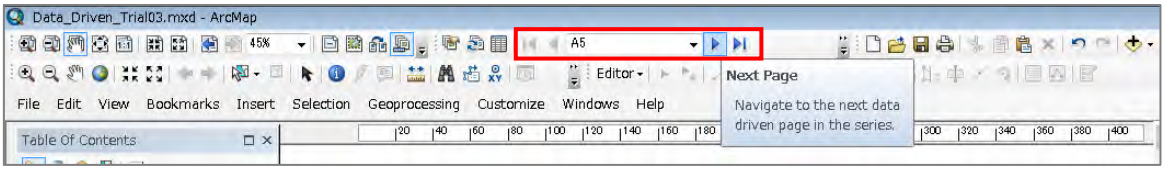
● Match

○ Don't Match

- ➢ When you have done that setup, the Grid Layer is shown up according to the current Page-Name.



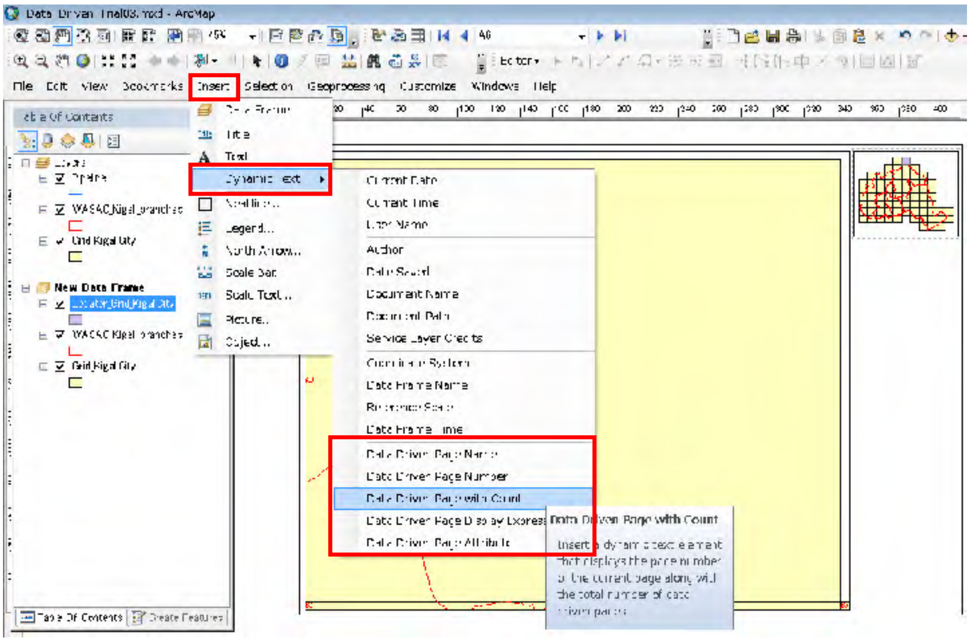
In the Data Driven Pages, you can go to the next page when you click [Next Page]. Please try and see the main map and locator map are automatically changed by the page name.



Navigate to the next data driven page in the series.

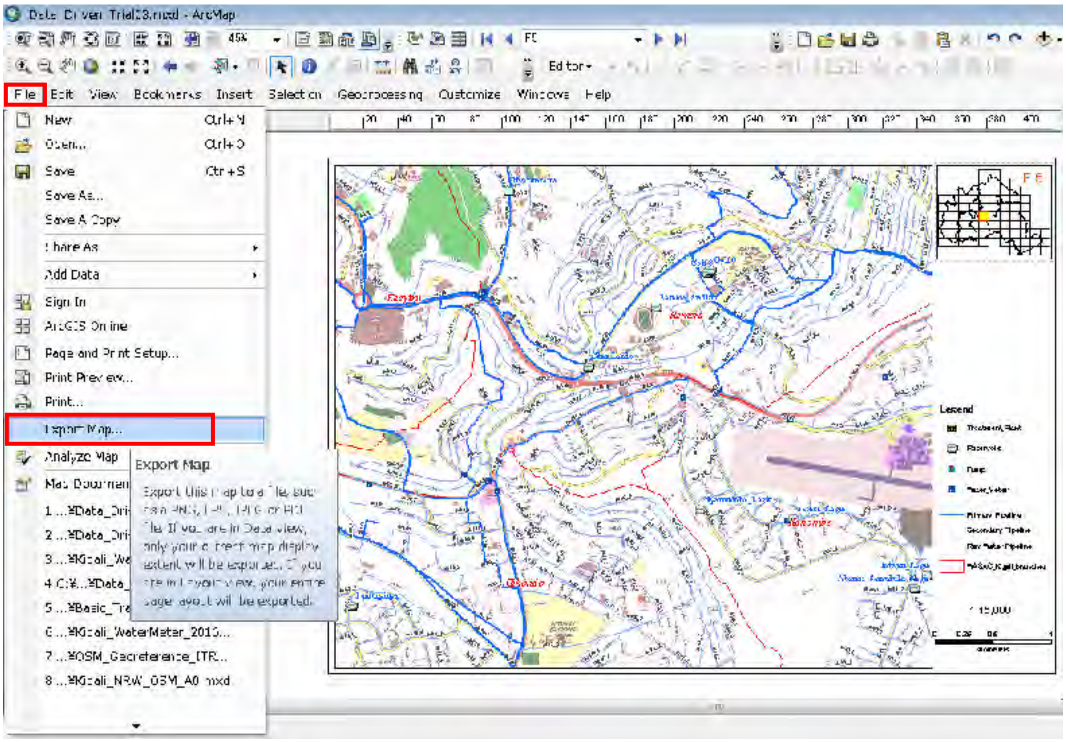
6. Design Layout and Export to PDF

- ➢ Text data that follows Data Driven Pages is inserted from [Insert > Dynamic Text > Data Driven Page Name/ Number/ Attribute etc.]



Insert a dynamic text element that displays the page number of the current page along with the total number of data driven pages.

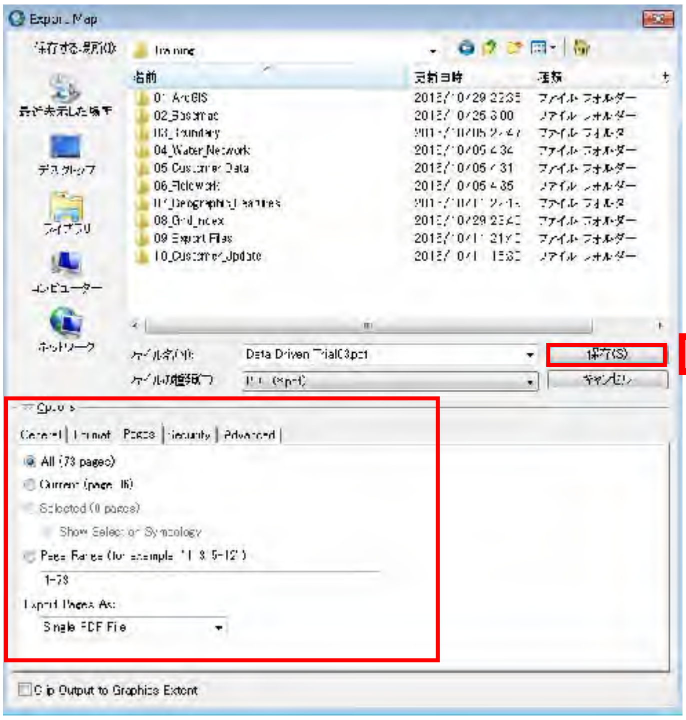
- When you completed your layout, create PDF data exporting the series of maps. [File > Export Map]



Export Map

Export this map to a file such as EMF, BMP, TIFF or PDF. If you are in Data view, only your current map display extent will be exported. If you are in Layout view, your entire page layout will be exported.

- In the [Export Map] Dialog, please select appropriate folder and file name to save the file. You can make optional settings such as exporting only current page, or exporting all/some pages in one PDF file.



名前	更新日時	種類
01_ArcGIS	2013/10/29 23:35	ファイル フォルダー
02_Basemap	2013/10/25 3:00	ファイル フォルダー
03_Boundary	2013/10/05 2:47	ファイル フォルダー
04_Water_Network	2013/10/05 4:34	ファイル フォルダー
05_Customer_Data	2013/10/05 4:31	ファイル フォルダー
06_Fieldwork	2013/10/05 4:35	ファイル フォルダー
07_Geographical_Features	2013/10/11 2:15	ファイル フォルダー
08_Grid_Index	2013/10/29 23:40	ファイル フォルダー
09_Export Files	2013/10/11 21:02	ファイル フォルダー
10_Customer_Update	2013/10/1 15:30	ファイル フォルダー

ファイル名(N): Data Driven Trial03.pdf

ファイルの種類(T): PDF (*.pdf)

● All (73 pages)

○ Current (page 16)

○ Selected (0 pages)

☐ Show Selection Symbology

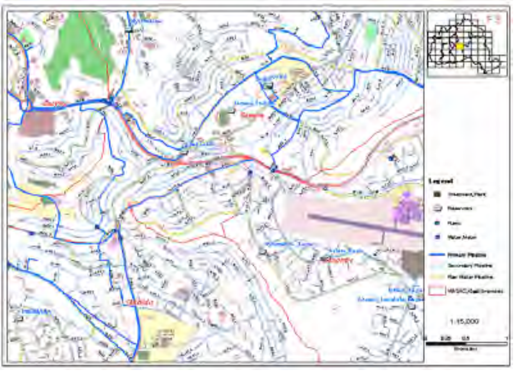
○ Page Range (for example: 1,3,5-12)

1-73

Export Pages As:

Single PDF File

☐ Clip Output to Graphics Extent



WASAC GIS Operation Manual
Data Update and Management for Water Network and Customer Information

1st Edition on 9th November 2016

JICA Project for Strengthening Non-Revenue Water Control in Kigali City Water Network [GIS]

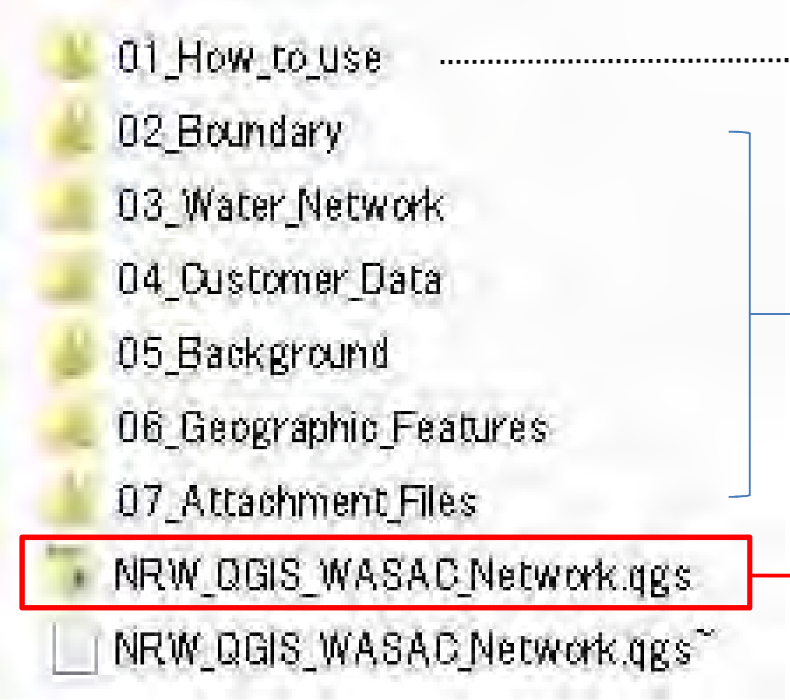
Folder Structure and how to open QGIS

Note:

**First of all, you have to install QGIS software on your computer.
If you have not installed it yet, please ask to GIS Engineer.**

**QGIS is free-software, and available for anyone.
It does not require the internet connection; however approximately 2 GB of available storage on your computer is required for Water Network data-sets and base-maps, and 20 GB of additional storage is required to use Satellite Images.**

Folder Structure:



01_How_to_use
02_Boundary
03_Water_Network
04_Customer_Data
05_Background
06_Geographic_Features
07_Attachment_Files
NRW_QGIS_WASAC_Network.qgs
NRW_QGIS_WASAC_Network.qgs~

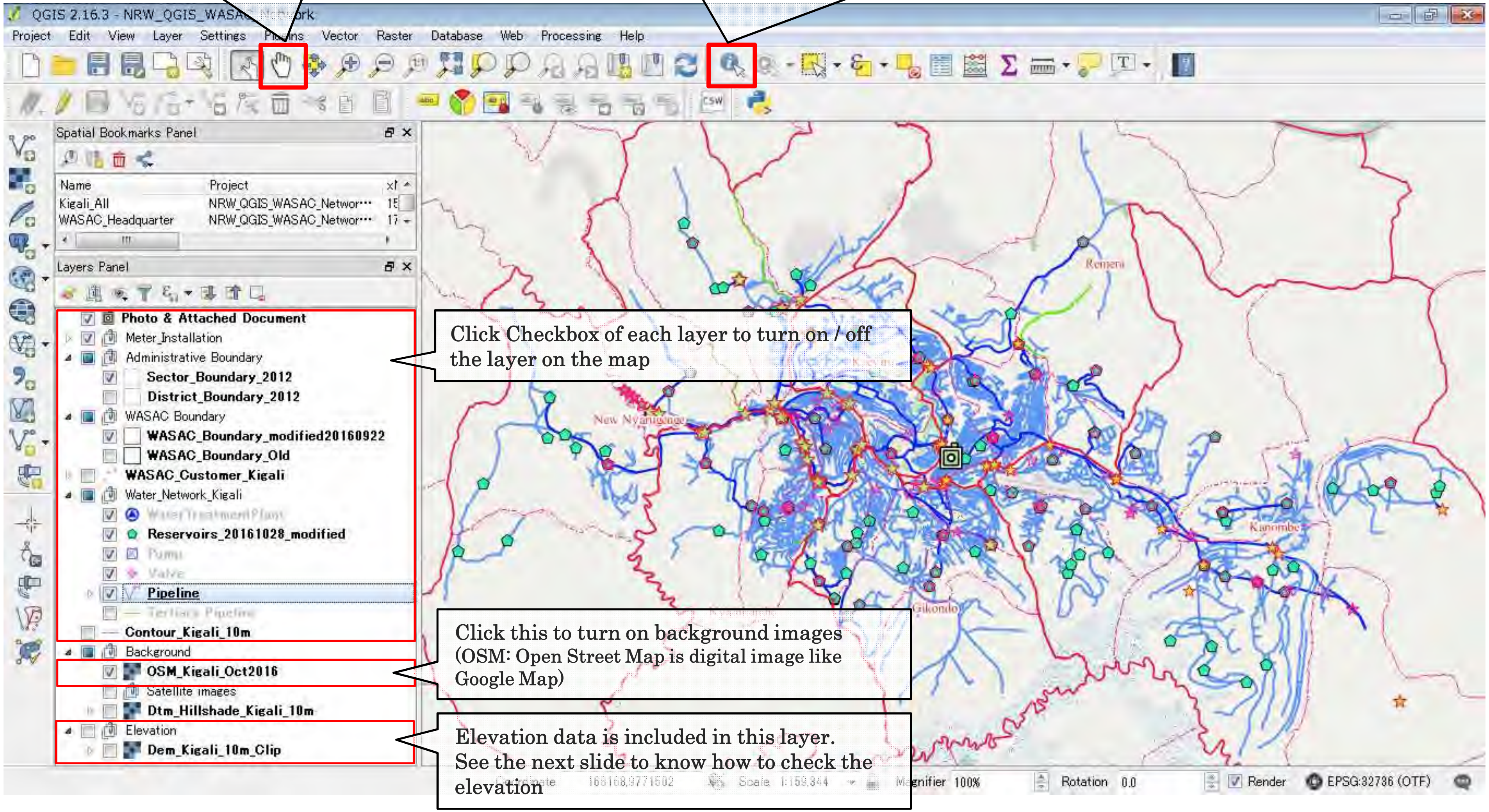
Installer & documents

Caution for View-Only Users:

Please do not change these folders and files.
These files are data-sets to be read by QGIS

Click here to start QGIS

How to view: basic map operation



To scroll map, click here and then you can scroll this map as you like

To check information of features, click here, select layer that you want to see, and click the feature. See next page for detailed explanation.

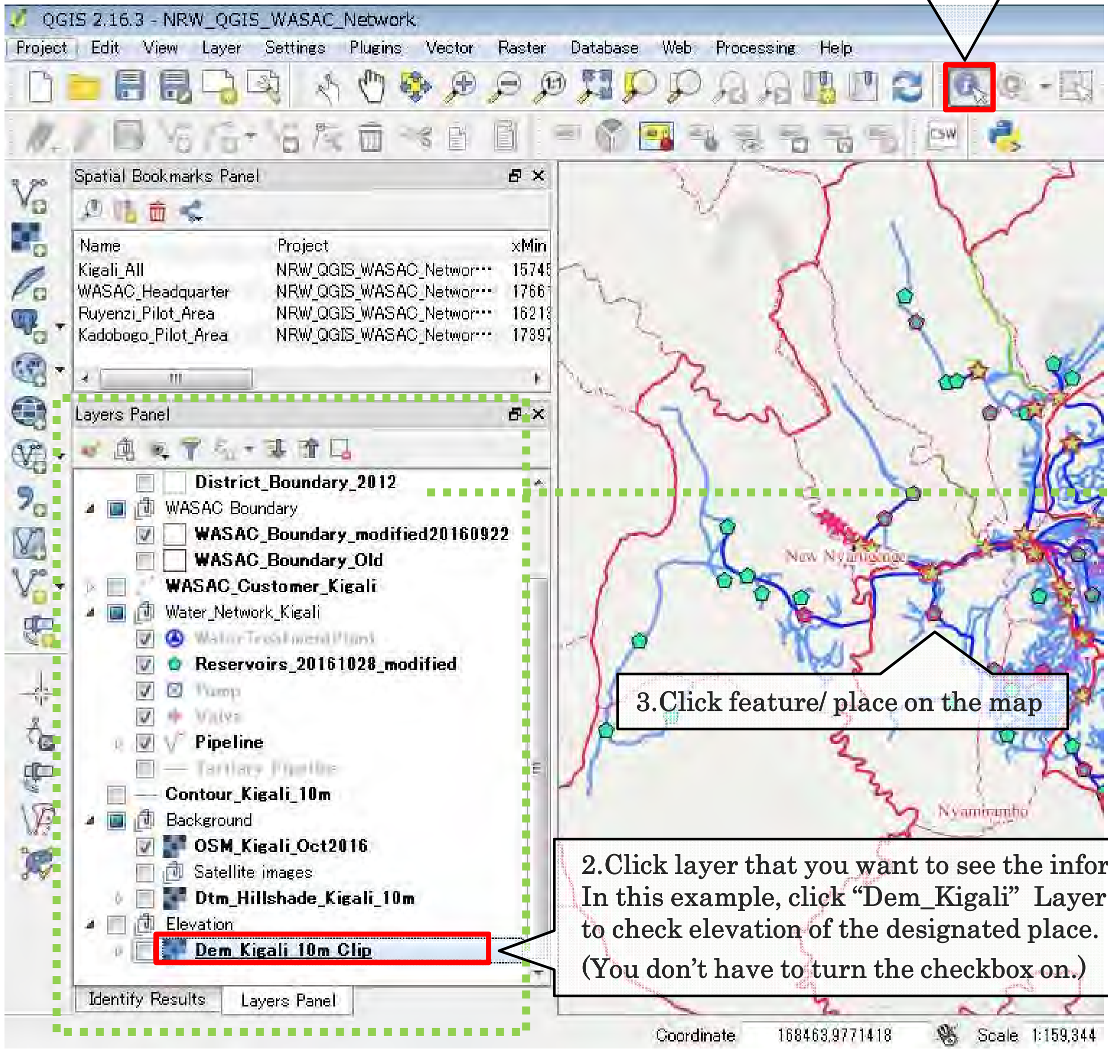
Click Checkbox of each layer to turn on / off the layer on the map

Click this to turn on background images (OSM: Open Street Map is digital image like Google Map)

Elevation data is included in this layer. See the next slide to know how to check the elevation

How to check information of data in GIS (Example)

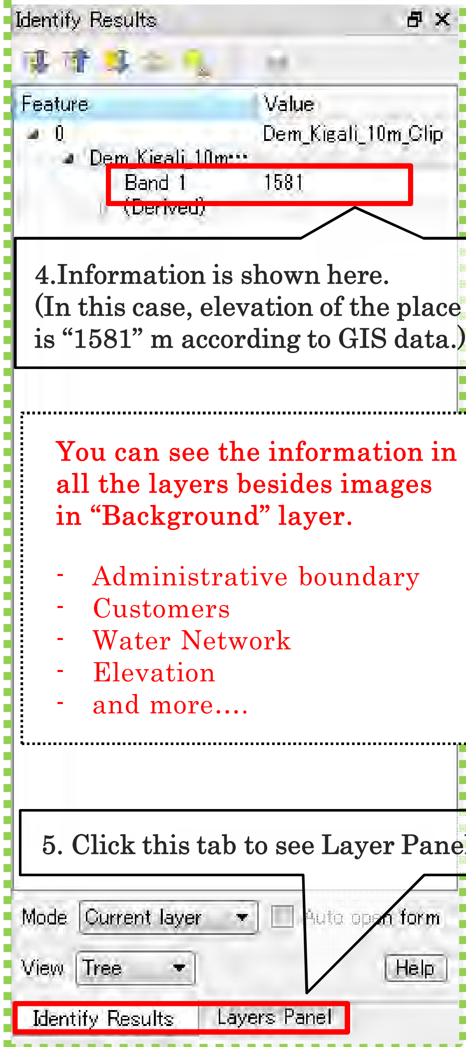
1.Click this icon.



Name	Project	xMin
Kigali_All	NRW_QGIS_WASAC_Networ···	1574
WASAC_Headquarter	NRW_QGIS_WASAC_Networ···	1766
Ruyenzi_Pilot_Area	NRW_QGIS_WASAC_Networ···	1621
Kadobogo_Pilot_Area	NRW_QGIS_WASAC_Networ···	1739

3.Click feature/ place on the map

2.Click layer that you want to see the information.
In this example, click "Dem_Kigali" Layer
to check elevation of the designated place.
(You don't have to turn the checkbox on.)



Feature	Value
0	Dem_Kigali_10m_Clip
Dem_Kigali_10m···	
Band 1	1581
(Derived)	

Mode: Current layer
☐ Auto open form
View: Tree

4.Information is shown here.
(In this case, elevation of the place is "1581" m according to GIS data.)

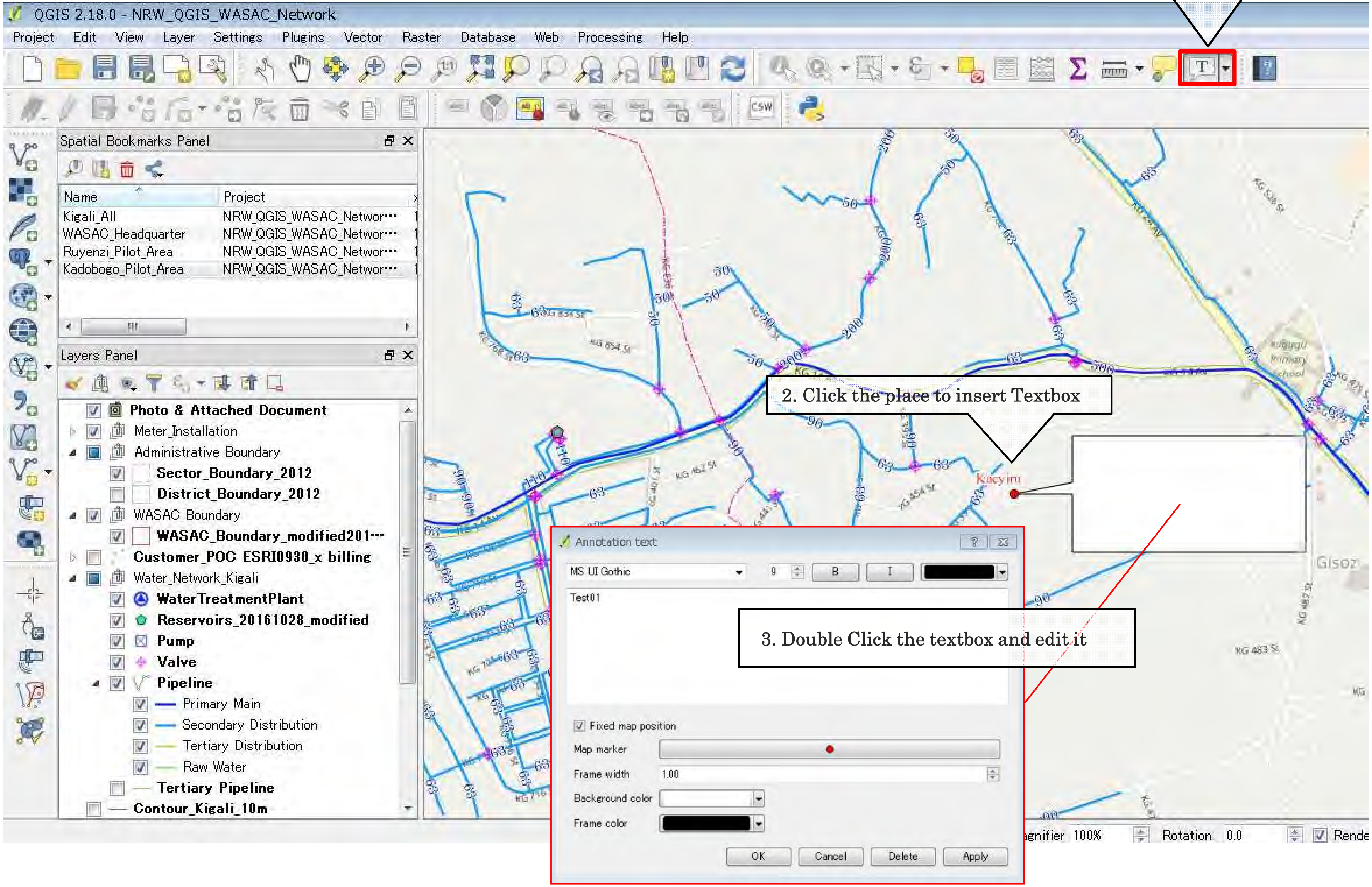
You can see the information in all the layers besides images in "Background" layer.

- Administrative boundary
- Customers
- Water Network
- Elevation
- and more....

5. Click this tab to see Layer Panel.

How to put comment on the map

1. Click “Text Annotation” icon



QGIS 2.18.0 - NRW_QGIS_WASAC_Network

Spatial Bookmarks Panel

Name	Project
Kigali_All	NRW_QGIS_WASAC_Networ···
WASAC_Headquarter	NRW_QGIS_WASAC_Networ···
Ruyenzi_Pilot_Area	NRW_QGIS_WASAC_Networ···
Kadobogo_Pilot_Area	NRW_QGIS_WASAC_Networ···

Layers Panel

- ☑ **Photo & Attached Document**
- ☑ Meter_Installation
- ☑ Administrative Boundary
  - ☑ **Sector_Boundary_2012**
  - ☐ **District_Boundary_2012**
- ☑ WASAC Boundary
  - ☑ **WASAC_Boundary_modified201···**
- ☐ **Customer_POC ESRI0930_x billing**
- ☑ Water_Network_Kigali
  - ☑ **WaterTreatmentPlant**
  - ☑ **Reservoirs_20161028_modified**
  - ☑ **Pump**
  - ☑ **Valve**
  - ☑ **Pipeline**
    - ☑ Primary Main
    - ☑ Secondary Distribution
    - ☑ Tertiary Distribution
    - ☑ Raw Water
  - ☐ **Tertiary Pipeline**
- ☐ **Contour_Kigali_10m**

2. Click the place to insert Textbox

Annotation text

MS UI Gothic · 9

Test01

☑ Fixed map position

Map marker

Frame width: 1.00

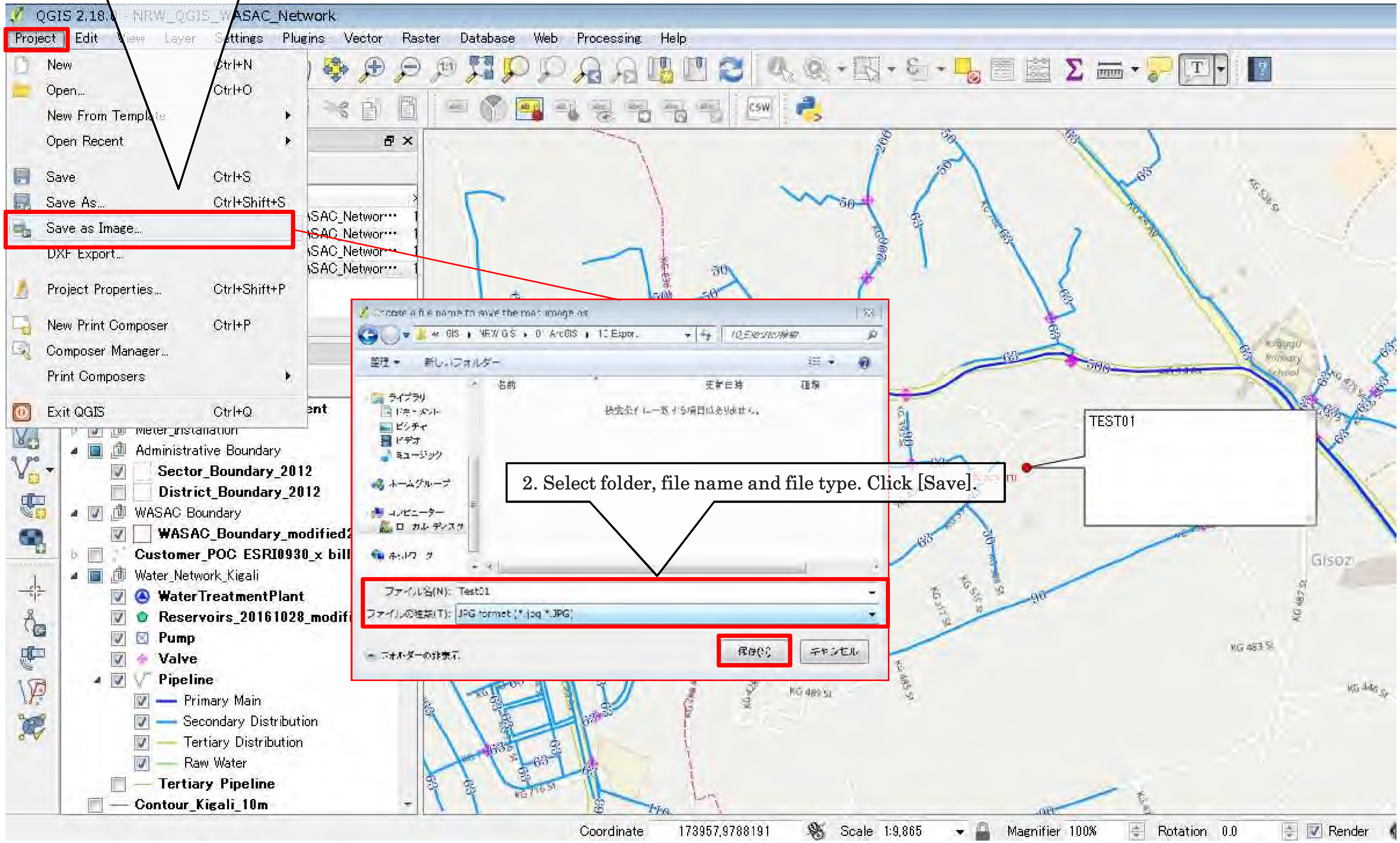
Background color

Frame color

3. Double Click the textbox and edit it

How to save a map as Image (JPEG)

1. Click [Project] in the menu bar, and click [Save as Image]



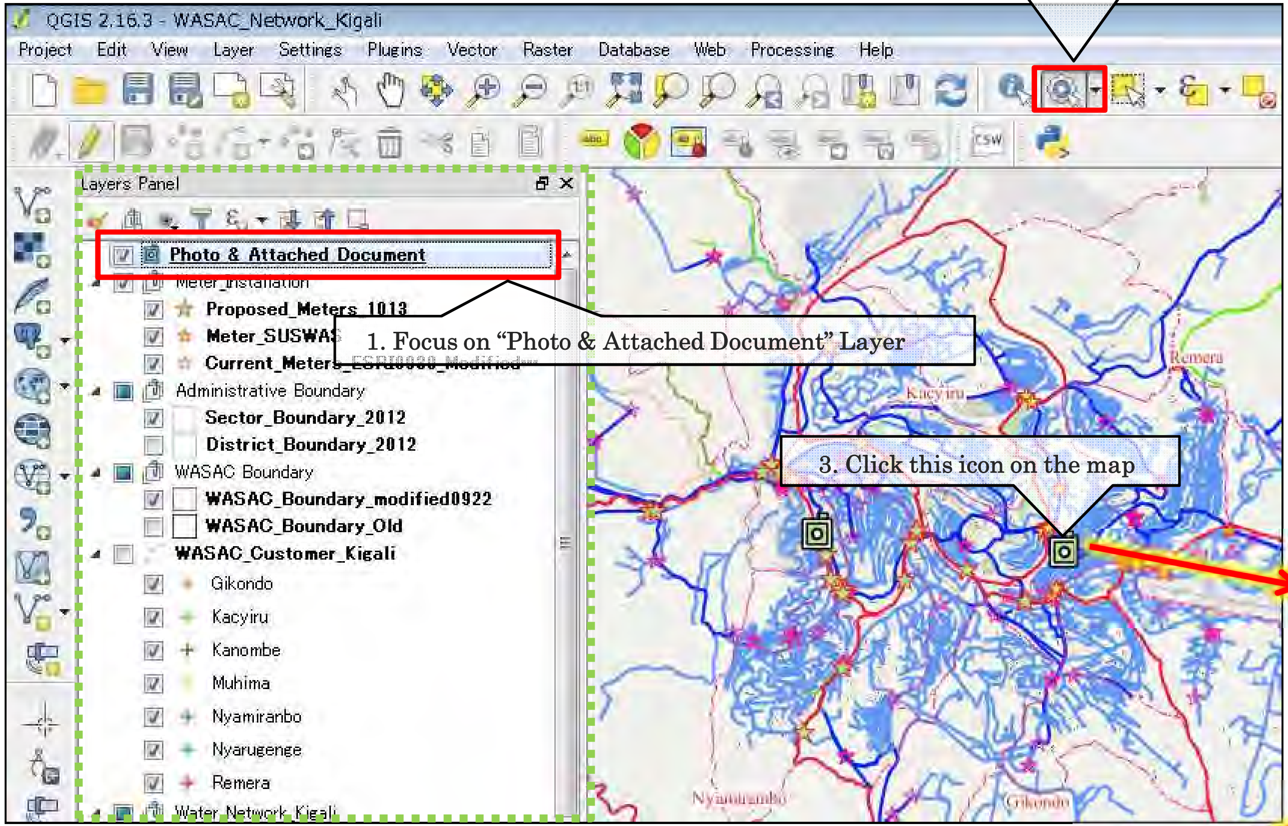
ファイル名(N): Test01

ファイルの種類(T): JPG format (*.jpg *.JPG)

2. Select folder, file name and file type. Click [Save].

How to open attachment files

From Action Button



2. Click "Run Feature Action" icon

1. Focus on "Photo & Attached Document" Layer

3. Click this icon on the map

4. Attached file is opened

From Attribute Table

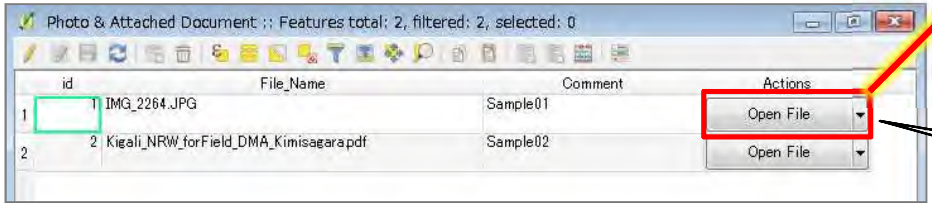


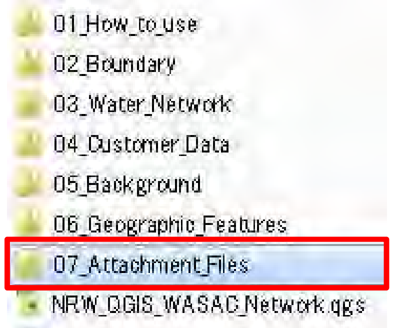
Photo & Attached Document :: Features total: 2, filtered: 2, selected: 0

	id	File_Name	Comment	Actions
1	1	IMG_2264.JPG	Sample01	Open File
2	2	Kigali_NRW_forField_DMA_Kimisagara.pdf	Sample02	Open File

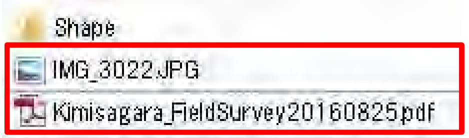
1. Click this button

How to insert Photo & Attached Document on the map

1. Folder

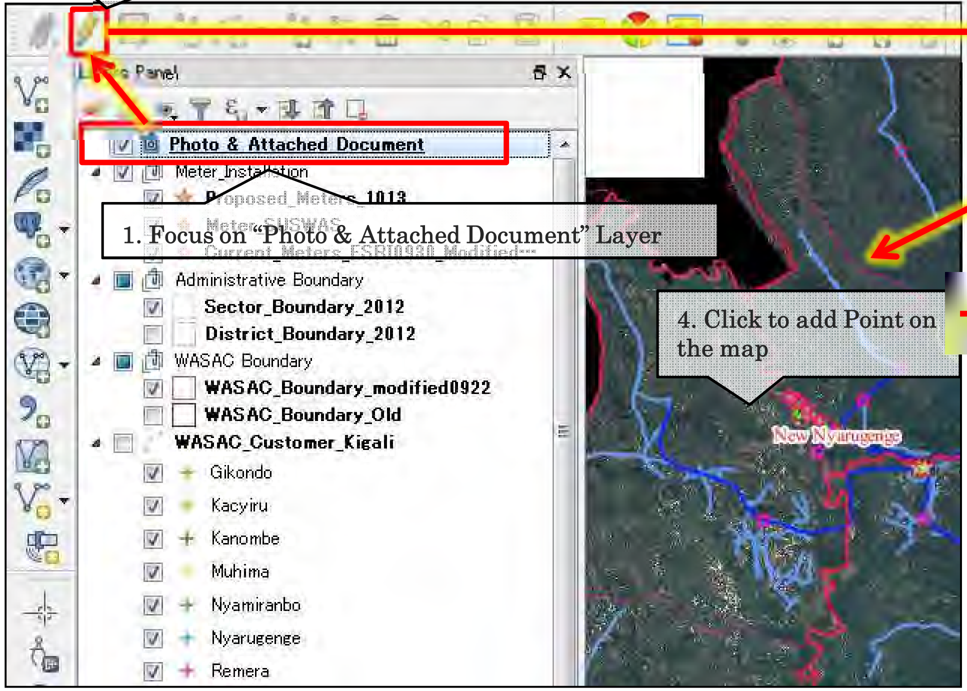

01_How_to_use
02_Boundary
03_Water_Network
04_Customer_Data
05_Background
06_Geographic_Features
07_Attachment_Files
NRW_QGIS_WASAC_Network.qgs

Put your photos and documents in this folder.
[¥07_Attachment_Files]


Shape
IMG_3022.JPG
Kimisagara_FieldSurvey20160825.pdf

2. QGIS

2. Click “Toggle Editing” icon



1. Focus on “Photo & Attached Document” Layer

3. Click “Add Feature” icon.

4. Click to add Point on the map

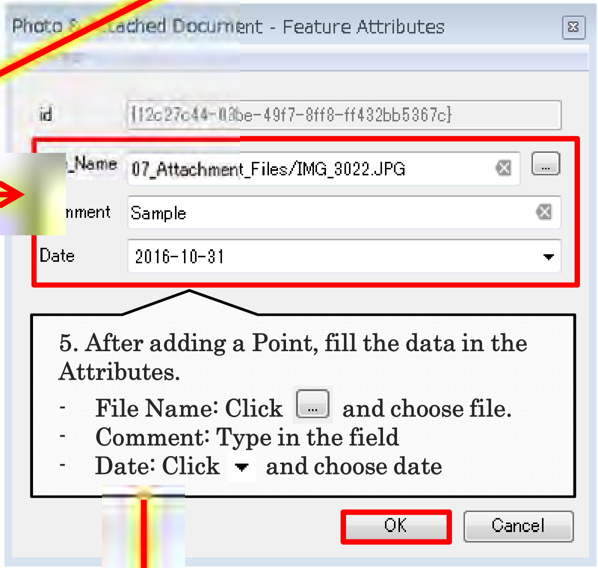


Photo & Attached Document - Feature Attributes

id: {12c27c44-03be-49f7-8ff8-ff432bb5367c}

_Name: 07_Attachment_Files/IMG_3022.JPG

nment: Sample

Date: 2016-10-31

5. After adding a Point, fill the data in the Attributes.

- File Name: Click ... and choose file.
- Comment: Type in the field
- Date: Click ▾ and choose date

7. Click “Toggle Editing” icon again to stop editing mode.

6. Click “Save Layer Edits” icon to save the data

Utilization of Geographic Information System

1. Data Sharing

- ■ ArcGIS Server
- ■ QGIS
- ■ Google Earth
- ■ Comparison

2. Analysis

- ◆ Asset Management
- ◆ Future Planning
- ◆ Water Outage Simulation
- ◆ Water Leakage Detection

3. Customer Service

- ☐ Map Viewer in Service Counter
- ☐ Customer's Inquiry Management

The most important factors for advancing utilization of GIS are ***Data Sharing*** and ***Continuous Update of Data***.

Sharing by PDF is basic, but may not contain all the data.

It has been widely recognized that GIS takes essential roles in ***Planning for Water Network*** and ***Asset Management***.

There are some examples of utilization of GIS in order to make ***Improvement of Customer Services***.

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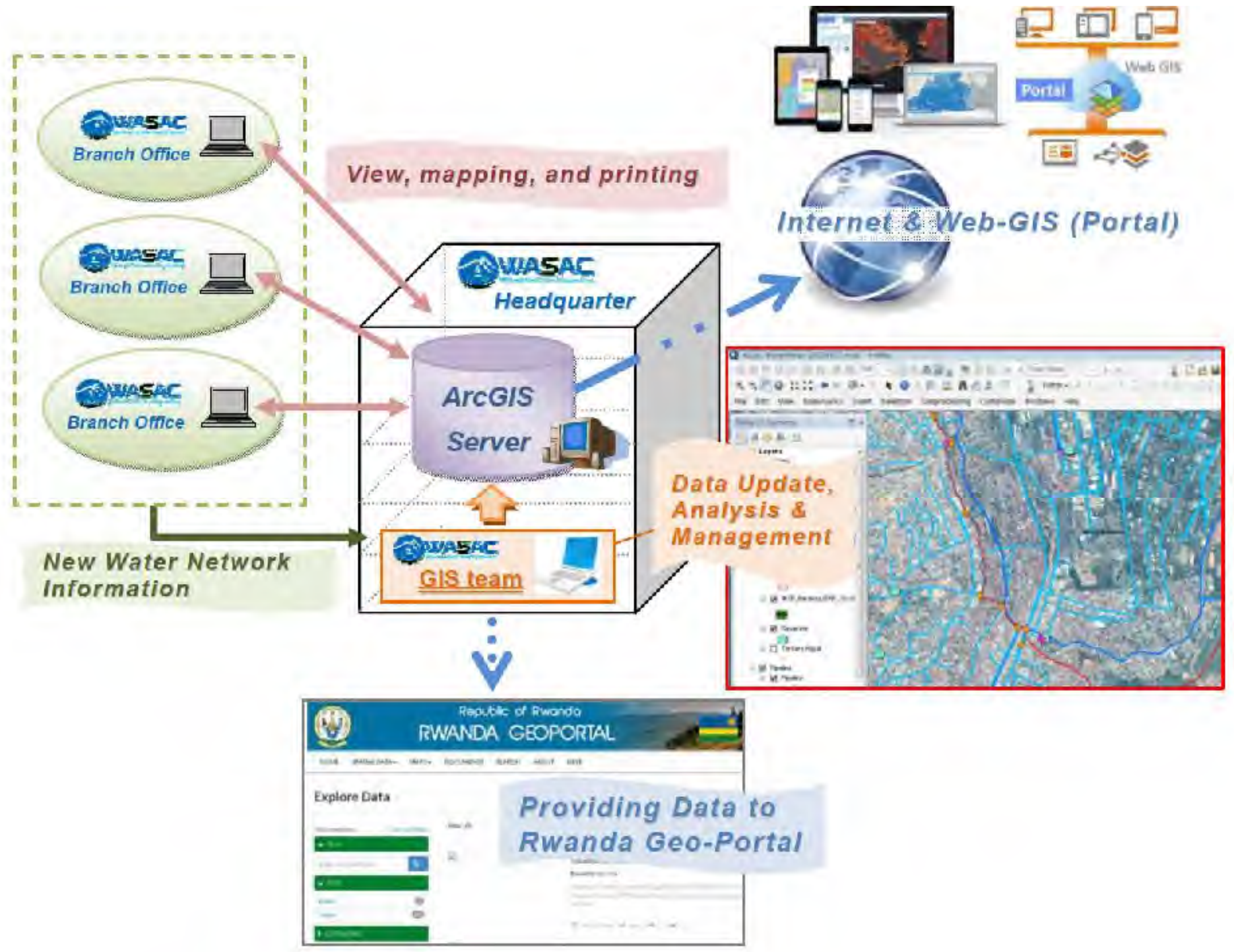
- ArcGIS is the most popular & powerful GIS software in the world

- ***ArcGIS Server*** enables everyone in the organization to access the GIS data.



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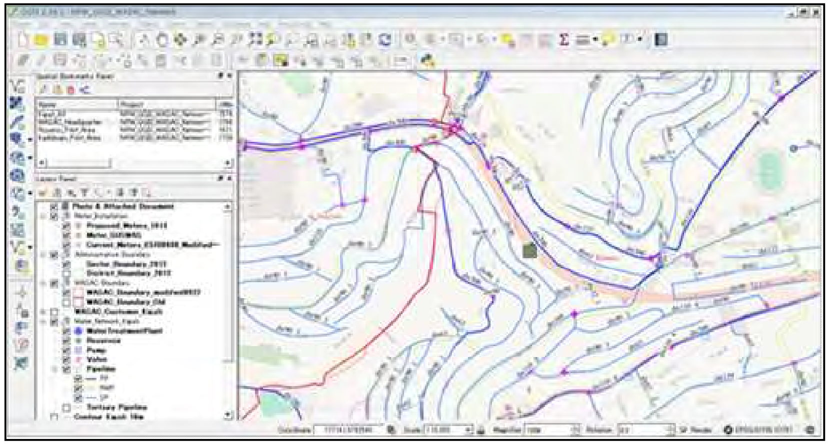
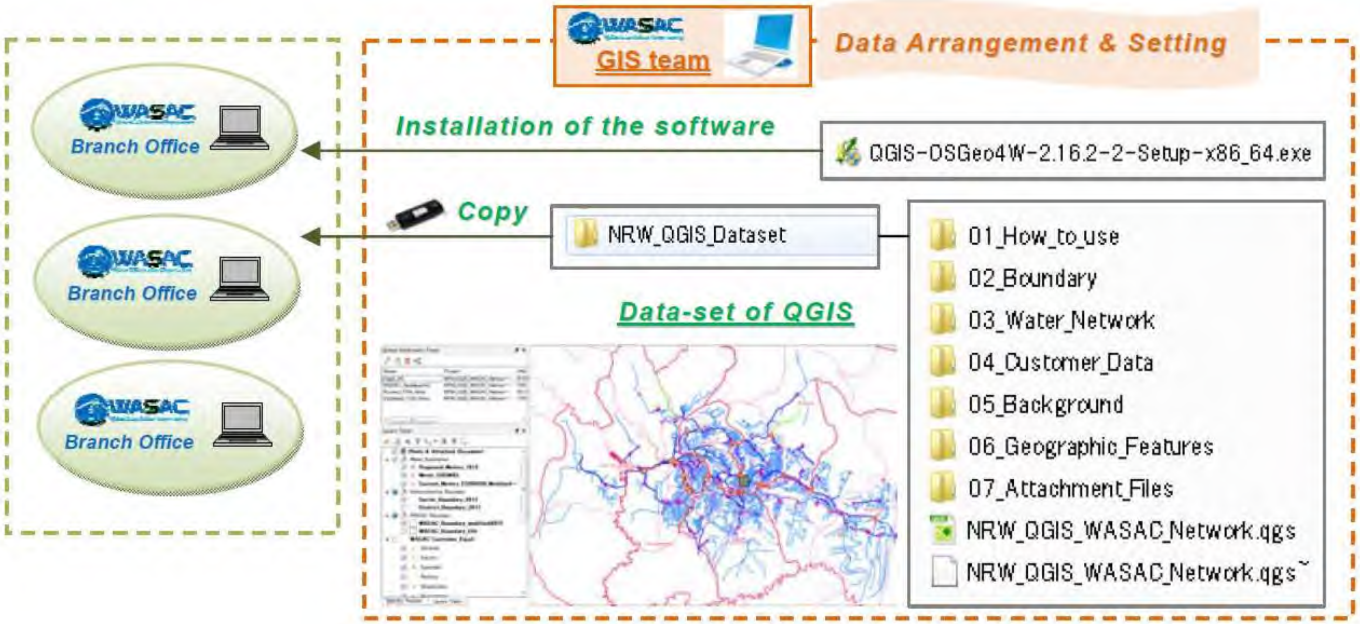
- ***QGIS*** is one of the most popular Free-GIS Software in the world.





WASAC GIS team

Data Arrangement & Setting

Installation of the software

QGIS-OSGeo4W-2.16.2-2-Setup-x86_64.exe

Copy

NRW_QGIS_Dataset

- 01_How_to_use
- 02_Boundary
- 03_Water_Network
- 04_Customer_Data
- 05_Background
- 06_Geographic_Features
- 07_Attachment_Files
- NRW_QGIS_WASAC_Network.qgs
- NRW_QGIS_WASAC_Network.qgs~

Data-set of QGIS

Branch Office

Branch Office

Branch Office

Utilization of Geographic Information System

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- ■ Comparison

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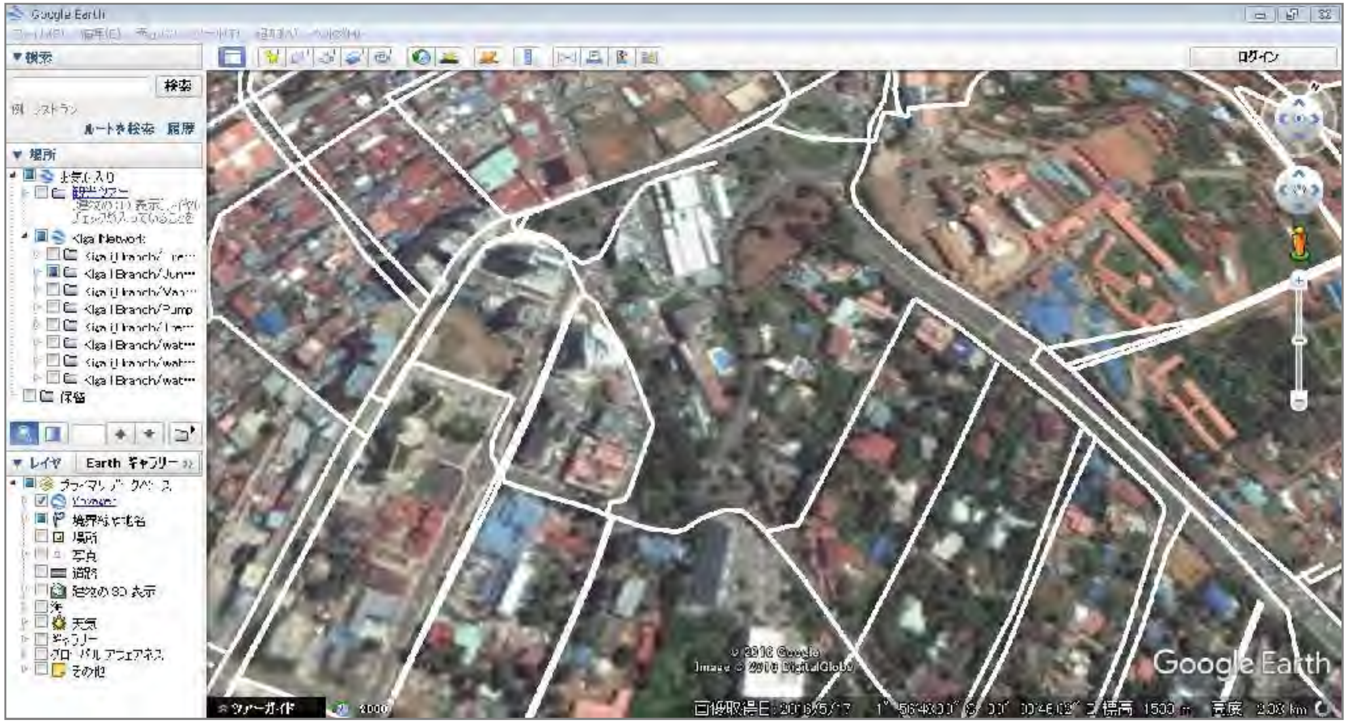
- ***Google Earth*** is very famous map viewer presented by Google.
- Using specific data-type called "**KML**", GIS data is available on it.



Utilization of Geographic Information System

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	ArcGIS Server	QGIS	Google Earth
Software Category	GIS Server	GIS Editor/Viewer	Map Viewer
Editing tools	Powerful	Possible	Limited
Spatial Analysis	Powerful	Possible	Limited
Cost	Expensive	Free	Free
Feature data type	Shape/GeoDatabase	Shape	KML
Data Sharing Method	Network connection to the server	Copy data-sets (by hand / File Storage)	Copy data-sets (by hand / Google Drive)
Internet Connection	Required (for Server connection)	Not required (as far as sharing by hand)	Sometimes required (to read base-map)
Interface	Skill required	Partly skill required	User Friendly
Setting difficulty	Skill required	Skill required	User Friendly

Conclusion:

- ArcGIS Server => In the future (require network connection)
- QGIS => Alternative (temporary) method until ArcGIS Server
- Google Earth => Optional (require data conversion and the internet)

- PDF => You can always ask GIS team to create PDF map as you wish!

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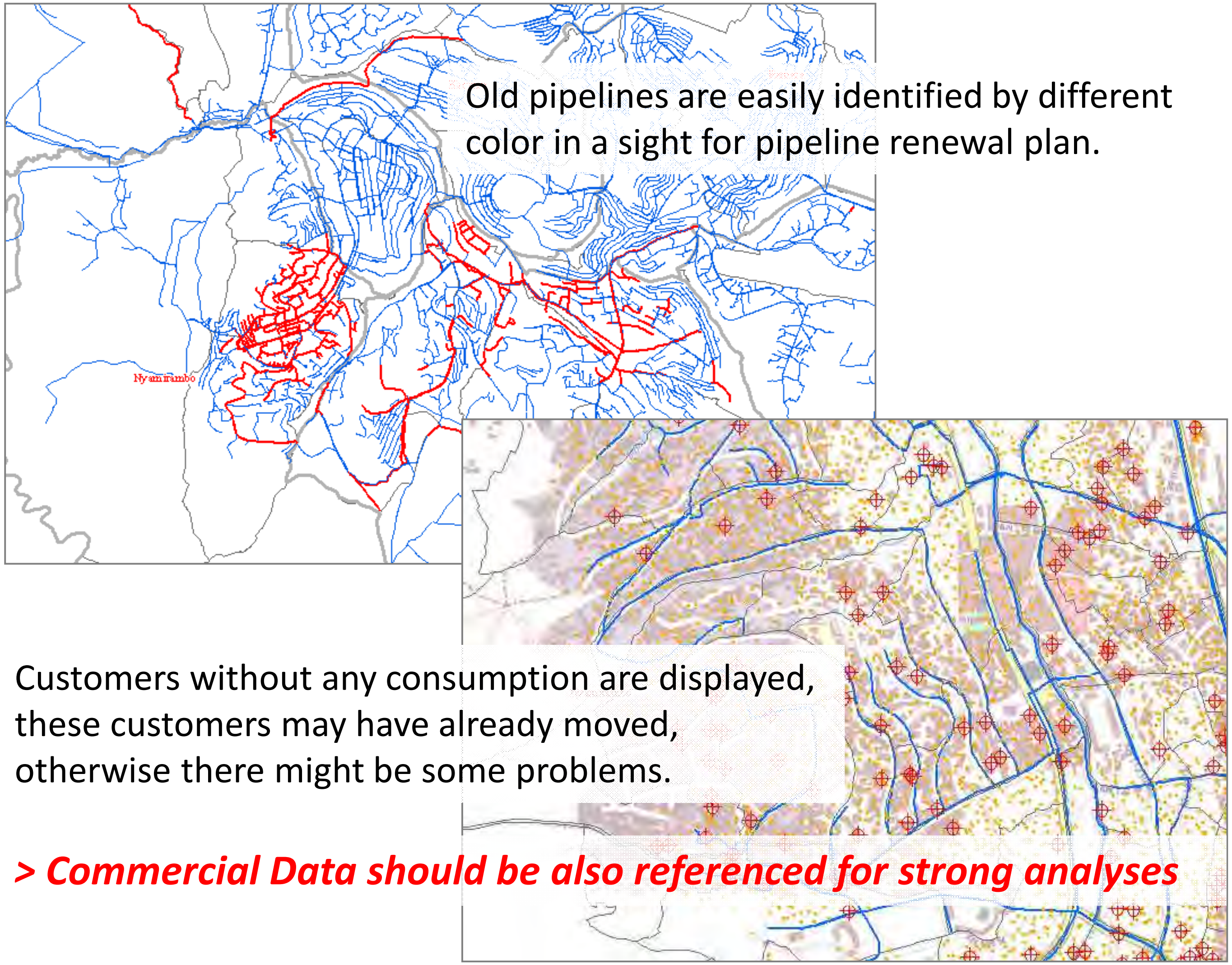
It has been widely recognized that GIS takes essential roles in Planning for Water Network and Asset Management



Old pipelines are easily identified by different color in a sight for pipeline renewal plan.

Customers without any consumption are displayed, these customers may have already moved, otherwise there might be some problems.

> Commercial Data should be also referenced for strong analyses

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Plans and Diagrams from the other department may provide further rationales for your plan when it is overlaid with Water Network data.

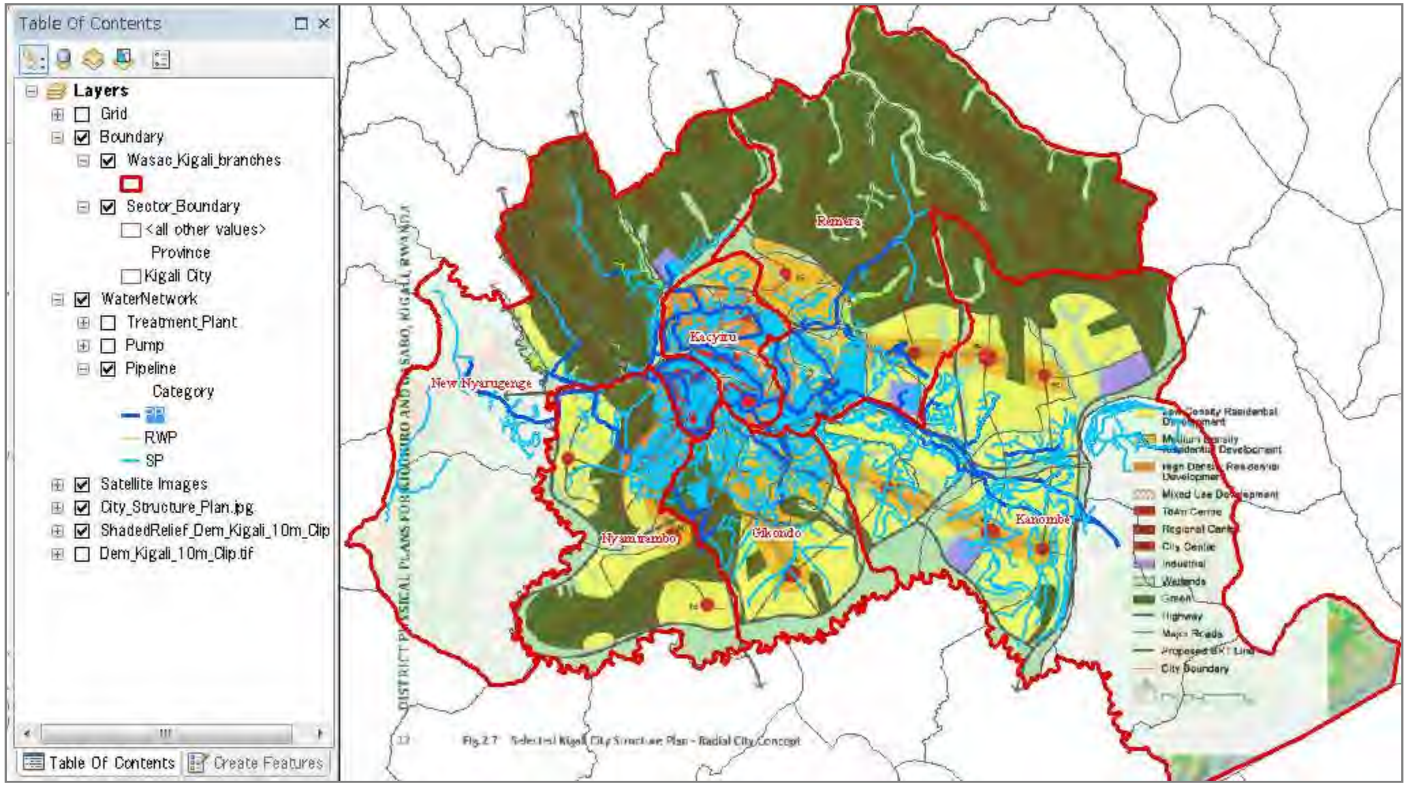

Table Of Contents

- Layers
  - ☐ Grid
  - ☑ Boundary
    - ☑ Wasac_Kigali_branches
    - ☑ Sector_Boundary
      - ☐ <all other values>
      - Province
      - ☐ Kigali City
  - ☑ WaterNetwork
    - ☐ Treatment_Plant
    - ☐ Pump
    - ☑ Pipeline
      - Category
      - PP
      - RWP
      - SP
  - ☑ Satellite Images
  - ☑ City_Structure_Plan.jpg
  - ☑ ShadedRelief_Dem_Kigali_10m_Clip
  - ☐ Dem_Kigali_10m_Clip.tif

Kigali City Structure Plan (Kigali City Master Plan Report 2013)
with the Current Water Network data

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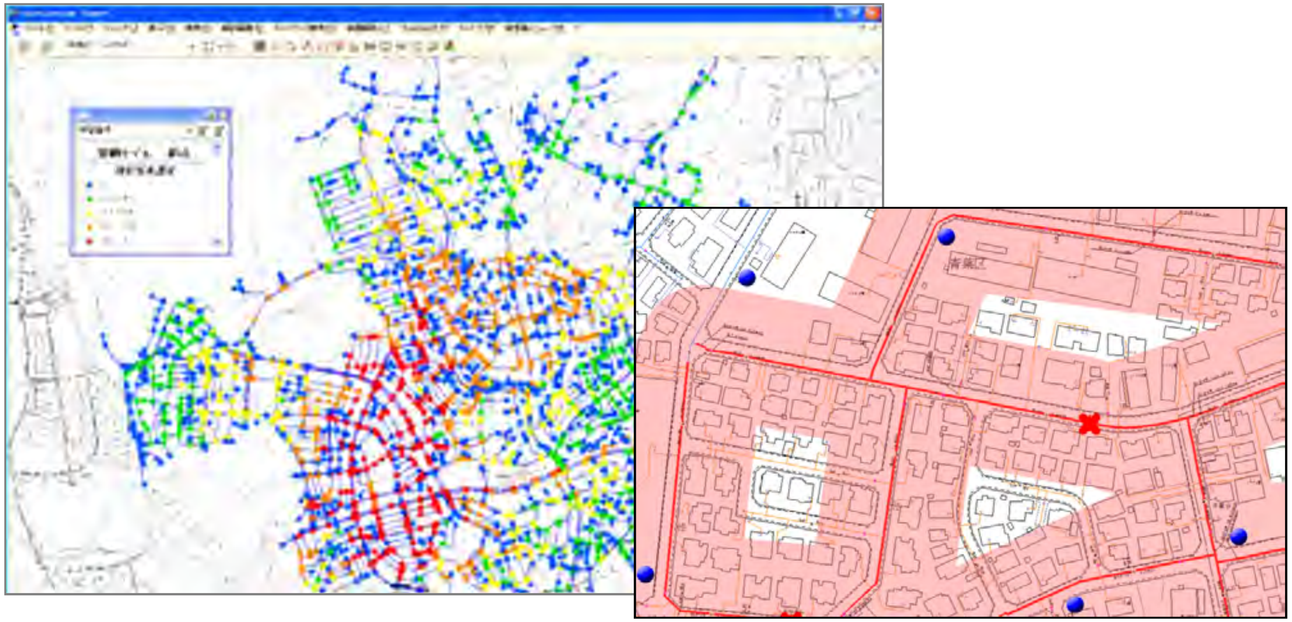
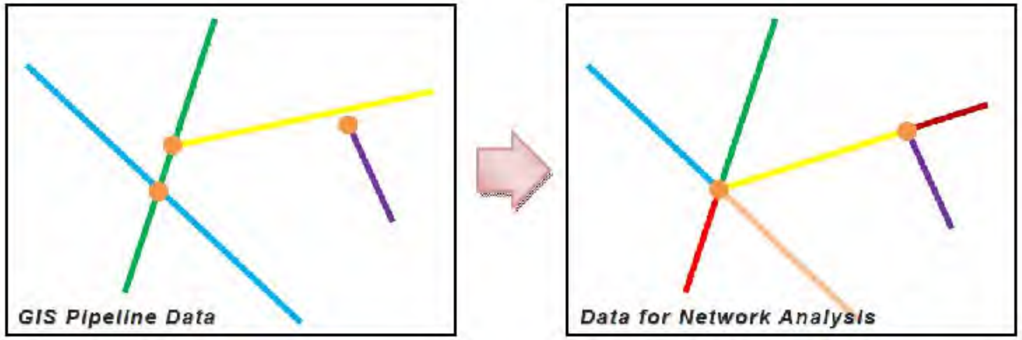
- Water Outage Simulation to identify houses suffering water outage during pipeline construction will be possible.



- However, current GIS data has to be converted &modified for that analysis..



Utilization of Geographic Information System

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- ◆ **Water Leakage Detection**

3. Customer Service
- ☐ Map Viewer in Service Counter
- ☐ Customer's Inquiry Management

- After establishment of **SCADA system**, Water Leakage Detection may become possible in collaboration with GIS Server.

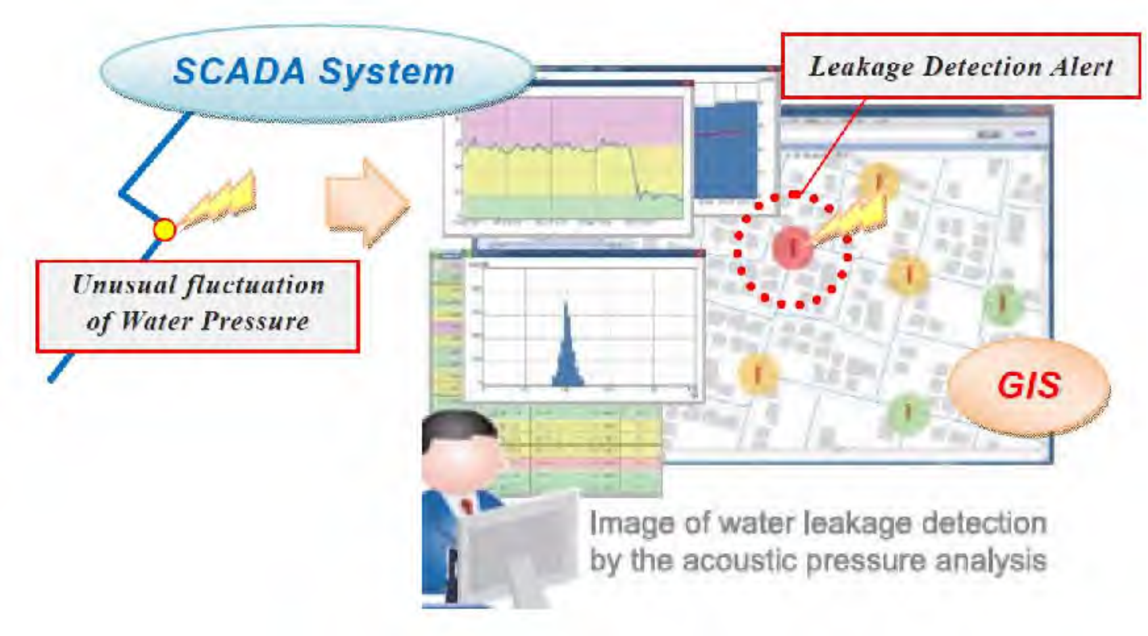

Image of water leakage detection by the acoustic pressure analysis

- This idea is somewhat ideal yet in the current facility in WASAC.
- Although general GIS software does not have the real-time synchronization with SCADA, it may be still possible to acquire the data manually and run the analysis.

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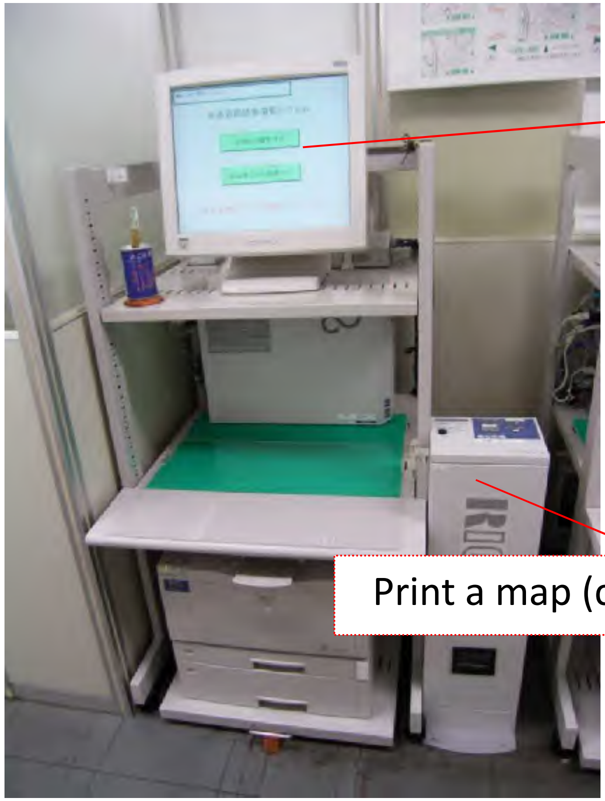
3. Customer Service

- ☐ **Map Viewer in Service Counter**
- ☐ Customer’s Inquiry Management

- GIS often contributes to **Improvement of Customer Service**

User Friendly GIS Viewer at the Customer Services Counter.




印刷したい箇所を印刷範囲枠に入れて下さい。
印刷する場合は【印刷】ボタンを選択して下さい。

Print a map (cost: JPY10 => RWF80 per 1 paper)

- ***Security for private information must be considered.***

Utilization of Geographic Information System

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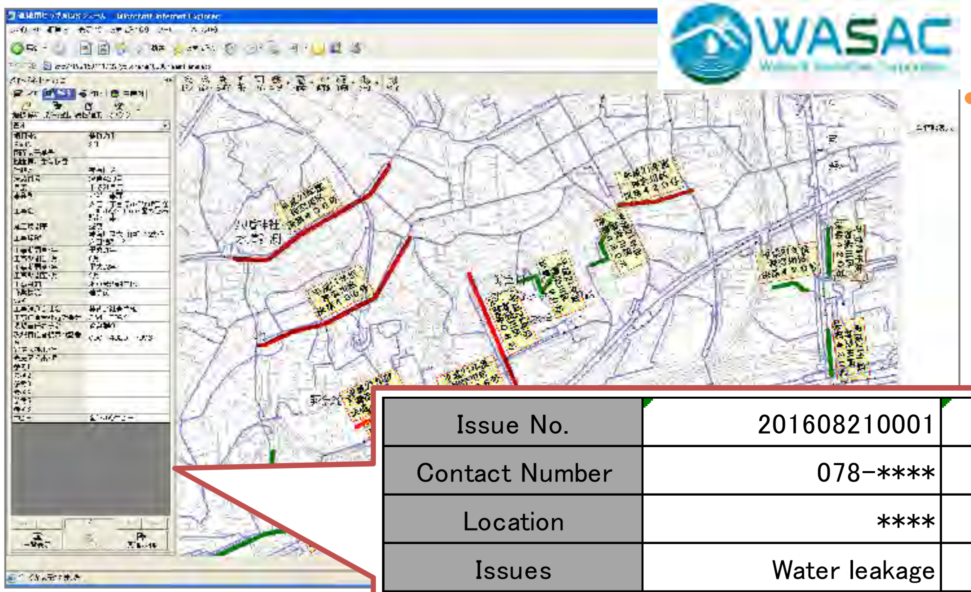
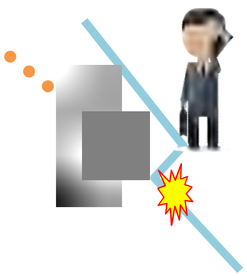
- ☐ **Customer's Inquiry Management**

- GIS often contributes to **Improvement of Customer Service**

Inquiry from Customers can be managed by GIS
- Who is taking a responsibility
- How is the current situation (already solved or not yet)





Issue No.	201608210001	201608250029
Contact Number	078-****	073-****
Location	****	****
Issues	Water leakage	Public tap was broken
Person in Charge	**** in *** branch	**** in *** branch
Reported Date	2016/8/21	2016/8/25
Status	Solved	To be surveyed
Due Date	2016/8/27	2016/9/30
Last update	2016/8/31	2016/8/31

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The main purpose of GIS in the organization is:

1. Convincing & reasonable planning

2. Improve efficiency on your daily duties

⇨

3. Interactive information sharing

Introduction to Hydraulic Analysis

Hiloki OWEN from Geoplan Japan

JICA Expert of Hydraulic Analysis

29th September 2016

Contents: September 29th

1. First Question
2. EPANET
   - Overview
   - Exercise
3. Pipeline Hydraulics
   - Introduction
   - Hazen-Williams Equation

What Do You Want to Do using Hydraulic Analysis?

People

Pipeline

WASAC

Pressure

Energy

Budget

Training

Dignity

Yourself

Cost

Benefit

Asset

Cost

Life

Public

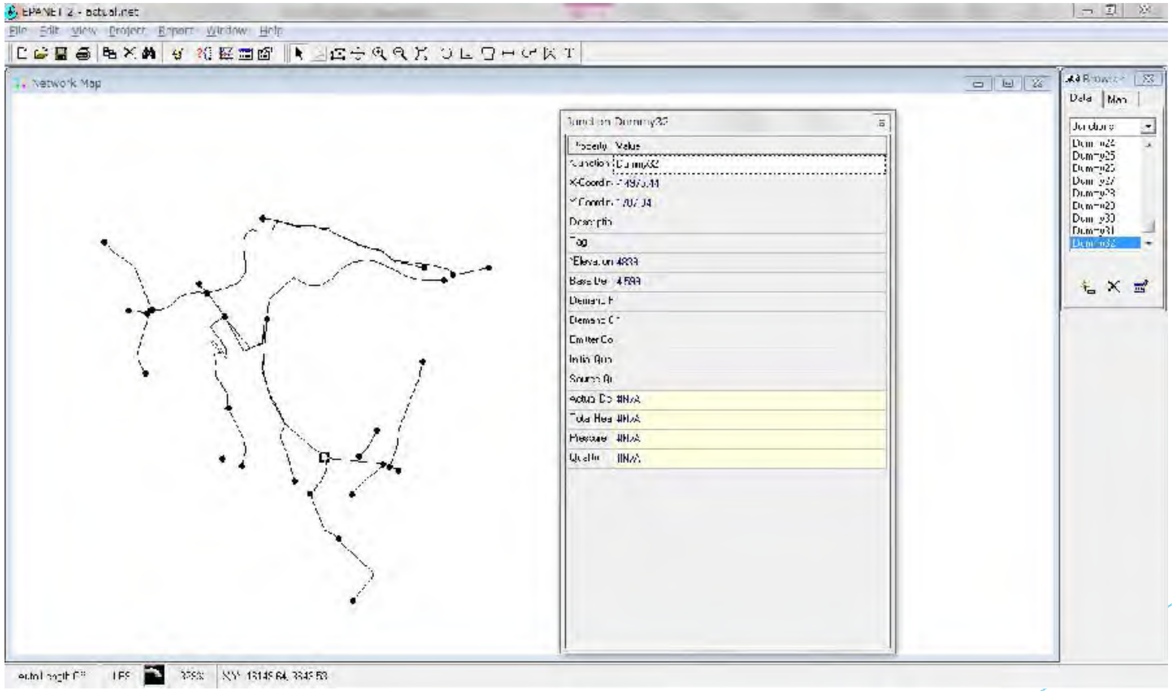
Chemical

Value

THINK!

2. EPANET: Overview

- Globally popular software for Hydraulic Analysis
- Free open source
- Developed by US Environmental Protection Agency
- https://www.epa.gov/water-research/epanet



2. EPANET: Overview

- Some advanced functions
  - Time series pattern, chlorine residual
- Able to accept an INP file of network data
  - a text file and easy to generate
- Allows some programming languages to call some functions in EPANET

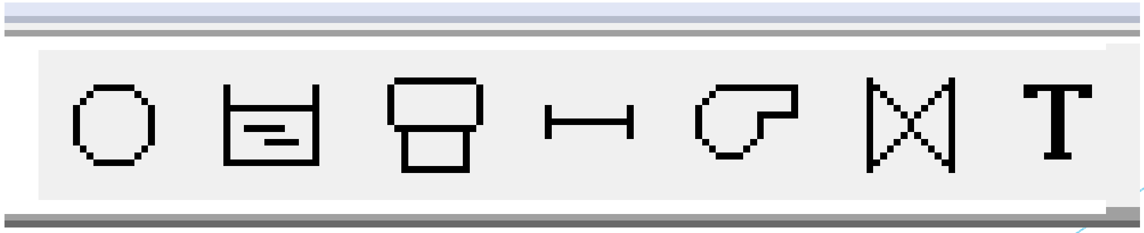
- GUI is not modern and not user-friendly
- Units are in American style (inch, feet, gallon per minute…)

- Allows other software to use EPANET as an analysis engine
  - Mike Urban uses EPANET
- **Insight and wisdom** is required for integration

2. EPANET: Overview

- Style is straightforward, simple and primitive
- Not difficult to learn how to use the app
- User Manual is also free
  - http://nepis.epa.gov/Adobe/PDF/P1007WWU.pdf

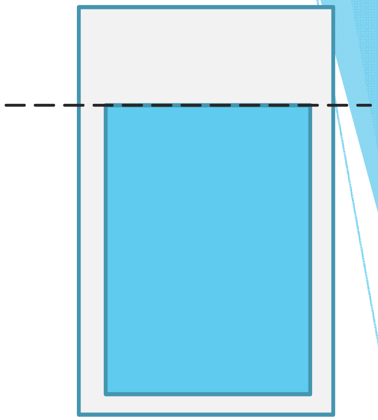
- Facility models are:
  - **junction, reservoir, tank, pipe, pump, valve**
  - ...and **label**



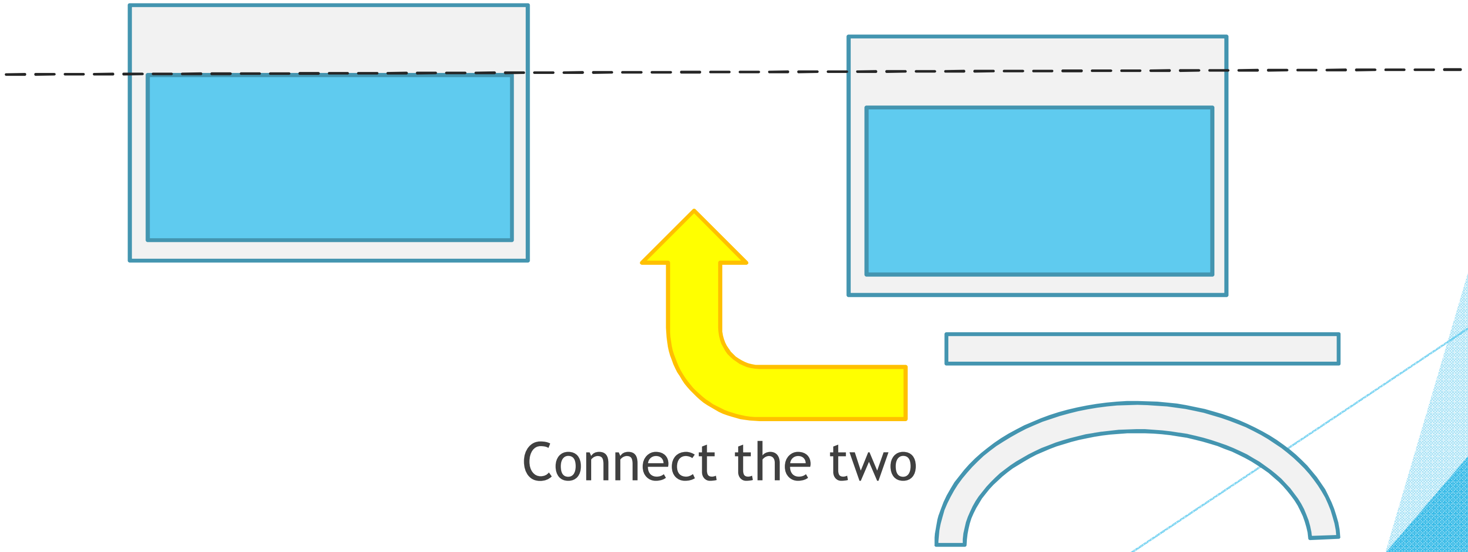
3. Pipeline Hydraulics

- Water surface is flat

  if no one touches or moves it



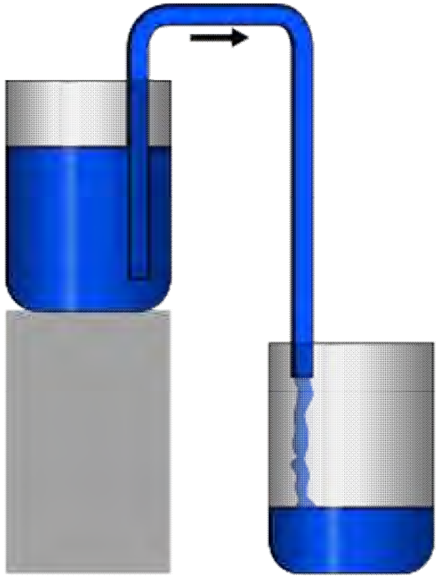
- The surfaces of connected water containers are going to be the same level



Connect the two

3. Pipeline Hydraulics

Siphon

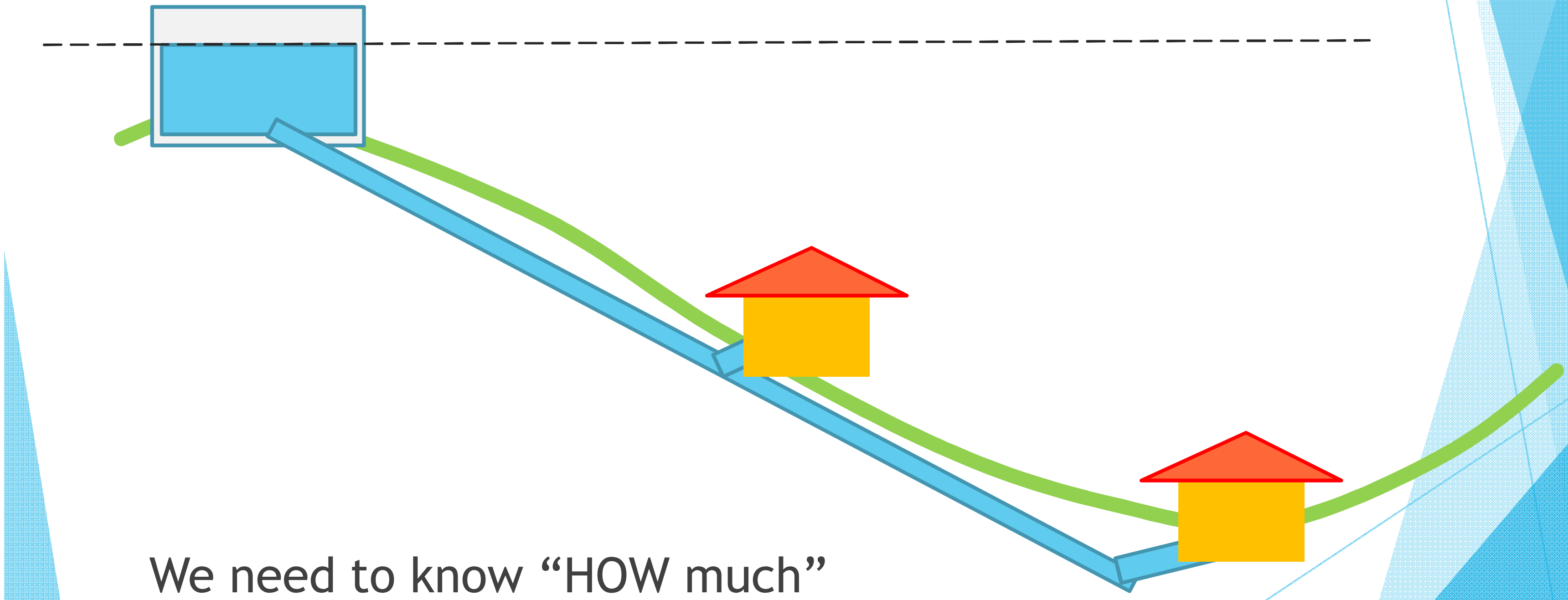


Images from Wikipedia

- Hydraulics sometimes **doesn’t match the human intuition**
- **Think** carefully!

3. Pipeline Hydraulics

1. How much is the pressure at each house, if water stops?
2. What will the pressure be, if water flows down?
3. What if more water flows?



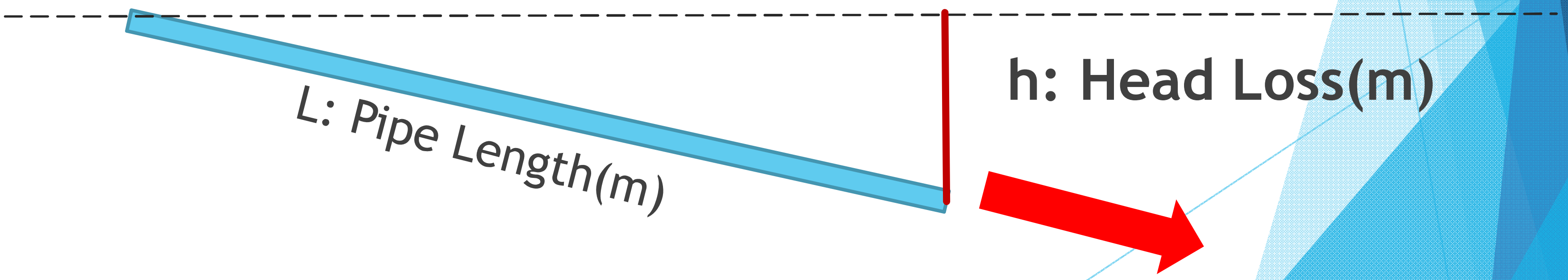
We need to know “HOW much”
as well as ”Whether Greater or Less”

3. Hazen-Williams Equation

Equation **to provide a reliable estimation of the head loss** of a pipe

$$h = 10.666C^{-1.85} * (D/1000)^{-4.87} * (Q/1000)^{1.85} * L$$

Pipe's specific attributes
- C: Roughness coefficient
- D: Pipe diameter(mm)



L: Pipe Length(m)

h: Head Loss(m)

Q: Flow rate(liter/sec)

3. Hazen-Williams Equation

$$h = \frac{10.666 * (Q/1000)^{1.85}}{C^{1.85} * (D/1000)^{4.87}} * L$$

- What the head loss will be if C increases?
- What if the diameter is bigger?
- What if more water flows?
- What if more the length is longer?

Make sense?

3. Hazen-Williams Equation

$h = 10.666C^{-1.85} * (D/1000)^{-4.87} * (Q/1000)^{1.85} * L$

To evaluate the equation, how do you set each parameter?

- How do you know the Q value?
- How about D?
- L?
- C?

3. Hazen-Williams Equation

Once h is known after evaluating the equation, then …

About a Junction

- How about the total head?
- the pressure?

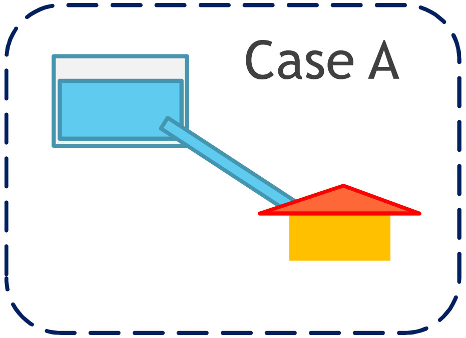
Pipe

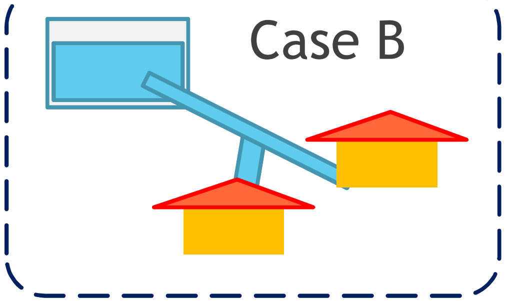
- How about the flow rate (in m3/sec)?
- Velocity (in m/sec)?
- Unit head loss?

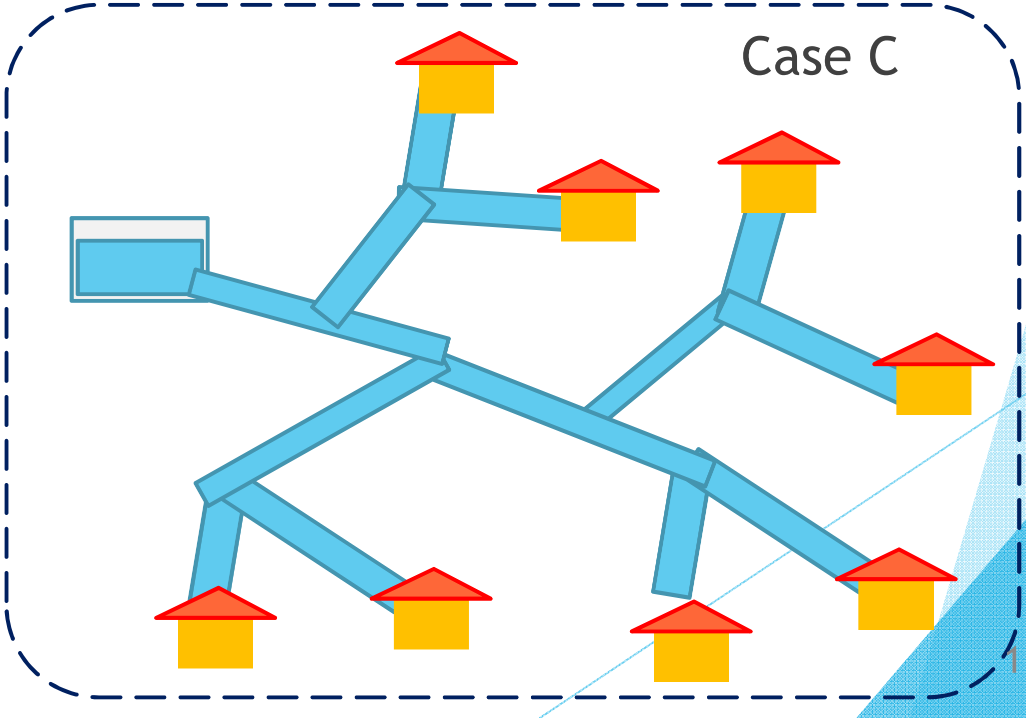
3. Hazen-Williams Equation

- If you know the mandatory parameters for the equation,

you can manually analyze the hydraulics of some simple networks

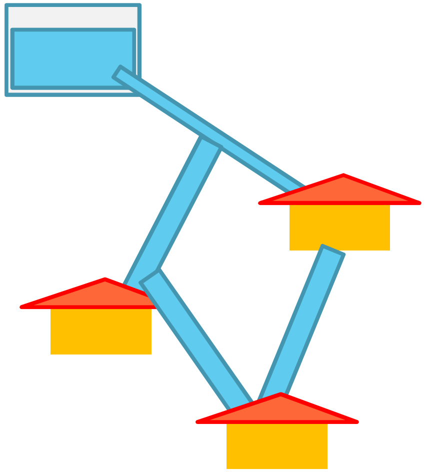






3. Hydraulic Analysis

- What if we want to analyze the real world network?
- One difficult point is interconnected branch pipes



3. Hydraulic Analysis

- Cannot solve the problem **analytically**

- Can solve it **numerically**

  Using computers

EPANET or Mike Urban
can be the solution

Introduction to Hydraulic Analysis 2

Hiloki OWEN from Geoplan Japan

JICA Expert of Hydraulic Analysis

6th October 2016

Contents: October 6th

1. Re: Pipeline Hydraulics
    - Hazen-Williams Equation
    - Siphon
2. How Do You Utilize HA for WASAC
    - Problem Solving Tools
3. Data Involved
    - Necessary Data for Hazen-Williams
    - Organization
4. Lecture Schedule

1. Pipeline Hydraulics

$$h = \frac{10.666 * (Q/1000)^{1.85}}{C^{1.85} * (D/1000)^{4.87}} * L$$

- Q: more water -> more friction -> larger loss
- D: bigger pipe -> smoother flow -> smaller loss
- L: longer pipe -> friction continues longer -> larger loss

1. Pipeline Hydraulics

$$h = \frac{10.666 * (Q/1000)^{1.85}}{C^{1.85} * (D/1000)^{4.87}} * L$$

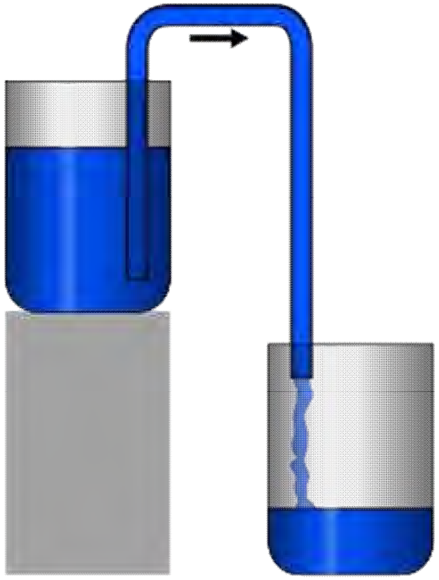
- C: older pipe -> smaller C -> more friction -> larger loss

C value	Material
145～155	PV(New), Brass, Stannum, Lead, Glass, etc.
140	Concrete, AC pipe
130	DI (New), Brick
100	DI (Old), Ceramic
60～80	DI (Extremely Old)

1. Pipeline Hydraulics

Siphon

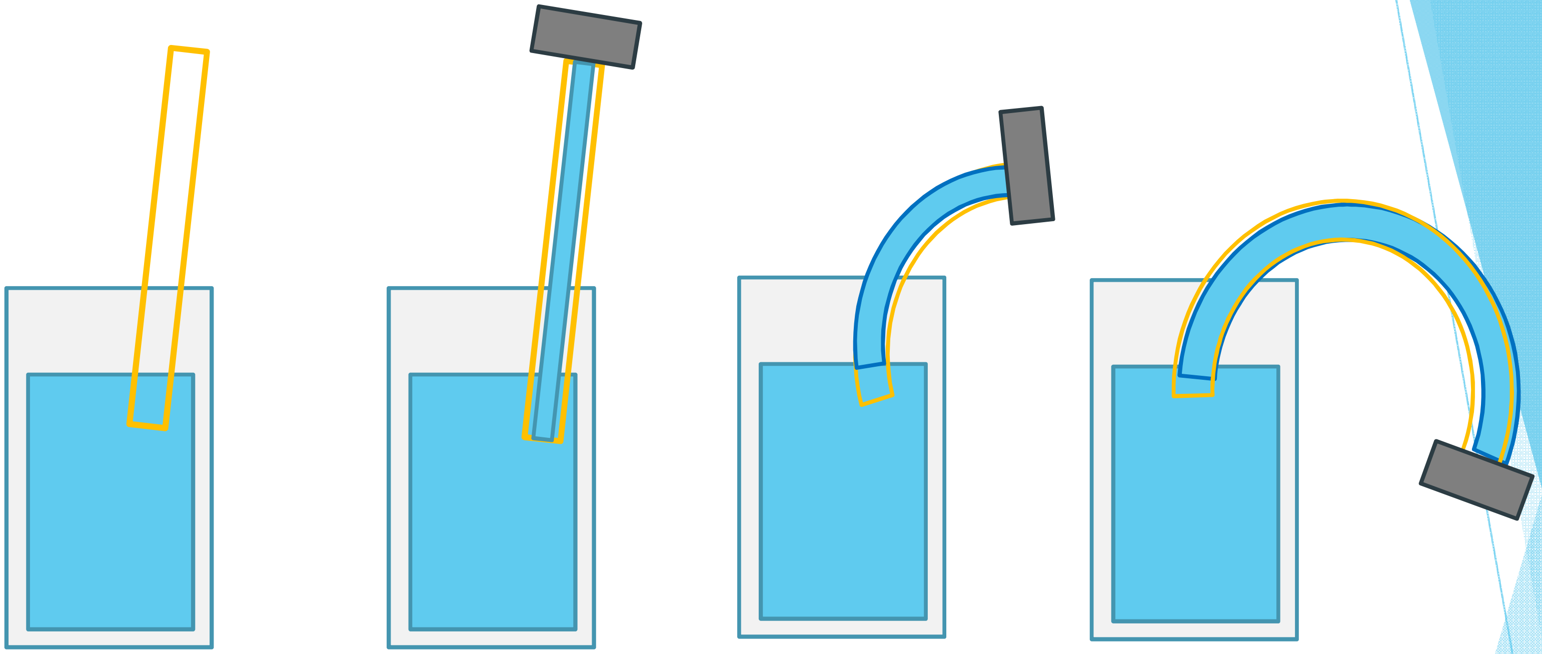
Water goes up

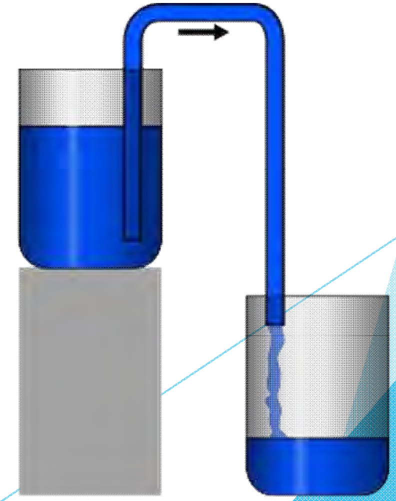


Irrigation system in US

Images from Wikipedia

1. Pipeline Hydraulics





2. How Do You Utilize HA for WASAC

1. Run a hydraulic analysis
2. Pressure will be calculated
3. High pressure areas and low pressure areas will be revealed

4. Then we are able to tackle the high pressure issue
   - We can begin a new project to install PRVs
   - …and so on

Note: HA doesn’t solve the pressure problem directly

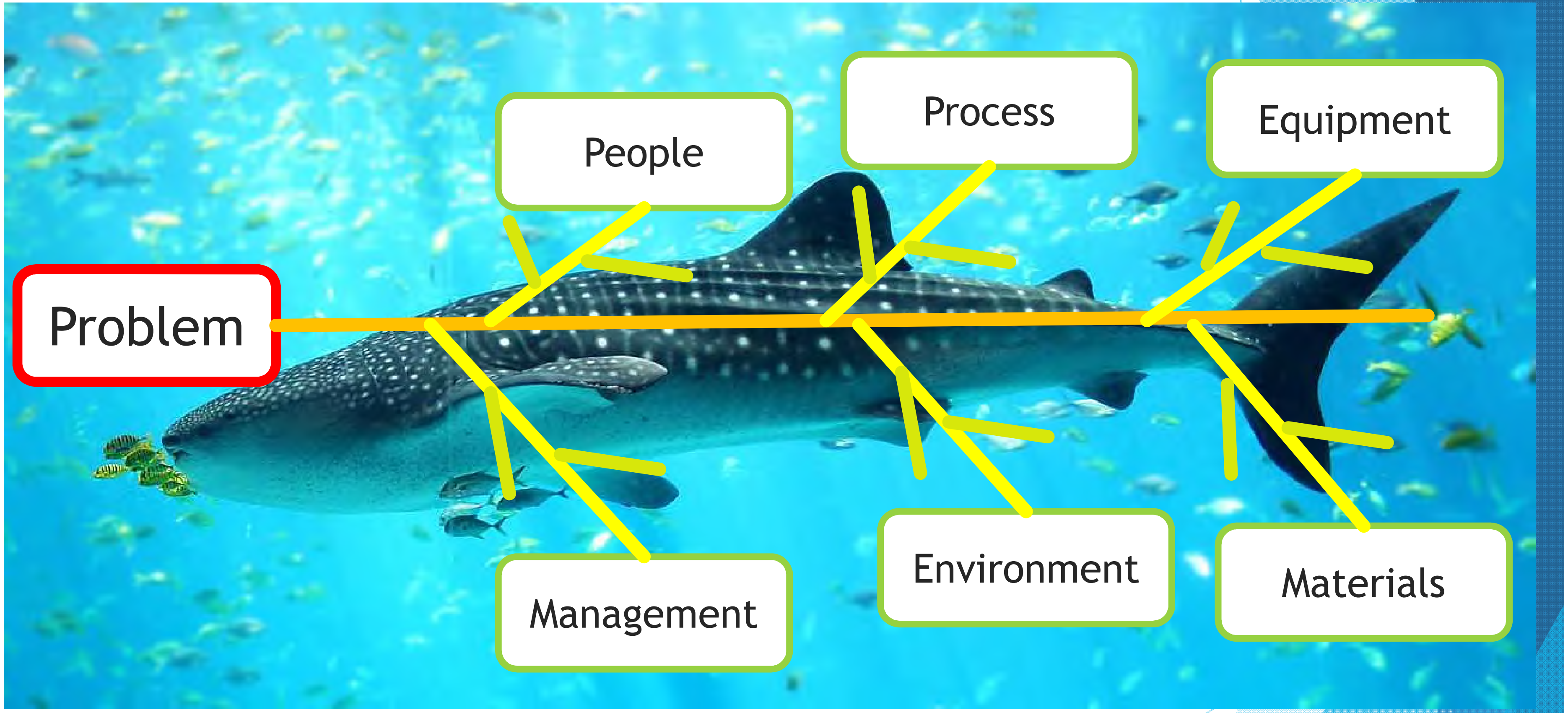
2. Toyota’s 5-Whys

The vehicle will not start. = **<u>the problem</u>**

1. Why?
   - The battery is dead.
2. Why?
   - The alternator is not functioning.
3. Why?
   - The alternator belt has broken.
4. Why?
   - The alternator belt was well beyond its useful service life and not replaced.
5. Why?
   - The vehicle was not maintained according to the recommended service schedule. = **<u>a root cause</u>**

(from wikipedia)

2. Fishbone Diagram



Problem

People

Process

Equipment

Management

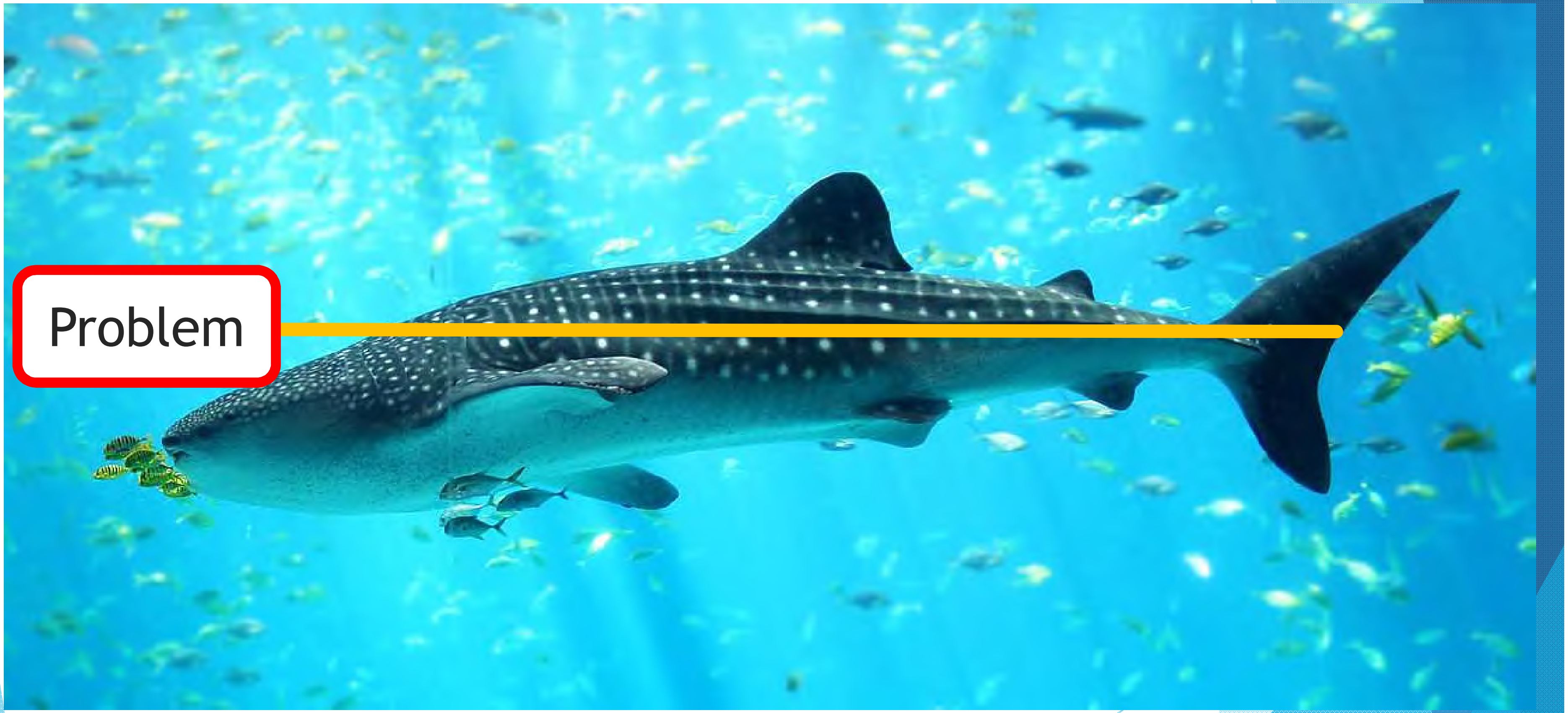
Environment

Materials

(from wikipedia)

2. Fishbone Diagram: Exercise

Pressure is too high in south Ruyenzi: WASAC problem

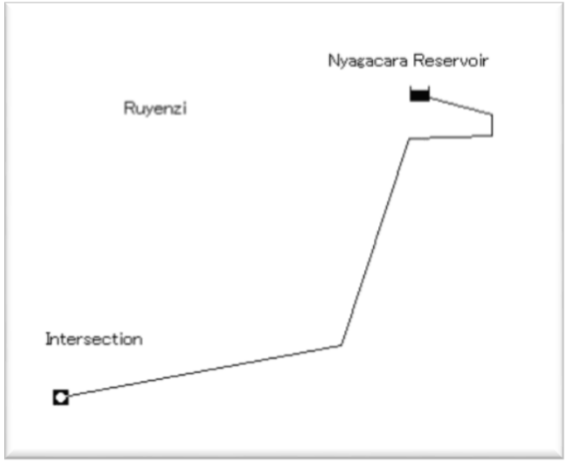


3. Data Involved

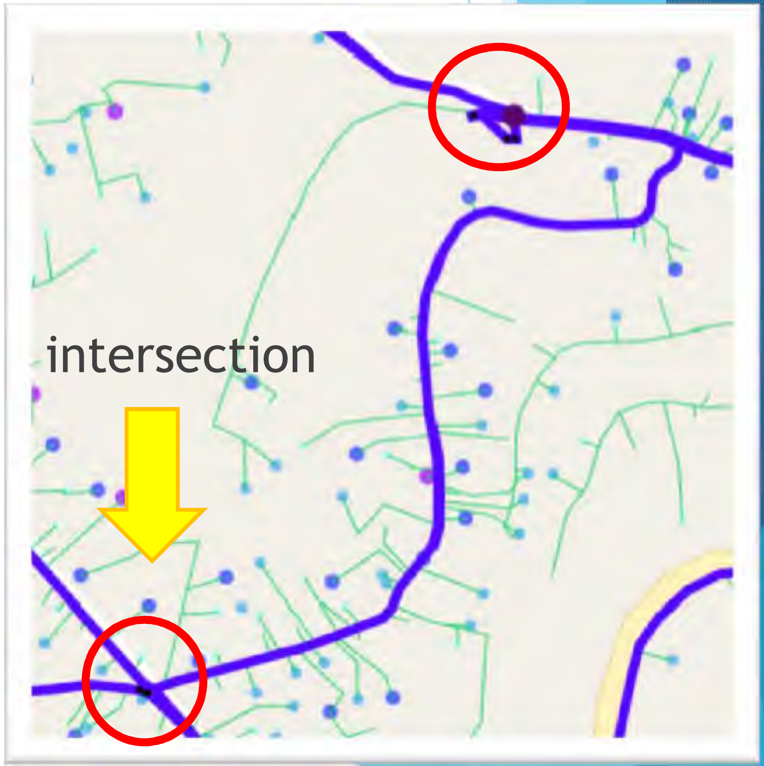
$$h = \frac{10.666 * (Q/1000)^{1.85}}{C^{1.85} * (D/1000)^{4.87}} * L$$

Calculate the **pressure** at the intersection

- How do you use the equation?
- What data is required?
- To whom should we ask for the data?



Nyagacara Reservoir



3. Data Involved

To calculate pressure…

1. C
    - Constant 120
2. D
    - Pipeline specs from GIS team
3. Q
    - Customer consumption from Billing Dept.
    - Customer location from GIS team
4. Total head of the reservoir
    - Reservoir spec from?
5. Elevation of the intersection
    - DEM from GIS team

3. Exercise

- C = 120
- Q = 10,000 ton/month
- D = 200 mm
  - h = ? m

- Total head of the reservoir = 1,523 m
- Elevation of the intersection = 1,497 m
  - Pressure = ? m

3. Thinking of Data…

1. What if Q is doubled?

2. What if much **<u>water leaks</u>** at the mid of the pipeline?

3. What if **<u>GIS data is wrong</u>** and D is actually 100mm?

4. What if an **<u>unknown pipe</u>** is actually connected to the pipeline?

4. Upcoming Schedule

- 13th Oct (Thu)

  3rd lecture and exercise to you by Owen

- 20th Oct (Thu)

  4th lecture and exercise to you by Owen

  Prepare for the final lecture!

- 27th Oct (Thu)

  Final lecture to **other WASAC staff by YOU** and Owen

- 11th Nov (Fri)

  Owen leaving Kigali

4. Final Lecture Contents

1. Very Basics of Hydraulics

   20min? By ?

2. How do You Get the Pressure at a Point? - Hazen-Williams Equation

   30min? By ?

3. Exercise using Hazen-Williams Equation

   20min? By ?

4. Short Introduction of Hydraulic Analysis

   15min? By ?

5. How should WASAC Use HA to Solve a Hydraulic Issue in WASAC?

   50min? By ?

Introduction to Hydraulic Analysis 3

Hiloki OWEN from Geoplan Japan

JICA Expert of Hydraulic Analysis

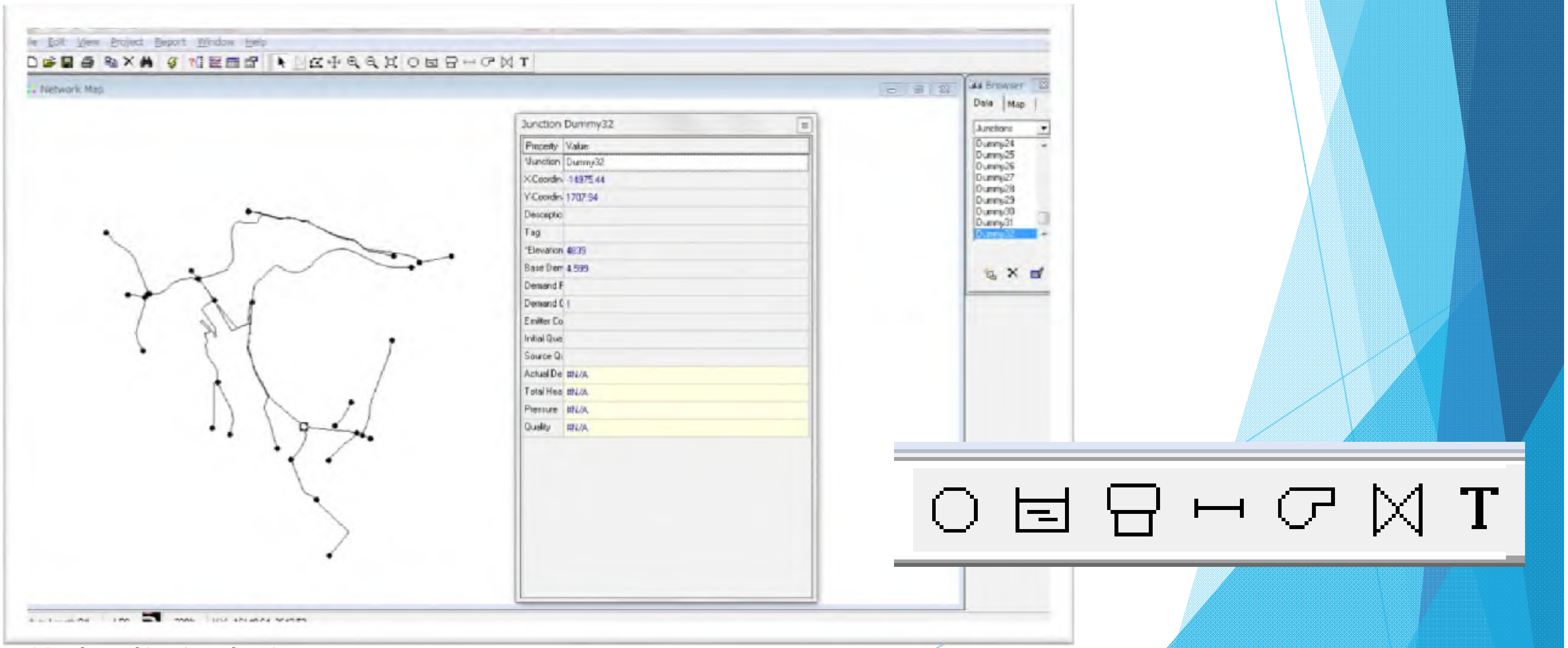
October 17th 2016

Contents: October 13th

1. EPANET Exercise
2. HA basics
3. HA's Limitation
4. Data Quality Issue

1. EPANET Overview

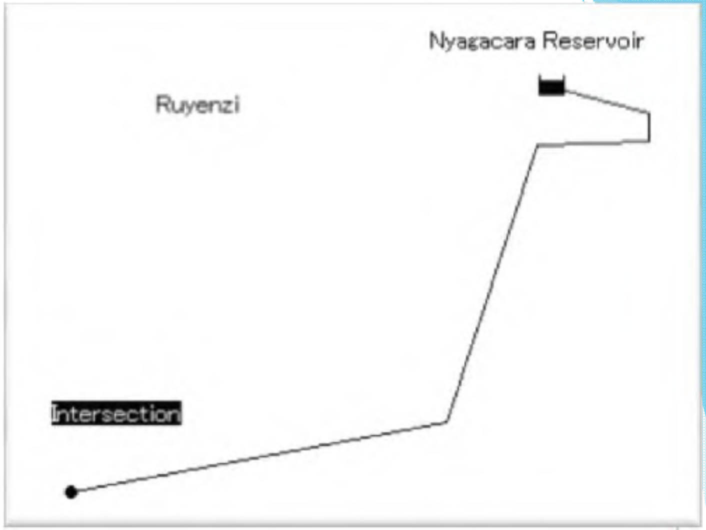
- Style is straightforward, simple and primitive
- Not difficult to learn how to use the app
- User Manual is free
  - http://nepis.epa.gov/Adobe/PDF/P1007WWU.pdf



Junction Dummy32

Property	Value
*Junction	Dummy32
X-Coordin	-14975.44
Y-Coordin	1707.94
Descriptio	
Tag	
*Elevation	4839
Base Dem	4.599
Demand P	
Demand C	1
Emitter Co	
Initial Qua	
Source Q	
Actual De	#N/A
Total Hea	#N/A
Pressure	#N/A
Quality	#N/A

1. EPANET Exercise



Junction

- Demand: 10,000 m3/month -> 3.85 L/sec
- Elevation: 1,500m
- C: 120 or 110 (assumption)

Pipe

- Length: 1,000 m
- Diameter: 200 mm

1. EPANET Exercise

Run the analysis!

- WARNING: Remember to set the unit for demand to

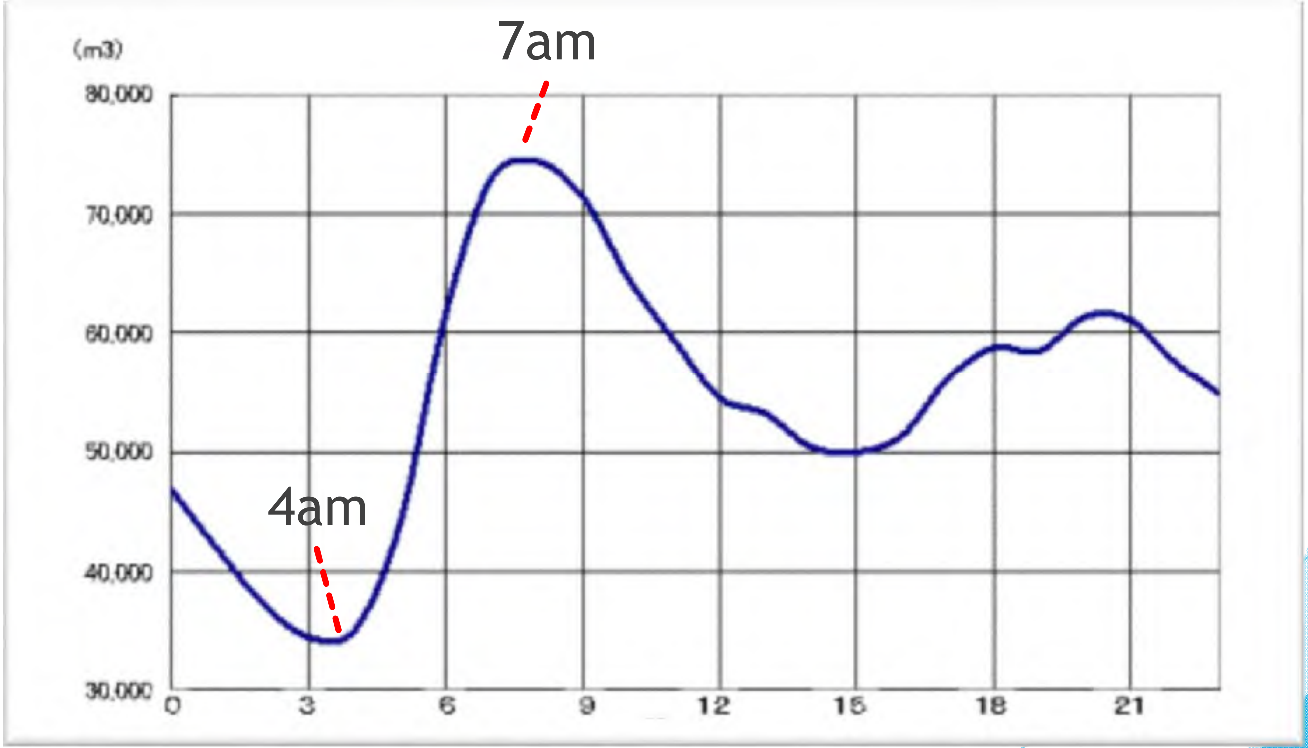
  LPS(Liter per Second)

  Project > Analysis Options > Flow Units

- Look at the pipe’s attributes
- How about the junction?

1. EPANET Exercise

- Modify the model, and run again
    - Set the demand twice or half
    - What will happen if you add too much demand?

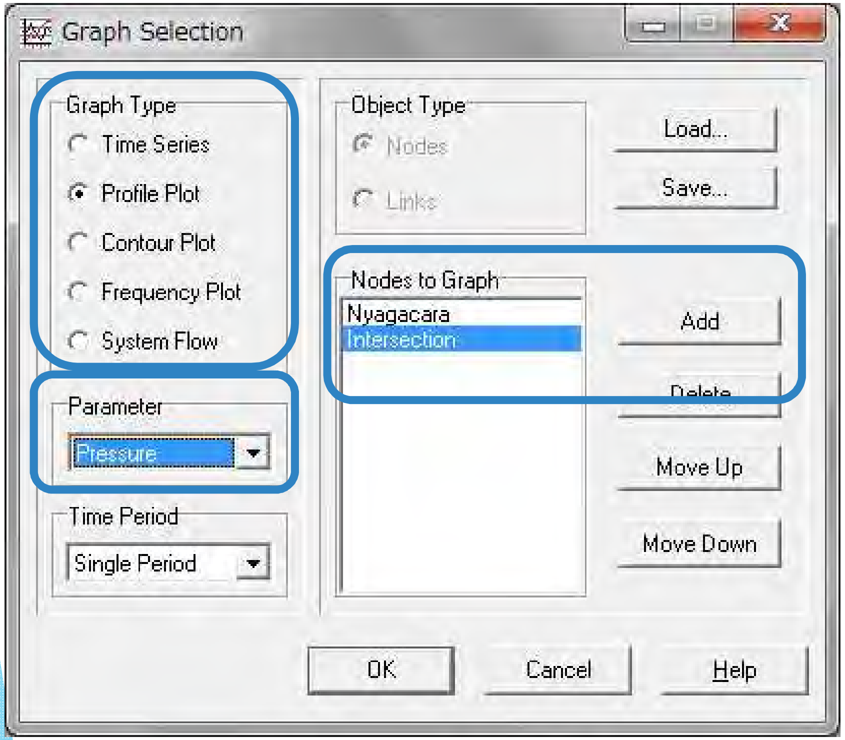


From Yokohama Waterworks

1. EPANET Visualization

Report > Graph

1. Graph Type: Profile Plot
2. Parameter: Pressure
3. Node of Graph: select nodes on the map and add them


Graph Selection

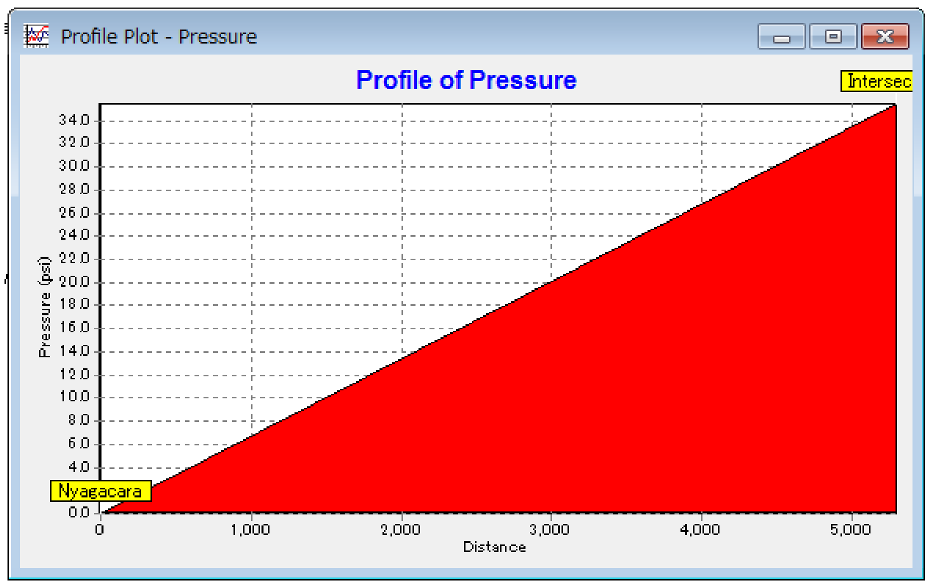
Graph Type
○ Time Series
● Profile Plot
○ Contour Plot
○ Frequency Plot
○ System Flow

Parameter: Pressure

Time Period: Single Period

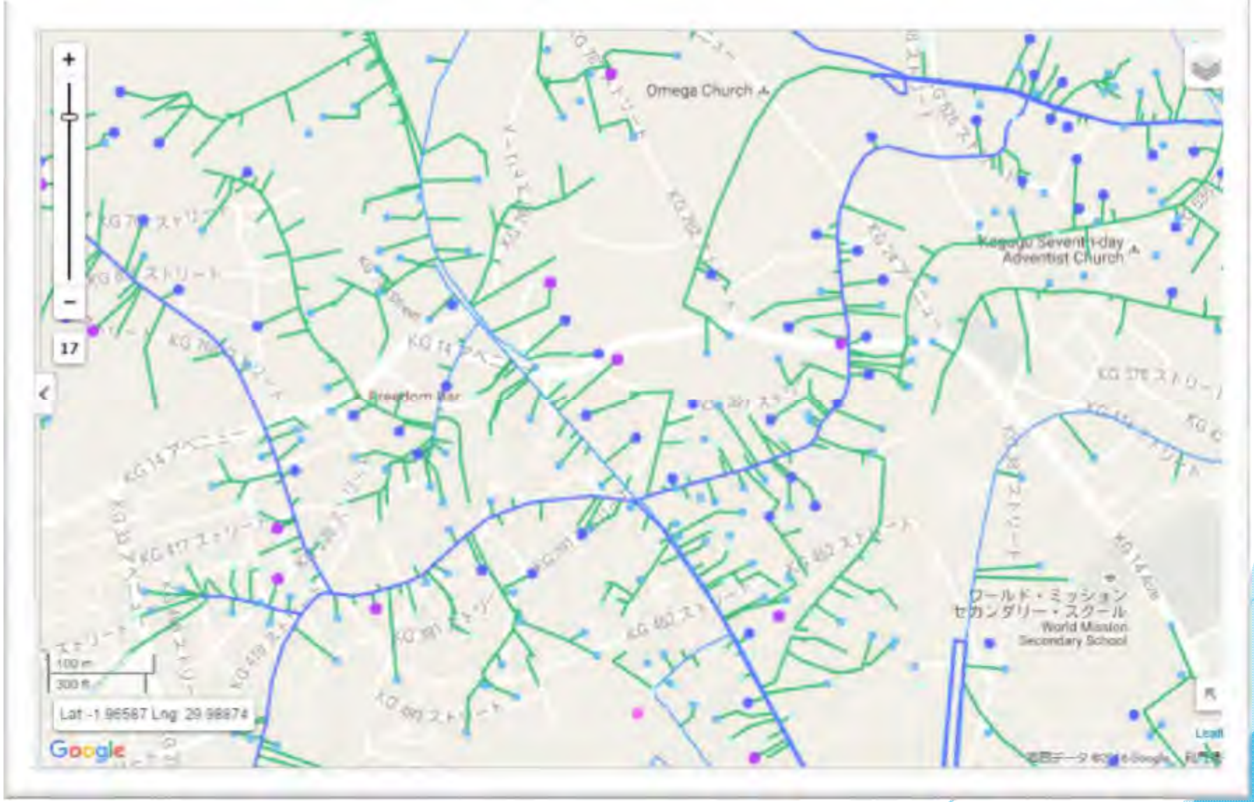
Object Type
● Nodes
○ Links

Nodes to Graph
Nyagacara
Intersection



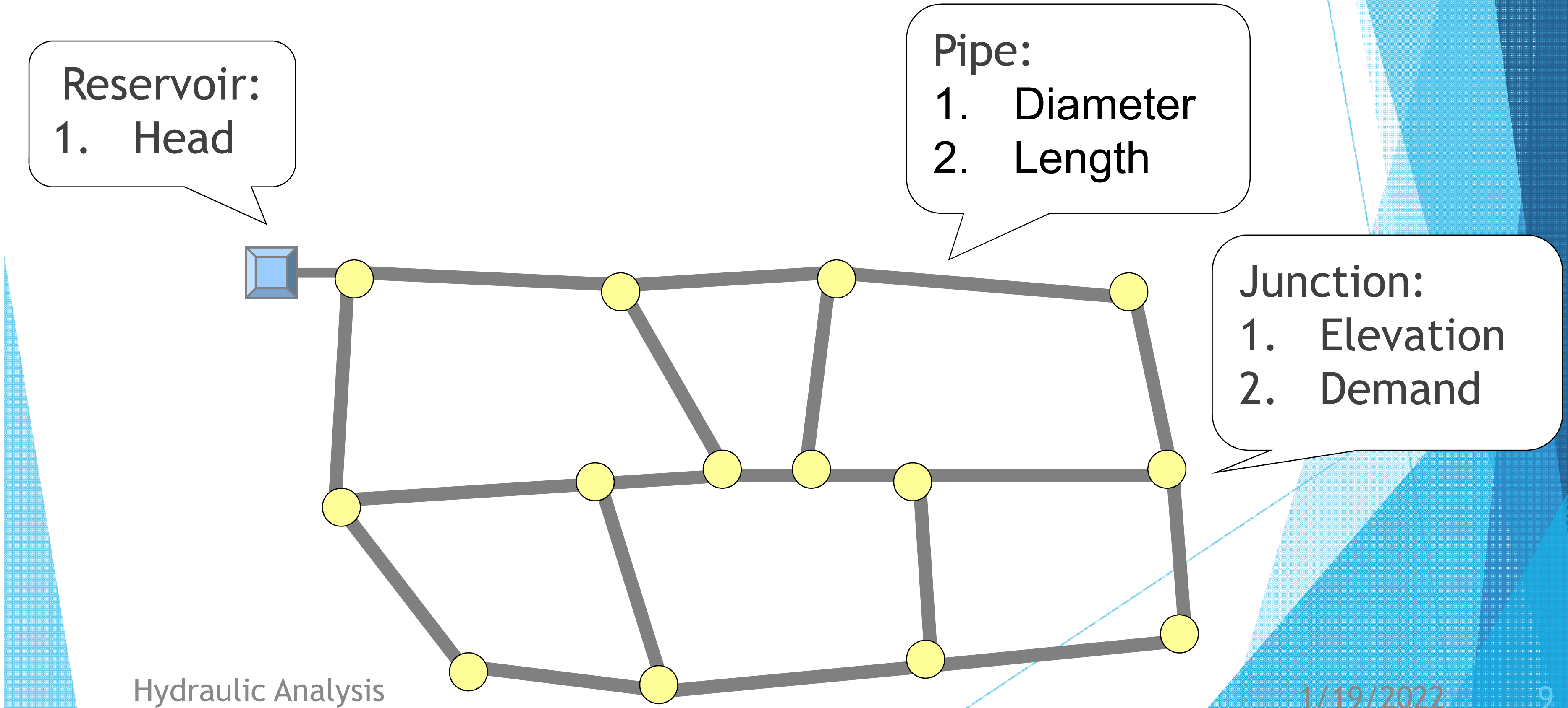
1. EPANET Exercise

- Modify the model, and run again
  - Add a few more junctions and pipes
  - Assign parameters to them



2. Hydraulic Analysis: Input

- A model for HA must be built
- Mike Urban generates an EPANET model from ArcMap data
- GP Water Suite generates an NWCalc model from Smallworld data



Reservoir:
1. Head

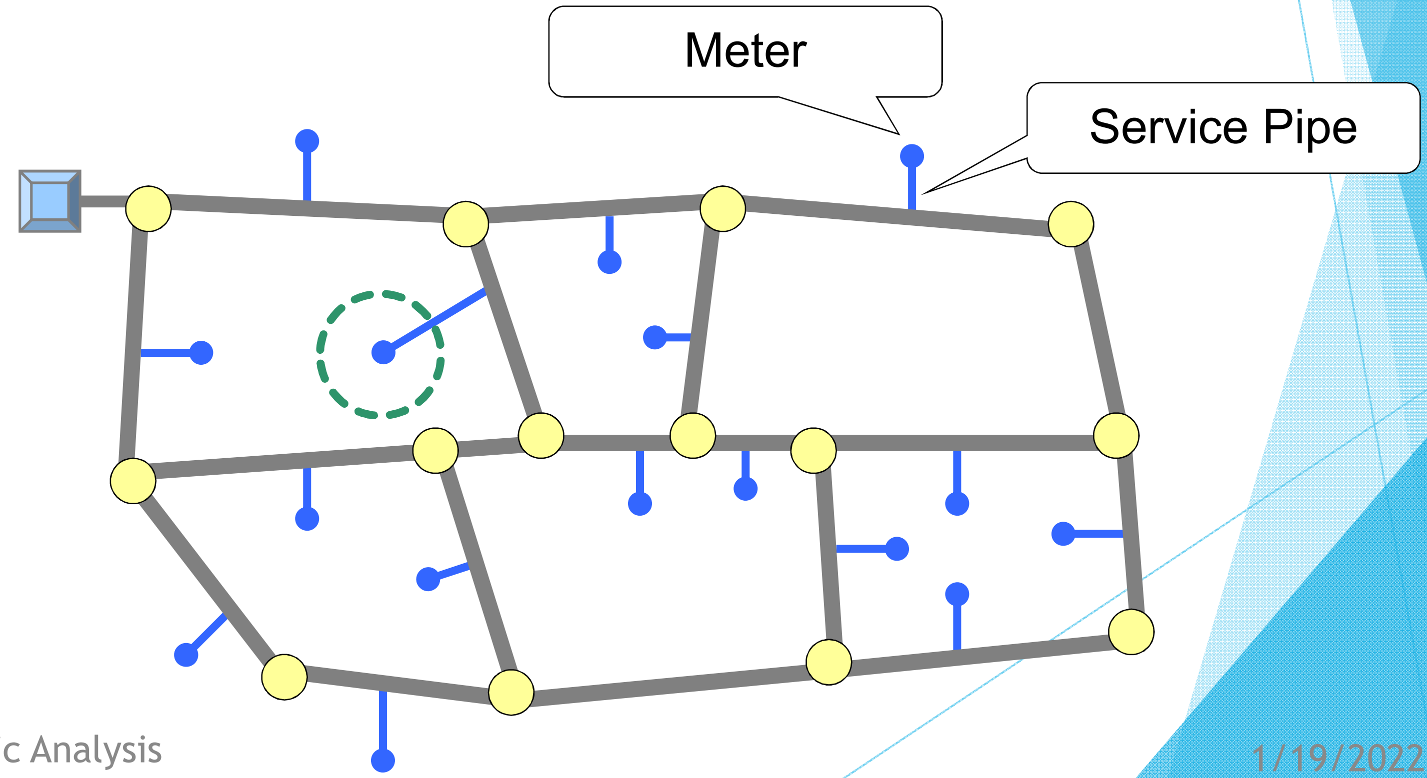
Pipe:
1. Diameter
2. Length

Junction:
1. Elevation
2. Demand

2. Hydraulic Analysis: Input

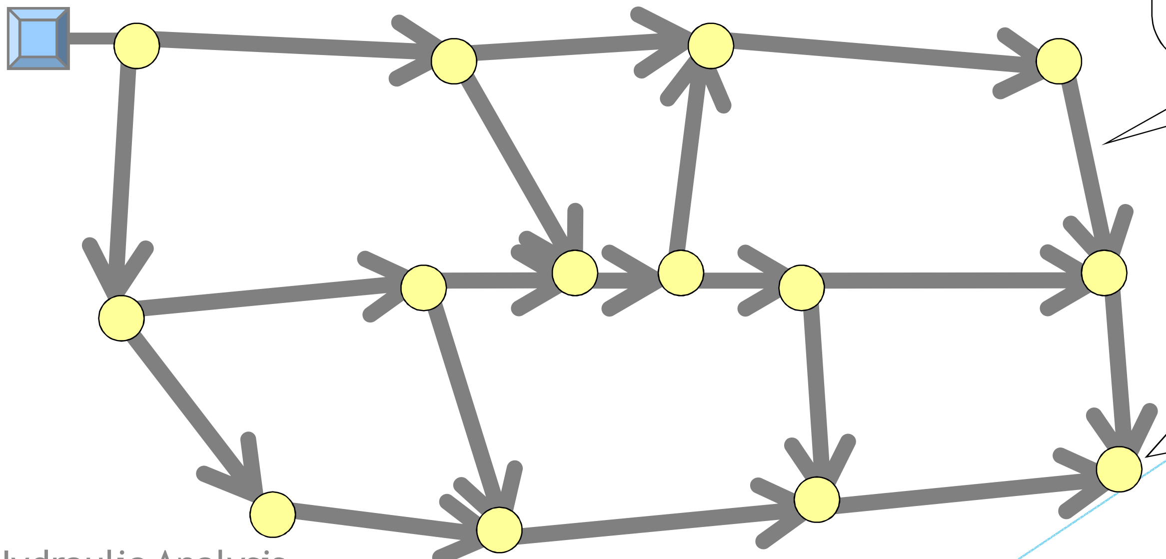
The consumption of each meter should be assigned to its nearest junction according to the distance:

1. measured simply on the map
2. measured along the network



2. Hydraulic Analysis: Output

- HA app tries to meet all the requirements
- Some error still remains
- Demands at junctions may be different from the original demands



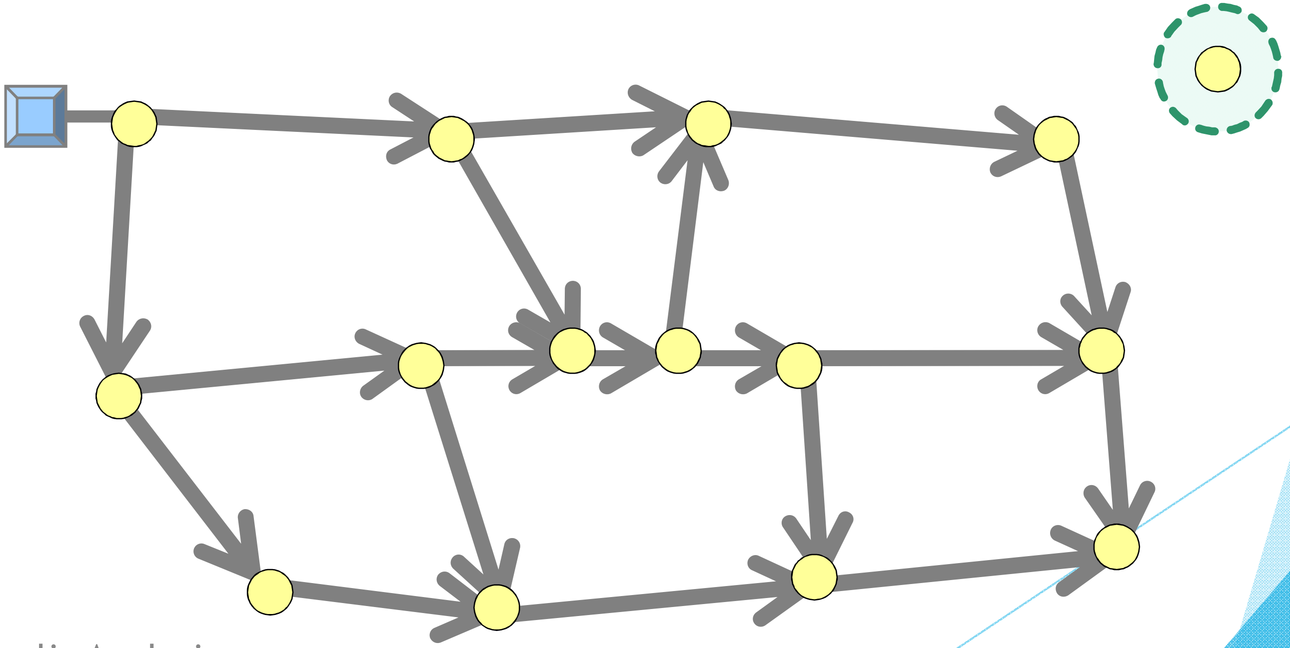
Reservoir:
1. Outlet quantity

Pipe:
1. Quantity
2. Velocity
3. Head loss ratio

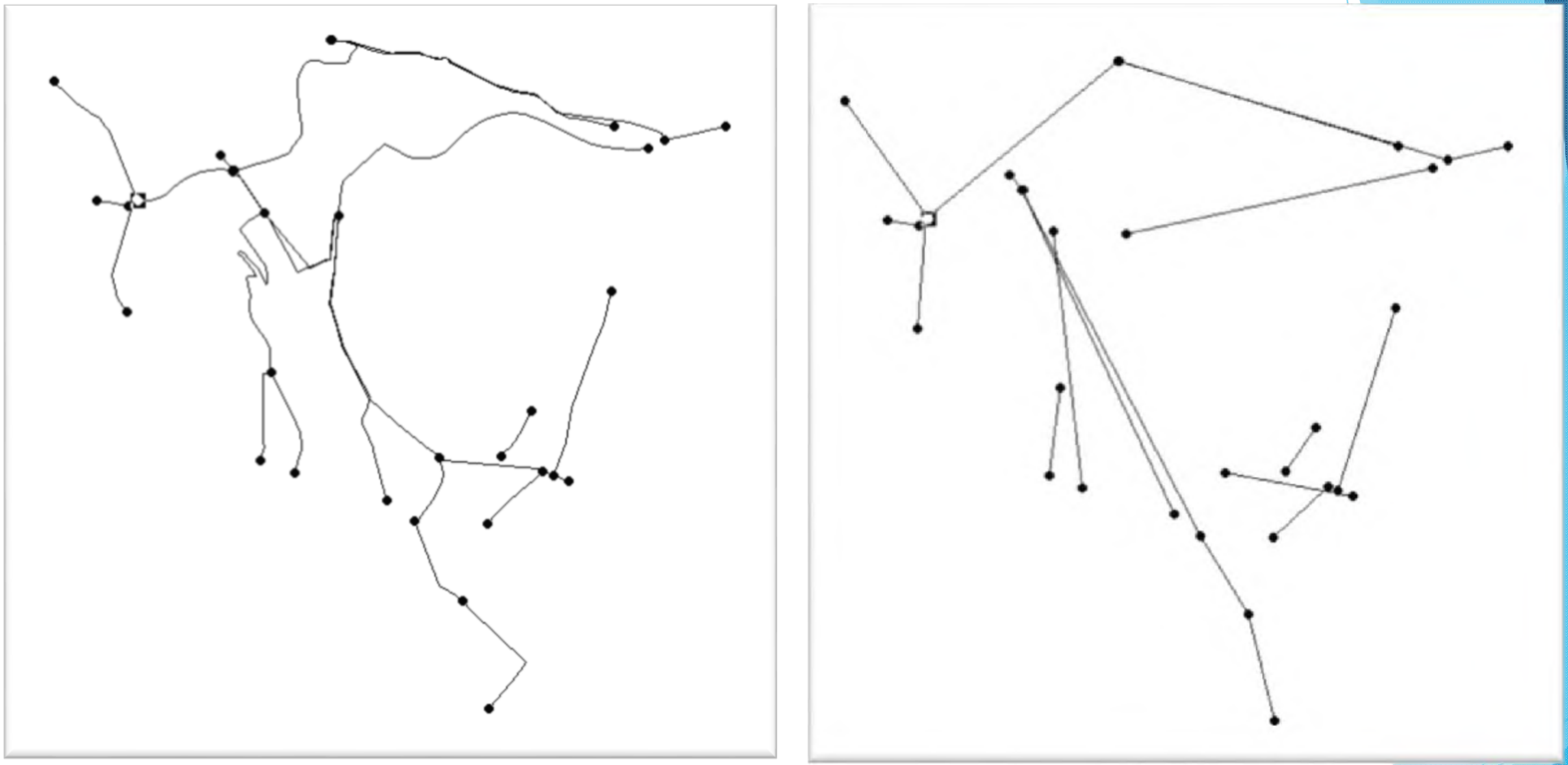
Junction:
1. Head
2. Pressure
3. Demand(Re)

3. EPANET Limitation

- Not allow isolated facilities
  - Every reservoir, pipe and junction should be connected
  - They should be part of a network
- If there is an isolated facility, then EPANET cannot run



3. EPANET Limitation



WASAC’s ArcMap data is not properly connected.

- Pipelines just **crossing over** each other on the map
- Not connected to each other

3. EPANET Limitation

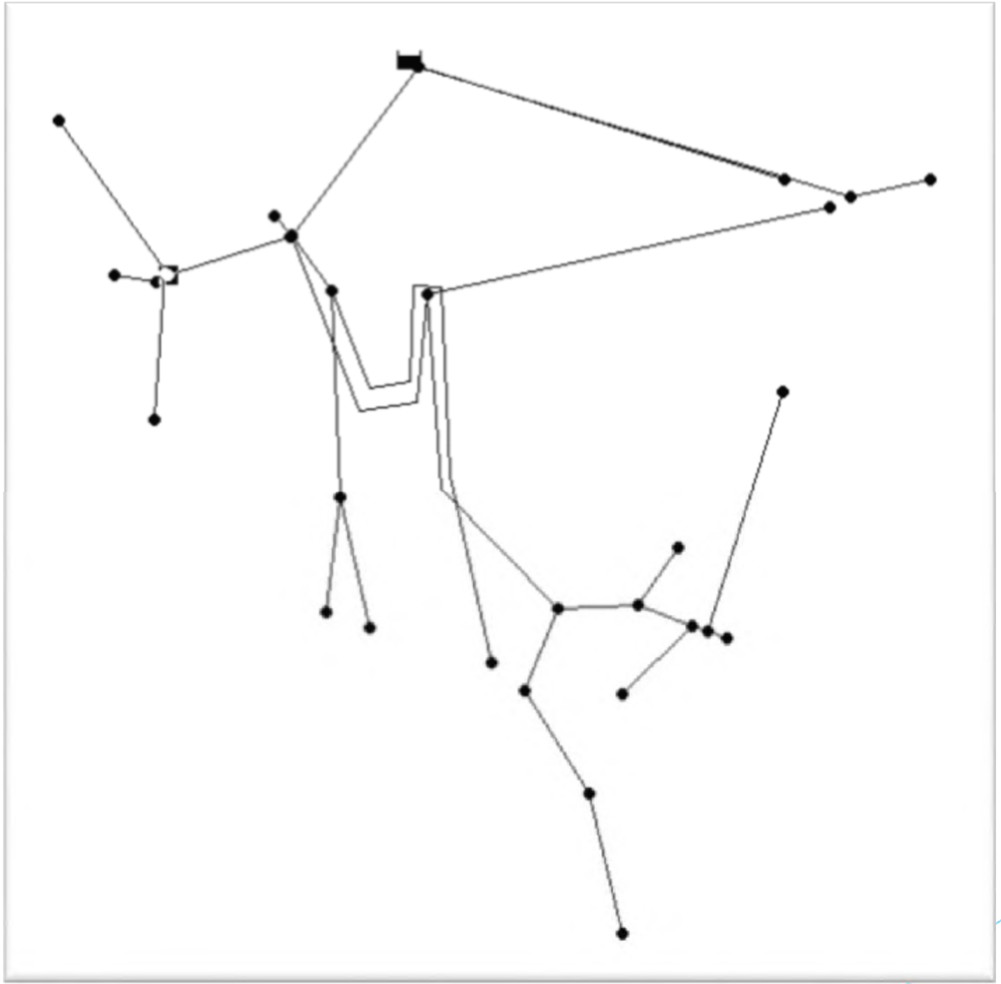
EPANET accepts valid data only

- Is that a problem of EPANET?
- Who should be responsible?

  EPA? Esri? GIS Team? WASAC Branches?
- What do you do with it?

3. EPANET-side Workaround

- Correct data **<u>manually on EPANET</u>**



4. Data Quality

Manual Data Correction

- Do you have any problem?
  - Why?

- Do it manually,

  if HA is **valuable enough** and you don’t have any workaround
- Pay for a solution, if it is valuable enough

  (even though it may be expensive)
- Leave it, if HA is not so valuable

Value First!
What do you want to achieve by HA?

4. Data Quality

- Data quality is a significant threat to your GIS
- HA requires more data than GIS
    - GIS is often used just for an inventory
    - HA requires more detail, how GIS data is connected

- Many utilities have in Africa introduced GIS (sometimes donated)
- The utilities often stop using GIS

4. Data Quality

Why?

1. GIS is too complicated or frustrating to users?
2. Users are not trained well?
3. GIS is used by very few people or used in very limited cases?
4. GIS administrators have left the job?
5. GIS data is not accurate and not reliable?
6. GIS data is not updated regularly?
7. Maintenance tasks are too much and time-consuming?
8. Utility's branches don't submit the latest data to GIS?
9. Utility cannot pay the maintenance and support fee?
10. Utility doesn't have an IT partner who can customize GIS?

Create Value!

4. Data Quality

- ArcMap can check the topology of the network
- Mike Urban may have a similar mechanism

Owen’s experience:

1. Smallworld can pick up suspicious facilities
2. If we looked at the suspicious data and are sure that the data is wrong, modify data manually
3. Sometimes go to the sites and clarify if they are really connected
4. If it is not worth going to the site, mark it “to do”

   We can run HA twice: if there is a connection or not

4. Data Quality

- Automatic correction may be good
- What is the problem of it?

- The problem of data quality arises from everywhere
- Strategic and well-organized approach is necessary
- Who should be responsible?

Introduction to Hydraulic Analysis 4

Hiloki OWEN from Geoplan Japan

JICA Expert of Hydraulic Analysis

October 24th 2016

Contents: October 13th

1. Functions of EPANET
    1. Colorizing Objects
    2. Contour
    3. Attribute Table
    4. Import and Export
2. EPANET in Practice
    1. Demand Multiplier
    2. Negative Pressure
    3. Pressure Reducing Valve
3. Schedule

1. Ruyenzi

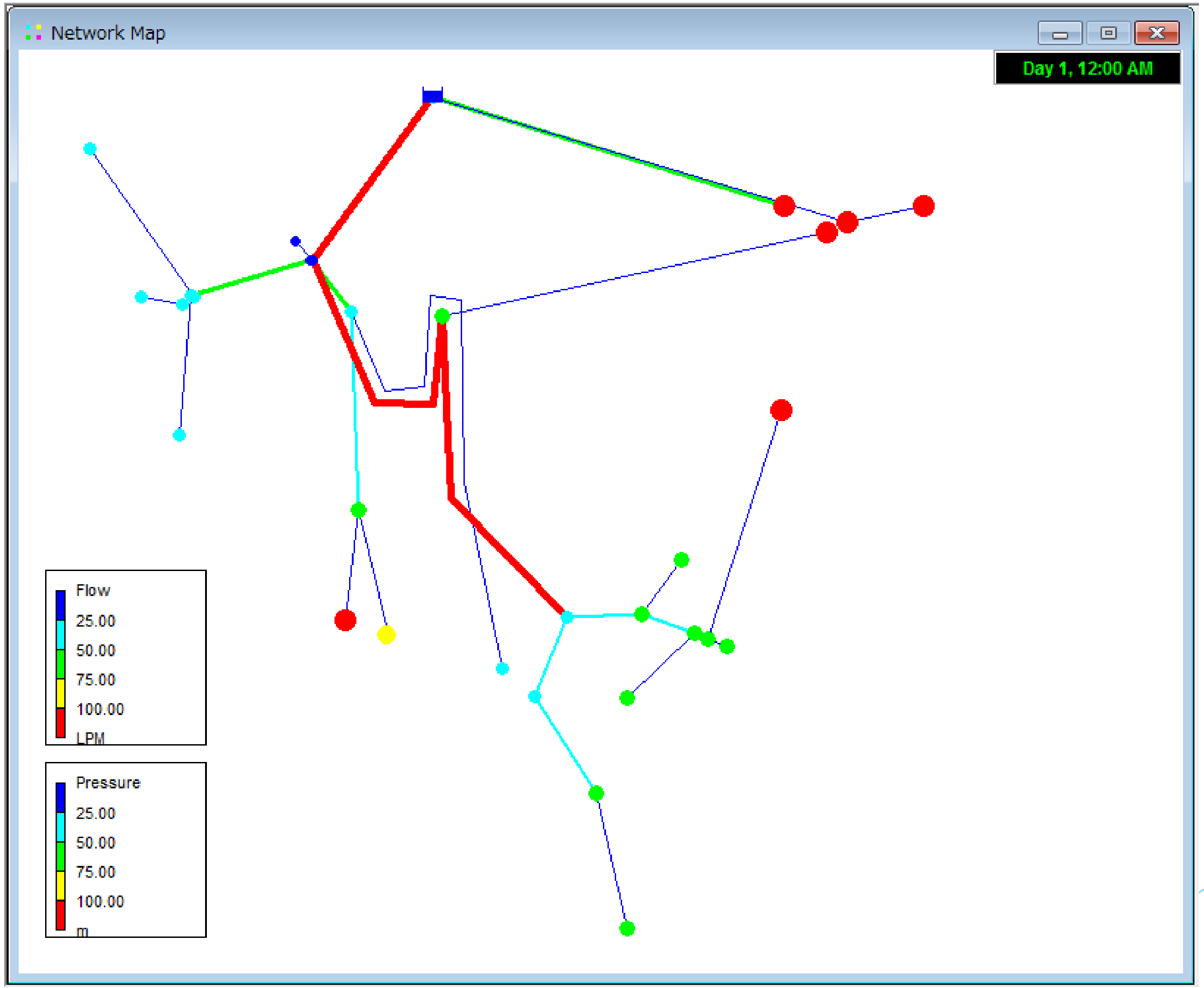
GIS shapefiles, a billing CSV file and DEM file

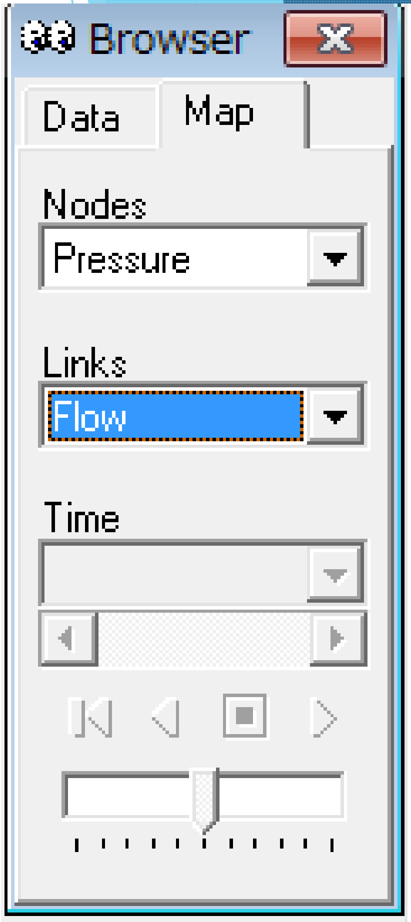
are all merged into EPANET inp file

- Each customer consumption from billing are assigned to the closest node according to the simple distance method
- Each node has an elevation according to the DEM data

After adjusting the model, run the analysis

1. Colorizing Objects



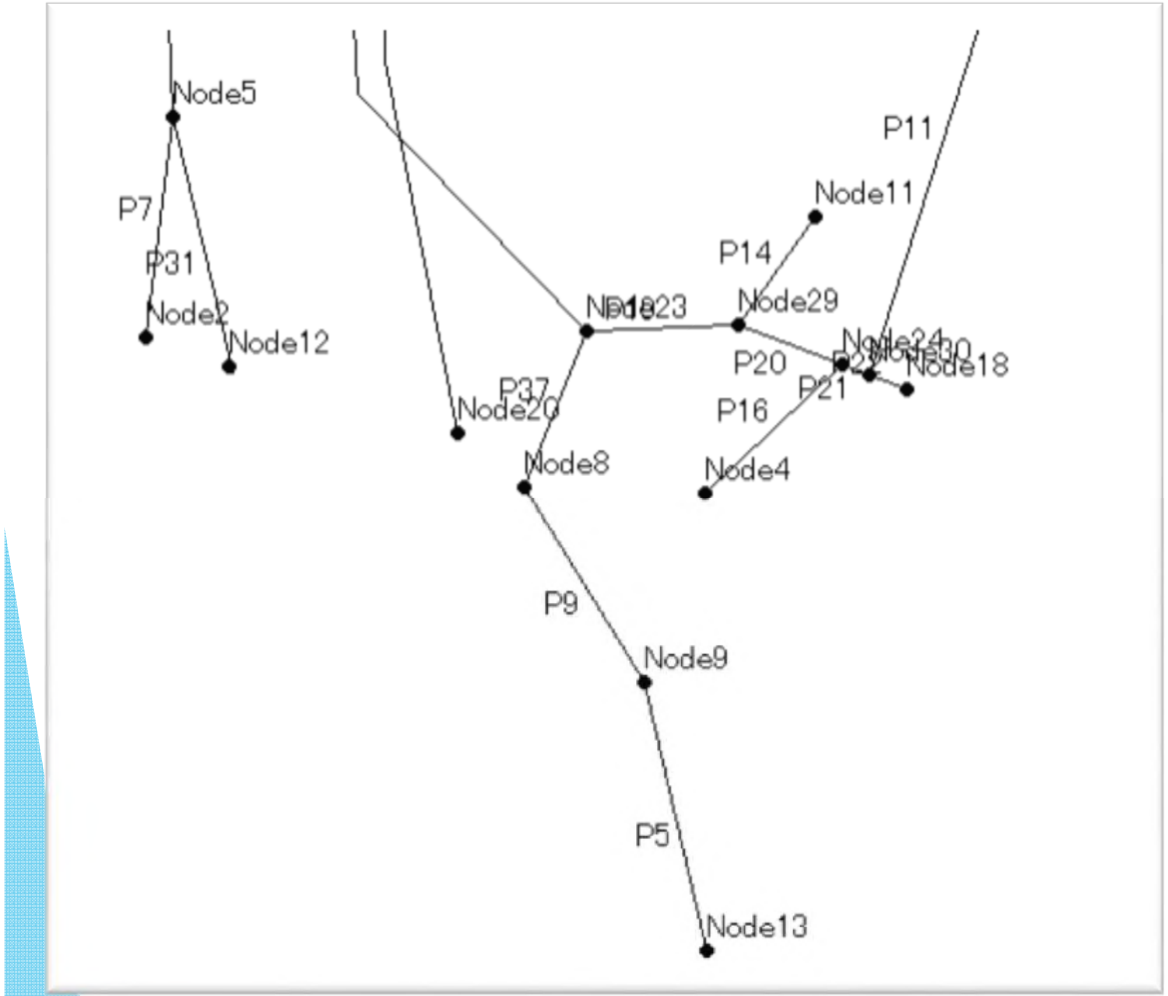


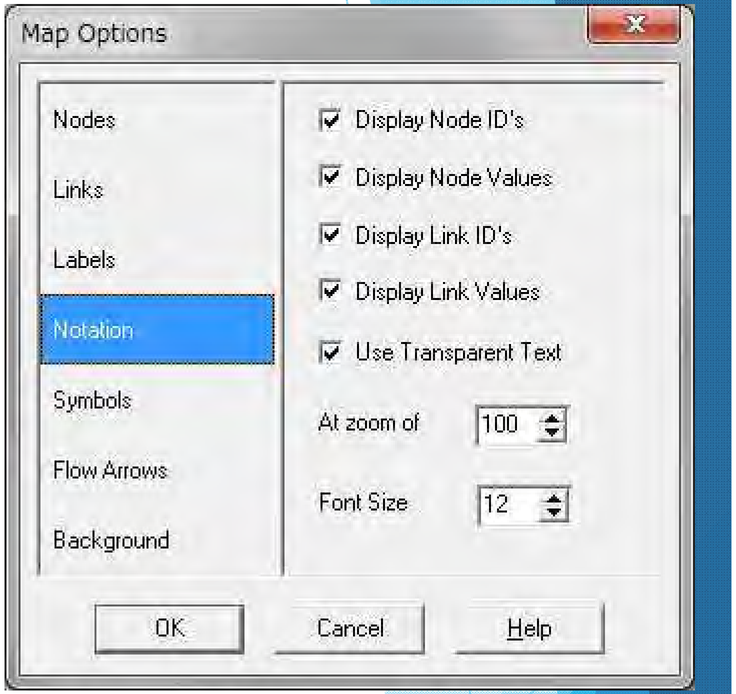
Nodes: Pressure

Links: Flow

1. Annotation

View > Options > Notation





☑ Display Node ID's

☑ Display Node Values

☑ Display Link ID's

☑ Display Link Values

☑ Use Transparent Text

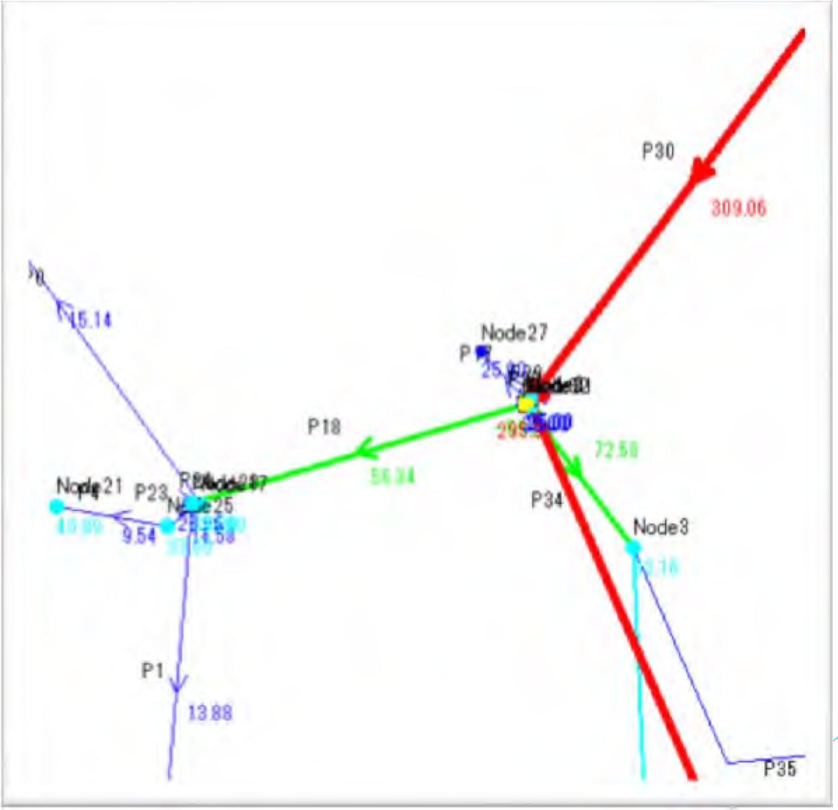
At zoom of: 100

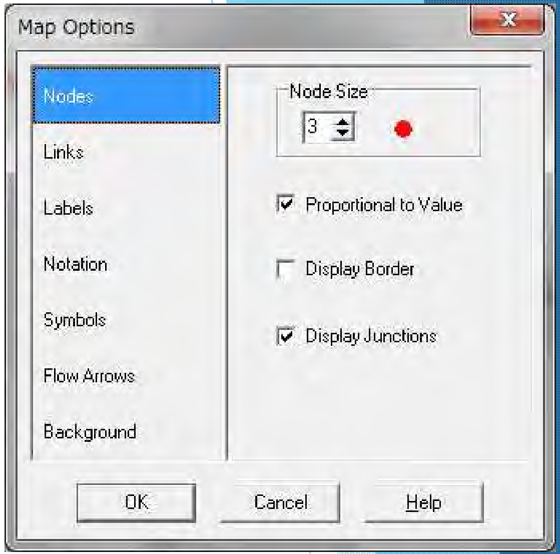
Font Size: 12

1. Style according to Attributes

View > Options

- High pressure nodes -> big
- Pipes carrying more water -> thick
- Flow Direction -> an arrow



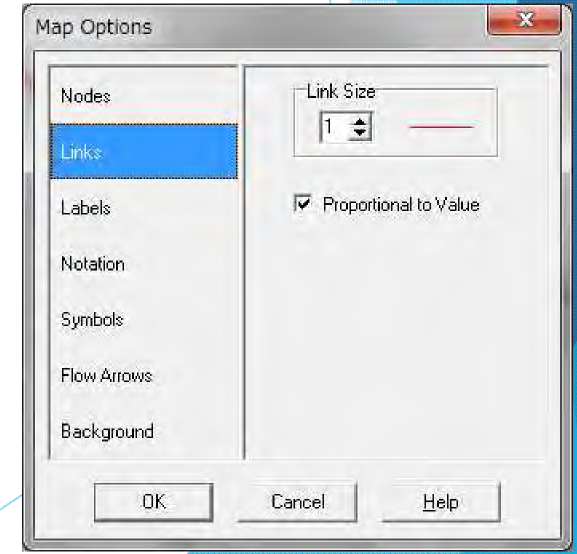


Node Size: 3

☑ Proportional to Value

☐ Display Border

☑ Display Junctions

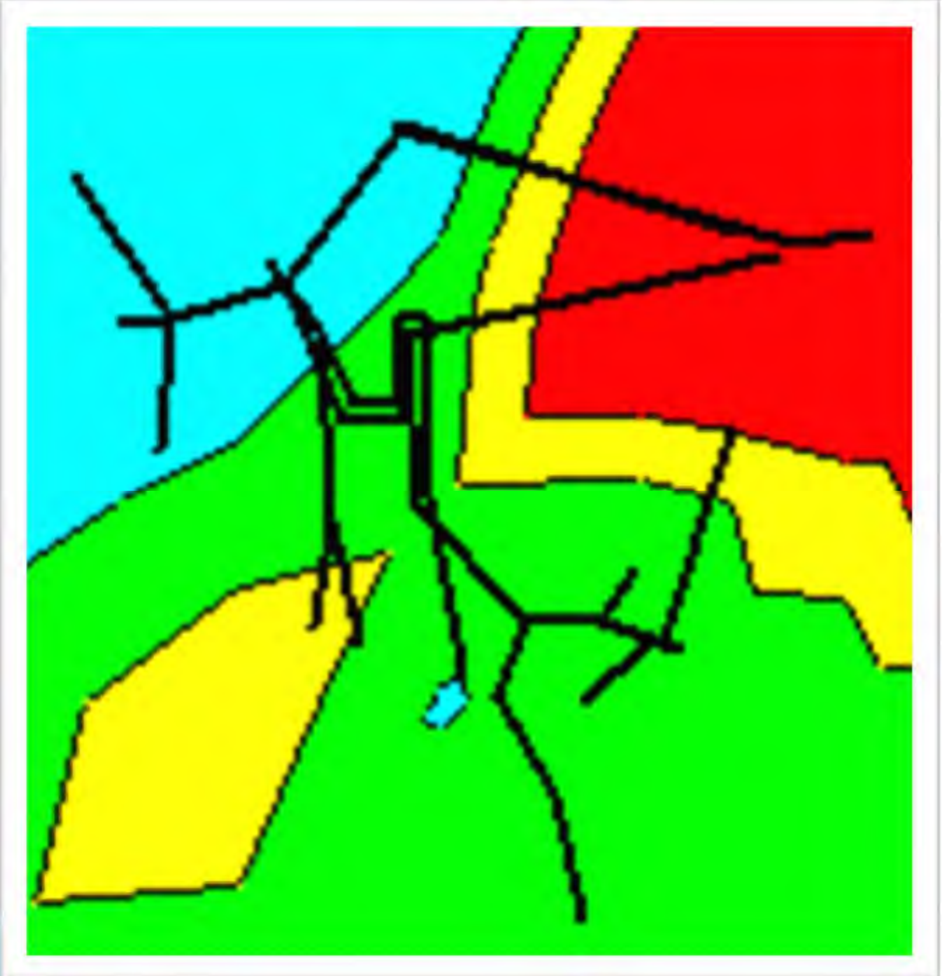


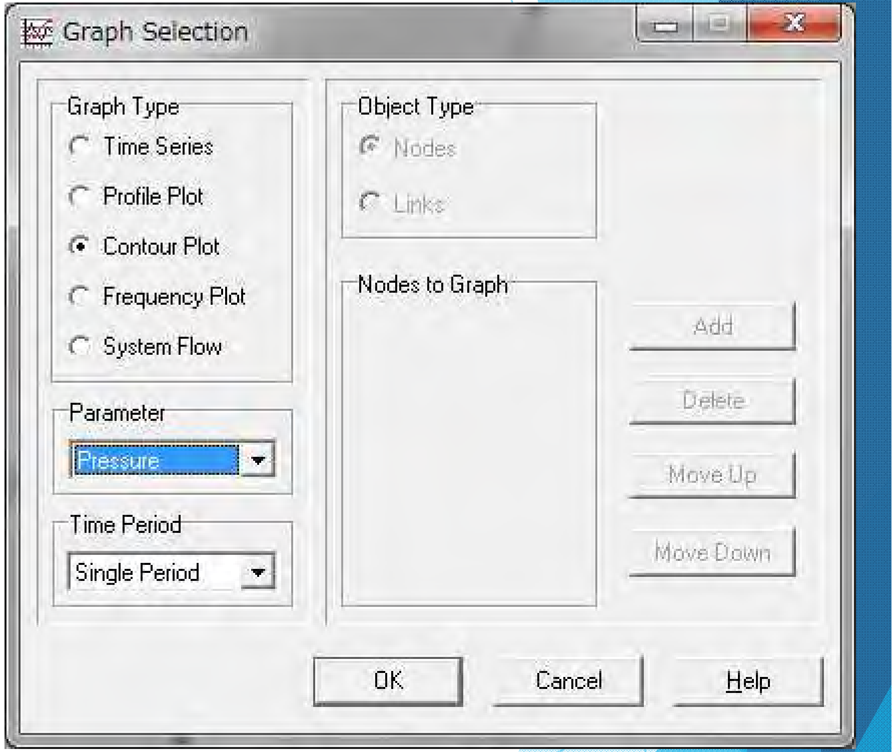
Link Size: 1

☑ Proportional to Value

1. Contour

Report > Graph





Graph Type
- ○ Time Series
- ○ Profile Plot
- ● Contour Plot
- ○ Frequency Plot
- ○ System Flow

Parameter: Pressure

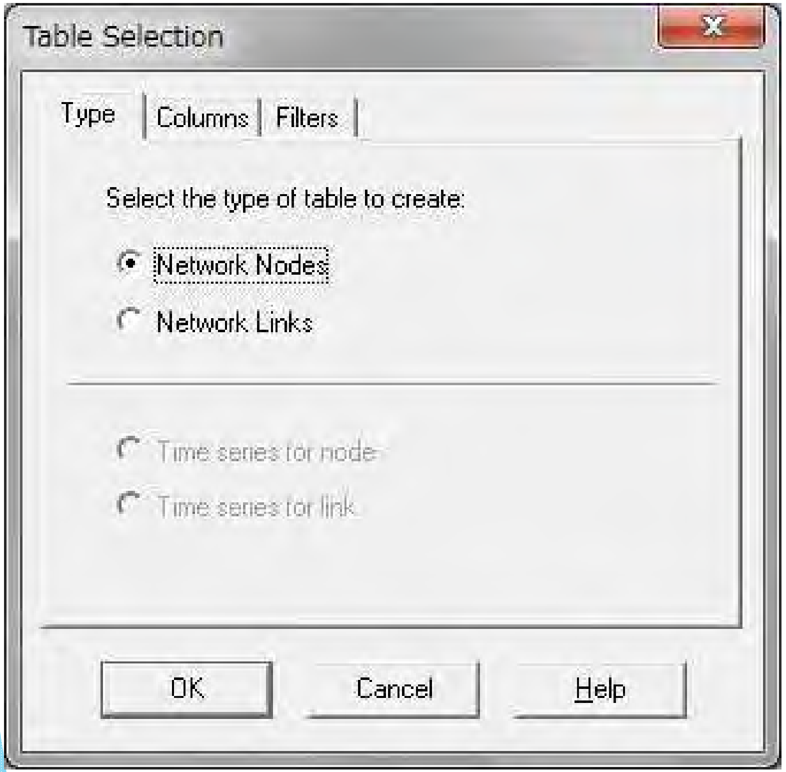
Time Period: Single Period

Object Type
- ● Nodes
- ○ Links

Nodes to Graph

1. Attribute Table

Report > Table



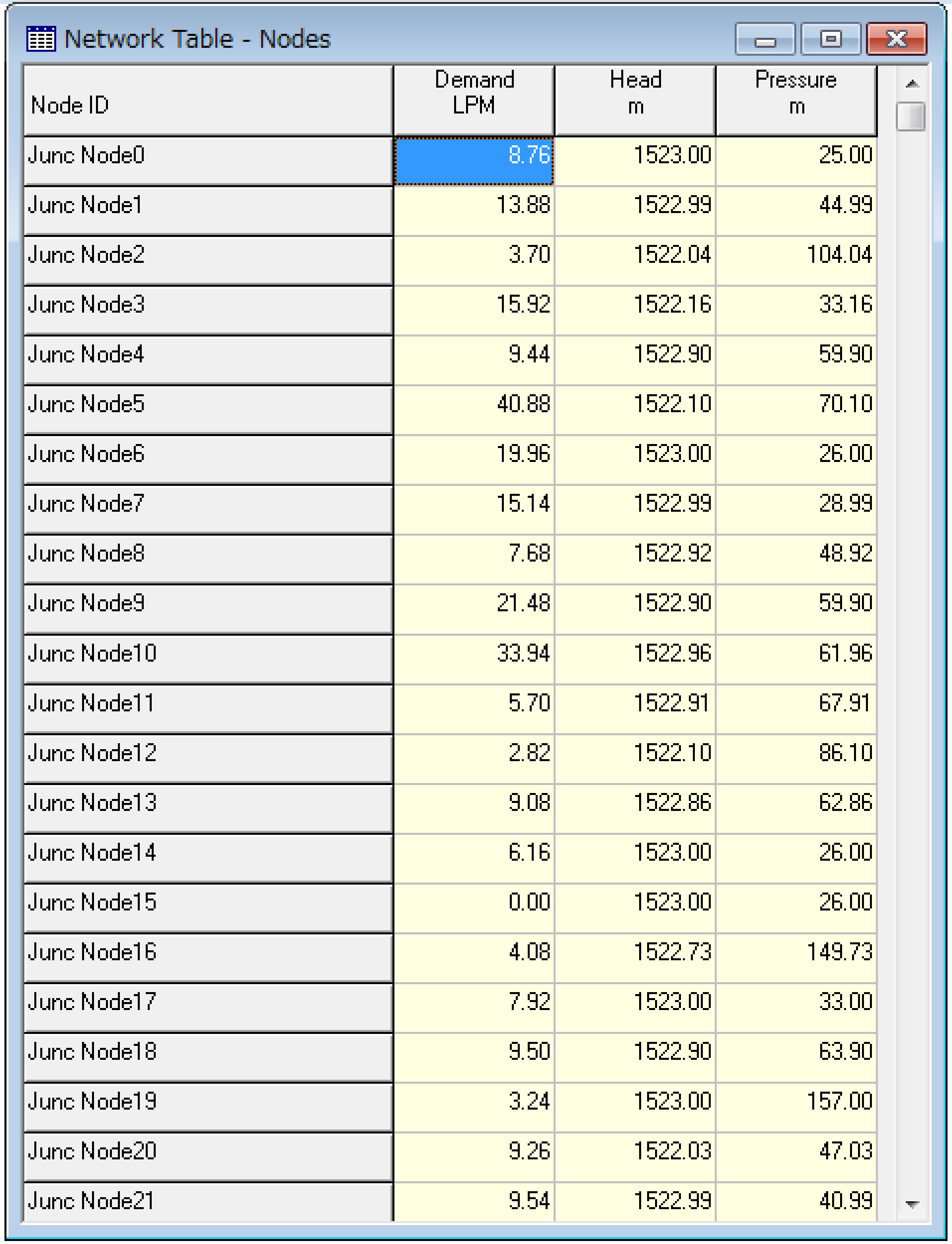
Select the type of table to create:

● Network Nodes

○ Network Links

○ Time series for node

○ Time series for link



Node ID	Demand LPM	Head m	Pressure m
Junc Node0	8.76	1523.00	25.00
Junc Node1	13.88	1522.99	44.99
Junc Node2	3.70	1522.04	104.04
Junc Node3	15.92	1522.16	33.16
Junc Node4	9.44	1522.90	59.90
Junc Node5	40.88	1522.10	70.10
Junc Node6	19.96	1523.00	26.00
Junc Node7	15.14	1522.99	28.99
Junc Node8	7.68	1522.92	48.92
Junc Node9	21.48	1522.90	59.90
Junc Node10	33.94	1522.96	61.96
Junc Node11	5.70	1522.91	67.91
Junc Node12	2.82	1522.10	86.10
Junc Node13	9.08	1522.86	62.86
Junc Node14	6.16	1523.00	26.00
Junc Node15	0.00	1523.00	26.00
Junc Node16	4.08	1522.73	149.73
Junc Node17	7.92	1523.00	33.00
Junc Node18	9.50	1522.90	63.90
Junc Node19	3.24	1523.00	157.00
Junc Node20	9.26	1522.03	47.03
Junc Node21	9.54	1522.99	40.99

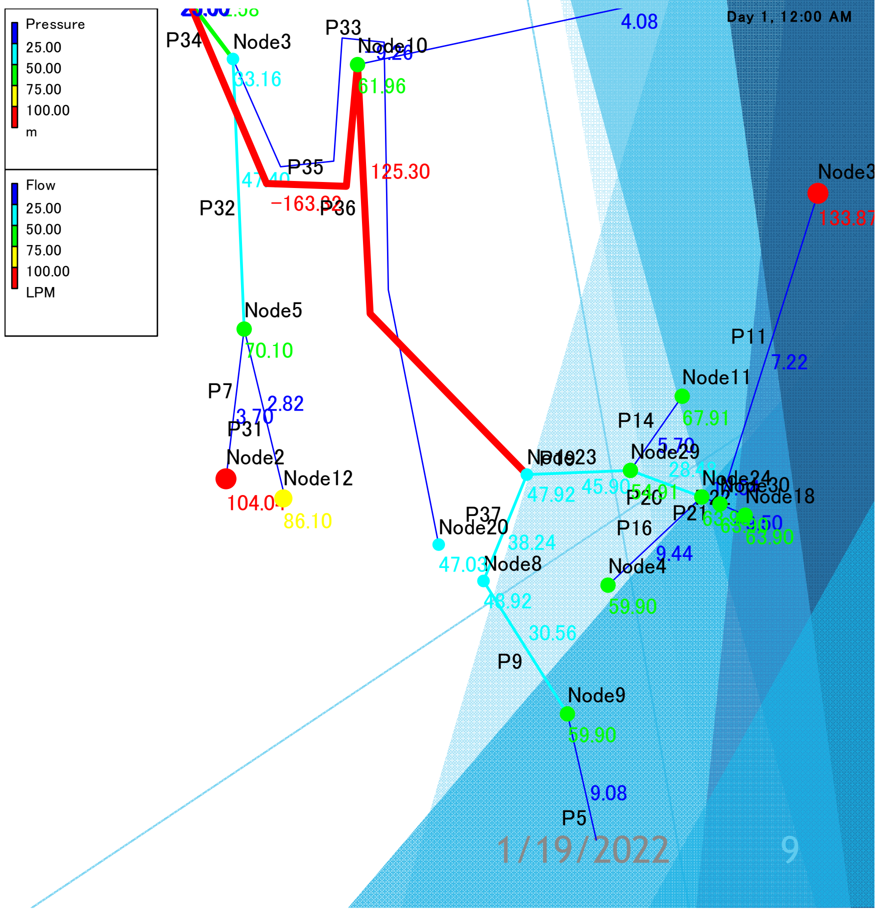
1. Map Data Export

Map can be exported to

- Image: emf format

The area displayed in the map window is exported

- CAD: dxf format
- Text



EPANET is not very good at exporting

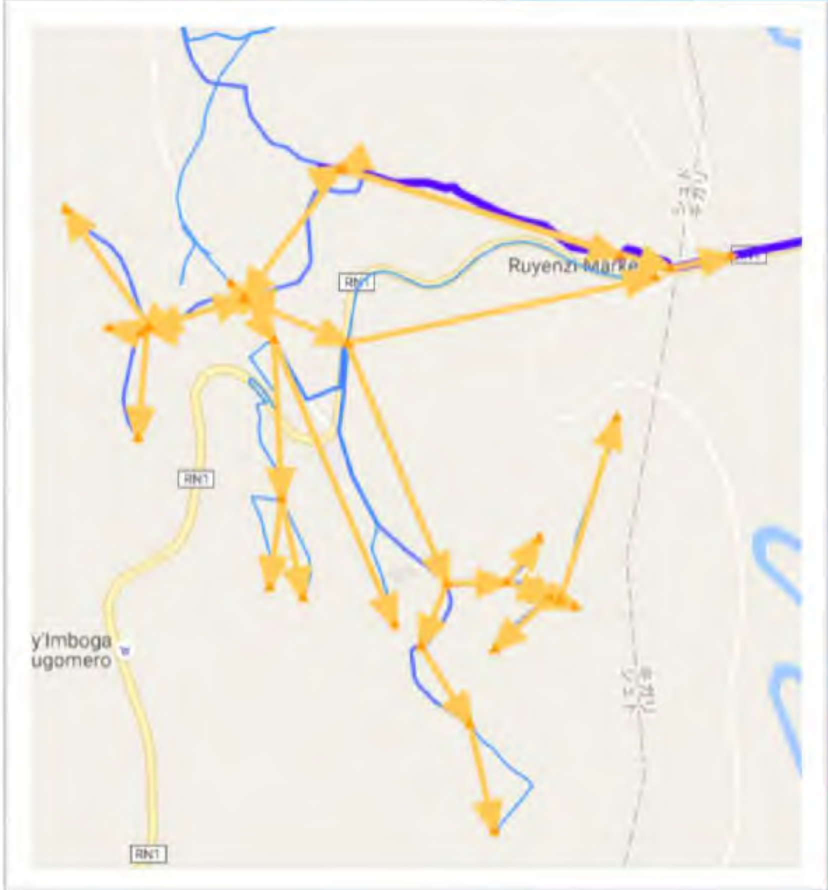
- PDF and CSV are not available

1. Analysis Result Export

Report > Full

- Analysis result can be exported to a text file
  - Converted to shapefile

    (and more…)
  - Then, onto ArcMap



File > Export > Network

- To a text file
- Note: Pressure and other attributes are not included

1. Data Import

- Net format is the default (native) format
  - Not plain text. The specification of the format is unclear
- Can also accept an inp format file
  - We can guess how it is interpreted

File > Open

- Select a map file or an inp file

Import > Network

- Select an inp file

1. EPANET Functions

- EPANET can do a lot of useful things
- Sometimes not user-friendly

- But we can export our network data to EPANET and import the analysis result

- EPANET can be an analysis engine

- If you don’t like using EPANET directly, you can use ArcGIS
- Mike Urban, instead, can call EPANET functions
- (Owen doesn’t use EPANET usually)

1. Ruyenzi

- Configure as you prefer

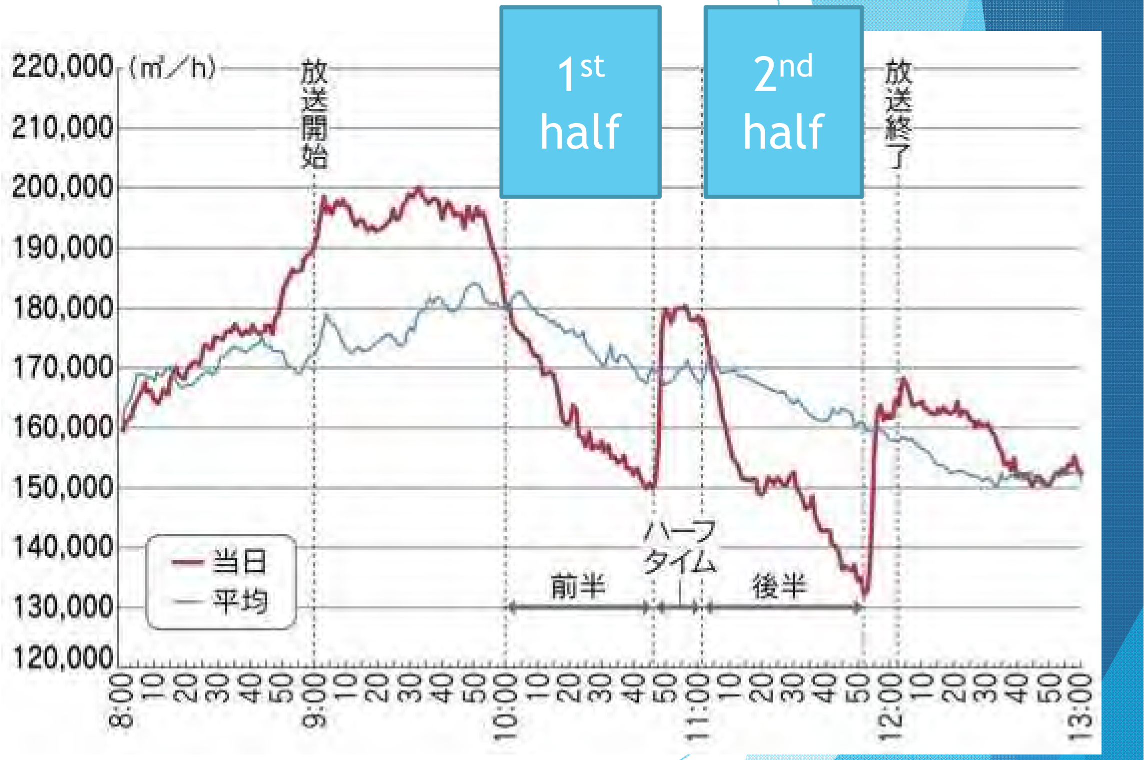
1. Run the analysis
2. Colorize nodes and pipes
3. Add annotations
4. Show a table of node attributes
5. Show the contour of pressure

- Which node has the highest pressure?
- Which pipe has the greatest flow?

2. When they use most water

- At 7am, people use most water on a day
- Because of tanks, the consumption pattern is complicated
- Plus, seasonal change
- How should you

  set the demands?



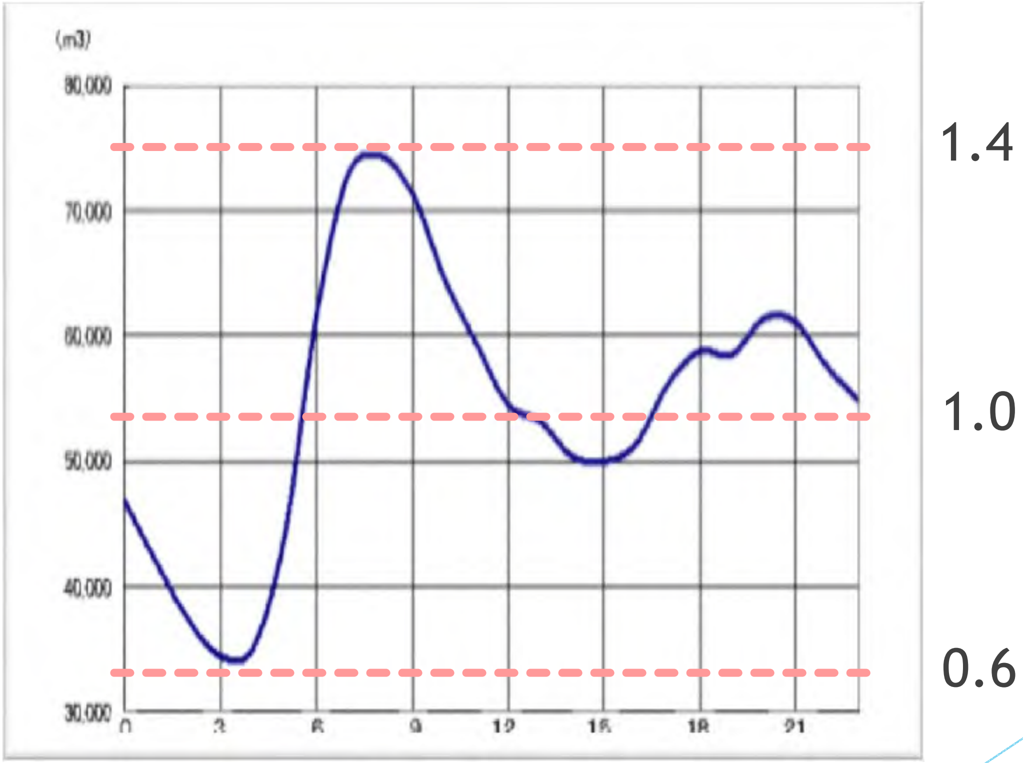
Data from Tokyo Waterworks
Football World Cup 2014, Japan vs Côte d'Ivoire
June 15th Sun

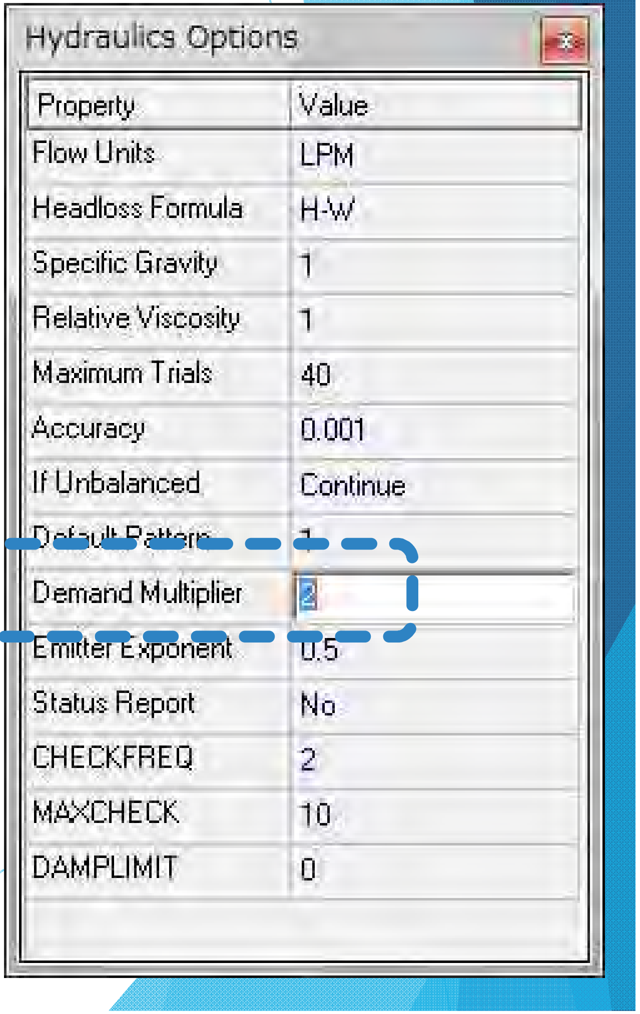
2. Demand Multiplier

- EPANET can multiply each demand by a specified number
- No need to edit the demand of every junction

- To analyze the case of max usage,

  1.3 ~ 1.5 is usually good





Hydraulics Options

Property	Value
Flow Units	LPM
Headloss Formula	H-W
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	2
Emitter Exponent	0.5
Status Report	No
CHECKFREQ	2
MAXCHECK	10
DAMPLIMIT	0

2. Negative Pressure

- Set a very large number to the multiplier
  - Some nodes have negative pressure

- Q is positive = water flows

- H-W equation doesn't use elevation or pressure directly

$$h = \frac{10.666 * (Q/1000)^{1.85}}{C^{1.85} * (D/1000)^{4.87}} * L$$

head = elevation + pressure

- Just describes how much the **<u>head decreases</u>** as a result
  - **<u>Doesn't care if the pressure is negative</u>** or not

2. Negative Pressure

- Water cannot reach such an area basically
- We shouldn’t use H-W equation in such a case

- If negative pressure is calculated where water is really available,

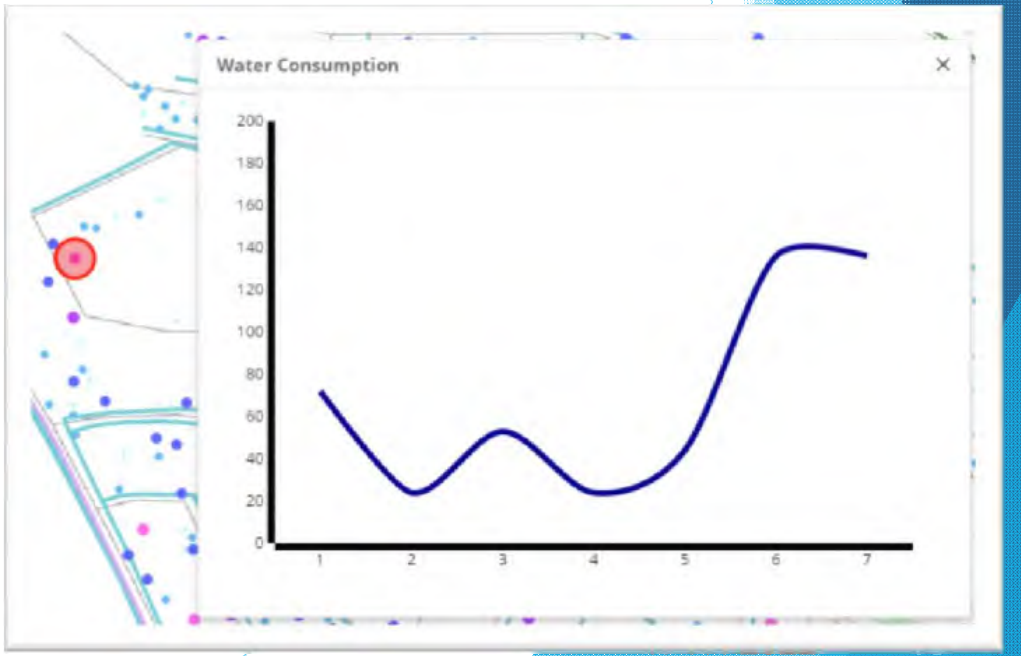
  we’ve made some mistakes
- We should create a model

  so that no junction has negative pressure

2. Demand Multiplier

- Metered consumption doesn’t include leaked water from pipes
  - Such water loss is a part of water flow in pipes, actually
  - Behaves according to H-W equation
- Many metered values change significantly
  - Unbelievable

- Multiplier should be larger



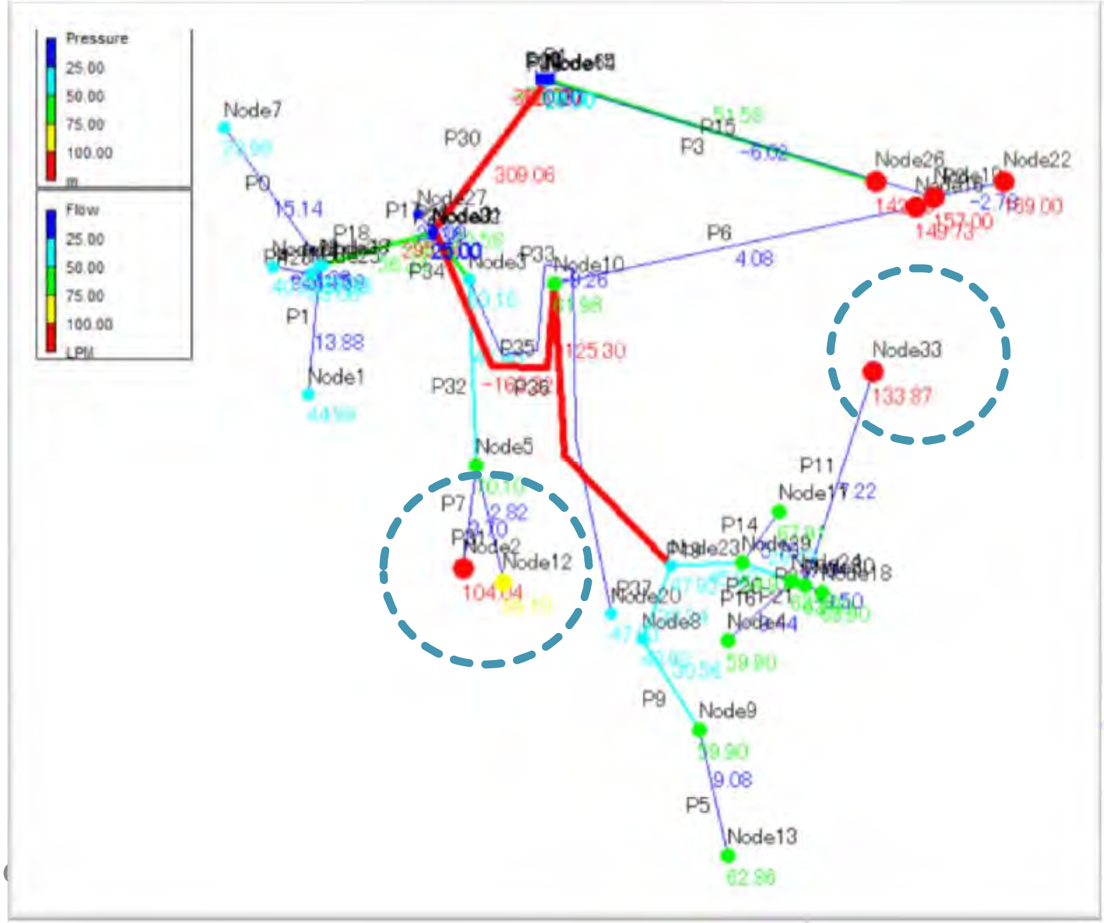
$$1.5 * (100/(100-\mathrm{NRW})) * \mathrm{margin}$$

$$\fallingdotseq 2.6$$

$(\mathrm{NRW} \fallingdotseq 30\%,\ \mathrm{margin} = 1.2)$

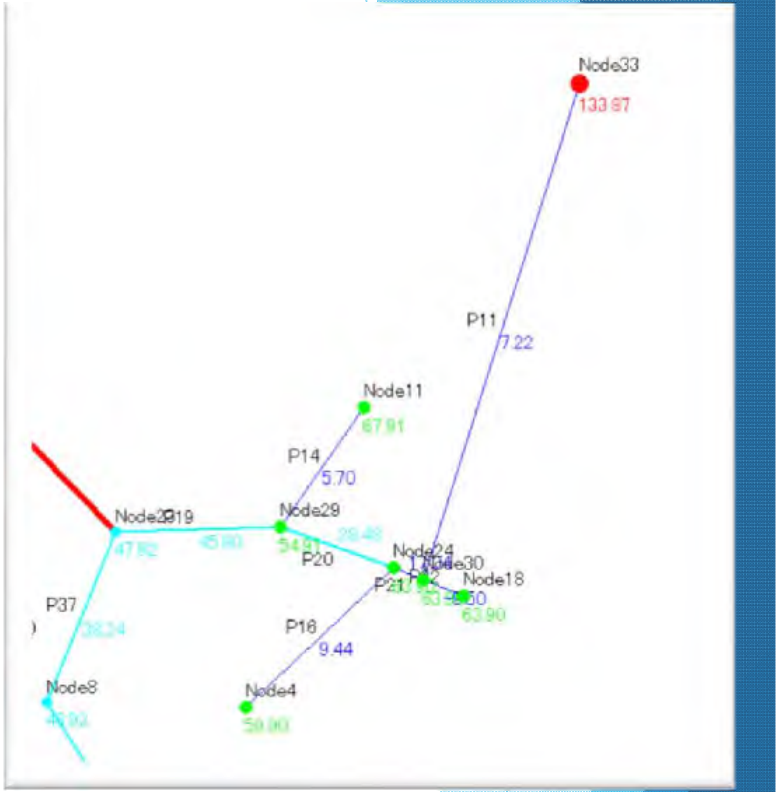
2. Ruyenzi – Pressure Problem

- Pressure is too high (>100 m)
- Pressure of 20 - 30 m is best
- Pressure of >50 m is a little too high



2. Pressure Reducing Valve

- Install a PRV, pressure reducing valve



On a pipe to install a PVC…

1. Add a pair of junctions
2. Add a pair of pipes

   to connect to the junctions
3. Delete the original pipe
4. Add a valve between the junctions
5. Enter an appropriate outlet pressure the Setting attribute
   - 20 m

3. Schedule

- Oct 21st – 23rd: Preparation for the 27th Training
  - Discussion between GIS team is included
  - Rehearsal is very good
    - Rosine and Vedaste can play the role of trainee
- Oct 27th: Training to other WASAC staff
  - GIS team is the trainers
  - Owen is an assistant trainer

- Oct 28th - Nov 10th: Additional Training to GIS team
  - Depending on your request
  - Practice of analyzing some regions in Kigali?
- Nov 11th: Owen’s flight to Tokyo

3. Training to Other WASAC Staff

On October 27th Thu, at WASAC HQ

1. Very Basics of Hydraulics

   20min? By Jean Paul?

2. How do You Get the Pressure at a Point? - Hazen-Williams Equation

   30min? By Claudien?

3. Exercise using Hazen-Williams Equation

   20min? By Claudien?

4. Short Introduction of Hydraulic Analysis

   10min? By Claudien?

5. What We Have Achieved So Far

   10min? By Claudien?

6. Discussion: What Should We Do Next using Hydraulic Analysis?

   15min? By Jean Paul?

Introduction of Hydraulic Analysis 5

Hiloki OWEN from Geoplan Japan

JICA Expert of Hydraulic Analysis

November 4th 2016

What Owen has done

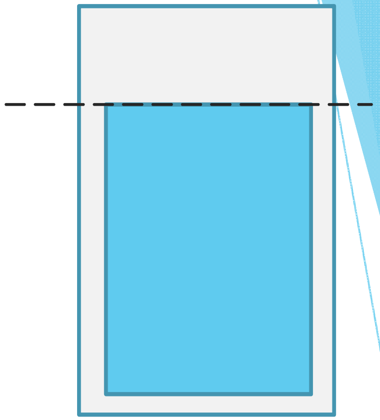
- Training of Hydraulic Analysis
    1. What do you want to do using Hydraulic Analysis?
    2. Very Basics of Hydraulics
    3. Hazen-Williams Equation
    4. Data Flow & Handling through WASAC
    5. Data Quality and Analysis' Reliability
    6. How to use EPANET
    7. How to use Mike Urban (on-going)

- Assisted other members, providing helpful data
- Introduced our modern technology

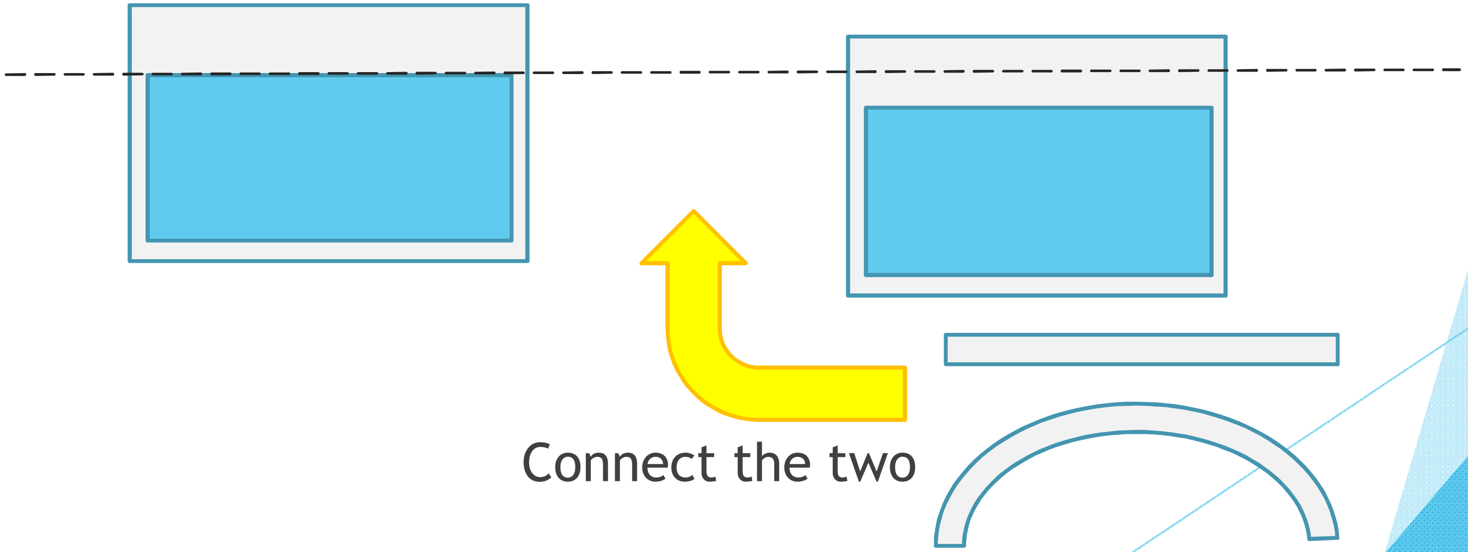
Hydraulics: Surface

- Water surface is flat

  if no one touches or moves it

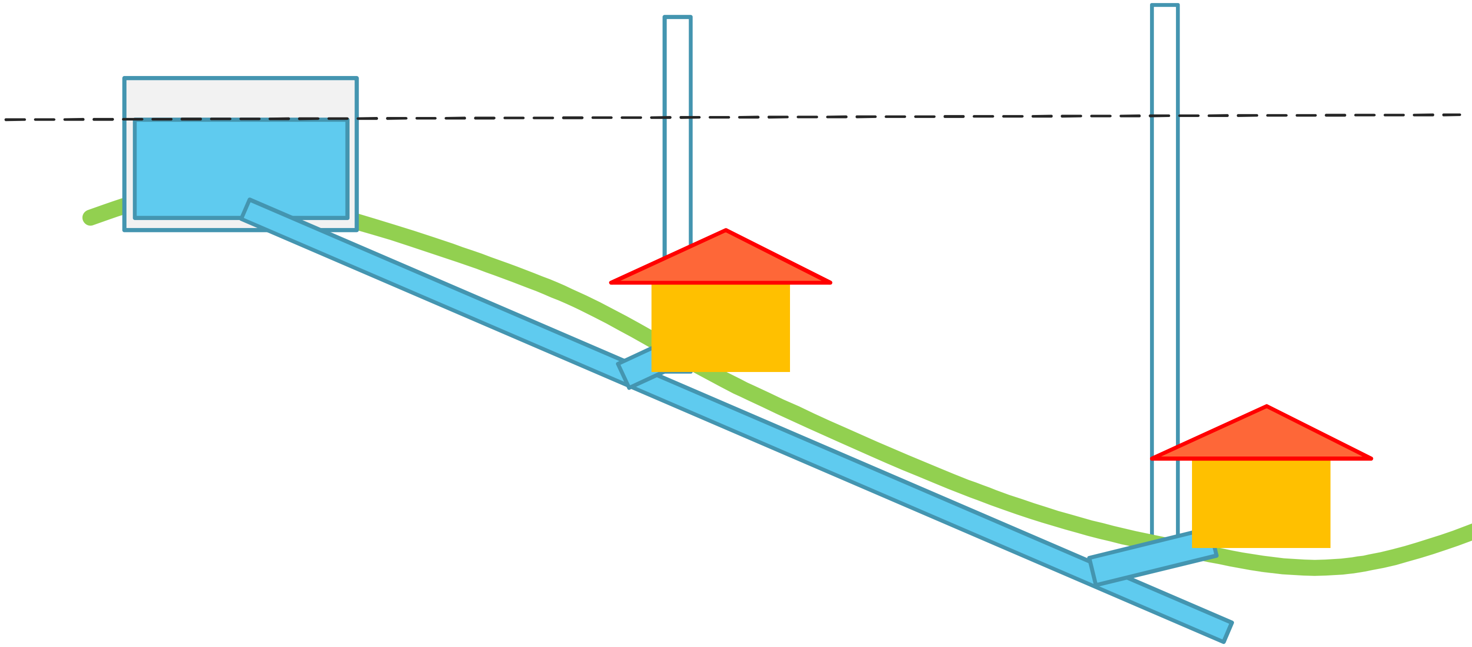


- The surfaces of connected water containers are going to be the same level



Connect the two

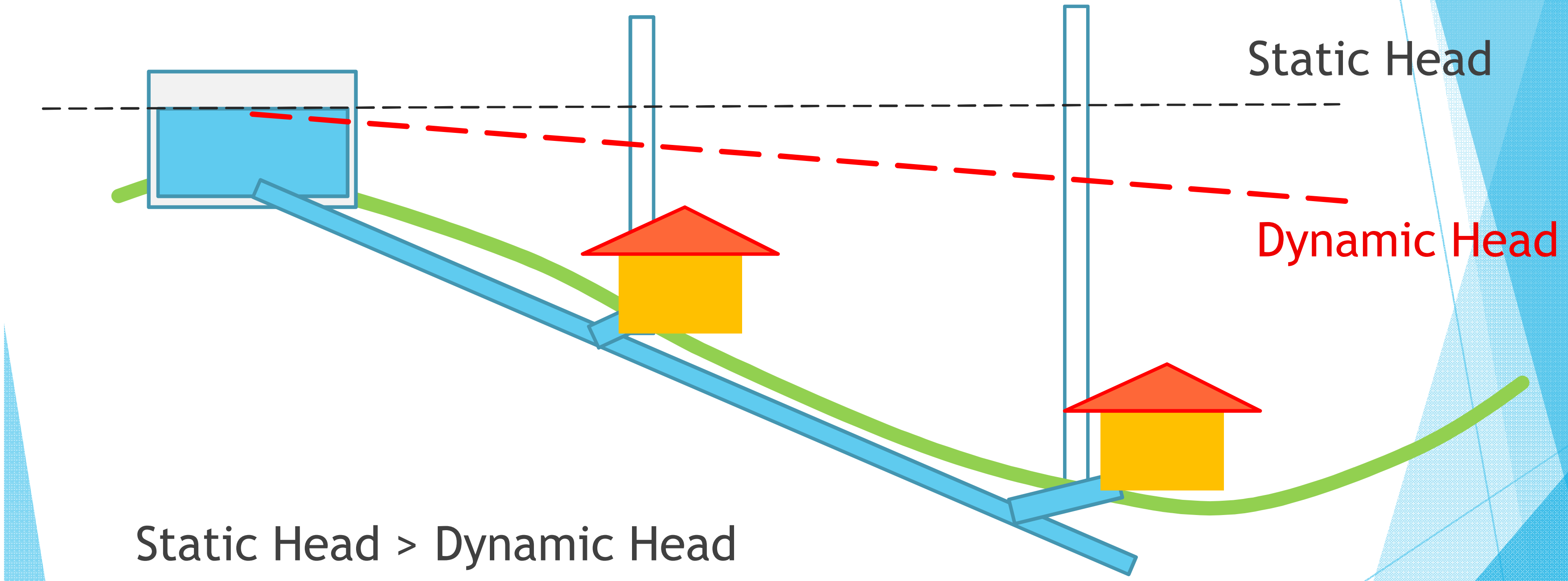
Hydraulics: Static Head



1. Think of a virtual surface of water
    - It is nearly constant
    - can be a good indicator for pressure
2. **<u>Head</u>** = Elevation + Pressure

Hydraulics: Flow Friction

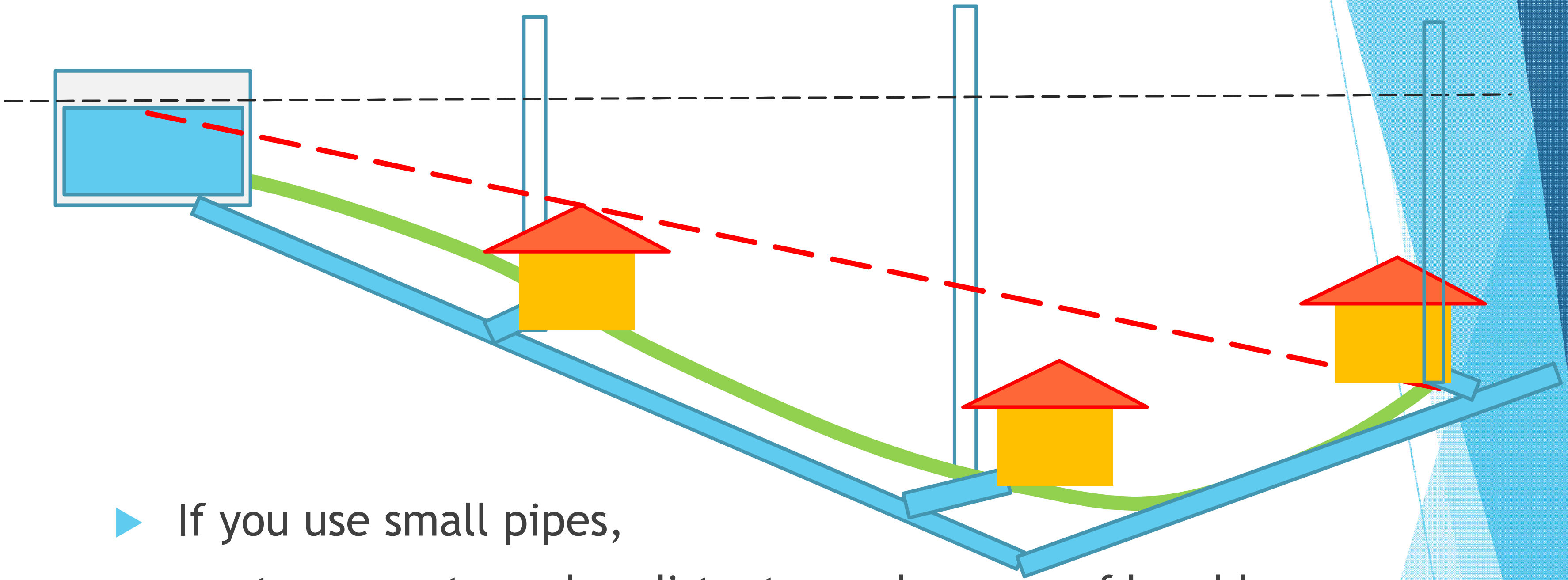
- When water flows through a pipe,
  its energy is going away because of friction



Static Head > Dynamic Head

(Static Head) – (Dynamic Head) = **Head Loss**

Hydraulics: Flow Friction



- If you use small pipes,

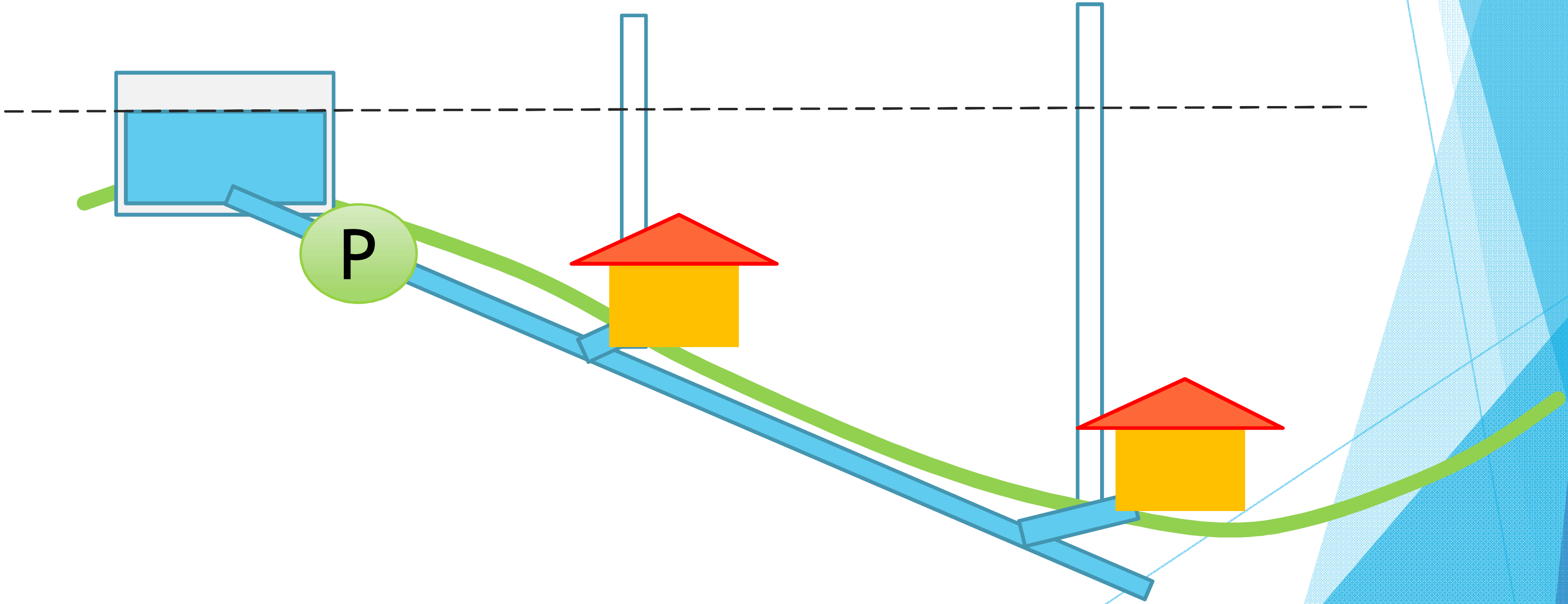
  water cannot reach a distant area because of head loss
- WASAC tends to use big enough pipes

  (excepting the trunk pipe from Nzove to Ntora)
- We can ignore head loss often
- We can roughly estimate pressure, thinking of the elev diff

Hydraulics: Pump

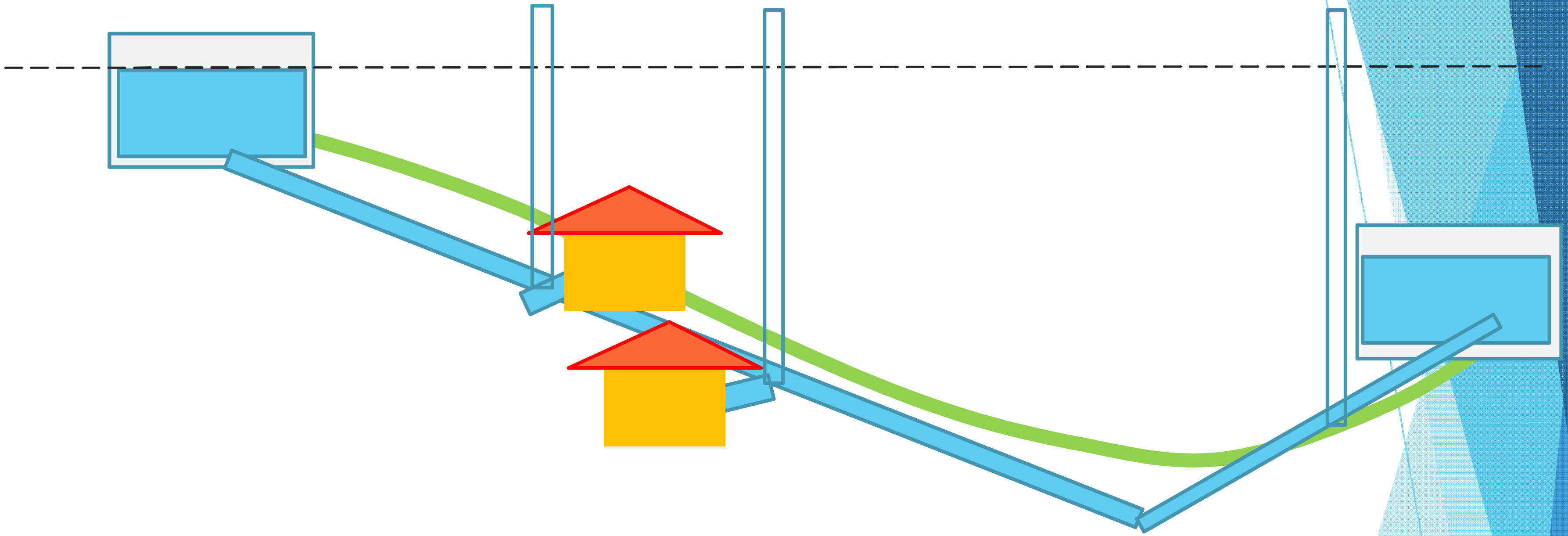
Virtual surface of water: **Head** = Elevation + Pressure

What if you install a pump



Hydraulics: Reservoir

What if you build a new reservoir



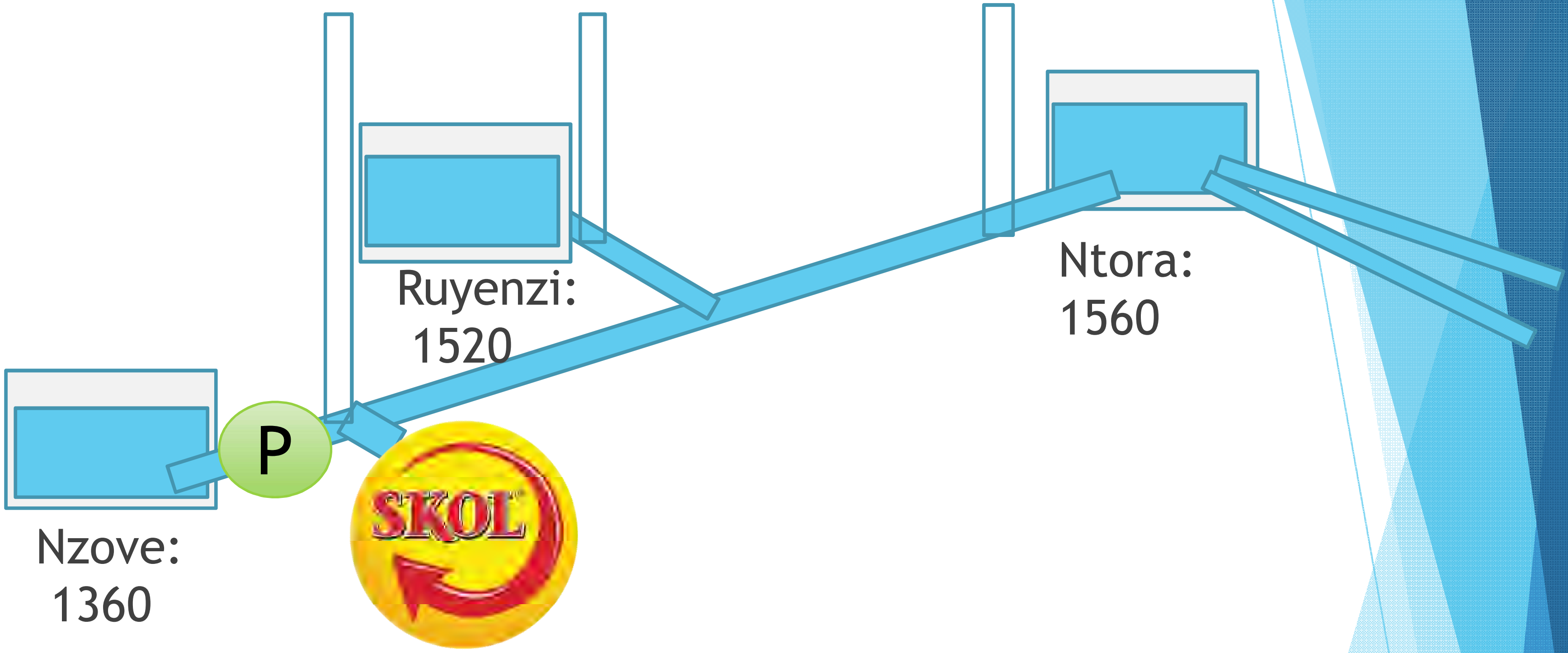
A directly connected area (without a PRV or pump)

has a similar head value

<u>Such a sub-area shouldn't have</u>

<u>two reservoirs of different elevations</u>

Hydraulics: Reservoirs in Kigali



- Critically important
- You’re able to support planners or others in WASAC using Hydraulics

What do you want to do using Hydraulic Analysis

What do you want to do using HA?

- HA software doesn't let you **<u>know</u>** the pressure and other attributes of your network
- It just **<u>provides a reasonable estimation from your input</u>**
  - Sometimes wrong because of many kinds of configuration
- It doesn't solve a general problem of water network
- You must define the issue you want to solve

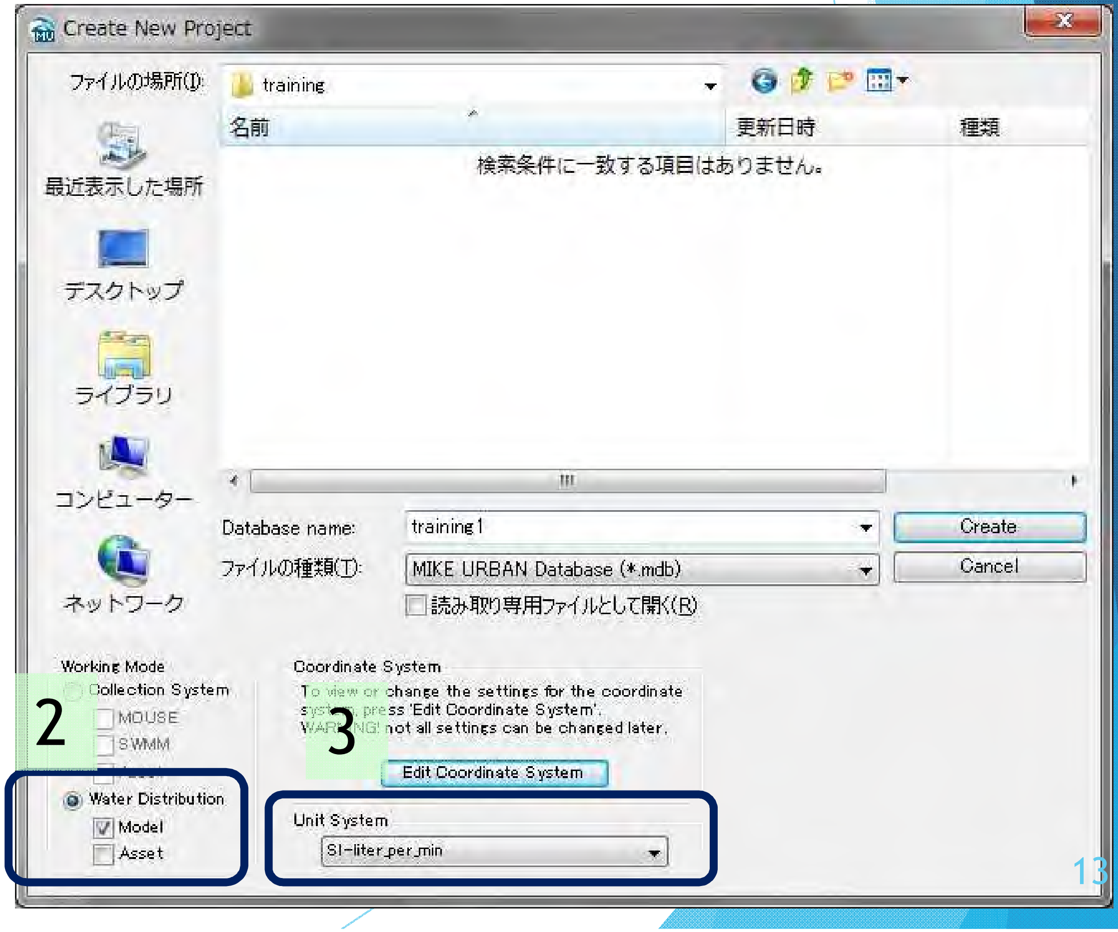
eg:

1. The pressure is very high in Ruyenzi area
2. Pressure should be reduced in area X, especially
3. Where should we install a PRV?
   - **<u>What the pressure will be</u>**, after installing the PRV to point Y?
   - How about installing it to point Z?

Mike Urban Exercise

Mike Urban: Create Project

1. Create new project
2. Check “Water Distribution Model”
3. Ensure Unit is SI_liter_per_min (or something you like)



Create New Project

ファイルの場所(I): training

検索条件に一致する項目はありません。

Database name: training1

ファイルの種類(T): MIKE URBAN Database (*.mdb)

☐ 読み取り専用ファイルとして開く(R)

Working Mode

○ Collection System

☐ MOUSE

☐ SWMM

☐

● Water Distribution

☑ Model

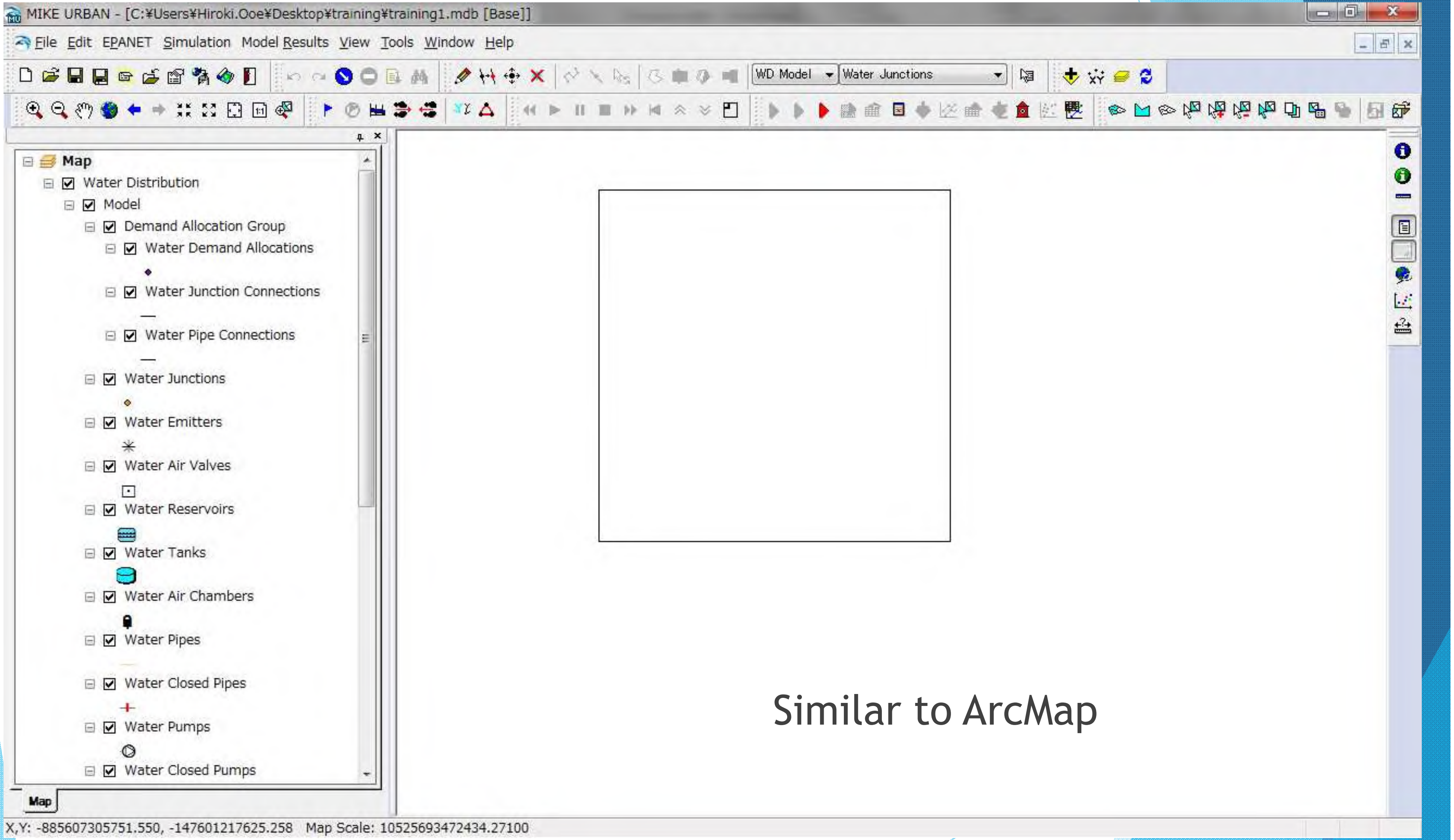
☐ Asset

Coordinate System

To view or change the settings for the coordinate system, press 'Edit Coordinate System'. WARNING! not all settings can be changed later.

Unit System: SI-liter_per_min

Mike Urban: Main Window

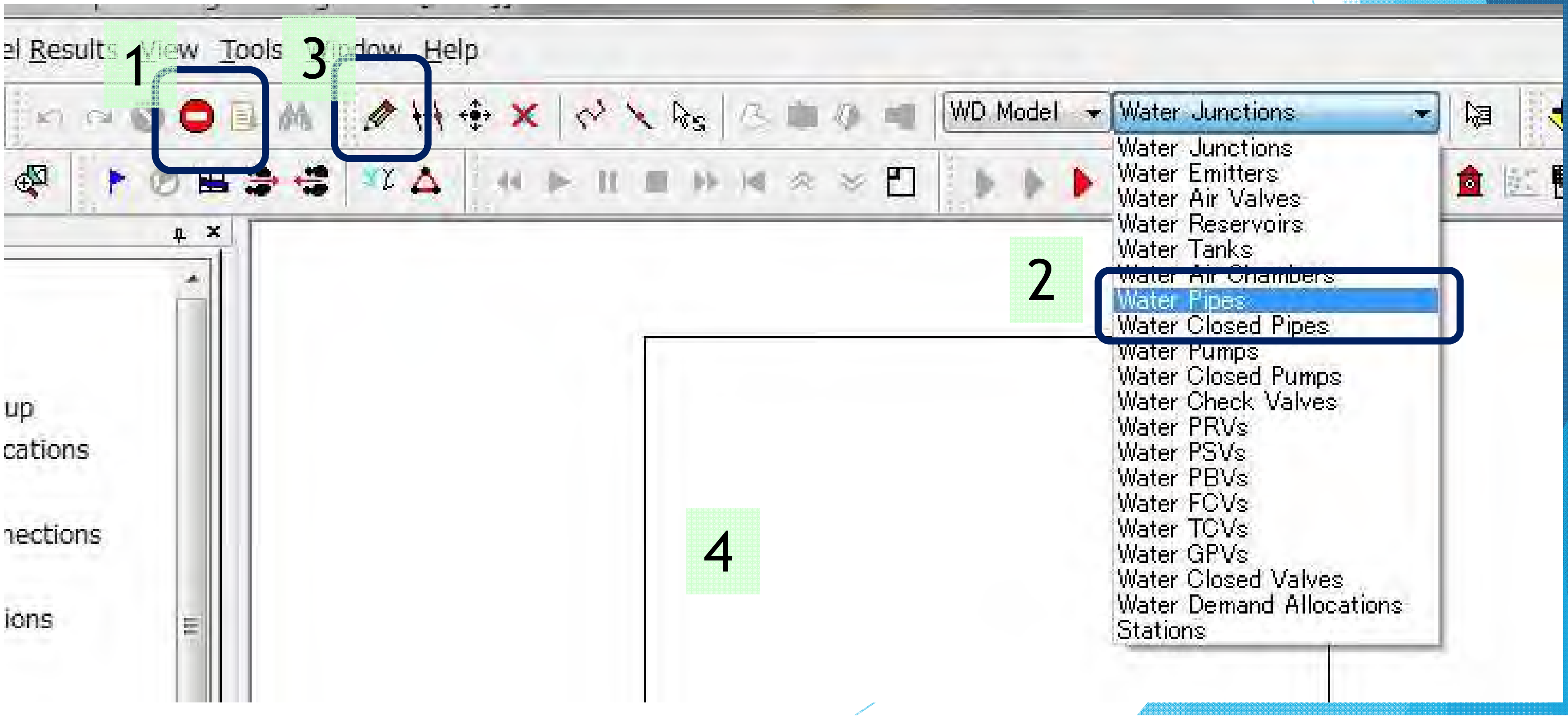


X,Y: -885607305751.550, -147601217625.258 Map Scale: 10525693472434.27100

Similar to ArcMap

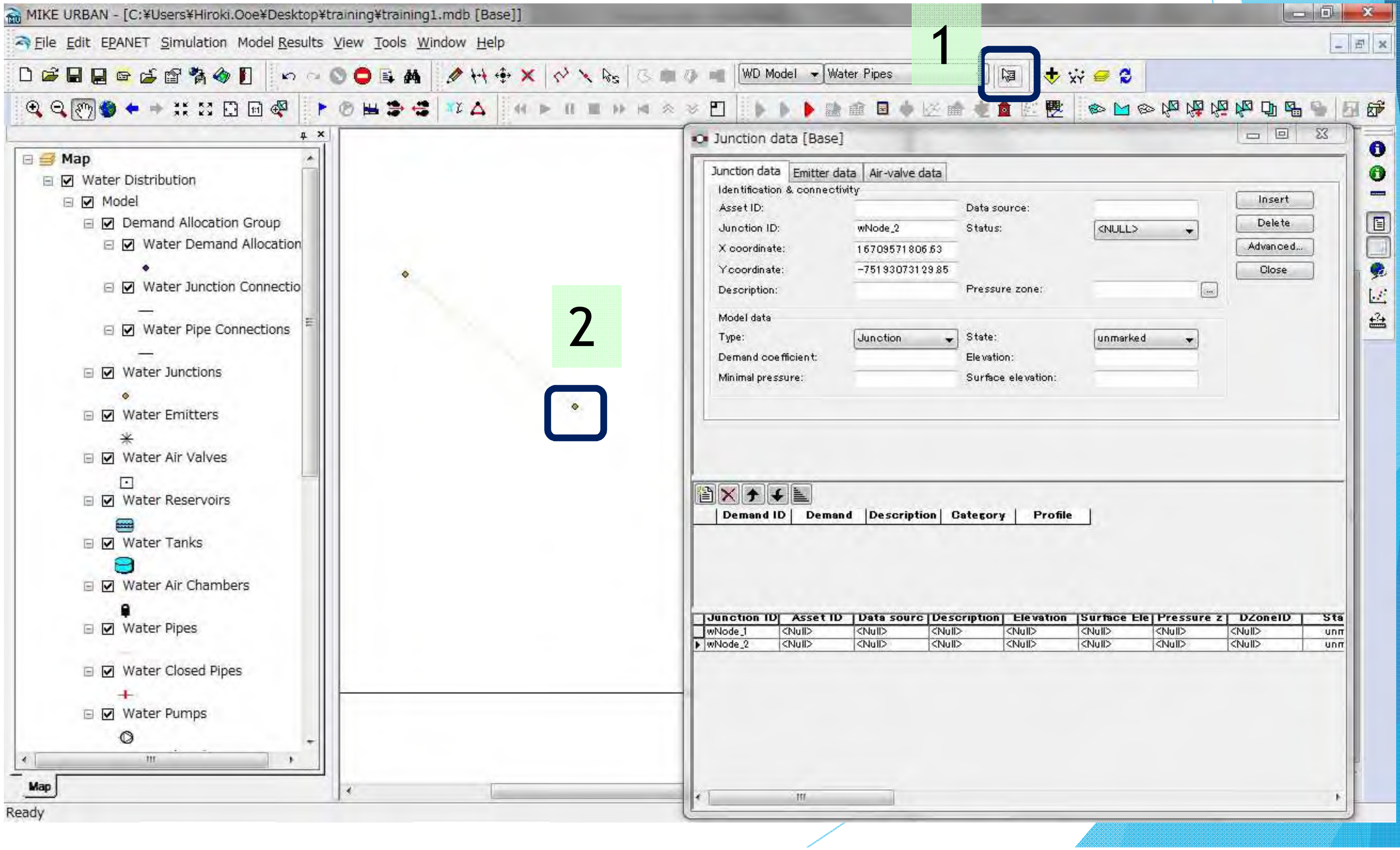
Mike Urban: Adding an Object

1. Start Editing
2. Select the object you want to add
3. Create Object
4. Click somewhere on the map



Mike Urban: Object Editor

1. Open Editor
2. Click an object



Identification & connectivity

Asset ID:

Junction ID: wNode_2

X coordinate: 16709571806.63

Y coordinate: -75193073129.85

Description:

Data source:

Status: <NULL>

Pressure zone:

Model data

Type: Junction

Demand coefficient:

Minimal pressure:

State: unmarked

Elevation:

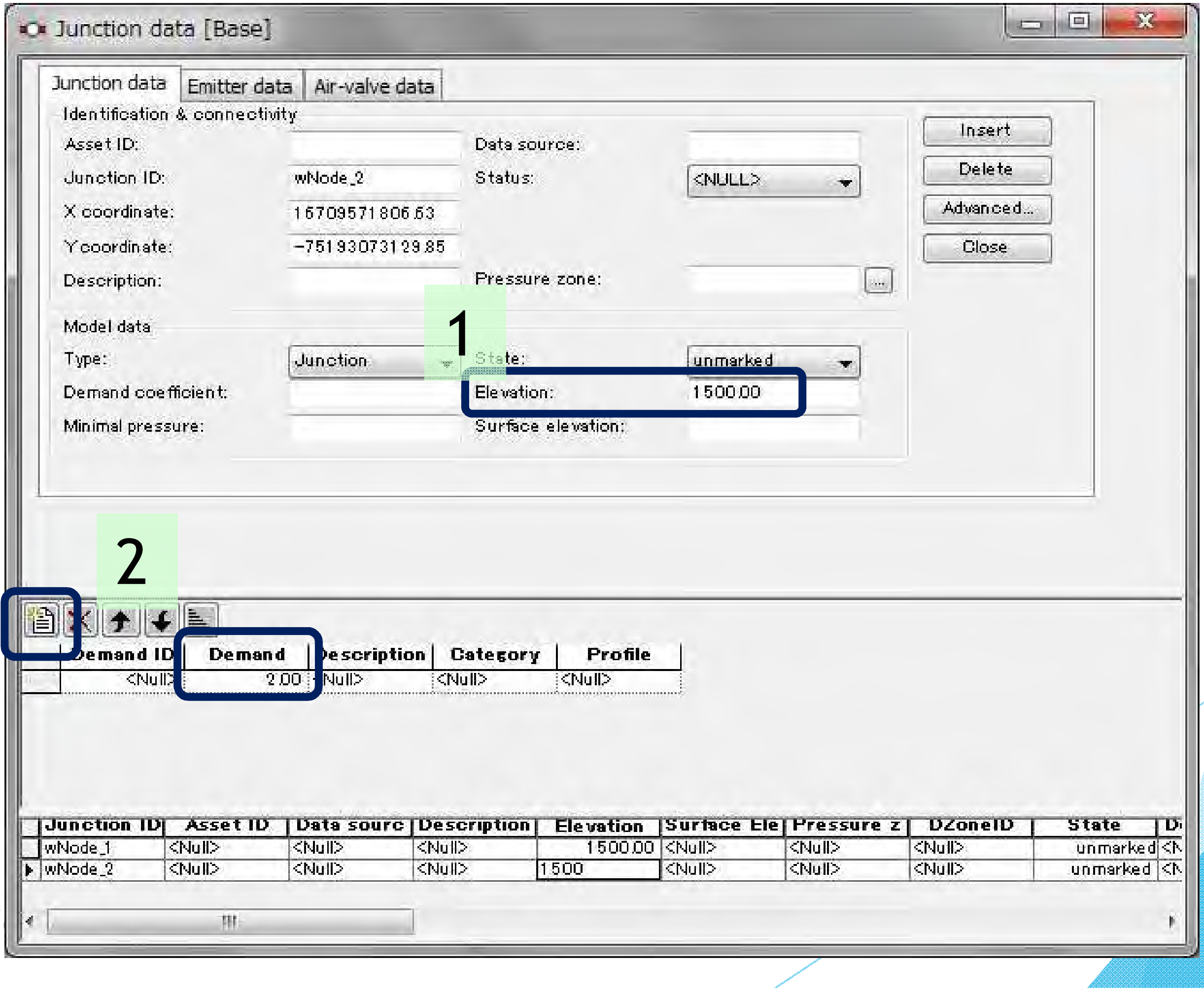
Surface elevation:

Demand ID	Demand	Description	Category	Profile

Junction ID	Asset ID	Data sourc	Description	Elevation	Surface Ele	Pressure z	DZoneID	Sta
wNode_1	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	unm
wNode_2	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	unm

Mike Urban: Junctions

1. Set the elevation to every junction (required)
2. Add a demand to some junctions



Junction data [Base]

Identification & connectivity

Asset ID:
Junction ID: wNode_2
X coordinate: 16709571806.63
Y coordinate: -7519307312985
Description:
Data source:
Status: <NULL>
Pressure zone:

Model data

Type: Junction
Demand coefficient:
Minimal pressure:
State: unmarked
Elevation: 1500.00
Surface elevation:

1

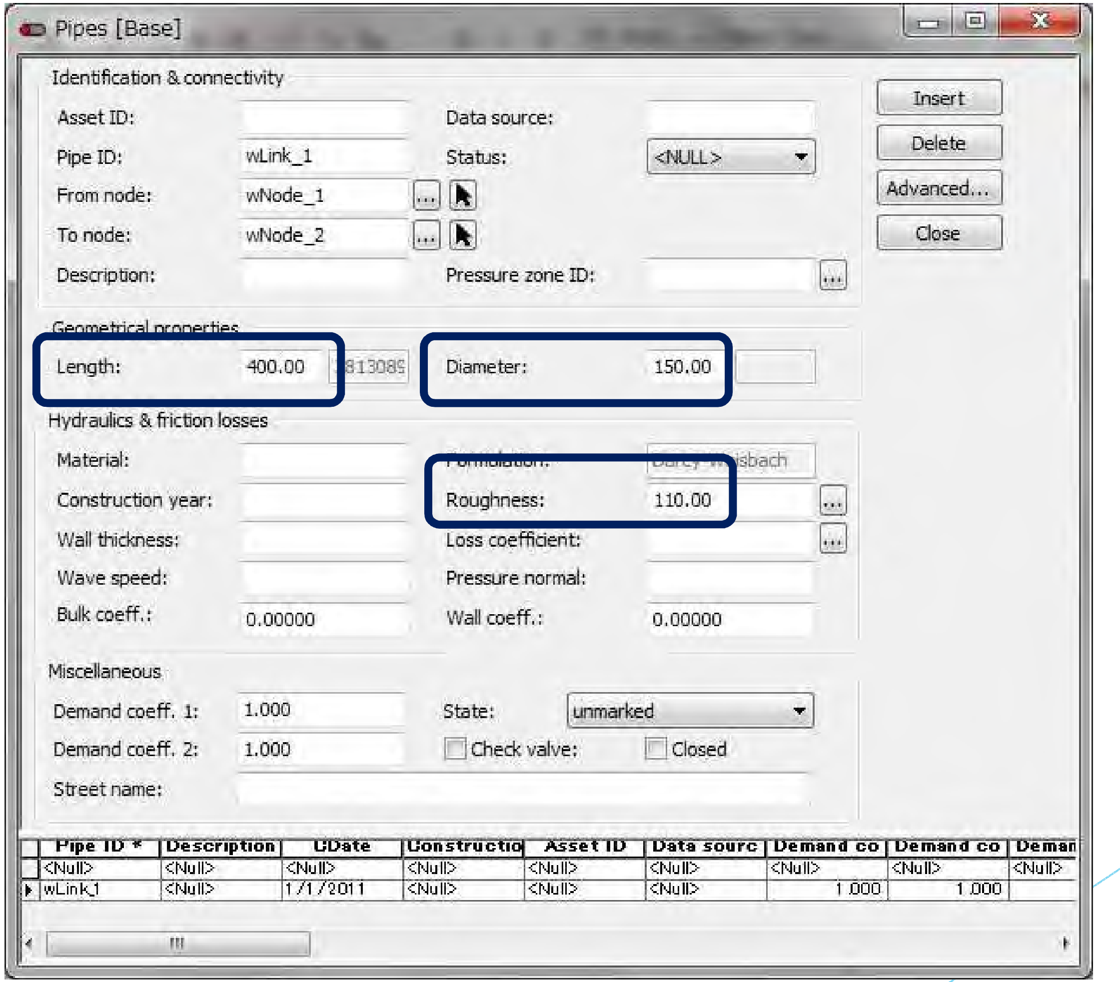
2

emand ID	Demand	escription	Category	Profile
<Null>	2.00	Null>	<Null>	<Null>

Junction ID	Asset ID	Data sourc	Description	Elevation	Surface Ele	Pressure z	DZoneID	State	D
wNode_1	<Null>	<Null>	<Null>	1500.00	<Null>	<Null>	<Null>	unmarked	<N
wNode_2	<Null>	<Null>	<Null>	1500	<Null>	<Null>	<Null>	unmarked	<N

Mike Urban: Pipes

- Set Length, Diameter and Roughness to every pipe (required)



Identification & connectivity

Asset ID:
Pipe ID: wLink_1
From node: wNode_1
To node: wNode_2
Description:
Data source:
Status: <NULL>
Pressure zone ID:

Geometrical properties

Length: 400.00 813089
Diameter: 150.00

Hydraulics & friction losses

Material:
Construction year:
Wall thickness:
Wave speed:
Bulk coeff.: 0.00000
Formulation: Darcy-Weisbach
Roughness: 110.00
Loss coefficient:
Pressure normal:
Wall coeff.: 0.00000

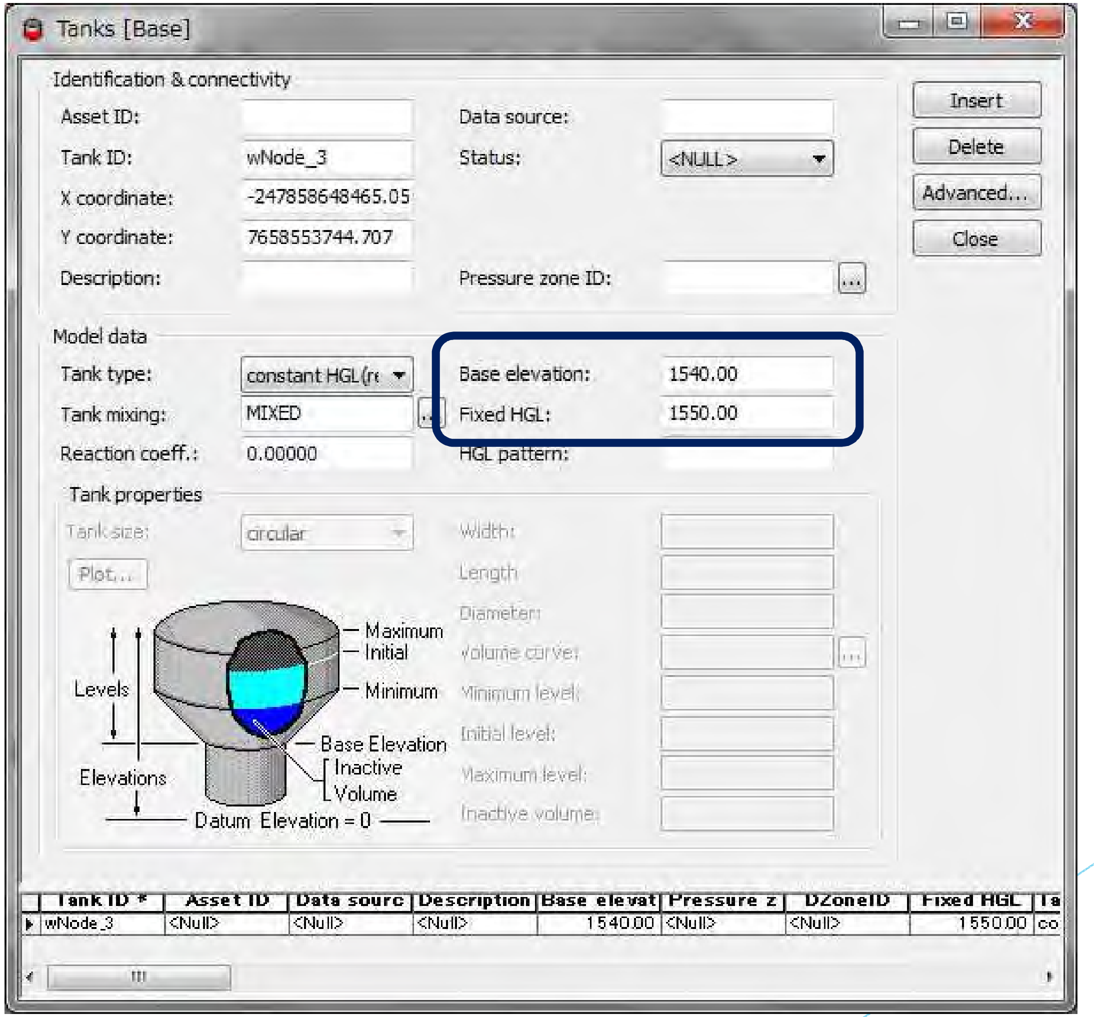
Miscellaneous

Demand coeff. 1: 1.000
Demand coeff. 2: 1.000
Street name:
State: unmarked
☐ Check valve:
☐ Closed

Pipe ID *	Description	CDate	Constructio	Asset ID	Data sourc	Demand co	Demand co	Deman
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
wLink_1	<Null>	1/1/2011	<Null>	<Null>	<Null>	1.000	1.000	

Mike Urban: Reservoirs

- Set Base elevation and Fix HGL (Fixed HGL is required)

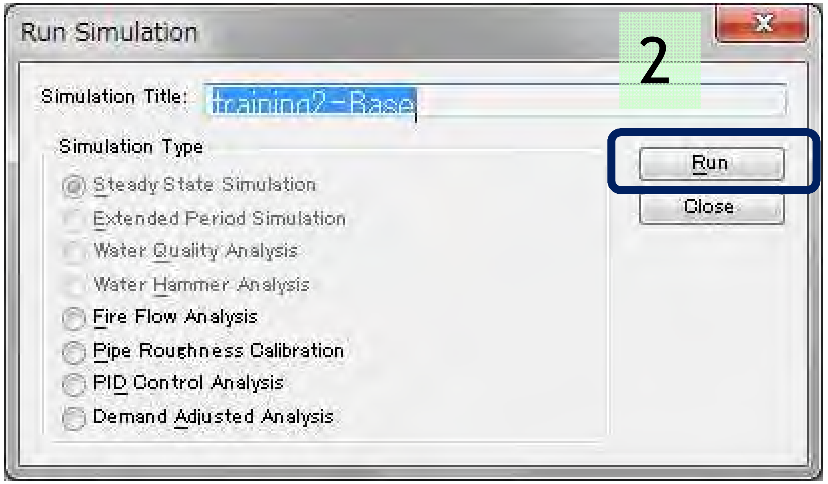


Asset ID:	
Tank ID:	wNode_3
X coordinate:	-247858648465.05
Y coordinate:	7658553744.707
Description:	
Data source:	
Status:	<NULL>
Pressure zone ID:	
Tank type:	constant HGL(re
Tank mixing:	MIXED
Reaction coeff.:	0.00000
Base elevation:	1540.00
Fixed HGL:	1550.00
HGL pattern:	
Tank size:	circular
Width:	
Length:	
Diameter:	
Volume curve:	
Minimum level:	
Initial level:	
Maximum level:	
Inactive volume:	

Tank ID *	Asset ID	Data sourc	Description	Base elevat	Pressure z	DZoneID	Fixed HGL	Ta
wNode_3	<Null>	<Null>	<Null>	1540.00	<Null>	<Null>	1550.00	co

Mike Urban: Running Analysis

1. Run Water Distribution Simulation
2. Run Simulation
3. Done

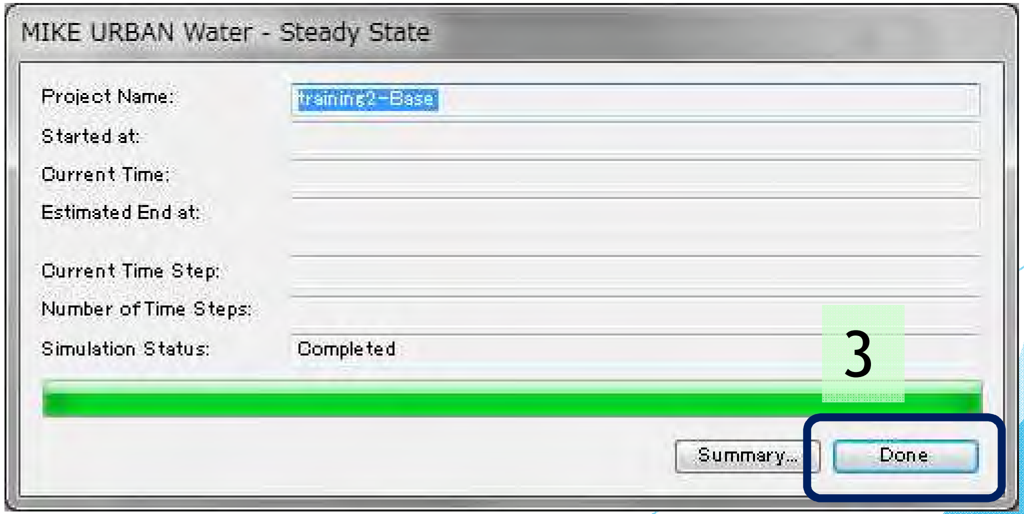


Run Simulation

Simulation Title: training2-Base

Simulation Type

- ● Steady State Simulation
- ○ Extended Period Simulation
- ○ Water Quality Analysis
- ○ Water Hammer Analysis
- ○ Fire Flow Analysis
- ○ Pipe Roughness Calibration
- ○ PID Control Analysis
- ○ Demand Adjusted Analysis

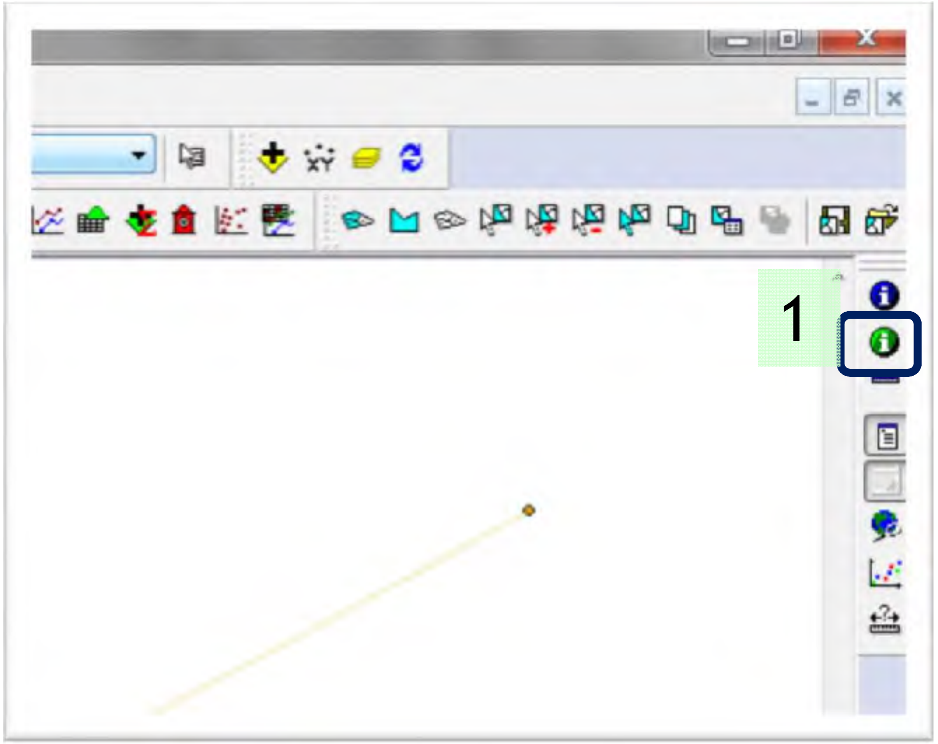


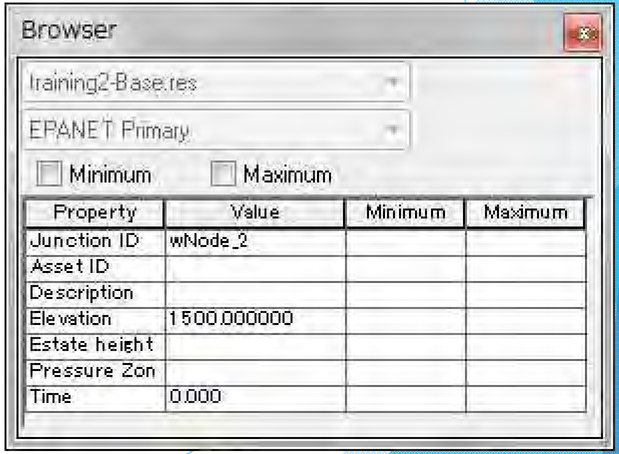
MIKE URBAN Water - Steady State

Project Name: training2-Base
Started at:
Current Time:
Estimated End at:
Current Time Step:
Number of Time Steps:
Simulation Status: Completed

Mike Urban: Check the result

1. Result Browser
2. Click an object on the map




Browser

training2-Base.res

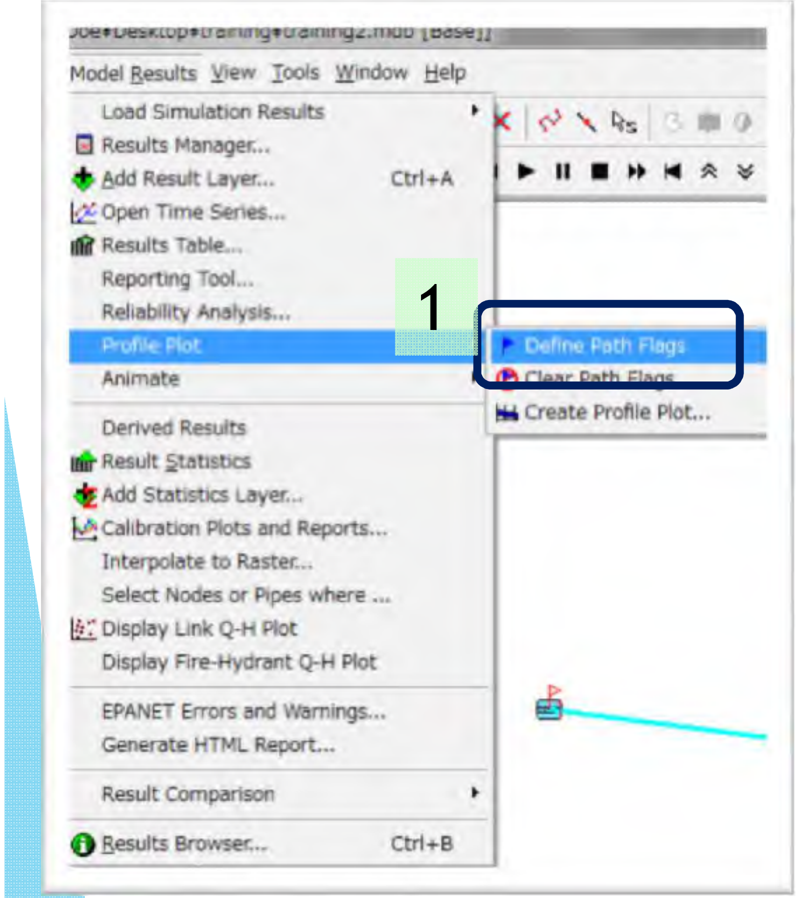
EPANET Primary

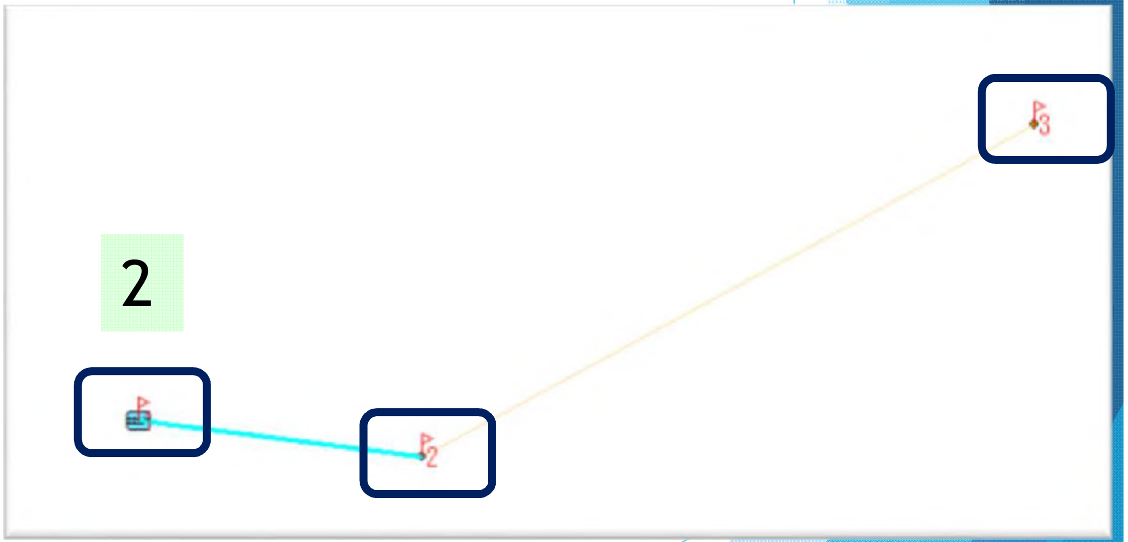
☐ Minimum ☐ Maximum

Property	Value	Minimum	Maximum
Junction ID	wNode_2		
Asset ID			
Description			
Elevation	1500.000000		
Estate height			
Pressure Zon			
Time	0.000		

Mike Urban: Check the result 1/2

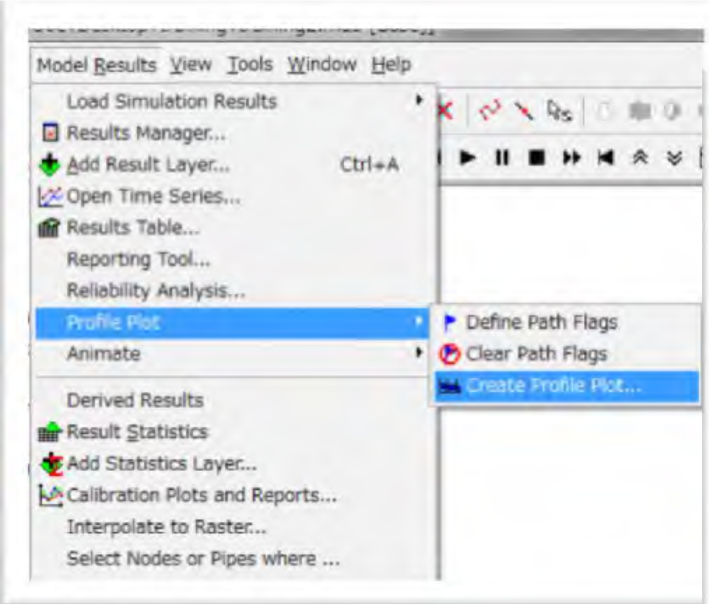
1. Model Results > Profile Plot > Define Path Flags
2. Click the objects along a path

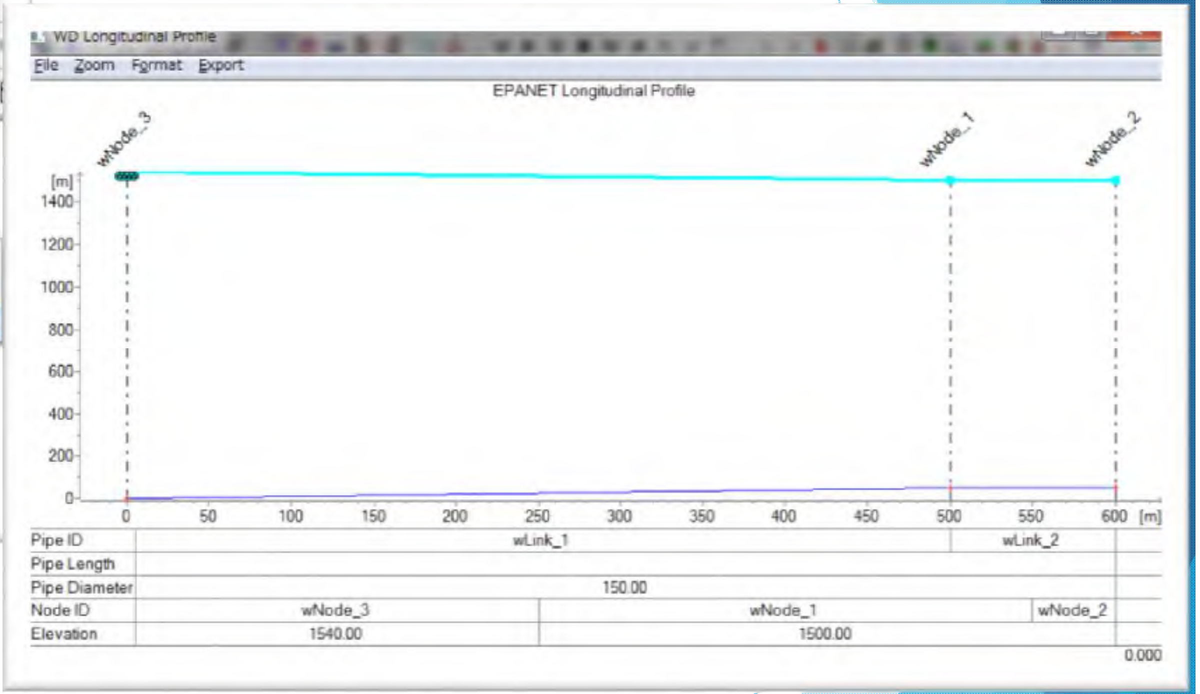




Mike Urban: Check the result 2/2

3. Create Profile Plot



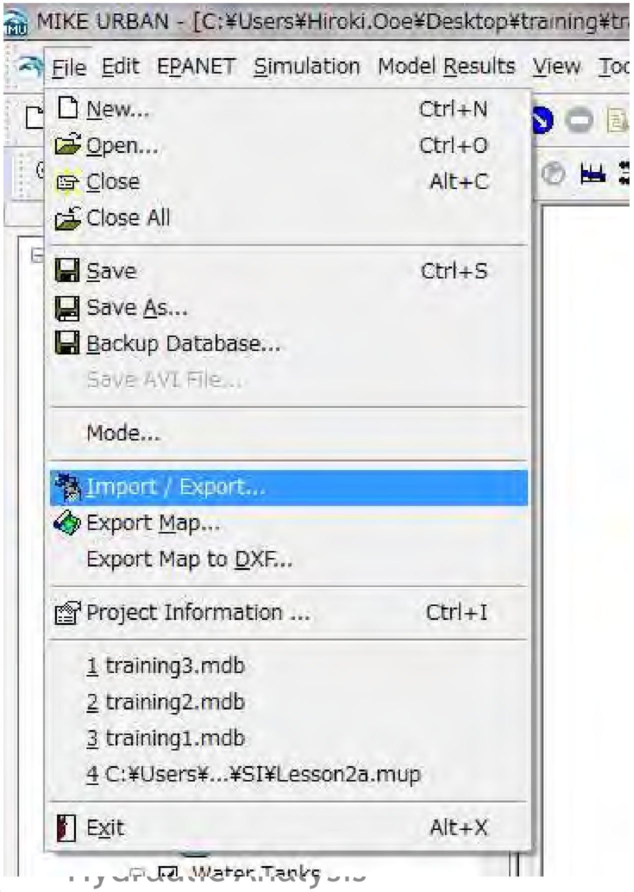


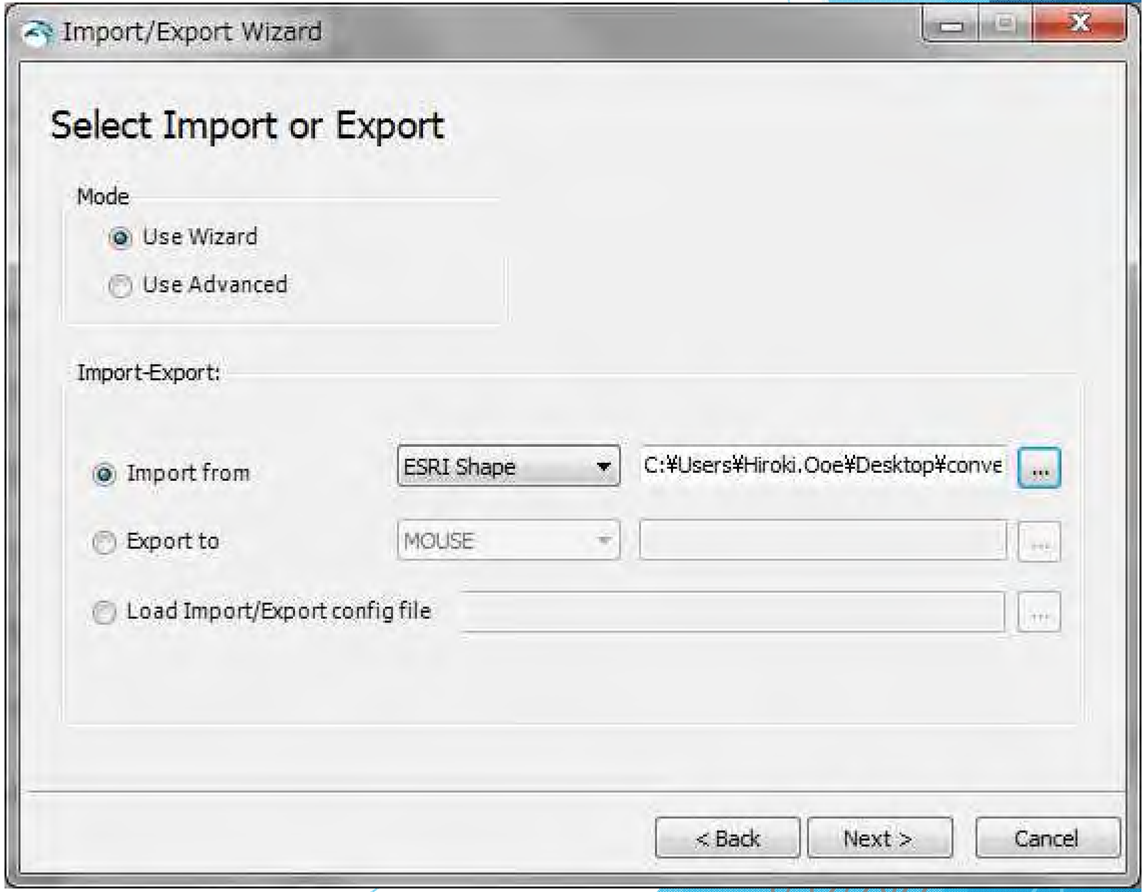
Pipe ID	wLink_1		wLink_2
Pipe Length			
Pipe Diameter	150.00		
Node ID	wNode_3	wNode_1	wNode_2
Elevation	1540.00	1500.00	

0.000

Mike Urban: Shapefile Import 1/5

1. File > Import/Export
2. Select the folder containing your shapefiles





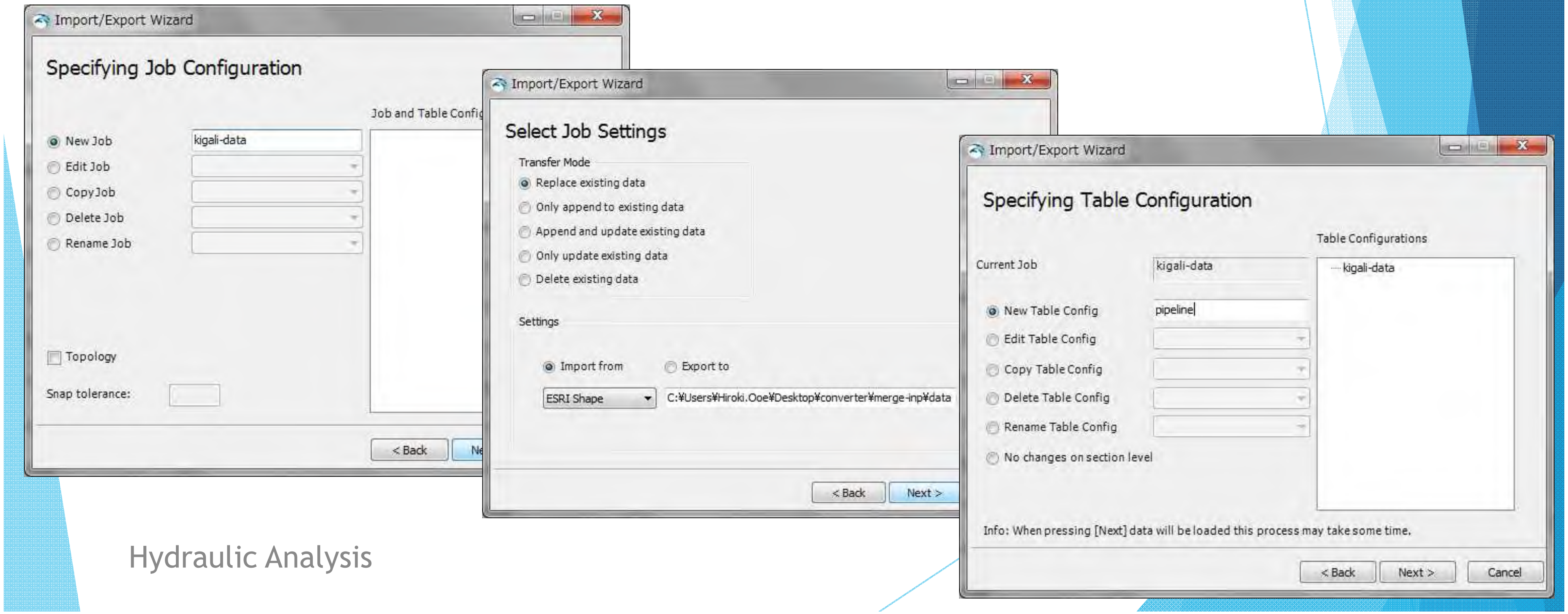
Select Import or Export

Mode
● Use Wizard
○ Use Advanced

Import-Export:
● Import from: ESRI Shape, C:¥Users¥Hiroki.Ooe¥Desktop¥conve ...
○ Export to: MOUSE
○ Load Import/Export config file

Mike Urban: Shapefile Import 2/5

3. Create an import job
    - the area name would be good for the job name
4. And replace the existing data
5. Create a table configuration
    - the object name would be good



Import/Export Wizard

Specifying Job Configuration

● New Job kigali-data
○ Edit Job
○ Copy Job
○ Delete Job
○ Rename Job

☐ Topology

Snap tolerance:

Import/Export Wizard

Select Job Settings

Transfer Mode
● Replace existing data
○ Only append to existing data
○ Append and update existing data
○ Only update existing data
○ Delete existing data

Settings
● Import from ○ Export to
ESRI Shape C:¥Users¥Hiroki.Ooe¥Desktop¥converter¥merge-inp¥data

Import/Export Wizard

Specifying Table Configuration

Current Job kigali-data

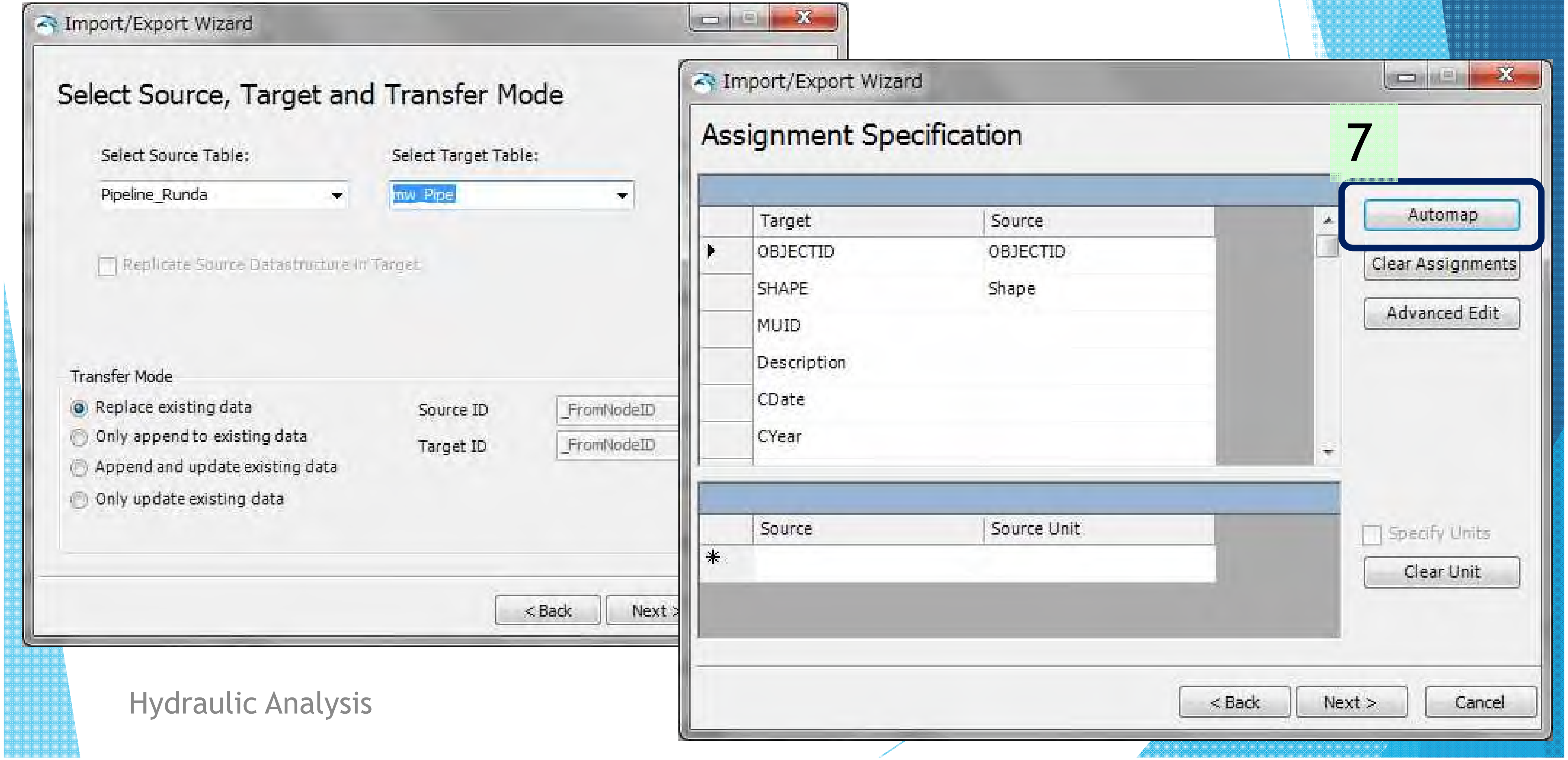
Table Configurations: kigali-data

● New Table Config pipeline
○ Edit Table Config
○ Copy Table Config
○ Delete Table Config
○ Rename Table Config
○ No changes on section level

Info: When pressing [Next] data will be loaded this process may take some time.

Mike Urban: Shapefile Import 3/5

6. Select the source (shapefile) and target (Mike) Tables
7. Specify corresponding fields of the two tables
    - Automap is useful



Select Source, Target and Transfer Mode

Select Source Table: Pipeline_Runda

Select Target Table: mw_Pipe

☐ Replicate Source Datastructure in Target

Transfer Mode

● Replace existing data
○ Only append to existing data
○ Append and update existing data
○ Only update existing data

Source ID: _FromNodeID

Target ID: _FromNodeID

Assignment Specification

Target	Source
OBJECTID	OBJECTID
SHAPE	Shape
MUID	
Description	
CDate	
CYear	

Source	Source Unit
*	

Mike Urban: Shapefile Import 4/5

8. Continue to repeat configurations if you need to import more
9. Stop editing if you finish configuration

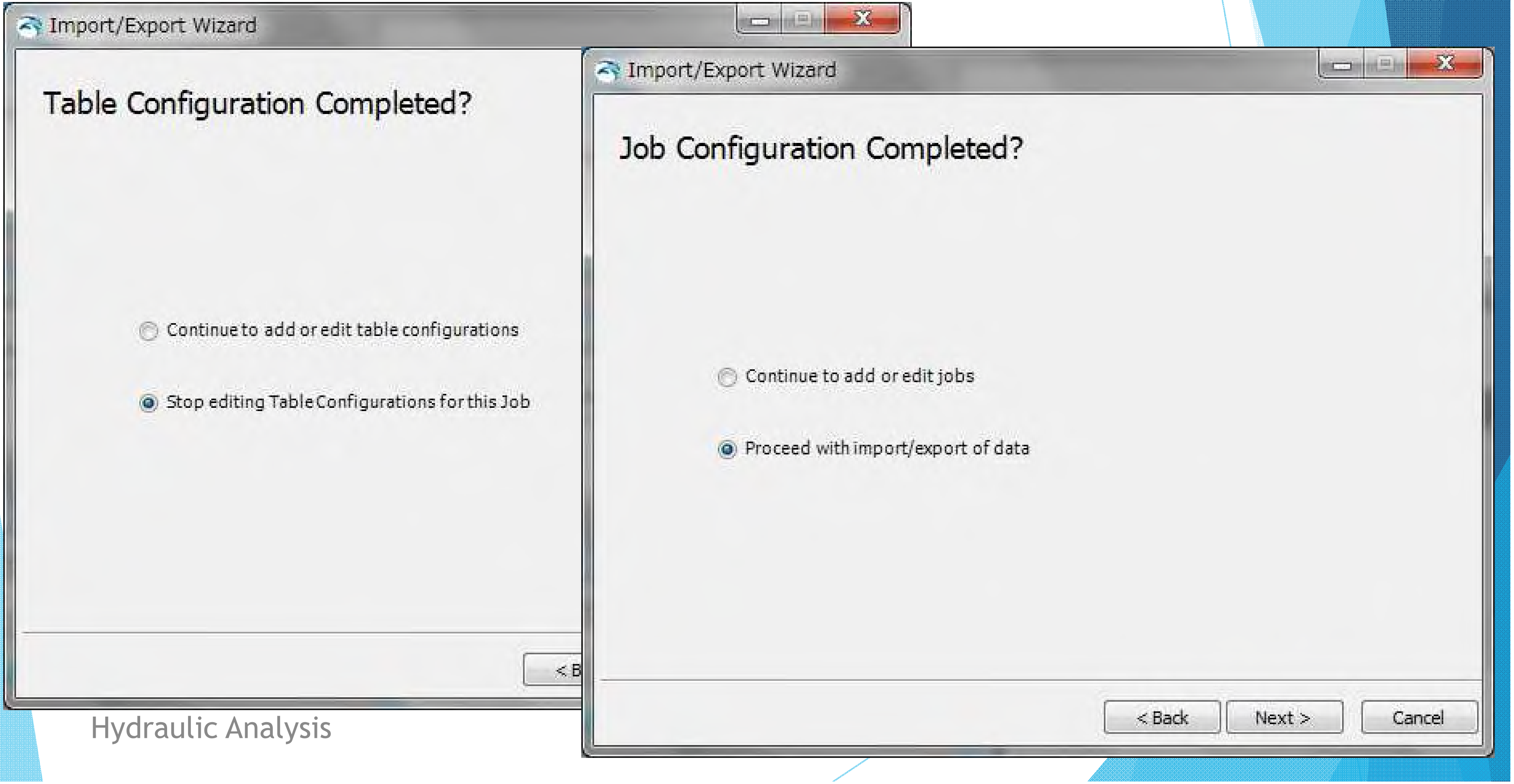


Table Configuration Completed?

○ Continue to add or edit table configurations

● Stop editing Table Configurations for this Job

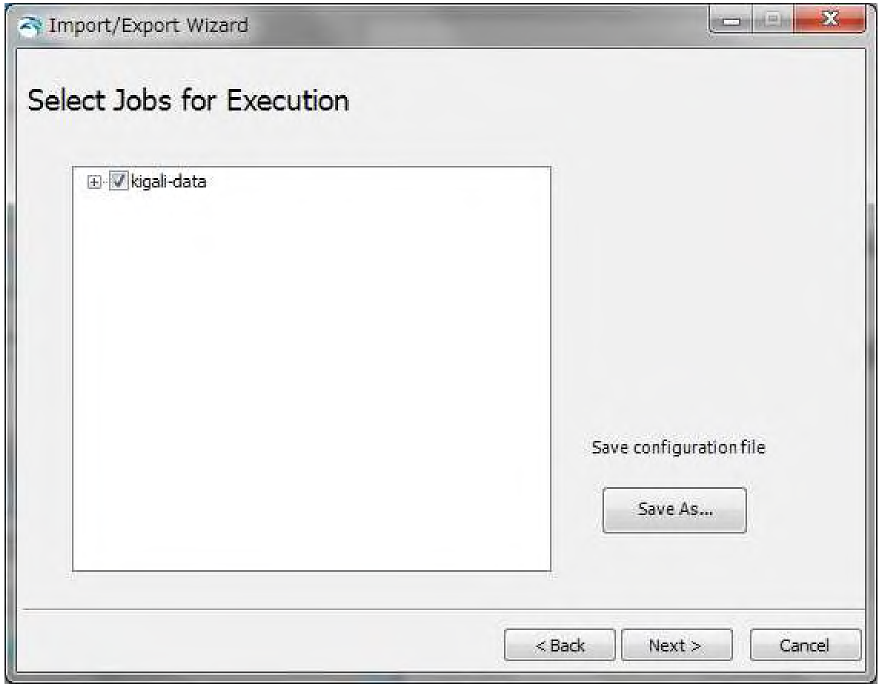
Job Configuration Completed?

○ Continue to add or edit jobs

● Proceed with import/export of data

Mike Urban: Shapefile Import 5/5

10. Start the Import job

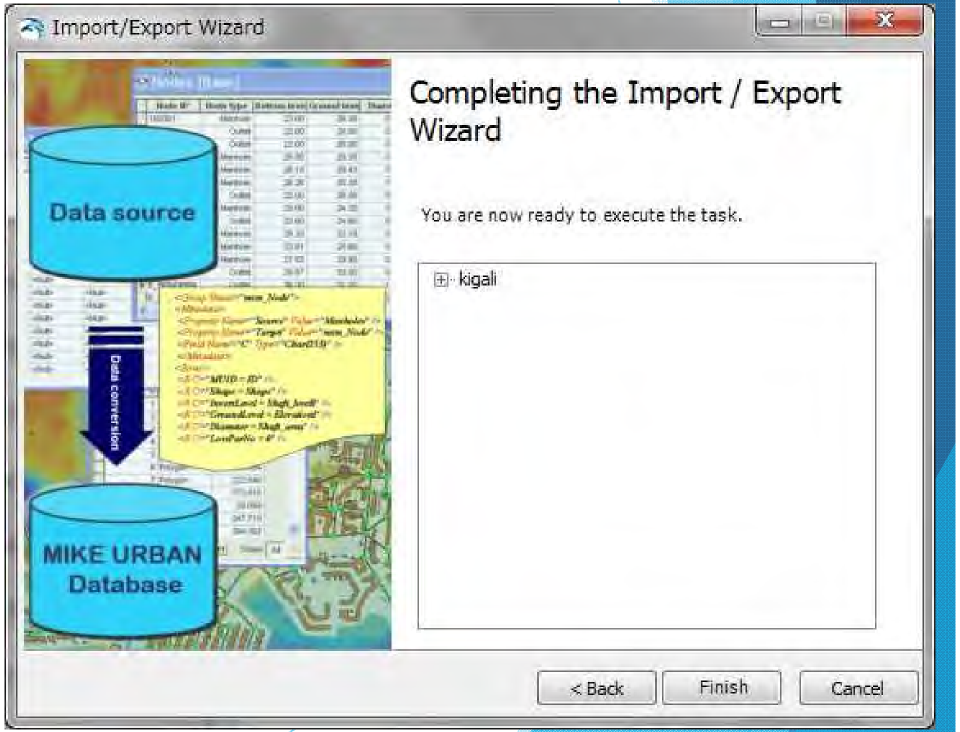


Import/Export Wizard

Select Jobs for Execution

⊞ ☑ kigali-data

Save configuration file



Import/Export Wizard

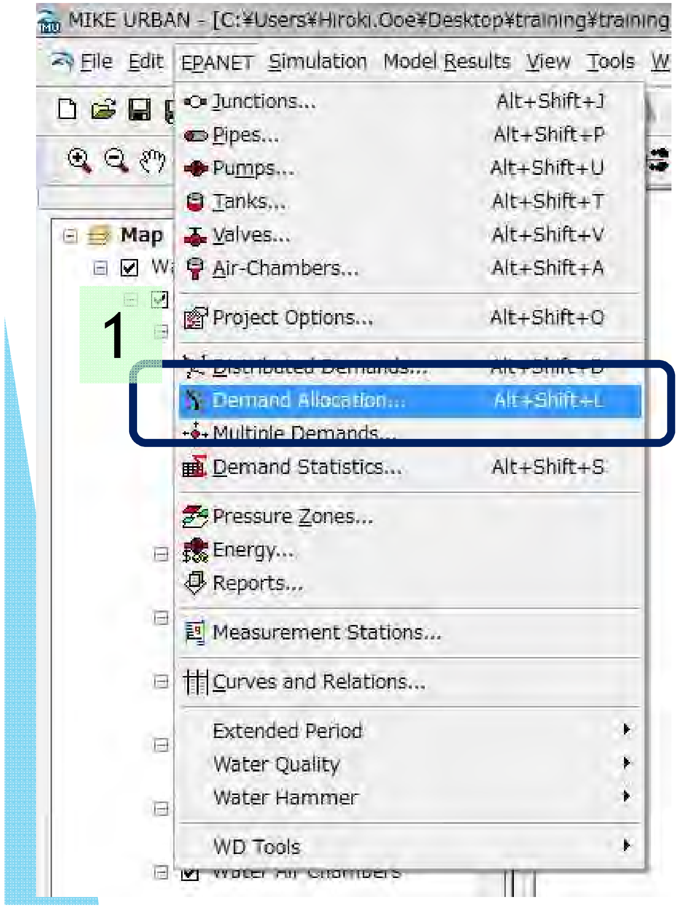
Completing the Import / Export Wizard

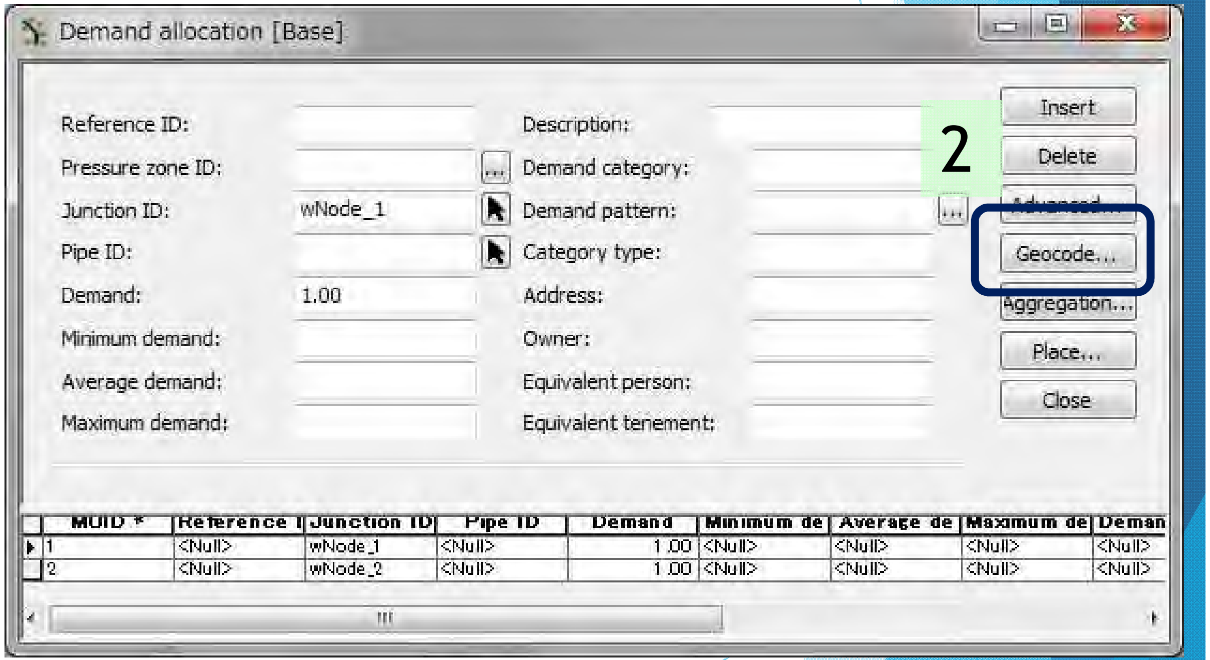
You are now ready to execute the task.

⊞ kigali

Mike Urban: Demand Allocation 1/3

1. EPANET > Demand Allocation
    - something like a customer meters
2. Geocode



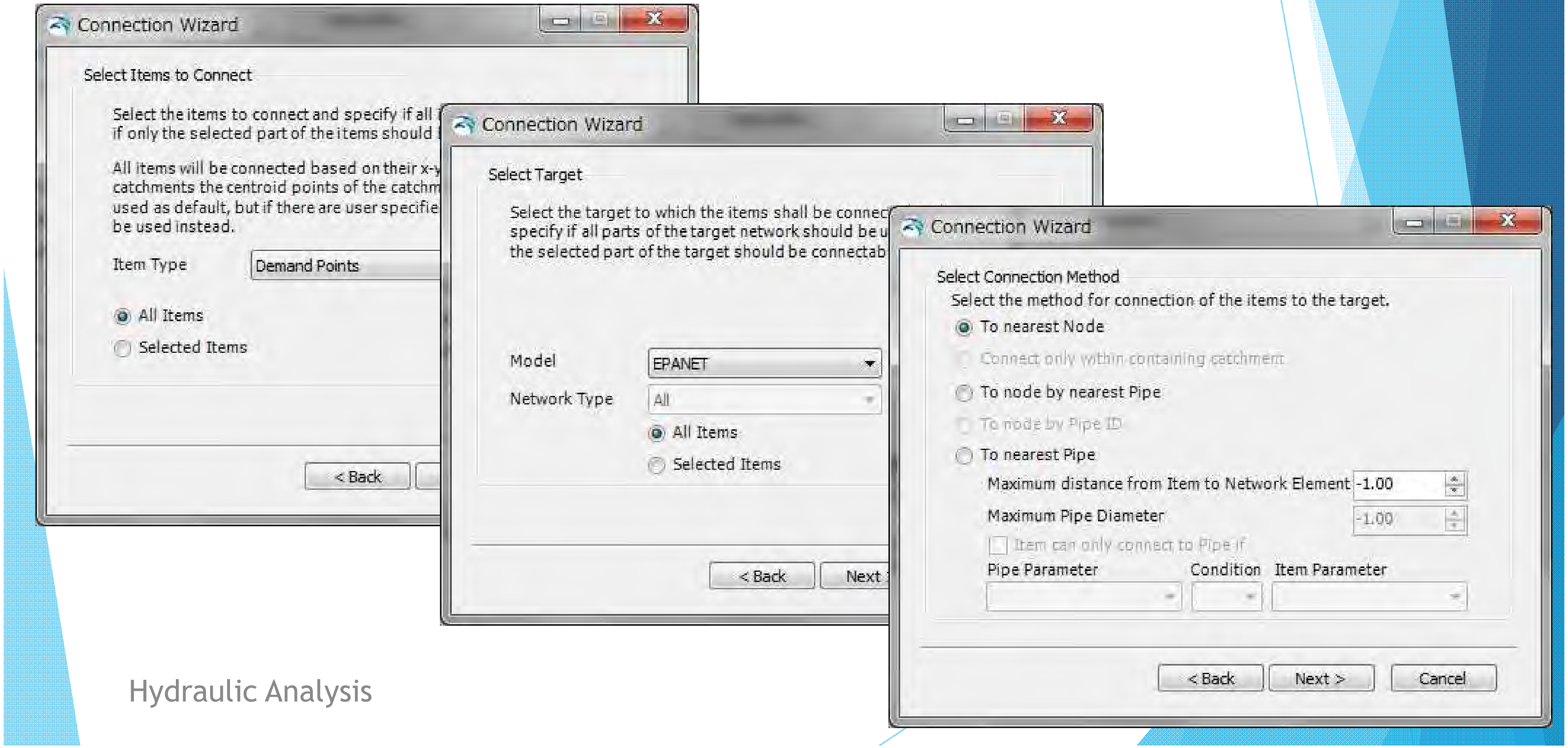


Reference ID:
Pressure zone ID:
Junction ID: wNode_1
Pipe ID:
Demand: 1.00
Minimum demand:
Average demand:
Maximum demand:
Description:
Demand category:
Demand pattern:
Category type:
Address:
Owner:
Equivalent person:
Equivalent tenement:

MUID *	Reference I	Junction ID	Pipe ID	Demand	Minimum de	Average de	Maximum de	Deman
1	<Null>	wNode_1	<Null>	1.00	<Null>	<Null>	<Null>	<Null>
2	<Null>	wNode_2	<Null>	1.00	<Null>	<Null>	<Null>	<Null>

Mike Urban: Demand Allocation 2/3

3. Connect demand points
4. …to EPANET model
5. …to EPANET nodes which are the nearest from demand points



Connection Wizard

Select Items to Connect

Select the items to connect and specify if all i
if only the selected part of the items should b

All items will be connected based on their x-y
catchments the centroid points of the catchm
used as default, but if there are user specifie
be used instead.

Item Type: Demand Points

● All Items
○ Selected Items

Connection Wizard

Select Target

Select the target to which the items shall be connec
specify if all parts of the target network should be u
the selected part of the target should be connectab

Model: EPANET

Network Type: All

● All Items
○ Selected Items

Connection Wizard

Select Connection Method

Select the method for connection of the items to the target.

● To nearest Node
○ Connect only within containing catchment
○ To node by nearest Pipe
○ To node by Pipe ID
○ To nearest Pipe

Maximum distance from Item to Network Element: -1.00

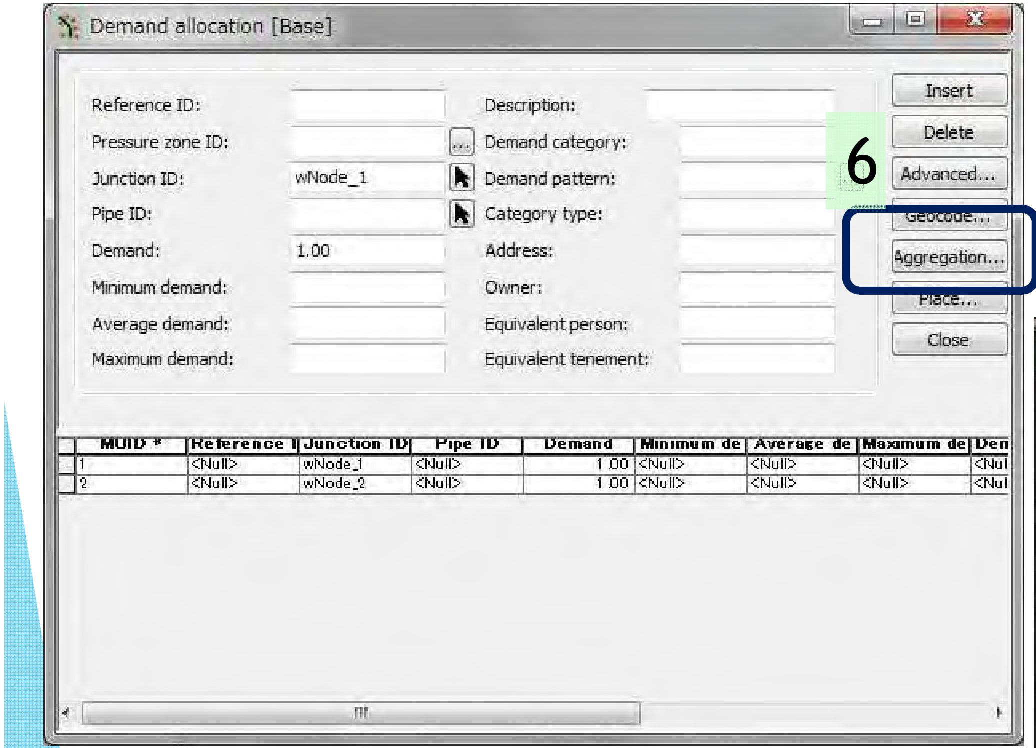
Maximum Pipe Diameter: -1.00

☐ Item can only connect to Pipe if

Pipe Parameter	Condition	Item Parameter

Mike Urban: Demand Allocation 3/3

6. Aggregation on the demand allocation editor
7. Aggregate demands to node demands

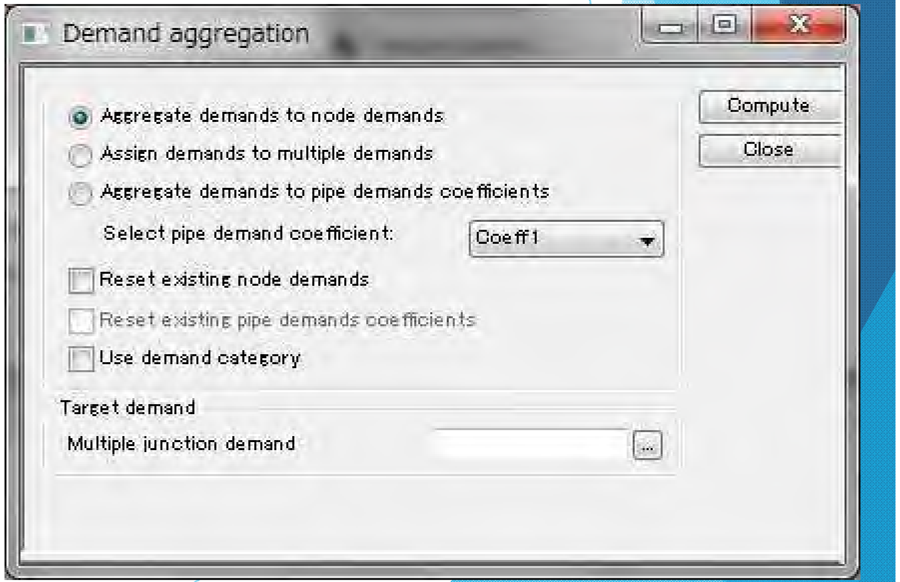


Demand allocation [Base]

Reference ID:
Pressure zone ID:
Junction ID: wNode_1
Pipe ID:
Demand: 1.00
Minimum demand:
Average demand:
Maximum demand:
Description:
Demand category:
Demand pattern:
Category type:
Address:
Owner:
Equivalent person:
Equivalent tenement:

6

MUID *	Reference I	Junction ID	Pipe ID	Demand	Minimum de	Average de	Maximum de	Den
1	<Null>	wNode_1	<Null>	1.00	<Null>	<Null>	<Null>	<Nul
2	<Null>	wNode_2	<Null>	1.00	<Null>	<Null>	<Null>	<Nul



Demand aggregation

● Aggregate demands to node demands
○ Assign demands to multiple demands
○ Aggregate demands to pipe demands coefficients
Select pipe demand coefficient: Coeff1
☐ Reset existing node demands
☐ Reset existing pipe demands coefficients
☐ Use demand category

Target demand
Multiple junction demand

Recommendation

Think

- Apps themselves don’t have a value
- There is still a gap between apps and solution to your problem
- Consider how to use it **for your value**

In the future,

- If an app doesn’t suit you enough, you can customize it
- Yokohama and many waterworks **customize** their GIS to use effectively
- Find a reliable partner to consult
- Quite important to **understand of your own organization and job**

Thank you

And

Good Bye

Pressure Calculation by Hydraulic Analysis

Types of water transmission

There are three types of water transmission

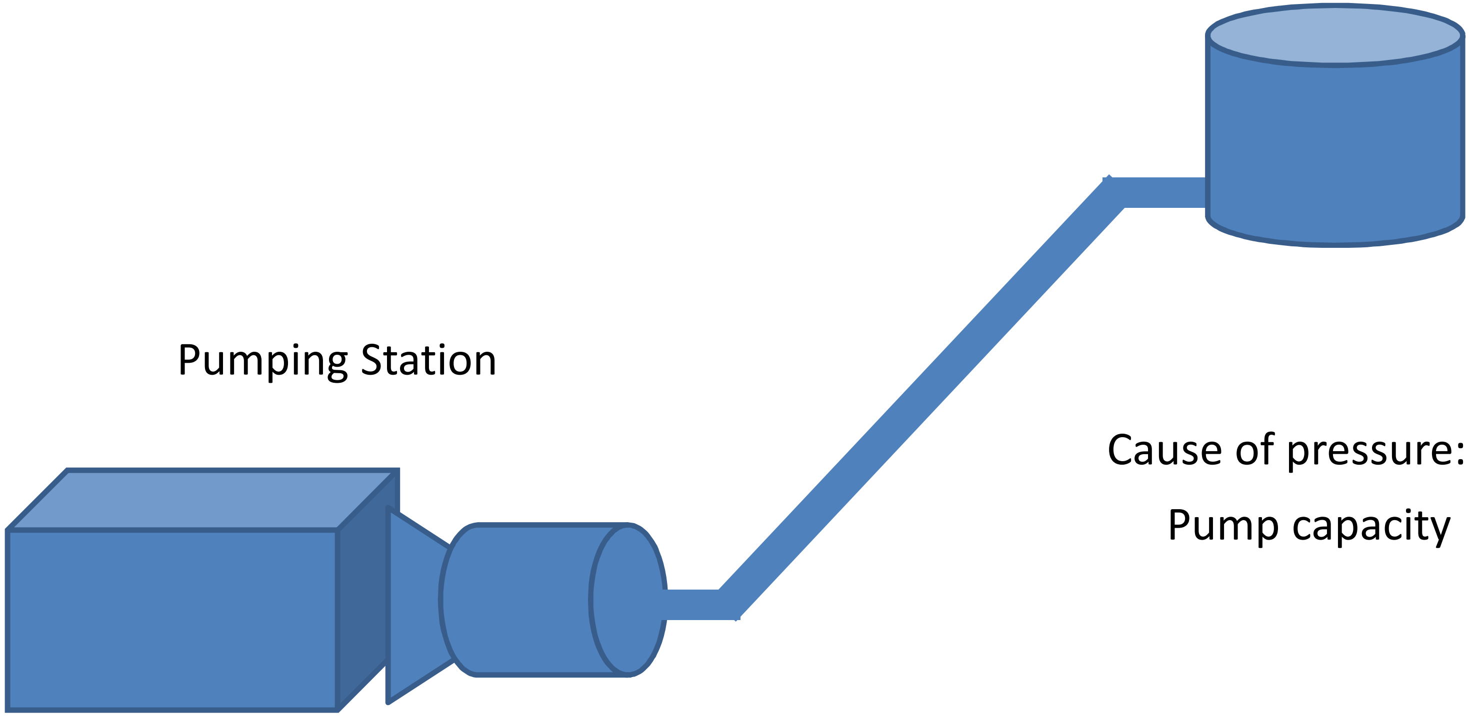
the gravity flow type

the pumped type

the combined type

Types of water transmission

1. By Pumping



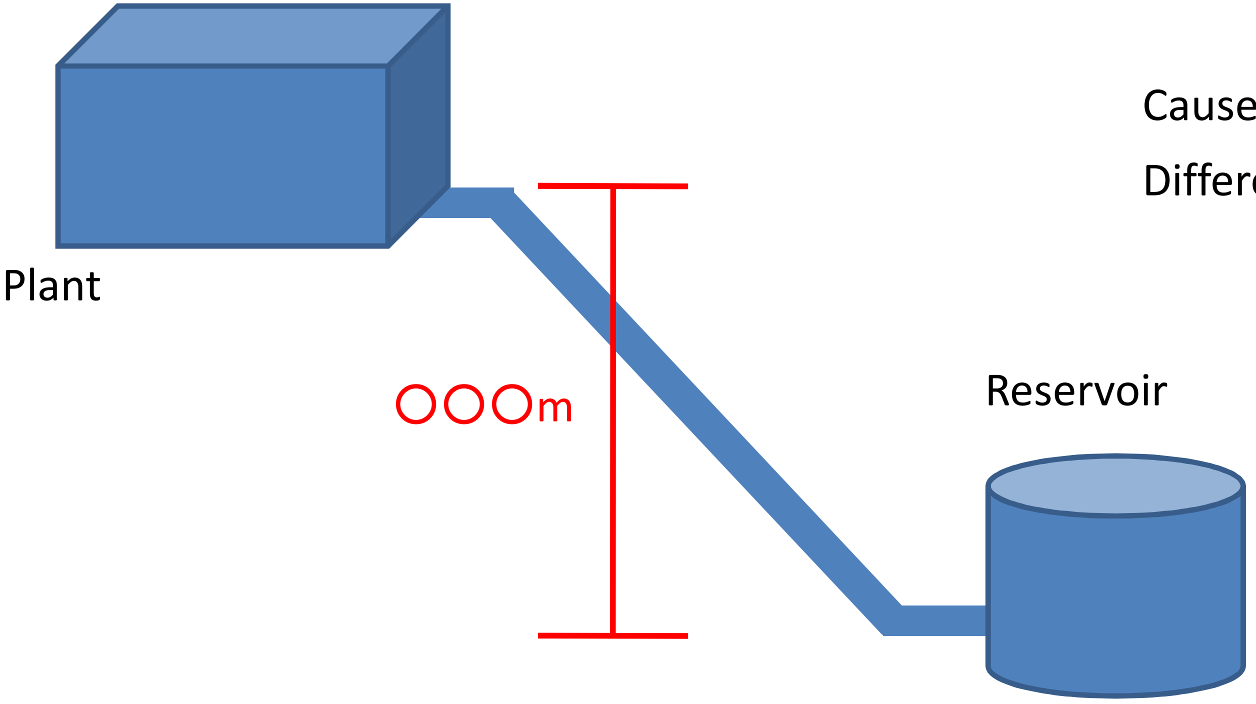
Pumping Station

Cause of pressure:

Pump capacity

Types of water transmission

2. By Gravity



Cause of pressure:

Difference of elevation

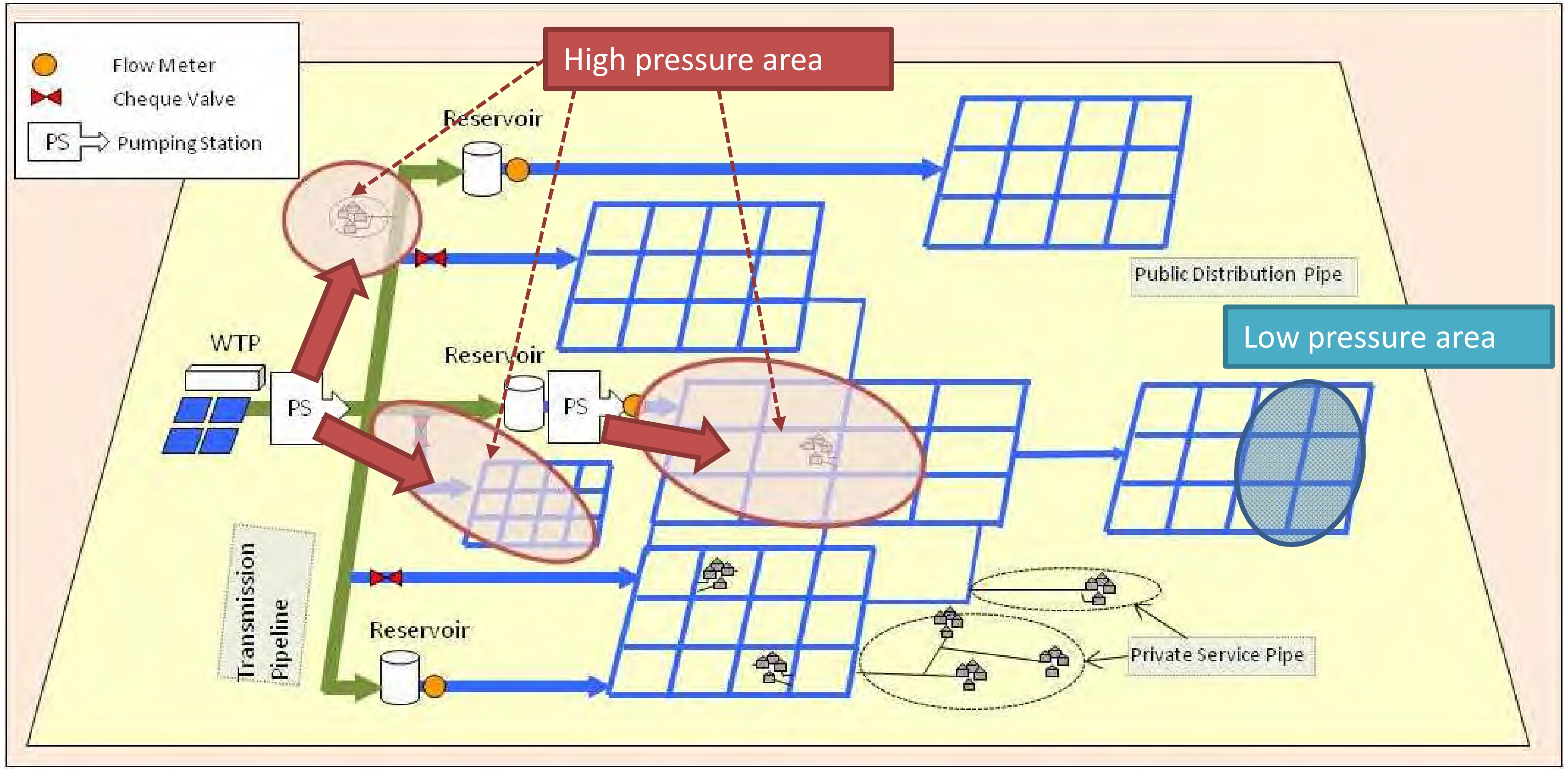
Types of water transmission

There are three types of water transmission in KIGALI

1. By Pumping
2. By Gravity
3. By Branch

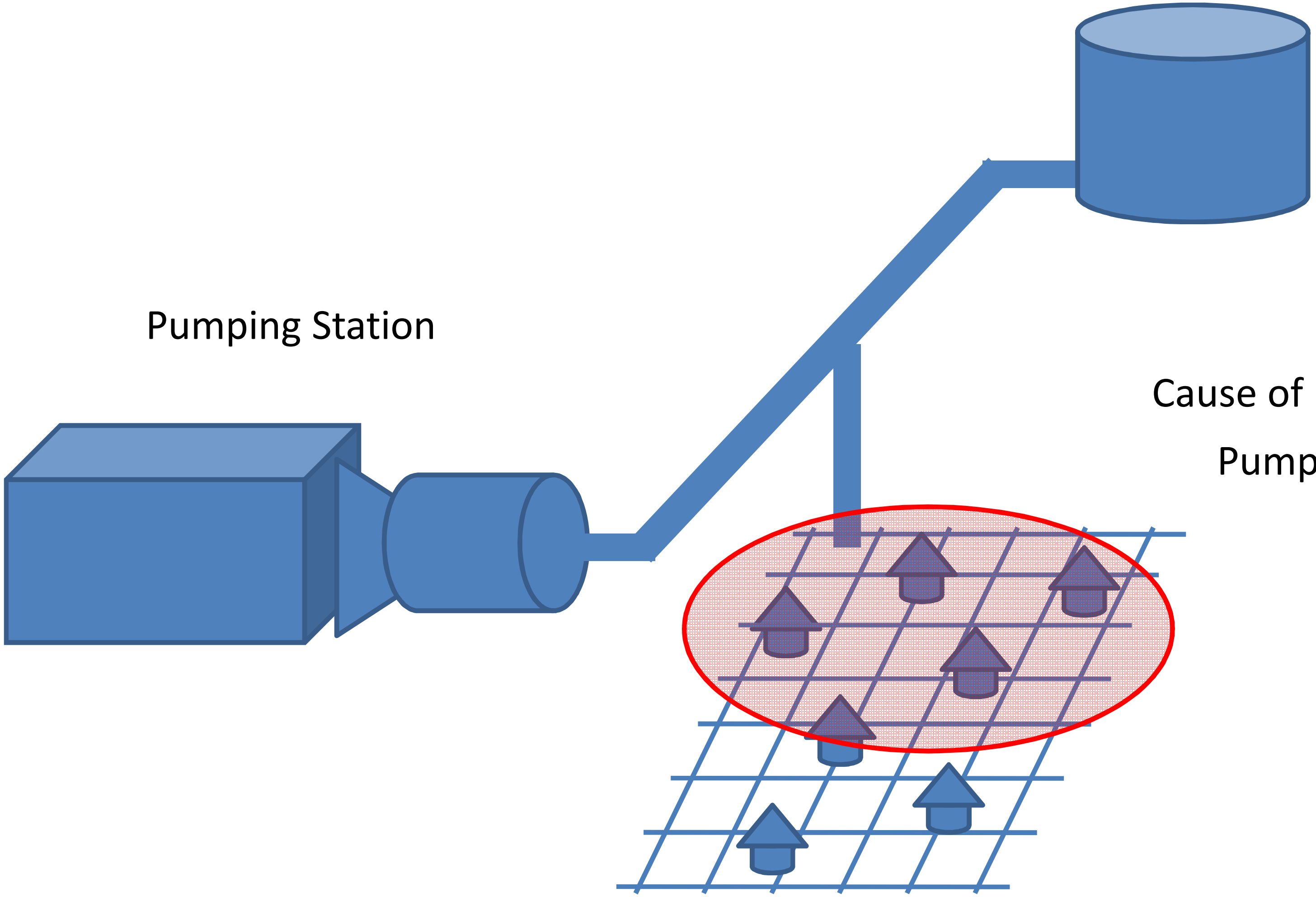
Types of water transmission

Network Condition of KIGALI



Types of water transmission

1. By Pumping



Pumping Station

Cause of pressure:

Pump capacity

Hydraulic Analysis for Pressure Calculation

Calculation sheet by Excel

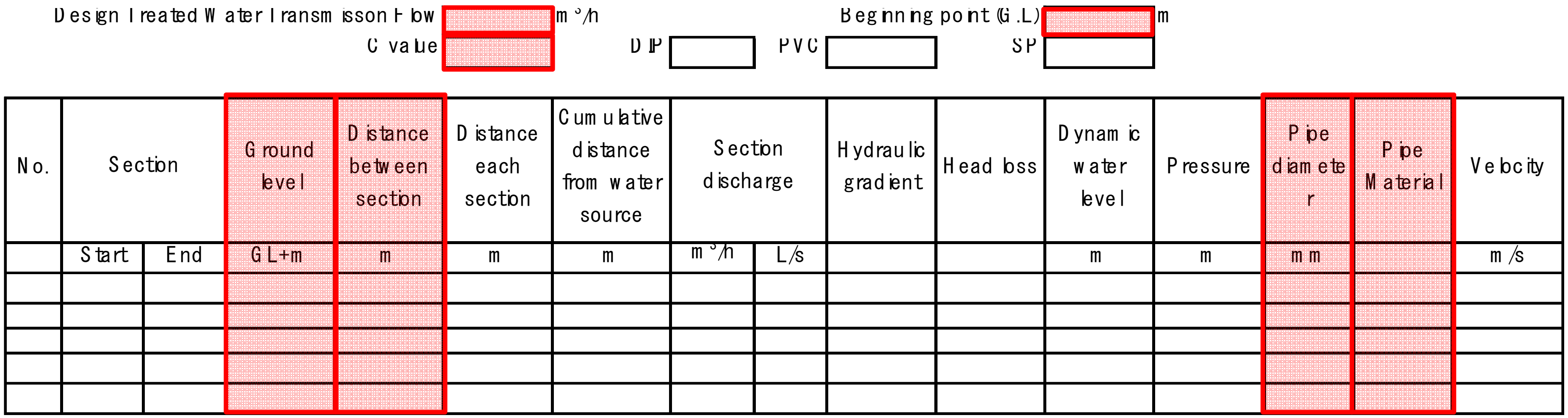
Design Treated Water Transmission Flow ☐ m^3/h Beginning point (G.L) ☐ m

C value ☐ DIP ☐ PVC ☐ SP ☐

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm		m/s

Hydraulic Analysis for Pressure Calculation

Calculation sheet by Excel



Design Treated Water Transmission Flow ☐ m³/h

Beginning point (G.L) ☐ m

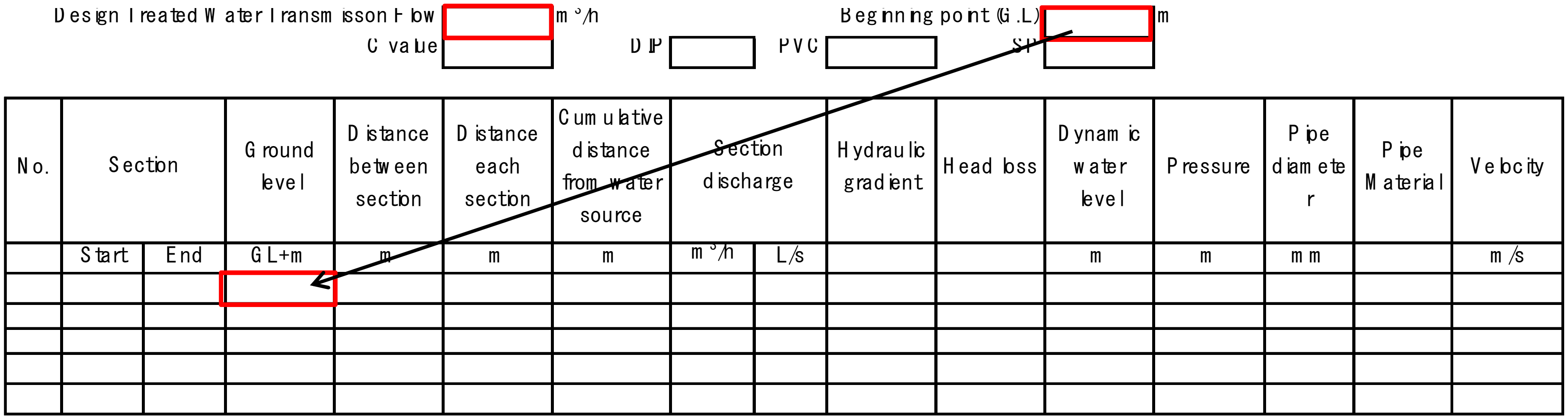
C value ☐

DIP ☐ PVC ☐ SP ☐

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s

Hydraulic Analysis for Pressure Calculation

Calculation sheet by Excel



Design Treated Water Transmission Flow ☐ m^3/h

Beginning point (G.L) ☐ m

C value ☐

DIP ☐

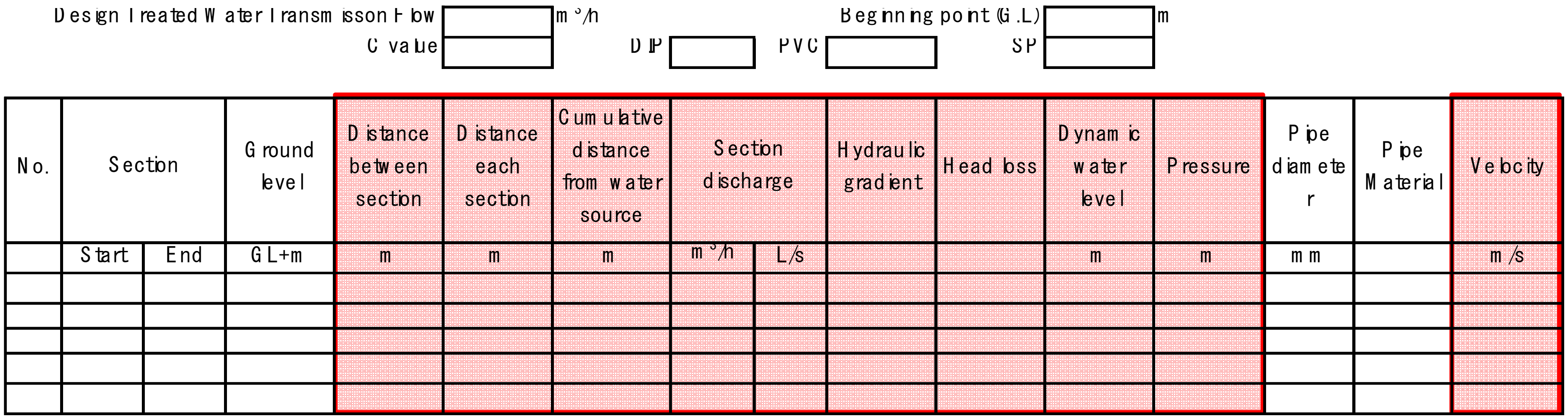
PVC ☐

SP ☐

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm		m/s

Hydraulic Analysis for Pressure Calculation

Calculation sheet by Excel



Design Treated Water Transmission Flow ___ m³/h

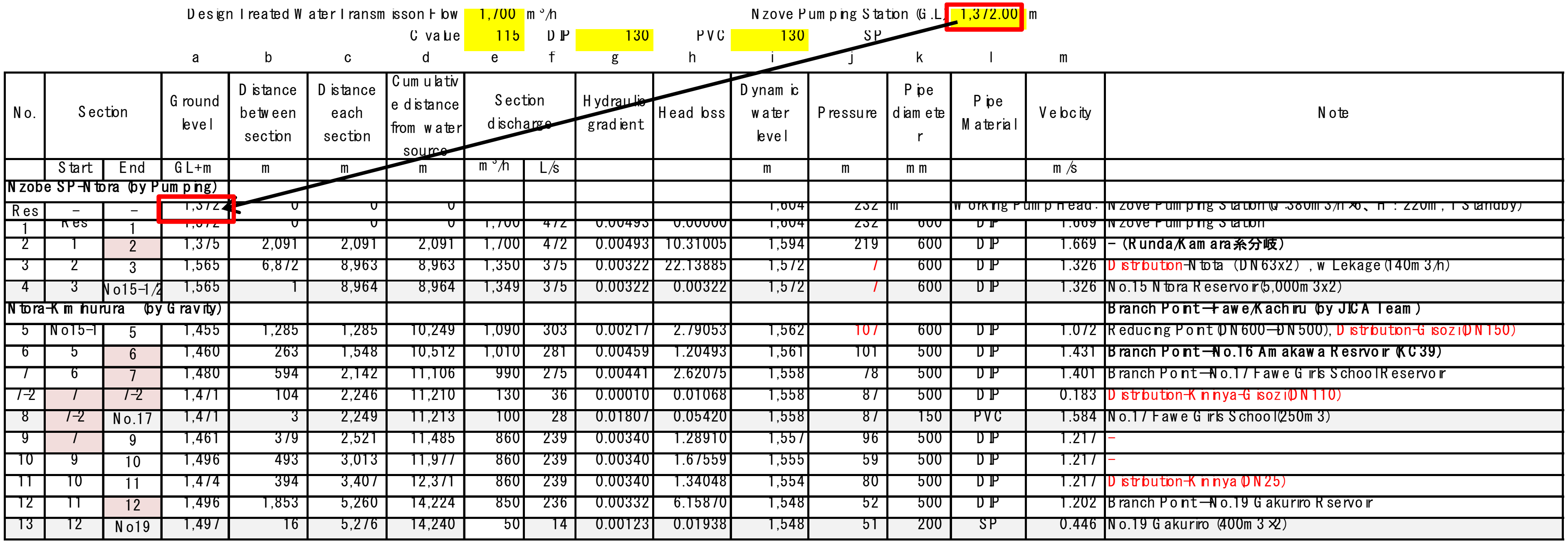
Beginning point (G.L) ___ m

C value ___ DIP ___ PVC ___ SP ___

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



Design Treated Water Transmission Flow 1,700 m^3/h

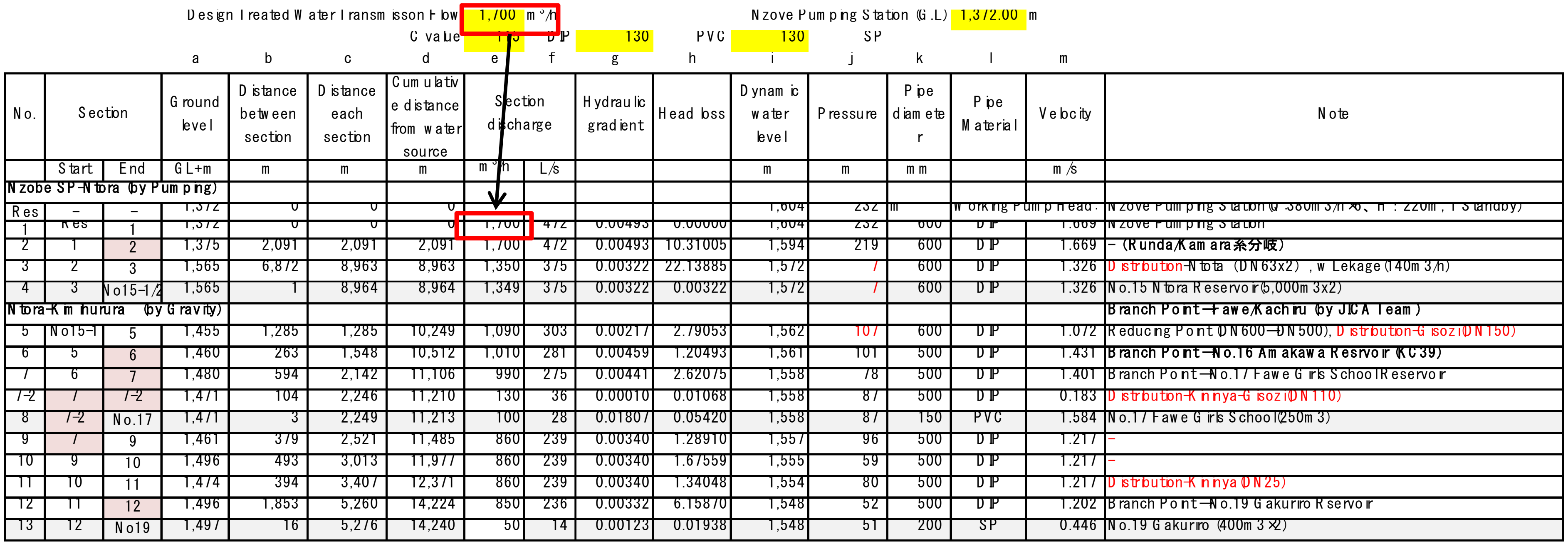
C value 115 DIP 130 PVC 130 SP

Nzove Pumping Station (G.L.) 1,372.00 m

			a	b	c	d	e	f	g	h	i	j	k	l	m	
No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head:		Nzove Pumping Station (Q:380m3/h×6、H：220m，1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	**- (Runda/Kamara系分岐)**
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2), w Lekage (140m 3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m 3x2)
Ntora-Kimihurura (by Gravity)																**Branch Point→Fawe/Kachiru (by JICA Team)**
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point→No.16 Amakawa Resrvoir (KC39)**
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point→No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m 3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	-
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	-
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point→No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m 3×2)

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



Design Treated Water Transmission Flow 1,700 m³/h

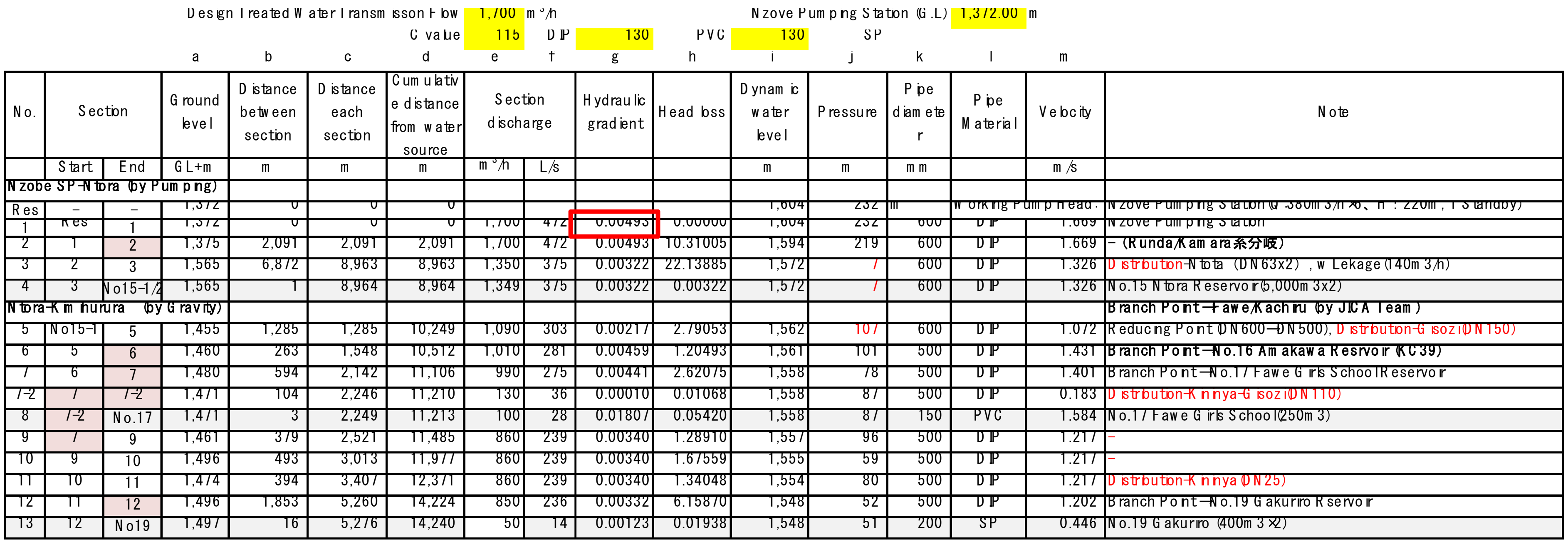
Nzove Pumping Station (G.L) 1,372.00 m

C value 1[illegible]5 DIP 130 PVC 130 SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
			a	b	c	d	e	f	g	h	i	j	k	l	m	
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head:		Nzove Pumping Station (Q:380m3/h×6、H: 220m, 1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	**– (Runda/Kamara系分岐)**
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2), w Lekage(140m3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir(5,000m3x2)
Ntora-Kimihurura (by Gravity)																**Branch Point−Fawe/Kachiru (by JICA Team)**
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point−No.16 Amakawa Resrvoir (KC39)**
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point−No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School(250m3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point−No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m3×2)

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



Design Treated Water Transmission Flow 1,700 m³/h Nzove Pumping Station (G.L) 1,372.00 m

C value 115 DIP 130 PVC 130 SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
			a	b	c	d	e	f	g	h	i	j	k	l	m	
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head:		Nzove Pumping Station (Q:380m 3/h×6、H:220m, 1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	**– (Runda/Kamara系分岐)**
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2), w Lekage (140m 3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m 3x2)
Ntora-Kimihurura (by Gravity)																**Branch Point→Fawe/Kachiru (by JICA Team)**
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point→No.16 Amakawa Resrvoir (KC39)**
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point→No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m 3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point→No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m 3×2)

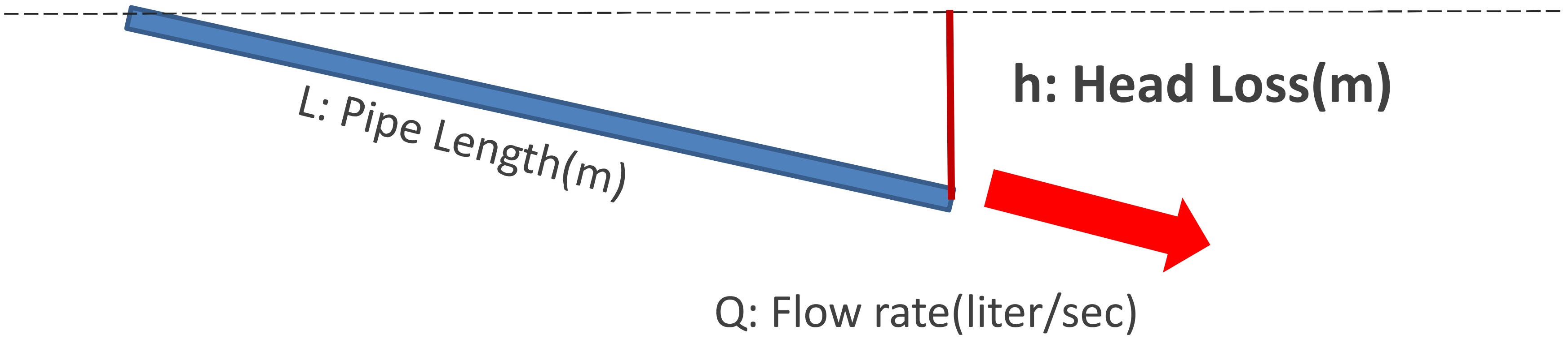
$$\text{Hydraulic gradient} = 10.666C^{-1.85} * (D/1000)^{-4.87} * (Q/1000)^{1.85}$$

Hydraulic Analysis for Pressure Calculation

- Hazen-Williams Equation

$$h = \overbrace{10.666C^{-1.85} * (D/1000)^{-4.87} * (Q/1000)^{1.85}}^{\textbf{Hydraulic gradient}} * L$$

Pipe's specific attributes
- C: Roughness coefficient
- D: Pipe diameter(mm)



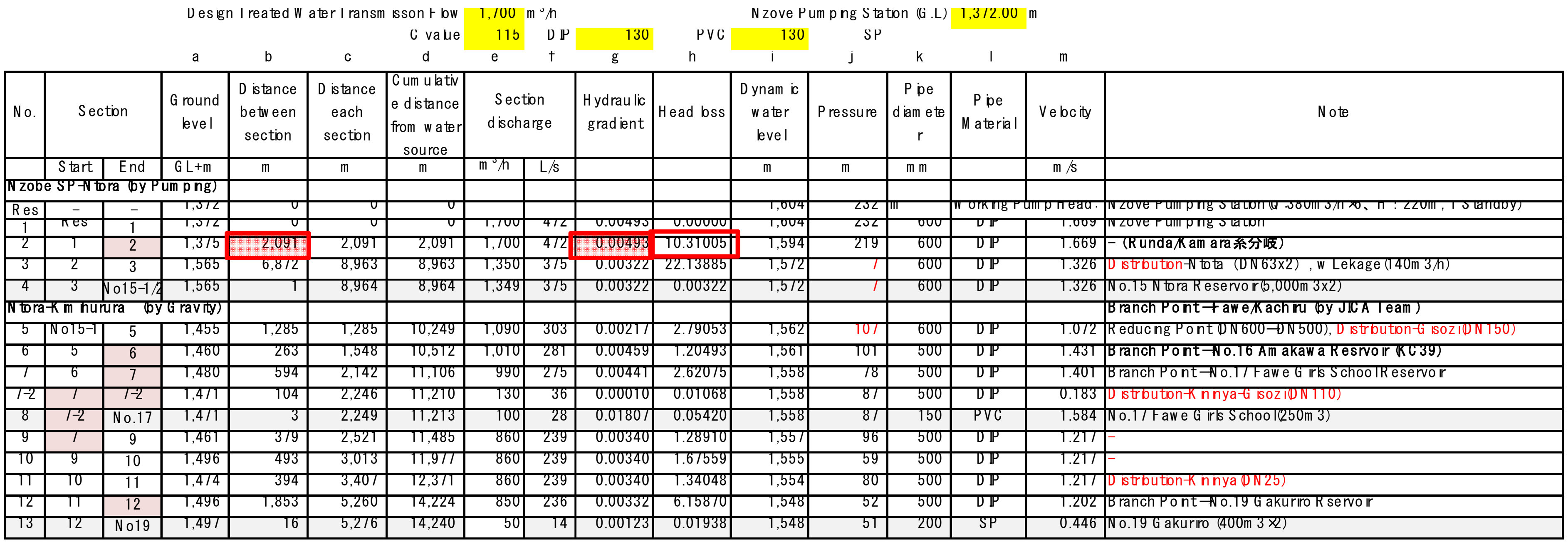
L: Pipe Length(m)

h: Head Loss(m)

Q: Flow rate(liter/sec)

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



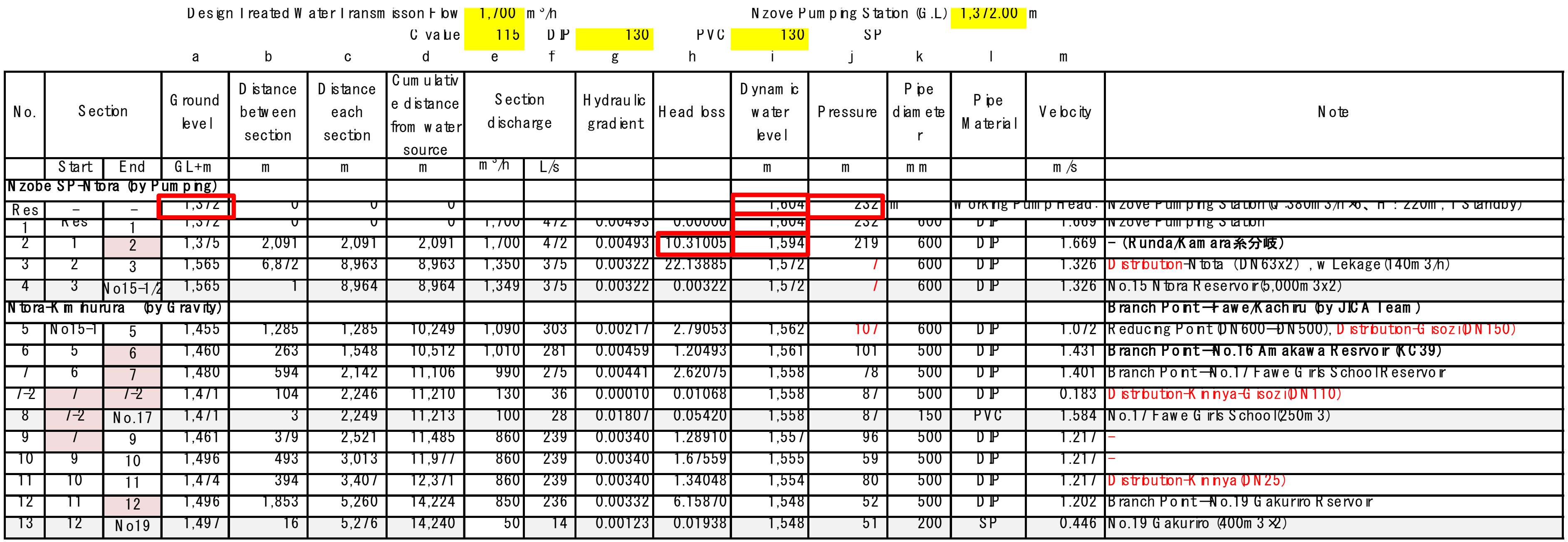
Design Treated Water Transmission Flow 1,700 m³/h   Nzove Pumping Station (G.L) 1,372.00 m
C value 115   DIP 130   PVC 130   SP

			a	b	c	d	e	f	g	h	i	j	k	l	m	
No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head:		Nzove Pumping Station (Q:380m3/h×6、H：220m，1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	– (Runda/Kamara糸分岐)
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2), w Lekage (140m 3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m 3x2)
Ntora-Kimihurura (by Gravity)																**Branch Point→Fawe/Kachiru (by JICA Team)**
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point→No.16 Amakawa Resrvoir (KC39)**
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point→No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m 3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point→No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m 3×2)

Head loss =	Hydraulic gradient ×	Pipe Length
10.31005	0.00493	2091

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



Design Treated Water Transmission Flow 1,700 m³/h

Nzove Pumping Station (G.L) 1,372.00 m

C value 115 DIP 130 PVC 130 SP

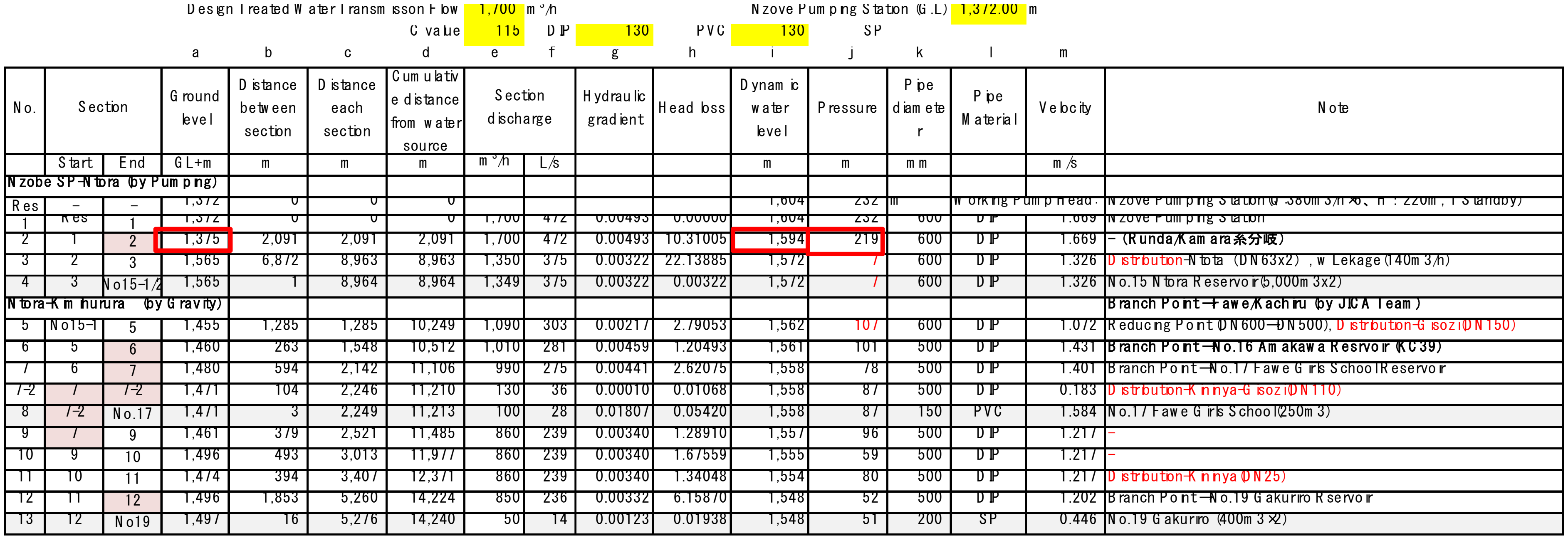
			a	b	c	d	e	f	g	h	i	j	k	l	m	
No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head:		Nzove Pumping Station (Q:380m3/h×6, H:220m, 1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	– (Runda/Kamara糸分岐)
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2), w Lekage (140m 3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m 3x2)
Ntora-Kimihurura (by Gravity)																**Branch Point-Fawe/Kachiru (by JICA Team)**
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point-No.16 Amakawa Resrvoir (KC39)**
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point-No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m 3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point-No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m 3×2)

First Dynamic water level =	Ground level +	Pressure
1604	1372	232

After Next Dynamic water level =	Before Dynamic water level -	Head loss
1594	1604	10.31005

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



Design Treated Water Transmission Flow 1,700 m^3/h Nzove Pumping Station (G.L) 1,372.00 m

C value 115 DIP 130 PVC 130 SP

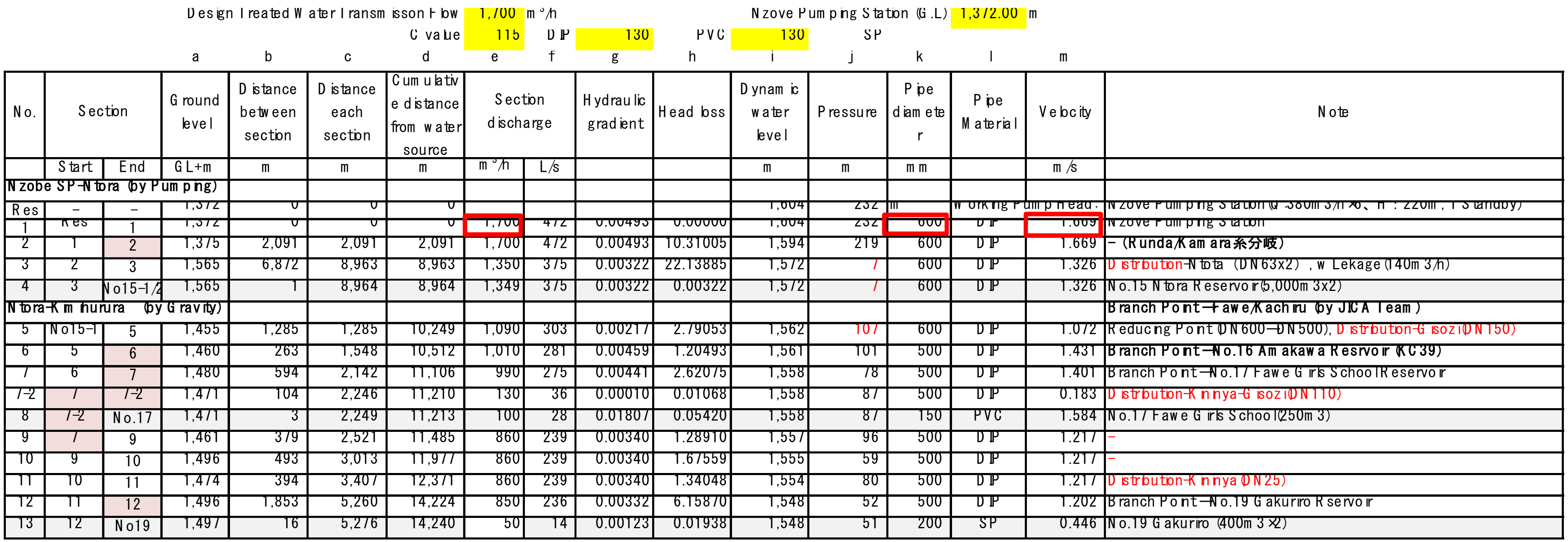
No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
			a	b	c	d	e	f	g	h	i	j	k	l	m	
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head :		Nzove Pumping Station (Q:380m 3/h×6、H：220m，1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	**– (Runda/Kamara系分岐)**
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2) , w Lekage (140m 3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m 3x2)
Ntora-Kimihurura (by Gravity)																**Branch Point→Fawe/Kachiru (by JICA Team)**
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	**Branch Point→No.16 Amakawa Resrvoir (KC39)**
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point→No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m 3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point→No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m 3×2)

First Pressure : Pump capacity or Dynamic water level – Ground level

Pressure = Dynamic water level - Ground level
219 1594 1375

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Nzove and Gakuriro Reservor



Design Treated Water Transmission Flow 1,700 m³/h — Nzove Pumping Station (G.L) 1,372.00 m

C value 115 — DIP 130 — PVC 130 — SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Note
			a	b	c	d	e	f	g	h	i	j	k	l	m	
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm		m/s	
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working Pump Head :		Nzove Pumping Station (Q:380m3/h×6、H：220m，1 Standby)
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	1.669	Nzove Pumping Station
2	1	2	1,375	2,091	2,091	2,091	1,700	472	0.00493	10.31005	1,594	219	600	DIP	1.669	–(Runda/Kamara系分岐)
3	2	3	1,565	6,872	8,963	8,963	1,350	375	0.00322	22.13885	1,572	7	600	DIP	1.326	Distribution-Ntota (DN63x2) , w Lekage (140m 3/h)
4	3	No15-1/2	1,565	1	8,964	8,964	1,349	375	0.00322	0.00322	1,572	7	600	DIP	1.326	No.15 Ntora Reservoir (5,000m 3x2)
Ntora-Kimihurura (by Gravity)																Branch Point→Fawe/Kachiru (by JICA Team)
5	No15-1	5	1,455	1,285	1,285	10,249	1,090	303	0.00217	2.79053	1,562	107	600	DIP	1.072	Reducing Point (DN600→DN500), Distribution-Gisozi (DN150)
6	5	6	1,460	263	1,548	10,512	1,010	281	0.00459	1.20493	1,561	101	500	DIP	1.431	Branch Point→No.16 Amakawa Resrvoir (KC39)
7	6	7	1,480	594	2,142	11,106	990	275	0.00441	2.62075	1,558	78	500	DIP	1.401	Branch Point→No.17 Fawe Girls School Reservoir
7-2	7	7-2	1,471	104	2,246	11,210	130	36	0.00010	0.01068	1,558	87	500	DIP	0.183	Distribution-Kininya-Gisozi (DN110)
8	7-2	No.17	1,471	3	2,249	11,213	100	28	0.01807	0.05420	1,558	87	150	PVC	1.584	No.17 Fawe Girls School (250m 3)
9	7	9	1,461	379	2,521	11,485	860	239	0.00340	1.28910	1,557	96	500	DIP	1.217	–
10	9	10	1,496	493	3,013	11,977	860	239	0.00340	1.67559	1,555	59	500	DIP	1.217	–
11	10	11	1,474	394	3,407	12,371	860	239	0.00340	1.34048	1,554	80	500	DIP	1.217	Distribution-Kininya (DN25)
12	11	12	1,496	1,853	5,260	14,224	850	236	0.00332	6.15870	1,548	52	500	DIP	1.202	Branch Point→No.19 Gakuriro Rservoir
13	12	No19	1,497	16	5,276	14,240	50	14	0.00123	0.01938	1,548	51	200	SP	0.446	No.19 Gakuriro (400m 3×2)

Velocity = Section discharge / Cross section of the pipe

1.669 m/s $1700\text{m}^3\text{/h} / 3600$ $0.6^2 \times \pi / 4$

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor

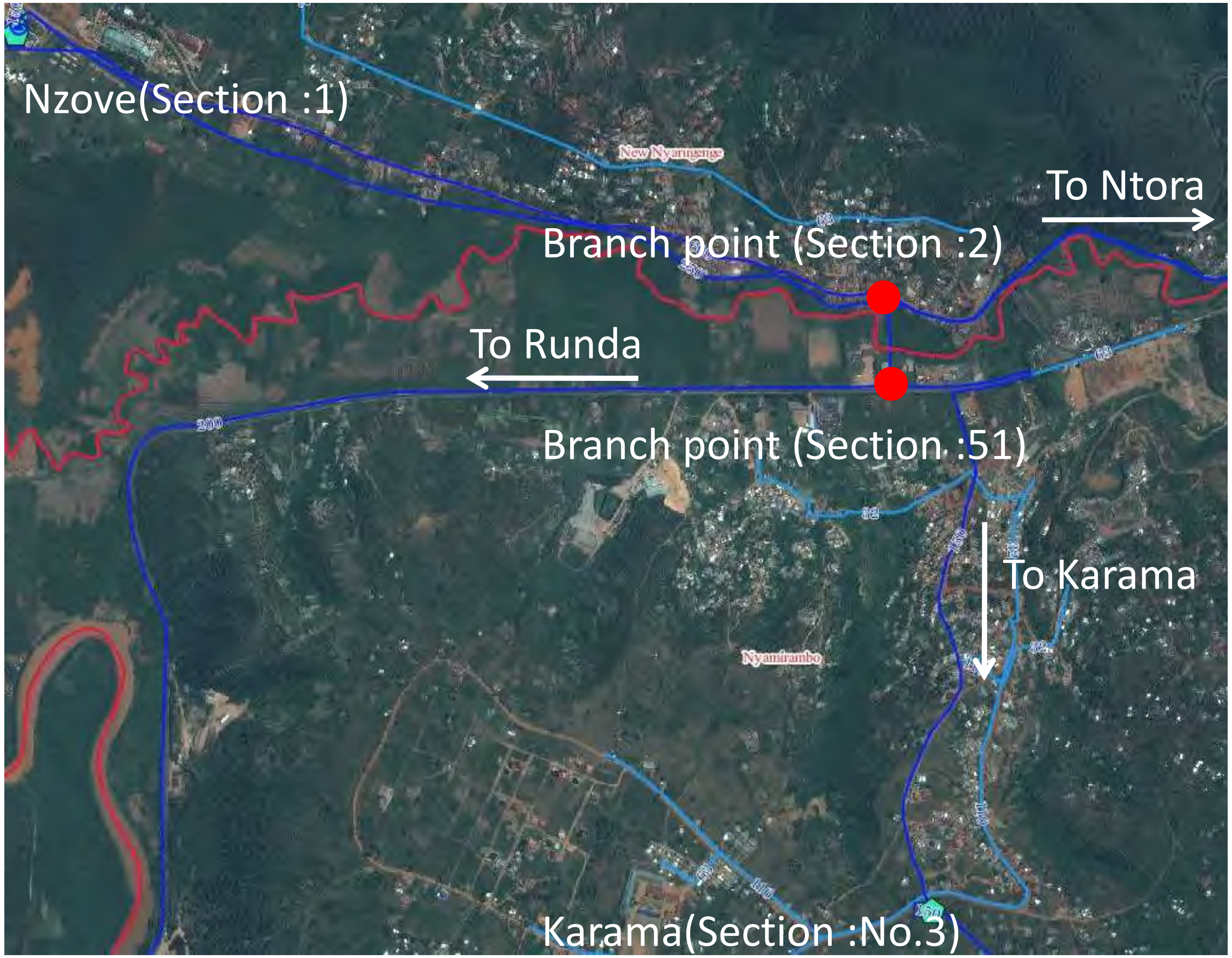
Design Treated Water Transmisson Flow 1,700 m^3/h Nzove Pumping Station (G.L) 1,372.00 m 40,800

C value 115 DIP 130 PVC 130 SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Note	Distributution (estimate)
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm			m^3/h
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working P	Nzove Pumping Station(Q:380m 3/h×6、H：220m，1 Standby)	
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	Nzove Pumping Station (Branch SKUL)	20
2	1	2	1,375	2,091	2,091	2,091	1,680	467	0.00483	10.10891	1,594	219	600	DIP	**–（Runda/Kamara系分岐）**	190
3	2	3	1,565	6,872	8,963	8,963	1,490	414	0.00387	26.58568	1,567	2	600	DIP	Distribution-Ntota （DN63x2），w Lekage(140m 3/h)	1
4	3	No15-1/2	1,565	1	8,964	8,964	1,489	414	0.00387	0.00387	1,567	2	600	DIP	No.15 Ntora Reservoir(5,000m 3x2)	
Nzobe-Runda (by Pumping)																
52	2	51	1,363	204	204	2,295	190	53	0.01818	3.71063	1,590	227	200	DIP	**Branch Point→Karara**	110
53	51	52	1,508	5,029	5,233	7,324	80	22	0.00285	14.32695	1,576	68	200	PVC	No.1 Buyenzi(Runda)(400m 3)	45
Nzobe-Karama (by Pumping)																
63	51	No.3	1,519	1,742	1,742	4,037	110	31	0.02736	47.66652	1,543	24	150	DIP	No.3 Karama (400m 3)	25

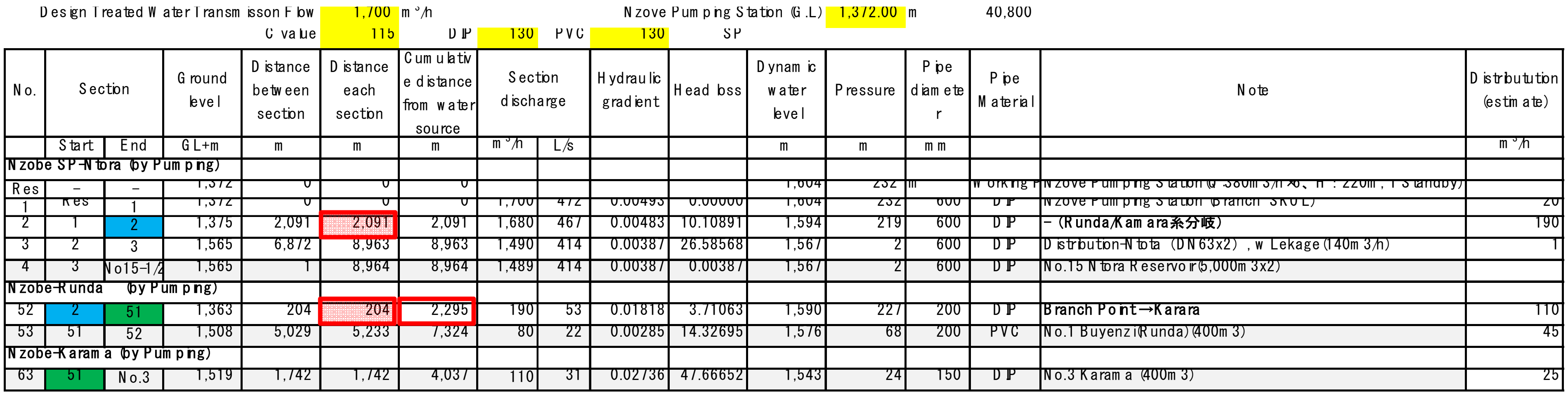
Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor



Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor



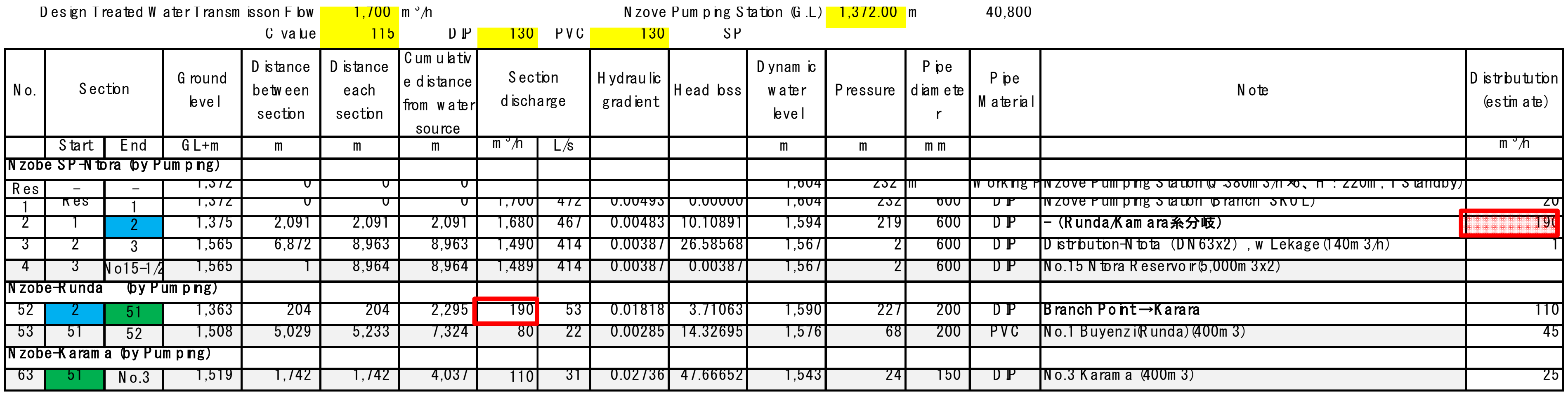
Design Treated Water Transmisson Flow 1,700 m^3/h Nzove Pumping Station (G.L) 1,372.00 m 40,800

C value 115 DIP 130 PVC 130 SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Note	Distributution (estimate)
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm			m^3/h
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working P	Nzove Pumping Station (Q 380m 3/h×6、H : 220m , 1 Standby)	
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	Nzove Pumping Station (Branch SKOL)	20
2	1	2	1,375	2,091	2,091	2,091	1,680	467	0.00483	10.10891	1,594	219	600	DIP	**– (Runda/Kamara系分岐)**	190
3	2	3	1,565	6,872	8,963	8,963	1,490	414	0.00387	26.58568	1,567	2	600	DIP	Distribution-Ntota (DN63x2) , w Lekage (140m 3/h)	1
4	3	No15-1/2	1,565	1	8,964	8,964	1,489	414	0.00387	0.00387	1,567	2	600	DIP	No.15 Ntora Reservoir (5,000m 3x2)	
Nzobe-Runda (by Pumping)																
52	2	51	1,363	204	204	2,295	190	53	0.01818	3.71063	1,590	227	200	DIP	**Branch Point→Karara**	110
53	51	52	1,508	5,029	5,233	7,324	80	22	0.00285	14.32695	1,576	68	200	PVC	No.1 Buyenzi (Runda) (400m 3)	45
Nzobe-Karama (by Pumping)																
63	51	No.3	1,519	1,742	1,742	4,037	110	31	0.02736	47.66652	1,543	24	150	DIP	No.3 Karama (400m 3)	25

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor



Design Treated Water Transmisson Flow 1,700 m³/h   Nzove Pumping Station (G.L) 1,372.00 m   40,800

C value 115   DIP 130   PVC 130   SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Note	Distributution (estimate)
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm			m³/h
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working P	Nzove Pumping Station(Q 380m3/h×6、H：220m，1 Standby)	
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	Nzove Pumping Station (Branch SKOL)	20
2	1	2	1,375	2,091	2,091	2,091	1,680	467	0.00483	10.10891	1,594	219	600	DIP	**–（Runda/Kamara系分岐）**	190
3	2	3	1,565	6,872	8,963	8,963	1,490	414	0.00387	26.58568	1,567	2	600	DIP	Distribution-Ntota （DN63x2）, w Lekage (140m 3/h)	1
4	3	No15-1/2	1,565	1	8,964	8,964	1,489	414	0.00387	0.00387	1,567	2	600	DIP	No.15 Ntora Reservoir(5,000m 3x2)	
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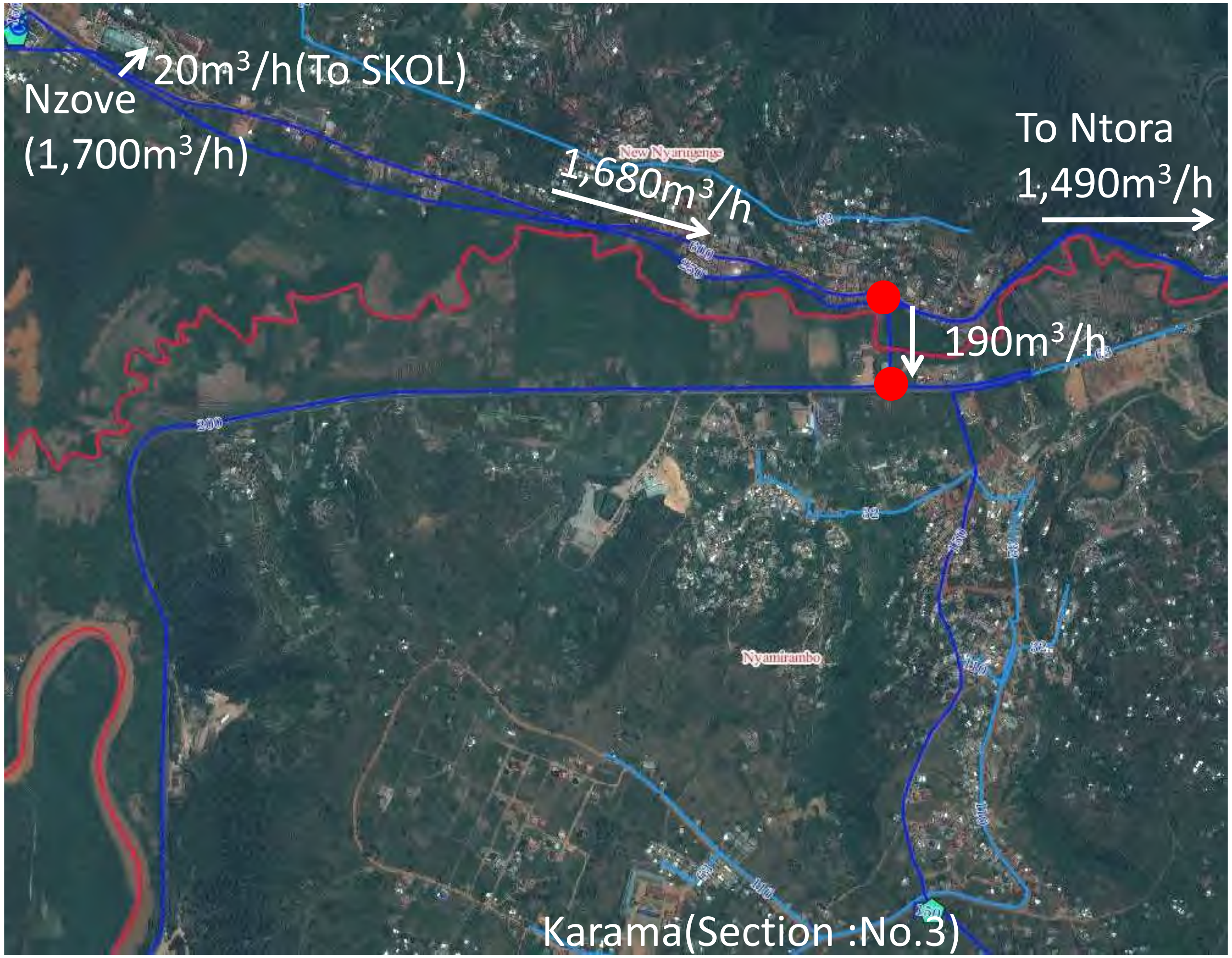
52	2	51	1,363	204	204	2,295	190	53	0.01818	3.71063	1,590	227	200	DIP	**Branch Point→Karara**	110
53	51	52	1,508	5,029	5,233	7,324	80	22	0.00285	14.32695	1,576	68	200	PVC	No.1 Buyenzi(Runda) (400m 3)	45
Nzobe-Karama (by Pumping)																
63	51	No.3	1,519	1,742	1,742	4,037	110	31	0.02736	47.66652	1,543	24	150	DIP	No.3 Karama (400m 3)	25

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor



Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor

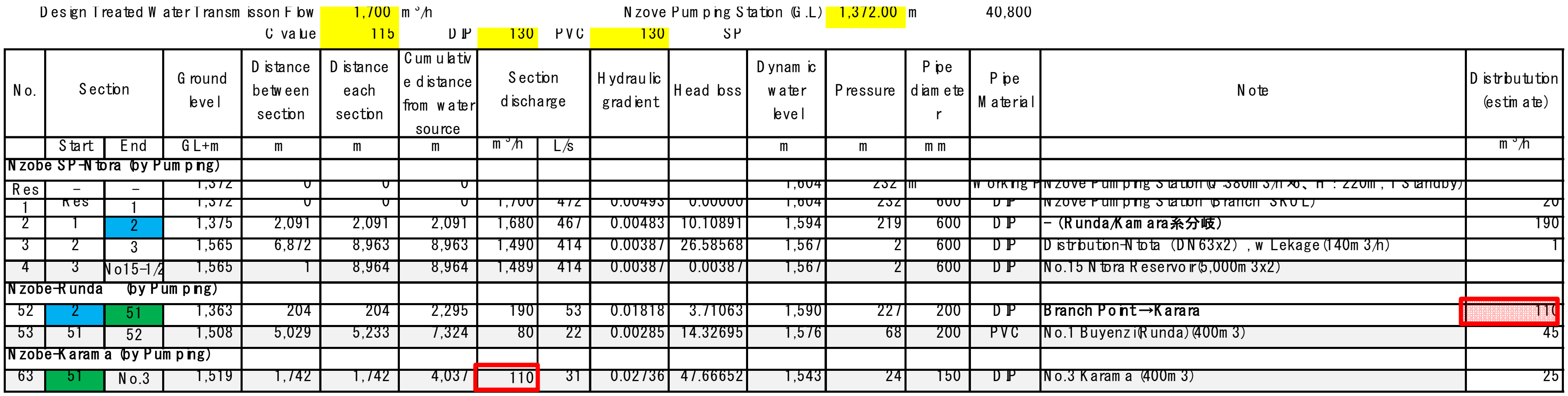
Design Treated Water Transmission Flow 1,700 m^3/h Nzove Pumping Station (G.L) 1,372.00 m 40,800

C value 115 DIP 130 PVC 130 SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Note	Distributution (estimate)
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm			m^3/h
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working P	Nzove Pumping Station (Q 380m 3/h×6、H：220m，1 Standby)	
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	Nzove Pumping Station (Branch SKUL)	20
2	1	2	1,375	2,091	2,091	2,091	1,680	467	0.00483	10.10891	1,594	219	600	DIP	**–（Runda/Kamara系分岐）**	190
3	2	3	1,565	6,872	8,963	8,963	1,490	414	0.00387	26.58568	1,567	2	600	DIP	Distribution-Ntota（DN63x2），w Lekage (140m 3/h)	1
4	3	No15-1/2	1,565	1	8,964	8,964	1,489	414	0.00387	0.00387	1,567	2	600	DIP	No.15 Ntora Reservoir (5,000m 3x2)	
Nzobe-Runda (by Pumping)																
52	2	51	1,363	204	204	2,295	190	53	0.01818	3.71063	1,590	227	200	DIP	**Branch Point→Karara**	110
53	51	52	1,508	5,029	5,233	7,324	80	22	0.00285	14.32695	1,576	68	200	PVC	No.1 Buyenzi (Runda) (400m 3)	45
Nzobe-Karama (by Pumping)																
63	51	No.3	1,519	1,742	1,742	4,037	110	31	0.02736	47.66652	1,543	24	150	DIP	No.3 Karama (400m 3)	25

Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor



Design Treated Water Transmission Flow 1,700 m^3/h — Nzove Pumping Station (G.L) 1,372.00 m — 40,800

C value 115 — DIP 130 — PVC 130 — SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Note	Distribution (estimate)
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm			m^3/h
Nzobe SP-Ntora (by Pumping)																
Res	－	－	1,372	0	0	0					1,604	232	m	Working P	Nzove Pumping Station (Q 380m 3/h×6、H : 220m , 1 Standby)	
1	Res	1	1,372	0	0	0	1,700	472	0.00493	0.00000	1,604	232	600	DIP	Nzove Pumping Station (Branch SKOL)	20
2	1	2	1,375	2,091	2,091	2,091	1,680	467	0.00483	10.10891	1,594	219	600	DIP	**－ (Runda/Kamara系分岐)**	190
3	2	3	1,565	6,872	8,963	8,963	1,490	414	0.00387	26.58568	1,567	2	600	DIP	Distribution-Ntota (DN63x2) , w Lekage (140m 3/h)	1
4	3	No15-1/2	1,565	1	8,964	8,964	1,489	414	0.00387	0.00387	1,567	2	600	DIP	No.15 Ntora Reservoir (5,000m 3x2)	
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53	51	52	1,508	5,029	5,233	7,324	80	22	0.00285	14.32695	1,576	68	200	PVC	No.1 Buyenzi (Runda) (400m 3)	45
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Hydraulic Analysis for Pressure Calculation

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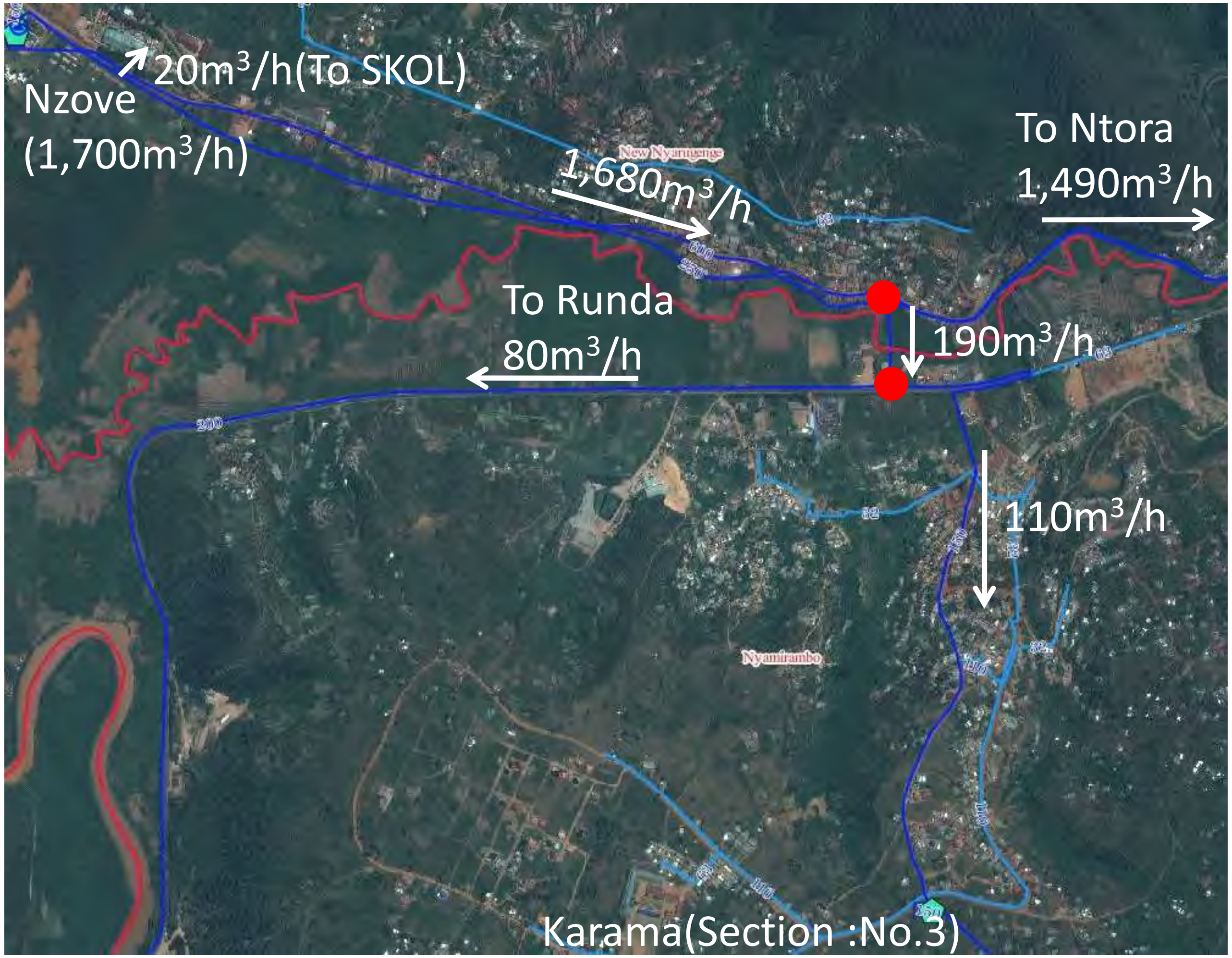
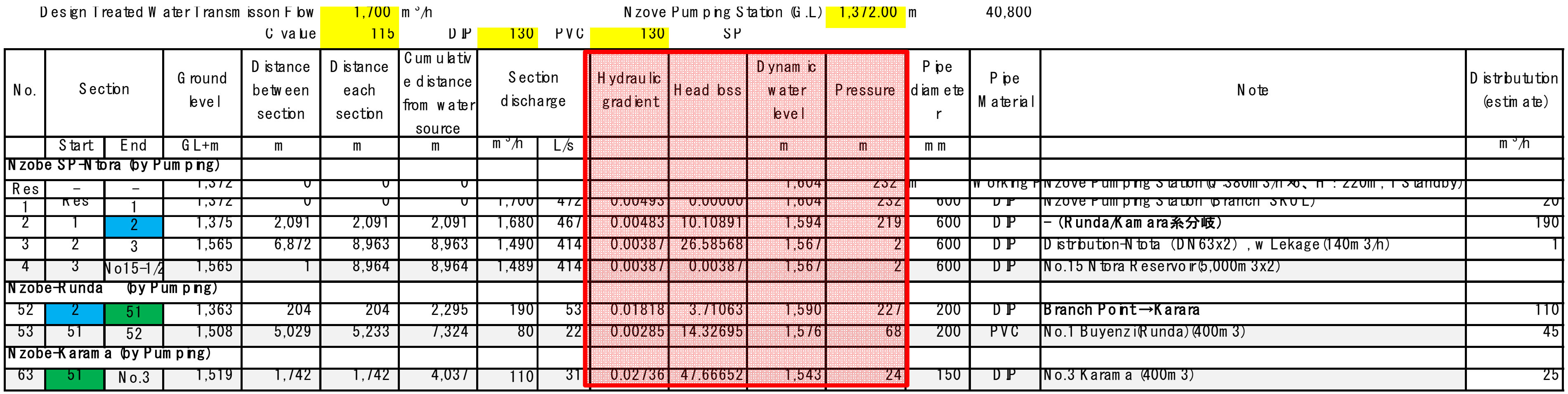


Hydraulic Analysis for Pressure Calculation

Hydraulic Analysis form Nzove PS to Runda and Karama Reservor



Design Treated Water Transmisson Flow 1,700 m³/h Nzove Pumping Station (G.L) 1,372.00 m 40,800
C value 115 DIP 130 PVC 130 SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Note	Distributution (estimate)
	Start	End	GL+m	m	m	m	m³/h	L/s			m	m	mm			m³/h
Nzobe SP-Ntora (by Pumping)																
Res	–	–	1,372	0	0	0					1,604	232	m	Working P	Nzove Pumping Station (Q 380m3/h×6、H：220m，1 Standby)	
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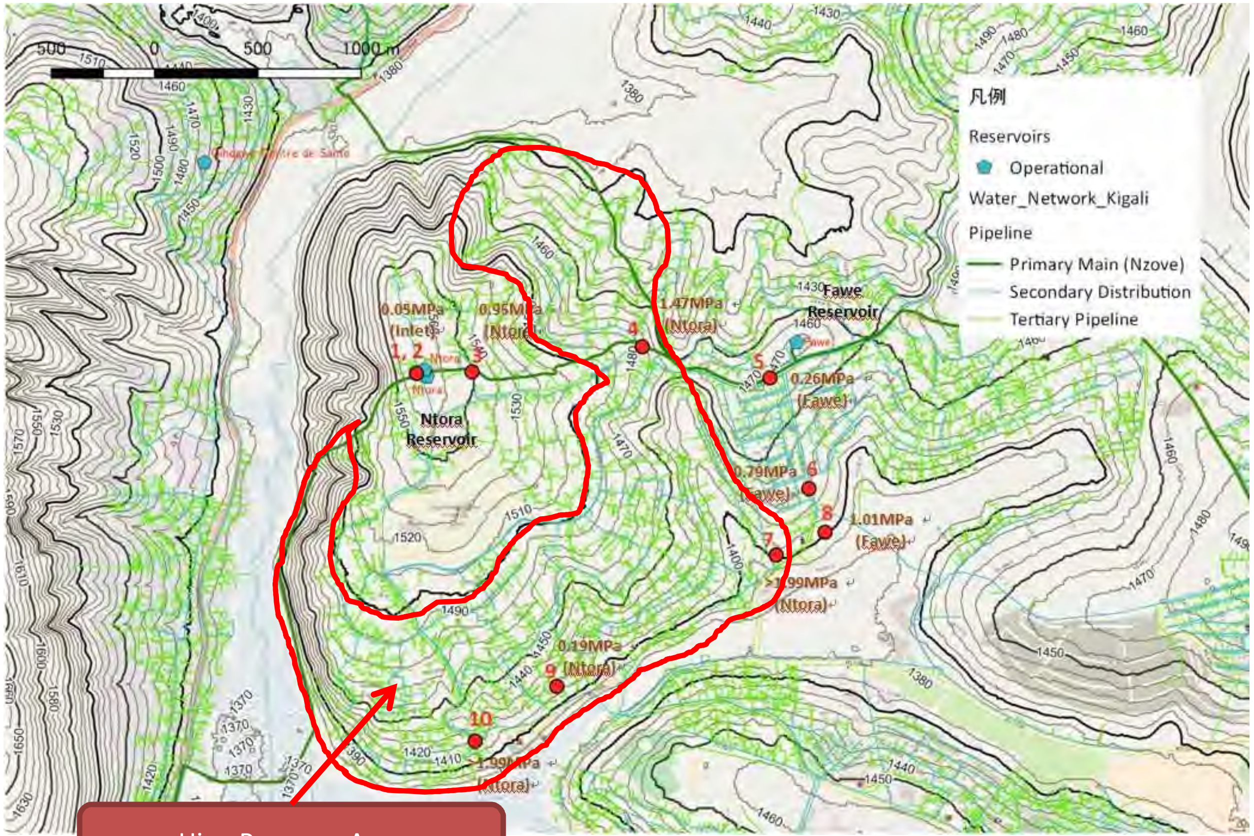
2	1	2	1,375	2,091	2,091	2,091	1,680	467	0.00483	10.10891	1,594	219	600	DIP	**－(Runda/Kamara系分岐)**	190
3	2	3	1,565	6,872	8,963	8,963	1,490	414	0.00387	26.58568	1,567	2	600	DIP	Distribution-Ntota（DN63x2）, w Lekage (140m3/h)	1
4	3	No15-1/2	1,565	1	8,964	8,964	1,489	414	0.00387	0.00387	1,567	2	600	DIP	No.15 Ntora Reservoir(5,000m3x2)	
Nzobe-Runda (by Pumping)																
52	2	51	1,363	204	204	2,295	190	53	0.01818	3.71063	1,590	227	200	DIP	**Branch Point→Karara**	110
53	51	52	1,508	5,029	5,233	7,324	80	22	0.00285	14.32695	1,576	68	200	PVC	No.1 Buyenzi(Runda) (400m3)	45
Nzobe-Karama (by Pumping)																
63	51	No.3	1,519	1,742	1,742	4,037	110	31	0.02736	47.66652	1,543	24	150	DIP	No.3 Karama (400m3)	25

High Pressure Zone by Pressure



Higu Pressure Area

Design Treated Water Transmisson Flow m^3/h Nzove Pumping Station (G.L) m 0

C value DIP PVC SP

No.	Section		Ground level	Distance between section	Distance each section	Cumulative distance from water source	Section discharge		Hydraulic gradient	Head loss	Dynamic water level	Pressure	Pipe diameter	Pipe Material	Velocity	Water Hammer	Designed Head	Note	Distribution (estimate)	Pressure Breaker @janction	Distributution1	Distributution2
	Start	End	GL+m	m	m	m	m^3/h	L/s			m	m	mm		m/s	m	m		m^3/h			
Res	-	-	0	0	0	0											#DIV/0!					
1	Res	1			0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!					
2	1	2			0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!					
3	2	3			0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!					
4	3	4			0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!					
5	4	5			0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!					
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30	29	30			0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!					

United States
Environmental Protection Agency

EPA/600/R-00/057
September 2000

EPANET 2

USERS MANUAL

By

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NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

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Although a reasonable effort has been made to assure that the results obtained are correct, the computer programs described in this manual are experimental. Therefore the author and the U.S. Environmental Protection Agency are not responsible and assume no liability whatsoever for any results or any use made of the results obtained from these programs, nor for any damages or litigation that result from the use of these programs for any purpose.

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to the air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

In order to meet regulatory requirements and customer expectations, water utilities are feeling a growing need to understand better the movement and transformations undergone by treated water introduced into their distribution systems. EPANET is a computerized simulation model that helps meet this goal. It predicts the dynamic hydraulic and water quality behavior within a drinking water distribution system operating over an extended period of time. This manual describes the operation of a newly revised version of the program that has incorporated many modeling enhancements made over the past several years.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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CONTENTS

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CHAPTER 1 - INTRODUCTION

1.1 What is EPANET

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EPANET can help assess alternative management strategies for improving water quality throughout a system. These can include:

- altering source utilization within multiple source systems,
- altering pumping and tank filling/emptying schedules,
- use of satellite treatment, such as re-chlorination at storage tanks,
- targeted pipe cleaning and replacement.

Running under Windows, EPANET provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded network maps, data tables, time series graphs, and contour plots.

1.2 Hydraulic Modeling Capabilities

Full-featured and accurate hydraulic modeling is a prerequisite for doing effective water quality modeling. EPANET contains a state-of-the-art hydraulic analysis engine that includes the following capabilities:

- places no limit on the size of the network that can be analyzed
- computes friction headloss using the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas
- includes minor head losses for bends, fittings, etc.
- models constant or variable speed pumps
- computes pumping energy and cost

- models various types of valves including shutoff, check, pressure regulating, and flow control valves
- allows storage tanks to have any shape (i.e., diameter can vary with height)
- considers multiple demand categories at nodes, each with its own pattern of time variation
- models pressure-dependent flow issuing from emitters (sprinkler heads)
- can base system operation on both simple tank level or timer controls and on complex rule-based controls.

1.3 Water Quality Modeling Capabilities

In addition to hydraulic modeling, EPANET provides the following water quality modeling capabilities:

- models the movement of a non-reactive tracer material through the network over time
- models the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) with time
- models the age of water throughout a network
- tracks the percent of flow from a given node reaching all other nodes over time
- models reactions both in the bulk flow and at the pipe wall
- uses n-th order kinetics to model reactions in the bulk flow
- uses zero or first order kinetics to model reactions at the pipe wall
- accounts for mass transfer limitations when modeling pipe wall reactions
- allows growth or decay reactions to proceed up to a limiting concentration
- employs global reaction rate coefficients that can be modified on a pipe-by-pipe basis
- allows wall reaction rate coefficients to be correlated to pipe roughness
- allows for time-varying concentration or mass inputs at any location in the network
- models storage tanks as being either complete mix, plug flow, or two-compartment reactors.

By employing these features, EPANET can study such water quality phenomena as:

- blending water from different sources
- age of water throughout a system
- loss of chlorine residuals
- growth of disinfection by-products
- tracking contaminant propagation events.

1.4 Steps in Using EPANET

One typically carries out the following steps when using EPANET to model a water distribution system:

1. Draw a network representation of your distribution system (see Section 6.1) or import a basic description of the network placed in a text file (see Section 11.4).
2. Edit the properties of the objects that make up the system (see Section 6.4)
3. Describe how the system is operated (see Section 6.5)
4. Select a set of analysis options (see Section 8.1)
5. Run a hydraulic/water quality analysis (see Section 8.2)
6. View the results of the analysis (see Chapter 9).

1.5 About This Manual

Chapter 2 of this manual describes how to install EPANET and offers up a quick tutorial on its use. Readers unfamiliar with the basics of modeling distribution systems might wish to review Chapter 3 first before working through the tutorial.

Chapter 3 provides background material on how EPANET models a water distribution system. It discusses the behavior of the physical components that comprise a distribution system as well as how additional modeling information, such as time variations and operational control, are handled. It also provides an overview of how the numerical simulation of system hydraulics and water quality performance is carried out.

Chapter 4 shows how the EPANET workspace is organized. It describes the functions of the various menu options and toolbar buttons, and how the three main windows – the Network Map, the Browser, and the Property Editor—are used.

Chapter 5 discusses the project files that store all of the information contained in an EPANET model of a distribution system. It shows how to create, open, and save these files as well as how to set default project options. It also discusses how to register calibration data that are used to compare simulation results against actual measurements.

Chapter 6 describes how one goes about building a network model of a distribution system with EPANET. It shows how to create the various physical objects (pipes, pumps, valves, junctions, tanks, etc.) that make up a system, how to edit the properties of these objects, and how to describe the way that system demands and operation change over time.

Chapter 7 explains how to use the network map that provides a graphical view of the system being modeled. It shows how to view different design and computed parameters in color-coded fashion on the map, how to re-scale, zoom, and pan the map, how to locate objects on the map, and what options are available to customize the appearance of the map.

Chapter 8 shows how to run a hydraulic/water quality analysis of a network model. It describes the various options that control how the analysis is made and offers some troubleshooting tips to use when examining simulation results.

Chapter 9 discusses the various ways in which the results of an analysis can be viewed. These include different views of the network map, various kinds of graphs and tables, and several different types of special reports.

Chapter 10 explains how to print and copy the views discussed in Chapter 9.

Chapter 11 describes how EPANET can import and export project scenarios. A scenario is a subset of the data that characterizes the current conditions under which a pipe network is being analyzed (e.g., consumer demands, operating rules, water quality reaction coefficients, etc.). It also discusses how to save a project's entire database to a readable text file and how to export the network map to a variety of formats.

Chapter 12 answers questions about how EPANET can be used to model special kinds of situations, such as modeling pneumatic tanks, finding the maximum flow available at a specific pressure, and modeling the growth of disinfection by-products.

The manual also contains several appendixes. Appendix A provides a table of units of expression for all design and computed parameters. Appendix B is a list of error message codes and their meanings that the program can generate. Appendix C describes how EPANET can be run from a command line prompt within a DOS window, and discusses the format of the files that are used with this mode of operation. Appendix D provides details of the procedures and formulas used by EPANET in its hydraulic and water quality analysis algorithms.

CHAPTER 2 - QUICK START TUTORIAL

This chapter provides a tutorial on how to use EPANET. If you are not familiar with the components that comprise a water distribution system and how these are represented in pipe network models you might want to review the first two sections of Chapter 3 first.

2.1 Installing EPANET

EPANET Version 2 is designed to run under the Windows 95/98/NT operating system of an IBM/Intel-compatible personal computer. It is distributed as a single file, **en2setup.exe**, which contains a self-extracting setup program. To install EPANET:

1. Select **Run** from the Windows Start menu.
2. Enter the full path and name of the **en2setup.exe** file or click the **Browse** button to locate it on your computer.
3. Click the **OK** button type to begin the setup process.

The setup program will ask you to choose a folder (directory) where the EPANET files will be placed. The default folder is **c:\Program Files\EPANET2**. After the files are installed your Start Menu will have a new item named EPANET 2.0. To launch EPANET simply select this item off of the Start Menu, then select EPANET 2.0 from the submenu that appears. (The name of the executable file that runs EPANET under Windows is **epanet2w.exe**.)

Should you wish to remove EPANET from your computer, you can use the following procedure:

1. Select **Settings** from the Windows Start menu.
2. Select **Control Panel** from the Settings menu.
3. Double-click on the **Add/Remove Programs** item.
4. Select EPANET 2.0 from the list of programs that appears.
5. Click the **Add/Remove** button.

2.2 Example Network

In this tutorial we will analyze the simple distribution network shown in Figure 2.1 below. It consists of a source reservoir (e.g., a treatment plant clearwell) from which water is pumped into a two-loop pipe network. There is also a pipe leading to a storage tank that floats on the system. The ID labels for the various components are shown in the figure. The nodes in the network have the characteristics shown in Table 2.1. Pipe properties are listed in Table 2.2. In addition, the pump (Link 9) can deliver 150 ft of head at a flow of 600 gpm, and the tank (Node 8) has a 60-ft diameter, a 3.5-ft water level, and a maximum level of 20 feet.

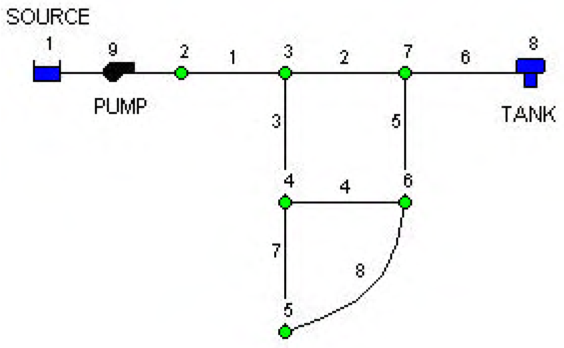


Figure 2.1 Example Pipe Network

Table 2.1 Example Network Node Properties

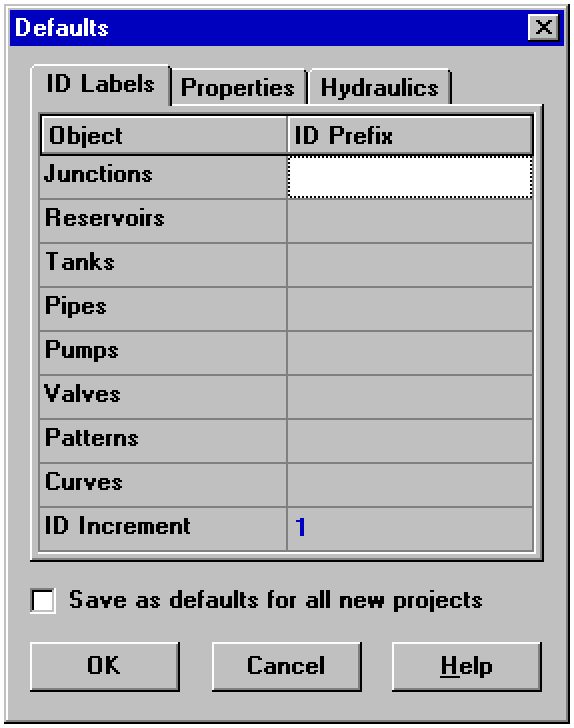
Node	Elevation (ft)	Demand (gpm)
1	700	0
2	700	0
3	710	150
4	700	150
5	650	200
6	700	150
7	700	0
8	830	0

Table 2.2 Example Network Pipe Properties

Pipe	Length (ft)	Diameter (inches)	C-Factor
1	3000	14	100
2	5000	12	100
3	5000	8	100
4	5000	8	100
5	5000	8	100
6	7000	10	100
7	5000	6	100
8	7000	6	100

2.3 Project Setup

Our first task is to create a new project in EPANET and make sure that certain default options are selected. To begin, launch EPANET, or if it is already running select **File** >> **New** (from the menu bar) to create a new project. Then select **Project** >> **Defaults** to open the dialog form shown in Figure 2.2. We will use this dialog to have EPANET automatically label new objects with consecutive numbers starting from 1 as they are added to the network. On the ID Labels page of the dialog, clear all of the ID Prefix fields and set the ID Increment to 1. Then select the Hydraulics page of the dialog and set the choice of Flow Units to GPM (gallons per minute). This implies that US Customary units will be used for all other quantities as well (length in feet, pipe diameter in inches, pressure in psi, etc.). Also select Hazen-Williams (H-W) as the headloss formula. If you wanted to save these choices for all future new projects you could check the **Save** box at the bottom of the form before accepting it by clicking the **OK** button.



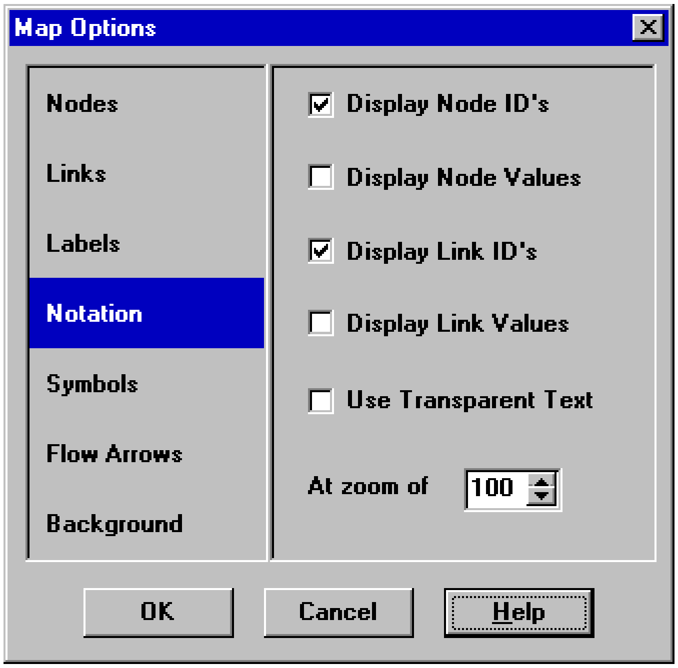
Object	ID Prefix
Junctions	
Reservoirs	
Tanks	
Pipes	
Pumps	
Valves	
Patterns	
Curves	
ID Increment	1

☐ Save as defaults for all new projects

Figure 2.2 Project Defaults Dialog

Next we will select some map display options so that as we add objects to the map, we will see their ID labels and symbols displayed. Select **View** >> **Options** to bring up the Map Options dialog form. Select the Notation page on this form and check the settings shown in Figure 2.3 below. Then switch to the Symbols page and check all of the boxes. Click the **OK** button to accept these choices and close the dialog.

Finally, before drawing our network we should insure that our map scale settings are acceptable. Select **View** >> **Dimensions** to bring up the Map Dimensions dialog. Note the default dimensions assigned for a new project. These settings will suffice for this example, so click the **OK** button.



Map Options

☑ Display Node ID's

☐ Display Node Values

☑ Display Link ID's

☐ Display Link Values

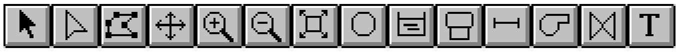
☐ Use Transparent Text

At zoom of 100

Figure 2.3 Map Options Dialog

2.4 Drawing the Network

We are now ready to begin drawing our network by making use of our mouse and the buttons contained on the Map Toolbar shown below. (If the toolbar is not visible then select **View** >> **Toolbars** >> **Map**).



First we will add the reservoir. Click the Reservoir button . Then click the mouse on the map at the location of the reservoir (somewhere to the left of the map).

Next we will add the junction nodes. Click the Junction button and then click on the map at the locations of nodes 2 through 7.

Finally add the tank by clicking the Tank button and clicking the map where the tank is located. At this point the Network Map should look something like the drawing in Figure 2.4.

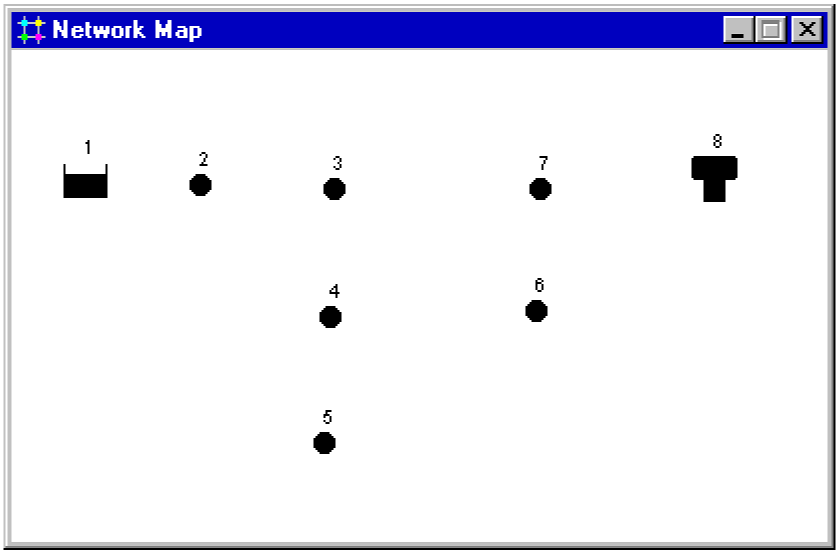


Figure 2.4 Network Map after Adding Nodes

Next we will add the pipes. Let's begin with pipe 1 connecting node 2 to node 3. First click the Pipe button on the Toolbar. Then click the mouse on node 2 on the map and then on node 3. Note how an outline of the pipe is drawn as you move the mouse from node 2 to 3. Repeat this procedure for pipes 2 through 7.

Pipe 8 is curved. To draw it, click the mouse first on Node 5. Then as you move the mouse towards Node 6, click at those points where a change of direction is needed to maintain the desired shape. Complete the process by clicking on Node 6.

Finally we will add the pump. Click the Pump button , click on node 1 and then on node 2.

Next we will label the reservoir, pump and tank. Select the Text button T on the Map Toolbar and click somewhere close to the reservoir (Node 1). An edit box will appear. Type in the word SOURCE and then hit the **Enter** key. Click next to the pump and enter its label, then do the same for the tank. Then click the Selection button on the Toolbar to put the map into Object Selection mode rather than Text Insertion mode.

At this point we have completed drawing the example network. Your Network Map should look like the map in Figure 2.1. If the nodes are out of position you can move them around by clicking the node to select it, and then dragging it with the left mouse button held down to its new position. Note how pipes connected to the node are moved along with the node. The labels can be repositioned in similar fashion. To re-shape the curved Pipe 8:

1. First click on Pipe 8 to select it and then click the button on the Map Toolbar to put the map into Vertex Selection mode.

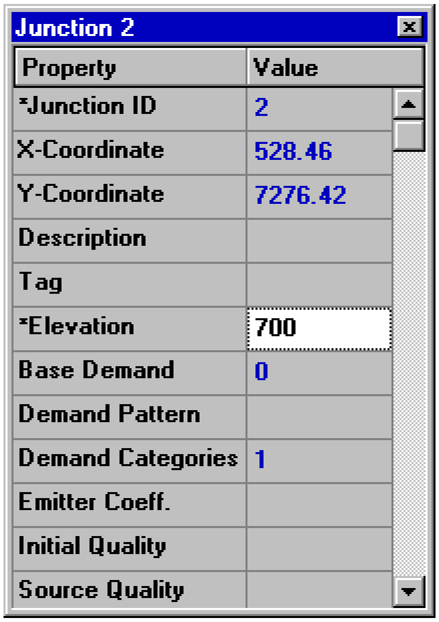
2. Select a vertex point on the pipe by clicking on it and then drag it to a new position with the left mouse button held down.
3. If required, vertices can be added or deleted from the pipe by right-clicking the mouse and selecting the appropriate option from the popup menu that appears.
4. When finished, click to return to Object Selection mode.

2.5 Setting Object Properties

As objects are added to a project they are assigned a default set of properties. To change the value of a specific property for an object one must select the object into the Property Editor (Figure 2.5). There are several different ways to do this. If the Editor is already visible then you can simply click on the object or select it from the Data page of the Browser. If the Editor is not visible then you can make it appear by one of the following actions:

- Double-click the object on the map.
- Right-click on the object and select **Properties** from the pop-up menu that appears.
- Select the object from the Data page of the Browser window and then click the Browser's Edit button .

Whenever the Property Editor has the focus you can press the F1 key to obtain fuller descriptions of the properties listed



Junction 2

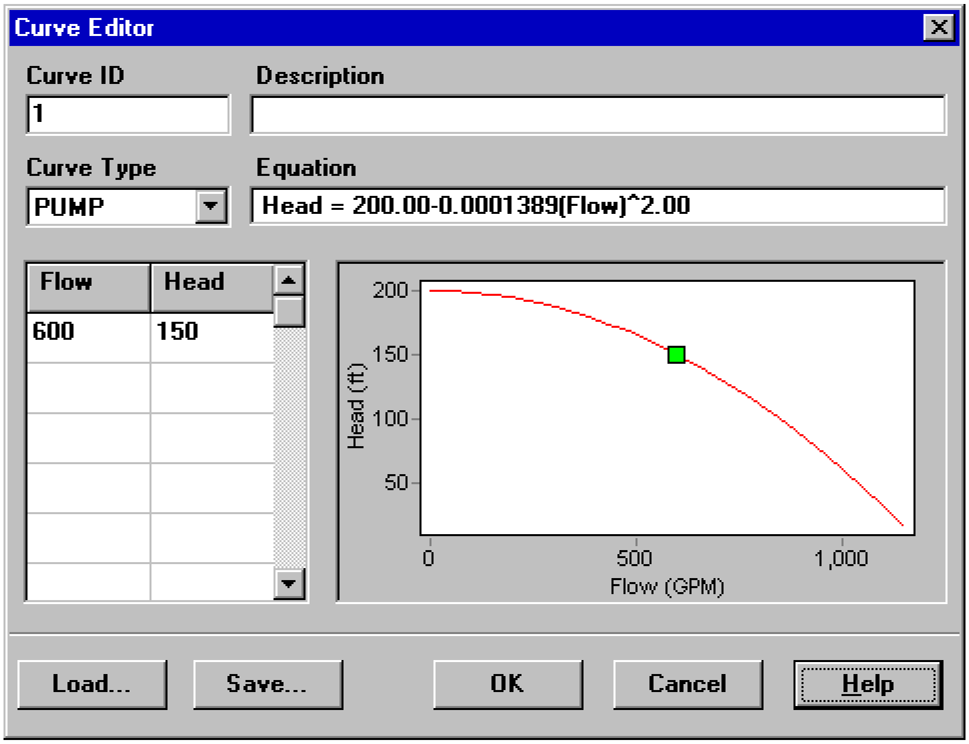
Property	Value
*Junction ID	2
X-Coordinate	528.46
Y-Coordinate	7276.42
Description	
Tag	
*Elevation	700
Base Demand	0
Demand Pattern	
Demand Categories	1
Emitter Coeff.	
Initial Quality	
Source Quality	

Figure 2.5 Property Editor

Let us begin editing by selecting Node 2 into the Property Editor as shown above. We would now enter the elevation and demand for this node in the appropriate fields. You can use the **Up** and **Down** arrows on the keyboard or the mouse to move between fields. We need only click on another object (node or link) to have its properties appear next in the Property Editor. (We could also press the **Page Down** or **Page Up** key to move to the next or previous object of the same type in the database.) Thus we can simply move from object to object and fill in elevation and demand for nodes, and length, diameter, and roughness (C-factor) for links.

For the reservoir you would enter its elevation (700) in the Total Head field. For the tank, enter 830 for its elevation, 4 for its initial level, 20 for its maximum level, and 60 for its diameter. For the pump, we need to assign it a pump curve (head versus flow relationship). Enter the ID label 1 in the Pump Curve field.

Next we will create Pump Curve 1. From the Data page of the Browser window, select Curves from the dropdown list box and then click the Add button . A new Curve 1 will be added to the database and the Curve Editor dialog form will appear (see Figure 2.6). Enter the pump's design flow (600) and head (150) into this form. EPANET automatically creates a complete pump curve from this single point. The curve's equation is shown along with its shape. Click **OK** to close the Editor.



Curve ID: 1

Curve Type: PUMP

Equation: Head = 200.00-0.0001389(Flow)^2.00

Flow	Head
600	150

Figure 2.6 Curve Editor

2.6 Saving and Opening Projects

Having completed the initial design of our network it is a good idea to save our work to a file at this point.

1. From the **File** menu select the **Save As** option.
2. In the Save As dialog that appears, select a folder and file name under which to save this project. We suggest naming the file **tutorial.net**. (An extension of **.net** will be added to the file name if one is not supplied.)
3. Click **OK** to save the project to file.

The project data is saved to the file in a special binary format. If you wanted to save the network data to file as readable text, use the **File** >> **Export** >> **Network** command instead.

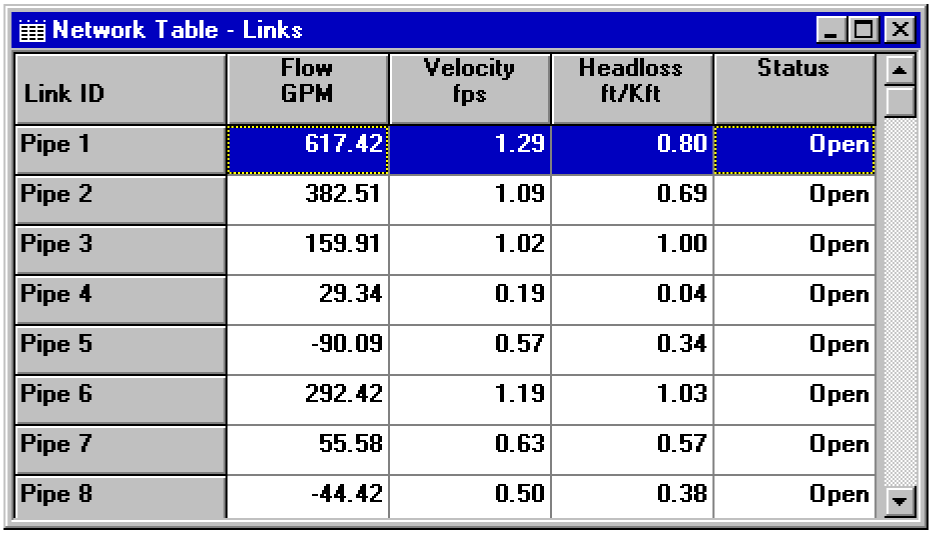
To open our project at some later time, we would select the **Open** command from the **File** menu.

2.7 Running a Single Period Analysis

We now have enough information to run a single period (or snapshot) hydraulic analysis on our example network. To run the analysis select **Project** >> **Run Analysis** or click the Run button ⚡ on the Standard Toolbar. (If the toolbar is not visible select **View** >> **Toolbars** >> **Standard** from the menu bar).

If the run was unsuccessful then a Status Report window will appear indicating what the problem was. If it ran successfully you can view the computed results in a variety of ways. Try some of the following:

- Select Node Pressure from the Browser's Map page and observe how pressure values at the nodes become color-coded. To view the legend for the color-coding, select **View** >> **Legends** >> **Node** (or right-click on an empty portion of the map and select Node Legend from the popup menu). To change the legend intervals and colors, right-click on the legend to make the Legend Editor appear.
- Bring up the Property Editor (double-click on any node or link) and note how the computed results are displayed at the end of the property list.
- Create a tabular listing of results by selecting **Report** >> **Table** (or by clicking the Table button ▦ on the Standard Toolbar). Figure 2.7 displays such a table for the link results of this run. Note that flows with negative signs means that the flow is in the opposite direction to the direction in which the pipe was drawn initially.

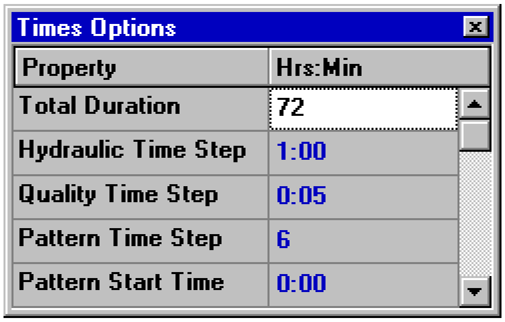


Link ID	Flow GPM	Velocity fps	Headloss ft/Kft	Status
Pipe 1	617.42	1.29	0.80	Open
Pipe 2	382.51	1.09	0.69	Open
Pipe 3	159.91	1.02	1.00	Open
Pipe 4	29.34	0.19	0.04	Open
Pipe 5	-90.09	0.57	0.34	Open
Pipe 6	292.42	1.19	1.03	Open
Pipe 7	55.58	0.63	0.57	Open
Pipe 8	-44.42	0.50	0.38	Open

Figure 2.7 Example Table of Link Results

2.8 Running an Extended Period Analysis

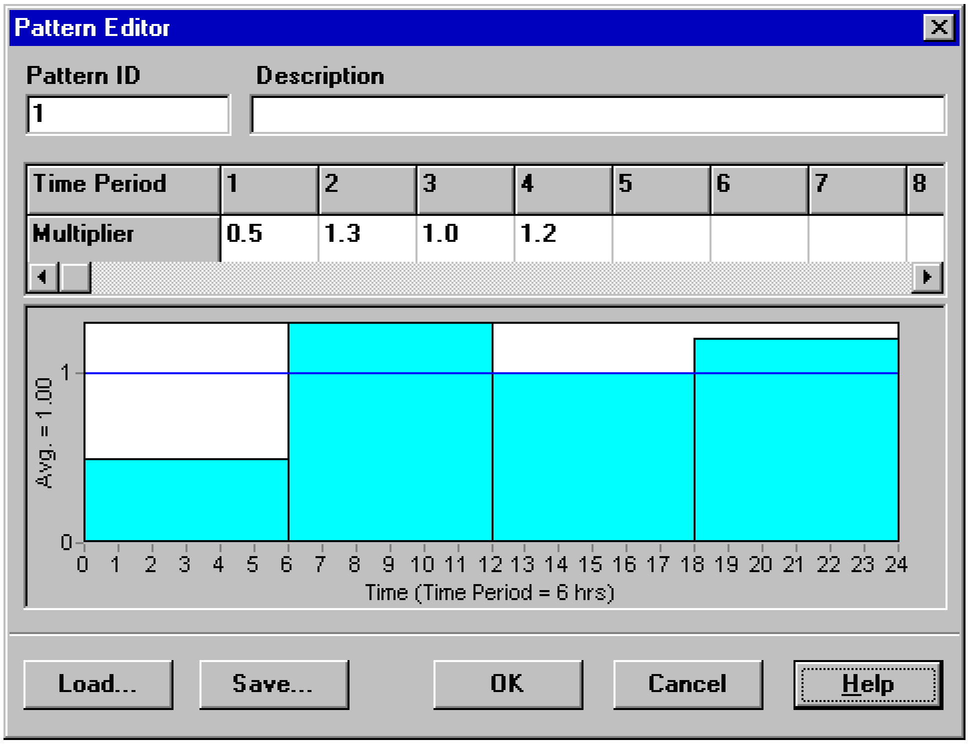
To make our network more realistic for analyzing an extended period of operation we will create a Time Pattern that makes demands at the nodes vary in a periodic way over the course of a day. For this simple example we will use a pattern time step of 6 hours thus making demands change at four different times of the day. (A 1-hour pattern time step is a more typical number and is the default assigned to new projects.) We set the pattern time step by selecting Options-Times from the Data Browser, clicking the Browser’s Edit button to make the Property Editor appear (if its not already visible), and entering 6 for the value of the Pattern Time Step (as shown in Figure 2.8 below). While we have the Time Options available we can also set the duration for which we want the extended period to run. Let’s use a 3-day period of time (enter 72 hours for the Duration property).



Property	Hrs:Min
Total Duration	72
Hydraulic Time Step	1:00
Quality Time Step	0:05
Pattern Time Step	6
Pattern Start Time	0:00

Figure 2.8 Times Options

To create the pattern, select the Patterns category in the Browser and then click the Add button. A new Pattern 1 will be created and the Pattern Editor dialog should appear (see Figure 2.9). Enter the multiplier values 0.5, 1.3, 1.0, 1.2 for the time periods 1 to 4 that will give our pattern a duration of 24 hours. The multipliers are used to modify the demand from its base level in each time period. Since we are making a run of 72 hours, the pattern will wrap around to the start after each 24-hour interval of time.



Pattern ID: 1

Description:

Time Period	1	2	3	4	5	6	7	8
Multiplier	0.5	1.3	1.0	1.2				

Figure 2.9 Pattern Editor

We now need to assign Pattern 1 to the Demand Pattern property of all of the junctions in our network. We can utilize one of EPANET’s Hydraulic Options to avoid having to edit each junction individually. If you bring up the Hydraulic Options in the Property Editor you will see that there is an item called Default Pattern. Setting its value equal to 1 will make the Demand Pattern at each junction equal Pattern 1, as long as no other pattern is assigned to the junction.

Next run the analysis (select **Project** >> **Run Analysis** or click the button on the Standard Toolbar). For extended period analysis you have several more ways in which to view results:

- The scrollbar in the Browser’s Time controls is used to display the network map at different points in time. Try doing this with Pressure selected as the node parameter and Flow as the link parameter.

- The VCR-style buttons in the Browser can animate the map through time. Click the Forward button ▶ to start the animation and the Stop button ■ to stop it.
- Add flow direction arrows to the map (select **View** >> **Options**, select the Flow Arrows page from the Map Options dialog, and check a style of arrow that you wish to use). Then begin the animation again and note the change in flow direction through the pipe connected to the tank as the tank fills and empties over time.
- Create a time series plot for any node or link. For example, to see how the water elevation in the tank changes with time:
    1. Click on the tank.
    2. Select **Report** >> **Graph** (or click the Graph button 📈 on the Standard Toolbar) which will display a Graph Selection dialog box.
    3. Select the Time Series button on the dialog.
    4. Select Head as the parameter to plot.
    5. Click **OK** to accept your choice of graph.

Note the periodic behavior of the water elevation in the tank over time (Figure 2.10).

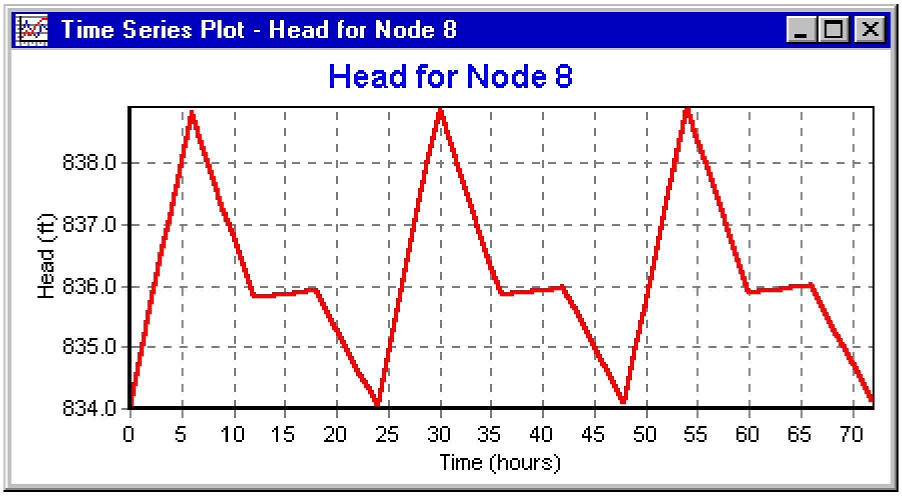


Figure 2.10 Example Time Series Plot

2.9 Running a Water Quality Analysis

Next we show how to extend the analysis of our example network to include water quality. The simplest case would be tracking the growth in water age throughout the network over time. To make this analysis we only have to select Age for the Parameter property in the Quality Options (select Options-Quality from the Data page of the Browser, then click the Browser's Edit button to make the Property Editor appear). Run the analysis and select Age as the parameter to view on the map. Create a time series plot for Age in the tank. Note that unlike water level, 72 hours is not enough time for the tank to reach periodic behavior for water age. (The default initial condition is to start all nodes with an age of 0.) Try repeating the simulation using a 240-hour duration or assigning an initial age of 60 hours to the tank (enter 60 as the value of Initial Quality in the Property Editor for the tank).

Finally we show how to simulate the transport and decay of chlorine through the network. Make the following changes to the database:

1. Select Options-Quality to edit from the Data Browser. In the Property Editor's Parameter field type in the word Chlorine.
2. Switch to Options-Reactions in the Browser. For Global Bulk Coefficient enter a value of -1.0. This reflects the rate at which chlorine will decay due to reactions in the bulk flow over time. This rate will apply to all pipes in the network. You could edit this value for individual pipes if you needed to.
3. Click on the reservoir node and set its Initial Quality to 1.0. This will be the concentration of chlorine that continuously enters the network. (Reset the initial quality in the Tank to 0 if you had changed it.)

Now run the example. Use the Time controls on the Map Browser to see how chlorine levels change by location and time throughout the simulation. Note how for this simple network, only junctions 5, 6, and 7 see depressed chlorine levels because of being fed by low chlorine water from the tank. Create a reaction report for this run by selecting **Report** >> **Reaction** from the main menu. The report should look like Figure 2.11. It shows on average how much chlorine loss occurs in the pipes as opposed to the tank. The term "bulk" refers to reactions occurring in the bulk fluid while "wall" refers to reactions with material on the pipe wall. The latter reaction is zero because we did not specify any wall reaction coefficient in this example.

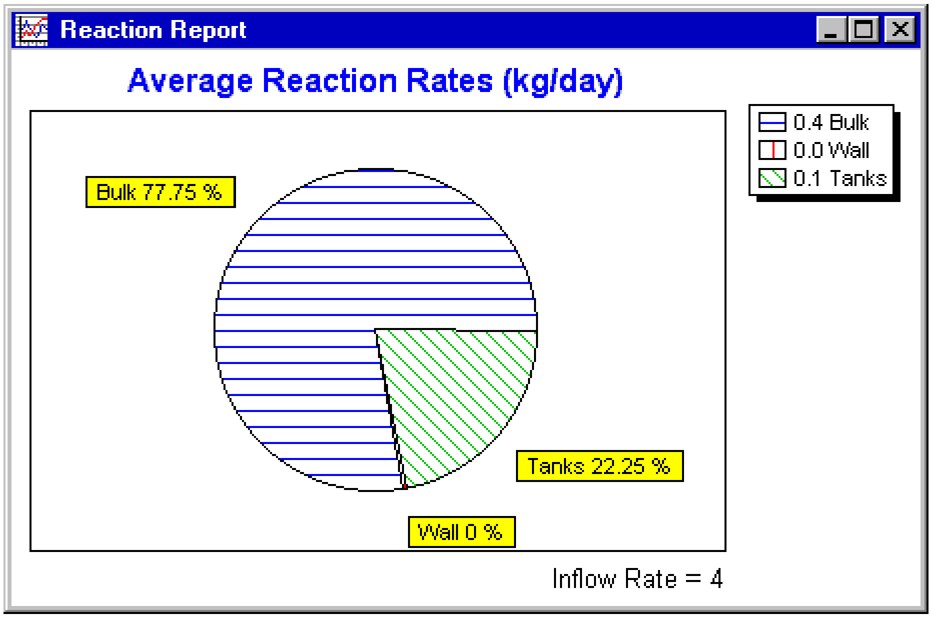


Figure 2.11 Example Reaction Report

We have only touched the surface of the various capabilities offered by EPANET. Some additional features of the program that you should experiment with are:

- Editing a property for a group of objects that lie within a user-defined area.
- Using Control statements to base pump operation on time of day or tank water levels.
- Exploring different Map Options, such as making node size be related to value.
- Attaching a backdrop map (such as a street map) to the network map.
- Creating different types of graphs, such as profile plots and contour plots.
- Adding calibration data to a project and viewing a calibration report.
- Copying the map, a graph, or a report to the clipboard or to a file.
- Saving and retrieving a design scenario (i.e., current nodal demands, pipe roughness values, etc.).

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CHAPTER 3 - THE NETWORK MODEL

This chapter discusses how EPANET models the physical objects that constitute a distribution system as well as its operational parameters. Details about how this information is entered into the program are presented in later chapters. An overview is also given on the computational methods that EPANET uses to simulate hydraulic and water quality transport behavior.

3.1 Physical Components

EPANET models a water distribution system as a collection of links connected to nodes. The links represent pipes, pumps, and control valves. The nodes represent junctions, tanks, and reservoirs. The figure below illustrates how these objects can be connected to one another to form a network.

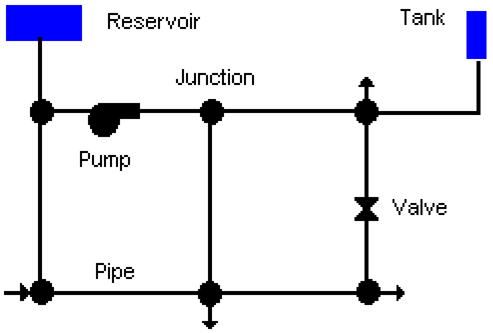


Figure 3.1 Physical Components in a Water Distribution System

Junctions

Junctions are points in the network where links join together and where water enters or leaves the network. The basic input data required for junctions are:

- elevation above some reference (usually mean sea level)
- water demand (rate of withdrawal from the network)
- initial water quality.

The output results computed for junctions at all time periods of a simulation are:

- hydraulic head (internal energy per unit weight of fluid)
- pressure
- water quality.

Junctions can also:

- have their demand vary with time
- have multiple categories of demands assigned to them
- have negative demands indicating that water is entering the network
- be water quality sources where constituents enter the network
- contain emitters (or sprinklers) which make the outflow rate depend on the pressure.

Reservoirs

Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, and tie-ins to other systems. Reservoirs can also serve as water quality source points.

The primary input properties for a reservoir are its hydraulic head (equal to the water surface elevation if the reservoir is not under pressure) and its initial quality for water quality analysis.

Because a reservoir is a boundary point to a network, its head and water quality cannot be affected by what happens within the network. Therefore it has no computed output properties. However its head can be made to vary with time by assigning a time pattern to it (see Time Patterns below).

Tanks

Tanks are nodes with storage capacity, where the volume of stored water can vary with time during a simulation. The primary input properties for tanks are:

- bottom elevation (where water level is zero)
- diameter (or shape if non-cylindrical)
- initial, minimum and maximum water levels
- initial water quality.

The principal outputs computed over time are:

- hydraulic head (water surface elevation)
- water quality.

Tanks are required to operate within their minimum and maximum levels. EPANET stops outflow if a tank is at its minimum level and stops inflow if it is at its maximum level. Tanks can also serve as water quality source points.

Emitters

Emitters are devices associated with junctions that model the flow through a nozzle or orifice that discharges to the atmosphere. The flow rate through the emitter varies as a function of the pressure available at the node:

$$q = C\ p^g$$

where q = flow rate, p = pressure, C = discharge coefficient, and γ = pressure exponent. For nozzles and sprinkler heads γ equals 0.5 and the manufacturer usually provides the value of the discharge coefficient in units of $\text{gpm/psi}^{0.5}$ (stated as the flow through the device at a 1 psi pressure drop).

Emitters are used to model flow through sprinkler systems and irrigation networks. They can also be used to simulate leakage in a pipe connected to the junction (if a discharge coefficient and pressure exponent for the leaking crack or joint can be estimated) or compute a fire flow at the junction (the flow available at some minimum residual pressure). In the latter case one would use a very high value of the discharge coefficient (e.g., 100 times the maximum flow expected) and modify the junction's elevation to include the equivalent head of the pressure target. EPANET treats emitters as a property of a junction and not as a separate network component.

Pipes

Pipes are links that convey water from one point in the network to another. EPANET assumes that all pipes are full at all times. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head. The principal hydraulic input parameters for pipes are:

- start and end nodes
- diameter
- length
- roughness coefficient (for determining headloss)
- status (open, closed, or contains a check valve).

The status parameter allows pipes to implicitly contain shutoff (gate) valves and check (non-return) valves (which allow flow in only one direction).

The water quality inputs for pipes consist of:

- bulk reaction coefficient
- wall reaction coefficient.

These coefficients are explained more thoroughly in Section 3.4 below.

Computed outputs for pipes include:

- flow rate
- velocity
- headloss
- Darcy-Weisbach friction factor
- average reaction rate (over the pipe length)
- average water quality (over the pipe length).

The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas:

- Hazen-Williams formula
- Darcy-Weisbach formula
- Chezy-Manning formula

The Hazen-Williams formula is the most commonly used headloss formula in the US. It cannot be used for liquids other than water and was originally developed for turbulent flow only. The Darcy-Weisbach formula is the most theoretically correct. It applies over all flow regimes and to all liquids. The Chezy-Manning formula is more commonly used for open channel flow.

Each formula uses the following equation to compute headloss between the start and end node of the pipe:

$$h_L = Aq^B$$

where h_L = headloss (Length), q = flow rate (Volume/Time), A = resistance coefficient, and B = flow exponent. Table 3.1 lists expressions for the resistance coefficient and values for the flow exponent for each of the formulas. Each formula uses a different pipe roughness coefficient that must be determined empirically. Table 3.2 lists general ranges of these coefficients for different types of new pipe materials. Be aware that a pipe’s roughness coefficient can change considerably with age.

With the Darcy-Weisbach formula EPANET uses different methods to compute the friction factor f depending on the flow regime:

- The Hagen–Poiseuille formula is used for laminar flow (Re < 2,000).
- The Swamee and Jain approximation to the Colebrook-White equation is used for fully turbulent flow (Re > 4,000).
- A cubic interpolation from the Moody Diagram is used for transitional flow (2,000 < Re < 4,000) .

Consult Appendix D for the actual equations used.

Table 3.1 Pipe Headloss Formulas for Full Flow
(for headloss in feet and flow rate in cfs)

Formula	*Resistance Coefficient (A)*	*Flow Exponent (B)*
Hazen-Williams	$4.727\ C^{-1.852}\ d^{-4.871}\ L$	1.852
Darcy-Weisbach	$0.0252\ f(\varepsilon,d,q)d^{-5}L$	2
Chezy-Manning	$4.66\ n^{2}\ d^{-5.33}\ L$	2
Notes: C = Hazen-Williams roughness coefficient ε = Darcy-Weisbach roughness coefficient (ft) f = friction factor (dependent on ε, d, and q) n = Manning roughness coefficient d = pipe diameter (ft) L = pipe length (ft) q = flow rate (cfs)		

Table 3.2 Roughness Coefficients for New Pipe

Material	*Hazen-Williams C (unitless)*	*Darcy-Weisbach e (feet x 10^{-3})*	*Manning's n (unitless)*
Cast Iron	130 – 140	0.85	0.012 - 0.015
Concrete or Concrete Lined	120 – 140	1.0 - 10	0.012 - 0.017
Galvanized Iron	120	0.5	0.015 - 0.017
Plastic	140 – 150	0.005	0.011 - 0.015
Steel	140 – 150	0.15	0.015 - 0.017
Vitrified Clay	110		0.013 - 0.015

Pipes can be set open or closed at preset times or when specific conditions exist, such as when tank levels fall below or above certain set points, or when nodal pressures fall below or above certain values. See the discussion of Controls in Section 3.2.

Minor Losses

Minor head losses (also called local losses) are caused by the added turbulence that occurs at bends and fittings. The importance of including such losses depends on the layout of the network and the degree of accuracy required. They can be accounted for by assigning the pipe a minor loss coefficient. The minor headloss becomes the product of this coefficient and the velocity head of the pipe, i.e.,

$$h_L = K\left(\frac{v^2}{2g}\right)$$

where K = minor loss coefficient, v = flow velocity (Length/Time), and g = acceleration of gravity (Length/Time^2). Table 3.3 provides minor loss coefficients for several types of fittings.

Table 3.3 Minor Loss Coefficients for Selected Fittings

FITTING	*LOSS COEFFICIENT*
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2
Short-radius elbow	0.9
Medium-radius elbow	0.8
Long-radius elbow	0.6
45 degree elbow	0.4
Closed return bend	2.2
Standard tee - flow through run	0.6
Standard tee - flow through branch	1.8
Square entrance	0.5
Exit	1.0

Pumps

Pumps are links that impart energy to a fluid thereby raising its hydraulic head. The principal input parameters for a pump are its start and end nodes and its pump curve (the combination of heads and flows that the pump can produce). In lieu of a pump curve, the pump could be represented as a constant energy device, one that supplies a constant amount of energy (horsepower or kilowatts) to the fluid for all combinations of flow and head.

The principal output parameters are flow and head gain. Flow through a pump is unidirectional and EPANET will not allow a pump to operate outside the range of its pump curve.

Variable speed pumps can also be considered by specifying that their speed setting be changed under these same types of conditions. By definition, the original pump curve supplied to the program has a relative speed setting of 1. If the pump speed doubles, then the relative setting would be 2; if run at half speed, the relative setting is 0.5 and so on. Changing the pump speed shifts the position and shape of the pump curve (see the section on Pump Curves below).

As with pipes, pumps can be turned on and off at preset times or when certain conditions exist in the network. A pump's operation can also be described by assigning it a time pattern of relative speed settings. EPANET can also compute the energy consumption and cost of a pump. Each pump can be assigned an efficiency curve and schedule of energy prices. If these are not supplied then a set of global energy options will be used.

Flow through a pump is unidirectional. If system conditions require more head than the pump can produce, EPANET shuts the pump off. If more than the maximum flow is required, EPANET extrapolates the pump curve to the required flow, even if this produces a negative head. In both cases a warning message will be issued.

Valves

Valves are links that limit the pressure or flow at a specific point in the network. Their principal input parameters include:

- start and end nodes
- diameter
- setting
- status.

The computed outputs for a valve are flow rate and headloss.

The different types of valves included in EPANET are:

- Pressure Reducing Valve (PRV)
- Pressure Sustaining Valve (PSV)
- Pressure Breaker Valve (PBV)
- Flow Control Valve (FCV)
- Throttle Control Valve (TCV)
- General Purpose Valve (GPV).

PRVs limit the pressure at a point in the pipe network. EPANET computes in which of three different states a PRV can be in:

- partially opened (i.e., active) to achieve its pressure setting on its downstream side when the upstream pressure is above the setting
- fully open if the upstream pressure is below the setting
- closed if the pressure on the downstream side exceeds that on the upstream side (i.e., reverse flow is not allowed).

PSVs maintain a set pressure at a specific point in the pipe network. EPANET computes in which of three different states a PSV can be in:

- partially opened (i.e., active) to maintain its pressure setting on its upstream side when the downstream pressure is below this value
- fully open if the downstream pressure is above the setting

- closed if the pressure on the downstream side exceeds that on the upstream side (i.e., reverse flow is not allowed).

PBVs force a specified pressure loss to occur across the valve. Flow through the valve can be in either direction. PBV's are not true physical devices but can be used to model situations where a particular pressure drop is known to exist.

FCVs limit the flow to a specified amount. The program produces a warning message if this flow cannot be maintained without having to add additional head at the valve (i.e., the flow cannot be maintained even with the valve fully open).

TCVs simulate a partially closed valve by adjusting the minor head loss coefficient of the valve. A relationship between the degree to which a valve is closed and the resulting head loss coefficient is usually available from the valve manufacturer.

GPVs are used to represent a link where the user supplies a special flow - head loss relationship instead of following one of the standard hydraulic formulas. They can be used to model turbines, well draw-down or reduced-flow backflow prevention valves.

Shutoff (gate) valves and check (non-return) valves, which completely open or close pipes, are not considered as separate valve links but are instead included as a property of the pipe in which they are placed.

Each type of valve has a different type of setting parameter that describes its operating point (pressure for PRVs, PSVs, and PBVs; flow for FCVs; loss coefficient for TCVs, and head loss curve for GPVs).

Valves can have their control status overridden by specifying they be either completely open or completely closed. A valve's status and its setting can be changed during the simulation by using control statements.

Because of the ways in which valves are modeled the following rules apply when adding valves to a network:

- a PRV, PSV or FCV cannot be directly connected to a reservoir or tank (use a length of pipe to separate the two)
- PRVs cannot share the same downstream node or be linked in series
- two PSVs cannot share the same upstream node or be linked in series
- a PSV cannot be connected to the downstream node of a PRV.

3.2 Non-Physical Components

In addition to physical components, EPANET employs three types of informational objects – curves, patterns, and controls - that describe the behavior and operational aspects of a distribution system.

Curves

Curves are objects that contain data pairs representing a relationship between two quantities. Two or more objects can share the same curve. An EPANET model can utilize the following types of curves:

- Pump Curve
- Efficiency Curve
- Volume Curve
- Head Loss Curve

Pump Curve

A Pump Curve represents the relationship between the head and flow rate that a pump can deliver at its nominal speed setting. Head is the head gain imparted to the water by the pump and is plotted on the vertical (Y) axis of the curve in feet (meters). Flow rate is plotted on the horizontal (X) axis in flow units. A valid pump curve must have decreasing head with increasing flow.

EPANET will use a different shape of pump curve depending on the number of points supplied (see Figure 3.2):

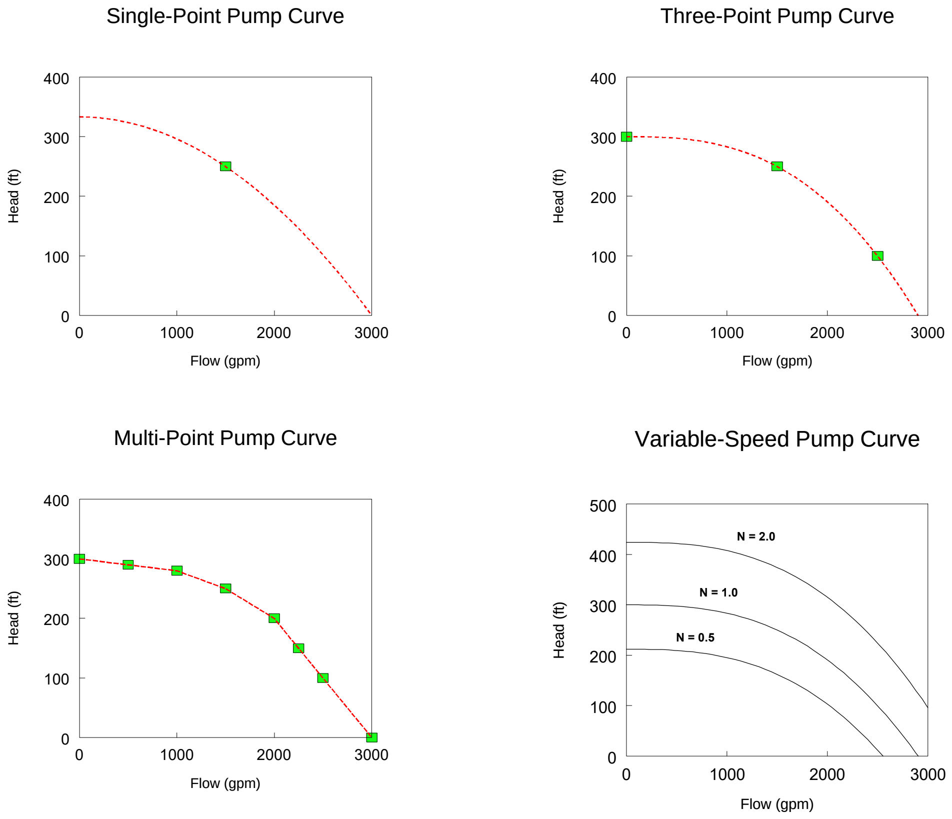


Figure 3.2 Example Pump Curves

Single-Point Curve - A single-point pump curve is defined by a single head-flow combination that represents a pump's desired operating point. EPANET adds two more points to the curve by assuming a shutoff head at zero flow equal to 133% of the design head and a maximum flow at zero head equal to twice the design flow. It then treats the curve as a three-point curve.

Three-Point Curve - A three-point pump curve is defined by three operating points: a Low Flow point (flow and head at low or zero flow condition), a Design Flow point (flow and head at desired operating point), and a Maximum Flow point (flow and head at maximum flow). EPANET tries to fit a continuous function of the form

$$h_G = A - Bq^C$$

through the three points to define the entire pump curve. In this function, h_g = head gain, q = flow rate, and A, B, and C are constants.

Multi-Point Curve – A multi-point pump curve is defined by providing either a pair of head-flow points or four or more such points. EPANET creates a complete curve by connecting the points with straight-line segments.

For variable speed pumps, the pump curve shifts as the speed changes. The relationships between flow (Q) and head (H) at speeds N1 and N2 are

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

<u>Efficiency Curve</u>

An Efficiency Curve determines pump efficiency (Y in percent) as a function of pump flow rate (X in flow units). An example efficiency curve is shown in Figure 3.3. Efficiency should represent wire-to-water efficiency that takes into account mechanical losses in the pump itself as well as electrical losses in the pump's motor. The curve is used only for energy calculations. If not supplied for a specific pump then a fixed global pump efficiency will be used.

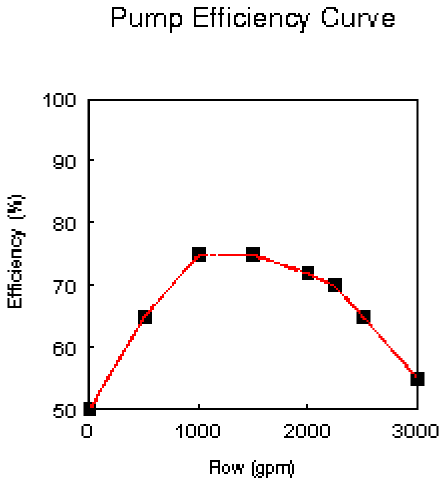


Figure 3.3 Pump Efficiency Curve

Volume Curve

A Volume Curve determines how storage tank volume (Y in cubic feet or cubic meters) varies as a function of water level (X in feet or meters). It is used when it is necessary to accurately represent tanks whose cross-sectional area varies with height. The lower and upper water levels supplied for the curve must contain the lower and upper levels between which the tank operates. An example of a tank volume curve is given below.

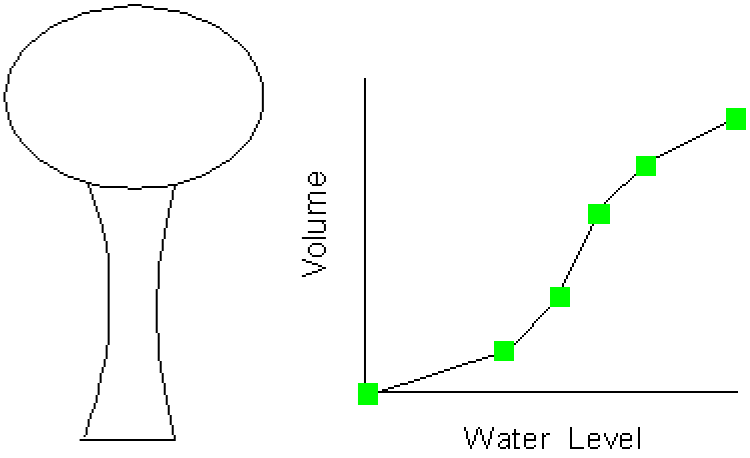


Figure 3.4 Tank Volume Curve

Headloss Curve

A Headloss Curve is used to described the headloss (Y in feet or meters) through a General Purpose Valve (GPV) as a function of flow rate (X in flow units). It provides the capability to model devices and situations with unique headloss-flow relationships, such as reduced flow - backflow prevention valves, turbines, and well draw-down behavior.

Time Patterns

A Time Pattern is a collection of multipliers that can be applied to a quantity to allow it to vary over time. Nodal demands, reservoir heads, pump schedules, and water quality source inputs can all have time patterns associated with them. The time interval used in all patterns is a fixed value, set with the project's Time Options (see Section 8.1). Within this interval a quantity remains at a constant level, equal to the product of its nominal value and the pattern's multiplier for that time period. Although all time patterns must utilize the same time interval, each can have a different number of periods. When the simulation clock exceeds the number of periods in a pattern, the pattern wraps around to its first period again.

As an example of how time patterns work consider a junction node with an average demand of 10 GPM. Assume that the time pattern interval has been set to 4 hours and a pattern with the following multipliers has been specified for demand at this node:

Period	1	2	3	4	5	6
Multiplier	0.5	0.8	1.0	1.2	0.9	0.7

Then during the simulation the actual demand exerted at this node will be as follows:

Hours	0-4	4-8	8-12	12-16	16-20	20-24	24-28
Demand	5	8	10	12	9	7	5

Controls

Controls are statements that determine how the network is operated over time. They specify the status of selected links as a function of time, tank water levels, and pressures at select points within the network. There are two categories of controls that can be used:

- Simple Controls
- Rule-Based Controls

Simple Controls

Simple controls change the status or setting of a link based on:

- the water level in a tank,
- the pressure at a junction,
- the time into the simulation,

- the time of day.

They are statements expressed in one of the following three formats:

```
LINK x status IF NODE y ABOVE/BELOW z
LINK x status AT TIME t
LINK x status AT CLOCKTIME c AM/PM
```

where:

x = a link ID label,
status = OPEN or CLOSED, a pump speed setting, or a control valve setting,
y = a node ID label,
z = a pressure for a junction or a water level for a tank,
t = a time since the start of the simulation in decimal hours or in hours:minutes notation,
c = a 24-hour clock time.

Some examples of simple controls are:

Control Statement	*Meaning*
`LINK 12 CLOSED IF NODE 23 ABOVE 20`	(Close Link 12 when the level in Tank 23 exceeds 20 ft.)
`LINK 12 OPEN IF NODE 130 BELOW 30`	(Open Link 12 if the pressure at Node 130 drops below 30 psi)
`LINK 12 1.5 AT TIME 16`	(Set the relative speed of pump 12 to 1.5 at 16 hours into the simulation)
`LINK 12 CLOSED AT CLOCKTIME 10 AM` `LINK 12 OPEN AT CLOCKTIME 8 PM`	(Link 12 is repeatedly closed at 10 AM and opened at 8 PM throughout the simulation)

There is no limit on the number of simple control statements that can be used.

Note: Level controls are stated in terms of the height of water above the tank bottom, not the elevation (total head) of the water surface.

Note: Using a pair of pressure controls to open and close a link can cause the system to become unstable if the pressure settings are too close to one another. In this case using a pair of Rule-Based controls might provide more stability.

Rule-Based Controls

Rule-Based Controls allow link status and settings to be based on a combination of conditions that might exist in the network after an initial hydraulic state of the system is computed. Here are several examples of Rule-Based Controls:

Example 1:
This set of rules shuts down a pump and opens a by-pass pipe when the level in a tank exceeds a certain value and does the opposite when the level is below another value.

```
RULE 1
IF   TANK   1 LEVEL ABOVE 19.1
THEN PUMP 335 STATUS IS CLOSED
AND  PIPE 330 STATUS IS OPEN

RULE 2
IF   TANK   1 LEVEL BELOW 17.1
THEN PUMP 335 STATUS IS OPEN
AND  PIPE 330 STATUS IS CLOSED
```

Example 2:
These rules change the tank level at which a pump turns on depending on the time of day.

```
RULE 3
IF   SYSTEM CLOCKTIME >= 8 AM
AND  SYSTEM CLOCKTIME < 6 PM
AND  TANK 1 LEVEL BELOW 12
THEN PUMP 335 STATUS IS OPEN

RULE 4
IF   SYSTEM CLOCKTIME >= 6 PM
OR   SYSTEM CLOCKTIME < 8 AM
AND  TANK 1 LEVEL BELOW 14
THEN PUMP 335 STATUS IS OPEN
```

A description of the formats used with Rule-Based controls can be found in Appendix C, under the [RULES] heading (page 150).

3.3 Hydraulic Simulation Model

EPANET's hydraulic simulation model computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. From one time step to the next reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution. The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the headloss relationship across each link in the network. This process, known as “hydraulically balancing” the network, requires using an iterative technique to solve the nonlinear equations involved. EPANET employs the “Gradient Algorithm” for this purpose. Consult Appendix D for details.

The hydraulic time step used for extended period simulation (EPS) can be set by the user. A typical value is 1 hour. Shorter time steps than normal will occur automatically whenever one of the following events occurs:

- the next output reporting time period occurs
- the next time pattern period occurs
- a tank becomes empty or full
- a simple control or rule-based control is activated.

3.4 Water Quality Simulation Model

Basic Transport

EPANET’s water quality simulator uses a Lagrangian time-based approach to track the fate of discrete parcels of water as they move along pipes and mix together at junctions between fixed-length time steps. These water quality time steps are typically much shorter than the hydraulic time step (e.g., minutes rather than hours) to accommodate the short times of travel that can occur within pipes.

The method tracks the concentration and size of a series of non-overlapping segments of water that fills each link of the network. As time progresses, the size of the most upstream segment in a link increases as water enters the link while an equal loss in size of the most downstream segment occurs as water leaves the link. The size of the segments in between these remains unchanged.

For each water quality time step, the contents of each segment are subjected to reaction, a cumulative account is kept of the total mass and flow volume entering each node, and the positions of the segments are updated. New node concentrations are then calculated, which include the contributions from any external sources. Storage tank concentrations are updated depending on the type of mixing model that is used (see below). Finally, a new segment will be created at the end of each link that receives inflow from a node if the new node quality differs by a user-specified tolerance from that of the link’s last segment.

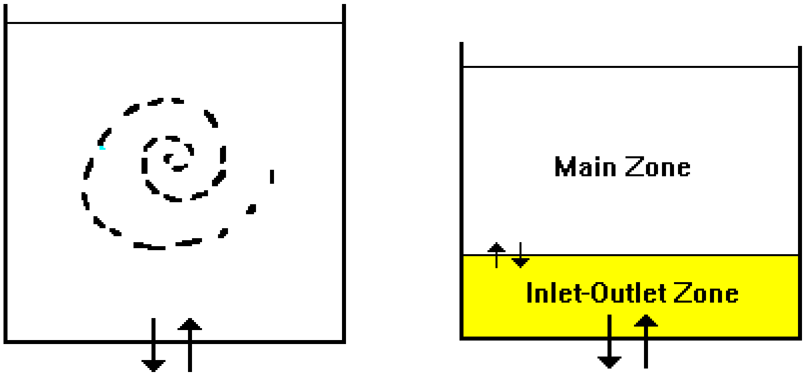
Initially each pipe in the network consists of a single segment whose quality equals the initial quality assigned to the upstream node. Whenever there is a flow reversal in a pipe, the pipe’s parcels are re-ordered from front to back.

Mixing in Storage Tanks

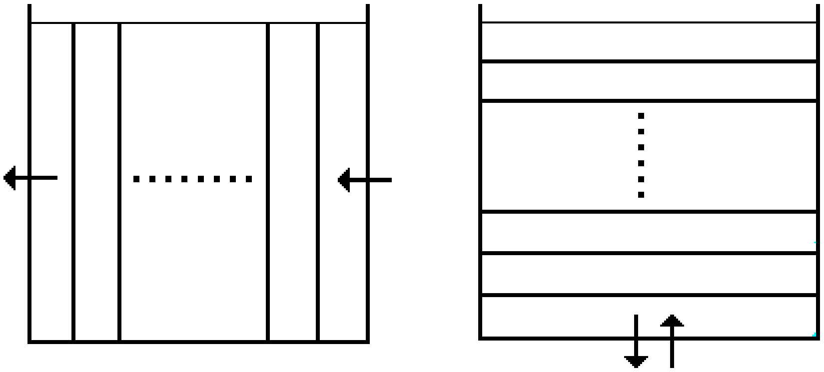
EPANET can use four different types of models to characterize mixing within storage tanks as illustrated in Figure 3.5:

- Complete Mixing
- Two-Compartment Mixing
- FIFO Plug Flow
- LIFO Plug Flow

Different models can be used with different tanks within a network.



(A) Complete Mixing (B) Two-Compartment Mixing



(C) Plug Flow - FIFO (D) Plug Flow - LIFO

Figure 3.5 Tank Mixing Models

The Complete Mixing model (Figure 3.5(a)) assumes that all water that enters a tank is instantaneously and completely mixed with the water already in the tank. It is the simplest form of mixing behavior to assume, requires no extra parameters to describe it, and seems to apply quite well to a large number of facilities that operate in fill-and-draw fashion.

The Two-Compartment Mixing model (Figure 3.5(b)) divides the available storage volume in a tank into two compartments, both of which are assumed completely mixed. The inlet/outlet pipes of the tank are assumed to be located in the first compartment. New water that enters the tank mixes with the water in the first compartment. If this compartment is full, then it sends its overflow to the second compartment where it completely mixes with the water already stored there. When water leaves the tank, it exits from the first compartment, which if full, receives an equivalent amount of water from the second compartment to make up the difference. The first compartment is capable of simulating short-circuiting between inflow and outflow while the second compartment can represent dead zones. The user must supply a single parameter, which is the fraction of the total tank volume devoted to the first compartment.

The FIFO Plug Flow model (Figure 3.5(c)) assumes that there is no mixing of water at all during its residence time in a tank. Water parcels move through the tank in a segregated fashion where the first parcel to enter is also the first to leave. Physically speaking, this model is most appropriate for baffled tanks that operate with simultaneous inflow and outflow. There are no additional parameters needed to describe this mixing model.

The LIFO Plug Flow model (Figure 3.5(d)) also assumes that there is no mixing between parcels of water that enter a tank. However in contrast to FIFO Plug Flow, the water parcels stack up one on top of another, where water enters and leaves the tank on the bottom. This type of model might apply to a tall, narrow standpipe with an inlet/outlet pipe at the bottom and a low momentum inflow. It requires no additional parameters be provided.

Water Quality Reactions

EPANET can track the growth or decay of a substance by reaction as it travels through a distribution system. In order to do this it needs to know the rate at which the substance reacts and how this rate might depend on substance concentration. Reactions can occur both within the bulk flow and with material along the pipe wall. This is illustrated in Figure 3.6. In this example free chlorine (HOCl) is shown reacting with natural organic matter (NOM) in the bulk phase and is also transported through a boundary layer at the pipe wall to oxidize iron (Fe) released from pipe wall corrosion. Bulk fluid reactions can also occur within tanks. EPANET allows a modeler to treat these two reaction zones separately.

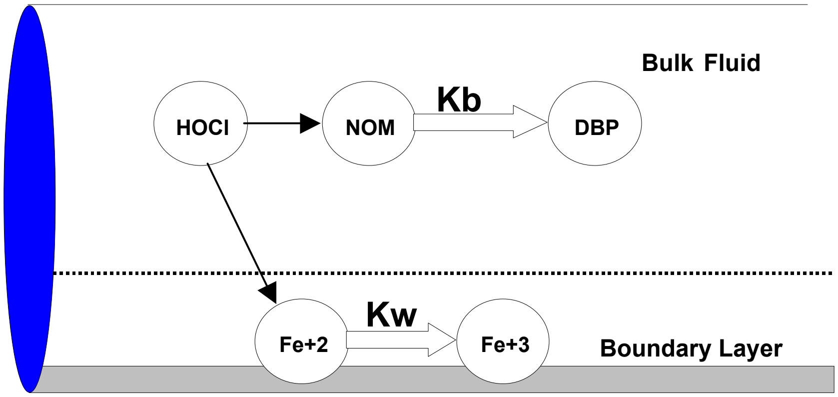


Figure 3.6 Reaction Zones Within a Pipe

Bulk Reactions

EPANET models reactions occurring in the bulk flow with n-th order kinetics, where the instantaneous rate of reaction (R in mass/volume/time) is assumed to be concentration-dependent according to

$$R = K_b C^n$$

Here K_b = a bulk reaction rate coefficient, C = reactant concentration (mass/volume), and n = a reaction order. K_b has units of concentration raised to the (1-n) power divided by time. It is positive for growth reactions and negative for decay reactions.

EPANET can also consider reactions where a limiting concentration exists on the ultimate growth or loss of the substance. In this case the rate expression becomes

$$R = K_b (C_L - C) C^{(n-1)} \qquad \text{for } n > 0,\ K_b > 0$$

$$R = K_b (C - C_L) C^{(n-1)} \qquad \text{for } n > 0,\ K_b < 0$$

where C_L = the limiting concentration. Thus there are three parameters (K_b, C_L, and n) that are used to characterize bulk reaction rates. Some special cases of well-known kinetic models include the following (See Appendix D for more examples):

Model	*Parameters*	*Examples*
First-Order Decay	$C_L = 0$, $K_b < 0$, $n = 1$	Chlorine
First-Order Saturation Growth	$C_L > 0$, $K_b > 0$, $n = 1$	Trihalomethanes
Zero-Order Kinetics	$C_L = 0$, $K_b <> 0$, $n = 0$	Water Age
No Reaction	$C_L = 0$, $K_b = 0$	Fluoride Tracer

The K_b for first-order reactions can be estimated by placing a sample of water in a series of non-reacting glass bottles and analyzing the contents of each bottle at different points in time. If the reaction is first-order, then plotting the natural log (C_t/Co) against time should result in a straight line, where C_t is concentration at time t and Co is concentration at time zero. K_b would then be estimated as the slope of this line.

Bulk reaction coefficients usually increase with increasing temperature. Running multiple bottle tests at different temperatures will provide more accurate assessment of how the rate coefficient varies with temperature

Wall Reactions

The rate of water quality reactions occurring at or near the pipe wall can be considered to be dependent on the concentration in the bulk flow by using an expression of the form

$$R = (A/V) K_w C^n$$

where K_w = a wall reaction rate coefficient and (A/V) = the surface area per unit volume within a pipe (equal to 4 divided by the pipe diameter). The latter term converts the mass reacting per unit of wall area to a per unit volume basis. EPANET limits the choice of wall reaction order to either 0 or 1, so that the units of K_w are either mass/area/time or length/time, respectively. As with K_b, K_w must be supplied to the program by the modeler. First-order K_w values can range anywhere from 0 to as much as 5 ft/day.

K_w should be adjusted to account for any mass transfer limitations in moving reactants and products between the bulk flow and the wall. EPANET does this automatically, basing the adjustment on the molecular diffusivity of the substance being modeled and on the flow's Reynolds number. See Appendix D for details. (Setting the molecular diffusivity to zero will cause mass transfer effects to be ignored.)

The wall reaction coefficient can depend on temperature and can also be correlated to pipe age and material. It is well known that as metal pipes age their roughness tends to increase due to encrustation and tuburculation of corrosion products on the pipe walls. This increase in roughness produces a lower Hazen-Williams C-factor or a higher Darcy-Weisbach roughness coefficient, resulting in greater frictional head loss in flow through the pipe.

There is some evidence to suggest that the same processes that increase a pipe's roughness with age also tend to increase the reactivity of its wall with some chemical species, particularly chlorine and other disinfectants. EPANET can make each pipe's K_w be a function of the coefficient used to describe its roughness. A different function applies depending on the formula used to compute headloss through the pipe:

Headloss Formula	*Wall Reaction Formula*
Hazen-Williams	$K_w = F / C$
Darcy-Weisbach	$K_w = -F / \log(e/d)$
Chezy-Manning	$K_w = F\,n$

where C = Hazen-Williams C-factor, e = Darcy-Weisbach roughness, d = pipe diameter, n = Manning roughness coefficient, and F = wall reaction - pipe roughness coefficient The coefficient F must be developed from site-specific field measurements and will have a different meaning depending on which head loss equation is used. The advantage of using this approach is that it requires only a single parameter, F, to allow wall reaction coefficients to vary throughout the network in a physically meaningful way.

Water Age and Source Tracing

In addition to chemical transport, EPANET can also model the changes in the age of water throughout a distribution system. Water age is the time spent by a parcel of water in the network. New water entering the network from reservoirs or source nodes enters with age of zero. Water age provides a simple, non-specific measure of the overall quality of delivered drinking water. Internally, EPANET treats age as a reactive constituent whose growth follows zero-order kinetics with a rate constant equal to 1 (i.e., each second the water becomes a second older).

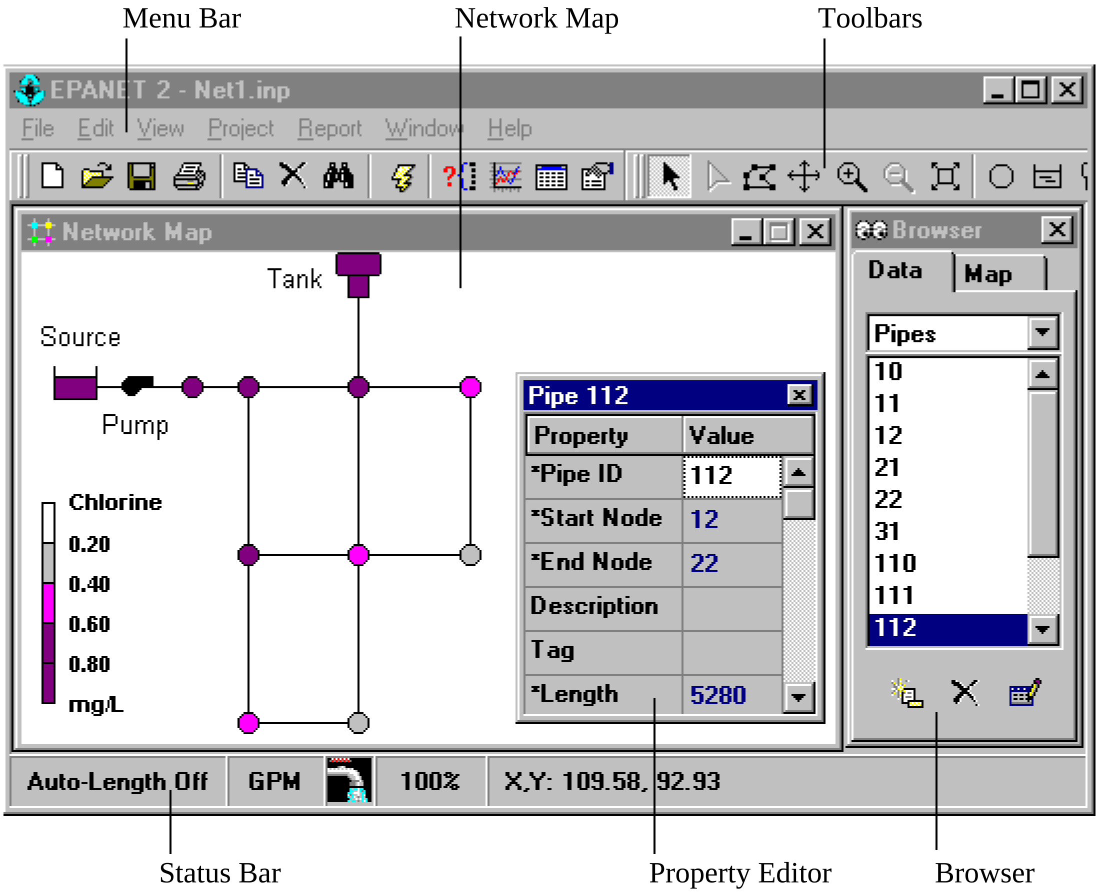
EPANET can also perform source tracing. Source tracing tracks over time what percent of water reaching any node in the network had its origin at a particular node. The source node can be any node in the network, including tanks or reservoirs. Internally, EPANET treats this node as a constant source of a non-reacting constituent that enters the network with a concentration of 100. Source tracing is a useful tool for analyzing distribution systems drawing water from two or more different raw water supplies. It can show to what degree water from a given source blends with that from other sources, and how the spatial pattern of this blending changes over time.

CHAPTER 4 - EPANET'S WORKSPACE

This chapter discusses the essential features of EPANET's workspace. It describes the main menu bar, the tool and status bars, and the three windows used most often – the Network Map, the Browser, and the Property Editor. It also shows how to set program preferences.

4.1 Overview

The basic EPANET workspace is pictured below. It consists of the following user interface elements: a Menu Bar, two Toolbars, a Status Bar, the Network Map window, a Browser window, and a Property Editor window. A description of each of these elements is provided in the sections that follow.



Pipe 112

Property	Value
*Pipe ID	112
*Start Node	12
*End Node	22
Description	
Tag	
*Length	5280

Auto-Length Off | GPM | 100% | X,Y: 109.58, 92.93

4.2 Menu Bar

The Menu Bar located across the top of the EPANET workspace contains a collection of menus used to control the program. These include:

- File Menu
- Edit Menu
- View Menu
- Project Menu
- Report Menu
- Window Menu
- Help Menu

File Menu

The File Menu contains commands for opening and saving data files and for printing:

Command	*Description*
New	Creates a new EPANET project
Open	Opens an existing project
Save	Saves the current project
Save As	Saves the current project under a different name
Import	Imports network data or map from a file
Export	Exports network data or map to a file
Page Setup	Sets page margins, headers, and footers for printing
Print Preview	Previews a printout of the current view
Print	Prints the current view
Preferences	Sets program preferences
Exit	Exits EPANET

Edit Menu

The Edit Menu contains commands for editing and copying.

Command	*Description*
Copy To	Copies the currently active view (map, report, graph or table) to the clipboard or to file
Select Object	Allows selection of an object on the map
Select Vertex	Allows selection of link vertices on the map
Select Region	Allows selection of an outlined region on the map
Select All	Makes the outlined region the entire viewable map area
Group Edit	Edits a property for the group of objects that fall within the outlined region of the map

View Menu

The View Menu controls how the network map is viewed.

Command	*Description*
Dimensions	Dimensions the map
Backdrop	Allows a backdrop map to be viewed
Pan	Pans across the map
Zoom In	Zooms in on the map
Zoom Out	Zooms out on the map
Full Extent	Redraws the map at full extent
Find	Locates a specific item on the map
Query	Searches for items on the map that meet specific criteria
Overview Map	Toggles the Overview Map on/off
Legends	Controls the display of map legends
Toolbars	Toggles the toolbars on/off
Options	Sets map appearance options

Project Menu

The Project menu includes commands related to the current project being analyzed.

Command	*Description*
Summary	Provides a summary description of the project's characteristics
Defaults	Edits a project's default properties
Calibration Data	Registers files containing calibration data with the project
Analysis Options	Edits analysis options
Run Analysis	Runs a simulation

Report Menu

The Report menu has commands used to report analysis results in different formats.

Command	*Description*
Status	Reports changes in the status of links over time
Energy	Reports the energy consumed by each pump
Calibration	Reports differences between simulated and measured values
Reaction	Reports average reaction rates throughout the network
Full	Creates a full report of computed results for all nodes and links in all time periods which is saved to a plain text file
Graph	Creates time series, profile, frequency, and contour plots of selected parameters
Table	Creates a tabular display of selected node and link quantities
Options	Controls the display style of a report, graph, or table

Window Menu

The Window Menu contains the following commands:

Command	*Description*
Arrange	Rearranges all child windows to fit within the main window
Close All	Closes all open windows (except the Map and Browser)
Window List	Lists all open windows; selected window currently has focus

Help Menu

The Help Menu contains commands for getting help in using EPANET:

Command	*Description*
Help Topics	Displays the Help system's Help Topics dialog box
Units	Lists the units of measurement for all EPANET parameters
Tutorial	Presents a short tutorial introducing the user to EPANET
About	Lists information about the version of EPANET being used

Context-sensitive Help is also available by pressing the F1 key.

4.3 Toolbars

Toolbars provide shortcuts to commonly used operations. There are two such toolbars:

- Standard Toolbar
- Map Toolbar

The toolbars can be docked underneath the Main Menu bar or dragged to any location on the EPANET workspace. When undocked, they can also be re-sized. The toolbars can be made visible or invisible by selecting **View** >> **Toolbars**.

Standard Toolbar

The Standard Toolbar contains speed buttons for commonly used commands.

Opens a new project (**File** >> **New**)

Opens an existing project (**File** >> **Open**)

Saves the current project (**File** >> **Save**)

Prints the currently active window (**File** >> **Print**)

Copies selection to the clipboard or to a file (**Edit** >> **Copy To**)

Deletes the currently selected item

Finds a specific item on the map (**View** >> **Find**)

Runs a simulation (**Project** >> **Run Analysis**)

Runs a visual query on the map (**View** >> **Query**)

Creates a new graph view of results (**Report** >> **Graph**)

Creates a new table view of results (**Report** >> **Table**)

Modifies options for the currently active view (**View** >> **Options** or **Report** >> **Options**)

Map Toolbar

The Map Toolbar contains buttons for working with the Network Map.

Selects an object on the map (**Edit** >> **Select Object**)

Selects link vertex points (**Edit** >> **Select Vertex**)

Selects a region on the map (**Edit** >> **Select Region**)

Pans across the map (**View** >> **Pan**)

Zooms in on the map (**View** >> **Zoom In**)

Zooms out on the map (**View** >> **Zoom Out**)

Draws map at full extent (**View** >> **Full Extent**)

Adds a junction to the map

Adds a reservoir to the map

Adds a tank to the map

Adds a pipe to the map

Adds a pump to the map

Adds a valve to the map

Adds a label to the map

4.4 Status Bar

The Status Bar appears at the bottom of the EPANET workspace and is divided into four sections which display the following information:

- **Auto-Length** – indicates whether automatic computation of pipe lengths is turned on or off
- **Flow Units -** displays the current flow units that are in effect
- **Zoom Level -** displays the current zoom in level for the map (100% is full scale)
- **Run Status -** a faucet icon shows:
  - no running water if no analysis results are available,

  - running water when valid analysis results are available,
  - a broken faucet when analysis results are available but may be invalid because the network data have been modified.

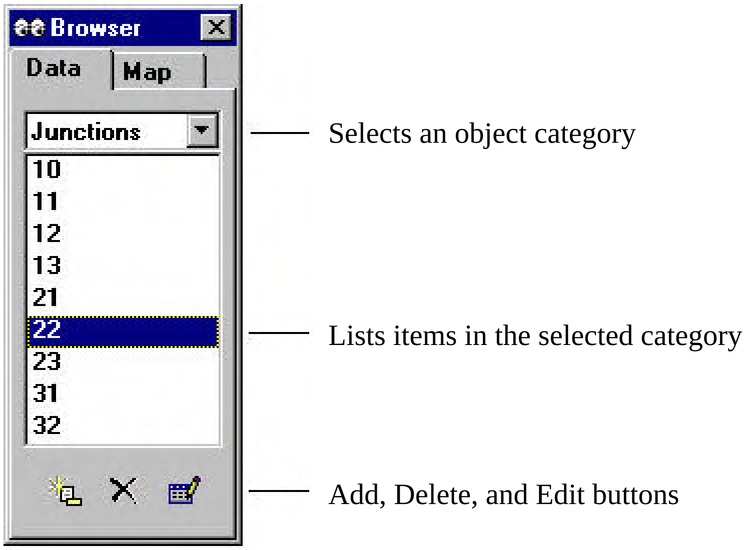
- **XY Location** - displays the map coordinates of the current position of the mouse pointer.

4.5 Network Map

The Network Map provides a planar schematic diagram of the objects comprising a water distribution network. The location of objects and the distances between them do not necessarily have to conform to their actual physical scale. Selected properties of these objects, such as water quality at nodes or flow velocity in links, can be displayed by using different colors. The color-coding is described in a Legend, which can be edited. New objects can be directly added to the map and existing objects can be clicked on for editing, deleting, and repositioning. A backdrop drawing (such as a street or topographic map) can be placed behind the network map for reference. The map can be zoomed to any scale and panned from one position to another. Nodes and links can be drawn at different sizes, flow direction arrows added, and object symbols, ID labels and numerical property values displayed. The map can be printed, copied onto the Windows clipboard, or exported as a DXF file or Windows metafile.

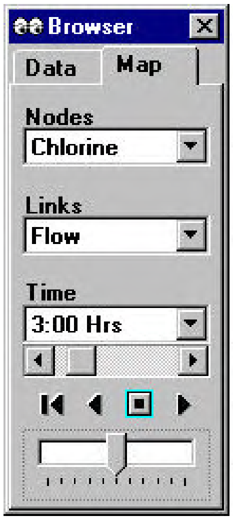
4.6 Data Browser

The Data Browser (shown below) is accessed from the Data tab on the Browser window. It gives access to the various objects, by category (Junctions, Pipes, etc.) that are contained in the network being analyzed. The buttons at the bottom are used to add, delete, and edit these objects.



4.7 Map Browser

The Map Browser (shown below) is accessed from the Map tab of the Browser Window. It selects the parameters and time period that are viewed in color-coded fashion on the Network Map. It also contains controls for animating the map through time.



Nodes: Chlorine

Links: Flow

Time: 3:00 Hrs

Selects a node variable for viewing

Selects a link variable for viewing

Selects a time period for viewing

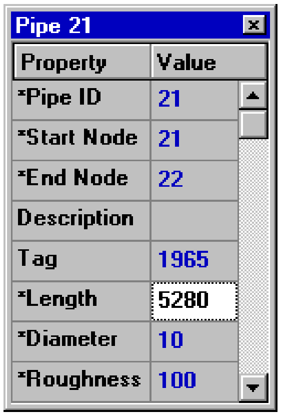
Animates the map display over time

Sets animation speed

The animation control pushbuttons on the Map Browser work as follows:

- ◀◀ Rewind (return to initial time)
- ◀ Animate back through time
- ■ Stop the animation
- ▶ Animate forward in time

4.8 Property Editor



Property	Value
*Pipe ID	21
*Start Node	21
*End Node	22
Description	
Tag	1965
*Length	5280
*Diameter	10
*Roughness	100

The Property Editor (shown at the left) is used to edit the properties of network nodes, links, labels, and analysis options. It is invoked when one of these objects is selected (either on the Network Map or in the Data Browser) and double-clicked or the Browser's Edit button is clicked. The following points help explain how to use the Editor.

- The Editor is a grid with two columns - one for the property's name and the other for its value.
- The columns can be re-sized by re-sizing the header at the top of the Editor with the mouse.
- The Editor window can be moved and re-sized via the normal Windows procedures.
- An asterisk next to a property name means that it is a required property -- its value cannot be left blank.
- Depending on the property, the value field can be one of the following:
    - a text box where you type in a value
    - a dropdown list box where you select from a list of choices
    - an ellipsis button which you click to bring up a specialized editor
    - a read-only label used to display computed results
- The property in the Editor that currently has focus will be highlighted with a white background.
- You can use both the mouse and the Up and Down arrow keys on the keyboard to move between properties.
- To begin editing the property with the focus, either begin typing a value or hit the Enter key.
- To have EPANET accept what you have entered, press the Enter key or move to another property; to cancel, press the Esc key.
- Clicking the Close button in the upper right corner of its title bar will hide the Editor.

4.9 Program Preferences

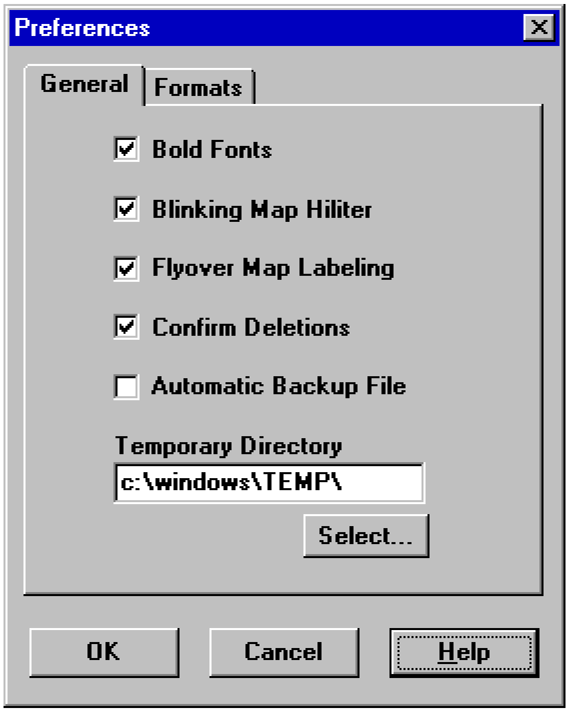
Program preferences allow you to customize certain program features. To set program preferences select **Preferences** from the **File** menu. A Preferences dialog form will appear containing two tabbed pages – one for General Preferences and one for Format Preferences.

General Preferences

The following preferences can be set on the General page of the Preferences dialog:

Preference	*Description*
Bold Fonts	Check to use bold fonts in all newly created windows
Blinking Map Hiliter	Check to make the selected node, link, or label on the map blink on and off
Flyover Map Labeling	Check to display the ID label and current parameter value in a hint-style box whenever the mouse is placed over a node or link on the network map
Confirm Deletions	Check to display a confirmation dialog box before deleting any object
Automatic Backup File	Check to save a backup copy of a newly opened project to disk named with a .bak extension
Temporary Directory	Name of the directory (folder) where EPANET writes its temporary files

Note: The Temporary Directory must be a file directory (folder) where the user has write privileges and must have sufficient space to store files which can easily grow to several tens of megabytes for larger networks and simulation runs. The original default is the Windows TEMP directory (usually c:\Windows\Temp).

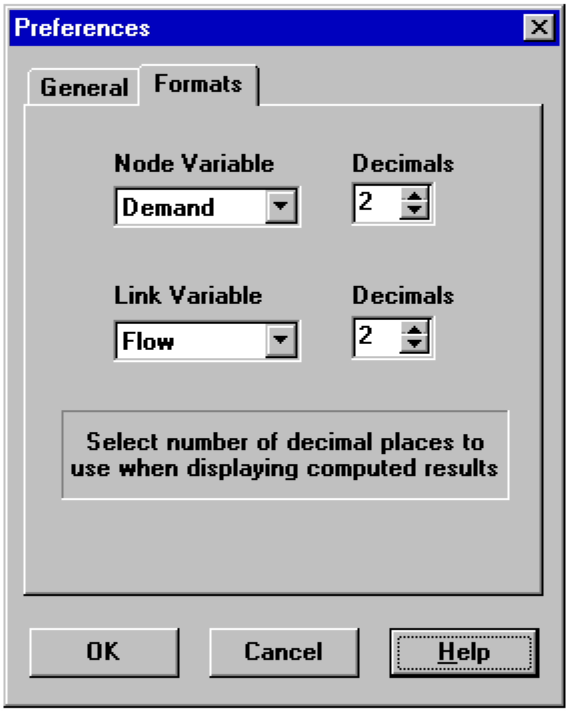


☑ Bold Fonts
☑ Blinking Map Hiliter
☑ Flyover Map Labeling
☑ Confirm Deletions
☐ Automatic Backup File

Temporary Directory
c:\windows\TEMP\

Formatting Preferences

The Formats page of the Preferences dialog box controls how many decimal places are displayed when results for computed parameters are reported. Use the dropdown list boxes to select a specific Node or Link parameter. Use the spin edit boxes to select the number of decimal places to use when displaying computed results for the parameter. The number of decimal places displayed for any particular input design parameter, such as pipe diameter, length, etc. is whatever the user enters.



Node Variable: Demand
Decimals: 2

Link Variable: Flow
Decimals: 2

Select number of decimal places to use when displaying computed results

(This page intentionally left blank.)

CHAPTER 5 - WORKING WITH PROJECTS

This chapter discusses how EPANET uses project files to store a piping network's data. It explains how to set certain default options for the project and how to register calibration data (observed measurements) with the project to use for model evaluation.

5.1 Opening and Saving Project Files

Project files contain all of the information used to model a network. They are usually named with a .NET extension.

To create a new project:

1. Select **File** >> **New** from the Menu Bar or click 🗋 on the Standard Toolbar.
2. You will be prompted to save the existing project (if changes were made to it) before the new project is created.
3. A new, unnamed project is created with all options set to their default values.

A new project is automatically created whenever EPANET first begins.

To open an existing project stored on disk:

1. Either select **File** >> **Open** from the Menu Bar or click 📂 on the Standard Toolbar.
2. You will be prompted to save the current project (if changes were made to it).
3. Select the file to open from the Open File dialog form that will appear. You can choose to open a file type saved previously as an EPANET project (typically with a .NET extension) or exported as a text file (typically with a .INP extension). EPANET recognizes file types by their content, not their names.
4. Click **OK** to close the dialog and open the selected file.

To save a project under its current name:

- Either select **File** >> **Save** from the Menu Bar or click 💾 on the Standard Toolbar.

To save a project using a different name:

1. Select **File** >> **Save As** from the Menu Bar.
2. A standard File Save dialog form will appear from which you can select the folder and name that the project should be saved under.

Note: Projects are always saved as binary .NET files. To save a project's data as readable ASCII text, use the **Export** >> **Network** command from the **File** menu.

5.2 Project Defaults

Each project has a set of default values that are used unless overridden by the EPANET user. These values fall into three categories:

- Default ID labels (labels used to identify nodes and links when they are first created)
- Default node/link properties (e.g., node elevation, pipe length, diameter, and roughness)
- Default hydraulic analysis options (e.g., system of units, headloss equation, etc.)

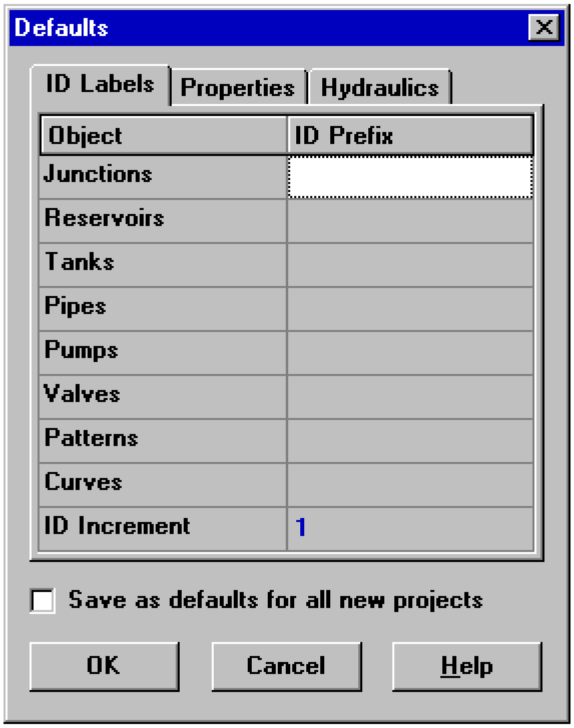
To set default values for a project:

1. Select **Project** >> **Defaults** from the Menu Bar.
2. A Defaults dialog form will appear with three pages, one for each category listed above.
3. Check the box in the lower right of the dialog form if you want to save your choices for use in all new future projects as well.
4. Click **OK** to accept your choice of defaults.

The specific items for each category of defaults will be discussed next.

Default ID Labels

The ID Labels page of the Defaults dialog form is shown in Figure 5.1 below. It is used to determine how EPANET will assign default ID labels to network components when they are first created. For each type of object one can enter a label prefix or leave the field blank if the default ID will simply be a number. Then one supplies an increment to be used when adding a numerical suffix to the default label. As an example, if J were used as a prefix for Junctions along with an increment of 5, then as junctions are created they receive default labels of J5, J10, J15 and so on. After an object has been created, the Property Editor can be used to modify its ID label if need be.



Object	ID Prefix
Junctions	
Reservoirs	
Tanks	
Pipes	
Pumps	
Valves	
Patterns	
Curves	
ID Increment	1

☐ Save as defaults for all new projects

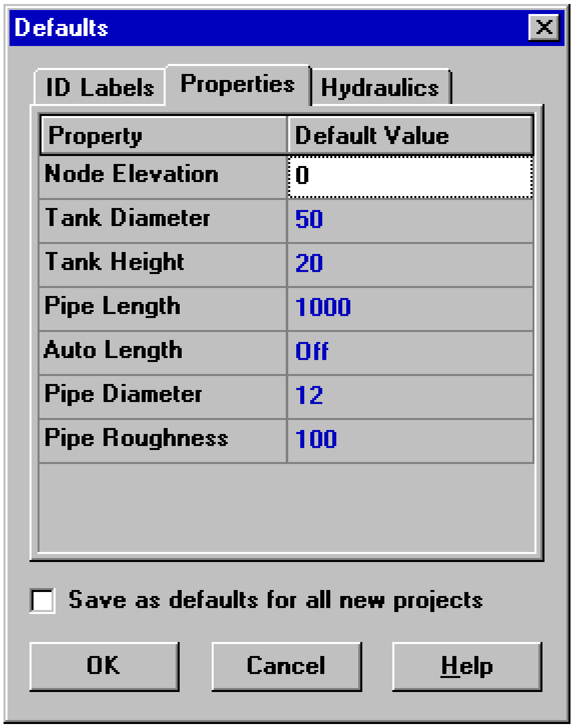
Figure 5.1 ID Labels Page of Project Defaults Dialog

Default Node/Link Properties

The Properties page of the Defaults dialog form is shown in Figure 5.2. It sets default property values for newly created nodes and links. These properties include:

- Elevation for nodes
- Diameter for tanks
- Maximum water level for tanks
- Length for pipes
- Auto-Length (automatic calculation of length) for pipes
- Diameter for pipes
- Roughness for pipes

When the Auto-Length property is turned on, pipe lengths will automatically be computed as pipes are added or repositioned on the network map. A node or link created with these default properties can always be modified later on using the Property Editor.



Property	Default Value
Node Elevation	0
Tank Diameter	50
Tank Height	20
Pipe Length	1000
Auto Length	Off
Pipe Diameter	12
Pipe Roughness	100

☐ Save as defaults for all new projects

Figure 5.2 Properties Page of the Project Defaults Dialog

Default Hydraulic Options

The third page of the Defaults dialog form is used to assign default hydraulic analysis options. It contains the same set of hydraulic options as the project's Hydraulic Options accessed from the Browser (see Section 8.1). They are repeated on the Project Defaults dialog so that they can be saved for use with future projects as well as with the current one. The most important Hydraulic Options to check when setting up a new project are Flow Units, Headloss Formula, and Default Pattern. The choice of Flow Units determines whether all other network quantities are expressed in Customary US units or in SI metric units. The choice of Headloss Formula defines the type of the roughness coefficient to be supplied for each pipe in the network. The Default Pattern automatically becomes the time pattern used to vary demands in an extended period simulation for all junctions not assigned any pattern.

5.3 Calibration Data

EPANET allows you to compare results of a simulation against measured field data. This can be done via Time Series plots for selected locations in the network or by special Calibration Reports that consider multiple locations. Before EPANET can use such calibration data it has to be entered into a file and registered with the project.

Calibration Files

A Calibration File is a text file containing measured data for a particular quantity taken over a particular period of time within a distribution system. The file provides observed data that can be compared to the results of a network simulation. Separate files should be created for different parameters (e.g., pressure, fluoride, chlorine, flow, etc.) and different sampling studies. Each line of the file contains the following items:

- Location ID - ID label (as used in the network model) of the location where the measurement was made
- Time - Time (in hours) when the measurement was made
- Value - Result of the measurement

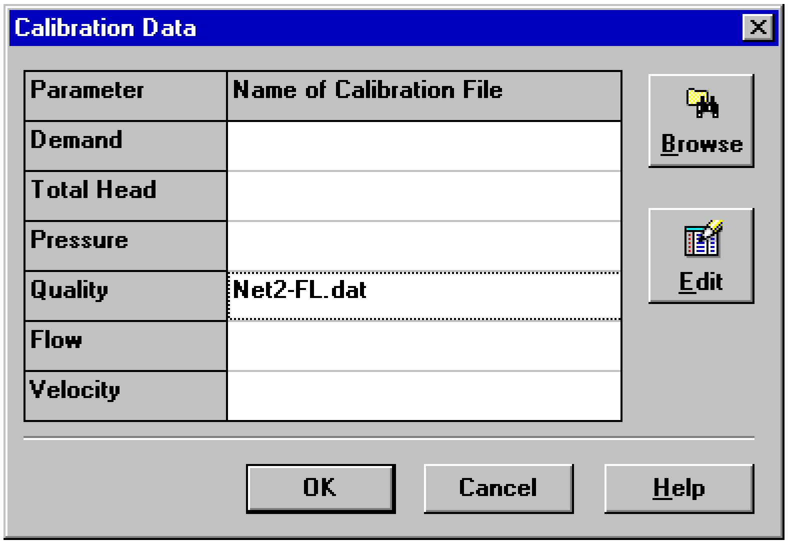
The measurement time is with respect to time zero of the simulation to which the Calibration File will be applied. It can be entered as either a decimal number (e.g., 27.5) or in hours:minutes format (e.g., 27:30). For data to be used in a single period analysis all time values can be 0. Comments can be added to the file by placing a semicolon (;) before them. For a series of measurements made at the same location the Location ID does not have to be repeated. An excerpt from a Calibration File is shown below.

```
;Fluoride Tracer Measurements
;Location    Time    Value
;--------------------------
   N1         0       0.5
              6.4     1.2
             12.7     0.9
   N2         0.5     0.72
              5.6     0.77
```

Registering Calibration Data

To register calibration data residing in a Calibration File:

1. Select **Project** >> **Calibration Data** from the Menu Bar.
2. In the Calibration Data dialog form shown in Figure 5.3, click in the box next to the parameter you wish to register data for.
3. Either type in the name of a Calibration File for this parameter or click the **Browse** button to search for it.
4. Click the **Edit** button if you want to open the Calibration File in Windows NotePad for editing.
5. Repeat steps 2 - 4 for any other parameters that have calibration data.
6. Click **OK** to accept your selections.



Parameter	Name of Calibration File
Demand	
Total Head	
Pressure	
Quality	Net2-FL.dat
Flow	
Velocity	

Figure 5.3 Calibration Data Dialog

5.4 Project Summary

To view a summary description of the current project select **Project** >> **Summary** from the Menu Bar. The Project Summary dialog form will appear in which you can edit a descriptive title for the project as well as add notes that further describe the project. When you go to open a previously saved file, the Open File dialog box will display both of these items as different file names are selected. This makes them very useful for locating specific network analyses. The form also displays certain network statistics, such as the number of junctions, pipes, pumps, etc.

CHAPTER 6 - WORKING WITH OBJECTS

EPANET uses various types of objects to model a distribution system. These objects can be accessed either directly on the network map or from the Data page of the Browser window. This chapter describes what these objects are and how they can be created, selected, edited, deleted, and repositioned.

6.1 Types of Objects

EPANET contains both physical objects that can appear on the network map, and non-physical objects that encompass design and operational information. These objects can be classified as followed:

(1) Nodes
  (a) Junctions
  (b) Reservoirs
  (c) Tanks

(2) Links
  (a) Pipes
  (b) Pumps
  (c) Valves

(3) Map Labels

(4) Time Patterns

(5) Curves

(6) Controls
  (a) Simple
  (b) Rule-Based

6.2 Adding Objects

Adding a Node

To add a Node using the Map Toolbar:

1. Click the button for the type of node (junction, reservoir, or tank) to add from the Map Toolbar if it is not already depressed.
2. Move the mouse to the desired location on the map and click.

To add a Node using the Browser:

1. Select the type of node (junction, reservoir, or tank) from the Object list of the Data Browser.
2. Click the Add button .
3. Enter map coordinates with the Property Editor (optional).

Adding a Link

To add a straight or curved-line Link using the Map Toolbar:

1. Click the button for the type of link to add (pipe , pump , or valve) from the Map Toolbar if it is not already depressed.
2. On the map, click the mouse over the link's start node.
3. Move the mouse in the direction of the link’s end node, clicking it at those intermediate points where it is necessary to change the link’s direction.
4. Click the mouse a final time over the link's end node.

Pressing the right mouse button or the Escape key while drawing a link will cancel the operation.

To add a straight line Link using the Browser:

1. Select the type of link to add (pipe, pump, or valve) from the Object list of the Data Browser.
2. Click the Add button.
3. Enter the From and To nodes of the link in the Property Editor.

Adding a Map Label

To add a label to the map:

1. Click the Text button on the Map Toolbar.
2. Click the mouse on the map where label should appear.
3. Enter the text for the label.
4. Press the **Enter** key.

Adding a Curve

To add a curve to the network database:

1. Select Curve from the object category list of the Data Browser.
2. Click the Add button.
3. Edit the curve using the Curve Editor (see below).

Adding a Time Pattern

To add a time pattern to the network:

1. Select Patterns from the object category list of the Data Browser.
2. Click the Add button.
3. Edit the pattern using the Pattern Editor (see below).

Using a Text File

In addition to adding individual objects interactively, you can import a text file containing a list of node ID's with their coordinates as well as a list of link ID's and their connecting nodes (see Section 11.4 - Importing a Partial Network).

6.3 Selecting Objects

To select an object on the map:

1. Make sure that the map is in Selection mode (the mouse cursor has the shape of an arrow pointing up to the left). To switch to this mode, either click the Select Object button on the Map Toolbar or choose **Select Object** from the **Edit** menu.
2. Click the mouse over the desired object on the map.

To select an object using the Browser:

1. Select the category of object from the dropdown list of the Data Browser.
2. Select the desired object from the list below the category heading.

6.4 Editing Visual Objects

The Property Editor (see Section 4.8) is used to edit the properties of objects that can appear on the Network Map (Junctions, Reservoirs, Tanks, Pipes, Pumps, Valves, or Labels). To edit one of these objects, select the object on the map or from the Data Browser, then click the Edit button on the Data Browser (or simply double-click the object on the map). The properties associated with each of these types of objects are described in Tables 6.1 to 6.7.

Note: The unit system in which object properties are expressed depends on the choice of units for flow rate. Using a flow rate expressed in cubic feet, gallons or acre-feet means that US units will be used for all quantities. Using a flow rate expressed in liters or cubic meters means that SI metric units will be used. Flow units are selected from the project's Hydraulic Options which can be accessed from the **Project** >> **Defaults** menu. The units used for all properties are summarized in Appendix A.

Table 6.1 Junction Properties

PROPERTY	*DESCRIPTION*
Junction ID	A unique label used to identify the junction. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other node. This is a required property.
X-Coordinate	The horizontal location of the junction on the map, measured in the map's distance units. If left blank the junction will not appear on the network map.
Y-Coordinate	The vertical location of the junction on the map, measured in the map's distance units. If left blank the junction will not appear on the network map.
Description	An optional text string that describes other significant information about the junction.
Tag	An optional text string (with no spaces) used to assign the junction to a category, such as a pressure zone.
Elevation	The elevation in feet (meters) above some common reference of the junction. This is a required property. Elevation is used only to compute pressure at the junction. It does not affect any other computed quantity.
Base Demand	The average or nominal demand for water by the main category of consumer at the junction, as measured in the current flow units. A negative value is used to indicate an external source of flow into the junction. If left blank then demand is assumed to be zero.
Demand Pattern	The ID label of the time pattern used to characterize time variation in demand for the main category of consumer at the junction. The pattern provides multipliers that are applied to the Base Demand to determine actual demand in a given time period. If left blank then the **Default Time Pattern** assigned in the Hydraulic Options (see Section 8.1) will be used.
Demand Categories	Number of different categories of water users defined for the junction. Click the ellipsis button (or hit the Enter key) to bring up a special Demands Editor which will let you assign base demands and time patterns to multiple categories of users at the junction. Ignore if only a single demand category will suffice.
Emitter Coefficient	Discharge coefficient for emitter (sprinkler or nozzle) placed at junction. The coefficient represents the flow (in current flow units) that occurs at a pressure drop of 1 psi (or meter). Leave blank if no emitter is present. See the Emitters topic in Section 3.1 for more details.
Initial Quality	Water quality level at the junction at the start of the simulation period. Can be left blank if no water quality analysis is being made or if the level is zero.
Source Quality	Quality of any water entering the network at this location. Click the ellipsis button (or hit the Enter key) to bring up the Source Quality Editor (see Section 6.5 below).

Table 6.2 Reservoir Properties

PROPERTY	*DESCRIPTION*
Reservoir ID	A unique label used to identify the reservoir. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other node. This is a required property.
X-Coordinate	The horizontal location of the reservoir on the map, measured in the map's distance units. If left blank the reservoir will not appear on the network map.
Y-Coordinate	The vertical location of the reservoir on the map, measured in the map's distance units. If left blank the reservoir will not appear on the network map.
Description	An optional text string that describes other significant information about the reservoir.
Tag	An optional text string (with no spaces) used to assign the reservoir to a category, such as a pressure zone
Total Head	The hydraulic head (elevation + pressure head) of water in the reservoir in feet (meters). This is a required property.
Head Pattern	The ID label of a time pattern used to model time variation in the reservoir's head. Leave blank if none applies. This property is useful if the reservoir represents a tie-in to another system whose pressure varies with time.
Initial Quality	Water quality level at the reservoir. Can be left blank if no water quality analysis is being made or if the level is zero.
Source Quality	Quality of any water entering the network at this location. Click the ellipsis button (or hit the Enter key) to bring up the Source Quality Editor (see Section 6.5 below).

Table 6.3 Tank Properties

PROPERTY	*DESCRIPTION*
Tank ID	A unique label used to identify the tank. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other node. This is a required property.
X-Coordinate	The horizontal location of the tank on the map, measured in the map's scaling units. If left blank the tank will not appear on the network map.
Y-Coordinate	The vertical location of the tank on the map, measured in the map's scaling units. If left blank the tank will not appear on the network map.
Description	Optional text string that describes other significant information about the tank.
Tag	Optional text string (with no spaces) used to assign the tank to a category, such as a pressure zone
Elevation	Elevation above a common datum in feet (meters) of the bottom shell of the tank. This is a required property.
Initial Level	Height in feet (meters) of the water surface above the bottom elevation of the tank at the start of the simulation. This is a required property.
Minimum Level	Minimum height in feet (meters) of the water surface above the bottom elevation that will be maintained. The tank will not be allowed to drop below this level. This is a required property.

Maximum Level	Maximum height in feet (meters) of the water surface above the bottom elevation that will be maintained. The tank will not be allowed to rise above this level. This is a required property.
Diameter	The diameter of the tank in feet (meters). For cylindrical tanks this is the actual diameter. For square or rectangular tanks it can be an equivalent diameter equal to 1.128 times the square root of the cross-sectional area. For tanks whose geometry will be described by a curve (see below) it can be set to any value. This is a required property.
Minimum Volume	The volume of water in the tank when it is at its minimum level, in cubic feet (cubic meters). This is an optional property, useful mainly for describing the bottom geometry of non-cylindrical tanks where a full volume versus depth curve will not be supplied (see below).
Volume Curve	The ID label of a curve used to describe the relation between tank volume and water level. If no value is supplied then the tank is assumed to be cylindrical.
Mixing Model	The type of water quality mixing that occurs within the tank. The choices include • MIXED (fully mixed), • 2COMP (two-compartment mixing), • FIFO (first-in-first-out plug flow), • LIFO (last-in-first-out plug flow). See the Mixing Models topic in Section 3.4 for more information.
Mixing Fraction	The fraction of the tank's total volume that comprises the inlet-outlet compartment of the two-compartment (2COMP) mixing model. Can be left blank if another type of mixing model is employed.
Reaction Coefficient	The bulk reaction coefficient for chemical reactions in the tank. Time units are 1/days. Use a positive value for growth reactions and a negative value for decay. Leave blank if the Global Bulk reaction coefficient specified in the project’s Reactions Options will apply. See Water Quality Reactions in Section 3.4 for more information.
Initial Quality	Water quality level in the tank at the start of the simulation. Can be left blank if no water quality analysis is being made or if the level is zero.
Source Quality	Quality of any water entering the network at this location. Click the ellipsis button (or hit the Enter key) to bring up the Source Quality Editor (see Section 6.5 below).

Table 6.4 Pipe Properties

PROPERTY	*DESCRIPTION*
Pipe ID	A unique label used to identify the pipe. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other link. This is a required property.
Start Node	The ID of the node where the pipe begins. This is a required property.
End Node	The ID of the node where the pipe ends. This is a required property.
Description	An optional text string that describes other significant information about the pipe.
Tag	An optional text string (with no spaces) used to assign the pipe to a category, perhaps one based on age or material
Length	The actual length of the pipe in feet (meters). This is a required property.
Diameter	The pipe diameter in inches (mm). This is a required property.
Roughness	The roughness coefficient of the pipe. It is unitless for Hazen-Williams or Chezy-Manning roughness and has units of millifeet (mm) for Darcy-Weisbach roughness. This is a required property.
Loss Coefficient	Unitless minor loss coefficient associated with bends, fittings, etc. Assumed 0 if left blank.
Initial Status	Determines whether the pipe is initially open, closed, or contains a check valve. If a check valve is specified then the flow direction in the pipe will always be from the Start node to the End node.
Bulk Coefficient	The bulk reaction coefficient for the pipe. Time units are 1/days. Use a positive value for growth and a negative value for decay. Leave blank if the Global Bulk reaction coefficient from the project's Reaction Options will apply. See Water Quality Reactions in Section 3.4 for more information.
Wall Coefficient	The wall reaction coefficient for the pipe. Time units are 1/days. Use a positive value for growth and a negative value for decay. Leave blank if the Global Wall reaction coefficient from the project's Reactions Options will apply. See Water Quality Reactions in Section 3.4 for more information.

Note: Pipe lengths can be automatically computed as pipes are added or repositioned on the network map if the **Auto-Length** setting is turned on. To toggle this setting On/Off either:

- Select **Project** >> **Defaults** and edit the Auto-Length field on the Properties page of the Defaults dialog form.
- Right-click over the Auto-Length section of the Status Bar and then click on the popup menu item that appears.

Be sure to provide meaningful dimensions for the network map before using the Auto-Length feature (see Section 7.2).

Table 6.5 Pump Properties

PROPERTY	*DESCRIPTION*
Pump ID	A unique label used to identify the pump. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other link. This is a required property.
Start Node	The ID of the node on the suction side of the pump. This is a required property
End Node	The ID of the node on the discharge side of the pump. This is a required property
Description	An optional text string that describes other significant information about the pump.
Tag	An optional text string (with no spaces) used to assign the pump to a category, perhaps based on age, size or location
Pump Curve	The ID label of the pump curve used to describe the relationship between the head delivered by the pump and the flow through the pump. Leave blank if the pump will be a constant energy pump (see below).
Power	The power supplied by the pump in horsepower (kw). Assumes that the pump supplies the same amount of energy no matter what the flow is. Leave blank if a pump curve will be used instead. Use when pump curve information is not available.
Speed	The relative speed setting of the pump (unitless). For example, a speed setting of 1.2 implies that the rotational speed of the pump is 20% higher than the normal setting.
Pattern	The ID label of a time pattern used to control the pump's operation. The multipliers of the pattern are equivalent to speed settings. A multiplier of zero implies that the pump will be shut off during the corresponding time period. Leave blank if not applicable.
Initial Status	State of the pump (open or closed) at the start of the simulation period.
Efficiency Curve	The ID label of the curve that represents the pump's wire-to-water efficiency (in percent) as a function of flow rate. This information is used only to compute energy usage. Leave blank if not applicable or if the global pump efficiency supplied with the project's Energy Options (see Section 8.1) will be used.
Energy Price	The average or nominal price of energy in monetary units per kw-hr. Used only for computing the cost of energy usage. Leave blank if not applicable or if the global value supplied with the project's Energy Options (Section 8.1) will be used.
Price Pattern	The ID label of the time pattern used to describe the variation in energy price throughout the day. Each multiplier in the pattern is applied to the pump's Energy Price to determine a time-of-day pricing for the corresponding period. Leave blank if not applicable or if the global pricing pattern specified in the project's Energy Options (Section 8.1) will be used.

Table 6.6 Valve Properties

PROPERTY	*DESCRIPTION*
ID Label	A unique label used to identify the valve. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other link. This is a required property.
Start Node	The ID of the node on the nominal upstream or inflow side of the valve. (PRVs and PSVs maintain flow in only a single direction.) This is a required property.
End Node	The ID of the node on the nominal downstream or discharge side of the valve. This is a required property.
Description	An optional text string that describes other significant information about the valve.
Tag	An optional text string (with no spaces) used to assign the valve to a category, perhaps based on type or location.
Diameter	The valve diameter in inches (mm). This is a required property.
Type	The valve type (PRV, PSV, PBV, FCV, TCV, or GPV). See Valves in Section 6.1for descriptions of the various types of valves. This is a required property.
Setting	A required parameter that describes the valve's operational setting. Valve Type — Setting Parameter PRV — Pressure (psi or m) PSV — Pressure (psi or m) PBV — Pressure (psi or m) FCV — Flow (flow units) TCV — Loss Coefficient (unitless) GPV — ID of head loss curve
Loss Coefficient	Unitless minor loss coefficient that applies when the valve is completely opened. Assumed 0 if left blank.
Fixed Status	Valve status at the start of the simulation. If set to OPEN or CLOSED then the control setting of the valve is ignored and the valve behaves as an open or closed link, respectively. If set to NONE, then the valve will behave as intended. A valve's fixed status and its setting can be made to vary throughout a simulation by the use of control statements. If a valve's status was fixed to OPEN/CLOSED, then it can be made active again using a control that assigns a new numerical setting to it.

Table 6.7 Map Label Properties

PROPERTY	*DESCRIPTION*
Text	The label's text.
X-Coordinate	The horizontal location of the upper left corner of the label on the map, measured in the map's scaling units. This is a required property.
Y-Coordinate	The vertical location of the upper left corner of the label on the map, measured in the map's scaling units. This is a required property.
Anchor Node	ID of node that serves as the label's anchor point (see Note 1 below). Leave blank if label will not be anchored.
Meter Type	Type of object being metered by the label (see Note 2 below). Choices are None, Node, or Link.
Meter ID	ID of the object (Node or Link) being metered.
Font	Launches a Font dialog that allows selection of the label's font, size, and style.

Notes:

1. A label's anchor node property is used to anchor the label relative to a given location on the map. When the map is zoomed in, the label will appear the same distance from its anchor node as it did under the full extent view. This feature prevents labels from wandering too far away from the objects they were meant to describe when a map is zoomed.

2. The Meter Type and ID properties determine if the label will act as a meter. Meter labels display the value of the current viewing parameter (chosen from the Map Browser) underneath the label text. The Meter Type and ID must refer to an existing node or link in the network. Otherwise, only the label text appears.

6.5 Editing Non-Visual Objects

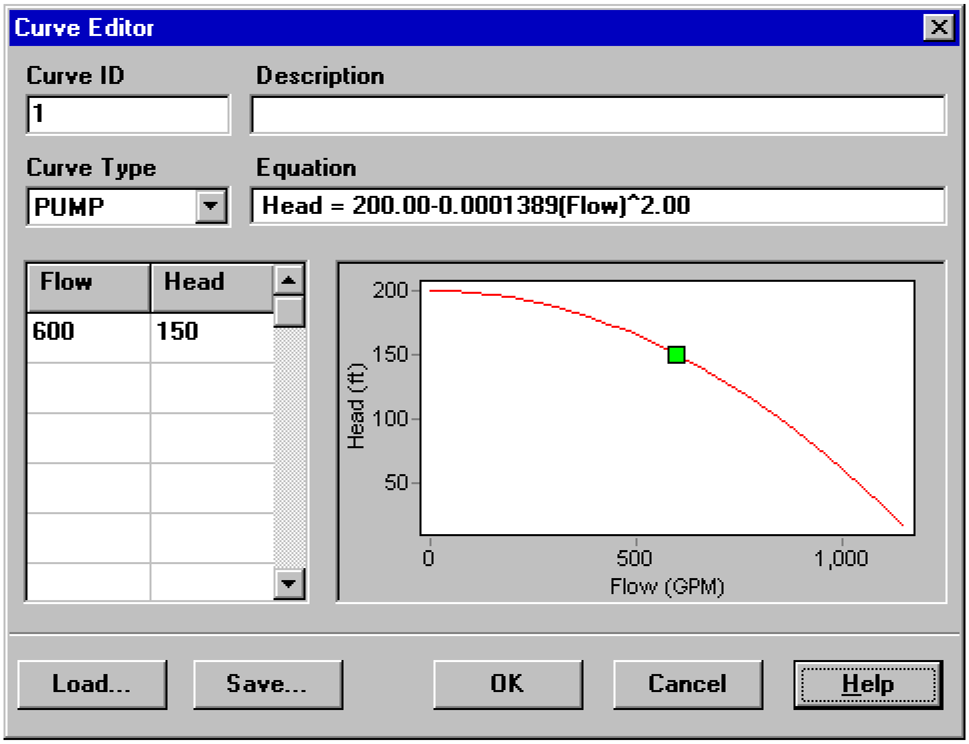
Curves, Time Patterns, and Controls have special editors that are used to define their properties. To edit one of these objects, select the object from the Data Browser and then click the Edit button. In addition, the Property Editor for Junctions contains an ellipsis button in the field for Demand Categories that brings up a special Demand Editor when clicked. Similarly, the Source Quality field in the Property Editor for Junctions, Reservoirs, and Tanks has a button that launches a special Source Quality editor. Each of these specialized editors is described next.

Curve Editor

The Curve Editor is a dialog form as shown in Figure 6.1. To use the Curve Editor, enter values for the following items:

Item	*Description*
Curve ID	ID label of the curve (maximum of 15 numerals or characters)
Description	Optional description of what the curve represents
Curve Type	Type of curve
X-Y Data	X-Y data points for the curve

As you move between cells in the X-Y data table (or press the Enter key) the curve is redrawn in the preview window. For single- and three-point pump curves, the equation generated for the curve will be displayed in the Equation box. Click the **OK** button to accept the curve or the **Cancel** button to cancel your entries. You can also click the **Load** button to load in curve data that was previously saved to file or click the **Save** button to save the current curve's data to a file.


Curve ID: 1

Description:

Curve Type: PUMP

Equation: Head = 200.00-0.0001389(Flow)^2.00

Flow	Head
600	150

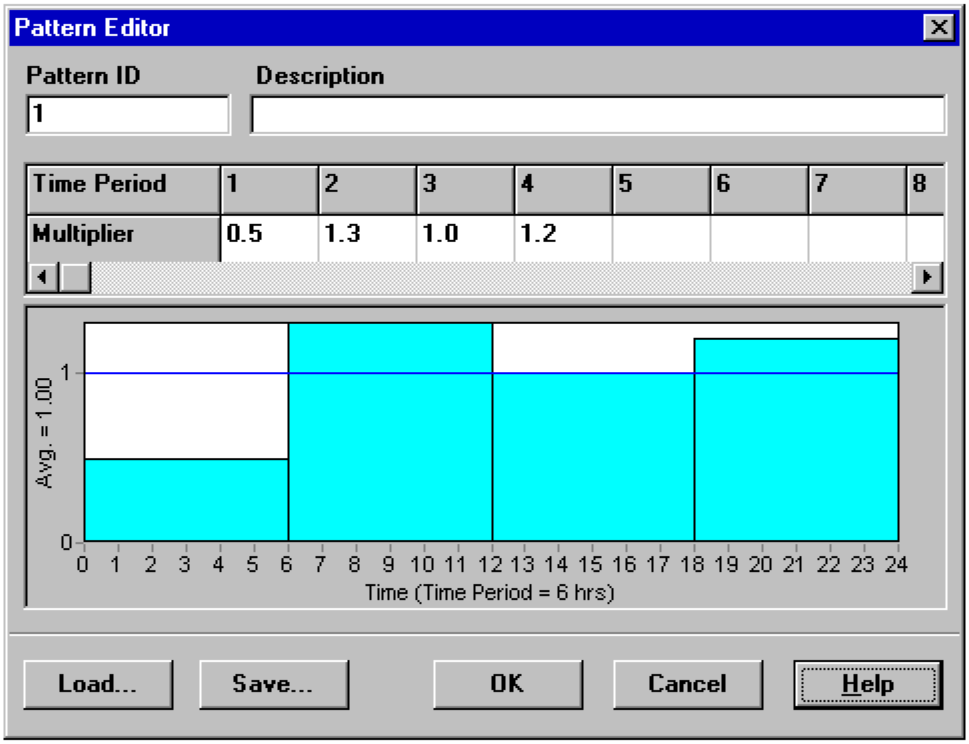
Figure 6.1 Curve Editor

Pattern Editor

The Pattern Editor, displayed in Figure 6.2, edits the properties of a time pattern object. To use the Pattern Editor enter values for the following items:

Item	*Description*
Pattern ID	ID label of the pattern (maximum of 15 numerals or characters)
Description	Optional description of what the pattern represents
Multipliers	Multiplier value for each time period of the pattern.

As multipliers are entered, the preview chart is redrawn to provide a visual depiction of the pattern. If you reach the end of the available Time Periods when entering multipliers, simply hit the **Enter** key to add on another period. When finished editing, click the **OK** button to accept the pattern or the **Cancel** button to cancel your entries. You can also click the **Load** button to load in pattern data that was previously saved to file or click the **Save** button to save the current pattern's data to a file.



Pattern ID: 1

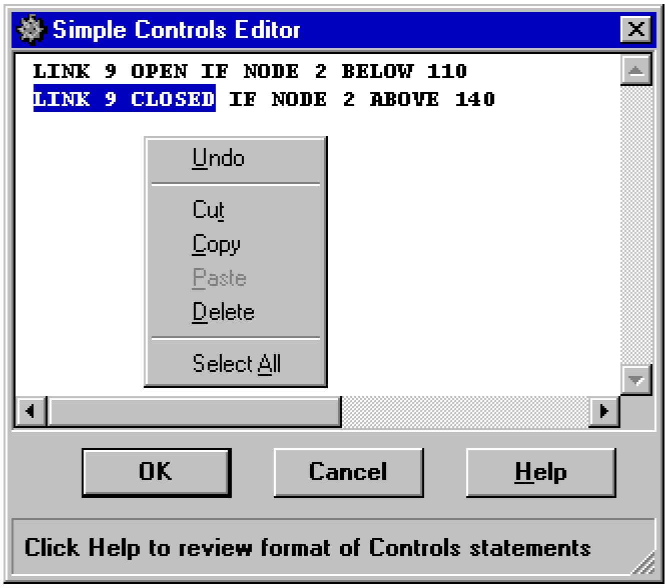
Description:

Time Period	1	2	3	4	5	6	7	8
Multiplier	0.5	1.3	1.0	1.2				

Figure 6.2 Pattern Editor

Controls Editor

The Controls Editor, shown in Figure 6.3, is a text editor window used to edit both simple and rule-based controls. It has a standard text-editing menu that is activated by right-clicking anywhere in the Editor. The menu contains commands for Undo, Cut, Copy, Paste, Delete, and Select All.



```
LINK 9 OPEN IF NODE 2 BELOW 110
LINK 9 CLOSED IF NODE 2 ABOVE 140
```

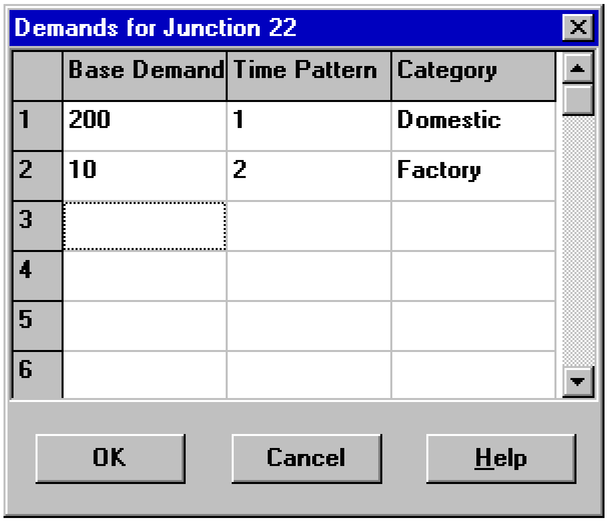
Figure 6.3 Controls Editor

Demand Editor

The Demand Editor is pictured in Figure 6.4. It is used to assign base demands and time patterns when there is more than one category of water user at a junction. The editor is invoked from the Property Editor by clicking the ellipsis button (or hitting the Enter key) when the Demand Categories field has the focus.

The editor is a table containing three columns. Each category of demand is entered as a new row in the table. The columns contain the following information:

- *Base Demand*: baseline or average demand for the category (required)
- *Time Pattern*: ID label of time pattern used to allow demand to vary with time (optional)
- *Category*: text label used to identify the demand category (optional)



	Base Demand	Time Pattern	Category
1	200	1	Domestic
2	10	2	Factory
3			
4			
5			
6			

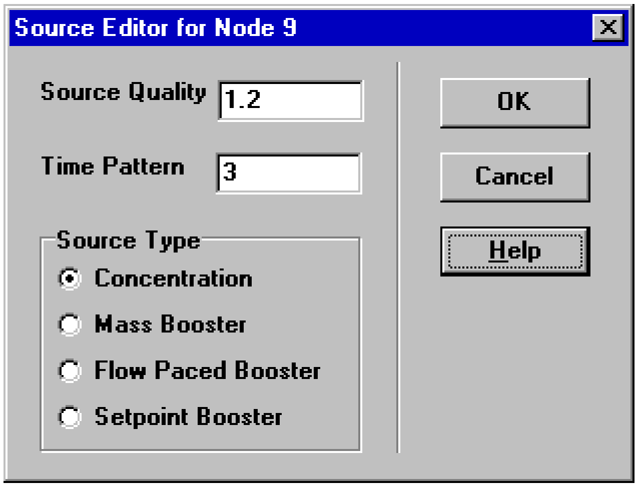
Figure 6.4 Demand Editor

The table initially is sized for 10 rows. If additional rows are needed select any cell in the last row and hit the **Enter** key.

Note: By convention, the demand placed in the first row of the editor will be considered the main category for the junction and will appear in the Base Demand field of the Property Editor.

Source Quality Editor

The Source Quality Editor is a pop-up dialog used to describe the quality of source flow entering the network at a specific node. This source might represent the main treatment works, a well head or satellite treatment facility, or an unwanted contaminant intrusion. The dialog form, shown in Figure 6.5, contains the following fields:



Source Quality 1.2

Time Pattern 3

Source Type
- ● Concentration
- ○ Mass Booster
- ○ Flow Paced Booster
- ○ Setpoint Booster

Figure 6.5 Source Quality Editor

Field	*Description*
Source Type	Select either: - Concentration - Mass Booster - Flow Paced Booster - Setpoint Booster
Source Quality	Baseline or average concentration (or mass flow rate per minute) of source – leave blank to remove the source
Quality Pattern	ID label of time pattern used to make source quality vary with time – leave blank if not applicable

A water quality source can be designated as a concentration or booster source.

- A **concentration source** fixes the concentration of any external inflow entering the network, such as flow from a reservoir or from a negative demand placed at a junction.
- A **mass booster source** adds a fixed mass flow to that entering the node from other points in the network.
- A **flow paced booster source** adds a fixed concentration to that resulting from the mixing of all inflow to the node from other points in the network.
- A **setpoint booster source** fixes the concentration of any flow leaving the node (as long as the concentration resulting from all inflow to the node is below the setpoint).

The concentration-type source is best used for nodes that represent source water supplies or treatment works (e.g., reservoirs or nodes assigned a negative demand). The booster-type source is best used to model direct injection of a tracer or additional disinfectant into the network or to model a contaminant intrusion.

6.6 Copying and Pasting Objects

The properties of an object displayed on the Network Map can be copied and pasted into another object from the same category. To copy the properties of an object to EPANET's internal clipboard:

1. Right-click the object on the map.
2. Select **Copy** from the pop-up menu that appears.

To paste copied properties into an object:

1. Right-click the object on the map.
2. Select **Paste** from the pop-up menu that appears.

6.7 Shaping and Reversing Links

Links can be drawn as polylines containing any number of straight-line segments that add change of direction and curvature to the link. Once a link has been drawn on the map, interior points that define these line segments can be added, deleted, and moved (see Figure 6.6). To edit the interior points of a link:

1. Select the link to edit on the Network Map and click ↖ on the Map Toolbar (or select **Edit** >> **Select Vertex** from the Menu Bar, or right-click on the link and select **Vertices** from the popup menu).
2. The mouse pointer will change shape to an arrow tip, and any existing vertex points on the link will be displayed with small handles around them. To select a particular vertex, click the mouse over it.
3. To add a new vertex to the link, right-click the mouse and select **Add Vertex** from the popup menu (or simply press the **Insert** key on the keyboard).
4. To delete the currently selected vertex, right-click the mouse and select **Delete Vertex** from the popup menu (or simply press the **Delete** key on the keyboard).
5. To move a vertex to another location, drag it with the left mouse button held down to its new position.
6. While in Vertex Selection mode you can begin editing the vertices for another link by clicking on the link. To leave Vertex Selection mode, right-click on the map and select **Quit Editing** from the popup menu, or select any other button on the Map Toolbar.

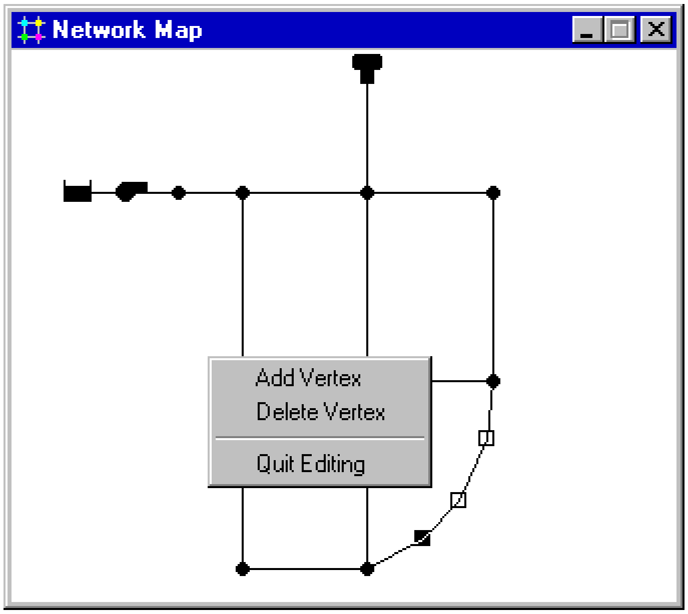


Figure 6.6 Reshaping a Link

A link can also have its direction reversed (i.e., its end nodes switched) by right-clicking on it and selecting **Reverse** from the pop-up menu that appears. This is useful for re-orienting pumps and valves that originally were added in the wrong direction.

6.8 Deleting an Object

To delete an object:

1. Select the object on the map or from the Data Browser.
2. Either:
    - click ☒ on the Standard Toolbar,
    - click the same button on the Data Browser,
    - press the **Delete** key on the keyboard.

Note: You can require that all deletions be confirmed before they take effect. See the General Preferences page of the Program Preferences dialog box described in Section 4.9.

6.9 Moving an Object

To move a node or label to another location on the map:

1. Select the node or label.
2. With the left mouse button held down over the object, drag it to its new location.
3. Release the left button.

Alternatively, new X and Y coordinates for the object can be typed in manually in the Property Editor. Whenever a node is moved all links connected to it are moved as well.

6.10 Selecting a Group of Objects

To select a group of objects that lie within an irregular region of the network map:

1. Select **Edit >> Select Region** or click ⛶ on the Map Toolbar.
2. Draw a polygon fence line around the region of interest on the map by clicking the left mouse button at each successive vertex of the polygon.
3. Close the polygon by clicking the right button or by pressing the **Enter** key; Cancel the selection by pressing the **Escape** key.

To select all objects currently in view on the map select **Edit** >> **Select All**. (Objects outside the current viewing extent of the map are not selected.)

Once a group of objects has been selected, you can edit a common property (see the following section) or delete the selected objects from the network. To do the latter, click ☒ or press the **Delete** key.

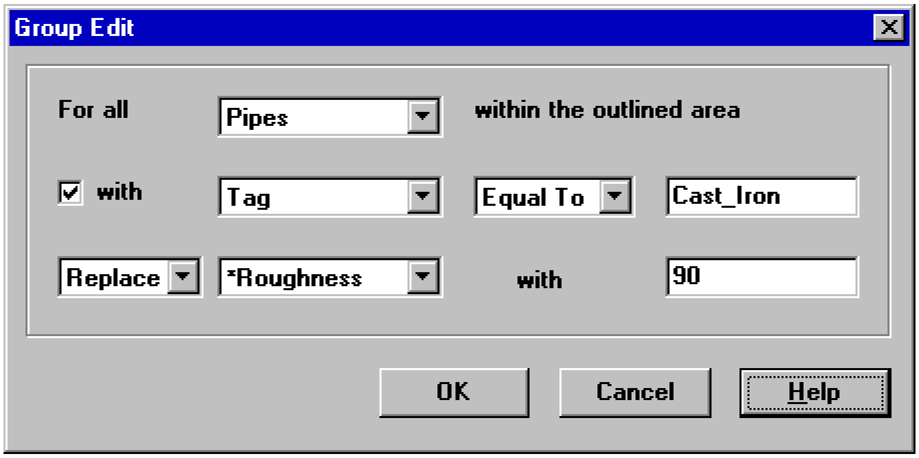
6.11 Editing a Group of Objects

To edit a property for a group of objects:

1. Select the region of the map that will contain the group of objects to be edited using the method described in previous section.
2. Select **Edit** >> **Group Edit** from the Menu Bar.
3. Define what to edit in the Group Edit dialog form that appears.

The Group Edit dialog form, shown in Figure 6.6, is used to modify a property for a selected group of objects. To use the dialog form:

1. Select a category of object (Junctions or Pipes) to edit.
2. Check the "with" box if you want to add a filter that will limit the objects selected for editing. Select a property, relation and value that define the filter. An example might be "with Diameter below 12".
3. Select the type of change to make - Replace, Multiply, or Add To.
4. Select the property to change.
5. Enter the value that should replace, multiply, or be added to the existing value.
6. Click **OK** to execute the group edit.



For all Pipes within the outlined area

☑ with Tag Equal To Cast_Iron

Replace *Roughness with 90

Figure 6.7 Group Edit Dialog

CHAPTER 7 - WORKING WITH THE MAP

EPANET displays a map of the pipe network being modeled. This chapter describes how you can manipulate this map to enhance your visualization of the system being modeled.

7.1 Selecting a Map View

One uses the Map Page of the Browser (Section 4.7) to select a node and link parameter to view on the map. Parameters are viewed on the map by using colors, as specified in the Map Legends (see below), to display different ranges of values.

Node parameters available for viewing include:

- Elevation
- Base Demand (nominal or average demand)
- Initial Quality (water quality at time zero)
- *Actual Demand (total demand at current time)
- *Hydraulic Head (elevation plus pressure head)
- *Pressure
- *Water Quality

Link parameters available for viewing include:

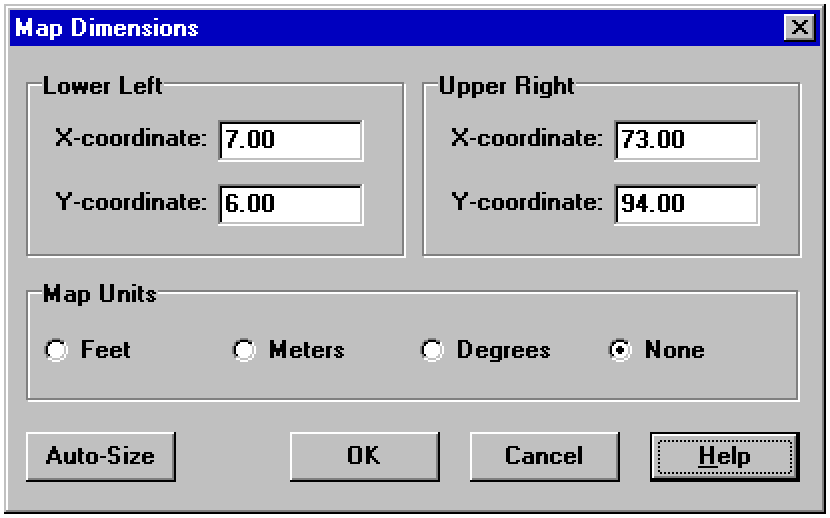
- Length
- Diameter
- Roughness Coefficient
- Bulk Reaction Coefficient
- Wall Reaction Coefficient
- *Flow Rate
- *Velocity
- *Headloss (per 1000 feet (or meters) of pipe)
- *Friction Factor (as used in the Darcy-Weisbach headloss formula)
- *Reaction Rate (average over length of pipe)
- *Water Quality (average over length of pipe)

The items marked with asterisks are computed quantities whose values will only be available if a successful analysis has been run on the network (see Chapter 8 – Analyzing a Network).

7.2 Setting the Map's Dimensions

The physical dimensions of the map must be defined so that map coordinates can be properly scaled to the computer's video display. To set the map's dimensions:

1. Select **View** >> **Dimensions**.
2. Enter new dimension information into the Map Dimensions dialog that appears (see Figure 7.1) or click the **Auto-Size** button to have EPANET compute dimensions based on the coordinates of objects currently included in the network.
3. Click the **OK** button to re-size the map.



Lower Left
X-coordinate: 7.00
Y-coordinate: 6.00

Upper Right
X-coordinate: 73.00
Y-coordinate: 94.00

Map Units
○ Feet ○ Meters ○ Degrees ● None

Figure 7.1 Map Dimensions Dialog

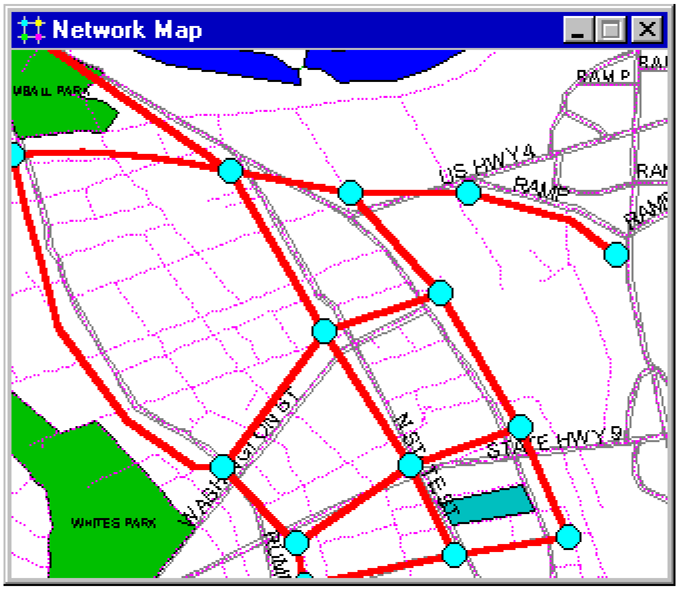
The information provided in the Map Dimensions dialog consists of the following:

Item	*Description*
Lower Left Coordinates	The X and Y coordinates of the lower left point on the map.
Upper Right Coordinates	The X and Y coordinates of the upper right point on the map.
Map Units	Units used to measure distances on the map. Choices are Feet, Meters, Degrees, and None (i.e., arbitrary units).

Note: If you are going to use a backdrop map with automatic pipe length calculation, then it is recommended that you set the map dimensions immediately after creating a new project. Map distance units can be different from pipe length units. The latter (feet or meters) depend on whether flow rates are expressed in US or metric units. EPANET will automatically convert units if necessary.

7.3 Utilizing a Backdrop Map

EPANET can display a backdrop map behind the pipe network map. The backdrop map might be a street map, utility map, topographic map, site development plan, or any other picture or drawing that might be useful. For example, using a street map would simplify the process of adding pipes to the network since one could essentially digitize the network's nodes and links directly on top of it.



The backdrop map must be a Windows enhanced metafile or bitmap created outside of EPANET. Once imported, its features cannot be edited, although its scale and extent will change as the map window is zoomed and panned. For this reason metafiles work better than bitmaps since they will not loose resolution when re-scaled. Most CAD and GIS programs have the ability to save their drawings and maps as metafiles.

Selecting **View** >> **Backdrop** from the Menu Bar will display a sub-menu with the following commands:

- **Load** (loads a backdrop map file into the project)
- **Unload** (unloads the backdrop map from the project)
- **Align** (aligns the pipe network with the backdrop)
- **Show/Hide** (toggles the display of the backdrop on and off)

When first loaded, the backdrop image is placed with its upper left corner coinciding with that of the network's bounding rectangle. The backdrop can be re-positioned relative to the network map by selecting **View** >> **Backdrop** >> **Align**. This allows an outline of the pipe network to be moved across the backdrop (by moving the mouse with the left button held down) until one decides that it lines up properly with the backdrop. The name of the backdrop file and its current alignment are saved along with the rest of a project's data whenever the project is saved to file.

For best results in using a backdrop map:

- Use a metafile, not a bitmap.
- Dimension the network map so that its bounding rectangle has the same aspect ratio (width-to-height ratio) as the backdrop.

7.4 Zooming the Map

To Zoom In on the map:

1. Select **View** >> **Zoom In** or click ⊕ on the Map Toolbar.
2. To zoom in 100%, move the mouse to the center of the zoom area and click the left button.
3. To perform a custom zoom, move the mouse to the upper left corner of the zoom area and with the left button pressed down, draw a rectangular outline around the zoom area. Then release the left button.

To Zoom Out on the map:

1. Select **View** >> **Zoom Out** or click ⊖ on the Map Toolbar.
2. Move the mouse to the center of the new zoom area and click the left button.
3. The map will be returned to its previous zoom level.

7.5 Panning the Map

To pan the map across the Map window:

1. Select **View** >> **Pan** or click ✥ on the Map Toolbar.
2. With the left button held down over any point on the map, drag the mouse in the direction you wish to pan in.
3. Release the mouse button to complete the pan.

To pan using the Overview Map (which is described in Section 7.7 below):

1. If not already visible, bring up the Overview Map by selecting **View** >> **Overview Map.**
2. Position the mouse within the zoom window displayed on the Overview Map.
3. With the left button held down, drag the zoom window to a new position.
4. Release the mouse button and the main map will be panned to an area corresponding to that of the Overview Map's zoom window.

7.6 Finding an Object

To find a node or link on the map whose ID label is known:

1. Select **View** >> **Find** or click on the Standard Toolbar**.**
2. In the Map Finder dialog box that appears, select **Node** or **Link** and enter an ID label.
3. Click **Find**.

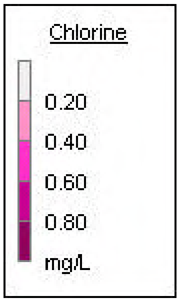
If the node/link exists it will be highlighted on the map and in the Browser. If the map is currently zoomed in and the node/link falls outside the current map boundaries, the map will be panned so that the node/link comes into view. The Map Finder dialog will also list the ID labels of the links that connect to a found node or the nodes attached to a found link.

To find a listing of all nodes that serve as water quality sources:

1. Select **View** >> **Find** or click on the Standard Toolbar**.**
2. In the Map Finder dialog box that appears, select **Sources**.
3. Click **Find**.

The ID labels of all water quality source nodes will be listed in the Map Finder. Clicking on any ID label will highlight that node on the map.

7.7 Map Legends



There are three types of map legends that can be displayed. The Node and Link Legends associate a color with a range of values for the current parameter being viewed on the map. The Time Legend displays the clock time of the simulation time period being viewed. To display or hide any of these legends check or uncheck the legend from the **View** >> **Legends** menu or right-click over the map and do the same from the popup menu that appears. Double-clicking the mouse over it can also hide a visible legend.

To move a legend to another location:

1. Press the left mouse button over the legend.
2. With the button held down, drag the legend to its new location and release the button.

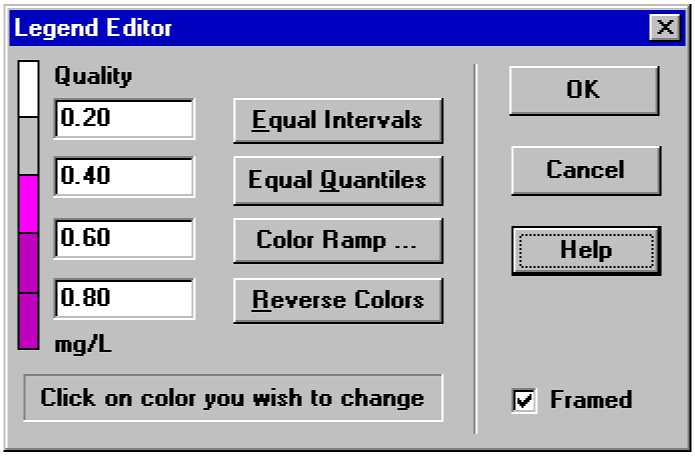
To edit the Node Legend:

1. Either select **View** >> **Legends** >> **Modify** >> **Node** or right-click on the legend if it is visible.
2. Use the Legend Editor dialog form that appears (see Figure 7.2) to modify the legend's colors and intervals.

A similar method is used to edit the Link Legend.

The Legend Editor (Figure 7.2) is used to set numerical ranges to which different colors are assigned for viewing a particular parameter on the network map. It works as follows:

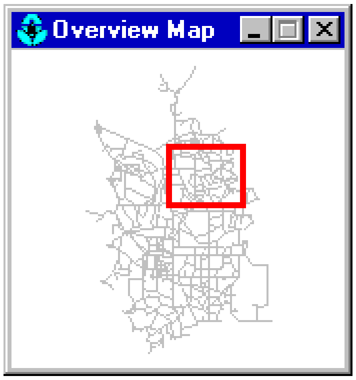
- Numerical values, in increasing order, are entered in the edit boxes to define the ranges. Not all four boxes need to have values.
- To change a color, click on its color band in the Editor and then select a new color from the Color Dialog box that will appear.
- Click the **Equal Intervals** button to assign ranges based on dividing the range of the parameter at the current time period into equal intervals.
- Click the **Equal Quantiles** button to assign ranges so that there are equal numbers of objects within each range, based on values that exist at the current time period.
- The **Color Ramp** button is used to select from a list of built-in color schemes.
- The **Reverse Colors** button reverses the ordering of the current set of colors (the color in the lowest range becomes that of the highest range and so on).
- Check **Framed** if you want a frame drawn around the legend.



Quality
0.20
0.40
0.60
0.80
mg/L
Click on color you wish to change
☑ Framed

Figure 7.2 Legend Editor Dialog

7.8 Overview Map

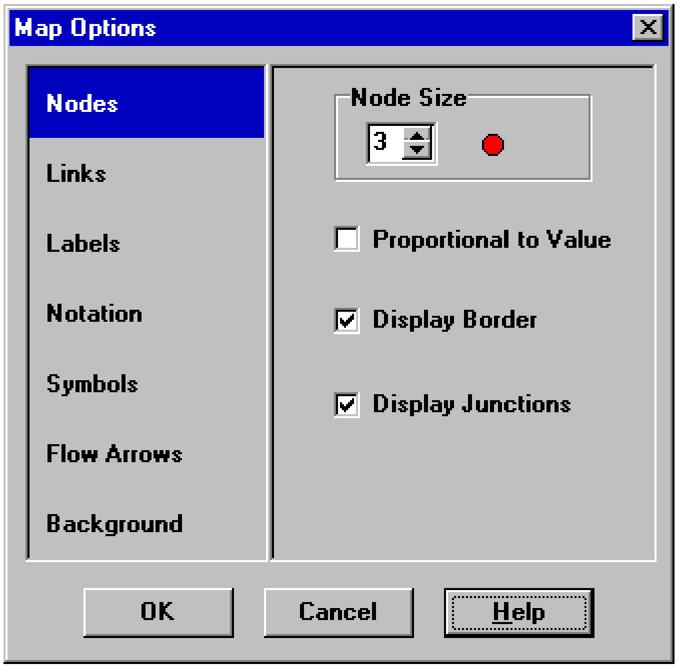


The Overview Map allows you to see where in terms of the overall system the main network map is currently focused. This zoom area is depicted by the rectangular boundary displayed on the Overview Map. As you drag this rectangle to another position the view within the main map will follow suit. The Overview Map can be toggled on and off by selecting **View** >> **Overview Map**. Clicking the mouse on its title bar will update its map image to match that of the main network map.

7.9 Map Display Options

There are several ways to bring up the Map Options dialog form (Figure 7.3) used to change the appearance of the Network Map:

- select **View** >> **Options**,
- click the Options button on the Standard Toolbar when the Map window has the focus,
- right-click on any empty portion of the map and select **Options** from the popup menu that appears.



Map Options

Nodes
Links
Labels
Notation
Symbols
Flow Arrows
Background

Node Size: 3

☐ Proportional to Value

☑ Display Border

☑ Display Junctions

Figure 7.3 Map Options Dialog

The dialog contains a separate page, selected from the panel on the left side of the form, for each of the following display option categories:

- *Nodes* (controls size of nodes and making size be proportional to value)
- *Links* (controls thickness of links and making thickness be proportional to value)
- Labels (turns display of map labels on/off)
- *Notation* (displays or hides node/link ID labels and parameter values)
- *Symbols* (turns display of tank, pump, valve symbols on/off)
- *Flow Arrows* (selects visibility and style of flow direction arrows)
- *Background* (changes color of map's background)

Node Options

The Nodes page of the Map Options dialog controls how nodes are displayed on the Network Map.

Option	*Description*
Node Size	Selects node diameter
Proportional to Value	Select if node size should increase as the viewed parameter increases in value
Display Border	Select if a border should be drawn around each node (recommended for light-colored backgrounds)
Display Junctions	Displays junction nodes (all junctions will be hidden unless this option is checked).

Link Options

The Links page of the Map Options dialog controls how links are displayed on the map.

Option	*Description*
Link Size	Sets thickness of links displayed on map
Proportional to Value	Select if link thickness should increase as the viewed parameter increases in value

Label Options

The Labels page of the Map Options dialog controls how labels are displayed on the map.

Option	*Description*
Display Labels	Displays map labels (labels will be hidden unless this option is checked)
Use Transparent Text	Displays label with a transparent background (otherwise an opaque background is used)
At Zoom Of	Selects minimum zoom at which labels should be displayed; labels will be hidden at zooms smaller than this unless they are meter labels

Notation Options

The Notation page of the Map Options dialog form determines what kind of annotation is provided alongside of the nodes and links of the map.

Option	*Description*
Display Node IDs	Displays node ID labels
Display Node Values	Displays value of current node parameter being viewed
Display Link IDs	Displays link ID labels
Display Link Values	Displays values of current link parameter being viewed
Use Transparent Text	Displays text with a transparent background (otherwise an opaque background is used)
At Zoom Of	Selects minimum zoom at which notation should be displayed; all notation will be hidden at zooms smaller than this

Note: Values of the current viewing parameter at only specific nodes and links can be displayed by creating Map Labels with meters for those objects. See Sections 6.2 and 6.4 as well as Table 6.7.

Symbol Options

The Symbols page of the Map Options dialog determines which types of objects are represented with special symbols on the map.

Option	*Description*
Display Tanks	Displays tank symbols
Display Pumps	Displays pump symbols
Display Valves	Displays valve symbols
Display Emitters	Displays emitter symbols
Display Sources	Displays **+** symbol for water quality sources
At Zoom Of	Selects minimum zoom at which symbols should be displayed; symbols will be hidden at zooms smaller than this

Flow Arrow Options

The Flow Arrows page of the Map Options dialog controls how flow-direction arrows are displayed on the network map.

Option	*Description*
Arrow Style	Selects style (shape) of arrow to display (select None to hide arrows)
Arrow Size	Sets arrow size
At Zoom Of	Selects minimum zoom at which arrows should be displayed; arrows will be hidden at zooms smaller than this

Note: Flow direction arrows will only be displayed after a network has been successfully analyzed (see Section 8.2 Running an Analysis).

Background Options

The Background page of the Map Options dialog offers a selection of colors used to paint the map's background with.

CHAPTER 8 - ANALYZING A NETWORK

After a network has been suitably described, its hydraulic and water quality behavior can be analyzed. This chapter describes how to specify options to use in the analysis, how to run the analysis and how to troubleshoot problems that might have occurred with the analysis.

8.1 Setting Analysis Options

There are five categories of options that control how EPANET analyzes a network: Hydraulics, Quality, Reactions, Times, and Energy. To set any of these options:

1. Select the Options category from the Data Browser or select **Project** >> **Analysis Options** from the menu bar.
2. Select Hydraulics, Quality, Reactions, Times, or Energy from the Browser.
3. If the Property Editor is not already visible, click the Browser's Edit button (or hit the **Enter** key).
4. Edit your option choices in the Property Editor.

As you are editing a category of options in the Property Editor you can move to the next or previous category by simply hitting the **Page Down** or **Page Up** keys, respectively.

Hydraulic Options

Hydraulic options control how the hydraulic computations are carried out. They consist of the following items:

Option	*Description*
Flow Units	Units in which nodal demands and link flow rates are expressed. Choosing units in gallons, cubic feet, or acre-feet implies that the units for all other network quantities are Customary US. Selecting liters or cubic meters causes all other units to be SI metric. Use caution when changing flow units as it might affect all other data supplied to the project. (See Appendix A, Units of Measurement.)
Headloss Formula	Formula used to compute headloss as a function of flow rate in a pipe. Choices are: • Hazen-Williams • Darcy-Weisbach • Chezy-Manning Because each formula measures pipe roughness differently, switching formulas might require that all pipe roughness coefficients be updated.

Specific Gravity	Ratio of the density of the fluid being modeled to that of water at 4 deg. C (unitless).
Relative Viscosity	Ratio of the kinematic viscosity of the fluid to that of water at 20 deg. C (1.0 centistokes or 0.94 sq ft/day) (unitless).
Maximum Trials	Maximum number of trials used to solve the nonlinear equations that govern network hydraulics at a given point in time. Suggested value is 40.
Accuracy	Convergence criterion used to signal that a solution has been found to the nonlinear equations that govern network hydraulics. Trials end when the sum of all flow changes divided by the sum of all link flows is less than this number. Suggested value is 0.001.
If Unbalanced	Action to take if a hydraulic solution is not found within the maximum number of trials. Choices are STOP to stop the simulation at this point or CONTINUE to use another 10 trials, with no link status changes allowed, in an attempt to achieve convergence.
Default Pattern	ID label of a time pattern to be applied to demands at those junctions where no time pattern is specified. If no such pattern exists then demands will not vary at these locations.
Demand Multiplier	Global multiplier applied to all demands to make total system consumption vary up or down by a fixed amount. E.g., 2.0 doubles all demands, 0.5 halves them, and 1.0 leaves them as is.
Emitter Exponent	Power to which pressure is raised when computing the flow through an emitter device. The textbook value for nozzles and sprinklers is ½. This may not apply to pipe leakage. Consult the discussion of Emitters in Section 3.1 for more details.
Status Report	Amount of status information to report after an analysis is made. Choices are: • NONE (no status reporting) • YES (normal status reporting – lists all changes in link status throughout the simulation) • FULL (full reporting – normal reporting plus the convergence error from each trial of the hydraulic analysis made in each time period) Full status reporting is only useful for debugging purposes.

Note: Choices for Hydraulic Options can also be set from the **Project >> Defaults** menu and saved for use with all future projects (see Section 5.2).

Water Quality Options

Water Quality Options control how the water quality analysis is carried out. They consist of the following:

Option	*Description*
Parameter	Type of water quality parameter being modeled. Choices include: • NONE (no quality analysis), • CHEMICAL (compute chemical concentration), • AGE (compute water age), • TRACE (trace the percent of flow originating from a specific node). In lieu of CHEMICAL, you can enter the actual name of the chemical being modeled (e.g., Chlorine).
Mass Units	Mass units used to express concentration. Choices are mg/L or µg/L. Units for Age and Trace analyses are fixed at hours and percent, respectively.
Relative Diffusivity	Ratio of the molecular diffusivity of the chemical being modeled to that of chlorine at 20 deg. C (0.00112 sq ft/day). Use 2 if the chemical diffuses twice as fast as chlorine, 0.5 if half as fast, etc. Applies only when modeling mass transfer for pipe wall reactions. Set to zero to ignore mass transfer effects.
Trace Node	ID label of the node whose flow is being traced. Applies only to flow tracing analyses.
Quality Tolerance	Smallest change in quality that will cause a new parcel of water to be created in a pipe. A typical setting might be 0.01 for chemicals measured in mg/L as well as water age and source tracing.

Note: The Quality Tolerance determines when the quality of one parcel of water is essentially the same as another parcel. For chemical analysis this might be the detection limit of the procedure used to measure the chemical, adjusted by a suitable factor of safety. Using too large a value for this tolerance might affect simulation accuracy. Using too small a value will affect computational efficiency. Some experimentation with this setting might be called for.

Reaction Options

Reaction Options set the types of reactions that apply to a water quality analysis. They include the following:

Option	*Description*
Bulk Reaction Order	Power to which concentration is raised when computing a bulk flow reaction rate. Use 1 for first-order reactions, 2 for second-order reactions, etc. Use any negative number for Michaelis-Menton kinetics. If no global or pipe-specific bulk reaction coefficients are assigned then this option is ignored.
Wall Reaction Order	Power to which concentration is raised when computing a bulk flow reaction rate. Choices are FIRST (1) for first-order reactions or ZERO (0) for constant rate reactions. If no global or pipe-specific wall reaction coefficients are assigned then this option is ignored.
Global Bulk Coefficient	Default bulk reaction rate coefficient (K_b) assigned to all pipes. This global coefficient can be overridden by editing this property for specific pipes. Use a positive number for growth, a negative number for decay, or 0 if no bulk reaction occurs. Units are concentration raised to the (1-n) power divided by days, where n is the bulk reaction order.
Global Wall Coefficient	Wall reaction rate coefficient (K_w) assigned to all pipes. Can be overridden by editing this property for specific pipes. Use a positive number for growth, a negative number for decay, or 0 if no wall reaction occurs. Units are ft/day (US) or m/day (SI) for first-order reactions and mass/sq ft/day (US) or mass/sq m/day (SI) for zero-order reactions.
Limiting Concentration	Maximum concentration that a substance can grow to or minimum value it can decay to. Bulk reaction rates will be proportional to the difference between the current concentration and this value. See discussion of Bulk Reactions in Section 3.4 for more details. Set to zero if not applicable.
Wall Coefficient Correlation	Factor correlating wall reaction coefficient to pipe roughness. See discussion of Wall Reactions in Section 3.4 for more details. Set to zero if not applicable.

Times Options

Times options set values for the various time steps used in an extended period simulation. These are listed below (times can be entered as decimal hours or in hours:minutes notation):

Option	*Description*
Total Duration	Total length of a simulation in hours. Use 0 to run a single period (snapshot) hydraulic analysis.
Hydraulic Time Step	Time interval between re-computation of system hydraulics. Normal default is 1 hour.
Quality Time Step	Time interval between routing of water quality constituent. Normal default is 5 minutes (0:05 hours).
Pattern Time Step	Time interval used with all time patterns. Normal default is 1 hour.
Pattern Start Time	Hours into all time patterns at which the simulation begins (e.g., a value of 2 means that the simulation begins with all time patterns starting at their second hour). Normal default is 0.
Reporting Time Step	Time interval between times at which computed results are reported. Normal default is 1 hour.
Report Start Time	Hours into simulation at which computed results begin to be reported. Normal default is 0.
Starting Time of Day	Clock time (e.g., 7:30 am, 10:00 pm) at which simulation begins. Default is 12:00 am (midnight).
Statistic	Type of statistical processing used to summarize the results of an extended period simulation. Choices are: • NONE (results reported at each reporting time step) • AVERAGE (time-averaged results reported) • MINIMUM (minimum value results reported) • MAXIMUM (maximum value results reported) • RANGE (difference between maximum and minimum results reported) Statistical processing is applied to all node and link results obtained between the Report Start Time and the Total Duration.

Note: To run a single-period hydraulic analyses (also called a snapshot analysis) enter 0 for Total Duration. In this case entries for all of the other time options, with the exception of Starting Time of Day, are not used. Water quality analyses always require that a non-zero Total Duration be specified.

Energy Options

Energy Analysis Options provide default values used to compute pumping energy and cost when no specific energy parameters are assigned to a given pump. They consist of the following:

Option	*Description*
Pump Efficiency (%)	Default pump efficiency.
Energy Price per Kwh	Price of energy per kilowatt-hour. Monetary units are not explicitly represented.
Price Pattern	ID label of a time pattern used to represent variations in energy price with time. Leave blank if not applicable.
Demand Charge	Additional energy charge per maximum kilowatt usage.

8.2 Running an Analysis

To run a hydraulic/water quality analysis:

1. Select **Project** >> **Run Analysis** or click ⚡ on the Standard Toolbar.
2. The progress of the analysis will be displayed in a Run Status window.
3. Click **OK** when the analysis ends.

If the analysis runs successfully the 🚰 icon will appear in the Run Status section of the Status Bar at the bottom of the EPANET workspace. Any error or warning messages will appear in a Status Report window. If you edit the properties of the network after a successful run has been made, the faucet icon changes to a broken faucet indicating that the current computed results no longer apply to the modified network.

8.3 Troubleshooting Results

EPANET will issue specific Error and Warning messages when problems are encountered in running a hydraulic/water quality analysis (see Appendix B for a complete listing). The most common problems are discussed below.

Pumps Cannot Deliver Flow or Head

EPANET will issue a warning message when a pump is asked to operate outside the range of its pump curve. If the pump is required to deliver more head than its shutoff head, EPANET will close the pump down. This might lead to portions of the network becoming disconnected from any source of water.

Network is Disconnected

EPANET classifies a network as being disconnected if there is no way to provide water to all nodes that have demands. This can occur if there is no path of open links between a junction with demand and either a reservoir, a tank, or a junction with a negative demand. If the problem is caused by a closed link EPANET will still compute a hydraulic solution (probably with extremely large negative pressures) and attempt to identify the problem link in its Status Report. If no connecting link(s) exist EPANET will be unable to solve the hydraulic equations for flows and pressures and will return an Error 110 message when an analysis is made. Under an extended period simulation it is possible for nodes to become disconnected as links change status over time.

Negative Pressures Exist

EPANET will issue a warning message when it encounters negative pressures at junctions that have positive demands. This usually indicates that there is some problem with the way the network has been designed or operated. Negative pressures can occur when portions of the network can only receive water through links that have been closed off. In such cases an additional warning message about the network being disconnected is also issued.

System Unbalanced

A System Unbalanced condition can occur when EPANET cannot converge to a hydraulic solution in some time period within its allowed maximum number of trials. This situation can occur when valves, pumps, or pipelines keep switching their status from one trial to the next as the search for a hydraulic solution proceeds. For example, the pressure limits that control the status of a pump may be set too close together. Or a pump's head curve might be too flat causing it to keep shutting on and off.

To eliminate the unbalanced condition one can try to increase the allowed maximum number of trials or loosen the convergence accuracy requirement. Both of these parameters are set with the project’s Hydraulic Options. If the unbalanced condition persists, then another hydraulic option, labeled “If Unbalanced”, offers two ways to handle it. One is to terminate the entire analysis once the condition is encountered. The other is to continue seeking a hydraulic solution for another 10 trials with the status of all links frozen to their current values. If convergence is achieved then a warning message is issued about the system possibly being unstable. If convergence is not achieved then a “System Unbalanced” warning message is issued. In either case, the analysis will proceed to the next time period.

If an analysis in a given time period ends with the system unbalanced then the user should recognize that the hydraulic results produced for this time period are inaccurate. Depending on circumstances, such as errors in flows into or out of storage tanks, this might affect the accuracy of results in all future periods as well.

Hydraulic Equations Unsolvable

Error 110 is issued if at some point in an analysis the set of equations that model flow and energy balance in the network cannot be solved. This can occur when some portion of a system demands water but has no links physically connecting it to any source of water. In such a case EPANET will also issue warning messages about nodes being disconnected. The equations might also be unsolvable if unrealistic numbers were used for certain network properties.

CHAPTER 9 - VIEWING RESULTS

This chapter describes the different ways in which the results of an analysis as well as the basic network input data can be viewed. These include different map views, graphs, tables, and special reports.

9.1 Viewing Results on the Map

There are several ways in which database values and results of a simulation can be viewed directly on the Network Map:

- For the current settings on the Map Browser (see Section 4.6), the nodes and links of the map will be colored according to the color-coding used in the Map Legends (see Section 7.6). The map's coloring will be updated as a new time period is selected in the Browser.
- When the Flyover Map Labeling program preference is selected (see Section 4.9), moving the mouse over any node or link will display its ID label and the value of the current viewing parameter for that node or link in a hint-style box.
- ID labels and viewing parameter values can be displayed next to all nodes and/or links by selecting the appropriate options on the Notation page of the Map Options dialog form (see Section 7.8).
- Nodes or links meeting a specific criterion can be identified by submitting a Map Query (see below).
- You can animate the display of results on the network map either forward or backward in time by using the Animation buttons on the Map Browser. Animation is only available when a node or link viewing parameter is a computed value (e.g., link flow rate can be animated but diameter cannot).
- The map can be printed, copied to the Windows clipboard, or saved as a DXF file or Windows metafile.

Submitting a Map Query

A Map Query identifies nodes or links on the network map that meet a specific criterion (e.g., nodes with pressure less than 20 psi, links with velocity above 2 ft/sec, etc.). See Figure 9.1 for an example. To submit a map query:

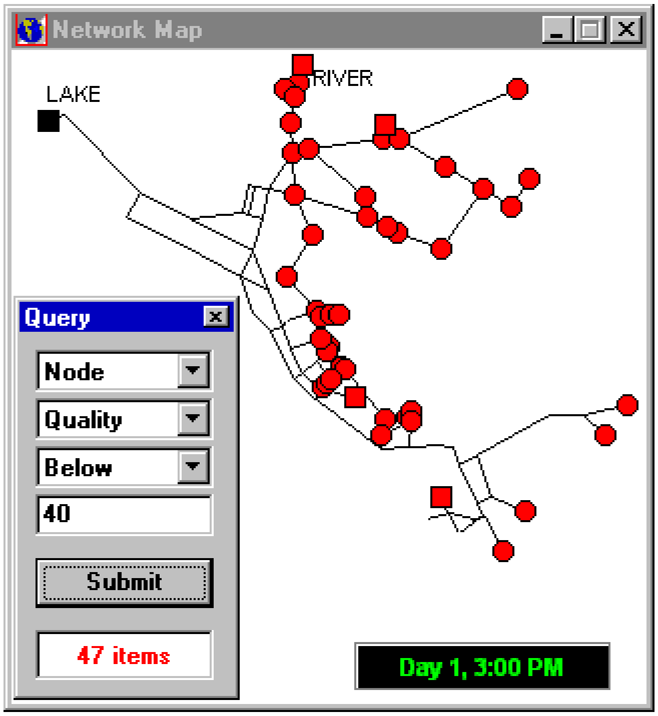


Figure 9.1 Results of a Map Query

1. Select a time period in which to query the map from the Map Browser.
2. Select **View** >> **Query** or click on the Map Toolbar.
3. Fill in the following information in the Query dialog form that appears:
    - Select whether to search for Nodes or Links
    - Select a parameter to compare against
    - Select **Above**, **Below,** or **Equals**
    - Enter a value to compare against
4. Click the **Submit** button. The objects that meet the criterion will be highlighted on the map.
5. As a new time period is selected in the Browser, the query results are automatically updated.
6. You can submit another query using the dialog box or close it by clicking the button in the upper right corner.

After the Query box is closed the map will revert back to its original display.

9.2 Viewing Results with a Graph

Analysis results, as well as some design parameters, can be viewed using several different types of graphs. Graphs can be printed, copied to the Windows clipboard, or saved as a data file or Windows metafile. The following types of graphs can be used to view values for a selected parameter (see Figure 9.2 for examples of each):

Type of Plot	*Description*	*Applies To*
Time Series Plot	Plots value versus time	Specific nodes or links over all time periods
Profile Plot	Plots value versus distance	A list of nodes at a specific time
Contour Plot	Shows regions of the map where values fall within specific intervals	All nodes at a specific time
Frequency Plot	Plots value versus fraction of objects at or below the value	All nodes or links at a specific time
System Flow	Plots total system production and consumption versus time	Water demand for all nodes over all time periods

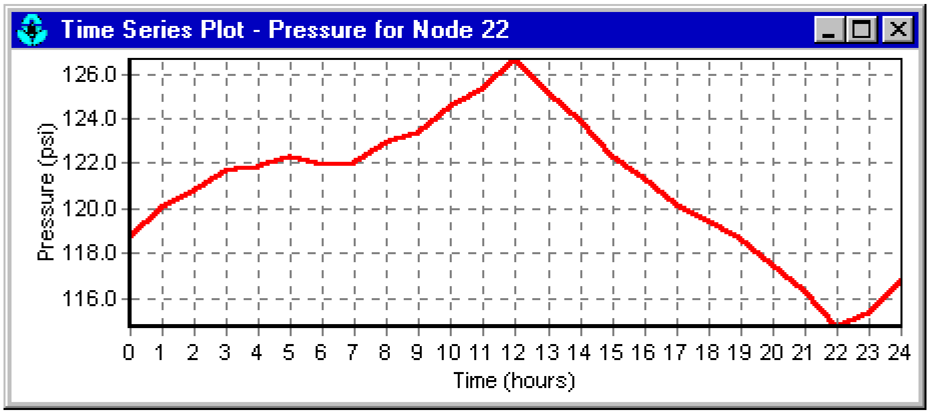
Note: When only a single node or link is graphed in a Time Series Plot the graph will also display any measured data residing in a Calibration File that has been registered with the project (see Section 5.3).

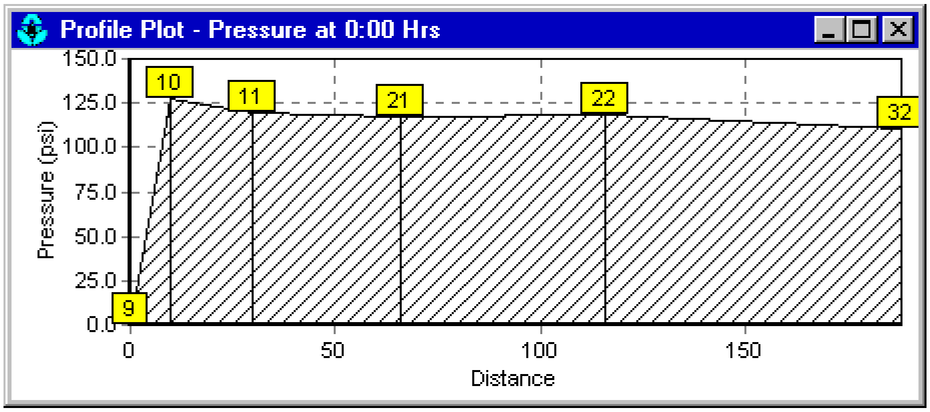
To create a graph:

1. Select **Report** >> **Graph** or click 📈 on the Standard Toolbar.
2. Fill in the choices on the Graph Selection dialog box that appears.
3. Click **OK** to create the graph.

The Graph Selection dialog, as pictured in Figure 9.3, is used to select a type of graph and its contents to display. The choices available in the dialog consist of the following:

Item	*Description*
Graph Type	Selects a graph type
Parameter	Selects a parameter to graph
Time Period	Selects a time period to graph (does not apply to Time Series plots)
Object Type	Selects either Nodes or Links (only Nodes can be graphed on Profile and Contour plots)
Items to Graph	Selects items to graph (applies only to Time Series and Profile plots)





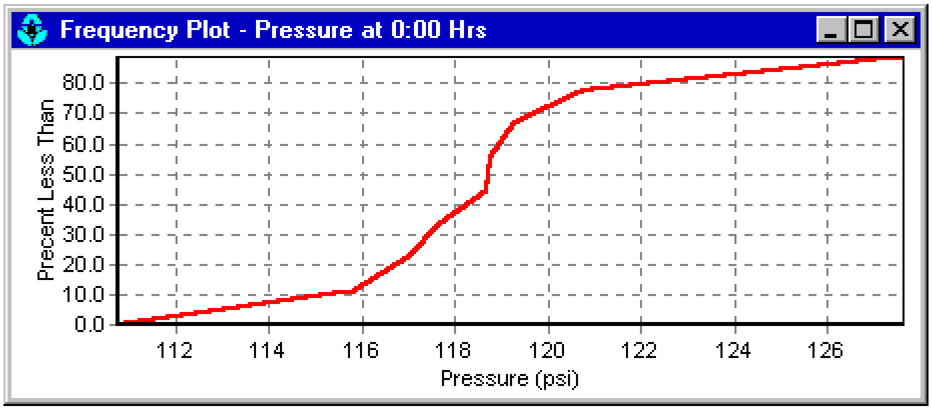
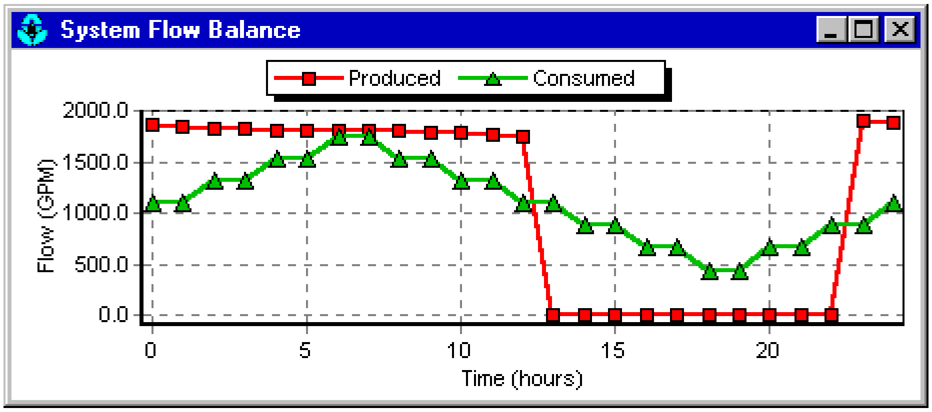


Figure 9.2 Examples of Different Types of Graphs



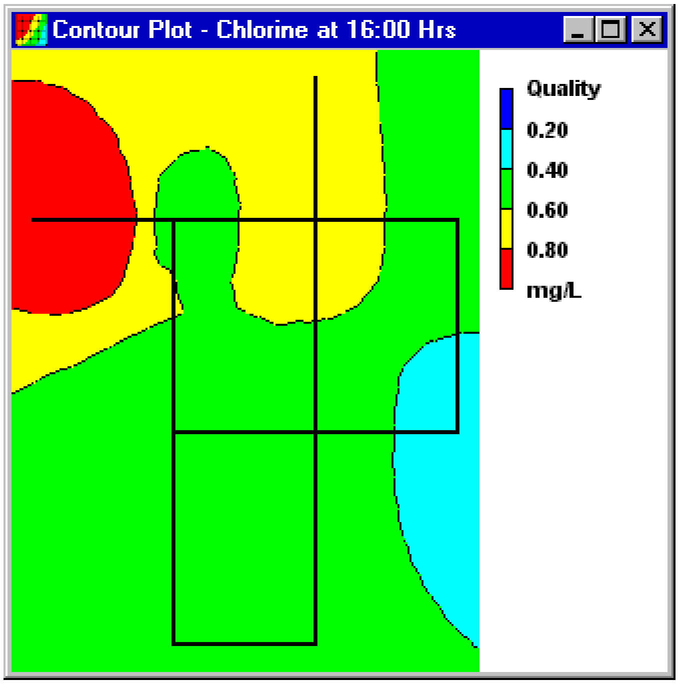
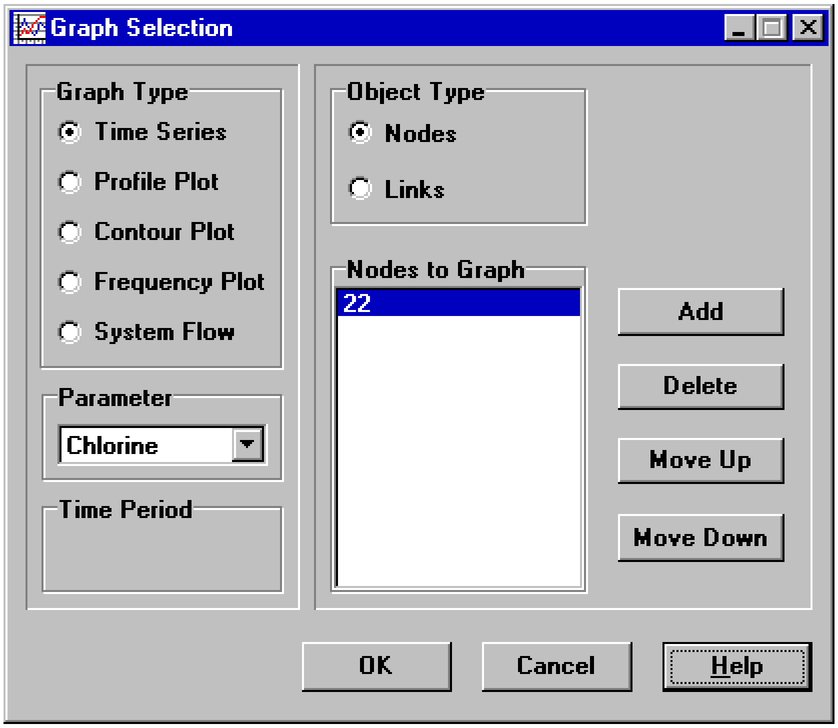


Figure 9.2 Continued From Previous Page



Graph Type: ● Time Series
Object Type: ● Nodes
Parameter: Chlorine
Nodes to Graph: 22

Figure 9.3 Graph Selection Dialog

Time Series plots and Profile plots require one or more objects be selected for plotting. To select items into the Graph Selection dialog for plotting:

1. Select the object (node or link) either on the Network Map or on the Data Browser. (The Graph Selection dialog will remain visible during this process).
2. Click the **Add** button on the Graph Selection dialog to add the selected item to the list.

In place of Step 2, you can also drag the object's label from the Data Browser onto the Form's title bar or onto the Items to Graph list box.

The other buttons on the **Graph Selection** dialog form are used as follows:

Button	*Purpose*
Load (Profile Plot Only)	Loads a previously saved list of nodes
Save (Profile Plot Only)	Saves current list of nodes to file
Delete	Deletes selected item from list
Move Up	Moves selected item on list up one position
Move Down	Moves selected item on list down one position

To customize the appearance of a graph:

1. Make the graph the active window (click on its title bar).
2. Select **Report** >> **Options**, or click on the Standard Toolbar, or right-click on the graph.
3. For a Time Series, Profile, Frequency or System Flow plot, use the resulting Graph Options dialog (Figure 9.4) to customize the graph's appearance.
4. For a Contour plot use the resulting Contour Options dialog to customize the plot.

Note: A Time Series, Profile, or Frequency plot can be zoomed by holding down the **Ctrl** key while drawing a zoom rectangle with the mouse's left button held down. Drawing the rectangle from left to right zooms in, drawing from right to left zooms out. The plot can also be panned in any direction by holding down the **Ctrl** key and moving the mouse across the plot with the right button held down.

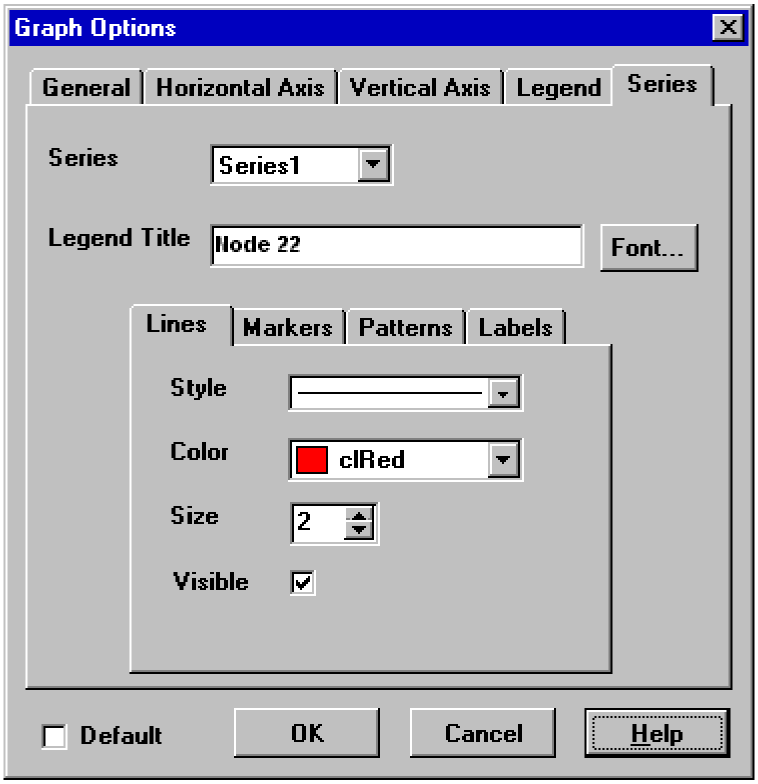
The Graph Options dialog form (Figure 9.4) is used to customize the appearance of an X-Y graph. To use the dialog box:

1. Select from among the five tabbed pages that cover the following categories of options:
    - General
    - Horizontal Axis
    - Vertical Axis
    - Legend
    - Series
2. Check the **Default** box if you wish to use the current settings as defaults for all new graphs as well.
3. Select **OK** to accept your selections.

The items contained on each page of the Graph Options dialog are as follows:

General Page

Option	*Description*
Panel Color	Color of the panel which surrounds the graph’s plotting area
Background Color	Color of graph's plotting area
View in 3D	Check if graph should be drawn in 3D
3D Effect Percent	Degree to which 3D effect is drawn
Main Title	Text of graph's main title
Font	Changes the font used for the main title



Series: Series1

Legend Title: Node 22

Style: ———

Color: 🟥 clRed

Size: 2

Visible ☑

☐ Default

Figure 9.4 Graph Options Dialog

Horizontal and Vertical Axis Pages

Option	*Description*
Minimum	Sets minimum axis value (minimum data value is shown in parentheses). Can be left blank.
Maximum	Sets maximum axis value (maximum data value is shown in parentheses). Can be left blank.
Increment	Sets increment between axis labels. Can be left blank.
Auto Scale	If checked then Minimum, Maximum, and Increment settings are ignored.
Gridlines	Selects type of gridline to draw.
Axis Title	Text of axis title
Font	Click to select a font for the axis title.

Legend Page

Option	*Description*
Position	Selects where to place the legend.
Color	Selects color to use for legend background.
Symbol Width	Selects width to use (in pixels) to draw symbol portion of the legend.
Framed	Places a frame around the legend.
Visible	Makes the legend visible.

Series Page

The Series page (see Figure 9.4) of the Graph Options dialog controls how individual data series (or curves) are displayed on a graph. To use this page:

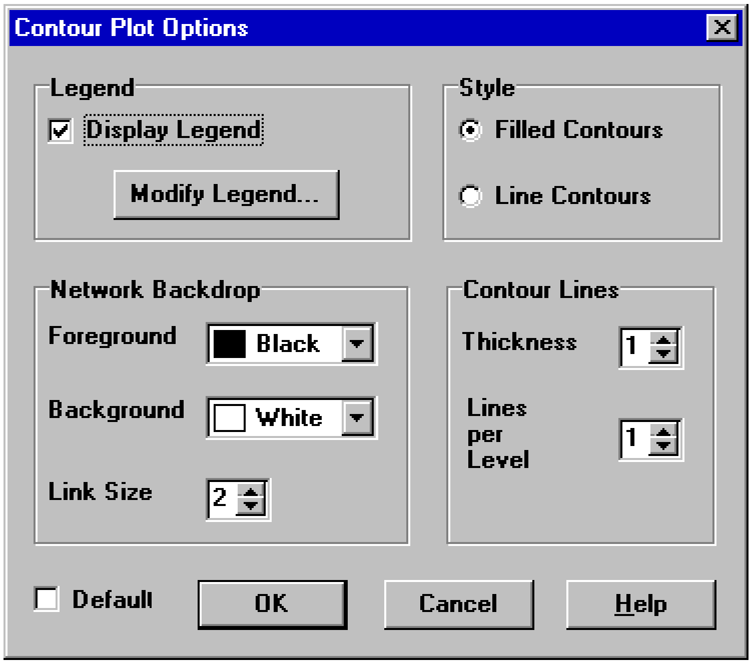
- Select a data series to work with from the Series combo box.
- Edit the title used to identify this series in the legend.
- Click the Font button to change the font used for the legend. (Other legend properties are selected on the Legend page of the dialog.)
- Select a property of the data series you would like to modify. The choices are:
    - Lines
    - Markers
    - Patterns
    - Labels

(Not all properties are available for some types of graphs.)

The data series properties that can be modified include the following:

Category	*Option*	*Description*
Lines	Style	Selects line style.
	Color	Selects line color.
	Size	Selects line thickness (only for solid line style).
	Visible	Determines if line is visible.
Markers	Style	Selects marker style.
	Color	Selects marker color.
	Size	Selects marker size.
	Visible	Determines if marker is visible.
Patterns	Style	Selects pattern style.
	Color	Selects pattern color.
	Stacking	Not used with EPANET.
Labels	Style	Selects what type of information is displayed in the label.
	Color	Selects the color of the label's background.
	Transparent	Determines if graph shows through label or not.
	Show Arrows	Determines if arrows are displayed on pie charts.
	Visible	Determines if labels are visible or not.

The Contour Options dialog form (Figure 9.5) is used to customize the appearance of a contour graph. A description of each option is provided below:



☑ Display Legend

● Filled Contours

○ Line Contours

Foreground: Black

Background: White

Link Size: 2

Thickness: 1

Lines per Level: 1

☐ Default

Figure 9.5 Contour Plot Options Dialog

Category	*Option*	*Description*
Legend	Display Legend	Toggles display of legend on/off
	Modify Legend	Changes colors and contour intervals
Network Backdrop	Foreground	Color of network image displayed on plot
	Background	Background color used for line contour plot
	Link Size	Thickness of lines used to display network
Style	Filled Contours	Plot uses colored area-filled contours
	Line Contours	Plot uses colored line contours
Contour Lines	Thickness	Thickness of lines used for contour intervals
	Lines per Level	Number of sub-contours per major contour level
Default		Saves choices as defaults for next contour plot

9.3 Viewing Results with a Table

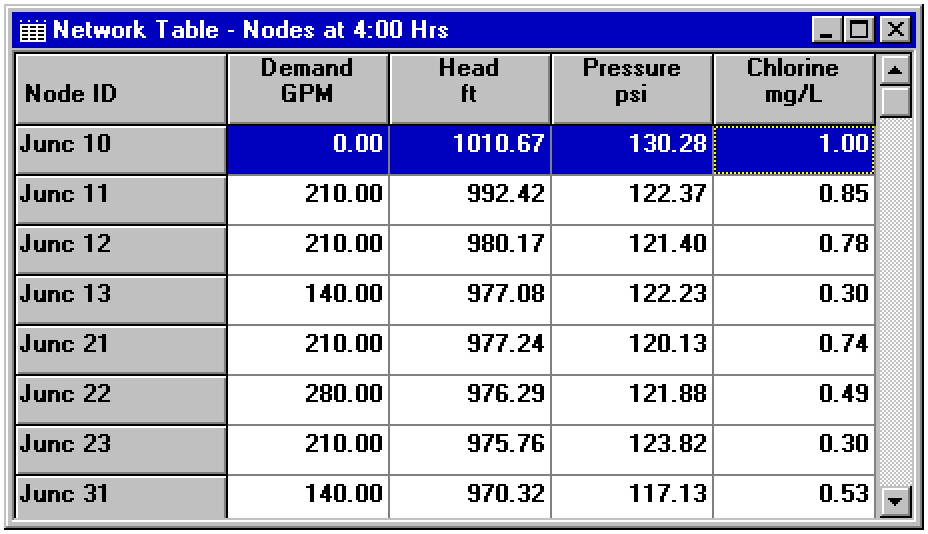
EPANET allows you to view selected project data and analysis results in a tabular format:

- A Network Table lists properties and results for all nodes or links at a specific period of time.
- A Time Series Table lists properties and results for a specific node or link in all time periods.

Tables can be printed, copied to the Windows clipboard, or saved to file. An example table is shown in Figure 9.6.

To create a table:

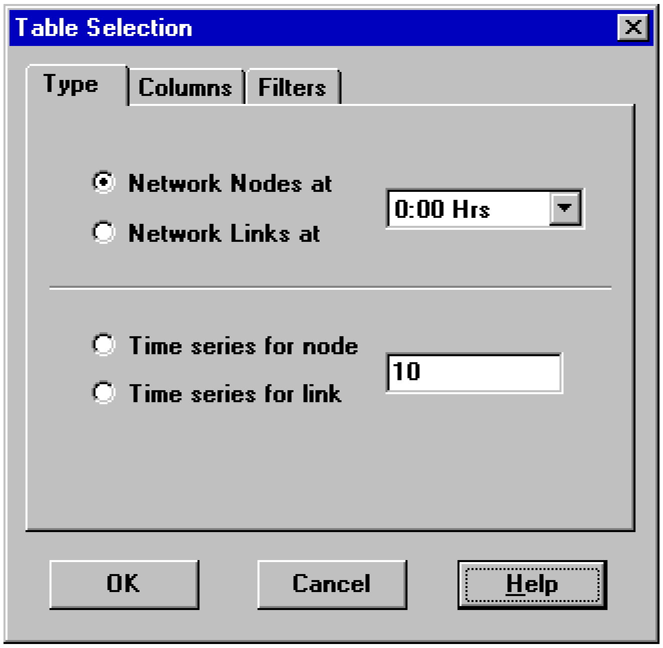
1. Select **View** >> **Table** or click on the Standard Toolbar.
2. Use the Table Options dialog box that appears to select:
    - the type of table
    - the quantities to display in each column
    - any filters to apply to the data



Node ID	Demand GPM	Head ft	Pressure psi	Chlorine mg/L
Junc 10	0.00	1010.67	130.28	1.00
Junc 11	210.00	992.42	122.37	0.85
Junc 12	210.00	980.17	121.40	0.78
Junc 13	140.00	977.08	122.23	0.30
Junc 21	210.00	977.24	120.13	0.74
Junc 22	280.00	976.29	121.88	0.49
Junc 23	210.00	975.76	123.82	0.30
Junc 31	140.00	970.32	117.13	0.53

Figure 9.6 Example Network Nodes Table

The Table Options dialog form has three tabbed pages as shown in Figure 9.7. All three pages are available when a table is first created. After the table is created, only the Columns and Filters tabs will appear. The options available on each page are as follows:



● Network Nodes at

○ Network Links at

0:00 Hrs

○ Time series for node

○ Time series for link

10

Figure 9.7 Table Selection Dialog

Type Page

The Type page of the Table Options dialog is used to select the type of table to create. The choices are:

- All network nodes at a specific time period
- All network links at a specific time period
- All time periods for a specific node
- All time periods for a specific link

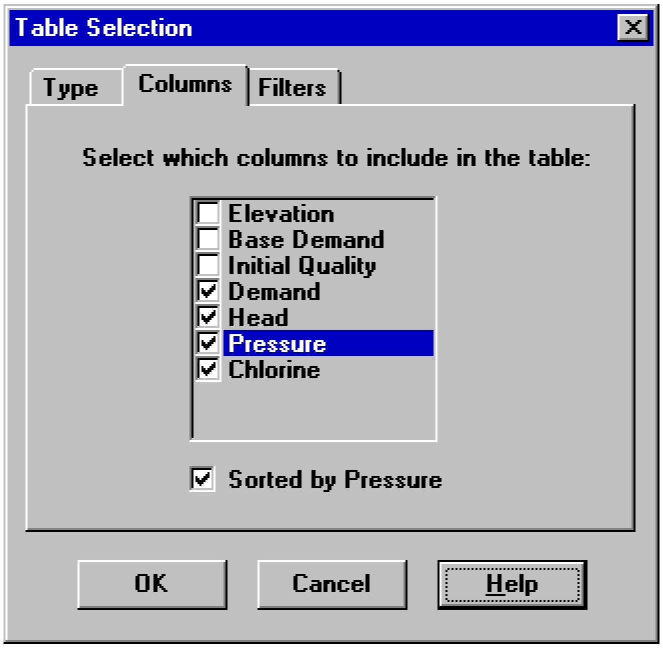
Data fields are available for selecting the time period or node/link to which the table applies.

Columns Page

The Columns page of the Table Options dialog form (Figure 9.8) selects the parameters that are displayed in the table's columns.

- Click the checkbox next to the name of each parameter you wish to include in the table, or if the item is already selected, click in the box to deselect it. (The keyboard's Up and Down Arrow keys can be used to move between the parameter names, and the spacebar can be used to select/deselect choices).

- To sort a Network-type table with respect to the values of a particular parameter, select the parameter from the list and check off the **Sorted By** box at the bottom of the form. (The sorted parameter does not have to be selected as one of the columns in the table.) Time Series tables cannot be sorted.



Select which columns to include in the table:

☐ Elevation
☐ Base Demand
☐ Initial Quality
☑ Demand
☑ Head
☑ Pressure
☑ Chlorine

☑ Sorted by Pressure

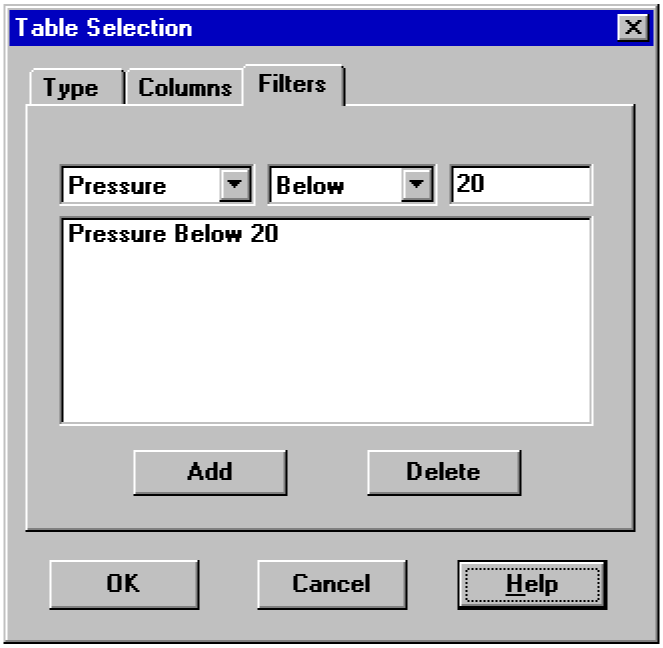
Figure 9.8 Columns Page of the Table Selection Dialog

Filters Page

The Filters page of the Table Options dialog form (Figure 9.9) is used to define conditions for selecting items to appear in a table. To filter the contents of a table:

- Use the controls at the top of the page to create a condition (e.g., Pressure Below 20).
- Click the **Add** button to add the condition to the list.
- Use the **Delete** button to remove a selected condition from the list.

Multiple conditions used to filter the table are connected by AND's. If a table has been filtered, a re-sizeable panel will appear at the bottom indicating how many items have satisfied the filter conditions.



Pressure | Below | 20

Pressure Below 20

Figure 9.9 Filters Page of the Table Selection Dialog

Once a table has been created you can add/delete columns or sort or filter its data:

- Select **Report** >> **Options** or click on the Standard Toolbar or right-click on the table.
- Use the Columns and Filters pages of the Table Selection dialog form to modify your table.

9.4 Viewing Special Reports

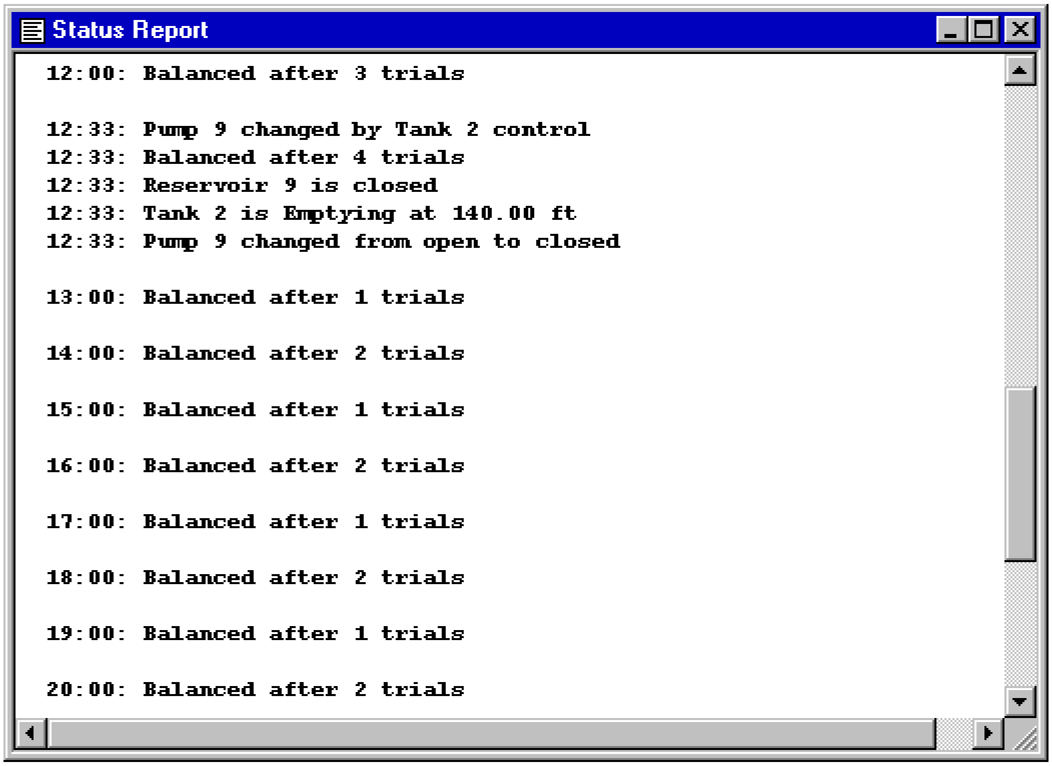
In addition to graphs and tables, EPANET can generate several other specialized reports. These include:

- Status Report
- Energy Report
- Calibration Report
- Reaction Report
- Full Report

All of these reports can be printed, copied to a file, or copied to the Windows clipboard (the Full Report can only be saved to file.)

Status Report

EPANET writes all error and warning messages generated during an analysis to a Status Report (see Figure 9.10). Additional information on when network objects change status is also written to this report if the Status Report option in the project's Hydraulics Options was set to Yes or Full. To view a status report on the most recently completed analysis select **Report** >> **Status** from the main menu.

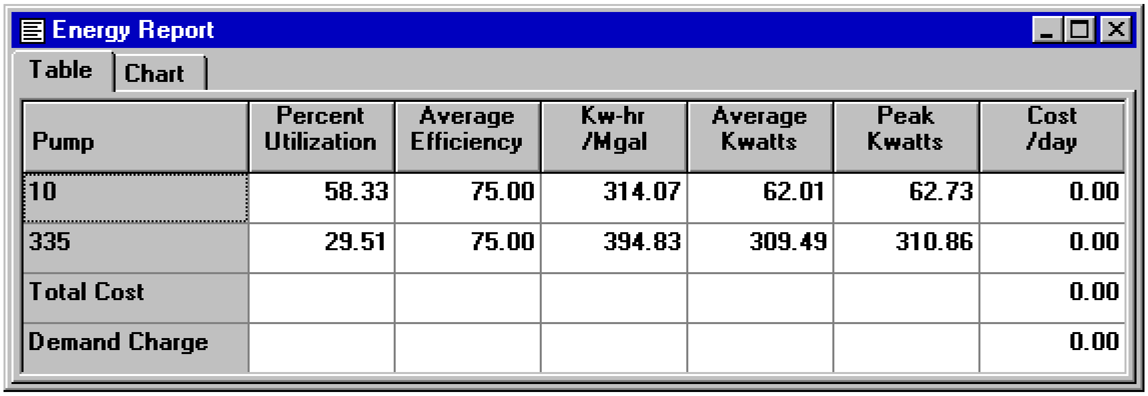


```
12:00: Balanced after 3 trials

12:33: Pump 9 changed by Tank 2 control
12:33: Balanced after 4 trials
12:33: Reservoir 9 is closed
12:33: Tank 2 is Emptying at 140.00 ft
12:33: Pump 9 changed from open to closed

13:00: Balanced after 1 trials

14:00: Balanced after 2 trials

15:00: Balanced after 1 trials

16:00: Balanced after 2 trials

17:00: Balanced after 1 trials

18:00: Balanced after 2 trials

19:00: Balanced after 1 trials

20:00: Balanced after 2 trials
```

Figure 9.10 Excerpt from a Status Report

Energy Report

EPANET can generate an Energy Report that displays statistics about the energy consumed by each pump and the cost of this energy usage over the duration of a simulation (see Figure 9.11). To generate an Energy Report select **Report** >> **Energy** from the main menu. The report has two tabbed pages. One displays energy usage by pump in a tabular format. The second compares a selected energy statistic between pumps using a bar chart.



Pump	Percent Utilization	Average Efficiency	Kw-hr /Mgal	Average Kwatts	Peak Kwatts	Cost /day
10	58.33	75.00	314.07	62.01	62.73	0.00
335	29.51	75.00	394.83	309.49	310.86	0.00
Total Cost						0.00
Demand Charge						0.00

Figure 9.11 Example Energy Report

Calibration Report

A Calibration Report can show how well EPANET's simulated results match measurements taken from the system being modeled. To create a Calibration Report:

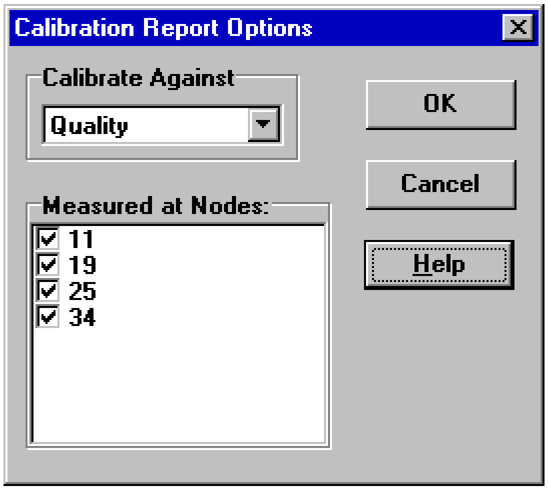
1. First make sure that Calibration Data for the quantity being calibrated has been registered with the project (see Section 5.3).
2. Select **Report** >> **Calibration** from the main menu.
3. In the Calibration Report Options form that appears (see Figure 9.12):
    - select a parameter to calibrate against
    - select the measurement locations to use in the report
4. Click **OK** to create the report.

After the report is created the Calibration Report Options form can be recalled to change report options by selecting **Report** >> **Options** or by clicking on the Standard Toolbar when the report is the current active window in EPANET's workspace.

A sample Calibration Report is shown in Figure 9.13. It contains three tabbed pages: Statistics, Correlation Plot, and Mean Comparisons.

Statistics Page

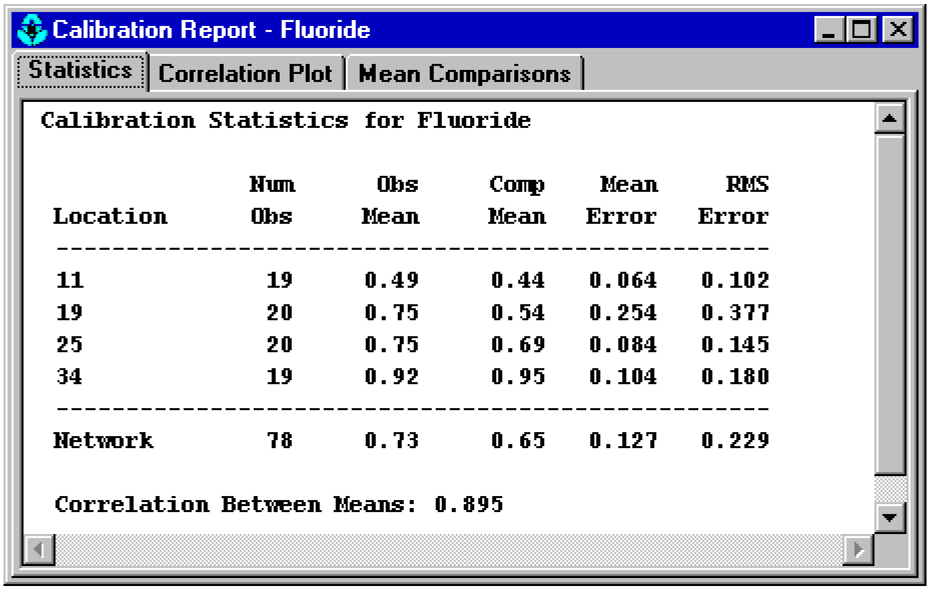
The Statistics page of a Calibration Report lists various error statistics between simulated and observed values at each measurement location and for the network as a whole. If a measured value at a location was taken at a time in-between the simulation's reporting time intervals then a simulated value for that time is found by interpolating between the simulated values at either end of the interval.



Calibrate Against: Quality

Measured at Nodes:
☑ 11
☑ 19
☑ 25
☑ 34

Figure 9.12 Calibration Report Options Dialog



```
Calibration Statistics for Fluoride

                  Num      Obs      Comp     Mean     RMS
 Location         Obs     Mean      Mean    Error   Error
 ---------------------------------------------------------
 11                19     0.49      0.44    0.064   0.102
 19                20     0.75      0.54    0.254   0.377
 25                20     0.75      0.69    0.084   0.145
 34                19     0.92      0.95    0.104   0.180
 ---------------------------------------------------------
 Network           78     0.73      0.65    0.127   0.229

 Correlation Between Means: 0.895
```

Figure 9.13 Example Calibration Report

The statistics listed for each measurement location are:

- Number of observations
- Mean of the observed values
- Mean of the simulated values
- Mean absolute error between each observed and simulated value
- Root mean square error (square root of the mean of the squared errors between the observed and simulated values).

These statistics are also provided for the network as a whole (i.e., all measurements and model errors pooled together). Also listed is the correlation between means (correlation coefficient between the mean observed value and mean simulated value at each location).

Correlation Plot Page

The Correlation Plot page of a Calibration Report displays a scatter plot of the observed and simulated values for each measurement made at each location. Each location is assigned a different color in the plot. The closer that the points come to the 45-degree angle line on the plot the closer is the match between observed and simulated values.

Mean Comparisons Page

The Mean Comparisons page of a Calibration Report presents a bar chart that compares the mean observed and mean simulated value for a calibration parameter at each location where measurements were taken.

Reaction Report

A Reaction Report, available when modeling the fate of a reactive water quality constituent, graphically depicts the overall average reaction rates occurring throughout the network in the following locations:

- the bulk flow
- the pipe wall
- within storage tanks.

A pie chart shows what percent of the overall reaction rate is occurring in each location. The chart legend displays the average rates in mass units per hour. A footnote on the chart shows the inflow rate of the reactant into the system.

The information in the Reaction Report can show at a glance what mechanism is responsible for the majority of growth or decay of a substance in the network. For example, if one observes that most of the chlorine decay in a system is occurring in the storage tanks and not at the walls of the pipes then one might infer that a corrective strategy of pipe cleaning and replacement will have little effect in improving chlorine residuals.

A Graph Options dialog box can be called up to modify the appearance of the pie chart by selecting **Report >> Options** or by clicking ▤ on the Standard Toolbar, or by right-clicking anywhere on the chart.

Full Report

When the 🚰 icon appears in the Run Status section of the Status Bar, a report of computed results for all nodes, links and time periods can be saved to file by selecting **Full** from the **Report** menu. This report, which can be viewed or printed outside of EPANET using any text editor or word processor, contains the following information:

- project title and notes
- a table listing the end nodes, length, and diameter of each link
- a table listing energy usage statistics for each pump
- a pair of tables for each time period listing computed values for each node (demand, head, pressure, and quality) and for each link (flow, velocity, headloss, and status).

This feature is useful mainly for documenting the final results of a network analysis on small to moderately sized networks (full report files for large networks analyzed over many time periods can easily consume dozens of megabytes of disk space). The other reporting tools described in this chapter are available for viewing computed results on a more selective basis.

CHAPTER 10 - PRINTING AND COPYING

This chapter describes how to print, copy to the Windows clipboard, or copy to file the contents of the currently active window in the EPANET workspace. This can include the network map, a graph, a table, a report, or the properties of an object selected from the Browser.

10.1 Selecting a Printer

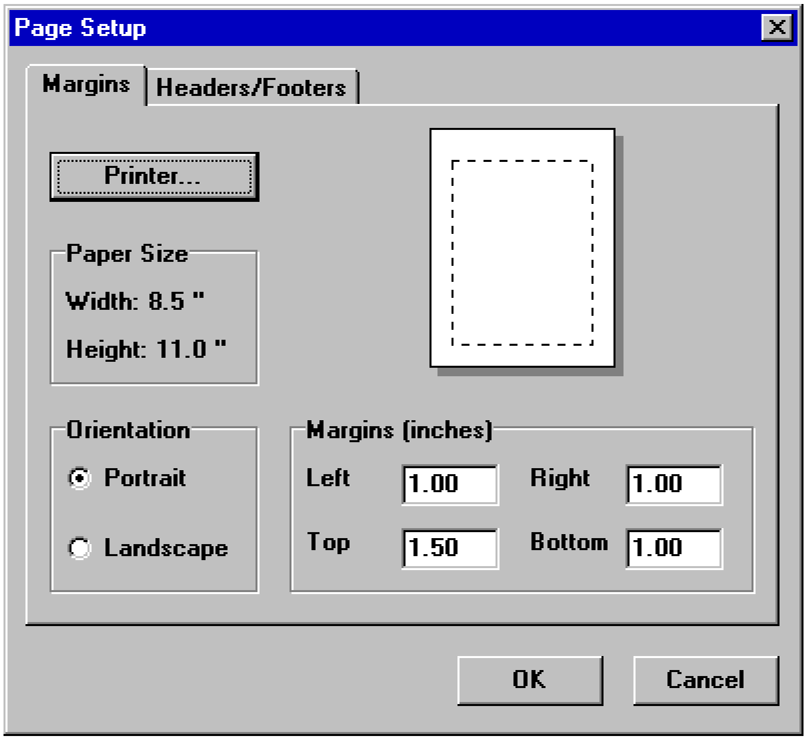
To select a printer from among your installed Windows printers and set its properties:

1. Select **File** >> **Page Setup** from the main menu.
2. Click the **Printer** button on the Page Setup dialog that appears (see Figure 10.1).
3. Select a printer from the choices available in the combo box in the next dialog that appears.
4. Click the **Properties** button to select the printer's properties (which vary with choice of printer).
5. Click **OK** on each dialog box to accept your selections.

10.2 Setting the Page Format

To format the printed page:

1. Select **File** >> **Page Setup** from the main menu.
2. Use the Margins page of the Page Setup dialog form that appears (Figure 10.1) to:
    - Select a printer
    - Select the paper orientation (Portrait or Landscape)
    - Set left, right, top, and bottom margins
3. Use the Headers/Footers page of the dialog box to:
    - Supply the text for a header that will appear on each page
    - Indicate whether the header should be printed or not
    - Supply the text for a footer that will appear on each page
    - Indicate whether the footer should be printed or not
    - Indicate whether or not pages should be numbered
4. Click **OK** to accept your choices.



Paper Size
Width: 8.5 "
Height: 11.0 "

Orientation
● Portrait
○ Landscape

Margins (inches)
Left 1.00
Right 1.00
Top 1.50
Bottom 1.00

Figure 10.1 Page Setup Dialog

10.3 Print Preview

To preview a printout, select **File** >> **Print Preview** from the main menu. A Preview form will appear which shows how each page of the object being printed will appear when printed.

10.4 Printing the Current View

To print the contents of the current window being viewed in the EPANET workspace select **File** >> **Print** from the main menu or click 🖨 on the Standard Toolbar. The following views can be printed:

- Data Browser (properties of the currently selected object)
- Network Map (at the current zoom level)
- Graphs (Time Series, Profile, Contour, Frequency and System Flow plots)
- Tables (Network and Time Series tables)
- Status, Energy, Calibration, and Reaction Reports.

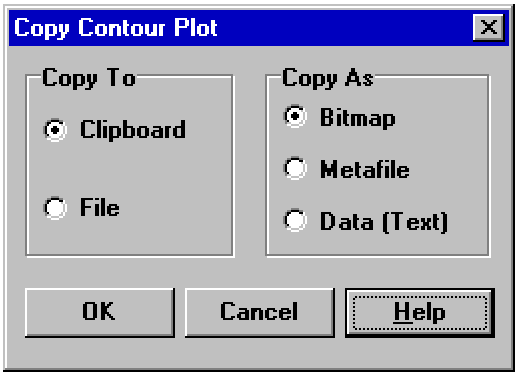
10.5 Copying to the Clipboard or to a File

EPANET can copy the text and graphics of the current window being viewed to both the Windows clipboard and to a file. Views that can be copied in this fashion include the Network Map, graphs, tables, and reports. To copy the current view to the clipboard or to file:

1. Select **Edit >> Copy To** from the main menu or click 📋.
2. Select choices from the Copy dialog that appears (see Figure 10.2) and click its **OK** button.
3. If you selected to copy-to-file, enter the name of the file in the Save As dialog box that appears and click **OK**.

Use the Copy dialog as follows to define how you want your data copied and to where:

1. Select a destination for the material being copied (Clipboard or File)
2. Select a format to copy in:
   - Bitmap (graphics only)
   - Metafile (graphics only)
   - Data (text, selected cells in a table, or data used to construct a graph)
3. Click **OK** to accept your selections or **Cancel** to cancel the copy request.



Copy Contour Plot

Copy To
● Clipboard
○ File

Copy As
● Bitmap
○ Metafile
○ Data (Text)

Figure 10.2 Copy Dialog

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CHAPTER 11 - IMPORTING AND EXPORTING

This chapter introduces the concept of Project Scenarios and describes how EPANET can import and export these and other data, such as the network map and the entire project database.

11.1 Project Scenarios

A Project Scenario consists of a subset of the data that characterizes the current conditions under which a pipe network is being analyzed. A scenario can consist of one or more of the following data categories:

- Demands (baseline demand plus time patterns for all categories) at all nodes
- Initial water quality at all nodes
- Diameters for all pipes
- Roughness coefficients for all pipes
- Reaction coefficients (bulk and wall) for all pipes
- Simple and rule-based controls

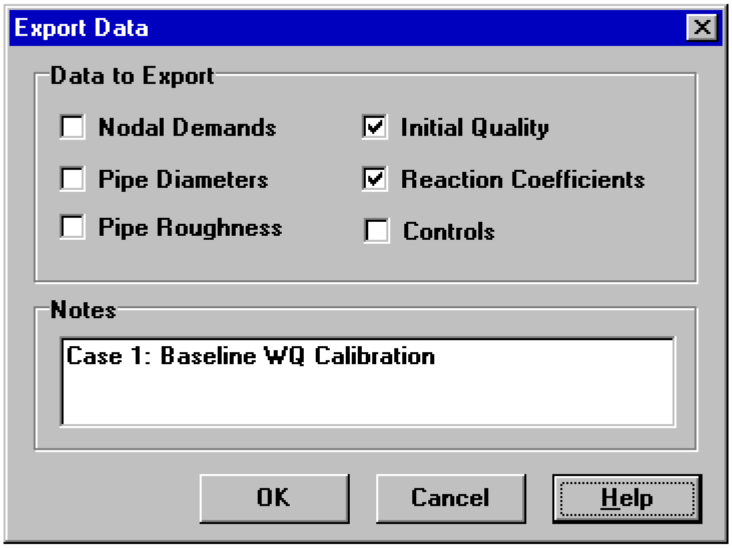
EPANET can compile a scenario based on some or all of the data categories listed above, save the scenario to file, and read the scenario back in at a later time.

Scenarios can provide more efficient and systematic analysis of design and operating alternatives. They can be used to examine the impacts of different loading conditions, search for optimal parameter estimates, and evaluate changes in operating policies. The scenario files are saved as ASCII text and can be created or modified outside of EPANET using a text editor or spreadsheet program.

11.2 Exporting a Scenario

To export a project scenario to a text file:

1. Select **File** >> **Export** >> **Scenario** from the main menu.
2. In the Export Data dialog form that appears (see Figure 11.1) select the types of data that you wish to save.
3. Enter an optional description of the scenario you are saving in the Notes memo field.
4. Select the **OK** button to accept your choices.
5. In the Save dialog box that next appears select a folder and name for the scenario file. Scenario files use the default extension .SCN.
6. Click **OK** to complete the export.



☐ Nodal Demands
☑ Initial Quality
☐ Pipe Diameters
☑ Reaction Coefficients
☐ Pipe Roughness
☐ Controls

Notes: Case 1: Baseline WQ Calibration

Figure 11.1 Export Data Dialog

The exported scenario can be imported back into the project at a later time as described in the next section.

11.3 Importing a Scenario

To import a project scenario from a file:

1. Select **File** >> **Import** >> **Scenario** from the main menu.
2. Use the Open File dialog box that appears to select a scenario file to import. The dialog's Contents panel will display the first several lines of files as they are selected, to help locate the desired file.
3. Click the **OK** button to accept your selection.

The data contained in the scenario file will replace any existing of the same kind in the current project.

11.4 Importing a Partial Network

EPANET has the ability to import a geometric description of a pipe network in a simple text format. This description simply contains the ID labels and map coordinates of the nodes and the ID labels and end nodes of the links. This simplifies the process of using other programs, such as CAD and GIS packages, to digitize network geometric data and then transfer these data to EPANET.

The format of a partial network text file looks as follows, where the text between brackets (< >) describes what type of information appears in that line of the file:

`[TITLE]`
<optional description of the file>

`[JUNCTIONS]`
<ID label of each junction>

`[PIPES]`
<ID label of each pipe followed by the ID labels of its end junctions>

`[COORDINATES]`
<Junction ID and its X and Y coordinates>

`[VERTICES]`
<Pipe ID and the X and Y coordinates of an intermediate vertex point>

Note that only junctions and pipes are represented. Other network elements, such as reservoirs and pumps, can either be imported as junctions or pipes and converted later on or simply be added in later on. The user is responsible for transferring any data generated from a CAD or GIS package into a text file with the format shown above.

In addition to this partial representation, a complete specification of the network can be placed in a file using the format described in Appendix C. This is the same format EPANET uses when a project is exported to a text file (see Section 11.7 below). In this case the file would also contain information on node and link properties, such as elevations, demands, diameters, roughness, etc.

11.5 Importing a Network Map

To import the coordinates for a network map stored in a text file:

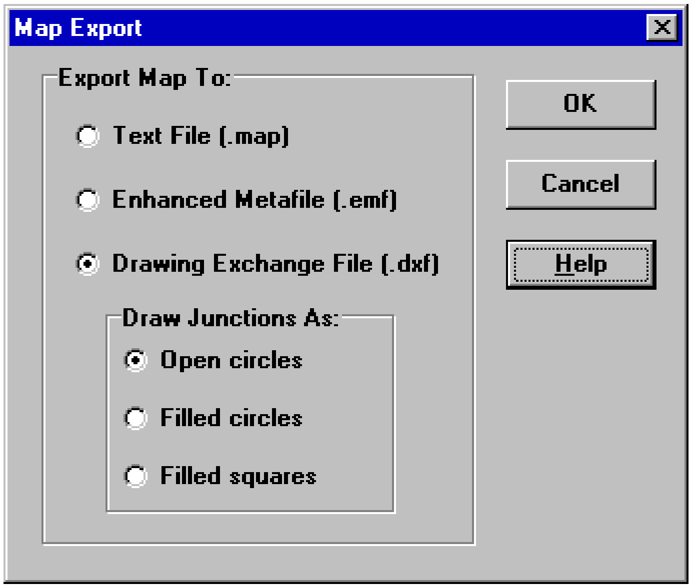
1. Select **File >> Import >> Map** from the main menu.
2. Select the file containing the map information from the Open File dialog that appears.
3. Click **OK** to replace the current network map with the one described in the file.

11.6 Exporting the Network Map

The current view of the network map can be saved to file using either Autodesk's DXF (Drawing Exchange Format) format, the Windows enhanced metafile (EMF) format, or EPANET's own ASCII text (map) format. The DXF format is readable by many Computer Aided Design (CAD) programs. Metafiles can be inserted into word processing documents and loaded into drawing programs for re-scaling and editing. Both formats are vector-based and will not loose resolution when they are displayed at different scales.

To export the network map at full extent to a DXF, metafile, or text file:

1. Select **File** >> **Export** >> **Map** from the main menu.
2. In the Map Export dialog form that appears (see Figure 11.2) select the format that you want the map saved in.
3. If you select DXF format, you have a choice of how junctions will be represented in the DXF file. They can be drawn as open circles, as filled circles, or as filled squares. Not all DXF readers can recognize the commands used in the DXF file to draw a filled circle.
4. After choosing a format, click OK and enter a name for the file in the Save As dialog form that appears.



Map Export

Export Map To:

○ Text File (.map)

○ Enhanced Metafile (.emf)

● Drawing Exchange File (.dxf)

Draw Junctions As:

● Open circles

○ Filled circles

○ Filled squares

Figure 11.2 Map Export Dialog

11.7 Exporting to a Text File

To export a project's data to a text file:

1. Select **File** >> **Export** >> **Network** from the main menu.
2. In the Save dialog form that appears enter a name for the file to save to (the default extension is .INP).
3. Click **OK** to complete the export.

The resulting file will be written in ASCII text format, with the various data categories and property labels clearly identified. It can be read back into EPANET for analysis at another time by using either the **File >> Open** or **File >> Import >> Network** commands. Complete network descriptions using this input format can also be created outside of EPANET using any text editor or spreadsheet program. A complete specification of the .INP file format is given in Appendix C.

It is a good idea to save an archive version of your database in this format so you have access to a human readable version of your data. However, for day-to-day use of EPANET it is more efficient to save your data using EPANET's special project file format (that creates a .NET file) by using the **File >> Save** or **File >> Save As** commands. This format contains additional project information, such as the colors and ranges chosen for the map legends, the set of map display options in effect, the names of registered calibration data files, and any printing options that were selected.

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CHAPTER 12 - FREQUENTLY ASKED QUESTIONS

How can I import a pipe network created with a CAD or GIS program?

See Section 11.4.

How do I model a groundwater pumping well?

Represent the well as a reservoir whose head equals the piezometric head of the groundwater aquifer. Then connect your pump from the reservoir to the rest of the network. You can add piping ahead of the pump to represent local losses around the pump.

If you know the rate at which the well is pumping then an alternate approach is to replace the well – pump combination with a junction assigned a negative demand equal to the pumping rate. A time pattern can also be assigned to the demand if the pumping rate varies over time.

How do I size a pump to meet a specific flow?

Set the status of the pump to CLOSED. At the suction (inlet) node of the pump add a demand equal to the required pump flow and place a negative demand of the same magnitude at the discharge node. After analyzing the network, the difference in heads between the two nodes is what the pump needs to deliver.

How do I size a pump to meet a specific head?

Replace the pump with a Pressure Breaker Valve oriented in the opposite direction. Convert the design head to an equivalent pressure and use this as the setting for the valve. After running the analysis the flow through the valve becomes the pump's design flow.

How can I enforce a specific schedule of source flows into the network from my reservoirs?

Replace the reservoirs with junctions that have negative demands equal to the schedule of source flows. (Make sure there is at least one tank or remaining reservoir in the network, otherwise EPANET will issue an error message.)

How can I analyze fire flow conditions for a particular junction node?

To determine the maximum pressure available at a node when the flow demanded must be increased to suppress a fire, add the fire flow to the node's normal demand, run the analysis, and note the resulting pressure at the node.

To determine the maximum flow available at a particular pressure, set the emitter coefficient at the node to a large value (e.g., 100 times the maximum expected flow) and add the required pressure head (2.3 times the pressure in psi) to the node's elevation. After running the analysis, the available fire flow equals the actual demand reported for the node minus any consumer demand that was assigned to it.

How do I model a reduced pressure backflow prevention valve?

Use a General Purpose Valve with a headloss curve that shows increasing head loss with decreasing flow. Information from the valve manufacturer should provide help in constructing the curve. Place a check valve (i.e., a short length of pipe whose status is set to CV) in series with the valve to restrict the direction of flow.

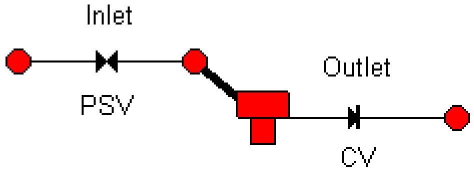
How do I model a pressurized pneumatic tank?

If the pressure variation in the tank is negligible, use a very short, very wide cylindrical tank whose elevation is set close to the pressure head rating of the tank. Select the tank dimensions so that changes in volume produce only very small changes in water surface elevation.

If the pressure head developed in the tank ranges between H1 and H2, with corresponding volumes V1 and V2, then use a cylindrical tank whose cross-sectional area equals (V2-V1)/(H2-H1).

How do I model a tank inlet that discharges above the water surface?

Use the configuration shown below:



The tank's inlet consists of a Pressure Sustaining Valve followed by a short length of large diameter pipe. The pressure setting of the PSV should be 0, and the elevation of its end nodes should equal the elevation at which the true pipe connects to the tank. Use a Check Valve on the tank's outlet line to prevent reverse flow through it.

How do I determine initial conditions for a water quality analysis?

If simulating existing conditions monitored as part of a calibration study, assign measured values to the nodes where measurements were made and interpolate (by eye) to assign values to other locations. It is highly recommended that storage tanks and source locations be included in the set of locations where measurements are made.

To simulate future conditions start with arbitrary initial values (except at the tanks) and run the analysis for a number of repeating demand pattern cycles so that the water quality results begin to repeat in a periodic fashion as well. The number of such cycles can be reduced if good initial estimates are made for the water quality in the tanks. For example, if modeling water age the initial value could be set to the tank's average residence time, which is approximately equal to the fraction of its volume it exchanges each day.

How do I estimate values of the bulk and wall reaction coefficients?

Bulk reaction coefficients can be estimated by performing a bottle test in the laboratory (see Bulk Reactions in Section 3.4). Wall reaction rates cannot be measured directly. They must be back-fitted against calibration data collected from field studies (e.g., using trial and error to determine coefficient values that produce simulation results that best match field observations). Plastic pipe and relatively new lined iron pipe are not expected to exert any significant wall demand for disinfectants such as chlorine and chloramines.

How can I model a chlorine booster station?

Place the booster station at a junction node with zero or positive demand or at a tank. Select the node into the Property Editor and click the ellipsis button in the Source Quality field to launch the Source Quality Editor. In the editor, set Source Type to SETPOINT BOOSTER and set Source Quality to the chlorine concentration that water leaving the node will be boosted to. Alternatively, if the booster station will use flow-paced addition of chlorine then set Source Type to FLOW PACED BOOSTER and Source Quality to the concentration that will be added to the concentration leaving the node. Specify a time pattern ID in the Time Pattern field if you wish to vary the boosting level with time.

How would I model THM growth in a network?

THM growth can be modeled using first-order saturation kinetics. Select Options – Reactions from the Data Browser. Set the bulk reaction order to 1 and the limiting concentration to the maximum THM level that the water can produce, given a long enough holding time. Set the bulk reaction coefficient to a positive number reflective of the rate of THM production (e.g., 0.7 divided by the THM doubling time). Estimates of the reaction coefficient and the limiting concentration can be obtained from laboratory testing. The reaction coefficient will increase with increasing water temperature. Initial concentrations at all network nodes should at least equal the THM concentration entering the network from its source node.

Can I use a text editor to edit network properties while running EPANET?

Save the network to file as ASCII text (select **File** >> **Export** >> **Network**). With EPANET still running, start up your text editor program. Load the saved network file into the editor. When you are done editing the file, save it to disk. Switch to EPANET and read in the file (select **File** >> **Open**). You can keep switching back and forth between the editor program and EPANET, as more changes are needed. Just remember to save the file after modifying it in the editor, and re-open it again after switching to EPANET. If you use a word processor (such as WordPad) or a spreadsheet as your editor, remember to save the file as plain ASCII text.

Can I run multiple EPANET sessions at the same time?

Yes. This could prove useful in making side-by-side comparisons of two or more different design or operating scenarios.

APPENDIX A - UNITS OF MEASUREMENT

PARAMETER	*US CUSTOMARY*	*SI METRIC*
Concentration	mg/L or μg/L	mg/L or μg/L
Demand	(see Flow units)	(see Flow units)
Diameter (Pipes)	inches	millimeters
Diameter (Tanks)	feet	meters
Efficiency	percent	percent
Elevation	feet	meters
Emitter Coefficient	flow units / $(\text{psi})^{1/2}$	flow units / $(\text{meters})^{1/2}$
Energy	kilowatt - hours	kilowatt - hours
Flow	CFS (cubic feet / sec) GPM (gallons / min) MGD (million gal / day) IMGD (Imperial MGD) AFD (acre-feet / day)	LPS (liters / sec) LPM (liters / min) MLD (megaliters / day) CMH (cubic meters / hr) CMD (cubic meters / day)
Friction Factor	unitless	unitless
Hydraulic Head	feet	meters
Length	feet	meters
Minor Loss Coeff.	unitless	unitless
Power	horsepower	kilowatts
Pressure	pounds per square inch	meters
Reaction Coeff. (Bulk)	1/day (1st-order)	1/day (1st-order)
Reaction Coeff. (Wall)	mass / L / day (0-order) ft / day (1st-order)	mass / L / day (0-order) meters / day (1st-order)
Roughness Coefficient	10^{-3} feet (Darcy-Weisbach), unitless otherwise	millimeters (Darcy-Weisbach), unitless otherwise
Source Mass Injection	mass / minute	mass / minute
Velocity	feet / second	meters / second
Volume	cubic feet	cubic meters
Water Age	hours	hours

Note: US Customary units apply when CFS, GPM, AFD, or MGD is chosen as flow units. SI Metric units apply when flow units are expressed using either liters or cubic meters.

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APPENDIX B - ERROR MESSAGES

ID	*Explanation*
101	An analysis was terminated due to insufficient memory available.
110	An analysis was terminated because the network hydraulic equations could not be solved. Check for portions of the network not having any physical links back to a tank or reservoir or for unreasonable values for network input data.
200	One or more errors were detected in the input data. The nature of the error will be described by the 200-series error messages listed below.
201	There is a syntax error in a line of the input file created from your network data. This is most likely to have occurred in .INP text created by a user outside of EPANET.
202	An illegal numeric value was assigned to a property.
203	An object refers to undefined node.
204	An object refers to an undefined link.
205	An object refers to an undefined time pattern.
206	An object refers to an undefined curve.
207	An attempt is made to control a check valve. Once a pipe is assigned a Check Valve status with the Property Editor, its status cannot be changed by either simple or rule-based controls.
208	Reference was made to an undefined node. This could occur in a control statement for example.
209	An illegal value was assigned to a node property.
210	Reference was made to an undefined link. This could occur in a control statement for example.
211	An illegal value was assigned to a link property.
212	A source tracing analysis refers to an undefined trace node.
213	An analysis option has an illegal value (an example would be a negative time step value).
214	There are too many characters in a line read from an input file. The lines in the .INP file are limited to 255 characters.
215	Two or more nodes or links share the same ID label.
216	Energy data were supplied for an undefined pump.
217	Invalid energy data were supplied for a pump.
219	A valve is illegally connected to a reservoir or tank. A PRV, PSV or FCV cannot be directly connected to a reservoir or tank. Use a length of pipe to separate the two.

220	A valve is illegally connected to another valve. PRVs cannot share the same downstream node or be linked in series, PSVs cannot share the same upstream node or be linked in series, and a PSV cannot be directly connected to the downstream node of a PRV.
221	A rule-based control contains a misplaced clause.
223	There are not enough nodes in the network to analyze. A valid network must contain at least one tank/reservoir and one junction node.
224	There is not at least one tank or reservoir in the network.
225	Invalid lower/upper levels were specified for a tank (e.g., the lower lever is higher than the upper level).
226	No pump curve or power rating was supplied for a pump. A pump must either be assigned a curve ID in its Pump Curve property or a power rating in its Power property. If both properties are assigned then the Pump Curve is used.
227	A pump has an invalid pump curve. A valid pump curve must have decreasing head with increasing flow.
230	A curve has non-increasing X-values.
233	A node is not connected to any links.
302	The system cannot open the temporary input file. Make sure that the EPANET Temporary Folder selected has write privileges assigned to it (see Section 4.9).
303	The system cannot open the status report file. See Error 302.
304	The system cannot open the binary output file. See Error 302.
308	Could not save results to file. This can occur if the disk becomes full.
309	Could not write results to report file. This can occur if the disk becomes full.

APPENDIX C - COMMAND LINE EPANET

C.1 General Instructions

EPANET can also be run as a console application from the command line within a DOS window. In this case network input data are placed into a text file and results are written to a text file. The command line for running EPANET in this fashion is:

```
epanet2d  inpfile  rptfile  outfile
```

Here `inpfile` is the name of the input file, `rptfile` is the name of the output report file, and `outfile` is the name of an optional binary output file that stores results in a special binary format. If the latter file is not needed then just the input and report file names should be supplied. As written, the above command assumes that you are working in the directory in which EPANET was installed or that this directory has been added to the PATH statement in your AUTOEXEC.BAT file. Otherwise full pathnames for the executable **epanet2d.exe** and the files on the command line must be used. The error messages for command line EPANET are the same as those for Windows EPANET and are listed in Appendix B.

C.2 Input File Format

The input file for command line EPANET has the same format as the text file that Windows EPANET generates from its **File** >> **Export** >> **Network** command. It is organized in sections, where each section begins with a keyword enclosed in brackets. The various keywords are listed below.

Network Components	*System Operation*	*Water Quality*	*Options and Reporting*	*Network Map/Tags*
[TITLE]	[CURVES]	[QUALITY]	[OPTIONS]	[COORDINATES]
[JUNCTIONS]	[PATTERNS]	[REACTIONS]	[TIMES]	[VERTICES]
[RESERVOIRS]	[ENERGY]	[SOURCES]	[REPORT]	[LABELS]
[TANKS]	[STATUS]	[MIXING]		[BACKDROP]
[PIPES]	[CONTROLS]			[TAGS]
[PUMPS]	[RULES]			
[VALVES]	[DEMANDS]			
[EMITTERS]				

The order of sections is not important. However, whenever a node or link is referred to in a section it must have already been defined in the [JUNCTIONS], [RESERVOIRS], [TANKS], [PIPES], [PUMPS], or [VALVES] sections. Thus it is recommended that these sections be placed first, right after the [TITLE] section. The network map and tags sections are not used by command line EPANET and can be eliminated from the file.

Each section can contain one or more lines of data. Blank lines can appear anywhere in the file and the semicolon (;) can be used to indicate that what follows on the line is a comment, not data. A maximum of 255 characters can appear on a line. The ID labels used to identify nodes, links, curves and patterns can be any combination of up to 15 characters and numbers.

Figure C.1 displays the input file that represents the tutorial network discussed in Chapter 2.

```
[TITLE]
EPANET TUTORIAL

[JUNCTIONS]
;ID   Elev   Demand
;------------------
2     0      0
3     710    650
4     700    150
5     695    200
6     700    150

[RESERVOIRS]
;ID   Head
;---------
1     700

[TANKS]
;ID  Elev  InitLvl  MinLvl  MaxLvl  Diam  Volume
;-----------------------------------------------
7    850   5        0       15      70    0

[PIPES]
;ID  Node1  Node2  Length  Diam  Roughness
;-----------------------------------------
1    2      3      3000    12    100
2    3      6      5000    12    100
3    3      4      5000    8     100
4    4      5      5000    8     100
5    5      6      5000    8     100
6    6      7      7000    10    100

[PUMPS]
;ID  Node1  Node2  Parameters
;---------------------------------
7    1      2      HEAD 1
```

Figure C.1 Example EPANET Input File (continued on next page)

```
[PATTERNS]
;ID   Multipliers
;-----------------------
1       0.5  1.3  1  1.2
[CURVES]
;ID  X-Value  Y-Value
;--------------------
1    1000     200

[QUALITY]
;Node InitQual
;-------------
1     1

[REACTIONS]
Global Bulk  -1
Global Wall  0

[TIMES]
Duration           24:00
Hydraulic Timestep 1:00
Quality Timestep   0:05
Pattern Timestep   6:00

[REPORT]
Page      55
Energy    Yes
Nodes     All
Links     All

[OPTIONS]
Units             GPM
Headloss          H-W
Pattern           1
Quality           Chlorine mg/L
Tolerance         0.01

[END]
```

Figure C.1 Example EPANET Input File (continued from previous page)

On the pages that follow the contents and formats of each keyword section are described in alphabetical order.

[BACKDROP]

Purpose:

Identifies a backdrop image and dimensions for the network map.

Formats:

DIMENSIONS	*LLx LLy URx URy*
UNITS	**FEET/METERS/DEGREES/NONE**
FILE	*filename*
OFFSET	*X Y*

Definitions:

DIMENSIONS provides the X and Y coordinates of the lower-left and upper-right corners of the map's bounding rectangle. Defaults are the extents of the nodal coordinates supplied in the [COORDINATES] section.

UNITS specifies the units that the map's dimensions are given in. Default is NONE.

FILE is the name of the file that contains the backdrop image.

OFFSET lists the X and Y distance that the upper-left corner of the backdrop image is offset from the upper-left corner of the map's bounding rectangle. Default is zero offset.

Remarks:

a. The [BACKDROP] section is optional and is not used at all when EPANET is run as a console application.

b. Only Windows Enhanced Metafiles and bitmap files can be used as backdrops.

[CONTROLS]

Purpose:

Defines simple controls that modify links based on a single condition.

Format:

One line for each control which can be of the form:

```
LINK linkID status IF NODE nodeID ABOVE/BELOW value
LINK linkID status AT TIME time
LINK linkID status AT CLOCKTIME clocktime AM/PM
```

where:

`linkID` = a link ID label

`status` = OPEN or CLOSED, a pump speed setting, or a control valve setting

`nodeID` = a node ID label

`value` = a pressure for a junction or a water level for a tank

`time` = a time since the start of the simulation in decimal hours or in hours:minutes format

`clocktime` = a 24-hour clock time (hours:minutes)

Remarks:

a. Simple controls are used to change link status or settings based on tank water level, junction pressure, time into the simulation or time of day.

b. See the notes for the [STATUS] section for conventions used in specifying link status and setting, particularly for control valves.

Examples:

```
[CONTROLS]
;Close Link 12 if the level in Tank 23 exceeds 20 ft.
LINK 12 CLOSED IF NODE 23 ABOVE 20

;Open Link 12 if pressure at Node 130 is under 30 psi
LINK 12 OPEN IF NODE 130 BELOW 30

;Pump PUMP02's speed is set to 1.5 at 16 hours into
;the simulation
LINK PUMP02 1.5 AT TIME 16

;Link 12 is closed at 10 am and opened at 8 pm
;throughout the simulation
LINK 12 CLOSED AT CLOCKTIME 10 AM
LINK 12 OPEN AT CLOCKTIME 8 PM
```

[COORDINATES]

Purpose:

Assigns map coordinates to network nodes.

Format:

One line for each node containing:

- Node ID label
- X-coordinate
- Y-coordinate

Remarks:

a. Include one line for each node displayed on the map.

b. The coordinates represent the distance from the node to an arbitrary origin at the lower left of the map. Any convenient units of measure for this distance can be used.

c. There is no requirement that all nodes be included in the map, and their locations need not be to actual scale.

d. A [COORDINATES] section is optional and is not used at all when EPANET is run as a console application.

Example:

```
[COORDINATES]
;Node        X-Coord.     Y-Coord
;-------------------------------
  1          10023        128
  2          10056        95
```

[CURVES]

Purpose:

Defines data curves and their X,Y points.

Format:

One line for each X,Y point on each curve containing:

- Curve ID label
- X value
- Y value

Remarks:

a. Curves can be used to represent the following relations:
  - Head v. Flow for pumps
  - Efficiency v. Flow for pumps
  - Volume v. Depth for tanks
  - Headloss v. Flow for General Purpose Valves

b. The points of a curve must be entered in order of increasing X-values (lower to higher).

c. If the input file will be used with the Windows version of EPANET, then adding a comment which contains the curve type and description, separated by a colon, directly above the first entry for a curve will ensure that these items appear correctly in EPANET's Curve Editor. Curve types include PUMP, EFFICIENCY, VOLUME, and HEADLOSS. See the examples below.

Example:

```
[CURVES]
;ID   Flow    Head
;PUMP: Curve for Pump 1
C1    0       200
C1    1000    100
C1    3000    0

;ID   Flow    Effic.
;EFFICIENCY:
E1    200     50
E1    1000    85
E1    2000    75
E1    3000    65
```

[DEMANDS]

Purpose:

Supplement to [JUNCTIONS] section for defining multiple water demands at junction nodes.

Format:

One line for each category of demand at a junction containing:

- Junction ID label
- Base demand (flow units)
- Demand pattern ID (optional)
- Name of demand category preceded by a semicolon (optional)

Remarks:

a. Only use for junctions whose demands need to be changed or supplemented from entries in [JUNCTIONS] section.

b. Data in this section replaces any demand entered in [JUNCTIONS] section for the same junction.

c. Unlimited number of demand categories can be entered per junction.

a. If no demand pattern is supplied then the junction demand follows the Default Demand Pattern specified in the [OPTIONS] section or Pattern 1 if no default pattern is specified. If the default pattern (or Pattern 1) does not exist, then the demand remains constant.

Example:

```
[DEMANDS]
;ID    Demand   Pattern    Category
;---------------------------------
J1     100       101     ;Domestic
J1     25        102     ;School
J256   50        101     ;Domestic
```

[EMITTERS]

Purpose:

Defines junctions modeled as emitters (sprinklers or orifices).

Format:

One line for each emitter containing:

- Junction ID label
- Flow coefficient, flow units at 1 psi (1 meter) pressure drop

Remarks:

a. Emitters are used to model flow through sprinkler heads or pipe leaks.

b. Flow out of the emitter equals the product of the flow coefficient and the junction pressure raised to a power.

c. The power can be specified using the EMITTER EXPONENT option in the [OPTIONS] section. The default power is 0.5, which normally applies to sprinklers and nozzles.

d. Actual demand reported in the program's results includes both the normal demand at the junction plus flow through the emitter.

e. An [EMITTERS] section is optional.

[ENERGY]

Purpose:

Defines parameters used to compute pumping energy and cost.

Formats:

```
GLOBAL          PRICE/PATTERN/EFFIC  value
PUMP   PumpID   PRICE/PATTERN/EFFIC  value
DEMAND CHARGE   value
```

Remarks:

c. Lines beginning with the keyword **`GLOBAL`** are used to set global default values of energy price, price pattern, and pumping efficiency for all pumps.

d. Lines beginning with the keyword **`PUMP`** are used to override global defaults for specific pumps.

e. Parameters are defined as follows:

- **`PRICE`** = average cost per kW-hour,
- **`PATTERN`** = ID label of time pattern describing how energy price varies with time,
- **`EFFIC`** = either a single percent efficiency for global setting or the ID label of an efficiency curve for a specific pump,
- **`DEMAND CHARGE`** = added cost per maximum kW usage during the simulation period.

f. The default global pump efficiency is 75% and the default global energy price is 0.

g. All entries in this section are optional. Items offset by slashes (/) indicate allowable choices.

Example:

```
[ENERGY]
GLOBAL PRICE      0.05   ;Sets global energy price
GLOBAL PATTERN    PAT1   ;and time-of-day pattern
PUMP   23  PRICE  0.10   ;Overrides price for Pump 23
PUMP   23  EFFIC  E23    ;Assigns effic. curve to Pump 23
```

[JUNCTIONS]

Purpose:

Defines junction nodes contained in the network.

Format:

One line for each junction containing:

- ID label
- Elevation, ft (m)
- Base demand flow (flow units) (optional)
- Demand pattern ID (optional)

Remarks:

b. A [JUNCTIONS] section with at least one junction is required.

c. If no demand pattern is supplied then the junction demand follows the Default Demand Pattern specified in the [OPTIONS] section or Pattern 1 if no default pattern is specified. If the default pattern (or Pattern 1) does not exist, then the demand remains constant.

d. Demands can also be entered in the [DEMANDS] section and include multiple demand categories per junction.

Example:

```
[JUNCTIONS]
;ID    Elev.   Demand   Pattern
;-------------------------------
J1    100      50       Pat1
J2    120      10              ;Uses default demand pattern
J3    115                      ;No demand at this junction
```

[LABELS]

Purpose:

Assigns coordinates to map labels.

Format:

One line for each label containing:

- X-coordinate
- Y-coordinate
- Text of label in double quotes
- ID label of an anchor node (optional)

Remarks:

a. Include one line for each label on the map.

b. The coordinates refer to the upper left corner of the label and are with respect to an arbitrary origin at the lower left of the map.

c. The optional anchor node anchors the label to the node when the map is re-scaled during zoom-in operations.

d. The [LABELS] section is optional and is not used at all when EPANET is run as a console application.

Example:

```
[LABELS]
;X-Coord.   Y-Coord.    Label              Anchor
;-----------------------------------------------
  1230      3459        “Pump 1”
  34.57     12.75       “North Tank”       T22
```

[MIXING]

Purpose:

Identifies the model that governs mixing within storage tanks.

Format:

One line per tank containing:

- Tank ID label
- Mixing model (MIXED, 2COMP, FIFO, or LIFO)
- Compartment volume (fraction)

Remarks:

a. Mixing models include:
   - Completely Mixed (MIXED)
   - Two-Compartment Mixing (2COMP)
   - Plug Flow (FIFO)
   - Stacked Plug Flow (LIFO)

b. The compartment volume parameter only applies to the two-compartment model and represents the fraction of the total tank volume devoted to the inlet/outlet compartment.

c. The [MIXING] section is optional. Tanks not described in this section are assumed to be completely mixed.

Example:

```
[MIXING]
;Tank      Model
;-----------------------
T12        LIFO
T23        2COMP     0.2
```

[OPTIONS]

Purpose:

Defines various simulation options.

Formats:

`UNITS`	`CFS/GPM/MGD/IMGD/AFD/` `LPS/LPM/MLD/CMH/CMD`
`HEADLOSS`	`H-W/D-W/C-M`
`HYDRAULICS`	`USE/SAVE` filename
`QUALITY`	`NONE/CHEMICAL/AGE/TRACE id`
`VISCOSITY`	value
`DIFFUSIVITY`	value
`SPECIFIC GRAVITY`	value
`TRIALS`	value
`ACCURACY`	value
`UNBALANCED`	`STOP/CONTINUE/CONTINUE n`
`PATTERN`	id
`DEMAND MULTIPLIER`	value
`EMITTER EXPONENT`	value
`TOLERANCE`	value
`MAP`	filename

Definitions:

UNITS sets the units in which flow rates are expressed where:

`CFS` = cubic feet per second

`GPM` = gallons per minute

`MGD` = million gallons per day

`IMGD` = Imperial MGD

`AFD` = acre-feet per day

`LPS` = liters per second

`LPM` = liters per minute

`MLD` = million liters per day

`CMH` = cubic meters per hour

`CMD` = cubic meters per day

For **`CFS, GPM, MGD, IMGD`**, and **`AFD`** other input quantities are expressed in US Customary Units. If flow units are in liters or cubic meters then Metric Units must be used for all other input quantities as well. (See Appendix A. Units of Measurement). The default flow units are **GPM**.

HEADLOSS selects a formula to use for computing head loss for flow through a pipe. The choices are the Hazen-Williams (**H-W**), Darcy-Weisbach (**D-W**), or Chezy-Manning (**C-M**) formulas. The default is **H-W**.

The **HYDRAULICS** option allows you to either **SAVE** the current hydraulics solution to a file or **USE** a previously saved hydraulics solution. This is useful when studying factors that only affect water quality behavior.

QUALITY selects the type of water quality analysis to perform. The choices are **NONE, CHEMICAL, AGE**, and **TRACE**. In place of **CHEMICAL** the actual name of the chemical can be used followed by its concentration units (e.g., **CHLORINE mg/L**). If **TRACE** is selected it must be followed by the ID label of the node being traced. The default selection is **NONE** (no water quality analysis).

VISCOSITY is the kinematic viscosity of the fluid being modeled relative to that of water at 20 deg. C (1.0 centistoke). The default value is 1.0.

DIFFUSIVITY is the molecular diffusivity of the chemical being analyzed relative to that of chlorine in water. The default value is 1.0. Diffusivity is only used when mass transfer limitations are considered in pipe wall reactions. A value of 0 will cause EPANET to ignore mass transfer limitations.

SPECIFIC GRAVITY is the ratio of the density of the fluid being modeled to that of water at 4 deg. C (unitless).

TRIALS are the maximum number of trials used to solve network hydraulics at each hydraulic time step of a simulation. The default is 40.

ACCURACY prescribes the convergence criterion that determines when a hydraulic solution has been reached. The trials end when the sum of all flow changes from the previous solution divided by the total flow in all links is less than this number. The default is 0.001.

UNBALANCED determines what happens if a hydraulic solution cannot be reached within the prescribed number of **TRIALS** at some hydraulic time step into the simulation. **"STOP"** will halt the entire analysis at that point. **"CONTINUE"** will continue the analysis with a warning message issued. **"CONTINUE n"** will continue the search for a solution for another "n" trials with the status of all links held fixed at their current settings. The simulation will be continued at this point with a message issued about whether convergence was achieved or not. The default choice is **"STOP"**.

PATTERN provides the ID label of a default demand pattern to be applied to all junctions where no demand pattern was specified. If no such pattern exists in the [PATTERNS] section then by default the pattern consists of a single multiplier equal to 1.0. If this option is not used, then the global default demand pattern has a label of "1".

The **DEMAND MULTIPLIER** is used to adjust the values of baseline demands for all junctions and all demand categories. For example, a value of 2 doubles all baseline demands, while a value of 0.5 would halve them. The default value is 1.0.

EMITTER EXPONENT specifies the power to which the pressure at a junction is raised when computing the flow issuing from an emitter. The default is 0.5.

MAP is used to supply the name of a file containing coordinates of the network's nodes so that a map of the network can be drawn. It is not used for any hydraulic or water quality computations.

`TOLERANCE` is the difference in water quality level below which one can say that one parcel of water is essentially the same as another. The default is 0.01 for all types of quality analyses (chemical, age (measured in hours), or source tracing (measured in percent)).

Remarks:

a. All options assume their default values if not explicitly specified in this section.

b. Items offset by slashes (/) indicate allowable choices.

Example:

```
[OPTIONS]
UNITS       CFS
HEADLOSS    D-W
QUALITY     TRACE  Tank23
UNBALANCED  CONTINUE  10
```

[PATTERNS]

Purpose:

Defines time patterns.

Format:

One or more lines for each pattern containing:

- Pattern ID label
- One or more multipliers

Remarks:

a. Multipliers define how some base quantity (e.g., demand) is adjusted for each time period.

a. All patterns share the same time period interval as defined in the [TIMES] section.

b. Each pattern can have a different number of time periods.

c. When the simulation time exceeds the pattern length the pattern wraps around to its first period.

d. Use as many lines as it takes to include all multipliers for each pattern.

Example:

```
[PATTERNS]
;Pattern P1
P1    1.1   1.4   0.9   0.7
P1    0.6   0.5   0.8   1.0
;Pattern P2
P2    1     1     1     1
P2    0     0     1
```

[PIPES]

Purpose:

Defines all pipe links contained in the network.

Format:

One line for each pipe containing:

- ID label of pipe
- ID of start node
- ID of end node
- Length, ft (m)
- Diameter, inches (mm)
- Roughness coefficient
- Minor loss coefficient
- Status (OPEN, CLOSED, or CV)

Remarks:

a. Roughness coefficient is unitless for the Hazen-Williams and Chezy-Manning head loss formulas and has units of millifeet (mm) for the Darcy-Weisbach formula. Choice of head loss formula is supplied in the [OPTIONS] section.

b. Setting status to CV means that the pipe contains a check valve restricting flow to one direction.

c. If minor loss coefficient is 0 and pipe is OPEN then these two items can be dropped form the input line.

Example:

```
[PIPES]
;ID   Node1  Node2   Length   Diam.  Roughness  Mloss    Status
;-------------------------------------------------------------
 P1    J1     J2     1200      12       120       0.2    OPEN
 P2    J3     J2      600       6       110       0      CV
 P3    J1     J10    1000      12       120
```

[PUMPS]

Purpose:

Defines all pump links contained in the network.

Format:

One line for each pump containing:

- ID label of pump
- ID of start node
- ID of end node
- Keyword and Value (can be repeated)

Remarks:

a. Keywords consists of:
  - **`POWER`** – power value for constant energy pump, hp (kW)
  - **`HEAD`** - ID of curve that describes head versus flow for the pump
  - **`SPEED`** - relative speed setting (normal speed is 1.0, 0 means pump is off)
  - **`PATTERN`** - ID of time pattern that describes how speed setting varies with time

b. Either **`POWER`** or **`HEAD`** must be supplied for each pump. The other keywords are optional.

Example:

```
[PUMPS]
;ID    Node1    Node2   Properties
;---------------------------------------------
Pump1   N12     N32     HEAD Curve1
Pump2   N121    N55     HEAD Curve1  SPEED 1.2
Pump3   N22     N23     POWER 100
```

[QUALITY]

Purpose:

Defines initial water quality at nodes.

Format:

One line per node containing:

- Node ID label
- Initial quality

Remarks:

a. Quality is assumed to be zero for nodes not listed.

b. Quality represents concentration for chemicals, hours for water age, or percent for source tracing.

c. The [QUALITY] section is optional.

[REACTIONS]

Purpose:

Defines parameters related to chemical reactions occurring in the network.

Formats:

`ORDER BULK/WALL/TANK`	value
`GLOBAL BULK/WALL`	value
`BULK/WALL/TANK`	pipeID value
`LIMITING POTENTIAL`	value
`ROUGHNESS CORRELATION`	value

Definitions:

`ORDER` is used to set the order of reactions occurring in the bulk fluid, at the pipe wall, or in tanks, respectively. Values for wall reactions must be either 0 or 1. If not supplied the default reaction order is 1.0.

`GLOBAL` is used to set a global value for all bulk reaction coefficients (pipes and tanks) or for all pipe wall coefficients. The default value is zero.

`BULK, WALL`, and **`TANK`** are used to override the global reaction coefficients for specific pipes and tanks.

`LIMITING POTENTIAL` specifies that reaction rates are proportional to the difference between the current concentration and some limiting potential value.

`ROUGHNESS CORRELATION` will make all default pipe wall reaction coefficients be related to pipe roughness in the following manner:

Head Loss Equation	Roughness Correlation
Hazen-Williams	F / C
Darcy-Weisbach	F / log(e/D)
Chezy-Manning	F*n

where F = roughness correlation, C = Hazen-Williams C-factor, e = Darcy-Weisbach roughness, D = pipe diameter, and n = Chezy-Manning roughness coefficient. The default value computed this way can be overridden for any pipe by using the **WALL** format to supply a specific value for the pipe.

Remarks:

a. Remember to use positive numbers for growth reaction coefficients and negative numbers for decay coefficients.

b. The time units for all reaction coefficients are 1/days.

c. All entries in this section are optional. Items offset by slashes (/) indicate allowable choices.

Example:

```
[REACTIONS]
ORDER WALL    0    ;Wall reactions are zero-order
GLOBAL BULK  -0.5  ;Global bulk decay coeff.
GLOBAL WALL  -1.0  ;Global wall decay coeff.
WALL   P220  -0.5  ;Pipe-specific wall coeffs.
WALL   P244  -0.7
```

[REPORT]

Purpose:

Describes the contents of the output report produced from a simulation.

Formats:

PAGESIZE	value	
FILE	filename	
STATUS	**YES/NO/FULL**	
SUMMARY	**YES/NO**	
ENERGY	**YES/NO**	
NODES	**NONE/ALL/**node1 node2 ...	
LINKS	**NONE/ALL/**link1 link2 ...	
parameter	**YES/NO**	
parameter	**BELOW/ABOVE/PRECISION**	value

Definitions:

PAGESIZE sets the number of lines written per page of the output report. The default is 0, meaning that no line limit per page is in effect.

FILE supplies the name of a file to which the output report will be written (ignored by the Windows version of EPANET).

STATUS determines whether a hydraulic status report should be generated. If **YES** is selected the report will identify all network components that change status during each time step of the simulation. If **FULL** is selected, then the status report will also include information from each trial of each hydraulic analysis. This level of detail is only useful for de-bugging networks that become hydraulically unbalanced. The default is **NO**.

SUMMARY determines whether a summary table of number of network components and key analysis options is generated. The default is **YES**.

ENERGY determines if a table reporting average energy usage and cost for each pump is provided. The default is NO.

NODES identifies which nodes will be reported on. You can either list individual node ID labels or use the keywords **NONE** or **ALL**. Additional **NODES** lines can be used to continue the list. The default is **NONE**.

LINKS identifies which links will be reported on. You can either list individual link ID labels or use the keywords **NONE** or **ALL**. Additional **LINKS** lines can be used to continue the list. The default is **NONE**.

The “parameter” reporting option is used to identify which quantities are reported on, how many decimal places are displayed, and what kind of filtering should be used to limit output reporting. Node parameters that can be reported on include:

- **`Elevation`**
- **`Demand`**
- **`Head`**
- **`Pressure`**
- **`Quality.`**

Link parameters include:

- **`Length`**
- **`Diameter`**
- **`Flow`**
- **`Velocity`**
- **`Headloss`**
- **`Position`** (same as status – open, active, closed)
- **`Setting`** (Roughness for pipes, speed for pumps, pressure/flow setting for valves)
- **`Reaction`** (reaction rate)
- **`F-Factor`** (friction factor).

The default quantities reported are **`Demand, Head, Pressure`**, and **`Quality`** for nodes and **`Flow, Velocity`**, and **`Headloss`** for links. The default precision is two decimal places.

Remarks:

a. All options assume their default values if not explicitly specified in this section.

b. Items offset by slashes (/) indicate allowable choices.

c. The default is to not report on any nodes or links, so a **NODES** or **LINKS** option must be supplied if you wish to report results for these items.

d. For the Windows version of EPANET, the only [REPORT] option recognized is **`STATUS`**. All others are ignored.

Example:

The following example reports on nodes N1, N2, N3, and N17 and all links with velocity above 3.0. The standard node parameters (Demand, Head, Pressure, and Quality) are reported on while only Flow, Velocity, and F-Factor (friction factor) are displayed for links.

```
[REPORT]
NODES N1 N2 N3 N17
LINKS ALL
FLOW YES
VELOCITY PRECISION 4
F-FACTOR PRECISION 4
VELOCITY ABOVE 3.0
```

[RESERVOIRS]

Purpose:

Defines all reservoir nodes contained in the network.

Format:

One line for each reservoir containing:

- ID label
- Head, ft (m)
- Head pattern ID (optional)

Remarks:

a. Head is the hydraulic head (elevation + pressure head) of water in the reservoir.

b. A head pattern can be used to make the reservoir head vary with time.

c. At least one reservoir or tank must be contained in the network.

Example:

```
[RESERVOIRS]
;ID    Head    Pattern
;---------------------
 R1    512             ;Head stays constant
 R2    120     Pat1    ;Head varies with time
```

[RULES]

Purpose:

Defines rule-based controls that modify links based on a combination of conditions.

Format:

Each rule is a series of statements of the form:

```
RULE ruleID
IF   condition_1
AND condition_2
OR   condition_3
AND condition_4
etc.
THEN action_1
AND   action_2
etc.
ELSE action_3
AND   action_4
etc.
PRIORITY value
```

where:

`ruleID` = an ID label assigned to the rule
`conditon_n` = a condition clause
`action_n` = an action clause
`Priority` = a priority value (e.g., a number from 1 to 5)

Condition Clause Format:

A condition clause in a Rule-Based Control takes the form of:

```
object id attribute relation value
```

where

`object` = a category of network object
`id` = the object's ID label
`attribute` = an attribute or property of the object
`relation` = a relational operator
`value` = an attribute value

Some example conditional clauses are:

```
JUNCTION 23 PRESSURE > 20
TANK T200 FILLTIME BELOW 3.5
LINK 44 STATUS IS OPEN
SYSTEM DEMAND >= 1500
SYSTEM CLOCKTIME = 7:30 AM
```

The Object keyword can be any of the following:

`NODE`	**`LINK`**	**`SYSTEM`**
`JUNCTION`	**`PIPE`**	
`RESERVOIR`	**`PUMP`**	
`TANK`	**`VALVE`**	

When **`SYSTEM`** is used in a condition no ID is supplied.

The following attributes can be used with Node-type objects:

`DEMAND`

`HEAD`

`PRESSURE`

The following attributes can be used with Tanks:

`LEVEL`

`FILLTIME` (hours needed to fill a tank)

`DRAINTIME` (hours needed to empty a tank)

These attributes can be used with Link-Type objects:

`FLOW`

`STATUS` (**`OPEN`**, **`CLOSED`**, or **`ACTIVE`**)

`SETTING` (pump speed or valve setting)

The **`SYSTEM`** object can use the following attributes:

`DEMAND` (total system demand)

`TIME` (hours from the start of the simulation expressed either as a decimal number or in hours:minutes format)

`CLOCKTIME` (24-hour clock time with **AM** or **PM** appended)

Relation operators consist of the following:

=	**IS**
<>	**NOT**
<	**BELOW**
>	**ABOVE**
<=	**>=**

Action Clause Format:

An action clause in a Rule-Based Control takes the form of:

```
object id STATUS/SETTING IS value
```

where

`object` = **`LINK`**, **`PIPE`**, **`PUMP`**, or **`VALVE`** keyword
`id` = the object's ID label
`value` = a status condition (**`OPEN`** or **`CLOSED`**), pump speed setting, or valve setting

Some example action clauses are:

```
LINK 23 STATUS IS CLOSED
PUMP P100 SETTING IS 1.5
VALVE 123 SETTING IS 90
```

Remarks:

a. Only the **`RULE, IF`** and **`THEN`** portions of a rule are required; the other portions are optional.

b. When mixing **`AND`** and **`OR`** clauses, the **`OR`** operator has higher precedence than **`AND`**, i.e.,

```
IF A or B and C
```

is equivalent to

```
IF (A or B) and C.
```

If the interpretation was meant to be

```
IF A or (B and C)
```

then this can be expressed using two rules as in

```
IF A THEN ...
IF B and C THEN ...
```

c. The **`PRIORITY`** value is used to determine which rule applies when two or more rules require that conflicting actions be taken on a link. A rule without a priority value always has a lower priority than one with a value. For two rules with the same priority value, the rule that appears first is given the higher priority.

Example:

```
[RULES]
RULE 1
IF   TANK   1 LEVEL ABOVE 19.1
THEN PUMP 335 STATUS IS CLOSED
AND  PIPE 330 STATUS IS OPEN

RULE 2
IF   SYSTEM CLOCKTIME >= 8 AM
AND  SYSTEM CLOCKTIME < 6 PM
AND  TANK 1 LEVEL BELOW 12
THEN PUMP 335 STATUS IS OPEN

RULE 3
IF   SYSTEM CLOCKTIME >= 6 PM
OR   SYSTEM CLOCKTIME < 8 AM
AND  TANK 1 LEVEL BELOW 14
THEN PUMP 335 STATUS IS OPEN
```

[SOURCES]

Purpose:

Defines locations of water quality sources.

Format:

One line for each water quality source containing:

- Node ID label
- Source type (**`CONCEN, MASS, FLOWPACED`**, or **`SETPOINT`**)
- Baseline source strength
- Time pattern ID (optional)

Remarks:

a. For **`MASS`** type sources, strength is measured in mass flow per minute. All other types measure source strength in concentration units.

b. Source strength can be made to vary over time by specifying a time pattern.

c. A **`CONCEN`** source:

- represents the concentration of any external source inflow to the node
- applies only when the node has a net negative demand (water enters the network at the node)
- if the node is a junction, reported concentration is the result of mixing the source flow and inflow from the rest of the network
- if the node is a reservoir, the reported concentration is the source concentration
- if the node is a tank, the reported concentration is the internal concentration of the tank
- is best used for nodes that represent source water supplies or treatment works (e.g., reservoirs or nodes assigned a negative demand)
- should not be used at storage tanks with simultaneous inflow/outflow.

d. A **`MASS, FLOWPACED`**, or **`SETPOINT`** source:

- represents a booster source, where the substance is injected directly into the network irregardless of what the demand at the node is
- affects water leaving the node to the rest of the network in the following way:
  - a **`MASS`** booster adds a fixed mass flow to that resulting from inflow to the node
  - a **`FLOWPACED`** booster adds a fixed concentration to the resultant inflow concentration at the node
  - a **`SETPOINT`** booster fixes the concentration of any flow leaving the node (as long as the concentration resulting from the inflows is below the setpoint)
- the reported concentration at a junction or reservoir booster source is the concentration that results after the boosting is applied; the reported concentration for a tank with a booster source is the internal concentration of the tank

- is best used to model direct injection of a tracer or disinfectant into the network or to model a contaminant intrusion.

e. A [SOURCES] section is not needed for simulating water age or source tracing.

Example:

```
[SOURCES]
;Node  Type    Strength  Pattern
;--------------------------------
  N1   CONCEN    1.2      Pat1    ;Concentration varies with time
  N44  MASS      12               ;Constant mass injection
```

[STATUS]

Purpose:

Defines initial status of selected links at the start of a simulation.

Format:

One line per link being controlled containing:

- Link ID label
- Status or setting

Remarks:

a. Links not listed in this section have a default status of **OPEN** (for pipes and pumps) or **ACTIVE** (for valves).

b. The status value can be **`OPEN`** or **`CLOSED`**. For control valves (e.g., PRVs, FCVs, etc.) this means that the valve is either fully opened or closed, not active at its control setting.

c. The setting value can be a speed setting for pumps or valve setting for valves.

d. The initial status of pipes can also be set in the [PIPES] section.

e. Check valves cannot have their status be preset.

f. Use [CONTROLS] or [RULES] to change status or setting at some future point in the simulation.

g. If a **`CLOSED`** or **`OPEN`** control valve is to become **`ACTIVE`** again, then its pressure or flow setting must be specified in the control or rule that re-activates it.

Example:

```
[STATUS]
; Link   Status/Setting
;----------------------
   L22    CLOSED       ;Link L22 is closed
   P14    1.5          ;Speed for pump P14
   PRV1   OPEN         ;PRV1 forced open
                       ;(overrides normal operation)
```

[TAGS]

Purpose:

Associates category labels (tags) with specific nodes and links.

Format:

One line for each node and link with a tag containing

- the keyword `NODE` or `LINK`
- the node or link ID label
- the text of the tag label (with no spaces)

Remarks:

a. Tags can be useful for assigning nodes to different pressure zones or for classifying pipes by material or age.

b. If a node or link's tag is not identified in this section then it is assumed to be blank.

c. The [TAGS] section is optional and has no effect on the hydraulic or water quality calculations.

Example:

```
[TAGS]
;Object  ID       Tag
;------------------------------
 NODE    1001     Zone_A
 NODE    1002     Zone_A
 NODE      45     Zone_B
 LINK     201     UNCI-1960
 LINK     202     PVC-1985
```

[TANKS]

Purpose:

Defines all tank nodes contained in the network.

Format:

One line for each tank containing:

- ID label
- Bottom elevation, ft (m)
- Initial water level, ft (m)
- Minimum water level, ft (m)
- Maximum water level, ft (m)
- Nominal diameter, ft (m)
- Minimum volume, cubic ft (cubic meters)
- Volume curve ID (optional)

Remarks:

a. Water surface elevation equals bottom elevation plus water level.

b. Non-cylindrical tanks can be modeled by specifying a curve of volume versus water depth in the [CURVES] section.

c. If a volume curve is supplied the diameter value can be any non-zero number

d. Minimum volume (tank volume at minimum water level) can be zero for a cylindrical tank or if a volume curve is supplied.

e. A network must contain at least one tank or reservoir.

Example:

```
[TANKS]
;ID   Elev.  InitLvl  MinLvl  MaxLvl  Diam  MinVol  VolCurve
;-----------------------------------------------------------
;Cylindrical tank
T1    100     15       5       25      120   0
;Non-cylindrical tank with arbitrary diameter
T2   100     15       5       25      1     0        VC1
```

[TIMES]

Purpose:

Defines various time step parameters used in the simulation.

Formats:

`DURATION`	Value (units)
`HYDRAULIC TIMESTEP`	Value (units)
`QUALITY TIMESTEP`	Value (units)
`RULE TIMESTEP`	Value (units)
`PATTERN TIMESTEP`	Value (units)
`PATTERN START`	Value (units)
`REPORT TIMESTEP`	Value (units)
`REPORT START`	Value (units)
`START CLOCKTIME`	Value (`AM/PM`)

`STATISTIC`	`NONE/AVERAGED/`
	`MINIMUM/MAXIMUM`
	`RANGE`

Definitions:

`DURATION` is the duration of the simulation. Use 0 to run a single period snapshot analysis. The default is 0.

`HYDRAULIC TIMESTEP` determines how often a new hydraulic state of the network is computed. If greater than either the `PATTERN` or `REPORT` time step it will be automatically reduced. The default is 1 hour.

`QUALITY TIMESTEP` is the time step used to track changes in water quality throughout the network. The default is 1/10 of the hydraulic time step.

`RULE TIMESTEP` is the time step used to check for changes in system status due to activation of rule-based controls between hydraulic time steps. The default is 1/10 of the hydraulic time step.

`PATTERN TIMESTEP` is the interval between time periods in all time patterns. The default is 1 hour.

`PATTERN START` is the time offset at which all patterns will start. For example, a value of 6 hours would start the simulation with each pattern in the time period that corresponds to hour 6. The default is 0.

`REPORT TIMESTEP` sets the time interval between which output results are reported. The default is 1 hour.

`REPORT START` is the length of time into the simulation at which output results begin to be reported. The default is 0.

`START CLOCKTIME` is the time of day (e.g., 3:00 PM) at which the simulation begins. The default is 12:00 AM midnight.

STATISTIC determines what kind of statistical post-processing should be done on the time series of simulation results generated. **AVERAGED** reports a set of time-averaged results, **MINIMUM** reports only the minimum values, **MAXIMUM** the maximum values, and **RANGE** reports the difference between the minimum and maximum values. **NONE** reports the full time series for all quantities for all nodes and links and is the default.

Remarks:

a. Units can be **SECONDS (SEC), MINUTES (MIN), HOURS**, or **DAYS**. The default is hours.

b. If units are not supplied, then time values can be entered as decimal hours or in hours:minutes notation.

c. All entries in the [TIMES] section are optional. Items offset by slashes (/) indicate allowable choices.

Example:

```
[TIMES]
DURATION           240 HOURS
QUALITY TIMESTEP   3 MIN
REPORT START       120
STATISTIC          AVERAGED
START CLOCKTIME    6:00 AM
```

[TITLE]

Purpose:

Attaches a descriptive title to the network being analyzed.

Format:

Any number of lines of text.

Remarks:

The [TITLE] section is optional.

[VALVES]

Purpose:

Defines all control valve links contained in the network.

Format:

One line for each valve containing:

- ID label of valve
- ID of start node
- ID of end node
- Diameter, inches (mm)
- Valve type
- Valve setting
- Minor loss coefficient

Remarks:

a. Valve types and settings include:

Valve Type	Setting
PRV (pressure reducing valve)	Pressure, psi (m)
PSV (pressure sustaining valve)	Pressure, psi (m)
PBV (pressure breaker valve)	Pressure, psi (m)
FCV (flow control valve)	Flow (flow units)
TCV (throttle control valve)	Loss Coefficient
GPV (general purpose valve)	ID of head loss curve

b. Shutoff valves and check valves are considered to be part of a pipe, not a separate control valve component (see [PIPES])

[VERTICES]

Purpose:

Assigns interior vertex points to network links.

Format:

One line for each point in each link containing such points that includes:

- Link ID label
- X-coordinate
- Y-coordinate

Remarks:

a. Vertex points allow links to be drawn as polylines instead of simple straight-lines between their end nodes.

b. The coordinates refer to the same coordinate system used for node and label coordinates.

c. A [VERTICES] section is optional and is not used at all when EPANET is run as a console application.

Example:

```
[COORDINATES]
;Node       X-Coord.    Y-Coord
;-------------------------------
  1         10023       128
  2         10056       95
```

C.3 Report File Format

Statements supplied to the [REPORT] section of the input file control the contents of the report file generated from a command-line run of EPANET. A portion of the report generated from the input file of Figure C.1 is shown in Figure C.2. In general a report can contain the following sections:

- Status Section
- Energy Section
- Nodes Section
- Links Section

Status Section

The Status Section of the output report lists the initial status of all reservoirs, tanks, pumps, valves, and closed pipes as well as any changes in the status of these components as they occur over time in an extended period simulation. The status of reservoirs and tanks indicates whether they are filling or emptying. The status of links indicates whether they are open or closed and includes the relative speed setting for pumps and the pressure/flow setting for control valves. To include a Status Section in the report use the command **STATUS YES** in the [REPORT] section of the input file.

Using **STATUS FULL** will also produce a full listing of the convergence results for all iterations of each hydraulic analysis made during a simulation. This listing will also show which components are changing status during the iterations. This level of detail is only useful when one is trying to debug a run that fails to converge because a component's status is cycling.

Energy Section

The Energy Section of the output report lists overall energy consumption and cost for each pump in the network. The items listed for each pump include:

- Percent Utilization (percent of the time that the pump is on-line)
- Average Efficiency
- Kilowatt-hours consumed per million gallons (or cubic meters) pumped
- Average Kilowatts consumed
- Peak Kilowatts used
- Average cost per day

Also listed is the total cost per day for pumping and the total demand charge (cost based on the peak energy usage) incurred. To include an Energy Section in the report the command **ENERGY YES** must appear in the [REPORT] section of the input file.

```
******************************************************************
*                           E P A N E T                          *
*                   Hydraulic and Water Quality                  *
*                   Analysis for Pipe Networks                   *
*                           Version 2.0                          *
******************************************************************

EPANET TUTORIAL

    Input Data File ................... tutorial.inp
    Number of Junctions................ 5
    Number of Reservoirs............... 1
    Number of Tanks ................... 1
    Number of Pipes ................... 6
    Number of Pumps ................... 1
    Number of Valves .................. 0
    Headloss Formula .................. Hazen-Williams
    Hydraulic Timestep ................ 1.00 hrs
    Hydraulic Accuracy ................ 0.001000
    Maximum Trials .................... 40
    Quality Analysis .................. Chlorine
    Water Quality Time Step ........... 5.00 min
    Water Quality Tolerance ........... 0.01 mg/L
    Specific Gravity .................. 1.00
    Relative Kinematic Viscosity ...... 1.00
    Relative Chemical Diffusivity ..... 1.00
    Demand Multiplier ................. 1.00
    Total Duration .................... 24.00 hrs
    Reporting Criteria:
       All Nodes
       All Links

Energy Usage:
----------------------------------------------------------------
           Usage   Avg.     Kw-hr      Avg.      Peak      Cost
Pump      Factor Effic.     /Mgal        Kw        Kw      /day
----------------------------------------------------------------
7         100.00  75.00    746.34     51.34     51.59      0.00
----------------------------------------------------------------
                                       Demand Charge:      0.00
                                       Total Cost:         0.00
```

Figure C.2 Excerpt from a Report File (continued on next page)

```
Node Results at 0:00 hrs:
 --------------------------------------------------------
                     Demand      Head  Pressure  Chlorine
 Node                   gpm        ft       psi      mg/L
 --------------------------------------------------------
 2                     0.00    893.37    387.10      0.00
 3                   325.00    879.78     73.56      0.00
 4                    75.00    874.43     75.58      0.00
 5                   100.00    872.69     76.99      0.00
 6                    75.00    872.71     74.84      0.00
 1                 -1048.52    700.00      0.00      1.00  Reservoir
 7                   473.52    855.00      2.17      0.00  Tank

 Link Results at 0:00 hrs:
 ----------------------------------------------
                       Flow  Velocity  Headloss
 Link                   gpm       fps   /1000ft
 ----------------------------------------------
 1                  1048.52      2.97      4.53
 2                   558.33      1.58      1.41
 3                   165.19      1.05      1.07
 4                    90.19      0.58      0.35
 5                    -9.81      0.06      0.01
 6                   473.52      1.93      2.53
 7                  1048.52      0.00   -193.37  Pump

 Node Results at 1:00 hrs:
 --------------------------------------------------------
                     Demand      Head  Pressure  Chlorine
 Node                   gpm        ft       psi      mg/L
 --------------------------------------------------------
 2                     0.00    893.92    387.34      1.00
 3                   325.00    880.42     73.84      0.99
 4                    75.00    875.12     75.88      0.00
 5                   100.00    873.40     77.30      0.00
 6                    75.00    873.43     75.15      0.00
 1                 -1044.60    700.00      0.00      1.00  Reservoir
 7                   469.60    855.99      2.59      0.00  Tank

 Link Results at 1:00 hrs:
 ----------------------------------------------
                       Flow  Velocity  Headloss
 Link                   gpm       fps   /1000ft
 ----------------------------------------------
 1                  1044.60      2.96      4.50
 2                   555.14      1.57      1.40
 3                   164.45      1.05      1.06
 4                    89.45      0.57      0.34
 5                   -10.55      0.07      0.01
 6                   469.60      1.92      2.49
 7                  1044.60      0.00   -193.92  Pump
```

Figure C.2 Excerpt from a Report File (continued from previous page)

Nodes Section

The Nodes Section of the output report lists simulation results for those nodes and parameters identified in the [REPORT] section of the input file. Results are listed for each reporting time step of an extended period simulation. The reporting time step is specified in the [TIMES] section of the input file. Results at intermediate times when certain hydraulic events occur, such as pumps turning on or off or tanks closing because they become empty or full, are not reported.

To have nodal results reported the [REPORT] section of the input file must contain the keyword **NODES** followed by a listing of the ID labels of the nodes to be included in the report. There can be several such **NODES** lines in the file. To report results for all nodes use the command **NODES ALL**.

The default set of reported quantities for nodes includes Demand, Head, Pressure, and Water Quality. You can specify how many decimal places to use when listing results for a parameter by using commands such as **PRESSURE PRECISION 3** in the input file (i.e., use 3 decimal places when reporting results for pressure). The default precision is 2 decimal places for all quantities. You can filter the report to list only the occurrences of values below or above a certain value by adding statements of the form **PRESSURE BELOW 20** to the input file.

Links Section

The Links Section of the output report lists simulation results for those links and parameters identified in the [REPORT] section of the input file. The reporting times follow the same convention as was described for nodes in the previous section.

As with nodes, to have any results for links reported you must include the keyword **LINKS** followed by a list of link ID labels in the [REPORT] section of the input file. Use the command **LINKS ALL** to report results for all links.

The default parameters reported on for links includes Flow, Velocity, and Headloss. Diameter, Length, Water Quality, Status, Setting, Reaction Rate, and Friction Factor can be added to these by using commands such as **DIAMETER YES** or **DIAMETER PRECISION 0**. The same conventions used with node parameters for specifying reporting precision and filters also applies to links.

C.4 Binary Output File Format

If a third file name is supplied to the command line that runs EPANET then the results for all parameters for all nodes and links for all reporting time periods will be saved to this file in a special binary format. This file can be used for special post-processing purposes. Data written to the file are 4-byte integers, 4-byte floats, or fixed-size strings whose size is a multiple of 4 bytes. This allows the file to be divided conveniently into 4-byte records. The file consists of four sections of the following sizes in bytes:

Section	*Size in bytes*
Prolog	852 + 20*Nnodes + 36*Nlinks + 8*Ntanks
Energy Use	28*Npumps + 4
Extended Period	(16*Nnodes + 32*Nlinks)*Nperiods
Epilog	28

where

Nnodes = number of nodes (junctions + reservoirs + tanks)
Nlinks = number of links (pipes + pumps + valves)
Ntanks = number of tanks and reservoirs
Npumps = number of pumps
Nperiods = number of reporting periods

and all of these counts are themselves written to the file's Prolog or Epilog sections.

Prolog Section

The prolog section of the binary Output File contains the following data:

Item	**Type**	**Number of Bytes**
Magic Number (= 516114521)	Integer	4
Version (= 200)	Integer	4
Number of Nodes (Junctions + Reservoirs + Tanks)	Integer	4
Number of Reservoirs & Tanks	Integer	4
Number of Links (Pipes + Pumps + Valves)	Integer	4
Number of Pumps	Integer	4
Number of Valves	Integer	4
Water Quality Option 0 = none 1 = chemical 2 = age 3 = source trace	Integer	4
Index of Node for Source Tracing	Integer	4
Flow Units Option 0 = cfs 1 = gpm 2 = mgd 3 = Imperial mgd 4 = acre-ft/day 5 = liters/second 6 = liters/minute 7 = megaliters/day 8 = cubic meters/hour 9 = cubic meters/day	Integer	4

Pressure Units Option 0 = psi 1 = meters 2 = kPa	Integer	4
Statistics Flag 0 = no statistical processing 1 = results are time-averaged 2 = only minimum values reported 3 = only maximum values reported 4 = only ranges reported	Integer	4
Reporting Start Time (seconds)	Integer	4
Reporting Time Step (seconds)	Integer	4
Simulation Duration (seconds)	Integer	4
Problem Title (1st line)	Char	80
Problem Title (2nd line)	Char	80
Problem Title (3rd line)	Char	80
Name of Input File	Char	260
Name of Report File	Char	260
Name of Chemical	Char	16
Chemical Concentration Units	Char	16
ID Label of Each Node	Char	16
ID Label of Each Link	Char	16
Index of Start Node of Each Link	Integer	4*Nlinks
Index of End Node of Each Link	Integer	4*Nlinks
Type Code of Each Link 0 = Pipe with CV 1 = Pipe 2 = Pump 3 = PRV 4 = PSV 5 = PBV 6 = FCV 7 = TCV 8 = GPV	Integer	4*Nlinks
Node Index of Each Tank	Integer	4*Ntanks
Cross-Sectional Area of Each Tank	Float	4*Ntanks
Elevation of Each Node	Float	4*Nnodes
Length of Each Link	Float	4*Nlinks
Diameter of Each Link	Float	4*Nlinks

There is a one-to-one correspondence between the order in which the ID labels for nodes and links are written to the file and the index numbers of these components. Also, reservoirs are distinguished from tanks by having their cross-sectional area set to zero.

Energy Use Section

The Energy Use section of the binary output file immediately follows the Prolog section. It contains the following data:

Item	Type	Number of Bytes
Repeated for each pump: ▪ Pump Index in List of Links ▪ Pump Utilization (%) ▪ Average Efficiency (%) ▪ Average Kwatts/Million Gallons (/Meter^3) ▪ Average Kwatts ▪ Peak Kwatts ▪ Average Cost Per Day	 Float Float Float Float Float Float Float	 4 4 4 4 4 4 4
Overall Peak Energy Usage	Float	4

The statistics reported in this section refer to the period of time between the start of the output reporting period and the end of the simulation.

Extended Period Section

The Extended Period section of the binary Output File contains simulation results for each reporting period of an analysis (the reporting start time and time step are written to the Output File's Prolog section and the number of steps is written to the Epilog section). For each reporting period the following values are written to the file:

Item	Type	Size in Bytes
Demand at Each Node	Float	4*Nnodes
Hydraulic Head at Each Node	Float	4*Nnodes
Pressure at Each Node	Float	4*Nnodes
Water Quality at Each Node	Float	4*Nnodes
Flow in Each Link (negative for reverse flow)	Float	4*Nlinks
Velocity in Each Link	Float	4*Nlinks
Headloss per 1000 Units of Length for Each Link (Negative of head gain for pumps and total head loss for valves)	Float	4*Nlinks
Average Water Quality in Each Link	Float	4*Nlinks
Status Code for Each Link 0 = closed (max. head exceeded) 1 = temporarily closed 2 = closed 3 = open 4 = active (partially open) 5 = open (max. flow exceeded) 6 = open (flow setting not met) 7 = open (pressure setting not met)	Float	4*Nlinks
Setting for Each Link: Roughness Coefficient for Pipes Speed for Pumps Setting for Valves	Float	4*Nlinks
Reaction Rate for Each Link (mass/L/day)	Float	4*Nlinks
Friction Factor for Each Link	Float	4*Nlinks

Epilog Section

The Epilog section of the binary output file contains the following data:

Item	Type	Number of Bytes
Average bulk reaction rate (mass/hr)	Float	4
Average wall reaction rate (mass/hr)	Float	4
Average tank reaction rate (mass/hr)	Float	4
Average source inflow rate (mass/hr)	Float	4
Number of Reporting Periods	Integer	4
Warning Flag: 0 = no warnings 1 = warnings were generated	Integer	4
Magic Number (= 516114521)	Integer	4

The mass units of the reaction rates both here and in the Extended Period output depend on the concentration units assigned to the chemical being modeled. The reaction rates listed in this section refer to the average of the rates seen in all pipes (or all tanks) over the entire reporting period of the simulation.

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APPENDIX D - ANALYSIS ALGORITHMS

D.1 Hydraulics

The method used in EPANET to solve the flow continuity and headloss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed a hybrid node-loop approach. Todini and Pilati (1987) and later Salgado et al. (1988) chose to call it the "Gradient Method". Similar approaches have been described by Hamam and Brameller (1971) (the "Hybrid Method) and by Osiadacz (1987) (the "Newton Loop-Node Method"). The only difference between these methods is the way in which link flows are updated after a new trial solution for nodal heads has been found. Because Todini's approach is simpler, it was chosen for use in EPANET.

Assume we have a pipe network with N junction nodes and NF fixed grade nodes (tanks and reservoirs). Let the flow-headloss relation in a pipe between nodes i and j be given as:

$$H_i - H_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2 \tag{D.1}$$

where H = nodal head, h = headloss, r = resistance coefficient, Q = flow rate, n = flow exponent, and m = minor loss coefficient. The value of the resistance coefficient will depend on which friction headloss formula is being used (see below). For pumps, the headloss (negative of the head gain) can be represented by a power law of the form

$$h_{ij} = -w^2 (h_0 - r\ (Q_{ij}/w)^n\ )$$

where h_0 is the shutoff head for the pump, ω is a relative speed setting, and r and n are the pump curve coefficients. The second set of equations that must be satisfied is flow continuity around all nodes:

$$\sum_j Q_{ij} - D_i = 0 \qquad \text{for i = 1,... N.} \tag{D.2}$$

where D_i is the flow demand at node i and by convention, flow into a node is positive. For a set of known heads at the fixed grade nodes, we seek a solution for all heads H_i and flows Q_{ij} that satisfy Eqs. (D.1) and (D.2).

The Gradient solution method begins with an initial estimate of flows in each pipe that may not necessarily satisfy flow continuity. At each iteration of the method, new nodal heads are found by solving the matrix equation:

$$\mathbf{AH} = \mathbf{F} \tag{D.3}$$

where **A** = an (NxN) Jacobian matrix, **H** = an (Nx1) vector of unknown nodal heads, and **F** = an (Nx1) vector of right hand side terms

The diagonal elements of the Jacobian matrix are:

$$A_{ii} = \sum_j p_{ij}$$

while the non-zero, off-diagonal terms are:

$$A_{ij} = -p_{ij}$$

where p_{ij} is the inverse derivative of the headloss in the link between nodes i and j with respect to flow. For pipes,

$$p_{ij} = \frac{1}{nr\left|Q_{ij}\right|^{n-1} + 2m\left|Q_{ij}\right|}$$

while for pumps

$$p_{ij} = \frac{1}{nw^2 r(Q_{ij}/w)^{n-1}}$$

Each right hand side term consists of the net flow imbalance at a node plus a flow correction factor:

$$F_i = \left(\sum_j Q_{ij} - D_i\right) + \sum_j y_{ij} + \sum_f p_{if} H_f$$

where the last term applies to any links connecting node i to a fixed grade node f and the flow correction factor y_{ij} is:

$$y_{ij} = p_{ij}\left(r\left|Q_{ij}\right|^n + m\left|Q_{ij}\right|^2\right)\mathrm{sgn}(Q_{ij})$$

for pipes and

$$y_{ij} = -p_{ij} w^2 \left(h_0 - r(Q_{ij}/w)^n\right)$$

for pumps, where sgn(x) is 1 if x > 0 and -1 otherwise. (Q_{ij} is always positive for pumps.)

After new heads are computed by solving Eq. (D.3), new flows are found from:

$$Q_{ij} = Q_{ij} - \left(y_{ij} - p_{ij}\left(H_i - H_j\right)\right) \qquad \text{D.4}$$

If the sum of absolute flow changes relative to the total flow in all links is larger than some tolerance (e.g., 0.001), then Eqs. (D.3) and (D.4) are solved once again. The flow update formula (D.4) always results in flow continuity around each node after the first iteration.

EPANET implements this method using the following steps:

1. The linear system of equations D.3 is solved using a sparse matrix method based on node re-ordering (George and Liu, 1981). After re-ordering the nodes to minimize the amount of fill-in for matrix A, a symbolic factorization is carried out so that only the non-zero elements of A need be stored and operated on in memory. For extended period simulation this re-ordering and factorization is only carried out once at the start of the analysis.
2. For the very first iteration, the flow in a pipe is chosen equal to the flow corresponding to a velocity of 1 ft/sec, while the flow through a pump equals the design flow specified for the pump. (All computations are made with head in feet and flow in cfs).
3. The resistance coefficient for a pipe (*r*) is computed as described in Table 3.1. For the Darcy-Weisbach headloss equation, the friction factor *f* is computed by different equations depending on the flow's Reynolds Number (Re):

   Hagen – Poiseuille formula for Re < 2,000 (Bhave, 1991):

$$f = \frac{64}{\mathrm{Re}}$$

   Swamee and Jain approximation to the Colebrook - White equation for Re > 4,000 (Bhave, 1991):

$$f = \frac{0.25}{\left[Ln\left(\frac{e}{3.7d} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

   Cubic Interpolation From Moody Diagram for 2,000 < Re < 4,000 (Dunlop, 1991):

$$f = (X1 + R(X2 + R(X3 + X4)))$$

$$R = \frac{\mathrm{Re}}{2000}$$

$$X1 = 7FA - FB$$

$$X2 = 0.128 - 17FA + 2.5FB$$

$$X3 = -0.128 + 13FA - 2FB$$

$$X4 = R(0.032 - 3FA + 0.5FB)$$

$$FA = (Y3)^{-2}$$

$$FB = FA\left(2 - \frac{0.00514215}{(Y2)(Y3)}\right)$$

$$Y2 = \frac{e}{3.7d} + \frac{5.74}{\mathrm{Re}^{0.9}}$$

$$Y3 = -0.86859Ln\left(\frac{e}{3.7d} + \frac{5.74}{4000^{0.9}}\right)$$

where e = pipe roughness and d = pipe diameter.

4. The minor loss coefficient based on velocity head (K) is converted to one based on flow (m) with the following relation:

$$m = \frac{0.02517K}{d^4}$$

5. Emitters at junctions are modeled as a fictitious pipe between the junction and a fictitious reservoir. The pipe's headloss parameters are $n = (1/\gamma)$, $r = (1/C)^n$, and $m = 0$ where C is the emitter's discharge coefficient and γ is its pressure exponent. The head at the fictitious reservoir is the elevation of the junction. The computed flow through the fictitious pipe becomes the flow associated with the emitter.

6. Open valves are assigned an r-value by assuming the open valve acts as a smooth pipe (f = 0.02) whose length is twice the valve diameter. Closed links are assumed to obey a linear headloss relation with a large resistance factor, i.e., $h = 10^8Q$, so that $p = 10^{-8}$ and $y = Q$. For links where $(r+m)Q < 10^{-7}$, $p = 10^7$ and $y = Q/n$.

7. Status checks on pumps, check valves (CVs), flow control valves, and pipes connected to full/empty tanks are made after every other iteration, up until the 10th iteration. After this, status checks are made only after convergence is achieved. Status checks on pressure control valves (PRVs and PSVs) are made after each iteration.

8. During status checks, pumps are closed if the head gain is greater than the shutoff head (to prevent reverse flow). Similarly, check valves are closed if the headloss through them is negative (see below). When these conditions are not present, the link is re-opened. A similar status check is made for links connected to empty/full tanks. Such links are closed if the difference in head across the link would cause an empty tank to drain or a full tank to fill. They are re-opened at the next status check if such conditions no longer hold.

9. Simply checking if $h < 0$ to determine if a check valve should be closed or open was found to cause cycling between these two states in some networks due to limits on numerical precision. The following procedure was devised to provide a more robust test of the status of a check valve (CV):

```
if |h| > Htol then
    if h < -Htol then       status = CLOSED
    if Q < -Qtol then       status = CLOSED
    else                    status = OPEN
else
    if Q < -Qtol then       status = CLOSED
else                        status = unchanged
```

where Htol = 0.0005 ft and Qtol = 0.001 cfs.

10. If the status check closes an open pump, pipe, or CV, its flow is set to 10^{-6} cfs. If a pump is re-opened, its flow is computed by applying the current head gain to its characteristic curve. If a pipe or CV is re-opened, its flow is determined by solving Eq. (D.1) for Q under the current headloss h, ignoring any minor losses.

11. Matrix coefficients for pressure breaker valves (PBVs) are set to the following: $p = 10^8$ and $y = 10^8$Hset, where Hset is the pressure drop setting for the valve (in feet). Throttle control valves (TCVs) are treated as pipes with r as described in item 6 above and m taken as the converted value of the valve setting (see item 4 above).

12. Matrix coefficients for pressure reducing, pressure sustaining, and flow control valves (PRVs, PSVs, and FCVs) are computed after all other links have been analyzed. Status checks on PRVs and PSVs are made as described in item 7 above. These valves can either be completely open, completely closed, or active at their pressure or flow setting.

13. The logic used to test the status of a PRV is as follows:

```
If current status = ACTIVE then
    if  Q < -Qtol               then new status = CLOSED
    if  Hi < Hset + Hml – Htol  then new status = OPEN
                                else new status = ACTIVE

If curent status = OPEN then
    if  Q < -Qtol               then new status = CLOSED
    if  Hi > Hset + Hml + Htol  then new status = ACTIVE
                                else  new status = OPEN

If current status = CLOSED then
    if  Hi > Hj + Htol
    and Hi < Hset – Htol        then new status = OPEN
    if Hi > Hj + Htol
    and  Hj < Hset - Htol       then new status = ACTIVE
                                else  new status = CLOSED
```

where Q is the current flow through the valve, Hi is its upstream head, Hj is its downstream head, Hset is its pressure setting converted to head, Hml is the minor loss when the valve is open (= mQ^2), and Htol and Qtol are the same values used for check valves in item 9 above. A similar set of tests is used for PSVs, except that when testing against Hset, the i and j subscripts are switched as are the > and < operators.

14. Flow through an active PRV is maintained to force continuity at its downstream node while flow through a PSV does the same at its upstream node. For an active PRV from node i to j:

$$p_{ij} = 0$$
$$F_j = F_j + 10^8\text{Hset}$$
$$A_{jj} = A_{jj} + 10^8$$

This forces the head at the downstream node to be at the valve setting Hset. An equivalent assignment of coefficients is made for an active PSV except the subscript for F and A is the upstream node i. Coefficients for open/closed PRVs and PSVs are handled in the same way as for pipes.

15. For an active FCV from node i to j with flow setting Qset, Qset is added to the flow leaving node i and entering node j, and is subtracted from F_i and added to F_j. If the head at node i is less than that at node j, then the valve cannot deliver the flow and it is treated as an open pipe.

16. After initial convergence is achieved (flow convergence plus no change in status for PRVs and PSVs), another status check on pumps, CVs, FCVs, and links to tanks is made. Also, the status of links controlled by pressure switches (e.g., a pump controlled by the pressure at a junction node) is checked. If any status change occurs, the iterations must continue for at least two more iterations (i.e., a convergence check is skipped on the very next iteration). Otherwise, a final solution has been obtained.

17. For extended period simulation (EPS), the following procedure is implemented:

    a. After a solution is found for the current time period, the time step for the next solution is the minimum of:

        - the time until a new demand period begins,
        - the shortest time for a tank to fill or drain,
        - the shortest time until a tank level reaches a point that triggers a change in status for some link (e.g., opens or closes a pump) as stipulated in a simple control,
        - the next time until a simple timer control on a link kicks in,
        - the next time at which a rule-based control causes a status change somewhere in the network.

    In computing the times based on tank levels, the latter are assumed to change in a linear fashion based on the current flow solution. The activation time of rule-based controls is computed as follows:

- Starting at the current time, rules are evaluated at a rule time step. Its default value is 1/10 of the normal hydraulic time step (e.g., if hydraulics are updated every hour, then rules are evaluated every 6 minutes).
- Over this rule time step, clock time is updated, as are the water levels in storage tanks (based on the last set of pipe flows computed).
- If a rule's conditions are satisfied, then its actions are added to a list. If an action conflicts with one for the same link already on the list then the action from the rule with the higher priority stays on the list and the other is removed. If the priorities are the same then the original action stays on the list.
- After all rules are evaluated, if the list is not empty then the new actions are taken. If this causes the status of one or more links to change then a new hydraulic solution is computed and the process begins anew.
- If no status changes were called for, the action list is cleared and the next rule time step is taken unless the normal hydraulic time step has elapsed.

b. Time is advanced by the computed time step, new demands are found, tank levels are adjusted based on the current flow solution, and link control rules are checked to determine which links change status.

c. A new set of iterations with Eqs. (D.3) and (D.4) are begun at the current set of flows.

D.2 Water Quality

The governing equations for EPANET’s water quality solver are based on the principles of conservation of mass coupled with reaction kinetics. The following phenomena are represented (Rossman et al., 1993; Rossman and Boulos, 1996):

Advective Transport in Pipes

A dissolved substance will travel down the length of a pipe with the same average velocity as the carrier fluid while at the same time reacting (either growing or decaying) at some given rate. Longitudinal dispersion is usually not an important transport mechanism under most operating conditions. This means there is no intermixing of mass between adjacent parcels of water traveling down a pipe. Advective transport within a pipe is represented with the following equation:

$$\frac{\partial C_i}{\partial t} = -u_i \frac{\partial C_i}{\partial x} + r(C_i) \qquad \text{D.5}$$

where C_i = concentration (mass/volume) in pipe i as a function of distance x and time t, u_i = flow velocity (length/time) in pipe i, and r = rate of reaction (mass/volume/time) as a function of concentration.

Mixing at Pipe Junctions

At junctions receiving inflow from two or more pipes, the mixing of fluid is taken to be complete and instantaneous. Thus the concentration of a substance in water leaving the junction is simply the flow-weighted sum of the concentrations from the inflowing pipes. For a specific node k one can write:

$$C_{i|x=0} \;=\; \frac{\sum_{j \in I_k} Q_j C_{j|x=L_j} \;+\; Q_{k,ext} C_{k,ext}}{\sum_{j \in I_k} Q_j \;+\; Q_{k,ext}} \qquad \text{D.6}$$

where i = link with flow leaving node k, I_k = set of links with flow into k, L_j = length of link j, Q_j = flow (volume/time) in link j, $Q_{k,ext}$ = external source flow entering the network at node k, and $C_{k,ext}$ = concentration of the external flow entering at node k. The notation $C_{i|x=0}$ represents the concentration at the start of link i, while $C_{i|x=L}$ is the concentration at the end of the link.

Mixing in Storage Facilities

It is convenient to assume that the contents of storage facilities (tanks and reservoirs) are completely mixed. This is a reasonable assumption for many tanks operating under fill-and-draw conditions providing that sufficient momentum flux is imparted to the inflow (Rossman and Grayman, 1999). Under completely mixed conditions the concentration throughout the tank is a blend of the current contents and that of any entering water. At the same time, the internal concentration could be changing due to reactions. The following equation expresses these phenomena:

$$\frac{\partial (V_s C_s)}{\partial t} \;=\; \sum_{i \in I_s} Q_i C_{i|x=L_i} \;-\; \sum_{j \in O_s} Q_j C_s \;+\; r(C_s) \qquad \text{D.7}$$

where V_s = volume in storage at time t, C_s = concentration within the storage facility, I_s = set of links providing flow into the facility, and O_s = set of links withdrawing flow from the facility.

Bulk Flow Reactions

While a substance moves down a pipe or resides in storage it can undergo reaction with constituents in the water column. The rate of reaction can generally be described as a power function of concentration:

$$r = kC^n$$

where k = a reaction constant and n = the reaction order. When a limiting concentration exists on the ultimate growth or loss of a substance then the rate expression becomes

$$R = K_b(C_L - C)C^{(n-1)} \qquad \text{for } n > 0, K_b > 0$$
$$R = K_b(C - C_L)C^{(n-1)} \qquad \text{for } n > 0, K_b < 0$$

where C_L = the limiting concentration.

Some examples of different reaction rate expressions are:

- *Simple First-Order Decay ($C_L = 0, K_b < 0, n = 1$)*

  $$R = K_b C$$

  The decay of many substances, such as chlorine, can be modeled adequately as a simple first-order reaction.

- *First-Order Saturation Growth ($C_L > 0, K_b > 0, n = 1$):*

  $$R = K_b(C_L - C)$$

  This model can be applied to the growth of disinfection by-products, such as trihalomethanes, where the ultimate formation of by-product (C_L) is limited by the amount of reactive precursor present.

- *Two-Component, Second Order Decay ($C_L \neq 0, K_b < 0, n = 2$):*

  $$R = K_b C(C - C_L)$$

  This model assumes that substance A reacts with substance B in some unknown ratio to produce a product P. The rate of disappearance of A is proportional to the product of A and B remaining. C_L can be either positive or negative, depending on whether either component A or B is in excess, respectively. Clark (1998) has had success in applying this model to chlorine decay data that did not conform to the simple first-order model.

- *Michaelis-Menton Decay Kinetics ($C_L > 0, K_b < 0, n < 0$):*

  $$R = \frac{K_b C}{C_L - C}$$

  As a special case, when a negative reaction order n is specified, EPANET will utilize the Michaelis-Menton rate equation, shown above for a decay reaction. (For growth reactions the denominator becomes $C_L + C$.) This rate equation is often used to describe enzyme-catalyzed reactions and microbial growth. It produces first-order behavior at low concentrations and zero-order behavior at higher concentrations. Note that for decay reactions, C_L must be set higher than the initial concentration present.

Koechling (1998) has applied Michaelis-Menton kinetics to model chlorine decay in a number of different waters and found that both K_b and C_L could be related to the water's organic content and its ultraviolet absorbance as follows:

$$K_b = -0.32UVA^{1.365}\frac{(100UVA)}{DOC}$$

$$C_L = 4.98UVA - 1.91DOC$$

where UVA = ultraviolet absorbance at 254 nm (1/cm) and DOC = dissolved organic carbon concentration (mg/L).

Note: These expressions apply only for values of K_b and C_L used with Michaelis-Menton kinetics.

- *Zero-Order growth ($C_L = 0$, $K_b = 1$, $n = 0$)*

  $R = 1.0$

  This special case can be used to model water age, where with each unit of time the "concentration" (i.e., age) increases by one unit.

The relationship between the bulk rate constant seen at one temperature (T1) to that at another temperature (T2) is often expressed using a van't Hoff - Arrehnius equation of the form:

$$K_{b2} = K_{b1}\theta^{T2-T1}$$

where θ is a constant. In one investigation for chlorine, θ was estimated to be 1.1 when T1 was 20 deg. C (Koechling, 1998).

Pipe Wall Reactions

While flowing through pipes, dissolved substances can be transported to the pipe wall and react with material such as corrosion products or biofilm that are on or close to the wall. The amount of wall area available for reaction and the rate of mass transfer between the bulk fluid and the wall will also influence the overall rate of this reaction. The surface area per unit volume, which for a pipe equals 2 divided by the radius, determines the former factor. The latter factor can be represented by a mass transfer coefficient whose value depends on the molecular diffusivity of the reactive species and on the Reynolds number of the flow (Rossman et. al, 1994). For first-order kinetics, the rate of a pipe wall reaction can be expressed as:

$$r = \frac{2k_w k_f C}{R(k_w + k_f)}$$

where k_w = wall reaction rate constant (length/time), k_f = mass transfer coefficient (length/time), and R = pipe radius. For zero-order kinetics the reaction rate cannot be any higher than the rate of mass transfer, so

$$r = MIN(k_w, k_f C)(2/R)$$

where k_w now has units of mass/area/time.

Mass transfer coefficients are usually expressed in terms of a dimensionless Sherwood number (Sh):

$$k_f = Sh \frac{D}{d}$$

in which D = the molecular diffusivity of the species being transported (length^2/time) and d = pipe diameter. In fully developed laminar flow, the average Sherwood number along the length of a pipe can be expressed as

$$Sh = 3.65 + \frac{0.0668(d/L)\,\mathrm{Re}\,Sc}{1 + 0.04\left[(d/L)\,\mathrm{Re}\,Sc\right]^{2/3}}$$

in which Re = Reynolds number and Sc = Schmidt number (kinematic viscosity of water divided by the diffusivity of the chemical) (Edwards et.al, 1976). For turbulent flow the empirical correlation of Notter and Sleicher (1971) can be used:

$$Sh = 0.0149\,\mathrm{Re}^{0.88}\,Sc^{1/3}$$

System of Equations

When applied to a network as a whole, Equations D.5-D.7 represent a coupled set of differential/algebraic equations with time-varying coefficients that must be solved for C_i in each pipe i and C_s in each storage facility s. This solution is subject to the following set of externally imposed conditions:

- initial conditions that specify C_i for all x in each pipe i and C_s in each storage facility s at time 0,
- boundary conditions that specify values for $C_{k,ext}$ and $Q_{k,ext}$ for all time t at each node k which has external mass inputs
- hydraulic conditions which specify the volume V_s in each storage facility s and the flow Q_i in each link i at all times t.

Lagrangian Transport Algorithm

EPANET's water quality simulator uses a Lagrangian time-based approach to track the fate of discrete parcels of water as they move along pipes and mix together at junctions between fixed-length time steps (Liou and Kroon, 1987). These water quality time steps are typically much shorter than the hydraulic time step (e.g., minutes rather than hours) to accommodate the short times of travel that can occur within pipes. As time progresses, the size of the most upstream segment in a pipe increases as water enters the pipe while an equal loss in size of the most downstream segment occurs as water leaves the link. The size of the segments in between these remains unchanged. (See Figure D.1).

The following steps occur at the end of each such time step:

1. The water quality in each segment is updated to reflect any reaction that may have occurred over the time step.
2. The water from the leading segments of pipes with flow into each junction is blended together to compute a new water quality value at the junction. The volume contributed from each segment equals the product of its pipe's flow rate and the time step. If this volume exceeds that of the segment then the segment is destroyed and the next one in line behind it begins to contribute its volume.
3. Contributions from outside sources are added to the quality values at the junctions. The quality in storage tanks is updated depending on the method used to model mixing in the tank (see below).
4. New segments are created in pipes with flow out of each junction, reservoir, and tank. The segment volume equals the product of the pipe flow and the time step. The segment's water quality equals the new quality value computed for the node.

To cut down on the number of segments, Step 4 is only carried out if the new node quality differs by a user-specified tolerance from that of the last segment in the outflow pipe. If the difference in quality is below the tolerance then the size of the current last segment in the outflow pipe is simply increased by the volume flowing into the pipe over the time step.

This process is then repeated for the next water-quality time step. At the start of the next hydraulic time step the order of segments in any links that experience a flow reversal is switched. Initially each pipe in the network consists of a single segment whose quality equals the initial quality assigned to the upstream node.

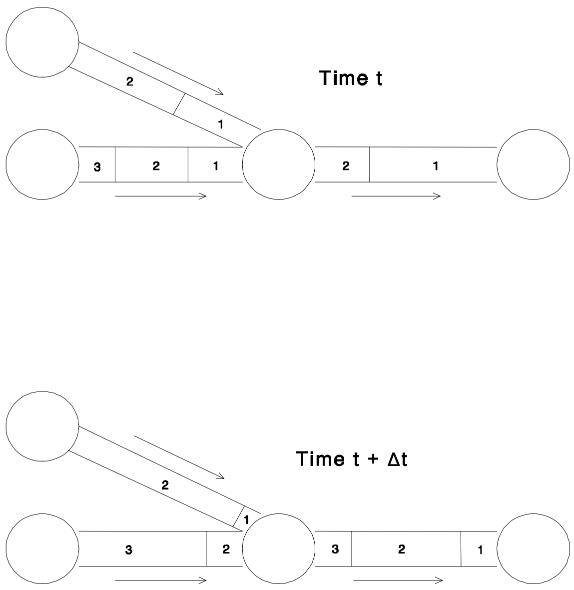

Figure D.1 Behavior of Segments in the Lagrangian Solution Method

D.3 References

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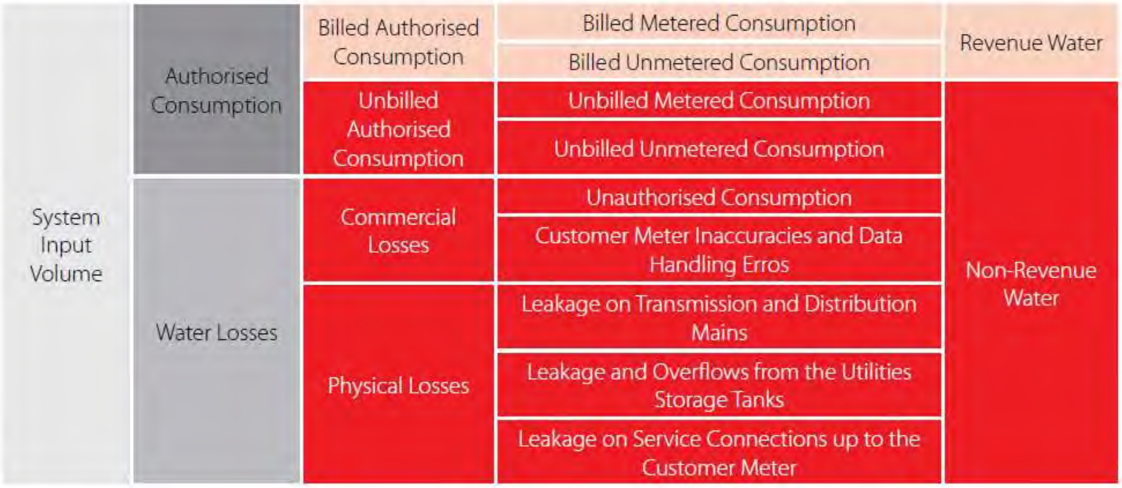
Composition of NRW

1. IWA's Water Balance Table for NRW

Figure 2.1: Water balance showing NRW components



System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Erros	
		Physical Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Service Connections up to the Customer Meter	

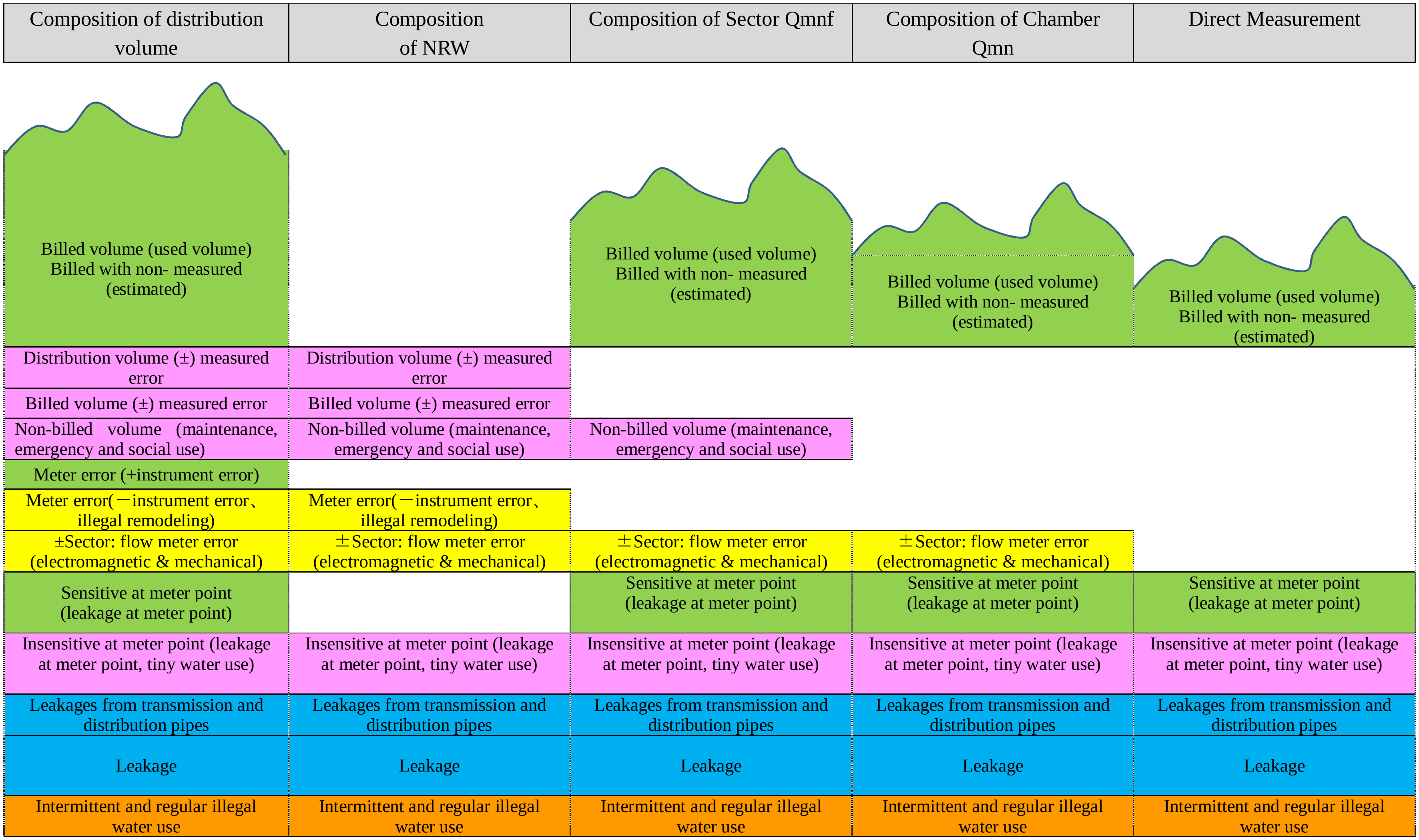
2. Explanation of Terminology

Recognized	Recognized bill	RW	❶Measured bill：Billed volume with meter
			❷Bill with non-measured：Estimated billed volume without meter
	Recognized non bill	NRW	❸Non billed with measured volume：water supply for special area (Slum)
			❹Non billed with non-measured volume：water supply enterprise
Losses	Apparent losses		❺Non recognized water supply：Illegal water supply
			❻Meter measuring error：Insensitive water volume, meter error, meter reading error
	Real losses		❼Leakage from transmission lines：Leakage from transmission and distribution pipes
			❽Leakage from water tanks：Leakages from reservoir and water tank
			❾Leakages from service pipes before meter：Leakages from service pipes before meter

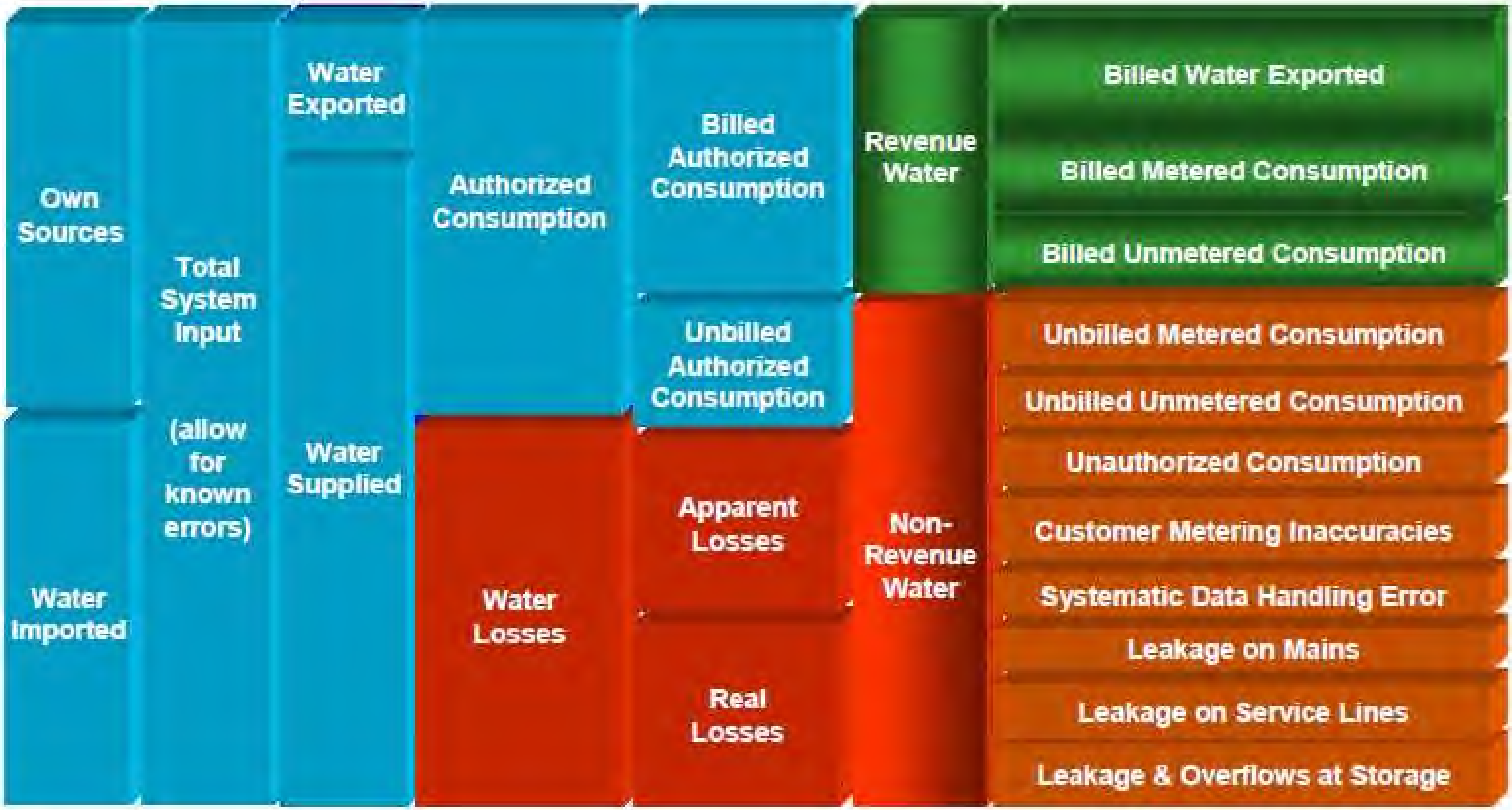
❶Measured bill：Charged volume with meter
❷Bill with non-measured：Estimated billed volume without meter
❸Non-billed with measured volume：water supply for special area (Slum) and emergency

❹Non-billed with non-measured：water supply enterprise volume
❺Non recognized water supply：Illegal supply
❻Meter measuring error：Insensitive water meter, meter error, meter reading error
❼Leakage from transmission lines：Leakage from transmission and distribution pipes
❽Leakage from water tanks：Leakages from reservoir and water tank
❾Leakages from service pipes before meter：Leakages from service pipes until meter

3. Composition for individual flow



Composition of distribution volume	Composition of NRW	Composition of Sector Qmnf	Composition of Chamber Qmn	Direct Measurement
Billed volume (used volume) Billed with non- measured (estimated)		Billed volume (used volume) Billed with non- measured (estimated)	Billed volume (used volume) Billed with non- measured (estimated)	Billed volume (used volume) Billed with non- measured (estimated)
Distribution volume (±) measured error	Distribution volume (±) measured error			
Billed volume (±) measured error	Billed volume (±) measured error			
Non-billed volume (maintenance, emergency and social use)	Non-billed volume (maintenance, emergency and social use)	Non-billed volume (maintenance, emergency and social use)		
Meter error (+instrument error)				
Meter error(－instrument error、illegal remodeling)	Meter error(－instrument error、illegal remodeling)			
±Sector: flow meter error (electromagnetic & mechanical)	±Sector: flow meter error (electromagnetic & mechanical)	±Sector: flow meter error (electromagnetic & mechanical)	±Sector: flow meter error (electromagnetic & mechanical)	
Sensitive at meter point (leakage at meter point)		Sensitive at meter point (leakage at meter point)	Sensitive at meter point (leakage at meter point)	Sensitive at meter point (leakage at meter point)
Insensitive at meter point (leakage at meter point, tiny water use)	Insensitive at meter point (leakage at meter point, tiny water use)	Insensitive at meter point (leakage at meter point, tiny water use)	Insensitive at meter point (leakage at meter point, tiny water use)	Insensitive at meter point (leakage at meter point, tiny water use)
Leakages from transmission and distribution pipes	Leakages from transmission and distribution pipes	Leakages from transmission and distribution pipes	Leakages from transmission and distribution pipes	Leakages from transmission and distribution pipes
Leakage	Leakage	Leakage	Leakage	Leakage
Intermittent and regular illegal water use	Intermittent and regular illegal water use	Intermittent and regular illegal water use	Intermittent and regular illegal water use	Intermittent and regular illegal water use



Own Sources	Total System Input (allow for known errors)	Water Exported	Authorized Consumption	Billed Authorized Consumption	Revenue Water	Billed Water Exported
		Water Supplied				Billed Metered Consumption
						Billed Unmetered Consumption
				Unbilled Authorized Consumption	Non-Revenue Water	Unbilled Metered Consumption
						Unbilled Unmetered Consumption
Water Imported			Water Losses	Apparent Losses		Unauthorized Consumption
						Customer Metering Inaccuracies
						Systematic Data Handling Error
				Real Losses		Leakage on Mains
						Leakage on Service Lines
						Leakage & Overflows at Storage

Figure 1 the AWWA/IWA Water Balance Table

(1) Composition of distribution water

Below table : Shows Composition of distribution water
IWA : Shows classification of IWA
❶～❾: Refer to explanation of terminology

		Authorised Con		Water Loss	
	IWA	B A Con	Un A Con	Com Loss	Physical Loss
		❶❷	❸❹	❺❻	❼❽❾
Billed volume (used volume) Billed with non- measured (estimated)	RW	❶ Billed with measured volume : Charged volume with meter ❷ Billed with non-measured volume : Estimated billed volume without meter			
Distribution volume (±) measured error	NRW			❻ Measured error : Insensitive bulk flow meter, instrument error and meter reading error	
Billed volume (±) measured error				❻ Measured error : insensitive meter、instrument error and meter reading error	
Non-billed volume (maintenance, emergency and social use)			❸ Non-billed measured volume : Supply for special area (Slum) ❹ Non-billed with non-measured volume: water supply enterprise		
Meter error (+instrument error)	RW	❶ Billed volume : Charged volume with meter			
Meter error (－instrument error, illegal remodeling)				❻ Measured error : Insensitive meter, instrument error and meter reading error	
±Sector: Flow meter error(electromagnetic & mechanical)				❻ Measured error : Insensitive meter, instrument error and meter reading error	
Sensitive at meter point (leakage at meter point)	RW	❶ Billed with measured volume : charged volume with meter			
Insensitive at meter point (leakage at meter point, tiny water use)	NRW			❻ Measured error : Insensitive meter, instrument error and meter reading error	
Leakages from transmission and distribution pipes					❼Leakage from transmission lines : Leakages from transmission and distribution pipes
Leakage					❾ Leakage from service pipe before meter : Leakage from service pipe until meter
Intermittent and regular illegal water use				❺Non recognized water supply : Illegal water supply	

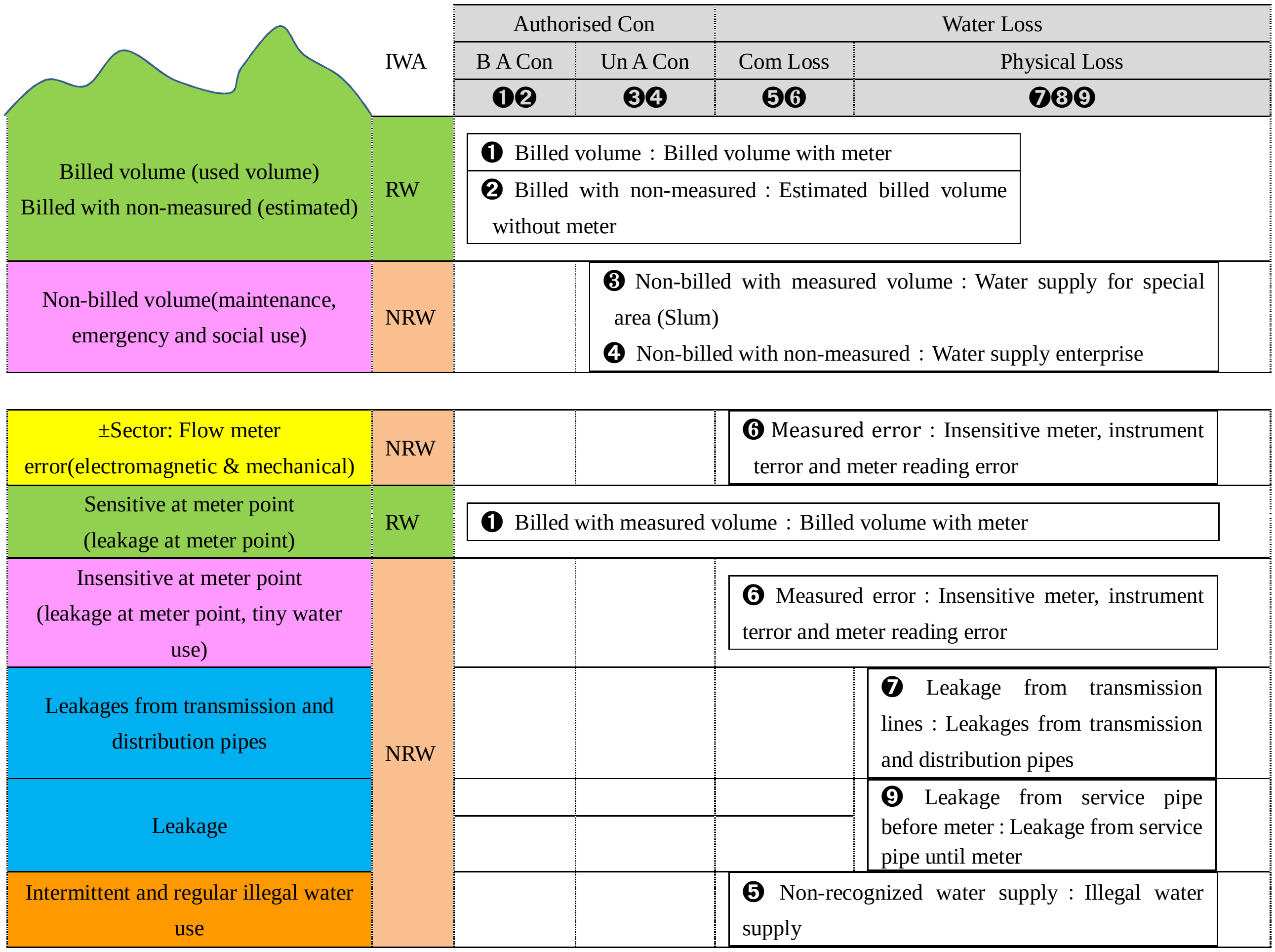
(2) Composition of NRW

Below table : Shows Composition of NRW volume
IWA : Shows classification of IWA
❶～❾: Refer to explanation of terminology

		Authorised Con		Water Loss	
	IWA	B A Con	Un A Con	Com Loss	Physical Loss
		❶❷	❸❹	❺❻	❼❽❾
Distribution volume(±) measured error	NRW			❻ Measured error : Insensitive bulk flow meter, instrument error and meter reading error	
Billed volume (±) measured error				❻ Measured error : Insensitive meter, instrument error and meter reading error	
Non-billed volume (maintenance, emergency & social use)			❸ Non-billed measured volume : Supply for special area (Slum) ❹ Non-billed with non-measured volume : Water supply enterprise		
Meter error (－instrument error, illegal remodeling)	NRW			❻ Measured error : Insensitive meter, instrument error and meter reading error	
±Sector: Flow meter error (electromagnetic & mechanical)				❻ Measured error : Insensitive meter, instrument error and meter reading error	
Insensitive at meter point (leakage at meter point, tiny water use)	NRW			❻ Measured error : Insensitive meter, instrument error and meter reading error	
Leakages from transmission and distribution pipes					❼ Leakage from transmission lines: Leakages from transmission and distribution pipes
Leakage					❾ Leakage from service pipe before meter : Leakage from service pipe until meter
Intermittent and regular illegal water use				❺ Non-recognized water supply : Illegal water supply	

(3) Composition of Sector Qmnf

Below table ：Shows composition of Sector Qmnf
IWA ： Shows classification of IWA
❶～❾: Refer to explanation of terminology



		Authorised Con		Water Loss	
	IWA	B A Con	Un A Con	Com Loss	Physical Loss
		❶❷	❸❹	❺❻	❼❽❾
Billed volume (used volume) Billed with non-measured (estimated)	RW	❶ Billed volume：Billed volume with meter ❷ Billed with non-measured：Estimated billed volume without meter			
Non-billed volume(maintenance, emergency and social use)	NRW		❸ Non-billed with measured volume：Water supply for special area (Slum) ❹ Non-billed with non-measured：Water supply enterprise		
±Sector: Flow meter error(electromagnetic & mechanical)	NRW			❻ Measured error：Insensitive meter, instrument terror and meter reading error	
Sensitive at meter point (leakage at meter point)	RW	❶ Billed with measured volume：Billed volume with meter			
Insensitive at meter point (leakage at meter point, tiny water use)	NRW			❻ Measured error：Insensitive meter, instrument terror and meter reading error	
Leakages from transmission and distribution pipes					❼ Leakage from transmission lines：Leakages from transmission and distribution pipes
Leakage					❾ Leakage from service pipe before meter : Leakage from service pipe until meter
Intermittent and regular illegal water use				❺ Non-recognized water supply：Illegal water supply	

(4) Composition of Chamber Qmnf

Below table : Shows composition of Chamber Qmnf
IWA : Shows classification of IWA
❶~❾: Refer to explanation of terminology

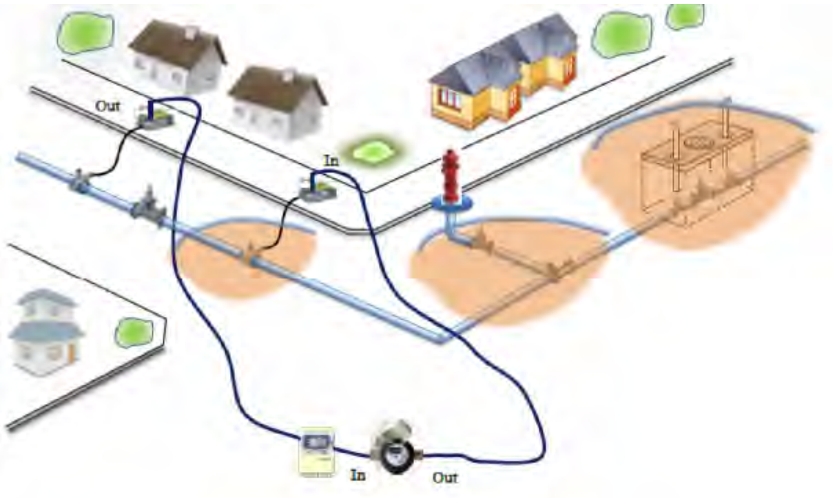
	IWA	Authorised Con		Water Loss	
		B A Con	Un A Con	Com Loss	Physical Loss
		❶❷	❸❹	❺❻	❼❽❾
Billed volume (used volume) Billed with non-measured (estimated)	RW	❶Billed with measured volume : Billed volume with meter ❷Billed with non-measured volume : Estimated billed volume without meter			
±Sector: Flow meter error (electromagnetic & mechanical)	NRW			❻ Measured error : Insensitive meter, instrument terror and meter reading error	
Sensitive at meter point (Leakage at meter point)	RW	❶ Billed with measured volume : Billed volume with meter			
Insensitive at meter point (leakage at meter point, tiny water use)	NRW			❻Measured error : Insensitive meter, instrument error and meter reading error	
Leakages from transmission and distribution pipes	NRW				❼ Leakage from transmission lines : Leakages from transmission and distribution pipes
Leakage	NRW				❾ Leakage from service pipe before meter : Leakage from service pipe until meter
Intermittent and regular illegal water use	NRW			❺ Non-recognized water supply : Illegal water supply	

(5) Direct Measurement

Below table : Shows composition of Direct Measurement
IWA : Shows classification of IWA
❶~❾: Refer to explanation of terminology

		Authorised Con		Water Loss	
	IWA	B A Con	Un A Con	Com Loss	Physical Loss
		❶❷	❸❹	❺❻	❼❽❾
Billed volume (used volume, night) Billed with non-measured (estimated, night)	RW	❶ Billed with measured volume : Billed volume with meter ❷ Billed with non-measured volume : Estimated billed volume without meter			

Sensitive at meter point (Leakage at meter point)	RW	❶ Billed with measured volume : Billed volume with meter			
Insensitive at meter point (leakage at meter point, tiny water use)	NRW			❻ Measured error : Insensitive meter, instrument error and meter reading error	
Leakages from transmission and distribution pipes					❼Leakage from transmission lines : Leakages from transmission and distribution pipes
Leakage					❾Leakage from service pipe before meter : Leakage from service pipe until meter
Intermittent and regular illegal water use				❺ Non-recognized water supply : Illegal water supply	



Direct Measurement

Handling and attention to use Ultrasonic Flow Meter and Electromagnetic Flow Meter

JICA Leak Detection Expert

Project for Strengthening Non-Revenue Water control in Kigali City Water Network

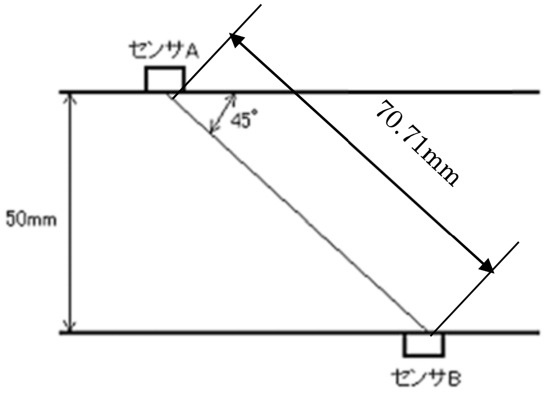
Handling and attention to use Ultrasonic Flow Meter and Electromagnetic Flow Meter

(1) A sound wave of ultrasonic flow meter

An ultrasonic wave has slower speed of sound wave velocity (speed of ultrasonic velocity) than electric wave and wavelength is short. Utilizing these characteristics, ultrasonic wave is applied for the field of distance meter, thickness meter, flow meter and diagnostic equipment for medical field.

(2) What is sound wave velocity?

In the air, sound wave velocity of the ultrasonic is 340 m/s against that of electric wave is 300,000,000 m/s (300,000 km/s). Sound wave velocity of the electric wave is faster than that of ultrasonic by 880,000 times. The electric wave will reach the same distance in shorter time than the ultrasonic wave.



As shown in the right figure, we try to measure the time of the sound wave velocity for the pipe diameter 50 mm with attached censer at an angle of 45 degree.

Distance of censer A and censer B is approximately 71 mm and ultrasonic wave will take 0.2 ms (mili sec≒0.00020 sec) and electric wave will take 0.2 ns (nano sec) respectively.

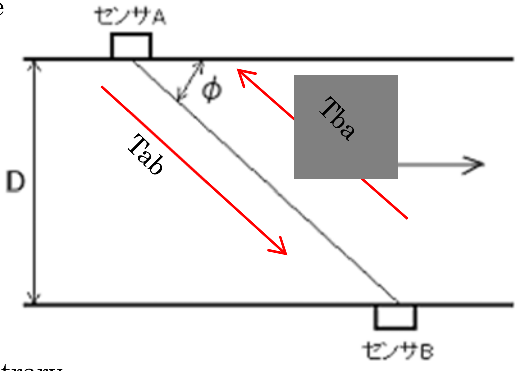
In practical problem, it will be very difficult to distinguish time difference of 0.2 ns to identify in the censer in the pipe. Accuracy of measuring nano speed will be not be high as we expected even though we can distinguish the time difference.

Therefore, ultrasonic wave is suitable to apply for short distance meter, thickness meter, flow meter and diagnostic equipment for medical field.

On the contrary, electric wave will be suitable to apply for long distance (30 km far targets) and big targets. Thus, electric wave will be used for radar, broadcast and communication equipment.

※1sec=1,000miri/sec
=1,000,000micro/sec
=1,000,000,000nano/sec

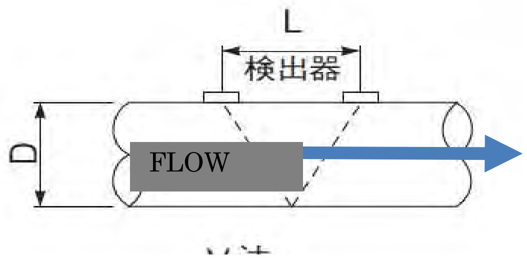
(3) Principle of measurement



Ultrasonic flow meter comprises of time difference of the transmit method,time difference by inverse number method 、 sing-around measurement method and Doppler method.
Each method has its own characteristics. Here explain the most frequently used method of time difference by inverse number method (frequency difference method).
Transducer (ultrasonic censer) will be installed at a certain location of pipe and receive ultrasonic wave.
When there is no flow, time to take from upstream A to downstream, Tab will be equal to time from downstream B to upstream A , Tba.

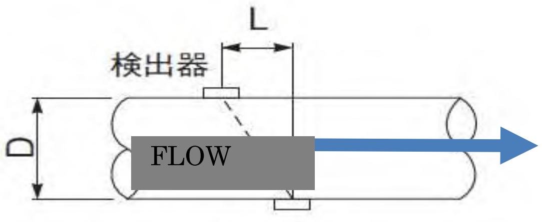
When there is flow, ultrasonic wave flow from A to B will be forward direction with follow wind.
Thus, speed of transmit of ultrasonic wave will be faster comparing with there is no flow. On the contrary, speed of transmit from B to A will be slower than speed when there is no flow against the flow with against wind.

(4) Method of installation of censer (V,Z,W, others)



① V method

This method is also called reflect mode
It is advisable to install by this mode method because installation of transducer is easy.
And when transduce cannot be installed at opposite side, transducer can easily installed at The opposite side by this reflect mode.
However, V method will be difficult for resin pipe, large size pipe and mortar lining pipe.



Z 法

② Z method

This method is also called direct mode
Route of ultrasonic wave can be shortened and used for transmit of wave is not good for pipe and When material of pipe is plastic, transmit of wave will be attenuated. In this case, it is advisable

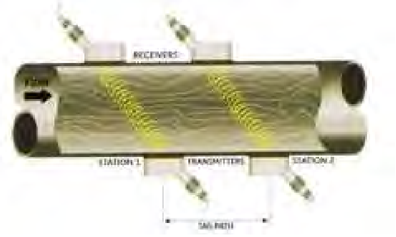
In addition to this, reflect mode needs two times of pipe length comparing with direct mode. When straight pipe is not enough, direct mode method is recommended to be installed.

③ **W method**

④ There are some flow meters which V method is superimposed to measure flow. This is called W method.

⑤ **Inside welding method**

Accuracy to measure only flow inside of pipe will be increased outstandingly. Censer is installed inside of pipe from the beginning to apply the welding method for large size transmission and distribution pipes.



(5) Characteristics of ultrasonic flow meter

1）**There is no obstacles inside of pipe**

There is no materials to disturb flow inside pipe.

AS a result of this, the following strong point will be available.

● Head loss will be zero but head loss will be occurred for small size pipe due to bindings.

● Structure is simple and trouble is seldom developed.

2） **Pipe is clean**

Foe U type pipe, when transmitter/receiver is installed at outside of pipe, flow measuring inside pipe is completely contactless with flow meter.

3）**No influence by density and viscosity of flow**

Signal of flow will be proportional to volume of the flow but not influenced by density and viscosity of the flow in principle.

4）**Wide range of measuring flow**

Full scale flow of the ultrasonic flow meter can be adjusted freely at the converter side. Signal of the flow will be appeared at nearly zero pint and wide range of flow can be measured by one ultrasonic flow meter. Wide range of ultrasonic flow meters have been made for diameter of several meters in large size and 4 mm in small size.

5）**High accuracy**

It is said that accuracy of the wetted type ultrasonic flow meter is 1 % to 2 % for full scale meter but now accuracy is 0.5 % of the indicated value due to the technological development.

More accuracy flow meter has been manufactured by increasing lateral line.

6）**Quick response**

Ultrasonic flow meter can be adjusted against variation of flow quickly because mass and thermal capacity are not involved.

It is also be able to adjust pulsatile flow.

7）**Possible to measure for opposite direction flow**

Structure of upstream and downstream is symmetrical and also can measure for the opposite flow.

There are some week points as follows:

1） **Need straight pipe**
Ultrasonic flow meter as well as differential pressure flowmeter will need straight pipe at the upstream 10 times of diameter and downstream 5 times of diameter pipe. Longer straight pipe will be necessary under some pipe line conditions (when lateral line be increased, straight pipe length be decreased but cost will increase).

2） **Week point for air bubble**
Air bubble in the fluid will block the flow of ultrasonic wave. Only small amount of air bubble will stop operation of ultrasonic flowmeter and this is the most outstanding week point. However, recently new ultrasonic flowmeter is made by devising signal processing against air bubble which is less influenced to measure the flow.

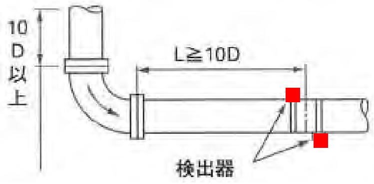
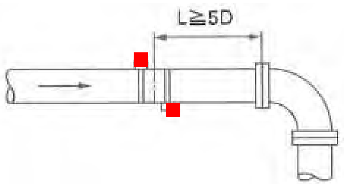
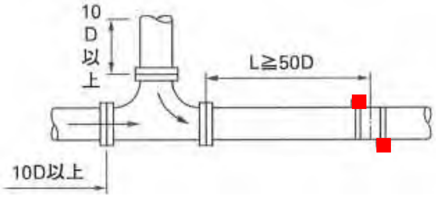
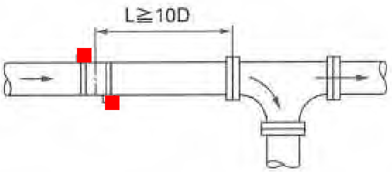
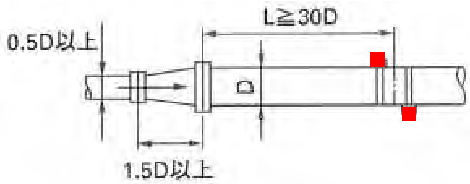
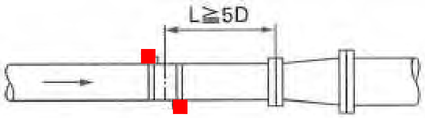
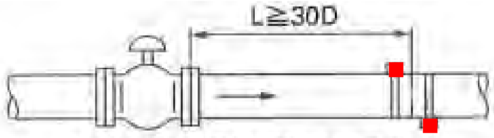
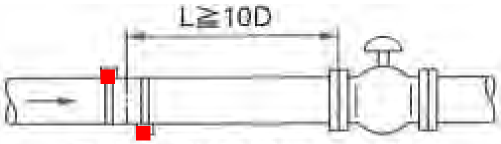
Clamp-on type ultrasonic flowmeter has following characteristics in addition to the above points.

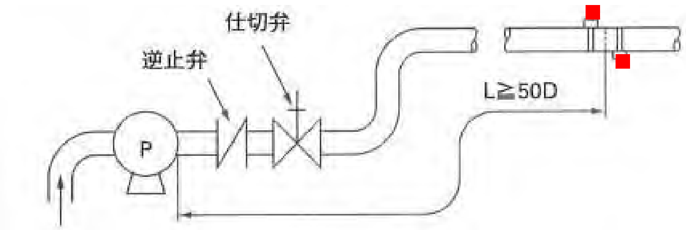
1）Cost is constant for large size meter.   2）Contactless completely with fluid
3） Repairing work can be made without interrupting flow.

However, error factor to estimate thickness of pipe and refraction of ultrasonic wave will increase. Thus, accuracy of the measurement at full scale will be 2 % to 3 %.

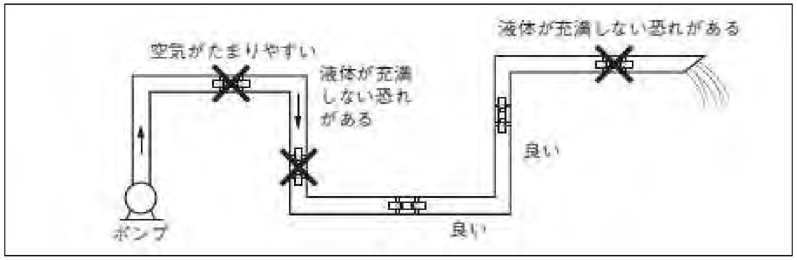
(6) Attention points to measure by ultrasonic flowmeter

Position of installation of censer will be greatly influenced to accuracy of measuring. The following conditions must be kept to measure and no guarantee for accuracy.

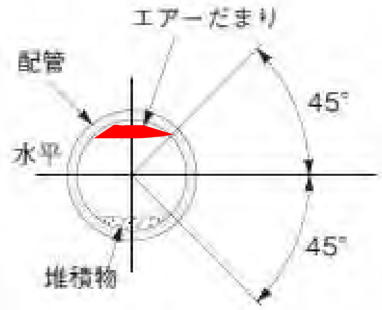
Position	Install at downstream of flow	Install at upstream of flow
Including 90 degree bend		
Including T-shaped pipe		
Including different diameter of pipes		
Valves are installed at the both side of flowmeter	 上流側弁で流量調節をする場合	 下流側弁で流量調節をする場合

Pumps are installed at both side of flowmeter		

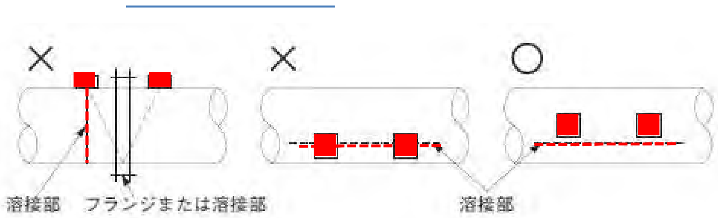
- To avoid pipeline which fluid will not be full flow。



- To avoid pipeline which dead air space will be occurred

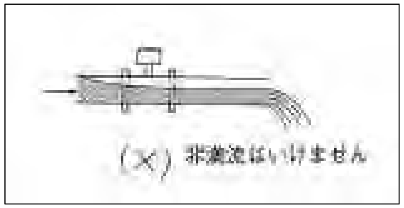


- To avoid welding place and joint

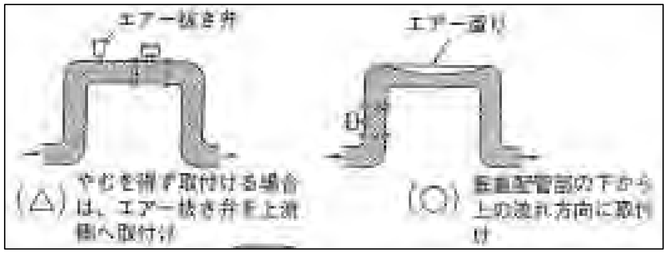


(7) Conditions of pipe where ultrasonic flowmeter be installed

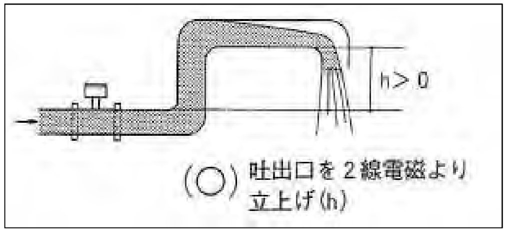
① No water filled



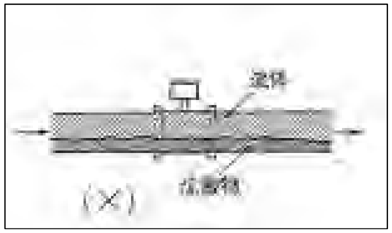
② Not approved appearance dead air space

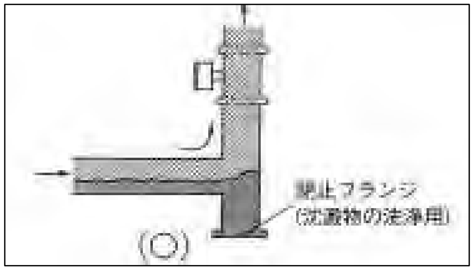


③ Pay attention to install near water tank

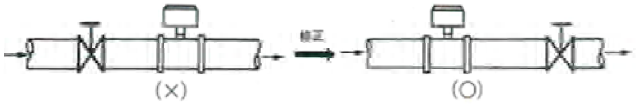


④ Sediment in the pipe

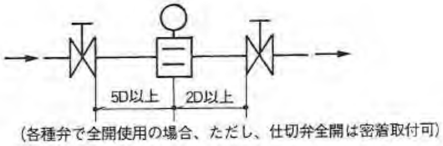




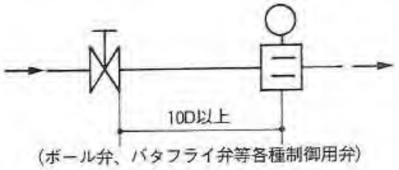
⑤ To install downstream of pipe



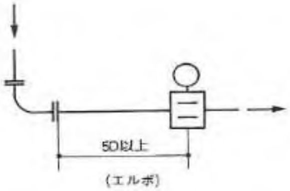
⑥ Need a certain length of straight pipe

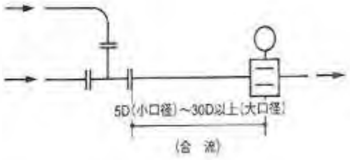


Approve close related use of sluice valve

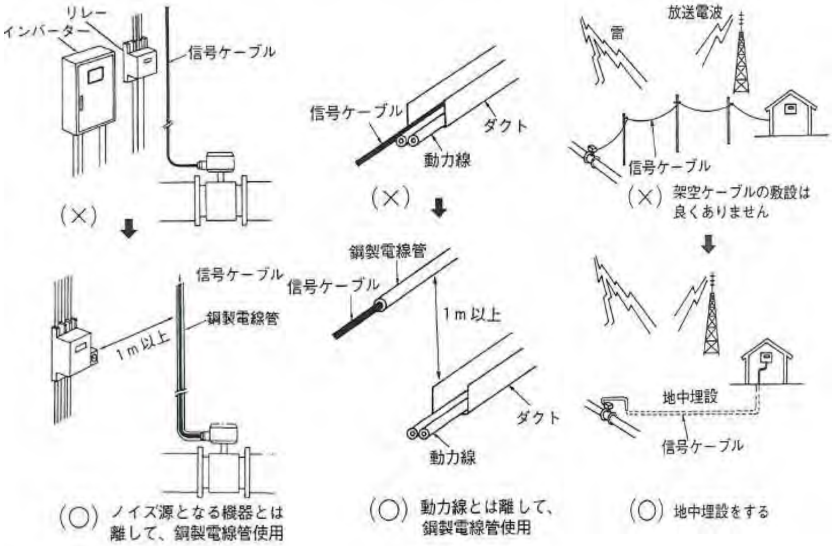


⑦ In case of elbow at upstream with junction flow





⑧ 電磁ノイズを避ける



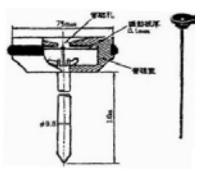
Left figure ; one meter distance should be kept from the equipment which will occur noise
Middle figure; Protect flowmeter with coated steel pipe
Right figure; not good position near aerial cable. Better install underground.

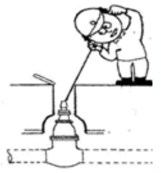
Method and Classification of Leakage Detection

CATEGORY 1
Acoustic leakage sound detection method

Acoustic bar

Structure is simple, less trouble and cheap. Contact tip of bar at place where noise happen and attach ear to head of acoustic bar.



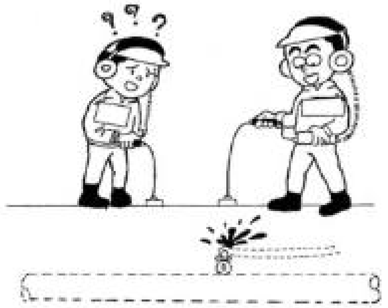


Electronic acoustic bar

Amplify vibration sound transmitted from bar and used for person with hard of hearing.

Headphone type leakage detector

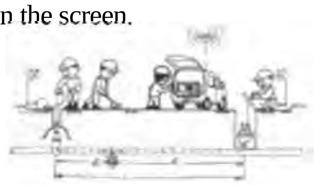
This is composed of leakage sound detector (pick up) and main body. And detect leakage sound and convert it to electric signal. The electric signal will be amplified to greet extent. The amplified sound can be heard by headphone and show by loudness by meter.



CATEGORY 2
Analysis of sound source method

Correlated leak detection method

Install two detectors (extension) at both side of pipe and observe/evaluate waveform shape difference.
To confirm whether interrelated waveform available or not. And input data of number of model pipeline, length (actual length), sound wave velocity, pipe material and diameter of pipe. Based on data, calculation will start. From leakage points, distance will show in the screen.

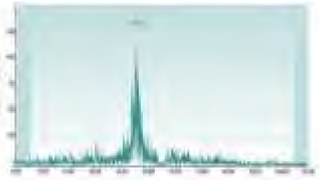


Sound-level meter

Install censer roger at fire hydrants, gate valves and water meters and record (memorize) the sound level in the measuring time. Analyze the data in three dimensions by special software. Based on the three dimension figure, Judge whether abnormal sound is found or any leakage from pipe line.

Multipoint correlation method

Logger type correlation leakage detector with non-wireless type.



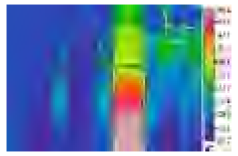
Time integration type leakage detector

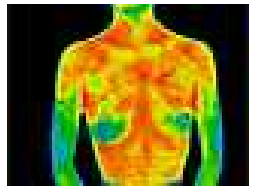
Leakage has its characteristic of continuous sound and integrated by time whether leakage is occurred or not.

CATEGORY 3
Mass spectrometric analysis/ geophysical exploration method

Investigate thermal source method

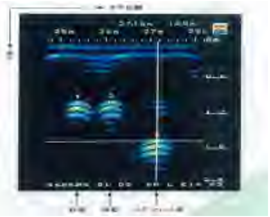
Temperature difference resulted from leakage will be found on the surface of road when pipe is installed under shallow place and surface of coating structure. This phenomenon occur when beginning of snow fall. Thermograph and radiometry detectors can measure source of heat.





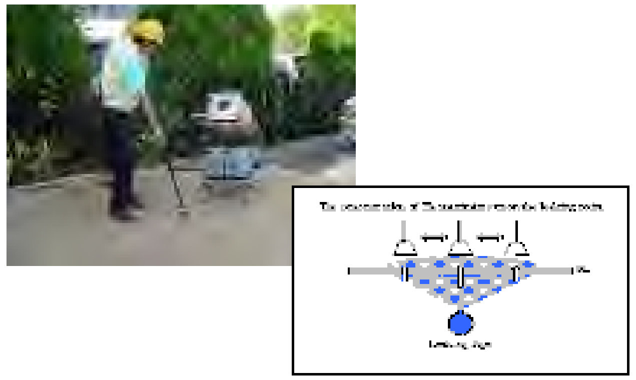
Radar method

Emit electromagnetic waves from antenna into the earth and differentiate soil and other materials (underground pipe, cave and ground water). Base on the information obtained , identify location of pipe, depth or any cave available due to leakage.



Permeation leakage/transpire detection method

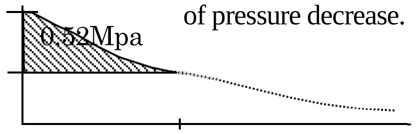
Inject noble gas into pipeline and detect gas at deterioration open point on the surface.



CATEGORY 4
Other methods

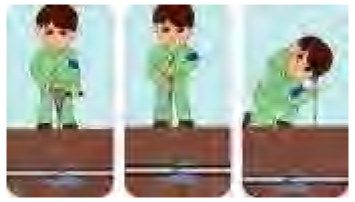
Pressure measurement method

Shout down both side of valves of pipeline where measuring leakage and observe pressure condition. If no leakage, pressure will not decrease but pressure will decrease when leakage occur form pipeline.
Calculate volume of leakage by measuring extent of pressure decrease.



Boring method

Even when leakage is found but it is difficult to pinpoint the place of the leakage. Boring method will identify exact place of leakage and improve burden of repairing work.



Air compressing method

Compressed air is injected to have air leakage in order to finout leakage when pressure is low, leakage is few and rarely occurrence of leakage noise。

What is leakage sound ?

CATEGORY 1
Occurrence of leakage sound

CATEGORY 2
Variation of leakage sound

CATEGORY 3
Transmission of leakage sound

CATEGORY 4
Frequency of leakage sound

Occurrence of leakage sound near damaged place

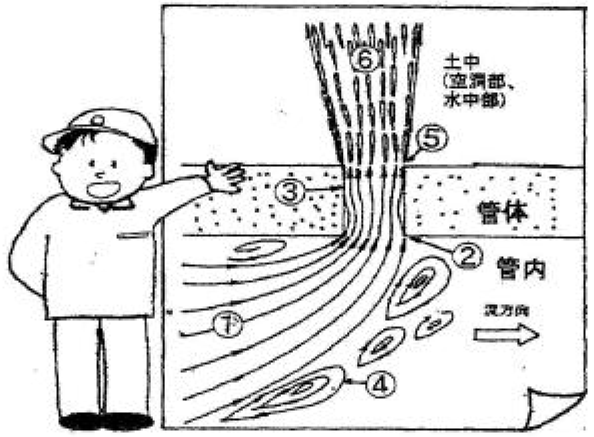
① ④→Low leakage sound resulted by vortex flow inside pipe.

② →Edge sound at point of damaged place.

③ ③ →Sticking spouted water/breakaway which resulted contraction flow sound and coanda effect sound by high and low sounds inside pipe.

⑥ →Spouted water sound which come from edge of damaged pipe into cave of soil will make high sound with mixed of air and water and air spout sound will occur.

④ → Spout from damaged edge into water sound is low comparing with cave sound.



Leakage sound will change according to the surrounding conditions

The less the pressure, the less the leakage sound. Contrary, the higher the pressure, the higher noise. If the pressure become over a certain level, it become saturation state.

No change by time passing

Reason to change leakage sound will be made by water pressure that will be changed in accordance with usage of water volume by customers. And leakage sound will be changed by time passing.

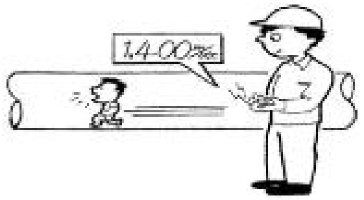
Leakage sound will change according to size of damaged place and speed of spouting water.

The more speed of damaged place, the bigger noise will be and the less speed, the low leakage sound will be.

Material of pipe	Diameter	Velocity (m/sec)
DCIP T	100	1,340
DCIP A	100	1,330
DCIP S	100	1,320
SUS	20	1,300
Copper Pipe	100	1,290
Lead Pipe	13	1,130
ACP	100	1,110
PVC	13	640

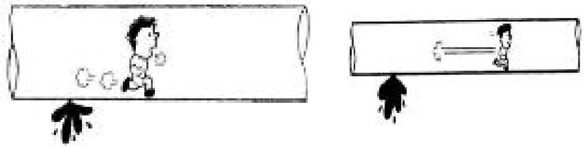
Location of transmitting leakage sound

Leakage sound will travel at the rate of approximately 1,400 m/sec in the water, 250 to 700 m/sec in the sandy soil and 1,000 to 2,000 m/sec in the loamy soil respectively.



Transmitting leakage sound is different for distribution pipe and service pipe

Allier formula (water hammer formula to calculate transmitting speed) is used to calculate transmitting speed for distribution pipe (thickness of pipe is rather thin comparing with diameter of pipe=CIP).



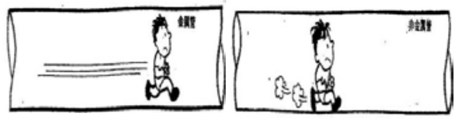
Near sound and far sound of leakage sounds

When leakage sound travel long distance, high sound of the leakage sound will attenuate big and disappear in middle of the distance. On the contrary, when leakage sound is low sound, it travel long distance due to attenuation is small.

When you hear the low sound, leakage will be found at far place than the place you heard leakage sound, in general.

Transmitting sound from metal pipe and nonmetal pipe

Transmitting speed of nonmetal pipe is slower than that of metal pipe and travel distance is short. The reason is due to difference of coefficient of elasticity.。



Leakage sound and transmitting distance		
	Long distance	Short distance
Diameter	Small diameter	Large diameter
Material	Ductile iron pipe/steel pipe Asbestos cement pipe Lead pipe/stainless steel pipe	Polyethylene pipe Vinyl pipe
Aging	New pipe （No scale layer, no corrosion）	Aged pipe （Many scale layer, many corrosion）
Leakage sound	Low noise（low frequency zone）	High noise（low frequency zone）

Applied technology for ・・・・

CATEGORY 1 Correlation method in water, Multi point correlation method

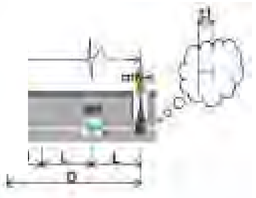
CATEGORY 2 Leak Zone Method、低周波探知工法

CATEGORY 3 Smart Ball Method 、 Helium Gasmethod

Correlation method in water

Most of the leakage sound will transmit in the water. And transmitting velocity in the water is 1,400 m/sec and it will travel long distance. Leakage from distribution pipe can be detected applying this principle.

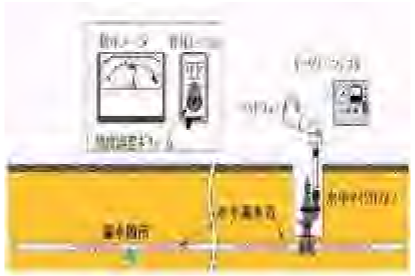
There are approximately 35 fire hydrants in Sector18. Multi point correlation method is applied and hydrophone censer will be used.



Leak Zone method

Leak Zone method can detect leakage around underground fire hydrant by installing submerged censer in the water.

Method is used for both metal pipe and nonmetal pipe. Principle is based on that leakage sound will transmit stronger at inside of water than that of at outer wall of pipe.



Water correlation is similar principle and investigate leakage with water microphone. There are approximately 35 fire hydrants in Sector18. Leakage which transmit in the water can be catch by this equipment. Investigate selected pipeline where any leakage are possible.

Low frequency wave method

Sound of leakage has frequency range from 100 Hz to 4,000 Hz.

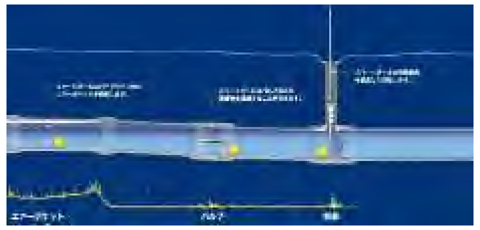
Leakage sound from PVC,PE will occur low frequency zone including less than 100 Hz frequency wave. This method is used exclusively for detection of leakage in the low frequency zone.

100HzDetector with filter

0-5000Hz Leakage detection equipment

Smart ball

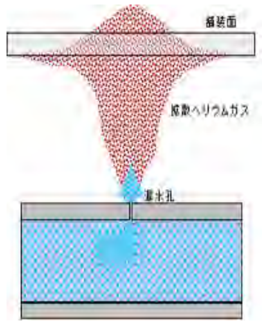
Method of smart ball mainly comprises of aluminum alloy core with diameter 66 mm and sponge shaped surrounded its periphery. Inside of the core, there are equipped with precision apparatus including sound censer, magnetic censer, thermometer and accelerometer and record equipment for collected data. And also equipped with emitting device for pulse signal and battery which work 12 hours in order to transmit location of the core ball.



- Targeted water pressure is ranged from 0.1 Mpa to 2 .0 Mpa.
- For insert smart ball and take away smart ball from pipe, more than 100 mm diameter of air valves is needed. And velocity of water is ranged from 0. 15 m/sec to 2.0 m/sec.

Tracer type leakage investigation

Tracer type leakage investigation will inject helium gas inside of pipe and mass analysis is made to detect very small amount of leakage without influenced by noise (traffic etc.). Helium gas content which detected by tracer leakage detection equipment will be measured and it is used where road surface leakage detection method is hard/difficult to applied.



Application range for leakage volume and detection method

Categories	Name	Name of used equipment	Junction range of detection	Acquisition distance	Conversion amount of acquisition range L/min					
					0.01	0.1	1	5	10	20
Mass spectrometric analysis	Permeation Helium gas detection equipment	Helium gas detector	Detection agent He Gas	NA	○	○	○	○	○	○
Acoustic leakage sound detection method	Tap/valve acoustic bar method	Acoustic sound detection bar	Transmitting sound of pipe	5m-100m		△	○	○	○	○
	Road surface acoustic bar method	Leakage detection equipment	Transmitting sound of pipe	NA			○	○	○	○
Analysis sound source method	Investigation by sound-level meter	Sound-level meter	Transmitting sound of pipe	0m-100m			○	○	○	○
	Investigation by pressure		Transmitting sound in water	0m-200m		△	○	○	○	○
	Investigation by correlation detector	Correlated leak detection equipment	Transmitting sound of pipe	0m-100m				○	○	○
			Transmitting sound in water	0m-200m		△	○	○	○	○
	Investigation by multipoint correlation detector	Multipoint correlation leak detection equipment	Transmitting sound of pipe	0m-250m			△	○	○	○
	Investigation by time integration detector	Time integration type leakage detector	Transmitting sound of pipe	0m-20m				○	○	○
Image analysis	Leakage detection technology of image instrumentation	Electromagnetic type leakage detector	Velocity of electromagnetic wave	NA					○	○
		Underground radar	Condition of soil	NA						○
Flow difference	Minimum night flow method	Electromagnetic flow meter	Range of flow	NA				○	○	○
	Flow measurement during spar time	Ultrasonic flow meter	Range of flow	NA				○	○	○
Pressure difference	NA	NA	NA	NA	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

○Mark Good

△Mark Better

For PVC pipe, PE pipe, acoustic bar and sound source methods will show less distance as described in the above table and it will also interrelated with transmitting distance.

Occurrence and transmission of leakage sound

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(1) Occurrence and variation of leakage sound
(2) Variation of leakage sound due to environment
(3) Transmission of leakage sound
(4) Leakage sound and dummy sound
(5) Acoustic leakage sound detection method and other leakage detection method
(6) Observation/examination on leakage transmission for large size pipe

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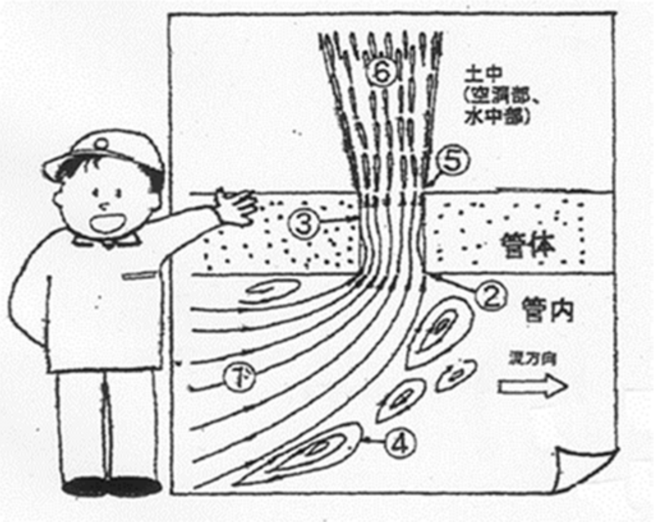
(1) Occurrence and variation of leakage sound

1) Leakage sound



Leakage sound will find out when pipeline is damaged and sound will occur from a hole where pressured water leaked outside and make noise.

1) Occurrence of leakage sound

Near the damaged parts 、①Inside of pipe and ④Low sound will occur by eddy flow in the pipe. It is classified as vibration sound resulted from low frequency wave influenced by Coanda effect.

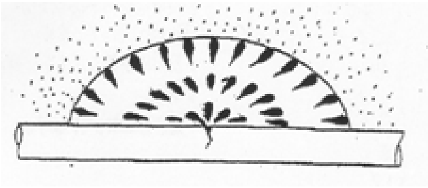
② At the edge point of damaged part, eddy will occur by complicated holes and leakage sound will occur during the eddy occur/disappear /move time and classified as edge sound with rather high frequency zone.

Inside of ③, high and low sound will occur and classified as high leakage sound audible range when water spouted from edge

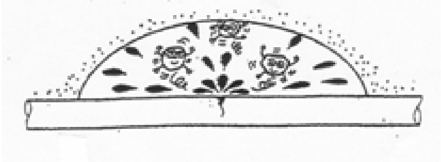
Spouted sound from damaged edge in the cave part i the soil ⑥, very high sound will be heard due to mixing water and air.

Spouted sound from damaged edge to water in the soil⑤, low sound will occur comparing with cave part. Emission sound to atmosphere is similar with the leakage sound from exposed pipe which form surrounding air and mixing zone.

Secondary leakage sound



Sound will be occurred from spouting water near cave in soil by leakage



Sound will be occurred by mixing sediment in the leakage water hit the pipe and wall of cave.

Main point:

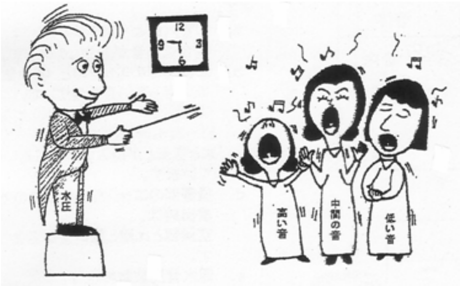
Characteristic of leakage sound is distributed ranging from low (below 0.1 kHz) to high sound (above 1.0 kHz). It is said that human being can easily hear sound ranging from 0.5 kHz to 2.0 kHz. Volume and tone quality of leakage sound is varied from material of pipe, quality, thickness, diameter, water pressure an size of leakage parts and different sounds will occur according to the different conditions. Therefore, experiences will be needed to detect by hearing leakage sound.

(2) Variation of leakage sound with environment

1) There are no same leakage sound

The leakage sound will not occur due to different size/dimension of damaged part, different pipe material/quality, different installation conditions, and different pressure conditions.

2) No change due to time passing.



Reason to change leakage sound will be resulted from water pressure change when customer use water in different time and simultaneously pressure will change. Consequently, it will change with time passing.

3) Leakage sound will change with size of damaged part and velocity of spouted water.

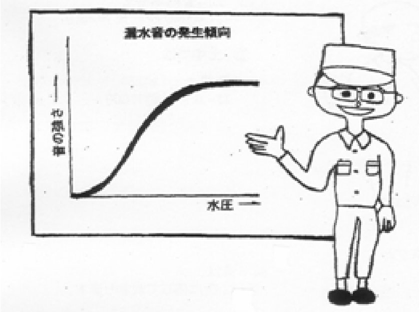
Leakage sound is complicatedly different according to sizes of damaged part and

dimensions. Leakage sound has characteristics as follow: The faster the velocity is, the higher the sound is and the slower the velocity, the lower the sound occur frequently.

Concretely, where size of damaged part is small with high pressure, high leakage sound will occur and contrary, where size of damaged part is large with big spouted water, low leakage sound will tend to occur.

4) Leakage sound will change according to pressure is changed.

Strength of leakage sound has characteristics as follow: the lower the pressure, the lower the sound is and contrary, the higher the pressure, the louder the sound is. If the pressure become a certain level high, it be come saturation state.



5) Leakage sound will change according to condition of surroundings

Leakage sound will change according to the depth of pipe laying and soil pressure against pipe will affect volume of spouted water. And sound of spherical shaped wave near the damaged part and sound of plane shaped wave distant from damaged part will transmit.

Main point:

Characteristic of transmitting leakage sound are as follows.

① The higher frequency wave will attenuate drastically in the general soil condition.

② High attenuation rate will occur where high frequency wave is above 800Hz.

③ Attenuation will be inverse proportion to square of the distance against depth of laying.

④ Attenuation rate for PVC pipe is bigger than Ductile Iron pipe and it will occur remarkably in the high frequency wave range.

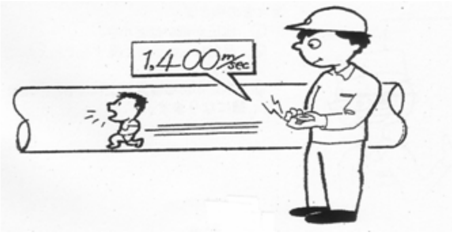
⑤ Attenuation rate will tend to become bigger for larger size pipes.

(3) Transmitting leakage sound

1) Location of transmitting leakage sound

Leakage sound will transmit at rate of speed around「approximately 1,400m/sec」 in the soil , 「approximately 250～700 m/sec」 in the sandy soil and「 approximately1,000m/sec ～ 2,000 m/sec」 in the loamy layer.

Speed of ransmitting will vary according to pipe material and diameter and transmitting leakage sound will also vary depending on pipe material and diameter.



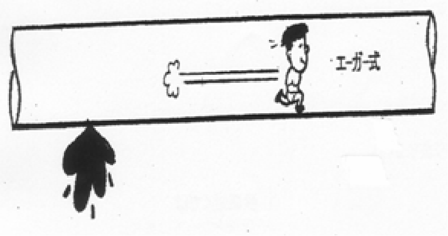
2) Transmitting leaka sound for diastribution pipe and service pipe

For distribution pipe (thickness is rather thin comparing with diameter=ductile iron pipe), following formula of アリエビ式 (velocity of water hummer transmit formula) is used.

$V = \left[(Ev/\rho)/(1 + Ev/E \times D/d) \right]^{1/2}$

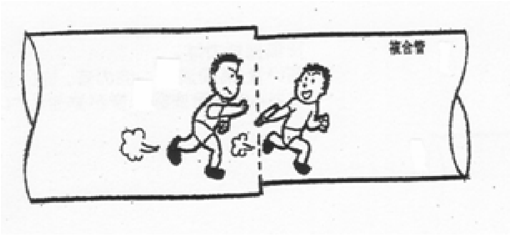
For service pipe (thickness of pipe is thick comparing with diameter=lead pipe, stainless pipe), エーガ formula is used.

$V = \left[(EV/\rho)/\{1 + 2Ev(r_1^2 + r_2^2)/E(r_1^2 - r_2^2)\} \right]^{1/2}$



V :Velocity of leakage sound transmitting (m/s)
Ev: Elastic modulus of water volume (2.11×10 kgf/m2)
E: Elastic modulus of pipe material (kgf/m2)
ρ:Density of fluid (10.97Kg･f･S/ m2)
D: Inner diameter of pipe (m)
d:Thickness of pipe (mm)
r_1:Inner radius of pipe (m)
r_2:管の半外径(m)

Pipe	Diameter	Velocity
DCIP T	100mm	1,340m/sec
DCIP A	100mm	1,330m/sec
DCIP S	100mm	1,320m/sec
SUS	20mm	1,300m/sec
COPPER	100mm	1,290m/sec
LEAD	13mm	1,130m/sec
ACP	100mm	1,110m/sec
PVC	13mm	640m/sec

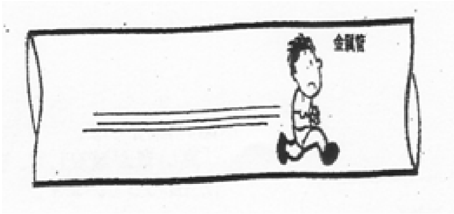


3) Leakage sound transmitting for composite pipe, metal and nonmetal pipes

- Transmitting speed will vary according to the junctions of pipe material and diameter. It is because elastic modulus will change depending on pipe material and diameter.

（Note）Elastic modulus is explained that when stress is added to the uniform elastic body, proportionally distortion will occur. Proportional constant in the formula is called elastic modulus and nonmetal pipe’s elastic modulus is bigger than that of metal pipe.

- Transmitting speed of leakage sound for nonmetal pipe is slower than that of metal pipe and distance is also shorter due to different elastic modulus.

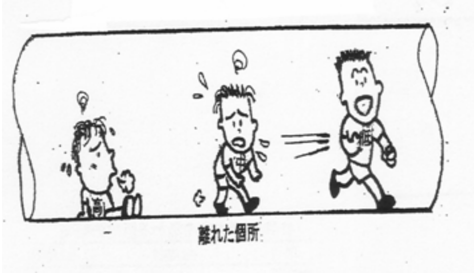


Transmitting distance	Far distance	Short distance
Diameter	Small	Large
Material	Ductile iron pipe・Steel pipe・Asbestos cement pipe・Lead pipe・Stainless pipe	Polyethylene pipe・Vinyl pipe
Aged year	New pipe（No scale layer and corrosion）	Old pipe（many scale layer and corrosion）
Joint	Welding・Lead joint	Rubber joint
Leakage sound	Low sound (Low frequency zone）	High sound（High frequency zone）

4) Frequency wave and attenuation of leakage sound

- When scale layer sticking inside of pipe, transmitting speed will vary according to formation of scale layer. And the more the scale layer formed, the slower the speed.

- Leakage sound will vary the place where we hear the sound and distance from source of sound. Various leakage sounds such as high sound (low frequency wave), middle sound and low sound (high frequency wave) will occur at the leakage point.



- Only low sound will be heard where high sound will be attenuated at the higher place than leakage location.

When leakage sound travel long distance, high sound of leakage will be attenuated and disappear in the middle of distance.

On the contrary, rate of attenuated for low sound is rather little and travel up to far place. When we hear low leakage sound, location of leakage place is rather far from the place where hearing sound in general, even though. It is defined as echo of leakage sound as imaging technical terms.

Main point:

Characteristics of attenuation for leakage sound is inverse proportional to distance. Rate of attenuation of vinyl pipe is bigger than that of ductile iron pipe and it tend to occur at the high frequency wave zone remarkably.

Spectrum of frequency of ductile iron pipe and stainless steel pipe where distance from leakage point is ranged from 5 m to 10 m is widely distributed and attenuation of the high frequency zone is remarkable. Most of the distribution is concentrated around 5 kHz area.

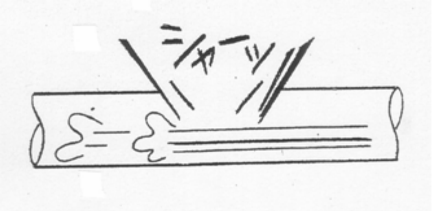
For lead pipe and vinyl pipe, remarkable attenuation occur in the high frequency zone comparing with ductile iron pipe and stainless steel pipe. Especially, frequency above 1～2KHz will almost disappear.

Leakage sound has irregular wave and travel in the underwater wave. Transmitting velocity which is used to calculate water hammer accord with the result of transmitting velocity. 「エーガー formula」is applied for lead pipe and vinyl pipe which has thick pipe wall comparing with diameter and「アリエビ formula」 is used for pipe which has thin pipe wall like ductile iron pipe.

(4) Sound and dummy sound

1) Sound resulted from water velocity in the pipe.

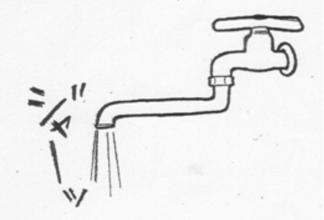
Sound will occur where valves are limited to open and velocity in the pipe water flow very fast. Leakage sound will occur at the location of cross-shaped and T-type pipes and frequency wave zone is ranging from 0.2 kHz to 3.0 kHz area.



2) Sound when water is consumed by customer.

Leakage sound will occur from cooking, washing, flushing toilet and other usages. The sound will make same sound as leakage and frequency zone is ranging from 0.5 kHz to 3.0 kHz area.

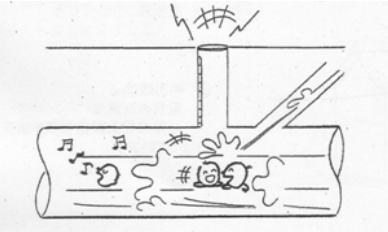
Discrimination method is to check whether water meter is rotating or not.



3) Sound resulted from sewerage flow.

Sound will occur when drainage is made in the sewerage pipe and frequency zone is ranging from approximately 0.2 kHz to 2.0 kHz area.

Discrimination method is to make it sure whether sound is different from leakage sound or not and whether sound is intermittently and continuously occur or not.

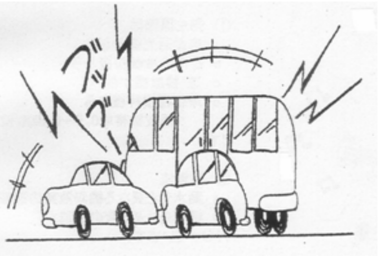


4) Sound resulted from traffic running.

Sound occur when traffic and train running and

frequency zone is ranging from approximately 1.0 kHz to 2.0 kHz area.

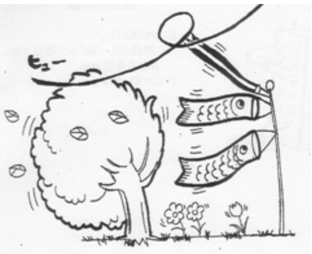
Discrimination method is to make it sure whether automobile and train are running or not and strength and weakness and continuation of sound (varied in the short period time).



5) Sound resulted from wind.

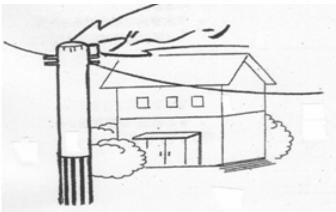
Sound occur when wind will blow at steel bar of acoustic bar and detection cable of the electronic leakage detection equipment and frequency zone is ranging from approximately 0.5 kHz to 0.8 kHz area.

Discrimination method is to cut off the wind by body and whether influence of wind will occur or not. Then, make it loop at 5 cm of detection cable and press by fingers and confirm noise reduction (easy to discriminate because special sound).



(Note) Investigation cannot be made under wind speed is more than 4 m/sec or 5 m/sec.

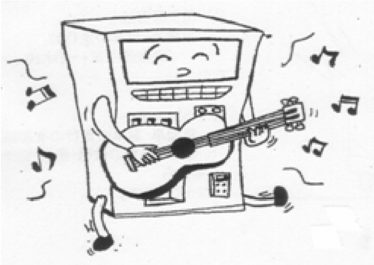
6) Sound resulted from electricity.



Sound will occur from electricity, telephone cable, transformer and street light and frequency zone is ranging from approximately 0.05 kHz to 0.5 kHz area.

Discrimination method is to check whether is occurred from electrical alternating current or availability of electrical facilities nearby.

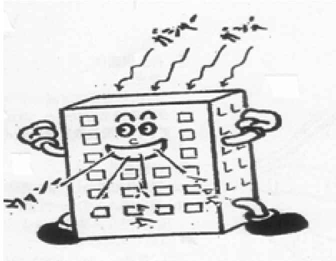
7) Sound resulted from sort of motors



Sound will occur from bending machine, air conditioner of building, ventilator and separate frame of septic tank and frequency zone is ranging from approximately 0.5 kHz to 0.8 kHz area.

Discrimination method is to stop operation of the machineries and confirm different sound of peal-like from leakage sound.

8) Sound resulted from building.



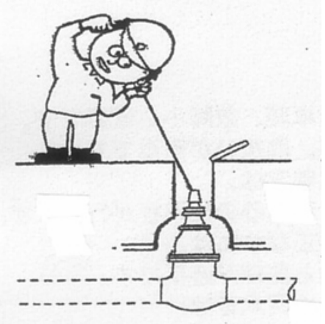
Sound occur from noise which travel in the air (wind sound, air conditioner, motor sound, automobile and train running sound) and newly combined in the building and frequency zone is ranging from approximately 0.3 kHz to 1.0 kHz area.

Discrimination method is to carry out comparison of sound hearing at 2 to 3 buildings nearby and confirm the different sound level and quality against leakage sound.

(5) Audible sound listening method and other leakage detection method

Leakage detection method by audible sound listening method

1) Leakage detection method by audible listening is to estimate leakage availability, condition and location which will occur from the damaged pipe and listening at exposed meters, appurtenances and listening at the surface of road and detecting leakage.



「Investigation of leakage」 is not sophisticated technology. It is easy to find out big leakage sound but on the other hand, it is difficult to find out where leakage sound is weak and many surface noises are exist.

2) Estimation of leakage condition

Estimation of leakage condition and place must be carried out as quickly and surely as possible. Big leakage volume? , dangerous leakage?, leakage from deep laying pipe?, complicated conditions of leakage?, metal and nonmetal pipes?, water pressure?, and it must be estimated in a short period time and be careful not to misidentify of leakage location.

Leakage location is not necessary to occur the place where leakage sound is strong or high position. It is because that leakage sound will vary according to reflection and /or bending through stone in the soil and other obstruction.

3) Outline of leakage and tone quality

Audible range of frequency zone of leakage sound detected by leakage detection equipment at present is classified as three categories of「0.2～5kHz」, 「less than Hz 」 and「low sound（below 0.5KHz）」as shown in Outline of leakage and the table below.

Item	High sound	Middle sound	Low sound
Frequency zone	Above1.0kHz	0.5～1.0kHz	Under 0.5kHz
Size of leakage	Small	big	Very big
Dimension of leakage hole	Complicated	Simple	Simple
Flow in leakage hole	Very fast	Slow	Very slow
Diameter of pipe	Small diameter	Middle diameter	Large diameter
Material of pipe	Steel pipe and stainless pipe	Ductile iron pipe, asbestos cement pipe, polyethylene pipe and vinyl pipe	
Distance	Near	Far	Very far
Water pressure	High	Low	Very low

(6) Observation of transmitting leakage sound for large size pipe

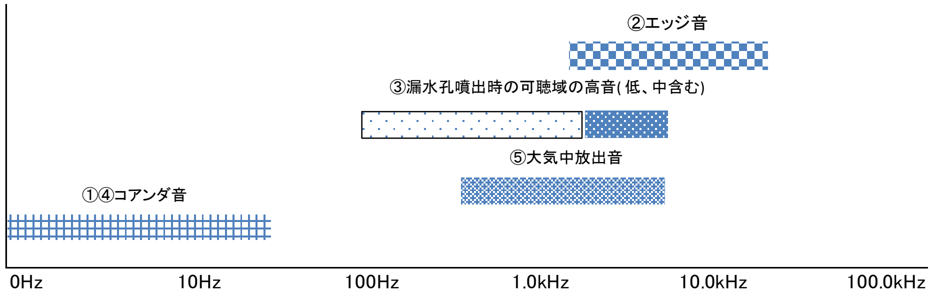
In this experimental leakage sound detection, it is easy to judge that handling low frequency wave is important matter by evaluating the results of Iwase line and Makabe trunk main. Items above-mentioned of (1)～(5), it is explained on general leakage sound and detection of leakage. Here, experiences to acquisition of leakage and literature regarding leakage detection is described for large size pipe.

1） Occurrence of leakage sound

This time, experiment has been carried out by occurring dummy leakage and observe on 2).

① ④	Vibration of ultra-low frequency by Coanda effect	Occurrence of ultra-low frequency is rare by spouted flow. When it occur, it is difficult to acquire 1-20Hz frequency zone.
②	Rather high frequency zone which is classified as edge sound	Complicated leakage hole by corrosion will make sound but it is less occur in dummy leakage.
③	High sound in the audible zone when spouted flow from leakage hole	It is estimated that this sound will frequently occur in the dummy leakage.
⑥	Ejective sound in the air	It is deemed that large number of dummy leakage sound for this time experiment.
⑤	Ejective sound in the water	Leakage sound will disappear and difficult to detect where the surrounding of the leakage is filled with water.

Following relation will be shown in the figure below.



High sound	Middle sound	Low sound	Ultra-low frequency
Above 1kHz	0.5-1.0kHz	Below 0.5 kHz	Below 20Hz

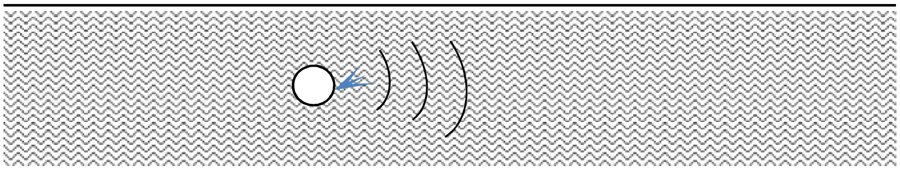
Audible range of leakage detection equipment at present in general is ranging from 200Hz to 5000 Hz. Relationship of level of sound is shown in the above table.

Comment:

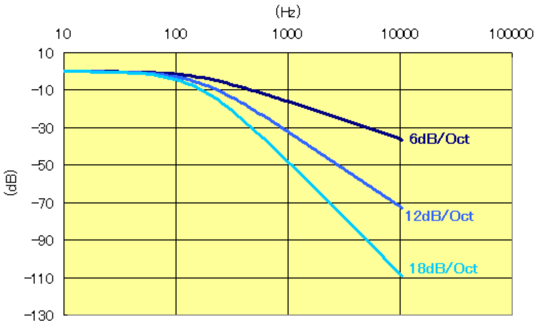
Relationship of sampling of natural occurrence of leakage sound and transmission of sound is difficult to monitor at present. However, excluding occurrence pattern resulted from special dimension of leakage, it is possible to acquire the low frequency audible zone of 500 Hz which is strong transmitting power for normal large size pipeline.

2） Travel distance of leakage sound

・Transmission characteristics in the soil



What kind of characteristic of leakage sound in the soil will have? And what kind of relationship will be found by this experiment? The following report has given by the Metropolitan Tokyo Water Supply Bureau.

High frequency	The higher frequency, the more attenuation occur.
Rate of attenuation	There are data regarding from 800Hz until 5dB/oct. Higher frequency above show remarkable attenuation. (oct means octave）. One octave comprises of 8 musical scale（do, re, mi, fa, sol, la, si and do. When one octave rises, frequency become 2 times. AS a reference to show in the figure, at the point of 6dB/oct, frequency become 2 times and signal size is half. When 12dB/oct equal to1/4 and 18dB/oct equal to 1/8. 
Laying depth	Attenuation will occur inverse proportional to depth of laying along the axis but not vertical.

Comment;

It is assumed that no cause and effect relationship between transmission in the soil and dummy leakage by this experiment.

・Characteristic of transmission in the pipe and transmission in the soil

Transmission in the pipe as well as experiment of transmission in the soil, Metropolitan Tokyo Water supply Bureau report the following.

Attenuation characteristic	Attenuation of leakage sound will be different for pipe material and attenuation will occur in the proportional to distance. Attenuation of vinyl pipe is big comparing with ductile iron pipe and it is found remarkable in the range of high frequency zone.
	Rate of attenuation of stainless steel pipe is very small comparing with lead pipe. Attenuation will be small for pie with elastic modulus (Young's modulus) is big.
	The more the pipe size, the more the rate of attenuation is. Rate of attenuation will remarkably increase for pipe diameter is larger than 1000mm.
	Water pressure and attenuation rate is not directly related. The higher the pressure, the higher the loudness of leakage sound is.
	For ductile iron pipe and stainless steel pipe, frequency spectrum is wide range of zone at the distance of 5m to 10m from leakage point and it will converge in the limit of 5,000 Hz.
	Attenuation of vinyl pipe occur remarkably at the high frequency zone and almost all composition of more than 1 to 2 kHz will disappear.

Leakage sound will transmit mainly in the piped water and simultaneously dispersed in the soil through pipe after reflection and absorption in the pipe. This relation is summarized in the table below.

Transmission distance	Primary factor to become longer	Primary factor to become shorter
Diameter	Small	Large
Material	Ductile iron pipe, steel pipe, lead pipe and stainless steel pipe	Polyethylene pipe and vinyl pipe
Aged	New (no scale layer and corrosion)	Old (many scale layer and corrosion)
Joint	Welding and lead joint	Rubber joint
Leakage sound	Low sound (approximately less than 1kHz)	High sound(approximately more than 1kHz)

Frequency zone	High sound(more than 1kHz)	Middle sound(less than 05〜1kHz)	Low sound (less than 0.5kHz)
Size of leakage hole	Small	Big	Very big
Dimension of leakage hole	Complicated	Simple	Simple
Flow in leakage hole	Very fast	Slow	Very slow
Diameter of pipe	Small	Large	Very large
Pipe material	Steel pipe and stainless steel pipe	Ductile iron pipe, asbestos cement pipe, vinyl pipe and polyethylene pipe	
Transmission distance	Short	Long	Very long
Water pressure	High	Low	Very low

Comment;

Dummy leakage which occurred this time, whether similarity with usual leakage sound or not is problem but it is difficult to get cause and effect relationship between soil transmissions. In the limited conditions, data was collected and data is not enough to issue specifications.

Considering literature and data collected this time, acquiring transmitting sound occurred at the low frequency zone effectively, more data is necessary to make matrix table to select diameter, pipe material, soil condition, depth of layer and water pressure individually in order to use makeshift countermeasure for symptomatic treatment (comfort care) of leakage by increasing monitoring activities.

Analysis of acoustic (sound) investigating

1. Terminology of acoustic (sound) investigation

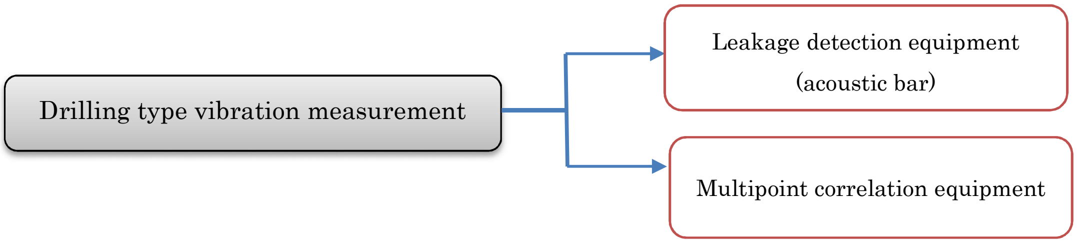
In the field of leakage detection industry, terminology is used for acoustic bar sound investigation to detect leakage by listening leakage sound at water tap and valve and to acquire leakage sound which transmit in the surface of ground.

Investigate leakage existence to contact at meter and water tap in the public road

Acquire leakage sound on the surface of ground occurring from laying pipe underground。

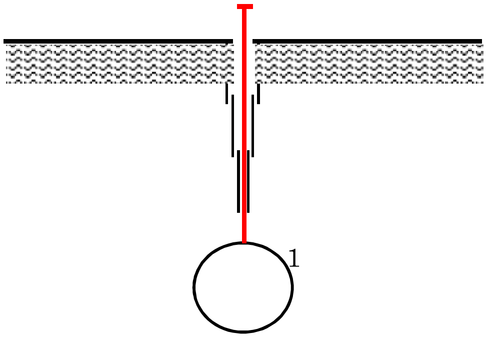
Specifications to be used for acoustic (sound) investigation this time is to drill seismometrics bar into the top of large size pipe and acquire leakage sound (dummy leakage sound) which transmit through pipe. This is called as drilling type vibration measurement method because seismometric bar is drilled into pipe.

The following system and equipment are used for drilling type vibration measurement method.



Experiment by multi point correlation equipment which is one of the drilling type vibration measurement methods is completed on 14 December. Here, acquiring leakage by leakage detection equipment (acoustic bar) which was carried out on 15 December is reported.

AS shown in the figure below, different size of drilling holes were made every 1 m pitch. Then carefully contact the seismometric bar with pipe not to damage pipe and investigate existence of leakage by using leakage detection equipment.



1. Photo at site

		
Drilling hole	Seismometric bar and leakage detection equipment	Seismometric bar and leakage detection equipment

2. Specification of leakage detection equipment

Leakage detection equipment of HG 10 A-II was used for acoustic sound investigation.

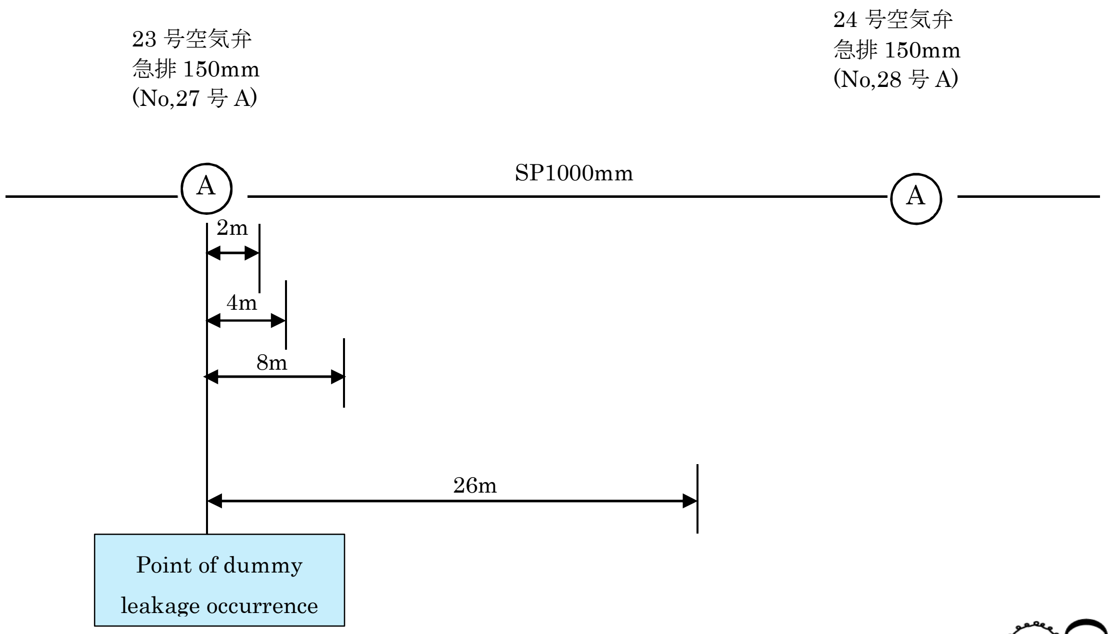
	
Leakage detection equipment HG 10 A-II	Electronic acoustic equipment FSD- 8D
Amplifier 59dB	Amplification degree 55dB
Sensitivity of censer 0.7V/G	NPC Piezoelectric element
Cost=500,000 Yen	Cost=80,000 Yen

Amplification degree of preamplifier HG 10 A-II is 59dB, voltage gain is Gi=20log10 and voltage amplification is expressed (dB). Voltage gain is a ratio of input to output and is called as gain. Voltage gain is expressed by logarithm base on 10 with unit of decibel [dB].

V/G means that accelerometer equipped in the amplifier is expressed v/g and speed censer equipped in the amplifier is expressed v/inch, 100 millivolt /g (100mV/g). And 100 v of AC voltage output is generated against 1 g acceleration. This AC voltage output will be converted into frequency in the vibration frequency and is equal to amplitude of vibration which is measured signal of AC amplitude. Spectrum of vibration is composed by this.

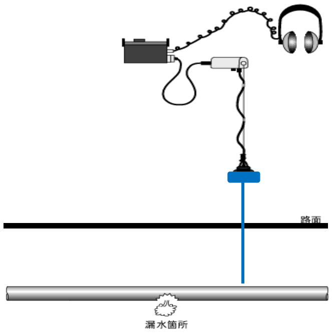
Electronic acoustic equipment use piezoelectric element as censer. Piezoelectric effect is phenomenon when pressure is applied to crystal and some kinds of ceramic and resulted into strain. Proportional to strain, voltage occur. NPC is a manufacture’s name.

3. Sketch of experiment pipeline



Generate dummy leakage at NO.27 point and drilling hole forward to NO.28, insert sensitive vibration bar in every 2 m pitch. Detection was carried out for 13 measuring points up to 26 m.

Volume of dummy leakage is 2Ltr/min、4Ltr/min and 8Ltr/min respectively.



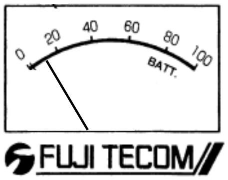
4. Results of acquiring dummy leakage sound by experienced staff

	2m	4m	6m	8m	10m	12m	14m	16m	18m	20m	22m	24m	26m
2L	○	○	×	×	×	×	×	×	×	×			
4L	○	○	○	○	△	○	○	×	×	×			
8L	○	○	○	○	○	○	○	○	○	△	○	△	×

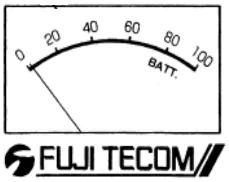
According to report from site, memo (record) has been made but not recorded by photos.
Later, data with photo will be made so that metric level of report can be seen.
Unit is mV.

Result of 2Ltr/min detection

Leakage sound was acquired at the distance by 4 m for 2Ltr/min detection.



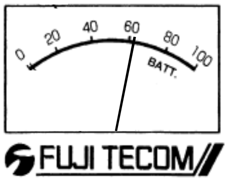
2m



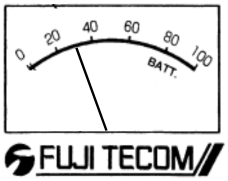
4m

Result of 4Ltr/min detection

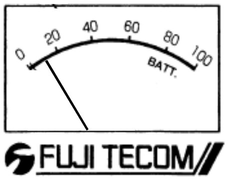
Leakage sound was acquired at the distance by 14 m for 4tr/min detection



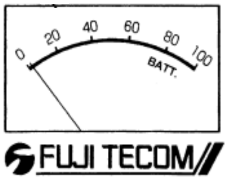
2m



6m



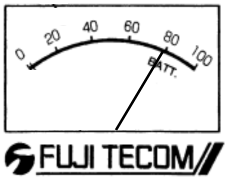
8m



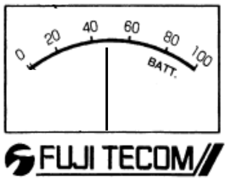
14m

Result of 8Ltr/min detection

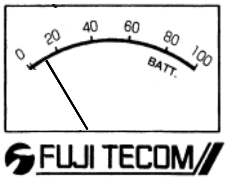
Leakage sound was acquired at the distance by 24 m for 8tr/min detection



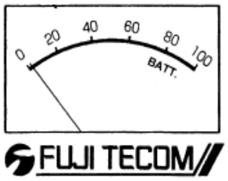
2m



8m



14m



22m

Summary of results of detection by leakage detection method

Leakage detection equipment HG 10 A-II has filter pass function and transmitting is bigger at low frequency zone of large size pipe. But contact distance of detection is ranging from 10m to 20 m. In this area, there is possibility that high and middle frequency wave will reach. Based on these fact, detection was carried out while setting filter pass. As a result, detection was effective
in the range of 200Hz to 1200 Hz.

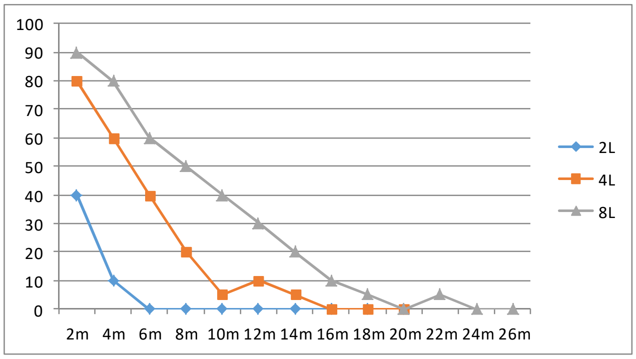
LOW			HIGH			フィルタ設定範囲
□ 100	□ 200	□ 400 Hz	□ 600	□ 800	□ 1200 Hz	
□			□			100 Hz ～ 600 Hz
□				□		100 Hz ～ 800 Hz
□					□	100 Hz ～1200 Hz
	□		□			200 Hz ～ 600 Hz
	□			□		200 Hz ～ 800 Hz
	□				□	200 Hz ～1200 Hz
		□	□			400 Hz ～ 600 Hz
		□		□		400 Hz ～ 800 Hz
		□			□	400 Hz ～1200 Hz

Filter pass is equipped with expensive detection equipment Its soundness is low and acquire effectively the sound ranging from 100 Hz to 600 Hz when setting as required at high 600 Hz. It is understood that frequency of the large pipe is approximately 500 Hz. Experiment was carried out at the range of 200 Hz to 1200 Hz so that sound which could be missing when frequency is ranging from 100 Hz to 600 Hz.

Leakage sound detection by seismometric steel bar

Result of 2Ltr/min detection is 4 m, 4 tr/min is 14 m and 8 tr is 24 m respectively.

The following graph is drawn for the purpose of visual judgement.



The above graph is made based on the field memo (record).

Vertical axis is mV.

Value of level meter is converted into sound pressure (acoustic pressure) and expressed as strength of sound (SPL: Sound Power Level) but it is not necessary to express the sound which occur at the leakage location.

Multi point correlation detection method with drilling type vibration measurement was carried out on 14 December.

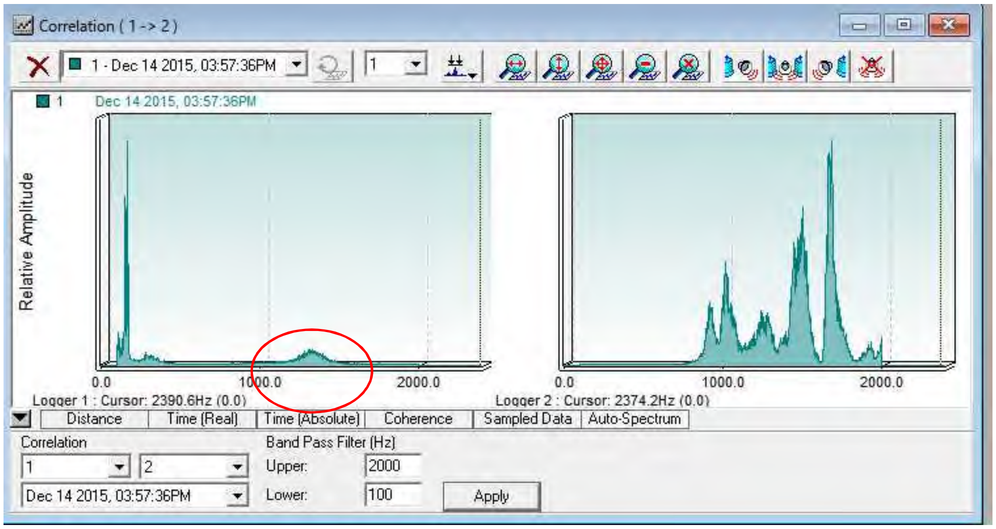
Relationship between dummy leakage and frequency for 2Ltr/min, 4Ltr/min and 8Ltr/min is explained below.

- 穿孔点振動伝搬多点相関式調査

距離、疑似漏水量	月日	時間	ロギング
100m/20.0Ltr/min	2015/12/14	2:31pm,2:32pm,2:33pm	1 分インターバル 3 回
100m/10.0Ltr/min	2015/12/14	2:45pm,2:46pm,2:47pm	1 分インターバル 3 回
50m/36.0Ltr/min	2015/12/14	3:02pm,3:03pm,3:04m	1 分インターバル 3 回
50m/20.0Ltr/min	2015/12/14	3:15pm,3:16pm,3:17pm	1 分インターバル 3 回
50m/8.0Ltr/min	2015/12/14	3:30pm,3:31pm,3:32pm	1 分インターバル 3 回
25m/4.0Ltr/min	2015/12/14	3:42pm,3:43pm,3:44pm	1 分インターバル 3 回
25m/2.0Ltr/min	2015/12/14	3:57pm,3:58pm,3:59pm	1 分インターバル 3 回

Censer No. 2 cover ☐ part. Relationship between frequency zone and acoustic (sound) investigation are studied.

In case of 2Ltr/min



Logger 1 : Cursor: 2390.6Hz (0.0)

Logger 2 : Cursor: 2374.2Hz (0.0)

Correlation: 1, 2

Dec 14 2015, 03:57:36PM

Band Pass Filter (Hz)

Upper: 2000

Lower: 100

Sound of ”1000～2000Hzis occurred more relatively.　It is understood that sound will not occur under the frequency of 500Hz? What is sound of frequency? General consideration is Ok)

Sound of 1000～2000Hz occurred relatively many as shown in the above graph.

Relative axis for left and right will not have the same scale.

Frequency which occur in the Loger2 is coming from only Logger2 itself and frequency below 500 Hz seldom appear in the Logger 2.

However, 500 Hz frequency arrive at Logger1 (precisely 2-300Hz) as shown in the graph.

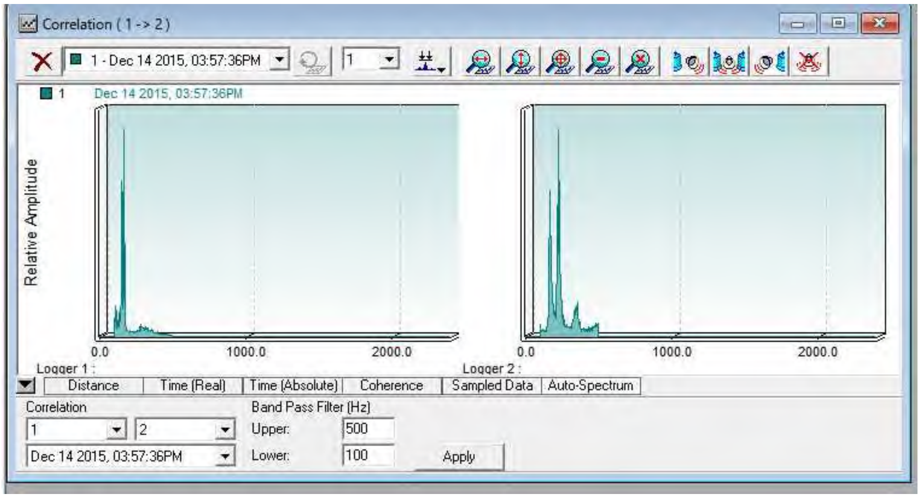
Sound of 1000 - 2000 Hz will prevail to that of 100-2000Hz and seems not to appear by 100-200 Hz.

▨ as Logger1 is rather low relative index but small amount frequency of 1000-1500Hzarrived.

Logger2 is location of dummy leakage and many frequency of 1000Hz to 2000Hz occur and frequency of 200 – 300 Hz arrive at Logger1. And a part of 1200 Hz arrive. Refer to shaded red area. →

Frequency below 500Hz seems not appear in Logger 2 for Spectrum of 0-2000 but it is not true. This should not be misunderstood.

Sound which occurred in Logger 2 surely arrive at Logger 1 when we select the frequency of 0-500Hz only as shown in the figure below. In this case, distance is 25 m.



Correlation: 1, 2, Dec 14 2015, 03:57:36PM

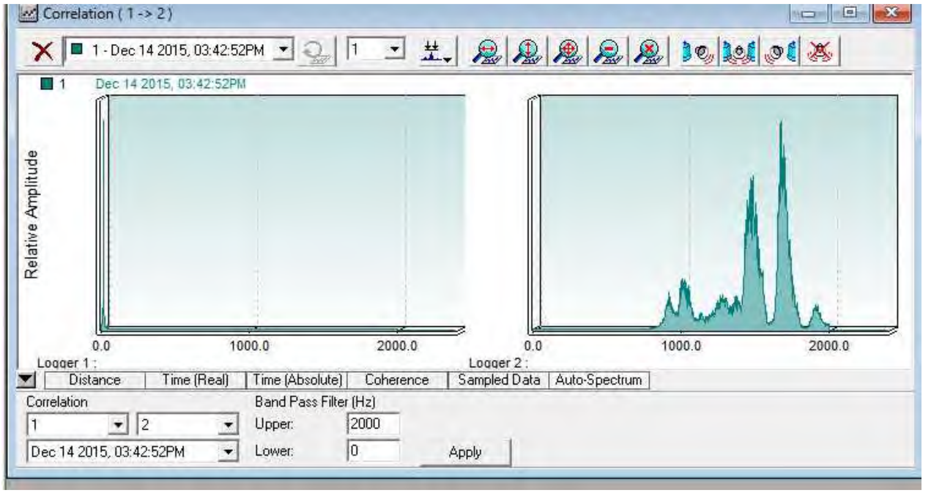
Band Pass Filter (Hz)

Upper: 500

Lower: 100

Continuation from previous section; Comparing frequency only below 500 Hz between Logger1 and Logger2, it is understood that both sounds will occur relatively same frequency. Precisely it is not same strength (relative index) but commonly used same meaning.

In case 4Ltr/min



Correlation: 1, 2, Dec 14 2015, 03:42:52PM

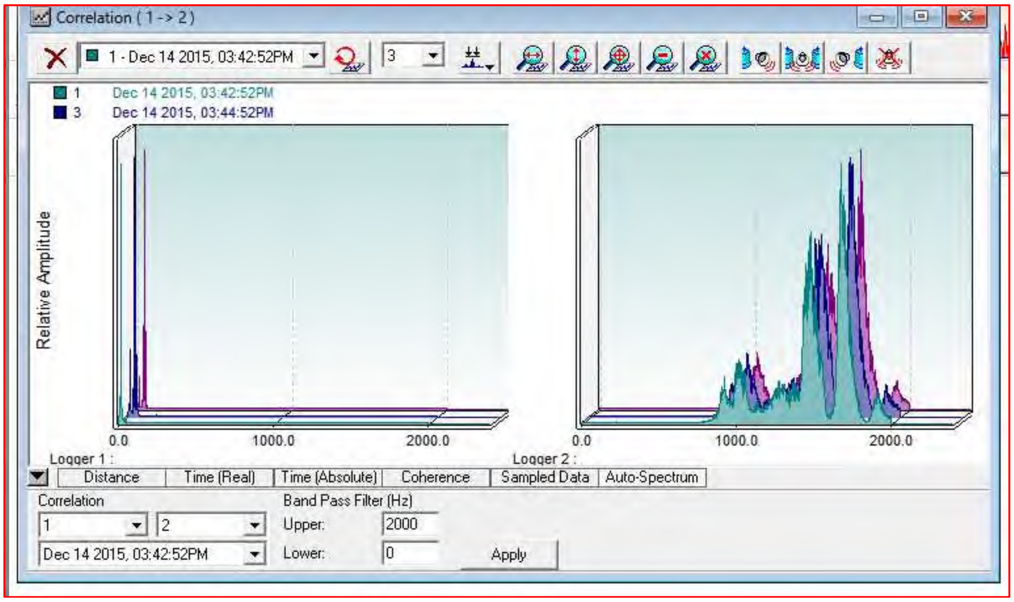
Band Pass Filter (Hz)

Upper: 2000

Lower: 0

Logger2 is location of dummy leakage point and many frequency of 1000Hz to 2000Hz occur and frequency of 200 – 300 Hz arrive at Logger1. And a part of 1200 Hz arrive in small amount. Distance is 25 m, in this case.

What is relative amplitude of Logger 1 in the frequency range of 1000～2000Hz?



Correlation (1 -> 2)

1 - Dec 14 2015, 03:42:52PM

3

1 Dec 14 2015, 03:42:52PM

3 Dec 14 2015, 03:44:52PM

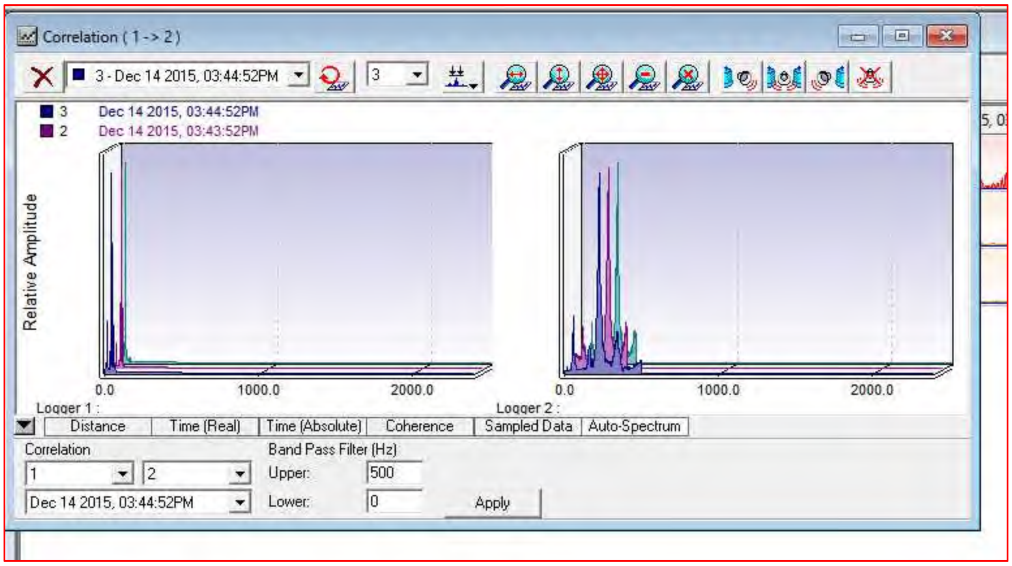
Correlation: 1, 2, Dec 14 2015, 03:42:52PM

Band Pass Filter (Hz)

Upper: 2000

Lower: 0

Above graph show three time of spectrum 0-2000 Hz for Logger1 and Logger 2.
Scale of relative index is not same. Therefore, comparing with frequency of 1000-2000 Hz, there is no sound occurrence in the over 200 Hz area.



Correlation (1 -> 2)

3 - Dec 14 2015, 03:44:52PM

3

3 Dec 14 2015, 03:44:52PM

2 Dec 14 2015, 03:43:52PM

Correlation: 1, 2, Dec 14 2015, 03:44:52PM

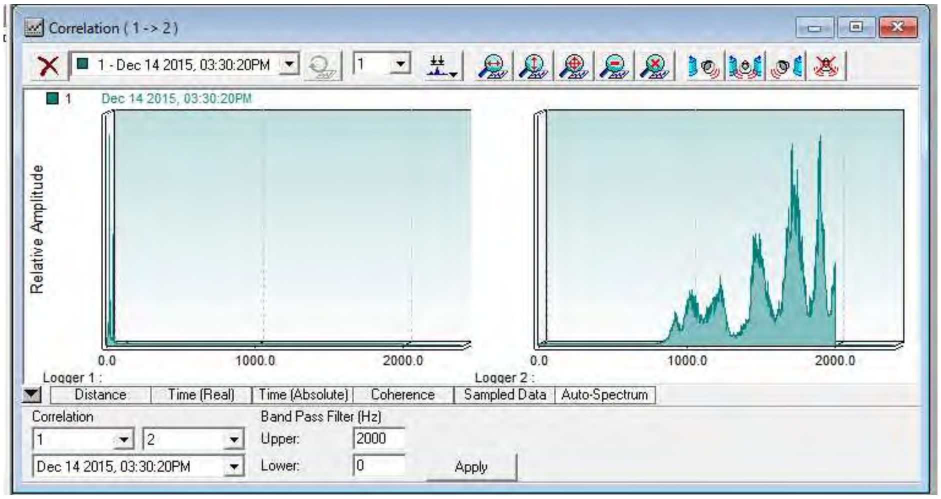
Band Pass Filter (Hz)

Upper: 500

Lower: 0

Above graph show three time of spectrum 0-500 Hz for Logger1 and Logger 2.
Scale of relative index is not taken into same. Sound of frequency 300-500 Hz is disappeared in Logger1 but below 300Hz is possibly arrive.

In case 8Ltr/min



Correlation (1 -> 2)

1 - Dec 14 2015, 03:30:20PM

1 Dec 14 2015, 03:30:20PM

Correlation: 1, 2

Dec 14 2015, 03:30:20PM

Band Pass Filter (Hz)
Upper: 2000
Lower: 0

Logger2 is location of dummy leakage point and many frequency of 1000Hz to 2000Hz occur and frequency of 200 – 300 Hz arrive at Logger1. And a part of 1200 Hz arrive in small amount. Distance is 50 m, in this case.

When we consider only transmitting frequency by acoustic leakage detection, it is not to always acquire appropriate results.

It is necessary to accumulate monitoring data and integrate data in order to make matrix table to look at the relationship between transmitting distance by diameter and frequency.

Manual for Leakage Detection

Measurement of Leakage Volume

JICA Leak Detection Expert

Project for Strengthening Non-Revenue Water control in
Kigali City Water Network

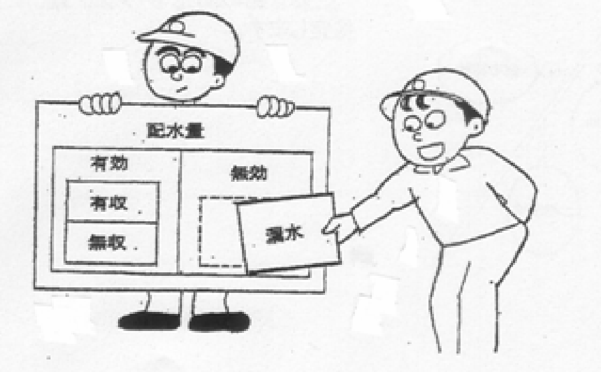
Measurement of Leakage Volume

1. Method of measurement of leakage

(1) Necessity to measure leakage volume

Before investigation to measure leakage volume, following investigation will carried out for each block; ① Present condition, ② Priority of leakage investigation, ③ Investigation method, ④ Objective of work, ⑤ Implementation period and ⑥ Recovery conditions.

After investigation to measure leakage, following will be carried out; ① Remaining leakage volume and ② Effectiveness of leakage investigation.

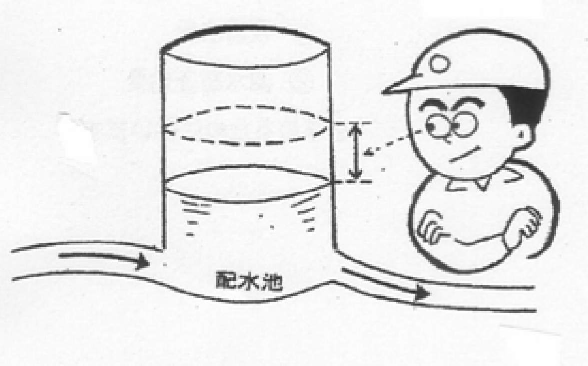


(2) Method to estimate leakage volume

Estimation of leakage volume without measuring is made by data, analysis of distribution volume and Non-revenue of Water (NRW).

(3) Method of estimation from accounted for water

Estimation is made from distribution volume and accounted for water in the specified block.

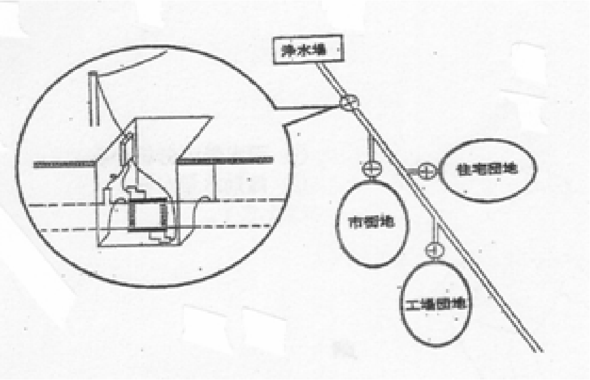


(4) Method to estimate from variation of level of reservoir

Estimation is made from data regarding variation of water volume at reservoir, tank and level of well.

(5) Method of estimation from data which measured along major pipeline

Estimation is made from measuring data of major pipeline(flow rate and pressure).



Main point:

Method to calculate leakage volume is by measuring actual flow and by calculating collected data, and also method to make out individual leakage and evaluate leakage in the specified block from all area.

① Method to calculate by measuring

a. Method by visualizing

Method by visualizing is to estimate leakage volume by drain water and visualize the strength of water flow and compare it with photo and diagram which standard leakage volume is defined at site. (refer to the supplement at the end of book).

b. Direct measuring method

Direct measuring method is to calculate leakage volume which water is collected from leakage pipe before repair work will be made with excavation of pipe. Leaking pipe will be covered by appliances and rubber tubes guiding leaks in to one container so that volume can be measured by measuring equipment.

c. Measuring method by demolition of pipe

This method is to calculate leakage by method a and/or method b mentioned above where cutting pipe for repair and fabricate demolished pipe. Pressure will be kept at equal pressure at site and can get relatively precise result. But it is difficult to measure good when leakage hole is big enough.

② Method of measuring leakage volume by calculation

Leakage volume is calculated from area of leakage hole and pressure by the following equation.

$$Q = C \cdot a \cdot P^n$$

Q : Leakage volume（m^3）
P : Water pressure（kgf/cm^2）
C: Coefficient of dimension of leakage hole
a : Area of leakage hole（cm^2）
n : Exponent（0.5 または 1.15）

Here, two exponents are used based on the hydraulic conditions.

$n = 0.5$ Assuming leakage hoe as orifice.

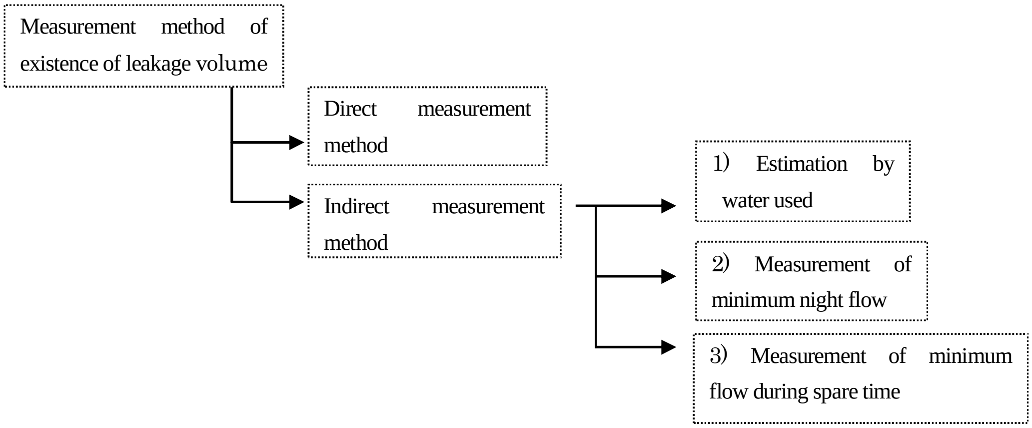
$n = 1.15$ Experimental value assuming seepage flow in to surrounding earth and sand from joint and crack od pipe.

2. Method of measurement of leakage

(1) Classification of measurement method

Understanding existence of leakage volume in the targeted area for leakage investigation is basic rule to proceed the prevention of leakage work. By knowing the existence of leakage volume, estimation of the conditions of the targeted area's water supply facility, sampling of prevention of leakage area, selection of working method, judgement of effect of work and selection of replacement of leaked pipe will be possible. And this will lead to implementing the effective maintenance of the pipeline.

Method to know existence of leakage volume is as follow.

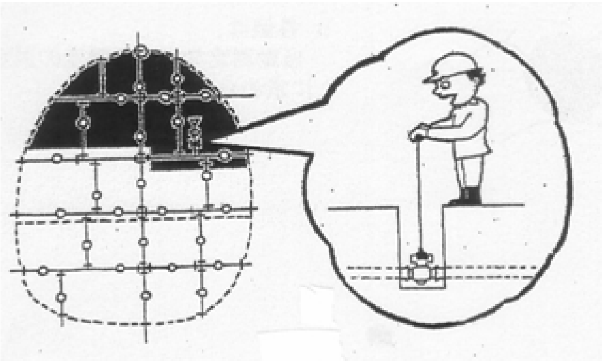


3. Method of measurement of leakage

⑴ Direct measurement method and indirect measurement method

- Indirect measurement method is to estimate leakage volume from minimum flow which leakage of the specified area is measured while water supply keep as usual conditions.

Good point is that accuracy is low comparing with direct measurement method because leakage included water usage and working period, cost and work force will smaller than that of direct measurement method.



- Direct measurement method is to measure leakage volume by stopping all water supply faculties related.

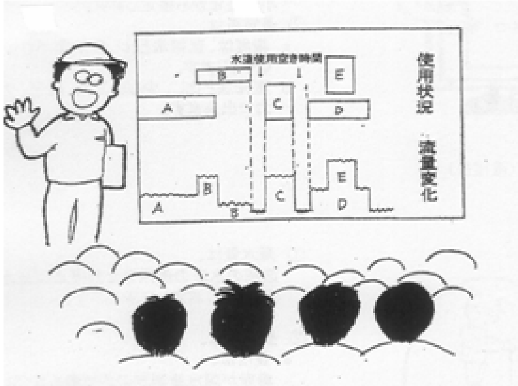
Leakage volume will be measured by stopping all water usage at targeted block (close stop valve).

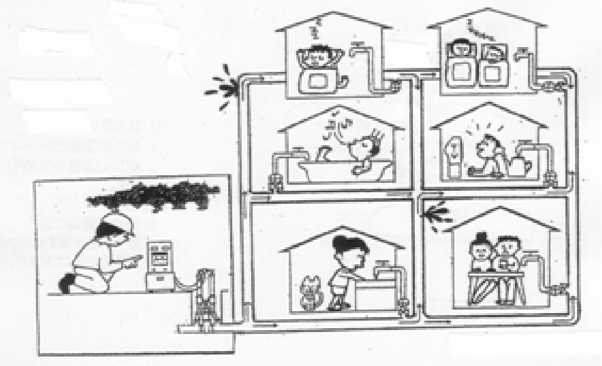
Good point is that accuracy is the highest in the leakage measurement methods. Weak point is that cost (functional investigation for work force, gate valve and stop valve) and longer implementation period is expensive due to mainly night work.

⑵ Detailed description of direct measurement method

Leakage volume is measured under water usage in normal conditions. Minimum night flow is measured during midnight (3 hours from 2:00 to 5:00 am) at the time zone (5 sec to 1 min) when water is not used and acquire minimum flow value (approximate value).

Measurement equipment can measure flow and pressure in term of second unit (electromagnetic and ultrasonic flow meter) and also equipped with automatic recording gage. In addition, mobile function is necessary.



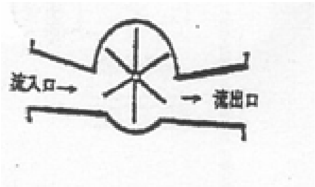


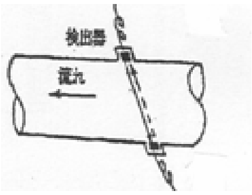
⑶ Apparatus for direct measurement method

Component drawings

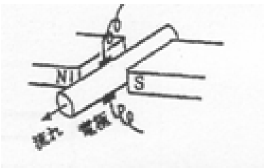
Type of measurement equipment

Type	Movement
Wheel type	Flow is measured by applying rotation of wheel which is proportional to inner wheel velocity.
Ultrasonic type	Ultrasonic wave is projected by transmitter attached to pipe and rate of transmitting velocity is depending on the velocity of water in the pipe. Flow rate is calculated by multiplication of area of



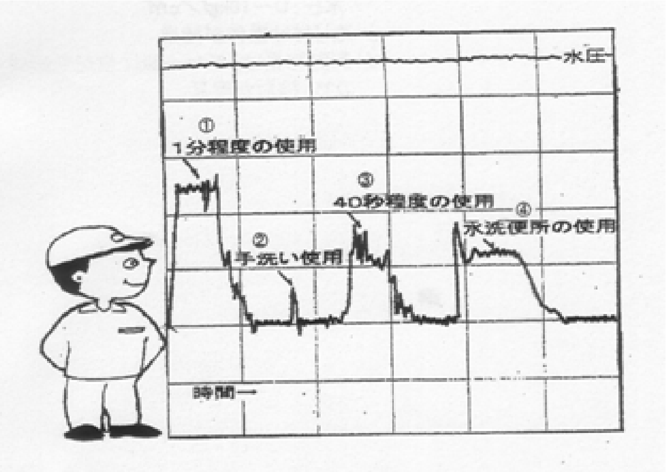


	pipe and velocity. Velocity is calculated from difference velocity between direction of flow and inverse transmission of ultrasonic wave.
Electromagnetic type	In the magnetic field, voltage is detected according to speed of flow in the pipe by the electrode attached to pipe. Flow of water in the pipe is calculated based on the detected voltage. Flow rate is calculated by multiplication of area of pipe and velocity.



⑷ Variation of water consumption rate

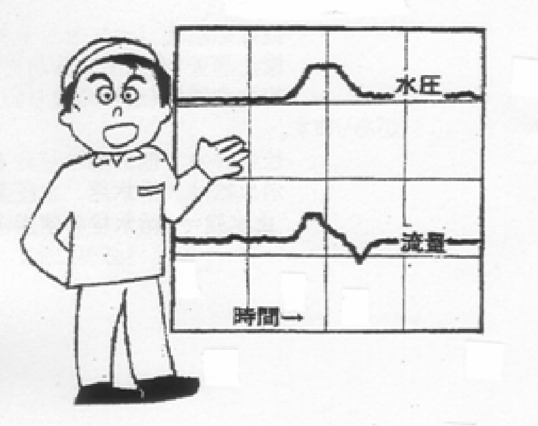
Classification of water usage include; ① Water use for washing ② Hand washing ③Cooking ④Flushing toilet and they use different volume of water.

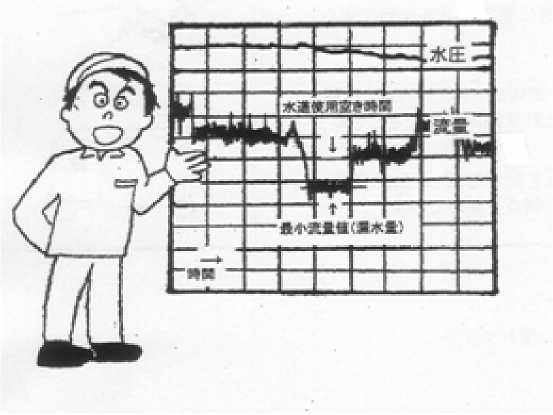


⑸ Judgment method for minimum night flow

Content of flow into the measurement equipment when water usage available is equal to inflow= (usage water) + (variation element) + (leakage volume).

Display of record of inflow will have time lag later than actual water usage and recorded (time lag of transmit by pressure wave of used water is approximately 0.7 sec). Namely, Amplitude of variation of inflow become bigger when location of measuring is far.





⑹ Preparation work and summary of data for measurement of leakage volume

Firstly, related drawings be collected and put in order. Block drawing, appurtenances (gate valve, off-set, location map of hydrant) and maintenance drawing of distribution pipe are needed to prepared.

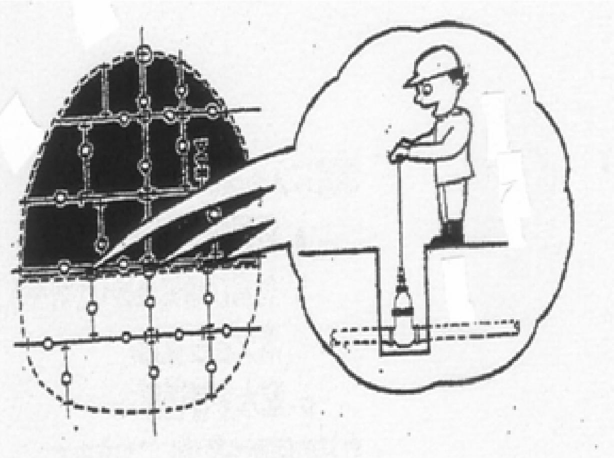
⑺ Investigation of function of valve etc.

When functional investigation is made, investigation of location of facilities (prepare off-set)、functional investigation (check whether usable or not) and cleaning room (take away earth and sand are necessary.

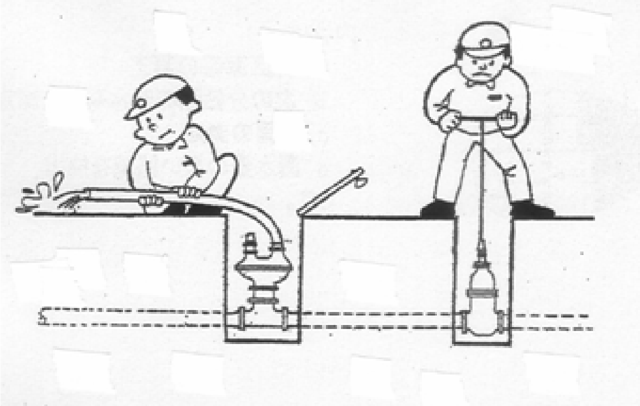
Valves are used to separate the specific block from other block and hydrants are used for drainage and measuring pressure. Stop valves are also used for stop water tap.

⑻ Replacement of defective appurtenances

Defective valves which are located at boundaries of the blocks should be replaced before measuring leakage volume because the defective valve will lead to inaccuracy result of the work.



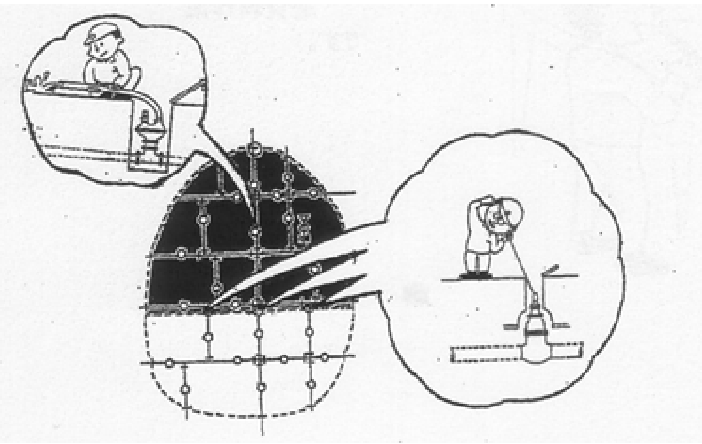
⑼ Verification process for separation of blocks and shut down work



Verification process should be made for every block separation from other blocks.

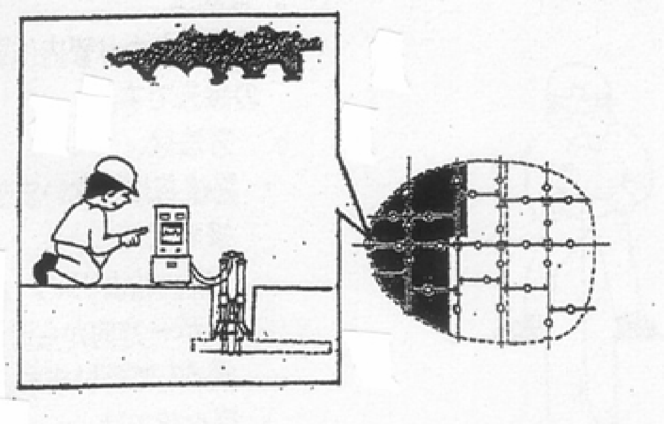
Verification method is to open the hydrant located at the high point whether water flow or not and sound investigation (acoustic bar and electronic leakage detector etc.) at the closed gate valves whether inflow sound can be heard or not.

⑽ Drainage work



Objective of drainage work is to remove scale layer which is accumulated for long time in the pipe. Drainage work will be done for every route of pipeline. Gate valves are operated and arranged in order that pipe water flow from one direction during drainage.

Drainage work from hydrant will continue until drain water become clear. Time will vary from 10 min to 20 min depending on the volume of scale layer.



⑾ Re-blocking and separation of each bloc and verification of shut down at the time of measuring

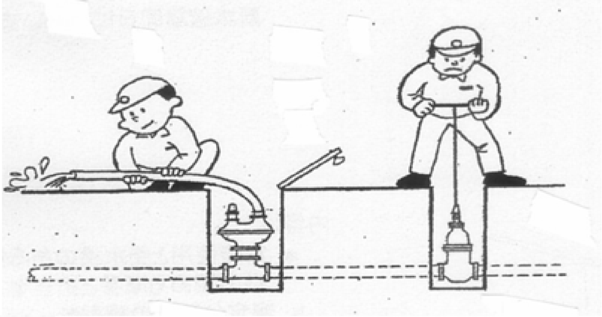
Checking whether any defective valve are existing or not in order to improve accuracy of measuring.

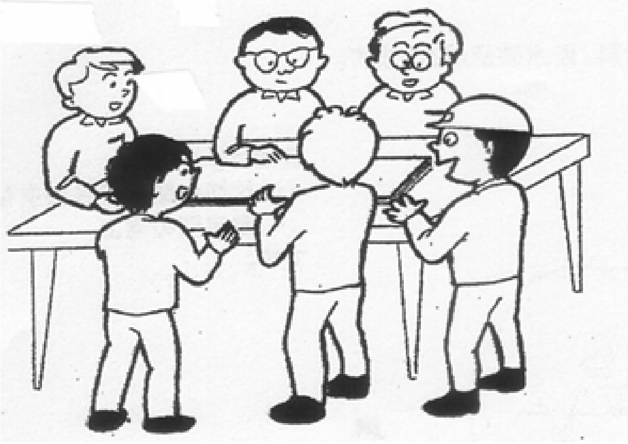
(12) Measurement of division of block (step test)

Content is to measure every division of block, verification of shut down for next division of block and measuring leakage in order to take sample for pipeline route which has lot of leakage.

(13) Disposal work after measuring.

Content is to carry out again drainage work, open the block to normal operation, check whether any valve and stop valve are opened or not and whether used inspect equipment is in order or not and finally complete the work at site.





(14) Analysis and documentation of measured data

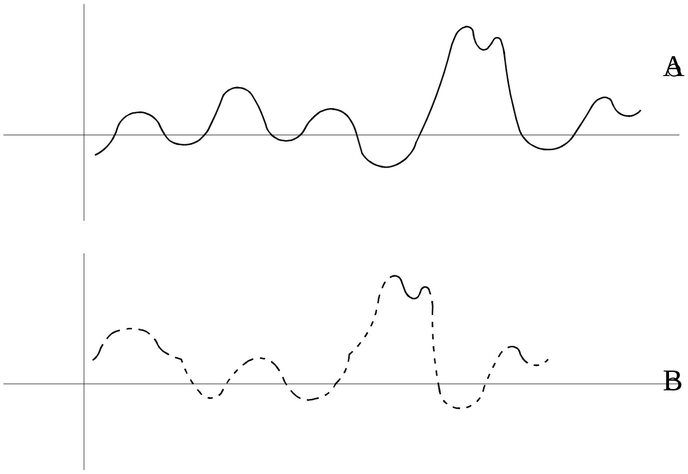
Content is to record the data (date of work, every division of block, leakage volume for all blocks), analysis of data, comparison of the data with other blocks and prepare the data for next investigation.

Main point:

If flow measurement during time when water is not consumed at all (spare time) should have been carried out, it will mean only leakage be measured. When [spare time] were available during night time zone, even it is a few time, measuring this flow will mean only leakage volume were measured. This is called as “Method of measurement of minimum night flow by using spare time when water is not consumed.”.

Principle of correlation

(1) Waveform

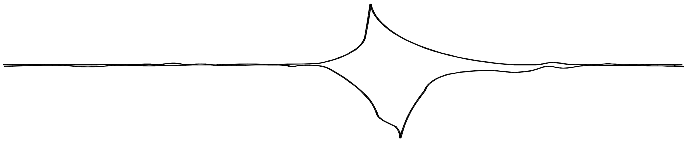


Above figure shows that waveform acquired at points A and B from dummy leakage sound including leakage sound.

The frequency of sound source and loudness of sound SPL (Sound Power Level) can be confirmed in the CRT screen when two-point correlation method is used (multi point correlation is combination of this type). Phenomenon is analyzed as follow:

① Same waveform will be detected when leakage exist between point A and Pint B.

② Waveform B will be detected in different time lag when waveform of A and B is different (sound source is located near point A and far from point B)

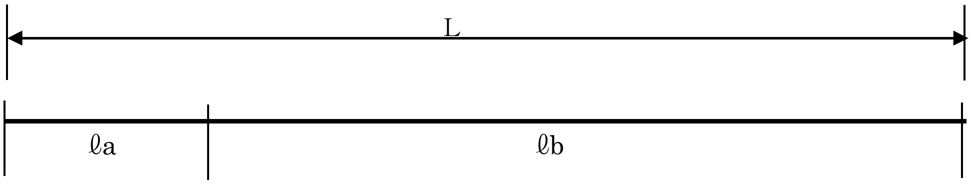


(2) Detected sound and correlation

A: Correlation will be appear when point A and point B has same sound.

B: When point A and point B do not have same sound, correlation phenomenon will not occur and peak waveform is not shaped.

C: Time difference is time passing from beginning of correlation to peak of detection of sound (τ ms) and is usually expressed as Time delayed (Td ms) in the calculation formula.



$\ell a = (L + \tau \cdot V)/2$

$L = \ell a + \ell b$

τ : time difference of leakage sound between 2 points (ms)

Where, when $\ell a < \ell b$, τ is expressed $-\tau$ (minus), and when $\ell a > \ell b$, τ is expressed $+\tau$ respectively.

Calculation of correlation coefficient

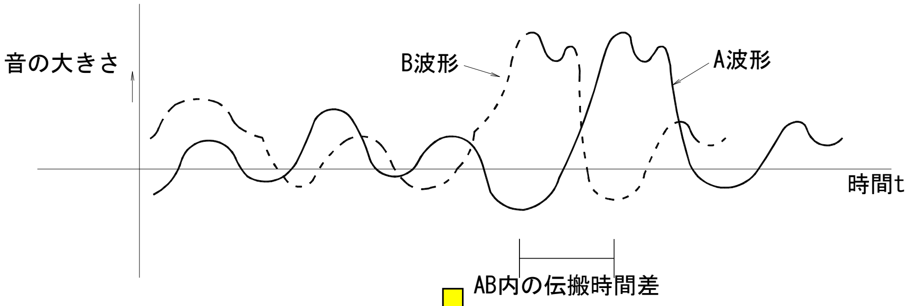
To put in concretely,

A) Intentionally delay the progressing waveform of A (circuit is already formed).

B) Calculate multiplication B with A (multiplication, addition and average circuit).

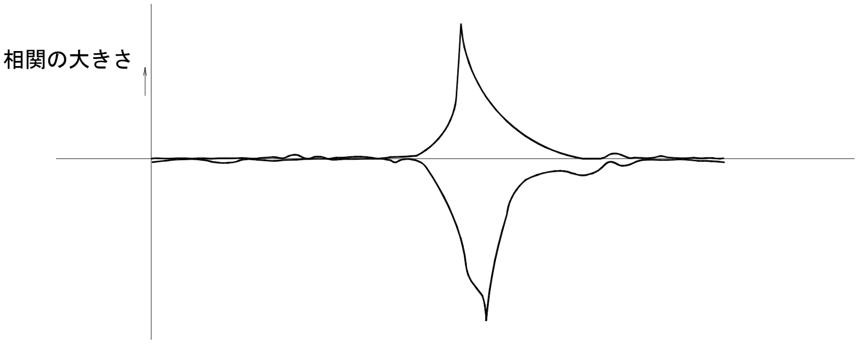
C) AS a result, CRT screen shows;

Maximum peak will be shaped in the char ○-○ as shown arrow when waveform A is delayed (only in case, waveform A and B overlapped).



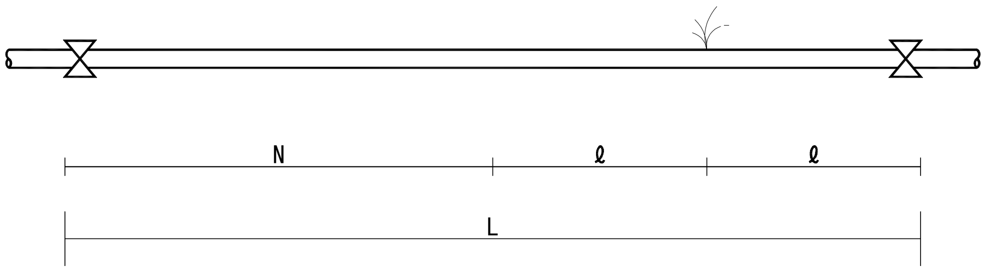
Waveform at A point is delayed at time unit in 0.5 ms, 0.25 ms and 0.1 ms .

Accuracy of the delayed time will influence whether error will become big or small and is important technical knowhow for manufacture.



Magnitude of correlation is section of Y axis which explained in the previous analysis of image for multi-point correlation.

(3) Calculation formula



$$N = Td \times V$$

$$\ell = \frac{L - (N)}{2}$$

$$\ell = \frac{L - (Td \times V)}{2}$$

$Td =$ Time delayed (m/s)

$V =$ Velocity of transmit m/ms

$\ell =$ Distance from B to location of leakage

$L =$ Length between A and B

① Necessity data for detection

Cell search distance between 2 points

- Pipe material and diameter (each manufacture installed their own data for velocity of transmit in circuit).

② Accuracy of detection

- Length of pipe: proportional to 1/2 of input error
- Input value (Velocity of transmit: input with manual by own)
- Resolution power 0.1ms, error for CIP(Cast Iron Pipe))≒ 1350m×1/1000sec=±0.135m

③ Example of calculation

- Where, L=7.2m and Td=1ms,
- Pipe material is CI (Cast Iron Pipe)), diameter φ100mm. Then, velocity of transmit is equal to 1,350m/s and time delayed (Td) is revised to 1.35m/ms.

•

$$\ell = \frac{7.2+(+1.0\times 1.35)}{2}$$

$$= \frac{8.55}{2} = 4.275\text{m}$$

•

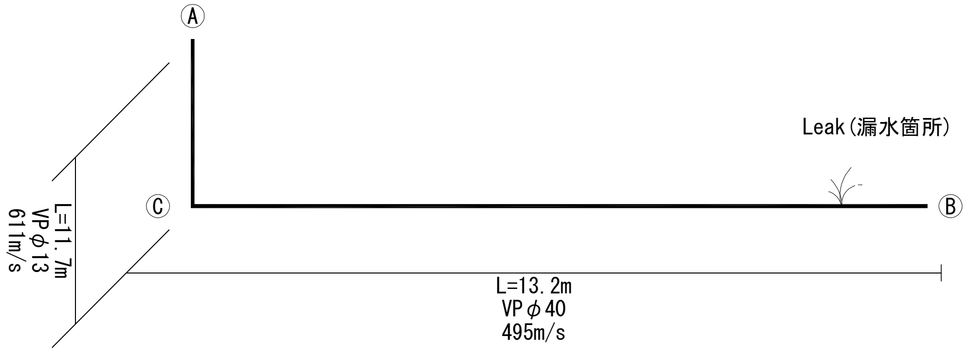
• 4.275m from point B

•

•

•

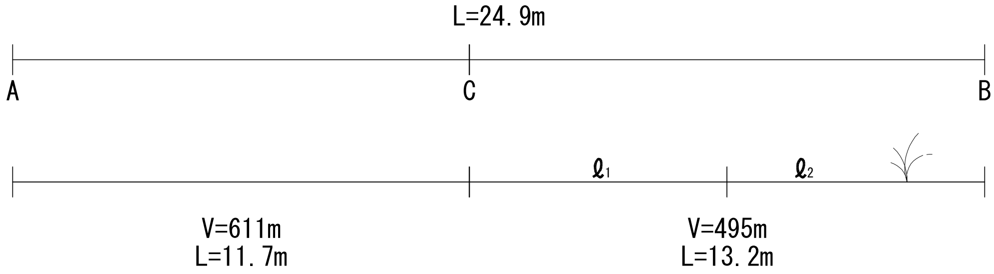
Example of calculation No. 1



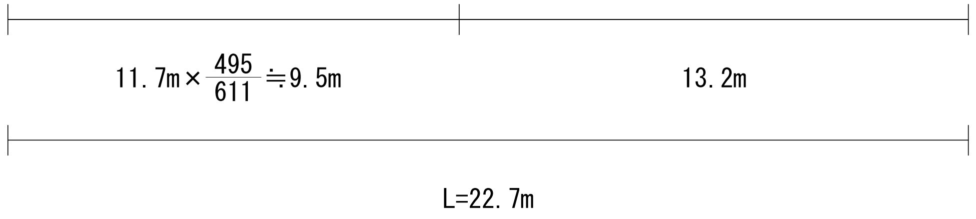
Condition

Log-time is equal to time delayed+27.0ms (appear at B point).

Assuming velocity of transmit at VP13 is 611m/sec and that is at VP40 is 495m/sec.



Calculation by equivalence pipe length method (transmittal velocity diameter ϕ 13 is converted to VP, diameter φ40)



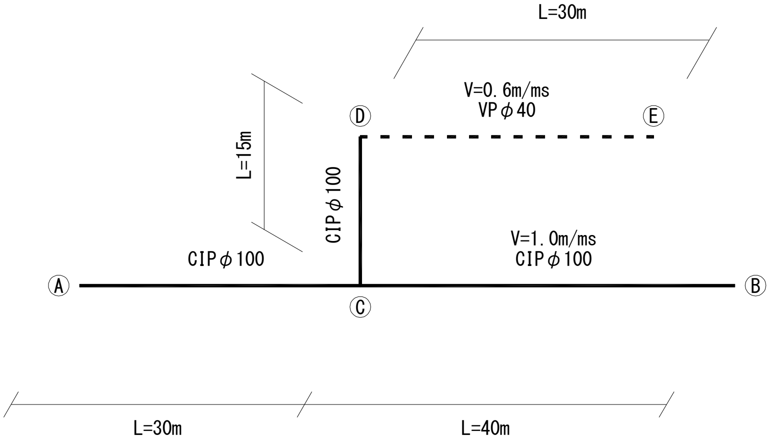
N=Td×V $\quad$ 27.0ms×(0.495m/ms)≒13.365≒13.4m

Convert into 1/1000

$$\ell=\frac{L-13.4}{2}$$
$$=\frac{9.3}{2}$$
$$=4.65\text{m}$$

(Leak appear at location of 4.65m from point B.

Example of calculation No. 2



CIP's V=1.0m/ms

VP's V=0.62m/ms

Here, V is abbreviation of velocity and VP is vinyl pipe

Condition

Assuming transmittal velocity of CIP100 is 1,000m/sec and that of VP40620m/sec.

Service pipe of D〜E is branched from CIP pipe of A〜C〜B〜D, diameter φ100.

Results of correlation investigation for A〜B, Td=10ms at point A and for A〜E, Td is 35ms at point E.

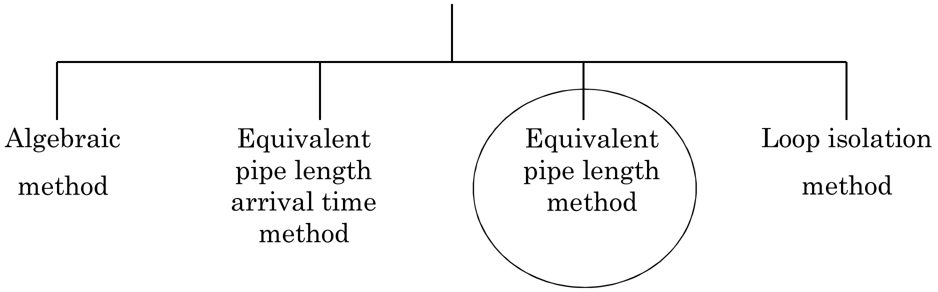
① Calculation of CIP for A〜C〜B division.

$$\ell = \frac{L-(Td\times V)}{2}$$

$$= \frac{70-(10ms\times 1.0m/ms)}{2} = 30$$

Td is 30 m a at point A for A〜C〜B.

② Calculation for A〜C〜D〜E division.



Calculation by equivalence pipe length

Converting into VP for A～C～D

$$45 \times \frac{0.6}{1.0} = 27.0\mathrm{m}$$

$$\begin{aligned}\ell &= (\mathrm{L} - \mathrm{Td} \times \mathrm{c}) \times 1/2 \\ &= \{(27 + 30) - (35\mathrm{ms} \times 0.6)\} \times 1/2 \\ &= \{57 - 21\} \times 1/2 \\ &= 18.0\end{aligned}$$

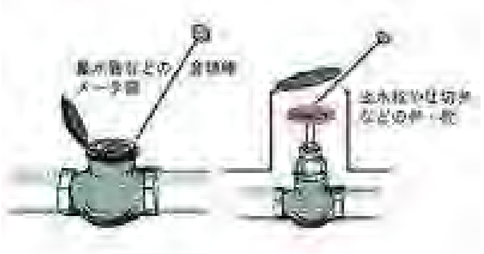
18.0m from point E (E＝location of censer B)

General leakage investigation in JAPAN

Method of Leakage Detection

Acoustic leakage sound detection method

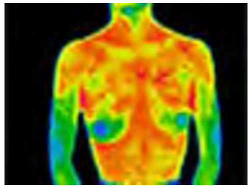
- Acoustic bar
- Headphone type leakage detector
- Electronic acoustic bar



Method of Leakage Detection

Mass spectrometric analysis/ geophysical exploration method

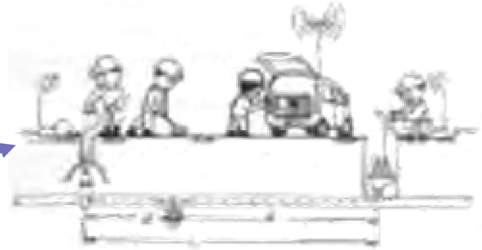
- Investigate thermal source method
- Radar method
- Permeation leakage/transpire detection method

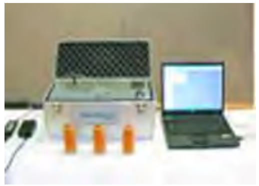


Method of Leakage Detection

Analysis of sound source method

- Correlated leak detection method
- Multipoint correlation method
- Sound-level meter
- Time integration type leakage detector

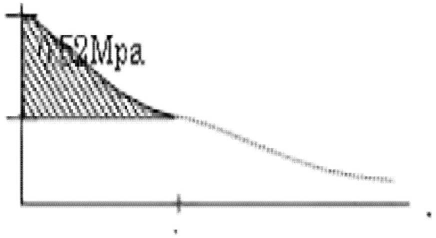




Method of Leakage Detection

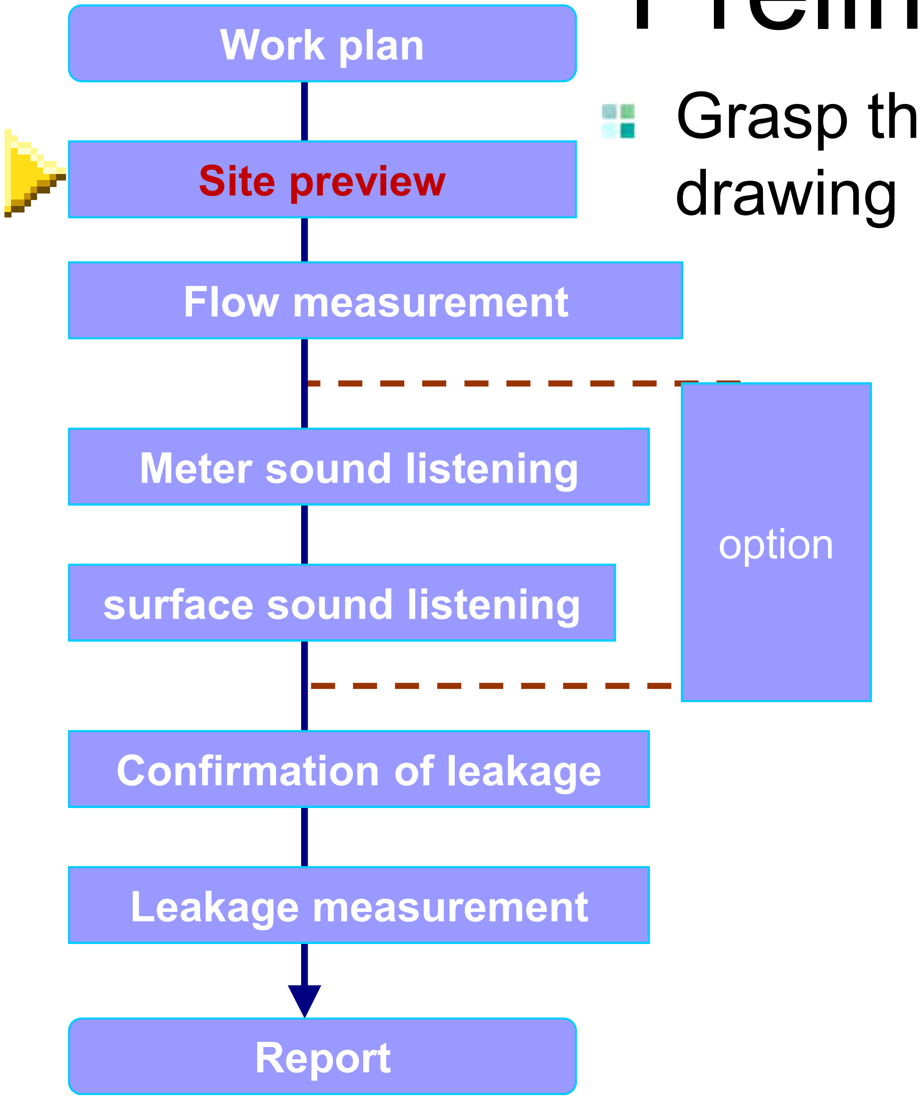
Other methods

- Pressure measurement method
- Air compressing method
- Boring method



Preliminary inspection

- Grasp the facility outline by piping drawing



Work plan

Site preview

Flow measurement

Meter sound listening

surface sound listening

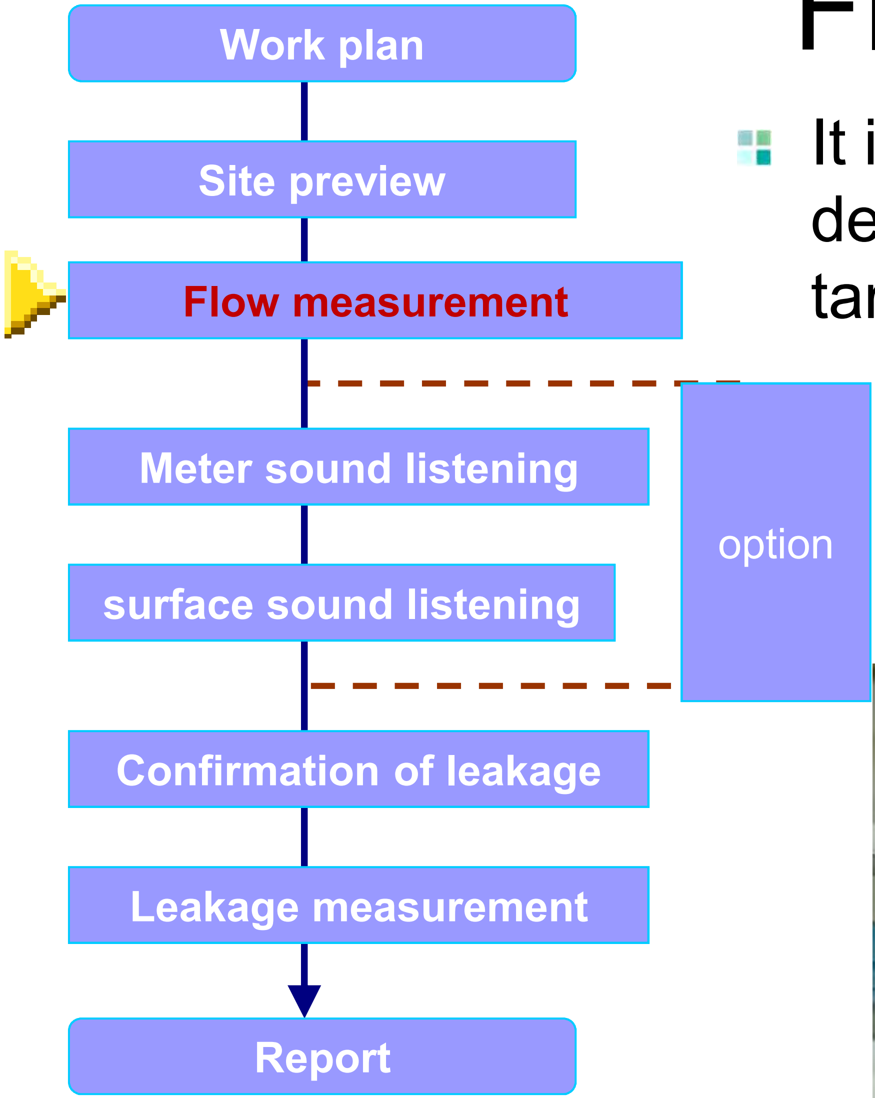
option

Confirmation of leakage

Leakage measurement

Report

Flow Measurement



Work plan

Site preview

Flow measurement

Meter sound listening

surface sound listening

option

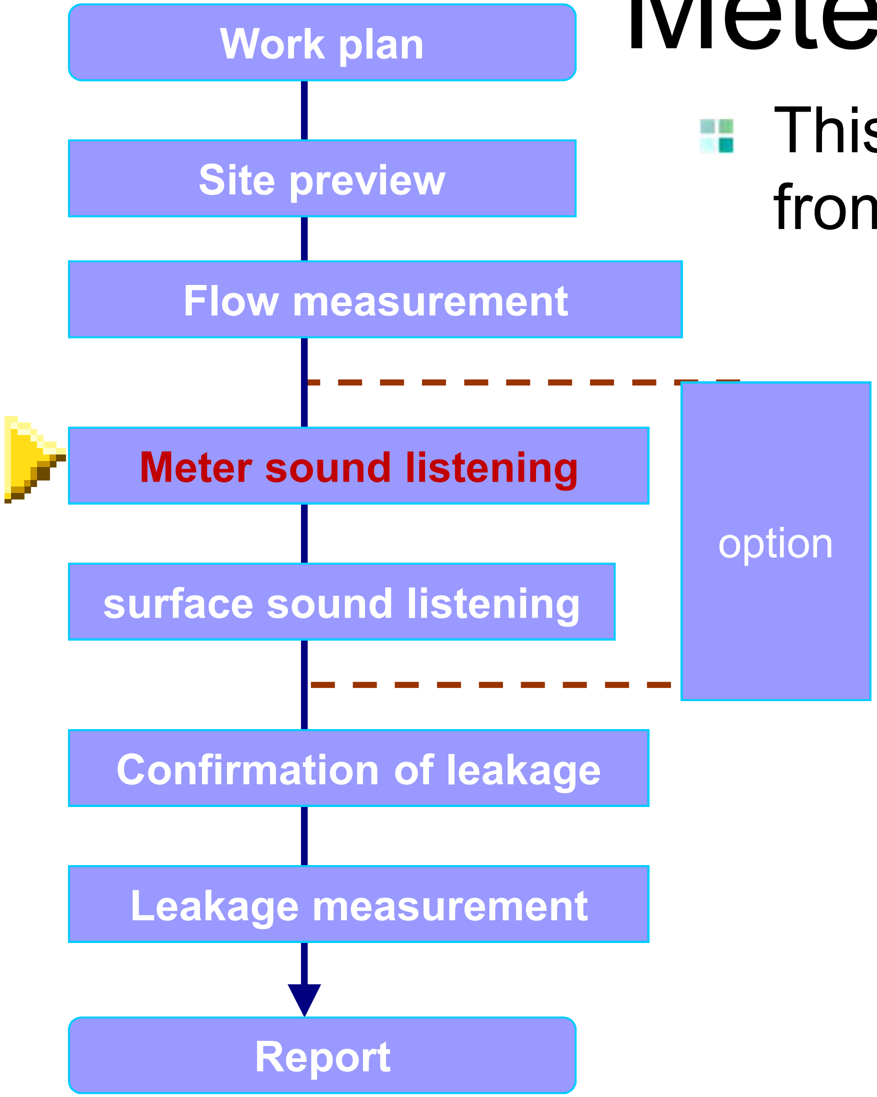
Confirmation of leakage

Leakage measurement

Report

- It is a task to investigate the degree of leakage in the survey target area

Meter Sound Listening



Work plan

Site preview

Flow measurement

Meter sound listening

surface sound listening

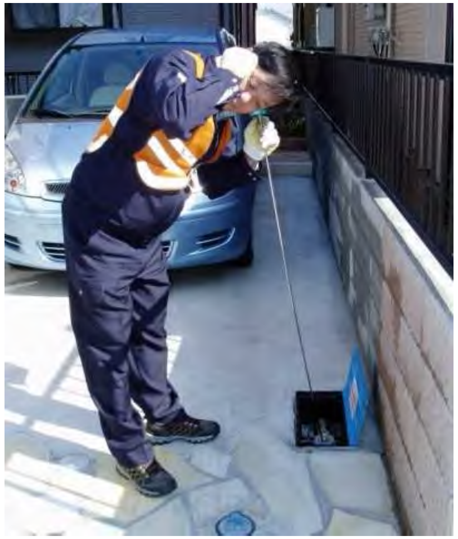
option

Confirmation of leakage

Leakage measurement

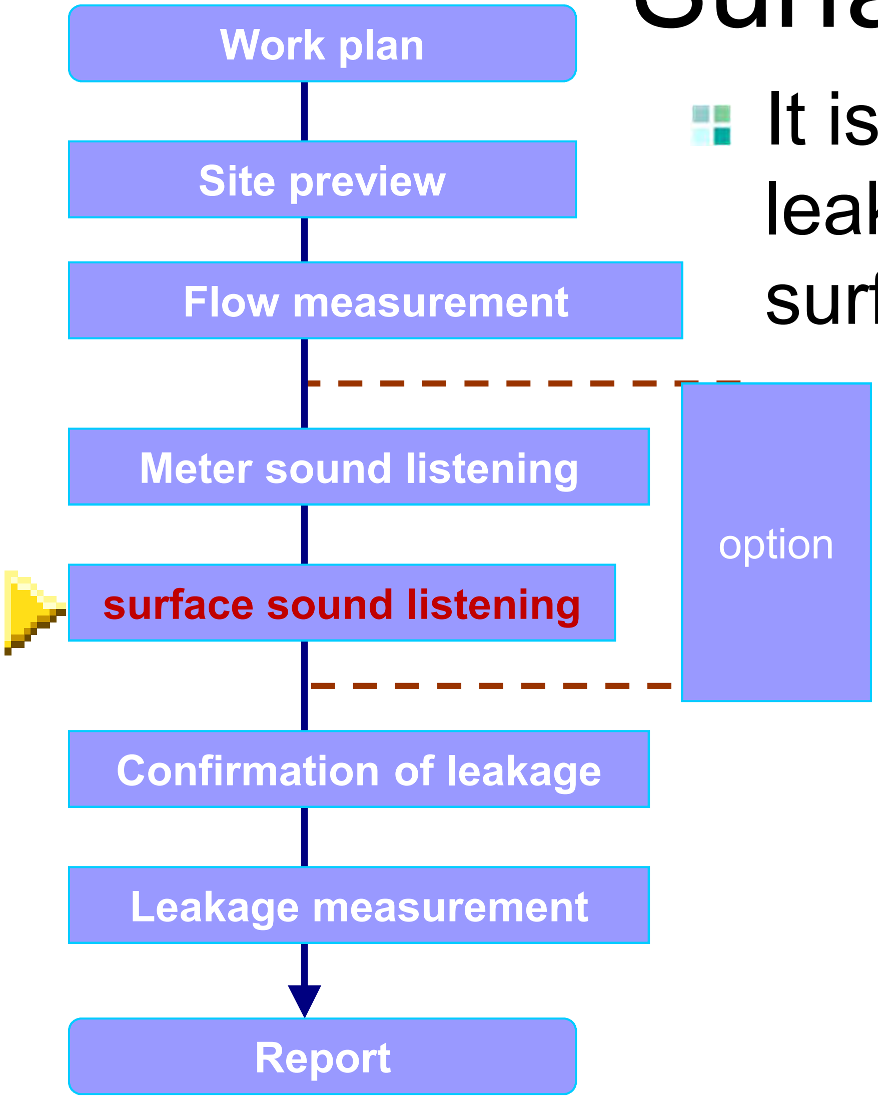
Report

- This is done to detect water leakage from water supply equipment



Surface sound listening

- It is a work to discover water leak noise from the road surface



Work plan

Site preview

Flow measurement

Meter sound listening

surface sound listening

option

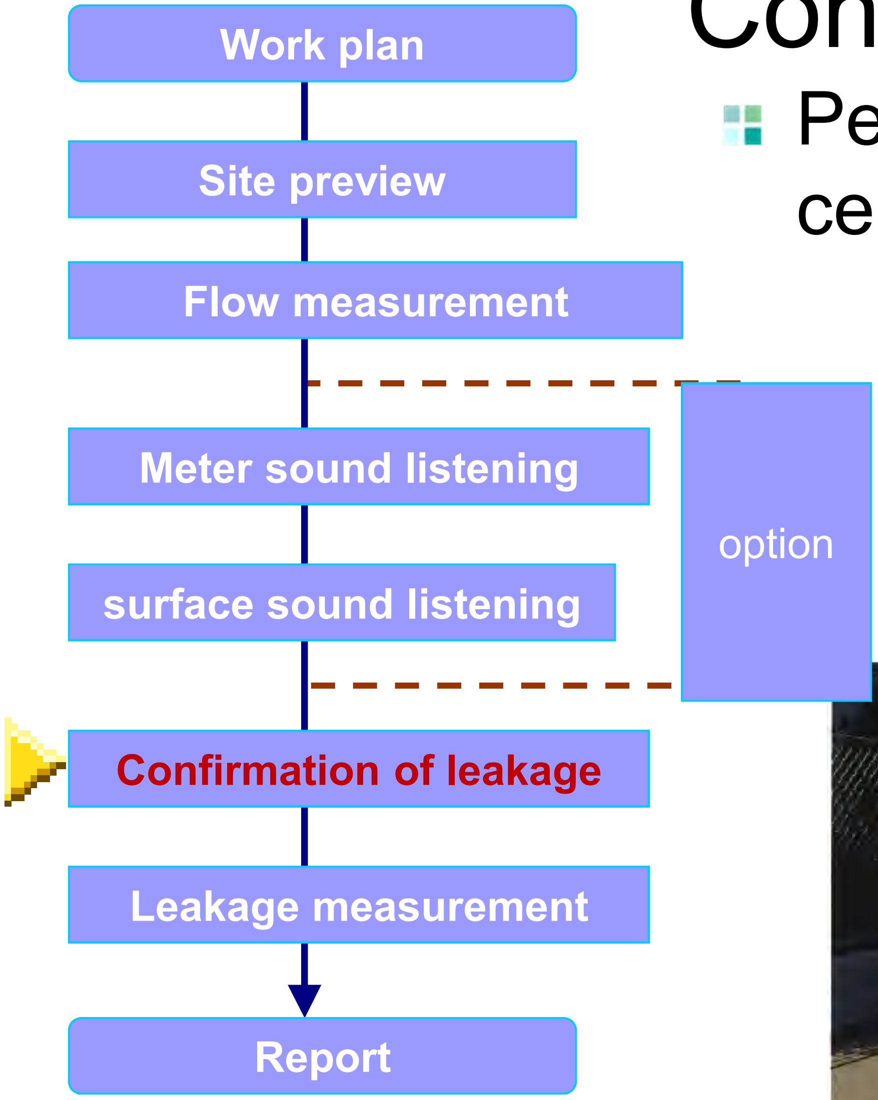
Confirmation of leakage

Leakage measurement

Report

Confirmation of leakage

- Perform a bowling and find the center point of water leakage



Work plan

Site preview

Flow measurement

Meter sound listening

surface sound listening

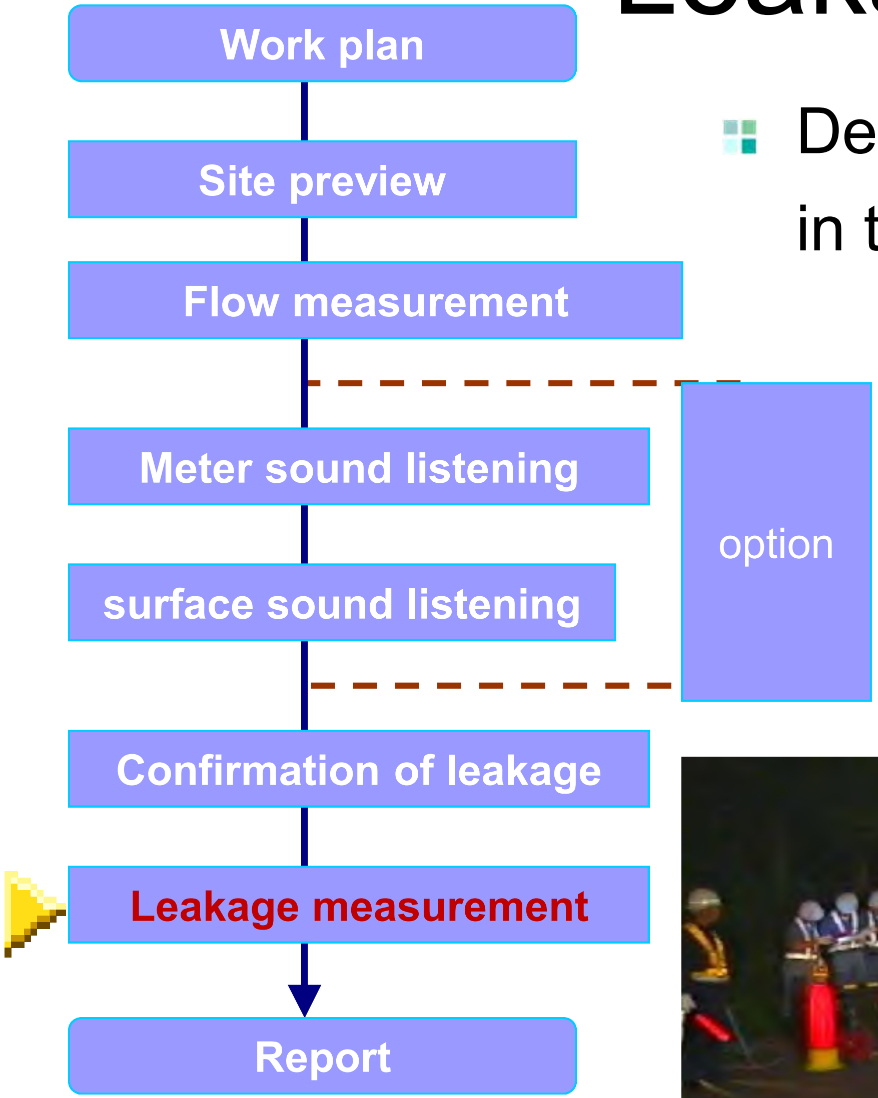
option

Confirmation of leakage

Leakage measurement

Report

Leakage Volume Survey



Work plan

Site preview

Flow measurement

Meter sound listening

surface sound listening

option

Confirmation of leakage

Leakage measurement

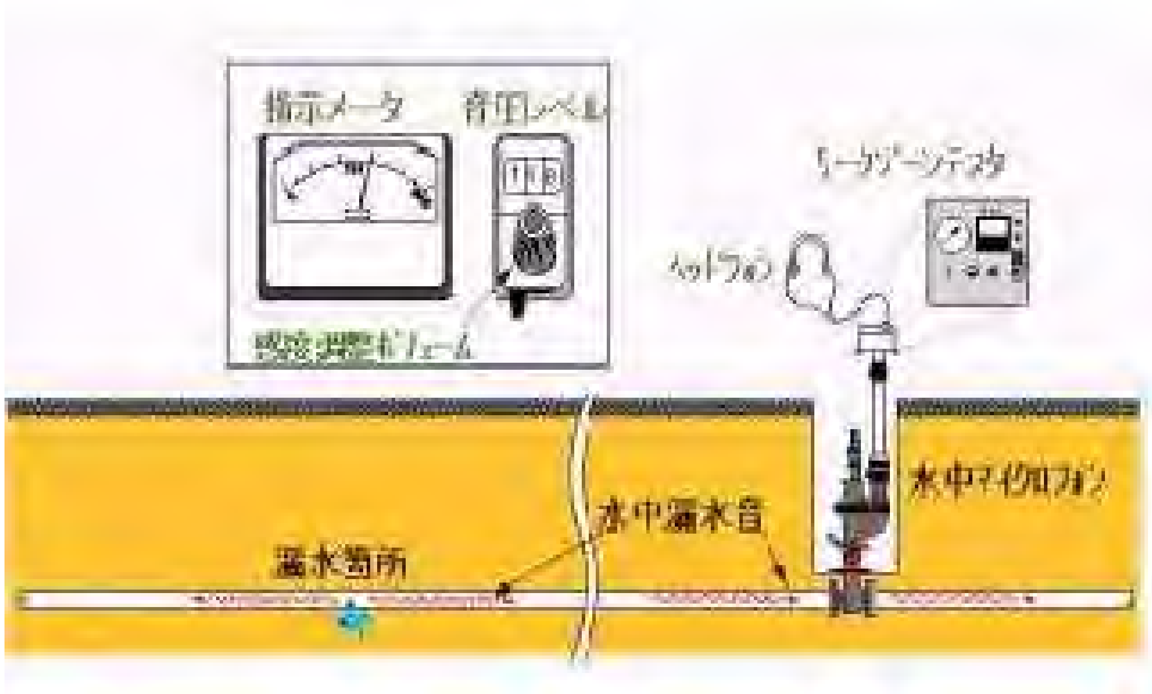
Report

- Determine how much leakage exists in the block to be surveyed.

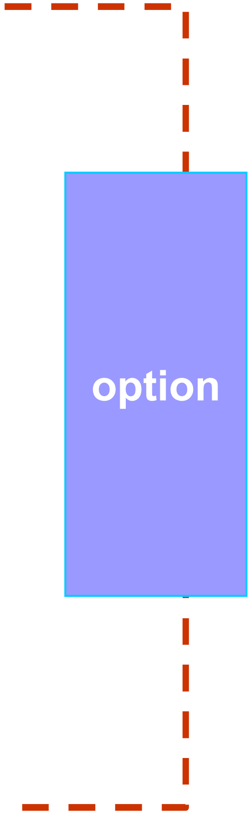
■Option 1 Leak zone test

option

- Underwater microphone sound of leakage propagating in the water distribution pipe

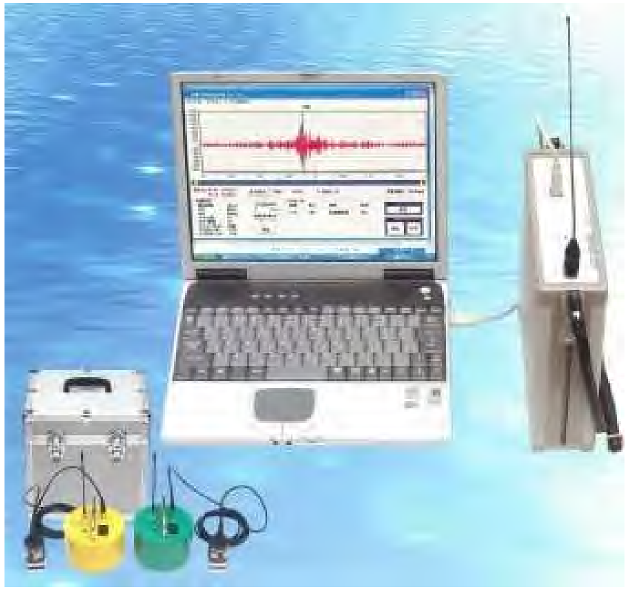


■Option 2 Correlation formula leakage investigation



option

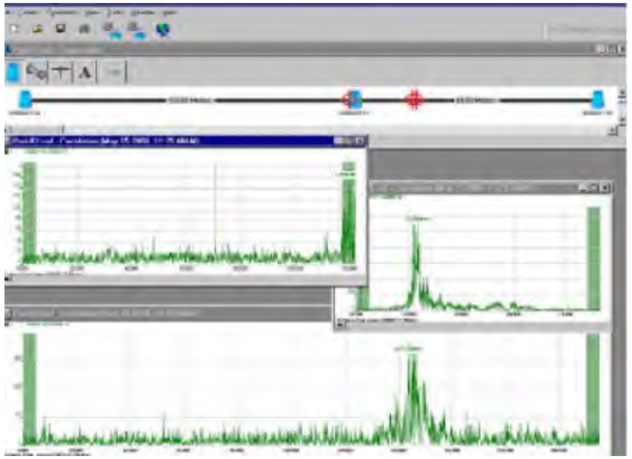
- Install the sensor on accessory equipment on the duct which is considered to have water leakage.
- Calculate the water leakage point based on data from 2 points.

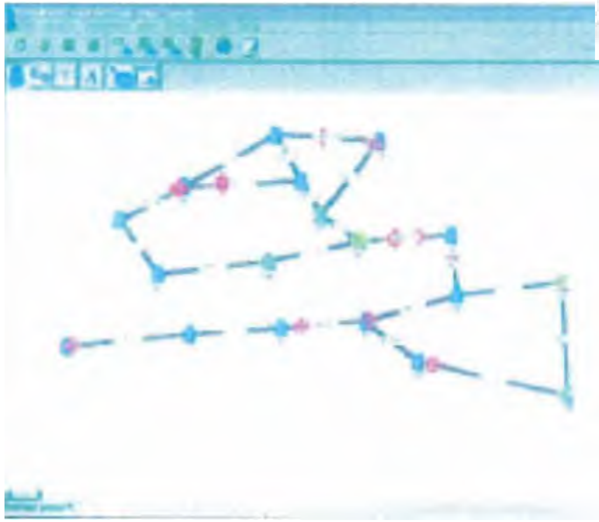


■Option 3 Multi-point Correlation Type Leakage Survey

option

- It is a non-wireless correlation survey instrument





センサーロガ
12個タイプ

■Option 4 Time integral type leakage investigation

option

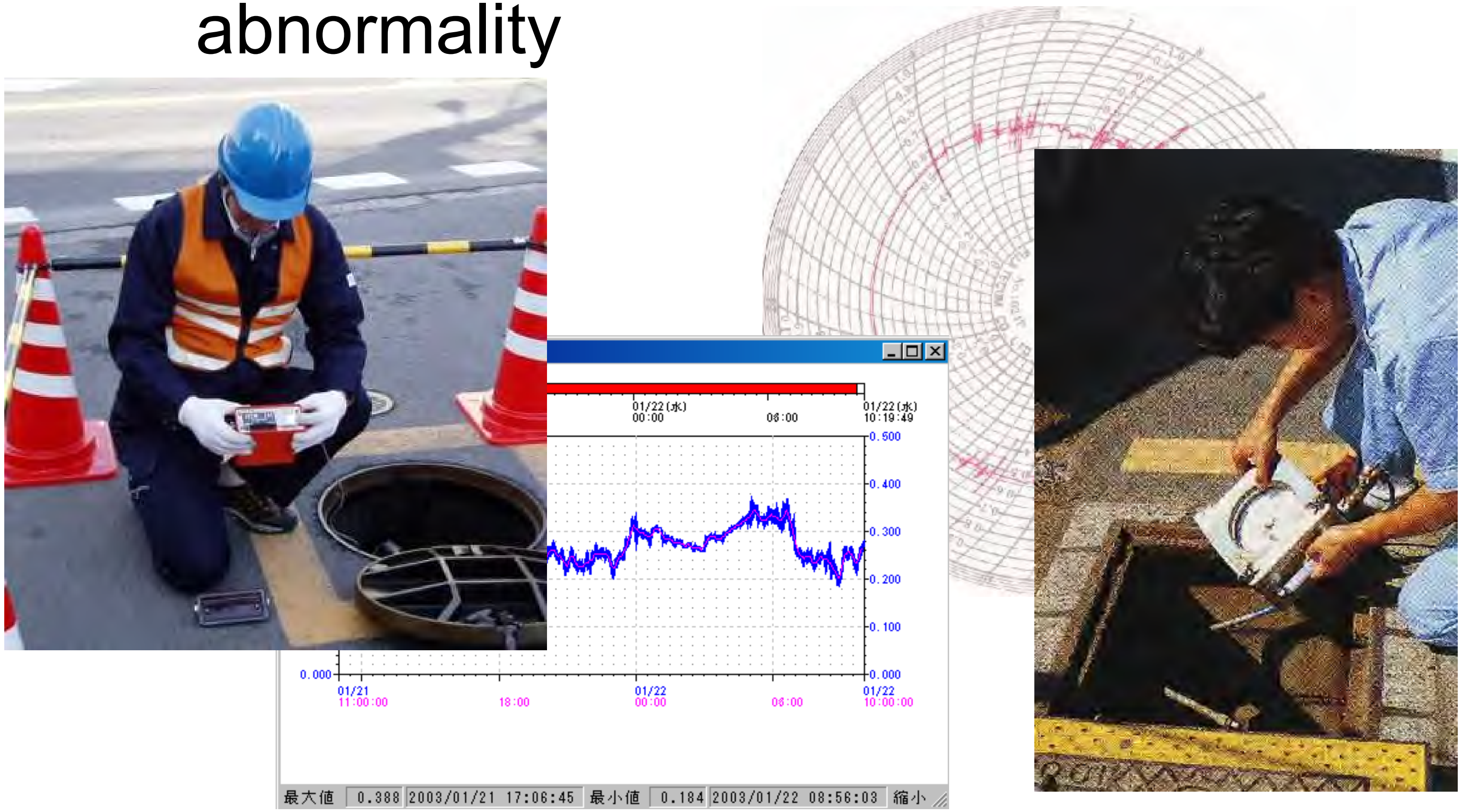
- It is a data logger type survey targeting water supply pipes

Option 5

Water pressure measurement survey

option

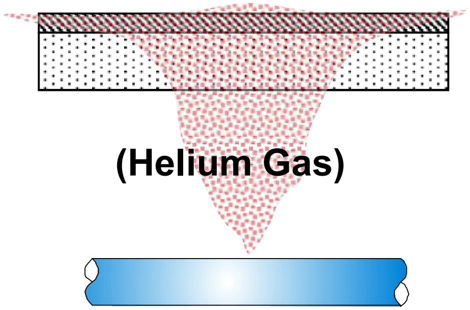
- We will investigate water pressure situation and water pressure abnormality



■Option 6 He Gas permeable leakage investigation

option

- Gas is injected and Gas passing through the ground surface is detected



Equipment Management List

1. Ultrasonic Flow Meter
2. Management List

No,	Category	Details, Quantity
1	Item name	
2	Date of Donation	
3	Donor	
4	Project name	
5	Receiving department	
6	Delivery date	

3. WASAC Management List

No,	Category	Details, Quantity
	Management department	
	Administrator	
	ID Number(1)	
	ID Number(2)	
	ID Number(3)	
	ID Number(4)	
	ID Number(5)	
	ID Number(6)	
	Storage place	

4. Lending Record

No,	Date	Name of opponent

5. Component Photo

No.	Name	Q,ty	Details	Photo
1	Main Unit	6pc	Ultrasonic flowmeter Main unit	
2	Battery	6pc	Ni-MH battery	
	AC adaptor	6pc	AC adaptor for main unit	
	Protection Cover	6pc	Protection cover for main unit	
	Transducer cable	18？	Connection cable for transducer and main unit Temperature range: -20 to 65 degree C Length : 7 m	
	Large transducers and mounting fixture	6set	Large transducer	
			magnet type mounting fixture	

		6set	belt type mounting fixture	
	Medium Transducers And Mounting fixture	6set	Ultrasonic transmitter-receiver sensors (to be used in combination with cables)	
	Mounting fixture	6set	mounting fixture 1	
		6set	mounting fixture 2	
		6set	Z-path method adaptor	
	Small transducers and mounting fixture	6set	Ultrasonic transmitter-receiver sensors (to be used in combination with cables)	
		6set	mounting fixture	
	Test piece	6pc	Calibration test piece for above sensor (No.4)	
	Thickness		Sensor thickness & sound	

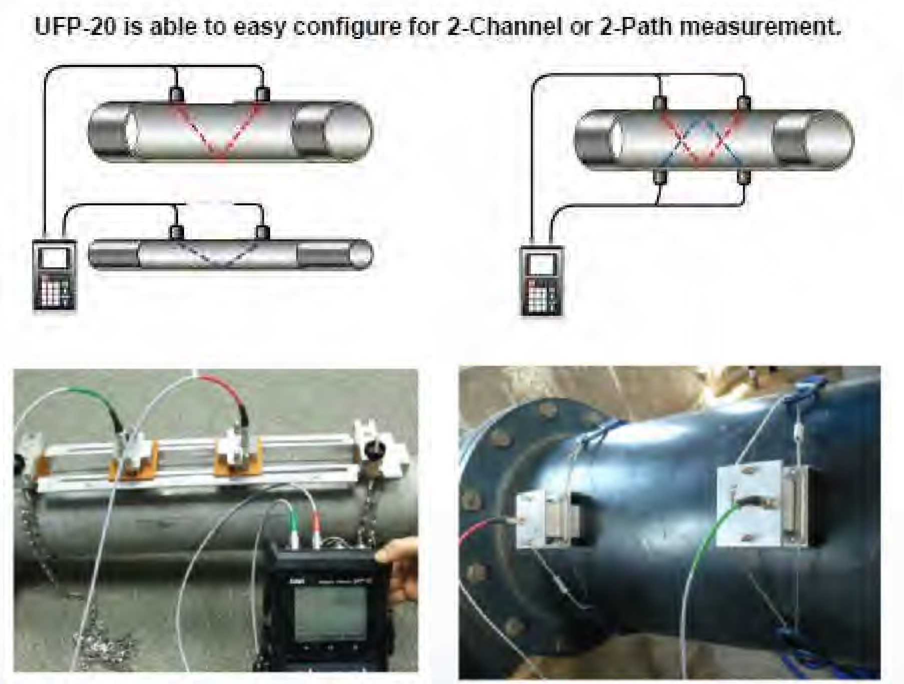
	gauge		speed measurement Length：0.7 m	
	Carrying Case	6pc	Carrying case for primary components	
	Carrying case for large transducer	6pc	Carrying case for large Transducer Kit	
	Carrying case for small/medium transducer	6pc	Carrying case for small/medium Transducer Kit	
	Cigarette lighter cable	6pc	Cable for cigarette lighter port of automobile to supply power to flowmeter Length：3 m	

6. Software , catalog ,manual

No,	Category	Type
1	Software	None
2	catalog	
3	manual	Printing, pdf

NRW(Leakage Survey and Measurement) Investigation machinery system

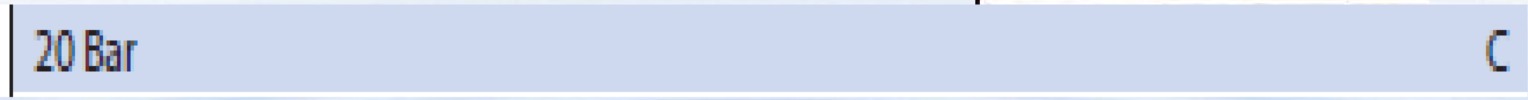
No,1 Ultrasonic Flow Meter



UFP-20 is able to easy configure for 2-Channel or 2-Path measurement.

Specification	**13A- 5000A Measurable**
Quantity	**6set**

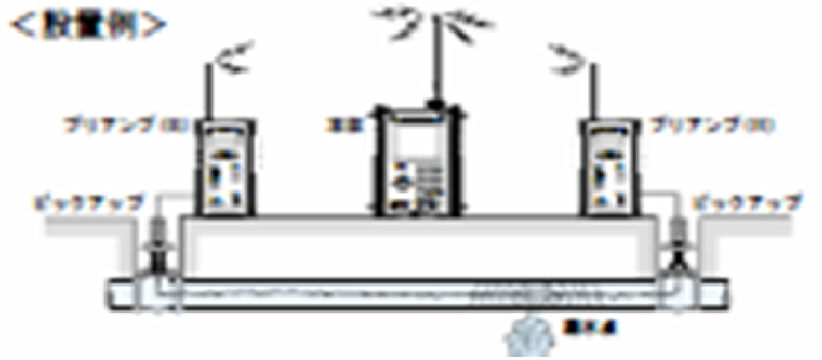
No,2 Flow and Pressure Data Logger

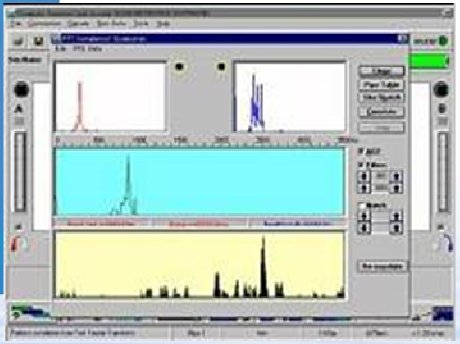

20 Bar

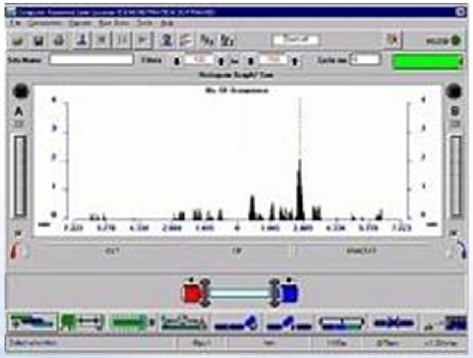
C

Specification	**Long Life Battery 10years ,Memory 80,000 Record**
Quantity	**6**

No,3 Correlation Leak Detector

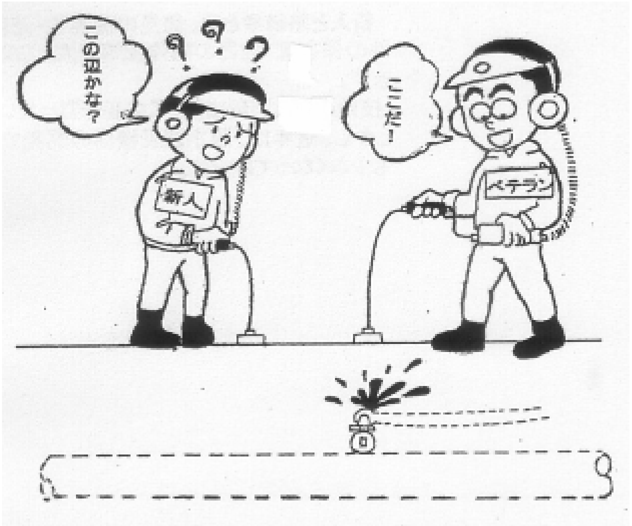


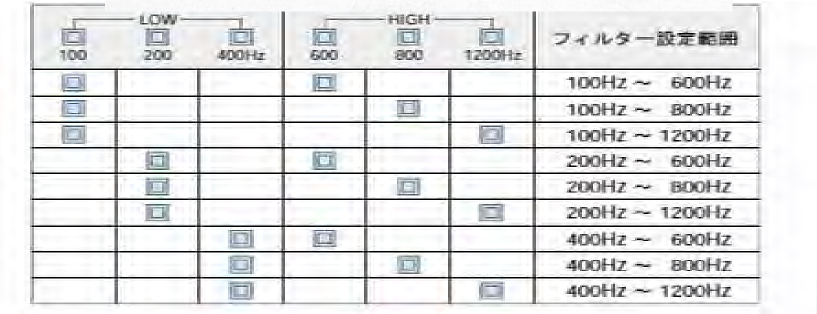




Specification	**Correlation type detector**
Quantity	**3**

No,4 Water Leak detector

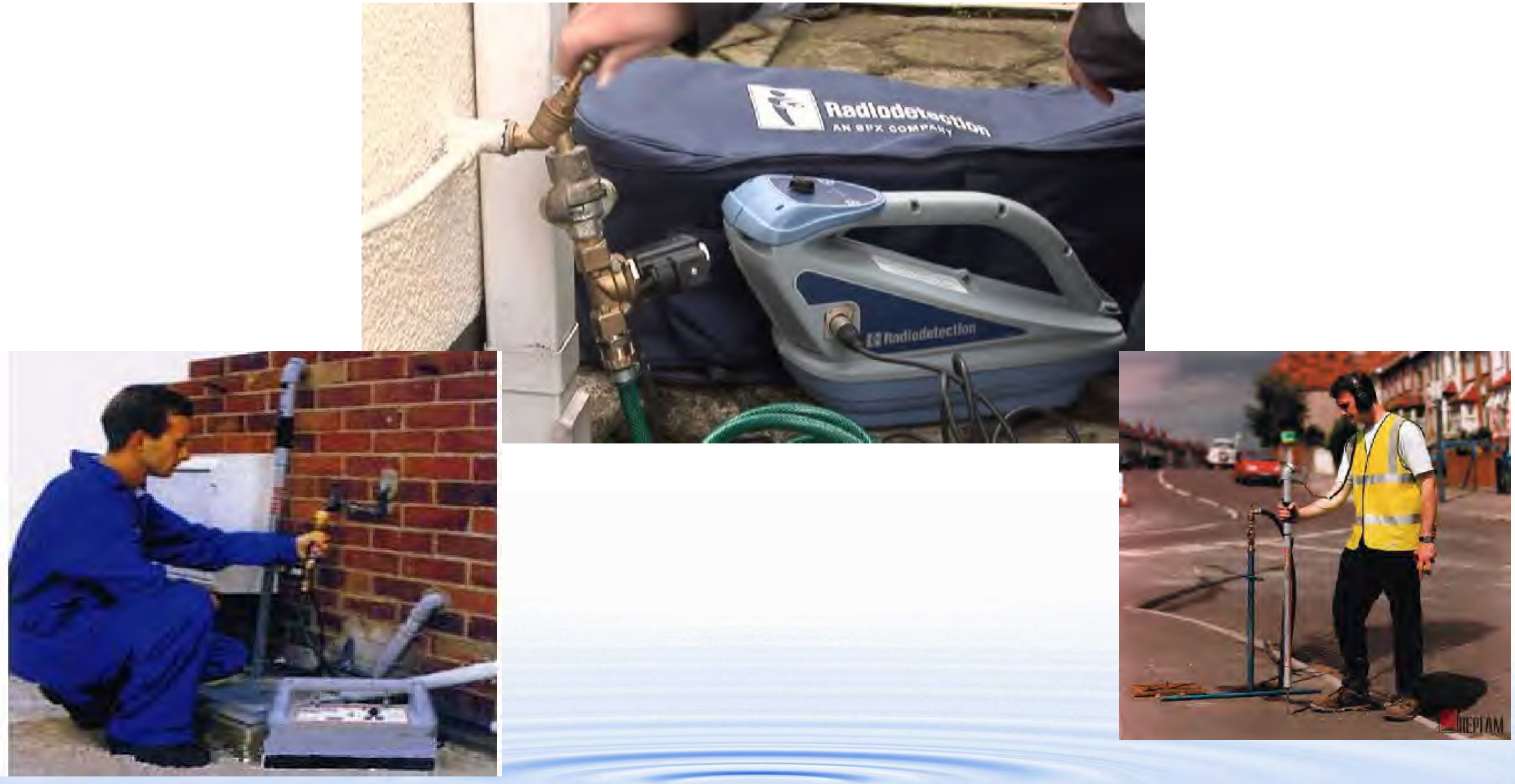




LOW			HIGH			フィルター設定範囲
□ 100	□ 200	□ 400Hz	□ 600	□ 800	□ 1200Hz	
□			□			100Hz ～ 600Hz
□				□		100Hz ～ 800Hz
□					□	100Hz ～ 1200Hz
	□		□			200Hz ～ 600Hz
	□			□		200Hz ～ 800Hz
	□				□	200Hz ～ 1200Hz
		□	□			400Hz ～ 600Hz
		□		□		400Hz ～ 800Hz
		□			□	400Hz ～ 1200Hz

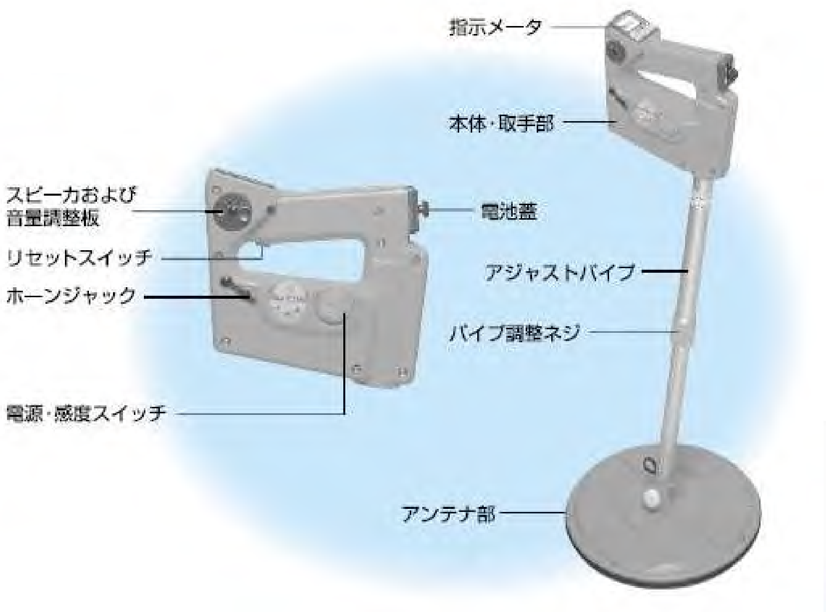
Specification	**Leaking Sound Dtector**
Quantity	**3**

No,5 Non-Metal Detector



Specification	Detecting the buried position of PE and PVC
Quantity	3

No,6 Metal Detector



Specification	**Detection of valve lid**
Quantity	**3**

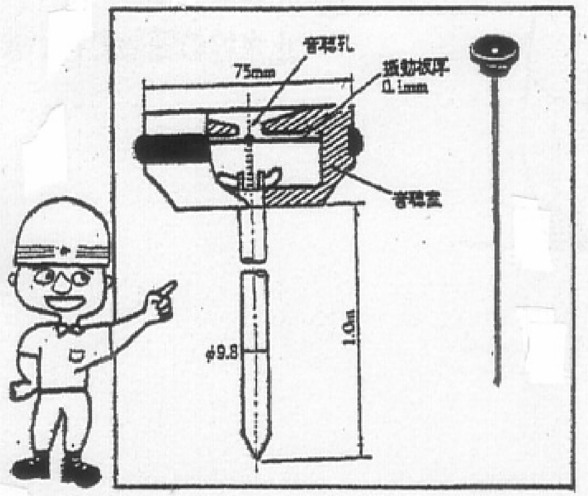
No,7 Iron Pipe Detector

Specification	**Detection of metal pipe**
Quantity	**3**

No,8 Electric sounding bar

Specification	Display water leak sound in mV.
Quantity	3

No,9 Leak Sounding Bar

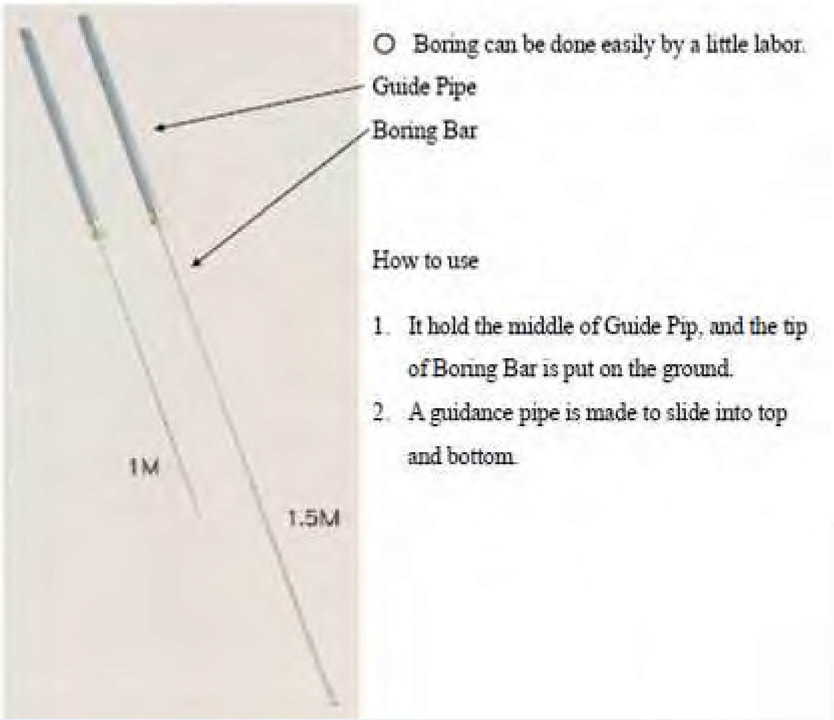


Specification	It is a stethoscope to hear the sound of water leakage
Quantity	9

No,10 Walking Measure

Specification	**Measure distance device**
Quantity	**3**

No,11 Boring bar



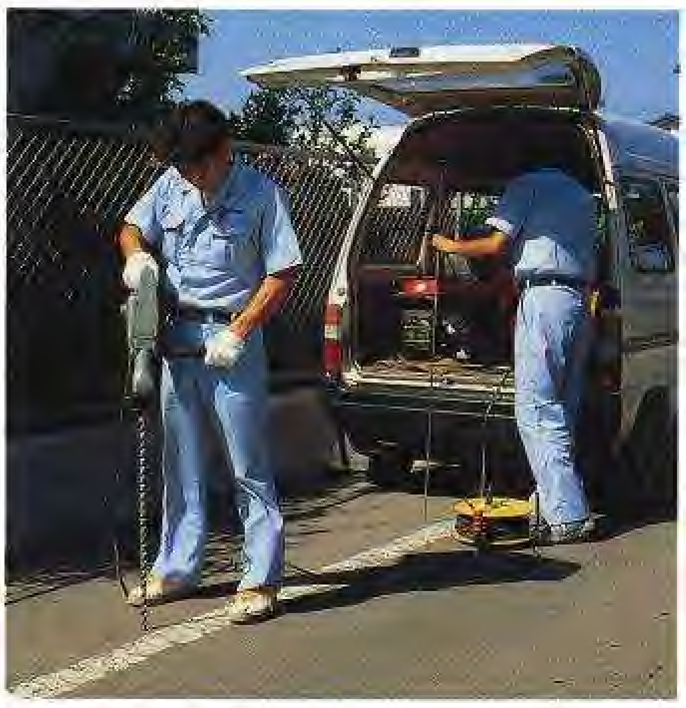
○ Boring can be done easily by a little labor.

How to use

1. It hold the middle of Guide Pip, and the tip of Boring Bar is put on the ground.
2. A guidance pipe is made to slide into top and bottom.

Specification	**It is a device that drills a road**
Quantity	**3**

No,12 Hummer drill



Specification	It is a device that drills a road.
Quantity	3

No,13 Hexagonal Bit

Specification	**Drill bit**
Quantity	**15**

No,14 Generator

- Gasoline Generator -

◆ AC Output：5.0KVA (Rated)
◆Voltage：AC 220V 50Hz
◆HONDA OHV 4-stroke engine
◆Long operating hours with large fuel tank
◆Voltage Regulation System：A.V.R (Automatic Voltage Regulator)
◆Starting System：Recoil

Specification	**5.0KV, 220V ,50Hz**
Quantity	**3**

No,15 Laptop Computer

Specification	DELL (Latitude Rugged 5414CTO)
Quantity	3

Project of the Strengthening Non-Revenue Water Control in Kigali City Water Network (Phase-1)

In-Room training & OJT of “Piping Works” as Activity 2-1 & 2-6

March ~ May 2017

Contents

1. Opening Address :
2. Presentation of the moderator and the facilitators :
3. Participants :
4. Purpose of Training :
5. Schedule :
6. Chapter of Training :
    - Chapter-1; Safety Management
    - Chapter-2; Soil Handling (Exc., B. Filling)
    - Chapter-3; Recording, Reporting, Documents
    - Chapter-4; Pipe Connection, Repairing
    - Chapter-5; Supplemental as a future recommendations
7. Closing Address (@ Head Office 16:00 30th.)

1. Opening Address :

- Mr. Methode Rutagungira (Director of UWSS)
- Mr. Bahige Jean Berschmas (Manager of NRW)
- Mr. Shigeo Otani (Leader of JICA Experts)
- Mr. Masanobu Mayusumi (JICA Observer / Advisor)

2. Presentation of the moderators & the facilitators

2-1. Moderators :

- Mr. Tokiya Momozono as JICA expert (2nd. Term)
- Mr. Hiroshi Takashima as JICA expert (1st. Term)

2-2. Facilitators :

Leader and staff of LD&PM, Others

- Mr. Désiré Ntamuturano (Head of LD&PM)
- Mr. Céléstin Mwambuta (Leader)
- Mr. Mugabo Jean Marie Vianney (Staff)
- Mr. Rutembesa Jean Marie Vianney (Staff)
- Other plumbing experts to operate the machines

3. Participants

3-1. Trainees :

"Water Distribution Officers (WDO) and Technicians"
from the 6 branch offices in Kigali City.

No.	Name of WDO	Branch Name
1	Mr. Pierre Claver Mukimbiri	Nyamirambo
2	Mr. Pierre Claver Mukimbiri	Kacyru
3	Mr. Egide Iyakare	Gikondo
4	Mr. Damascene Nsengimana	Nyarugenge
5	Mr. Etienne Rutagengwa	Remera
6	Mr. Muhawenimana Antoine	Kanombe
* Other participants (e.g. Branch Manager, Technicians …etc.) to be participated.		

3. Participants

3-2. Other Trainees :

Following 14 branch offices (out of Kigali City) to be done by WASAC (LD&PM) in future.

- Nyanza
- Ruhango
- Rubavu
- Gicumbi
- Ngoma
- Huye
- Muhanga
- Rusizi
- Rwamagana
- Bugesera
- Nyamagabe
- Karongi
- Musanze
- Nyagatare

4. Purpose of Training

4-1. knowledge, skills and technique

on NRW control are acquired by WASAC

as a one of the Project Goal, Output-2 of PDM.

“Basic Knowledge, skills and technique on NRW control are acquired by WASAC”

4-2. Improvement of … as a “WASAC’s Mission”

➢ Safety	[=Integrity + α]
➢ Quality	[=Professionalism]
➢ Efficient use of resources (manpower, material, work time & duration, budget)	[=Efficiency & Innovation]
➢ Credibility of the customers	[=Customer Oriented]

* Refer to the “WASAC, Commercial Policy & Procedure Manual” on 19/Aug./2016

(3. New Customer Connection Policy Statement & 7. Reconnections Procedure)

5. Schedule

- 1st. Term …29/March ~ 30/Apr.

  1st.-1 29 / March @ WASAC Head Office

  1st.-2 30 / March @ WASAC Store (M.C.) and site

- 2nd. Term …April ~ May (*to be fixed later on)

  2nd.-1 ?? / April @ WASAC Head Office

  2nd.-2 ?? / April @ WASAC Store (M.C., Site)

  3rd.-3 ?? / May @ WASAC Store (M.C., Site)

Abbreviation

- AASHTO = American Association of State-Highway & Transportation Officials
- ACI = American Concrete Institute
- ANSI = American National Standards Institute
- BSI = British Standards Institution
- B. Office = Branch Office of WASAC
- DIN = German National Standards Organization
- FIDIC = Fédération International des Ingénieurs Conseils
- IEC = International Electrotechnical Commission
- LD&PM = Leak Detection & Pressure Management
- MC = Magasin Centrale (WASAC Main Store in Kigali)
- NRW = Non Revenue Water
- MININFRA = Ministry of Infrastructure
- REG = Rwanda Energy Group
- RTDA = Rwanda Transport Development Agency
- UWSS = Urban Water & Sanitation Services
- WOS = Water Operation Services

6. Chapter of Training

- **Chapter-1;** **Safety Management**
  (Accidents, Damage, Time Loss)
- **Chapter-2;** **Soil Handling (Exc., B. Filling)**
  (Quality, Accidents, Damage)
- **Chapter-3;** **Recording, Reporting, Documents**
  (Quality, Inspection, Up-date Drawings, Budget)
- **Chapter-4;** **Pipe Connection, Repairing**
  (Quality, Damage, Time Loss)
- **Chapter-5;** **Supplemental as a future recommendations**
  (Concrete, Mechanical & Electrical, Inspection …etc.)

* Note : a part of photo and writing are quoted from web site which are open to the public.

Chapter-1; Safety Management

- § 1-1 Prior consultation with concerned authorities.
- § 1-2 Public announcement (Customer satisfaction) :
- § 1-3 Confirmation of the obstacle matters :
- § 1-4 Identify the working area
  (to avoid third party accidents):
- § 1-5 Protect workers and third party against accidents:

Chapter-1; Safety Management

- § 1-1 Prior consultation with concerned authorities.
  - ✓ MNINFRA, RTDA, REG, Traffic Police…etc.

Shearing INFO, Planning, Collaboration, Supporting

REPUBULIKA Y'U RWANDA

UBUMWE - UMURIMO - GUKUNDA IGIHUGU

Rwanda Energy Group

REG

RWANDA NATIONAL POLICE

Service · Protection · Integrity

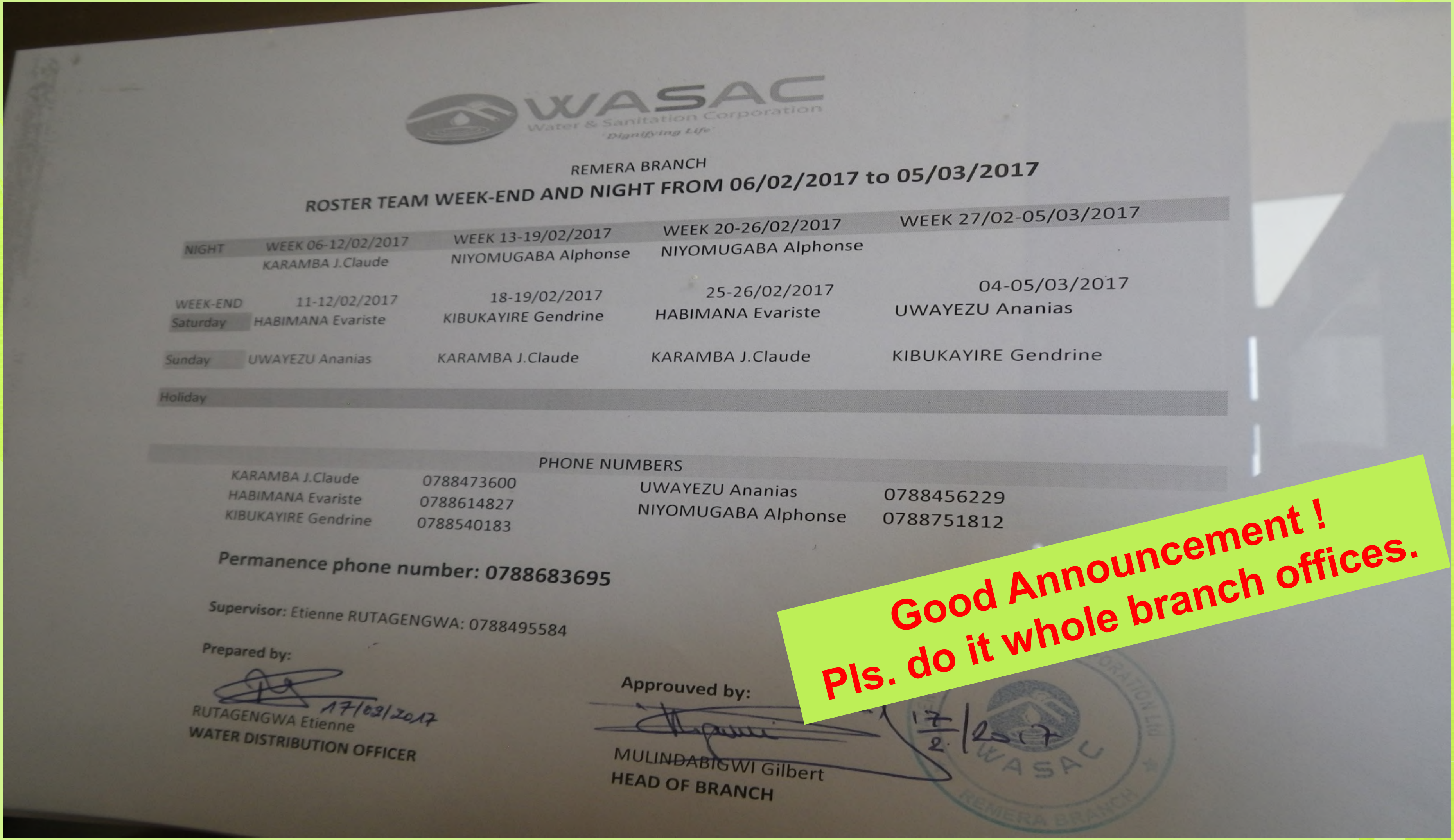
Chapter-1; Safety Management

- § 1-2 Public announcement (Customer satisfaction) :
  - ✓ Mass media (Radio, TV), SNS & WASAC Web site, Announcement by the mater leaders for local area…etc.

Mass media (Radio, TV, SNS)

Chapter-1; Safety Management

- § 1-2 Public announcement -1 :



WASAC
Water & Sanitation Corporation
'Dignifying Life'

REMERA BRANCH

ROSTER TEAM WEEK-END AND NIGHT FROM 06/02/2017 to 05/03/2017

NIGHT	WEEK 06-12/02/2017	WEEK 13-19/02/2017	WEEK 20-26/02/2017	WEEK 27/02-05/03/2017
	KARAMBA J.Claude	NIYOMUGABA Alphonse	NIYOMUGABA Alphonse	
WEEK-END	11-12/02/2017	18-19/02/2017	25-26/02/2017	04-05/03/2017
Saturday	HABIMANA Evariste	KIBUKAYIRE Gendrine	HABIMANA Evariste	UWAYEZU Ananias
Sunday	UWAYEZU Ananias	KARAMBA J.Claude	KARAMBA J.Claude	KIBUKAYIRE Gendrine
Holiday				

PHONE NUMBERS

KARAMBA J.Claude	0788473600	UWAYEZU Ananias	0788456229
HABIMANA Evariste	0788614827	NIYOMUGABA Alphonse	0788751812
KIBUKAYIRE Gendrine	0788540183		

Permanence phone number: 0788683695

Supervisor: Etienne RUTAGENGWA: 0788495584

Prepared by:

17/03/2017

RUTAGENGWA Etienne
WATER DISTRIBUTION OFFICER

Approuved by:

17/2/2017

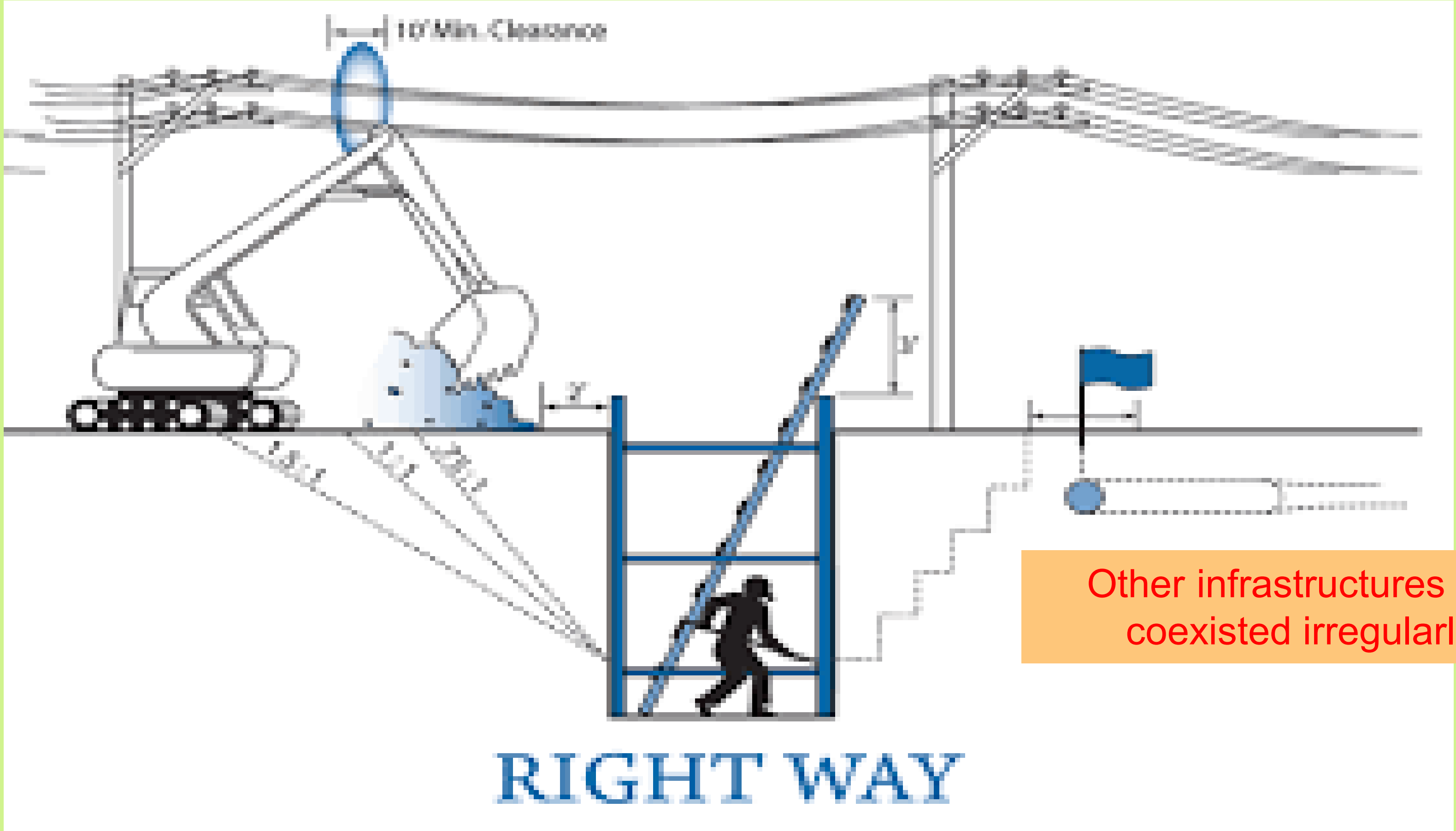
MULINDABIGWI Gilbert
HEAD OF BRANCH

Good Announcement !
Pls. do it whole branch offices.

Emergency organization sheet for night & weekend hours (Remera)

Chapter-1; Safety Management

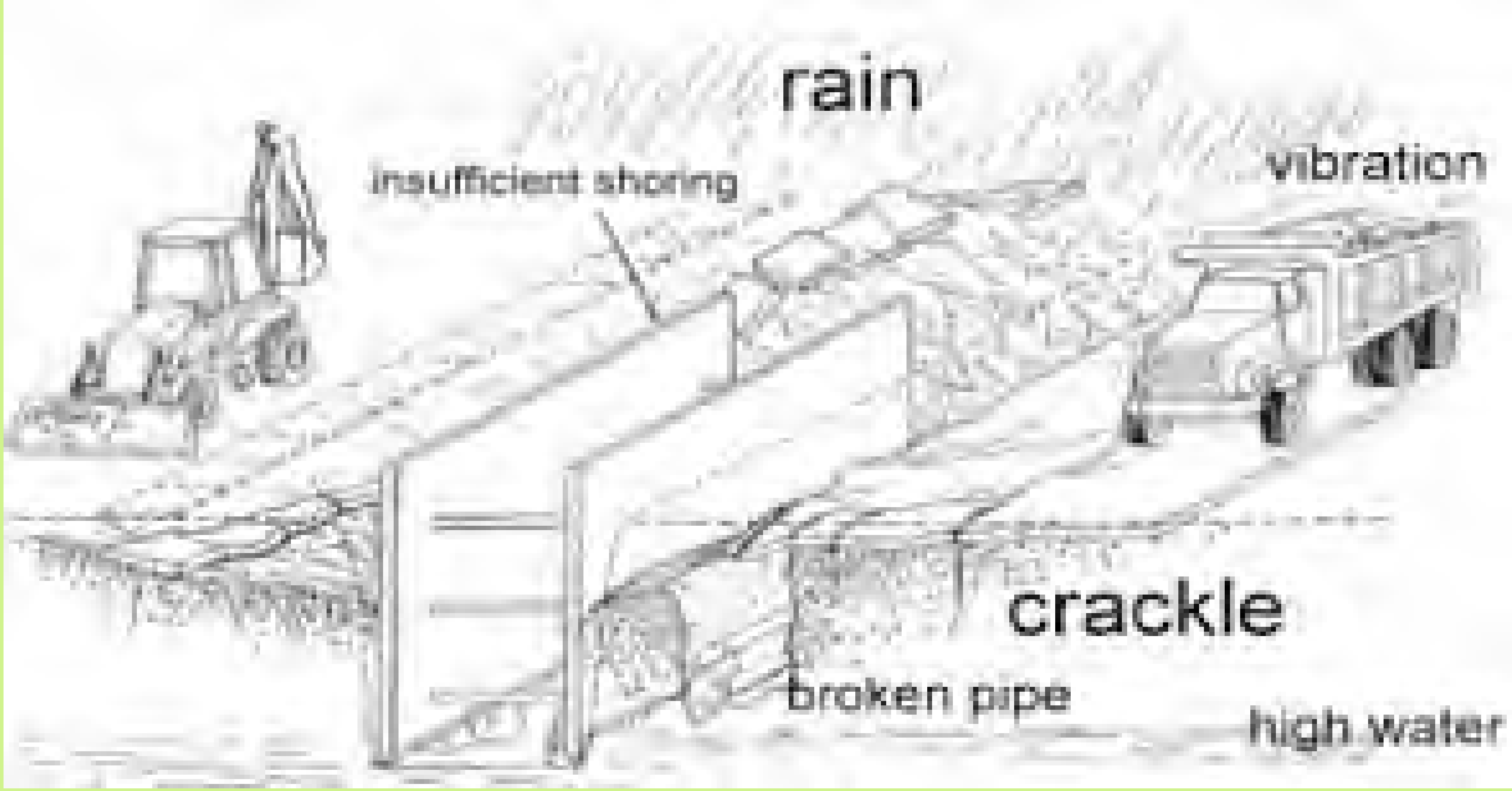
- § 1-3 Confirmation of the obstacle matters :
  Duration, Protection, Emergency organization
  with above authorities § 1-1 .



Other infrastructures are coexisted irregularly

Chapter-1; Safety Management

- § 1-3 Confirmation of the obstacle matters : Duration, Protection, Emergency organization with above authorities § 1-1 .



Chapter-1; Safety Management

- § 1-4 Identify the working area :

  Protection by net, tape, Inst. sign Boards for restriction to enter (e.g. “No Entry”, “Keep Out” …etc.)

How to protect
your workers and third party persons
on
your Branch Office ?

Chapter-1; Safety Management

- § 1-5 Protect workers and third party against accidents:

WASAC Store has this fence net

Chapter-1; Safety Management

- § 1-5 Protect workers and third party against accidents:

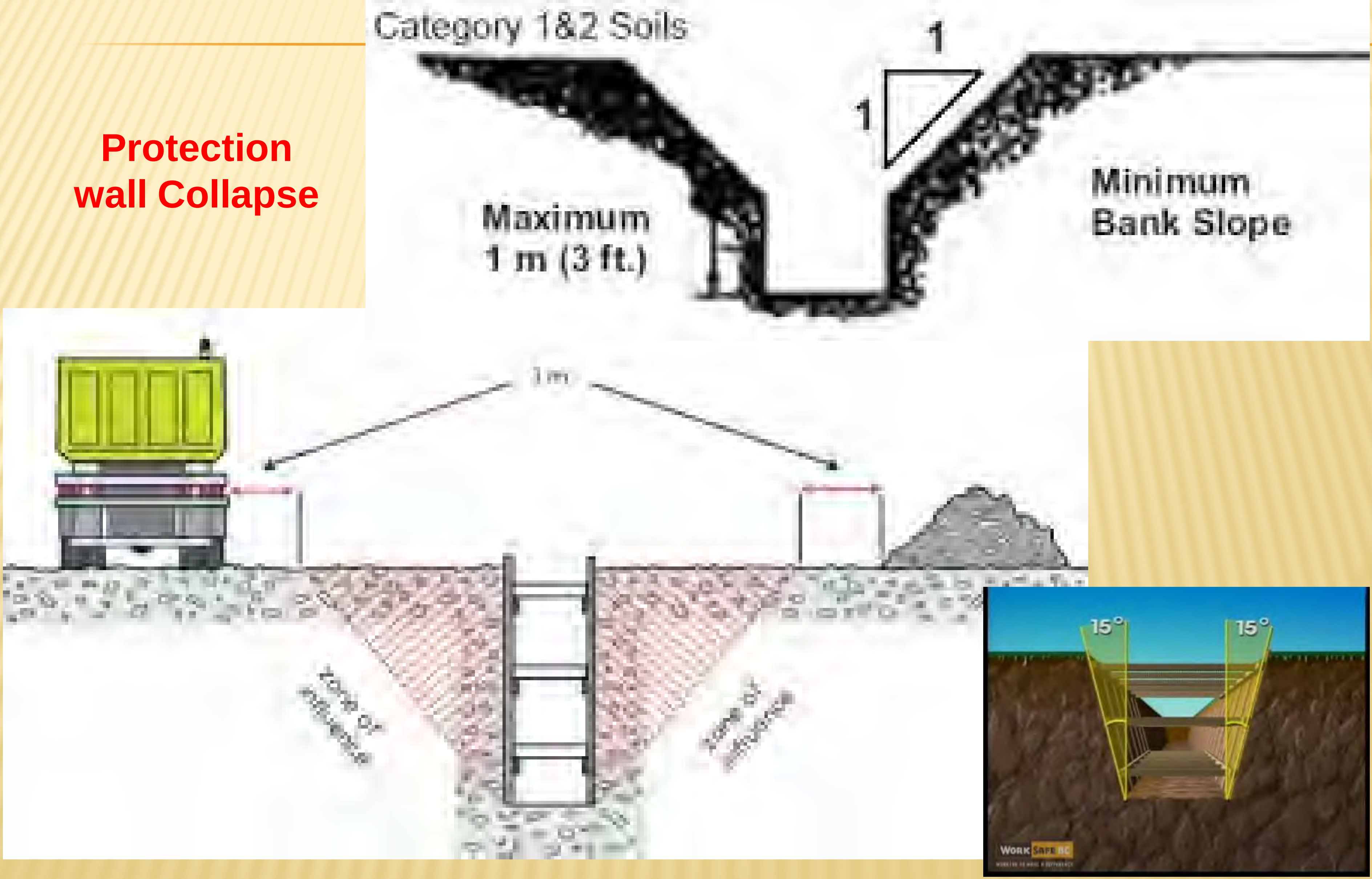
Tool-Box Meeting
as
Safety Meeting

CHAPTER-2; SOIL HANDLING

Soil Wall Collapse !!

CHAPTER-2; SOIL HANDLING

Protection wall Collapse



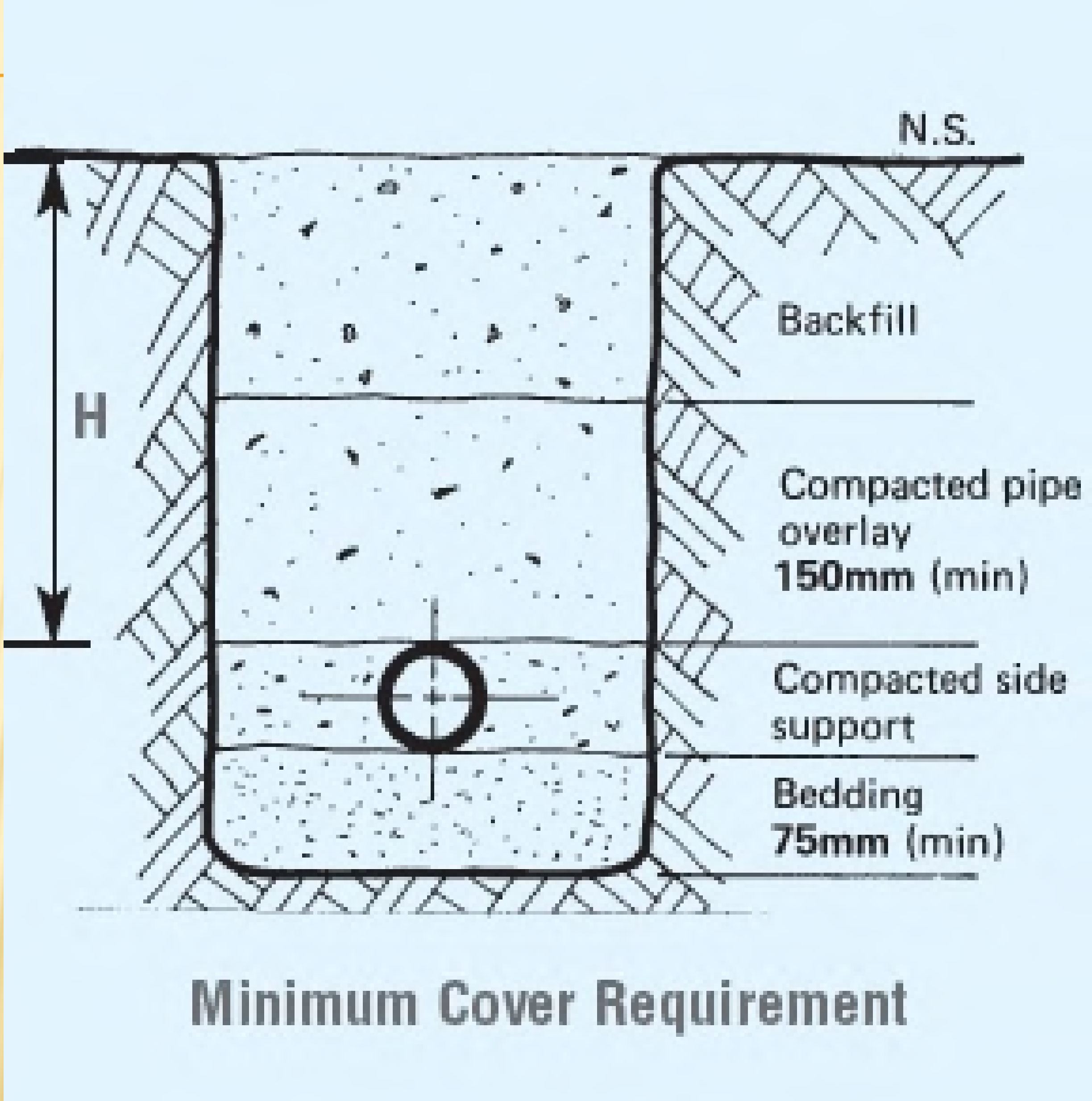
CHAPTER-2; SOIL HANDLING

Protection wall Collapse

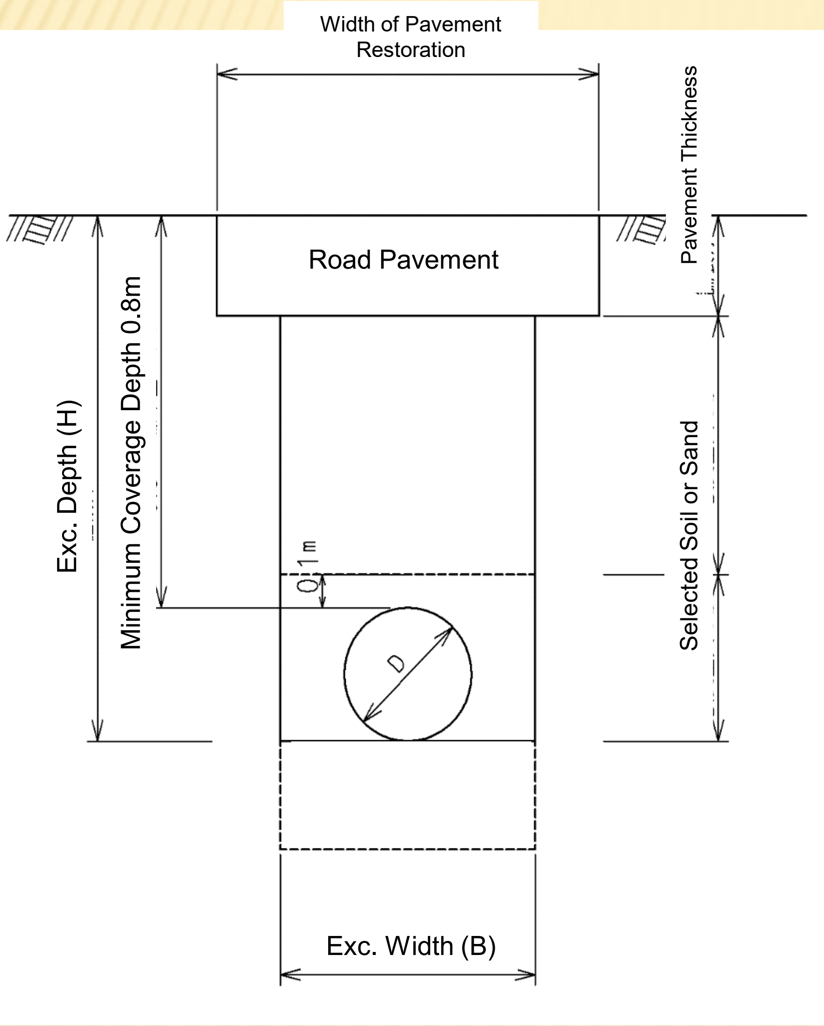
www.alamy.com - D61KHE

It is available to use wooden piles, timber plates

CHAPTER-2; SOIL HANDLING

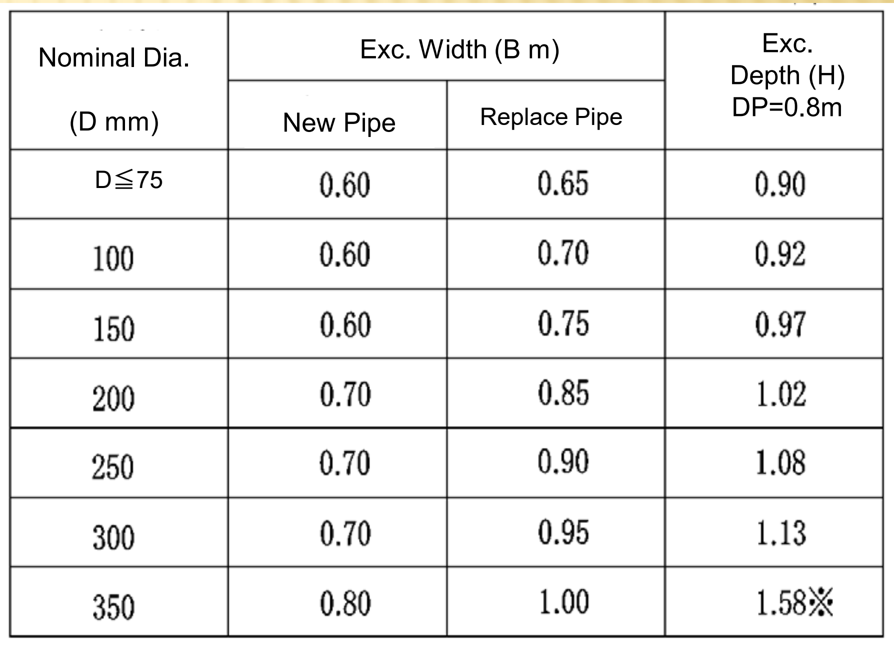


CHAPTER-2; SOIL HANDLING



Standard Dimension of Pipe Trench as reference of

Bureau of Waterworks Tokyo Metropolitan Government



Nominal Dia. (D mm)	Exc. Width (B m)		Exc. Depth (H) DP=0.8m
	New Pipe	Replace Pipe	
D≦75	0.60	0.65	0.90
100	0.60	0.70	0.92
150	0.60	0.75	0.97
200	0.70	0.85	1.02
250	0.70	0.90	1.08
300	0.70	0.95	1.13
350	0.80	1.00	1.58※

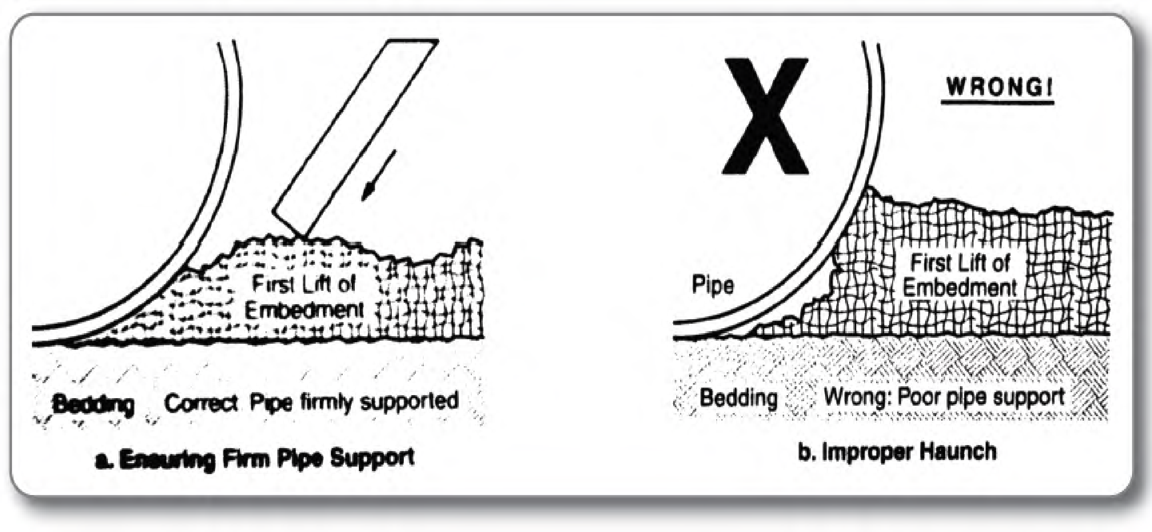
CHAPTER-2; SOIL HANDLING

Back filling soil should be removed rocks, stones, other hard objects and gavages in the vicinity of the buried pipe line.

What is problem ?

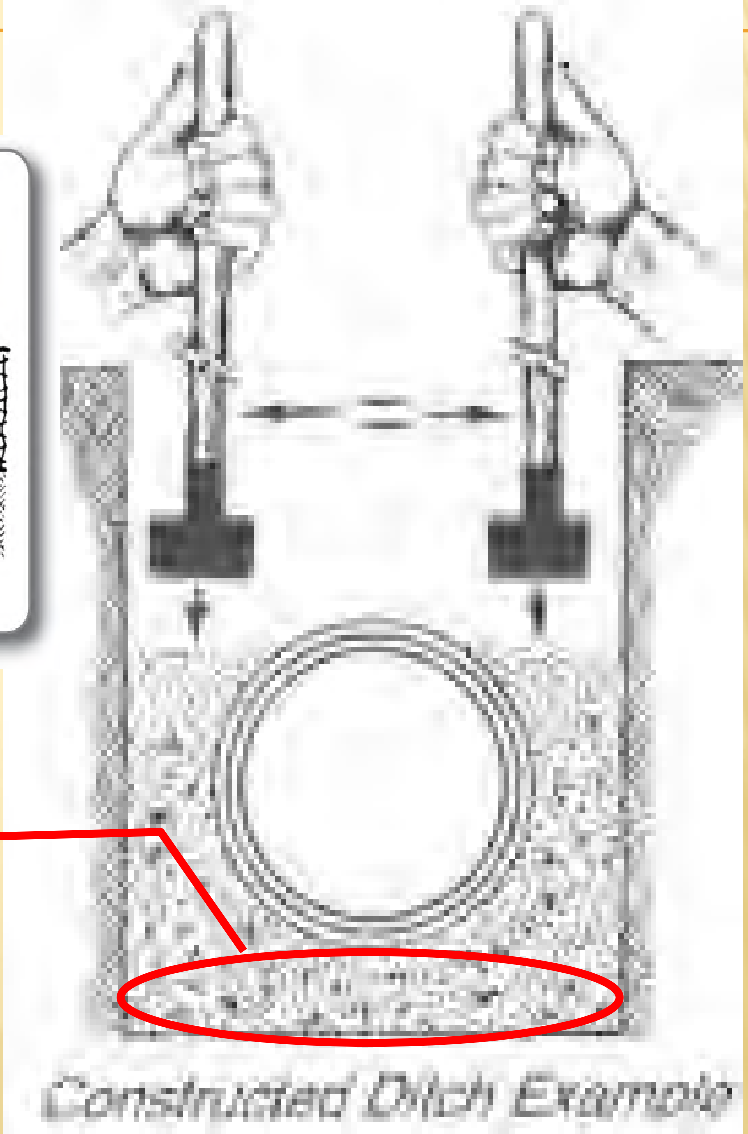
CHAPTER-2; SOIL HANDLING

Backfilling under the pipes



This parts is most important for carefully back filling and compaction.

Are you want to come back there and repair it again ??



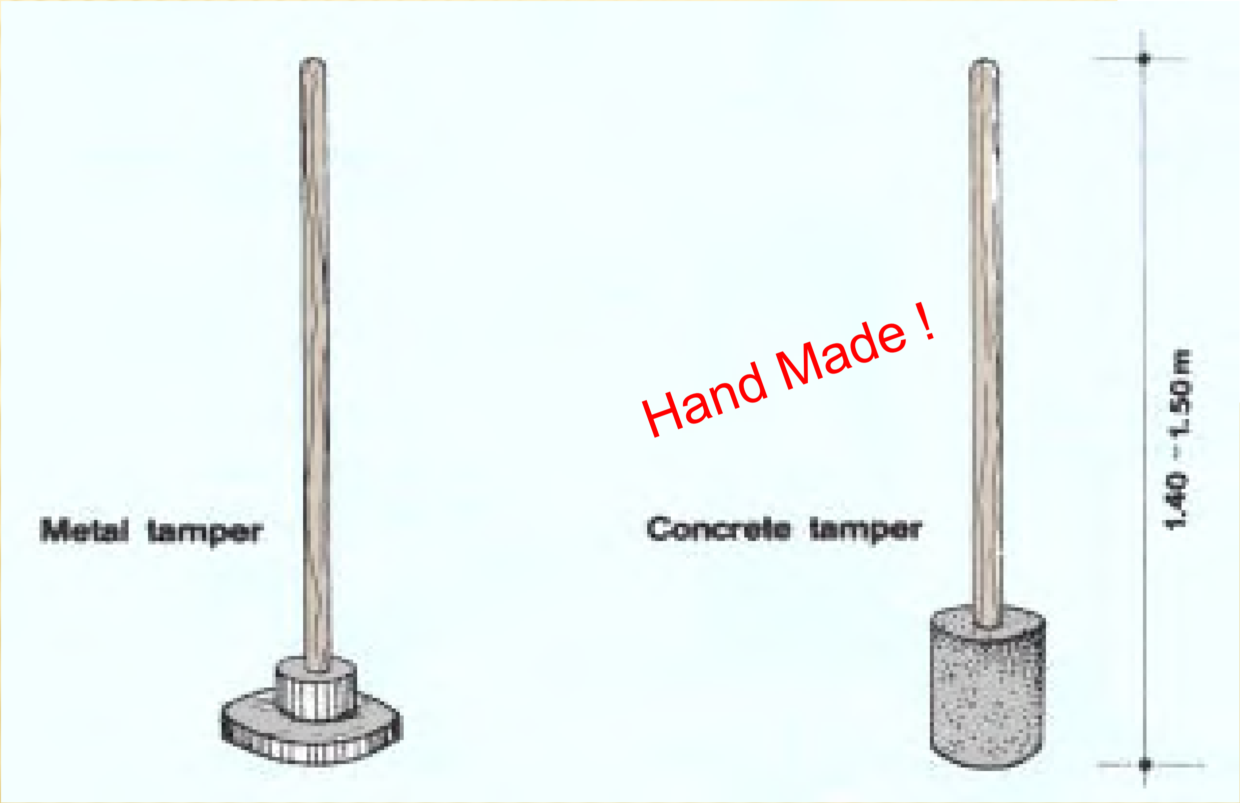
CHAPTER-2; SOIL HANDLING

Compacting with the feet is recommendable
when there are not hand compactor.

CHAPTER-2; SOIL HANDLING

HAND COMPACTORS

Portable ! & Low price ! than machine compactor



Hand Made !

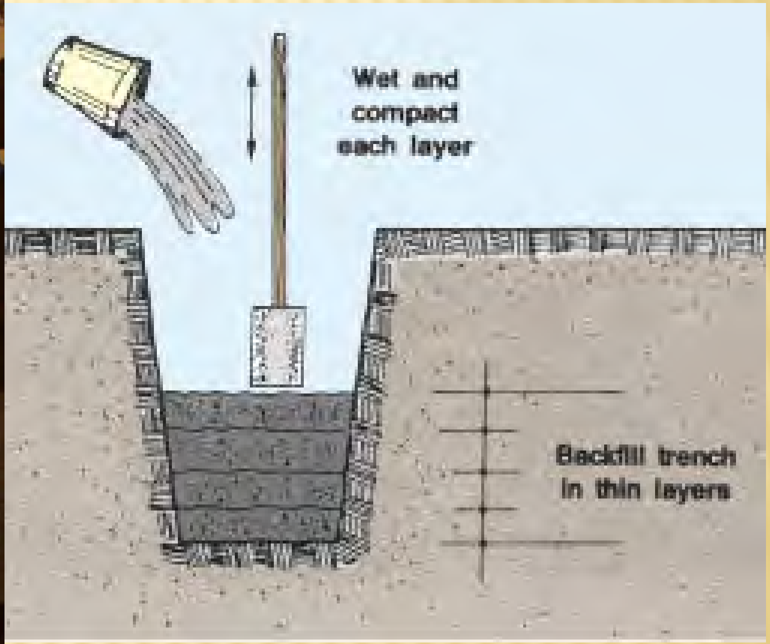
CHAPTER-2; SOIL HANDLING

HAND COMPACTION

Back filling and compaction
should be done
by each layers.
(t=100~150mm approx.)

CHAPTER-2; SOIL HANDLING

Back Filling with wet density



The thickness of each layer shall be determined in accordance with the capacity of the compaction equipment.
(e.g. 150~300mm/each by machine compactor. Soil density to be 90% maximum)

CHAPTER-2; SOIL HANDLING

Back Filling and Inspection

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

- § 3-1 : Daily Reports (log book)
- § 3-2 : Technical standards & Specifications
- § 3-3 : Drawings of pipe lines

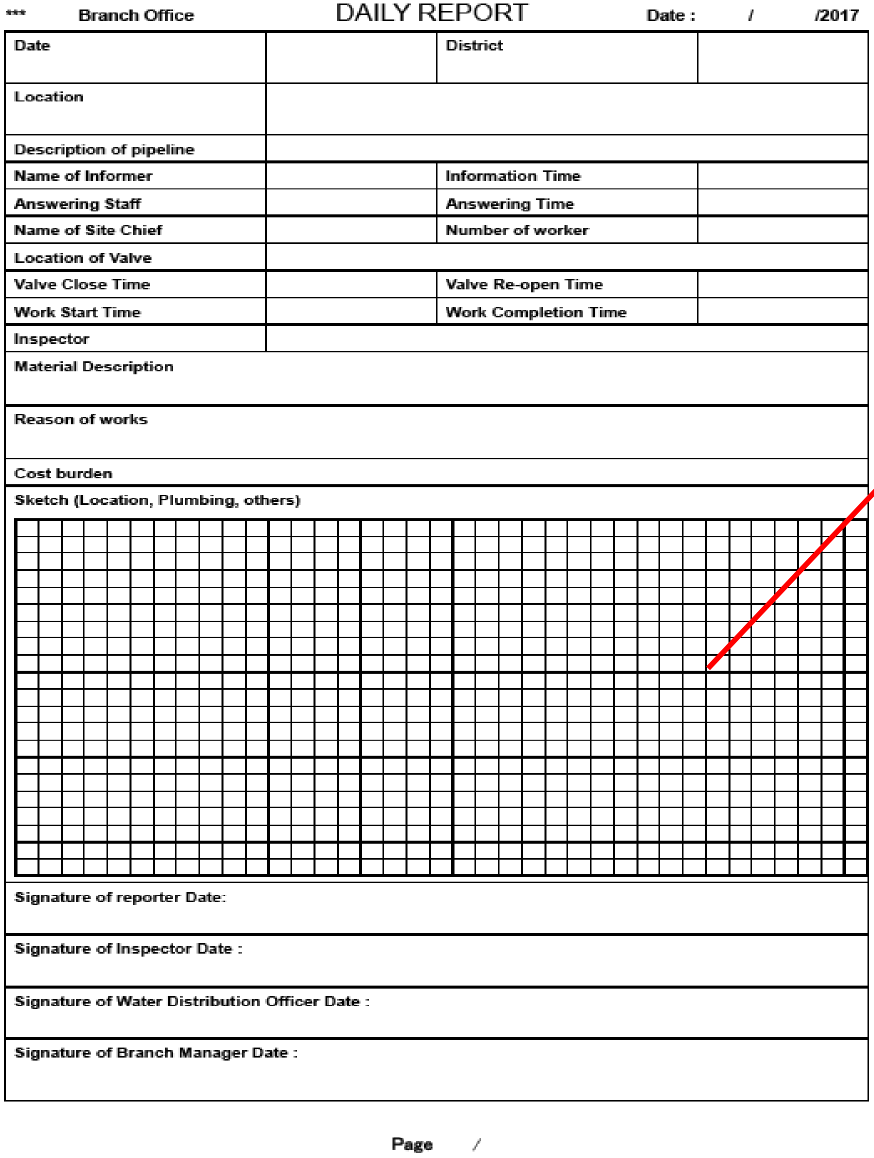
CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

§ 3-1 : Notebook of the Daily Report for piping works (WASAC B.

Good Job !!!

Pls. add. more INFO on it.

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS



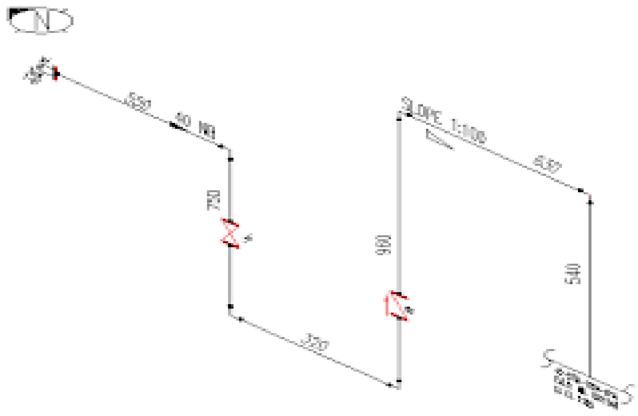
*** Branch Office DAILY REPORT Date : / /2017

Date		District	
Location			
Description of pipeline			
Name of Informer		Information Time	
Answering Staff		Answering Time	
Name of Site Chief		Number of worker	
Location of Valve			
Valve Close Time		Valve Re-open Time	
Work Start Time		Work Completion Time	
Inspector			
Material Description			
Reason of works			
Cost burden			
Sketch (Location, Plumbing, others)			
Signature of reporter Date:			
Signature of Inspector Date :			
Signature of Water Distribution Officer Date :			
Signature of Branch Manager Date :			

Page /

Note book of the Daily report
for piping works
as log book
(example)

Sketch by hand writing
about location map, piping layout
list of pipe material…etc.
any information can be wrote
as log book.



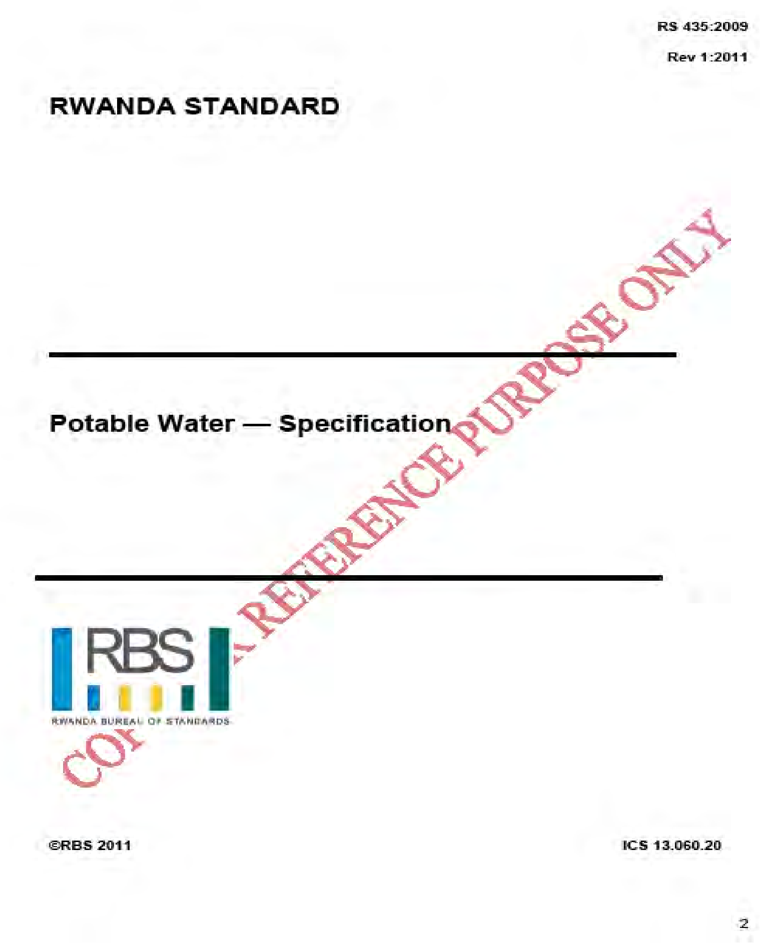
CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

Standards & Technical Specifications of Rwanda (MININFRA, WASAC) (Sample)

Required contents (Example)

- Earth Work
  (Incl. retaining wall, protection work…etc.)
- Material standards
- Pipe Connection, Installation
- Pipe Flashing, Disinfection, Pressure Test
- Backfilling
- Road crossing, Restoration
- Concrete Works
  (Thrust Block, Valve Chamber, Pipe Bridge…etc.)
- Steel Works (Re-Steel Bar)

Please have the standards in your office.



RS 435:2009
Rev 1:2011

RWANDA STANDARD

Potable Water — Specification

RWANDA BUREAU OF STANDARDS

©RBS 2011

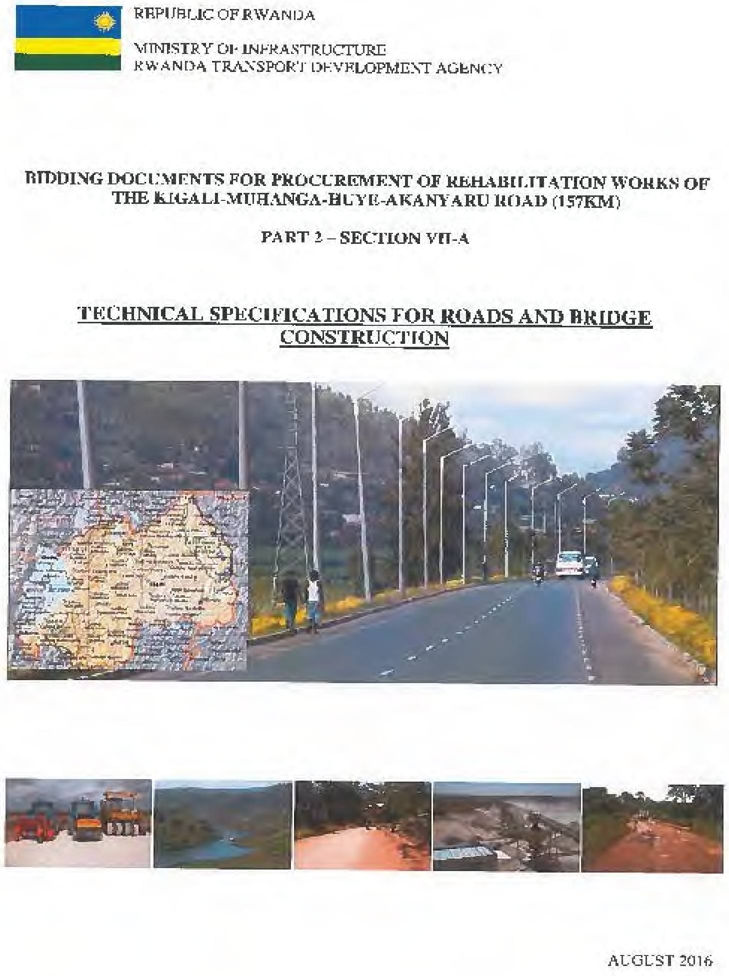
ICS 13.060.20

2

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

Technical Standards & Specifications of Rwanda (MININFRA, RTDA) (Sample)

Pipe works under the roads, which are under the jurisdiction of RTDA should be based on the technical specifications of RTDA.



REPUBLIC OF RWANDA

MINISTRY OF INFRASTRUCTURE
RWANDA TRANSPORT DEVELOPMENT AGENCY

BIDDING DOCUMENTS FOR PROCUREMENT OF REHABILITATION WORKS OF THE KIGALI-MUHANGA-HUYE-AKANYARU ROAD (157KM)

PART 2 – SECTION VII-A

TECHNICAL SPECIFICATIONS FOR ROADS AND BRIDGE CONSTRUCTION

AUGUST 2016

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

International Standards of the Contract, Specification * for your reference
by the Fédération International des Ingénieurs Conseils (FIDIC)

Fédération Internationale des Ingénieurs-Conseils
International Federation of Consulting Engineers
Internationale Vereinigung Beratender Ingenieure
Federación Internacional de Ingenieros Consultores

Conditions of Contract for
Construction

FOR BUILDING AND ENGINEERING WORKS DESIGNED BY THE EMPLOYER

GENERAL CONDITIONS
GUIDANCE FOR THE PREPARATION OF PARTICULAR CONDITIONS
FORMS OF LETTER OF TENDER, CONTRACT AGREEMENT AND
DISPUTE ADJUDICATION AGREEMENT

ISBN 2 88432 022 9

FIRST EDITION 1999

Fédération Internationale des Ingénieurs-Conseils
International Federation of Consulting Engineers
Internationale Vereinigung Beratender Ingenieure
Federación Internacional de Ingenieros Consultores

Client/Consultant
Model Services Agreement

AGREEMENT
GENERAL CONDITIONS
PARTICULAR CONDITIONS
APPENDICES A, B AND C

ISBN 978 – 2 – 88432 – 048 – 1

FOURTH EDITION 2006

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

The Guidelines for Drinking Water Quality
by the World Health Organization (WHO)

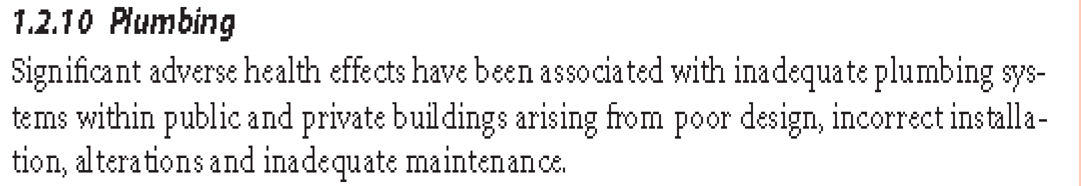
* for your reference

Guidelines for
Drinking-water Quality

FOURTH EDITION

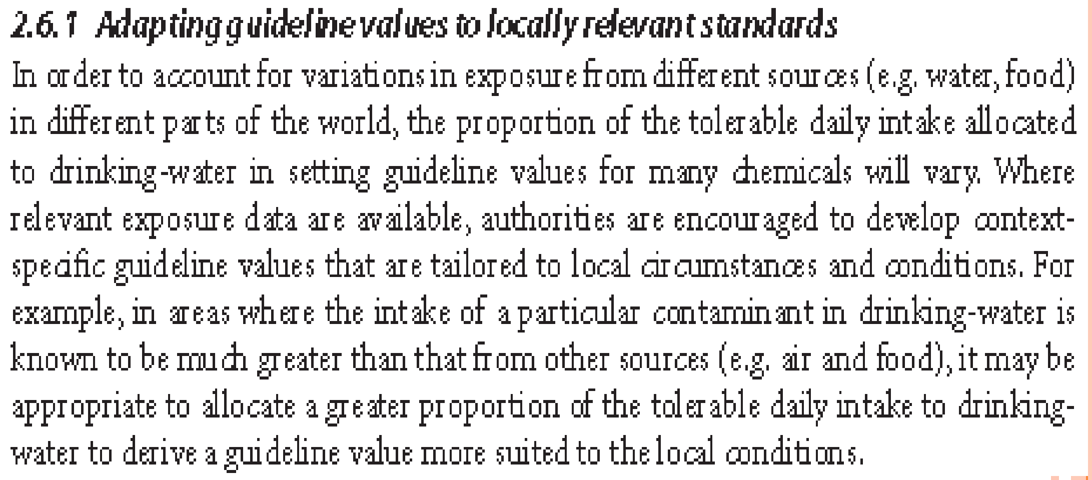
World Health
Organization

It is desirable to grasp summary of
Water Quality Standards (Rwanda Standards)
as Water Distribution Officer.
The Officer shall also manage pipe lines in term of quality.



1.2.10 Plumbing

Significant adverse health effects have been associated with inadequate plumbing systems within public and private buildings arising from poor design, incorrect installation, alterations and inadequate maintenance.



2.6.1 Adapting guideline values to locally relevant standards

In order to account for variations in exposure from different sources (e.g. water, food) in different parts of the world, the proportion of the tolerable daily intake allocated to drinking-water in setting guideline values for many chemicals will vary. Where relevant exposure data are available, authorities are encouraged to develop context-specific guideline values that are tailored to local circumstances and conditions. For example, in areas where the intake of a particular contaminant in drinking-water is known to be much greater than that from other sources (e.g. air and food), it may be appropriate to allocate a greater proportion of the tolerable daily intake to drinking-water to derive a guideline value more suited to the local conditions.

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

§ 3-3 : Drawings of pipe lines

General Drawing of the pipe network (WASAC) (example)

It should be delivered to the whole branch offices by the WASAC Head Office.

Also, it to be up dated and delivered to the Branch offices.

Good display !
Pls. do it whole branch offices.

Displayed the general drawing of pipe net work on wall to grasp and manage for whole office staff

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

§ 3-3 : Drawings of pipe lines

Detail Drawings of the pipe lines (WASAC, Branch Office)

Some Branch Office has a drawing
of pipe lines
which were made by handwriting.
However,
it is effectiveness for management.

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

§ 3-3 : Drawings of pipe lines

Detail Drawings of the pipe lines (WASAC, Branch Office)

Some Branch Office has a drawing of pipe lines
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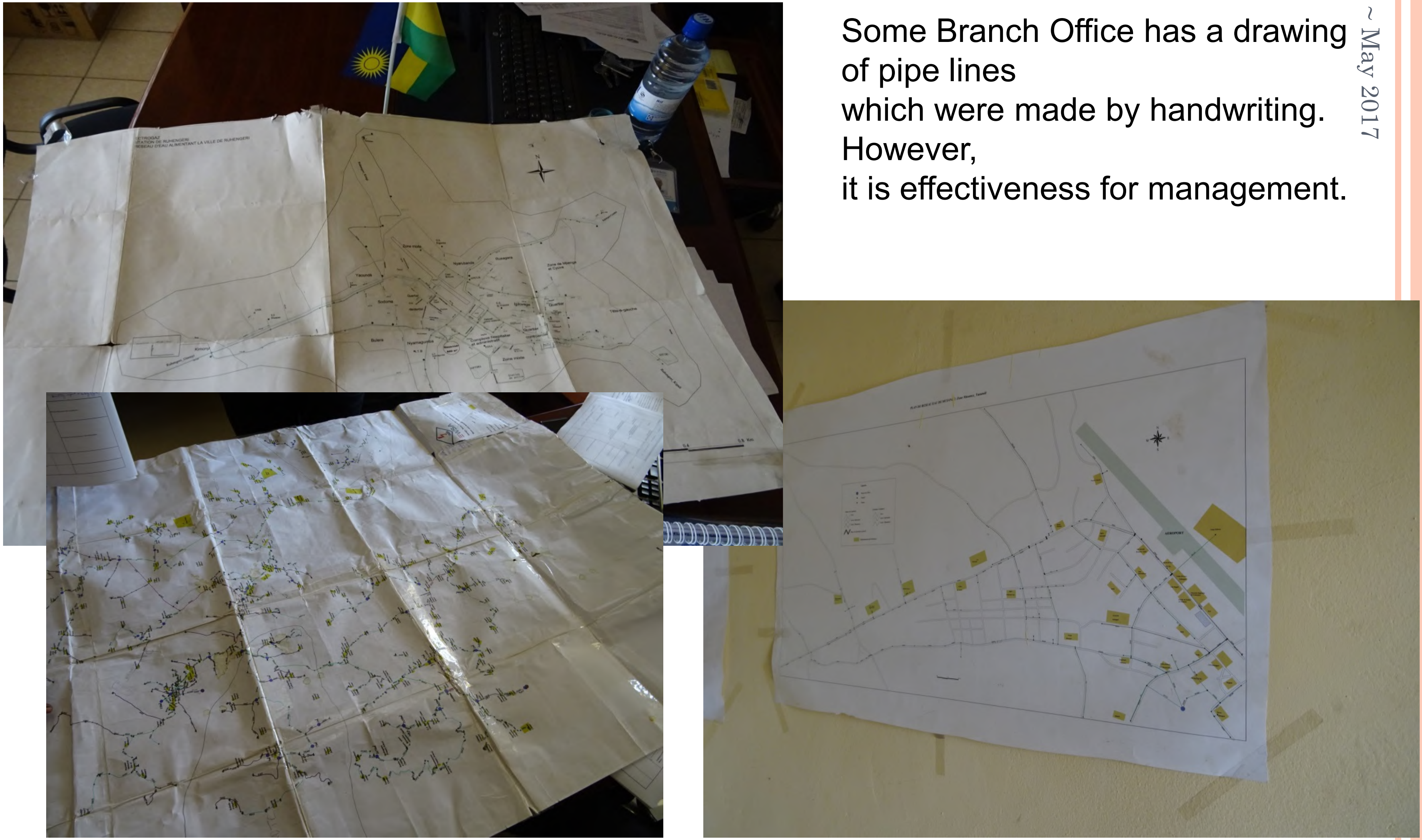
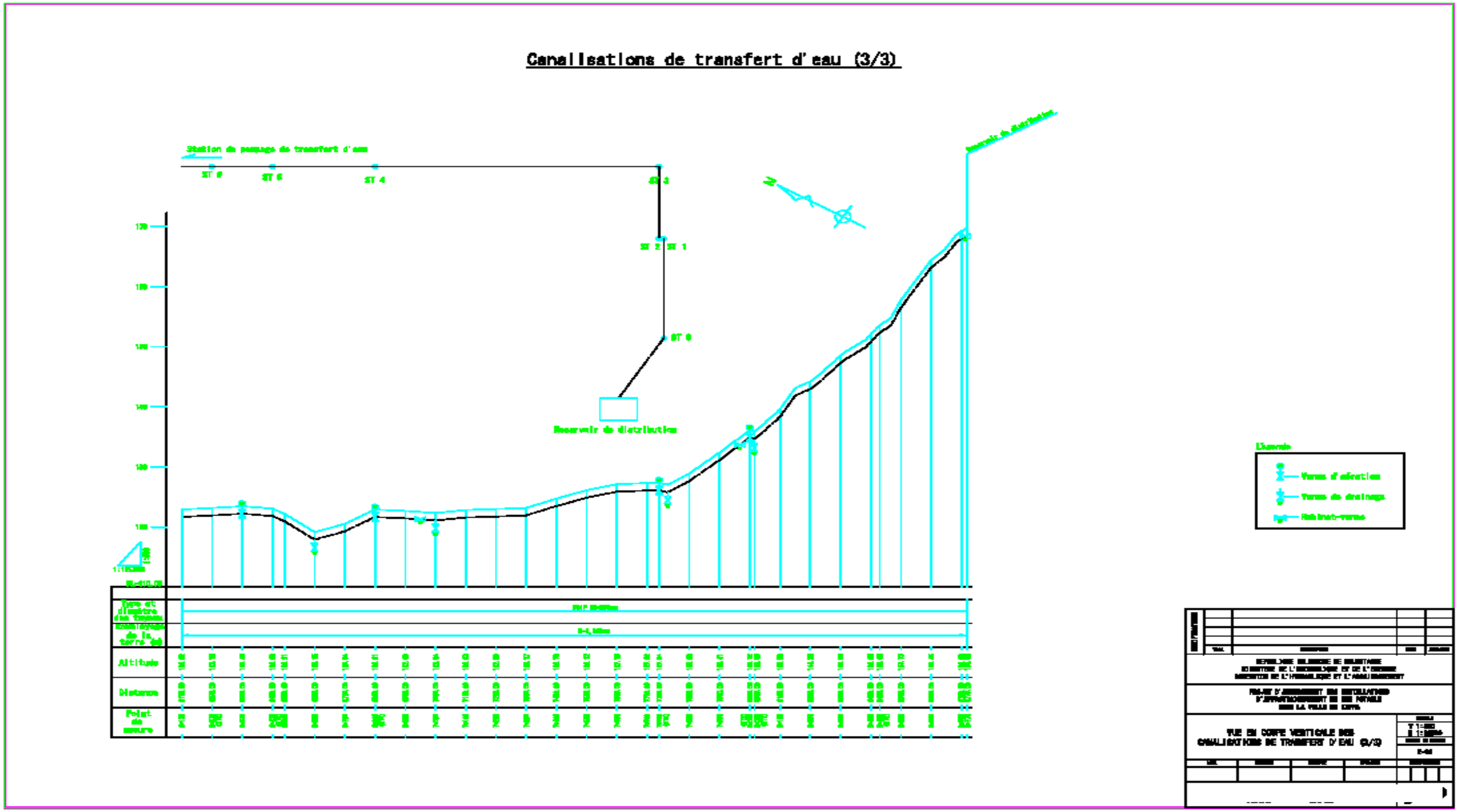


§ 3-3 : Drawings of pipe lines

Detail Drawings of the pipe line section (Sample)
Similar drawings such as section drawings of the pipe lines
to be delivered to the whole Branch offices by the WASAC Head Office.



CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

§ 3-3 : Drawings of pipe lines

Detail Drawings of the pipe lines (Sample)

It to be delivered to the whole Branch offices by the WASAC Head Office.

Also, it to be up dated and delivered to the Branch offices.

Mar. ~ May 2017

CHAPTER-3;RECORDING, REPORTING, DOCUMENTS

§ 3-3 : Drawings of pipe lines

Detail Drawings of the pipe lines (WASAC)
(example)
It to be delivered to the whole Branch offices by the WASAC Head Office.
Also, it to be up dated and delivered to the Branch offices.

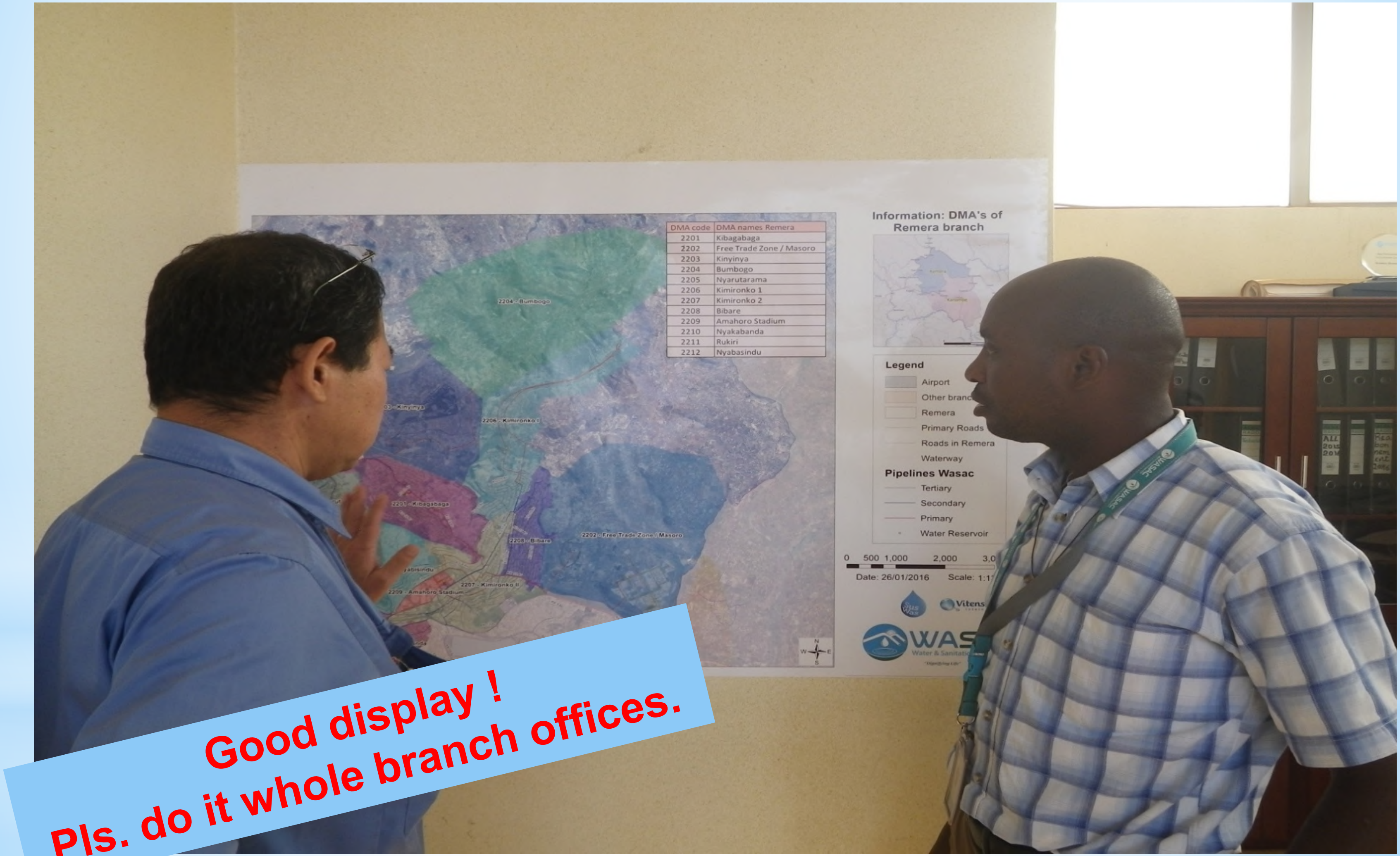
?

* Chapter-4; Pipe Connection

◆ § 4-1	: Summary of pipe connection
◆ § 4-2	: Pipe Stock
◆ § 4-3	: Pipe Drilling
◆ § 4-4	: Pipe Connection
◆ § 4-5	: Elec. Welding
◆ § 4-6	: Threading
◆ § 4-7	: Butte Welding
◆ § 4-8	: Welding of Polypropylene Pipes
◆ § 4-9	: Thrust Block for Pipe Bend
◆ § 4-10	: Pipe Layout (Inlet, Outlet, Overflow, Drain)
◆ § 4-11	: Asphalt (Concrete) Pavement of Road

* Chapter-4; Pipe Connection

◆ § 4-1 : Summary of pipe connection



Good display !
Pls. do it whole branch offices.

General Drawing (Pipe network) is displayed at Branch Office

Chapter-4; Pipe Connection

◆ § 4-1 : Summary of pipe connection

For safety :

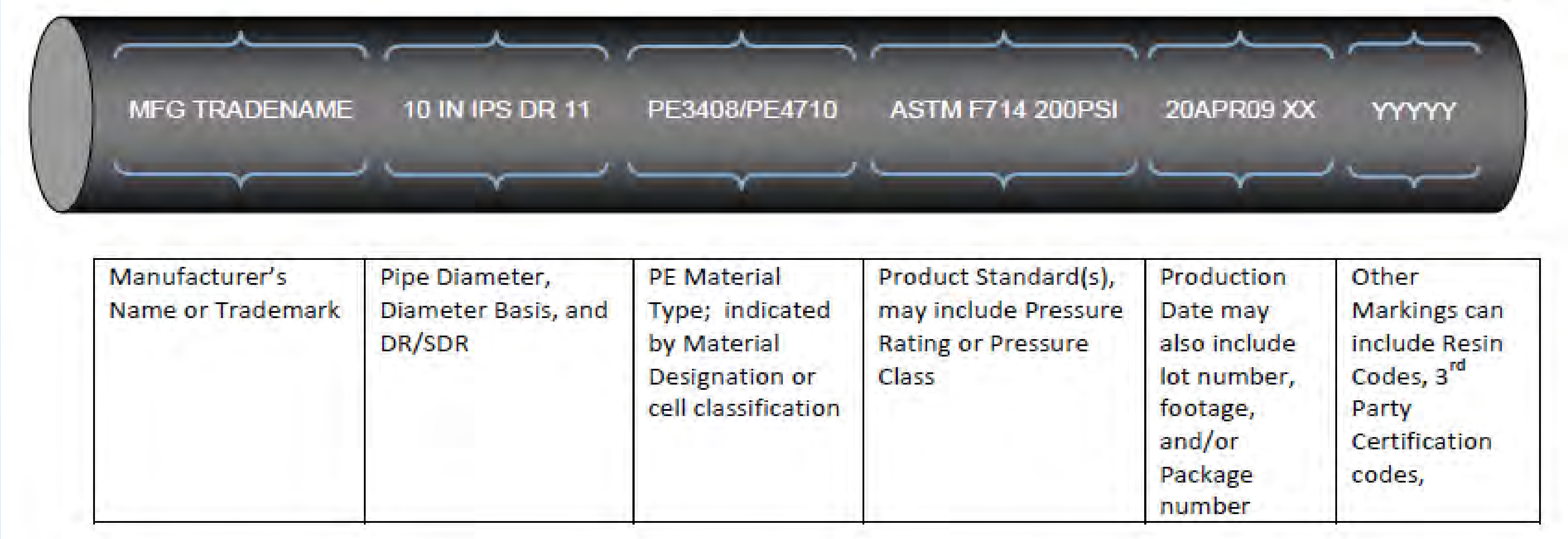
Flushing & Disinfecting !!

Water pipe installation should be flushed and disinfected in accordance with the standard of Rwanda (e.g. AWWA C651 Chlorine disinfection …etc.)

Pipe quality :

Check the Marking !!

Rwanda standards (e.g. ASTM, AWWA …etc.) require the markings on pipe.



Manufacturer's Name or Trademark	Pipe Diameter, Diameter Basis, and DR/SDR	PE Material Type; indicated by Material Designation or cell classification	Product Standard(s), may include Pressure Rating or Pressure Class	Production Date may also include lot number, footage, and/or Package number	Other Markings can include Resin Codes, 3rd Party Certification codes,

Chapter-4; Pipe Connection

◆ § 4-2 : Pipe Stock

Current condition of
Material stock at the Branch Office

What is problem ?

* Chapter-4; Pipe Connection

◆ § 4-2 : Pipe Stock

Current condition of
Material stock at the Branch Office

What is problem ?

* Chapter-4; Pipe Connection

◆ § 4-2 : Pipe stock

Store of the Branch Office is also desirable to be managed their stock material.

* Chapter-4; Pipe Connection

◆ § 4-2 : Pipe stock

Store of the Branch Office is also desirable to be managed their stock material.

* Chapter-4; Pipe Connection

◆ § 4-2 : Summary of the machines

Pipeline shall be installed under the public roads except drainage, canal, other lines (Elec., Telephone cable lines)

Existing pipe line under the drain canal
(depth 200mm approx. !!)
Pipes to be exposed by canal corrosion.

* Chapter-4; Pipe Connection

◆ § 4-3 : Pipe drilling

Pipe drilling
for
a clamp saddle installation

What is problem ?

Drilling Tools

◆ § 4-4 : Pipe connection

Pipe repairing works

What is cause of damage ?

Need corroboration
with
REG, Traffic Police, District.

* Chapter-4; Pipe Connection

◆ § 4-4 : PVC pipe connection

Are you check and inspect pipe connection works ?
Client (WASAC) believe 100% the outsourcing (local consultants & Contractors) ?

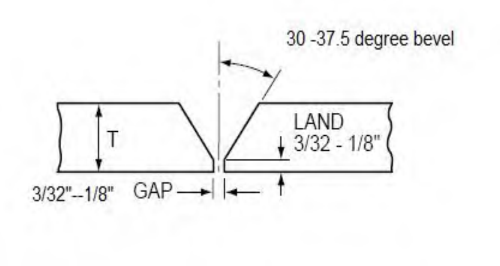
* Chapter-4; Pipe Connection

◆ § 4-5 : Elec. Welding

No Good 👎

Pipe welding works

Did you confirm standard of the welding lot ?
Did you confirm the Ampere of the welder ?
Are you grasp the standard of welding works ?

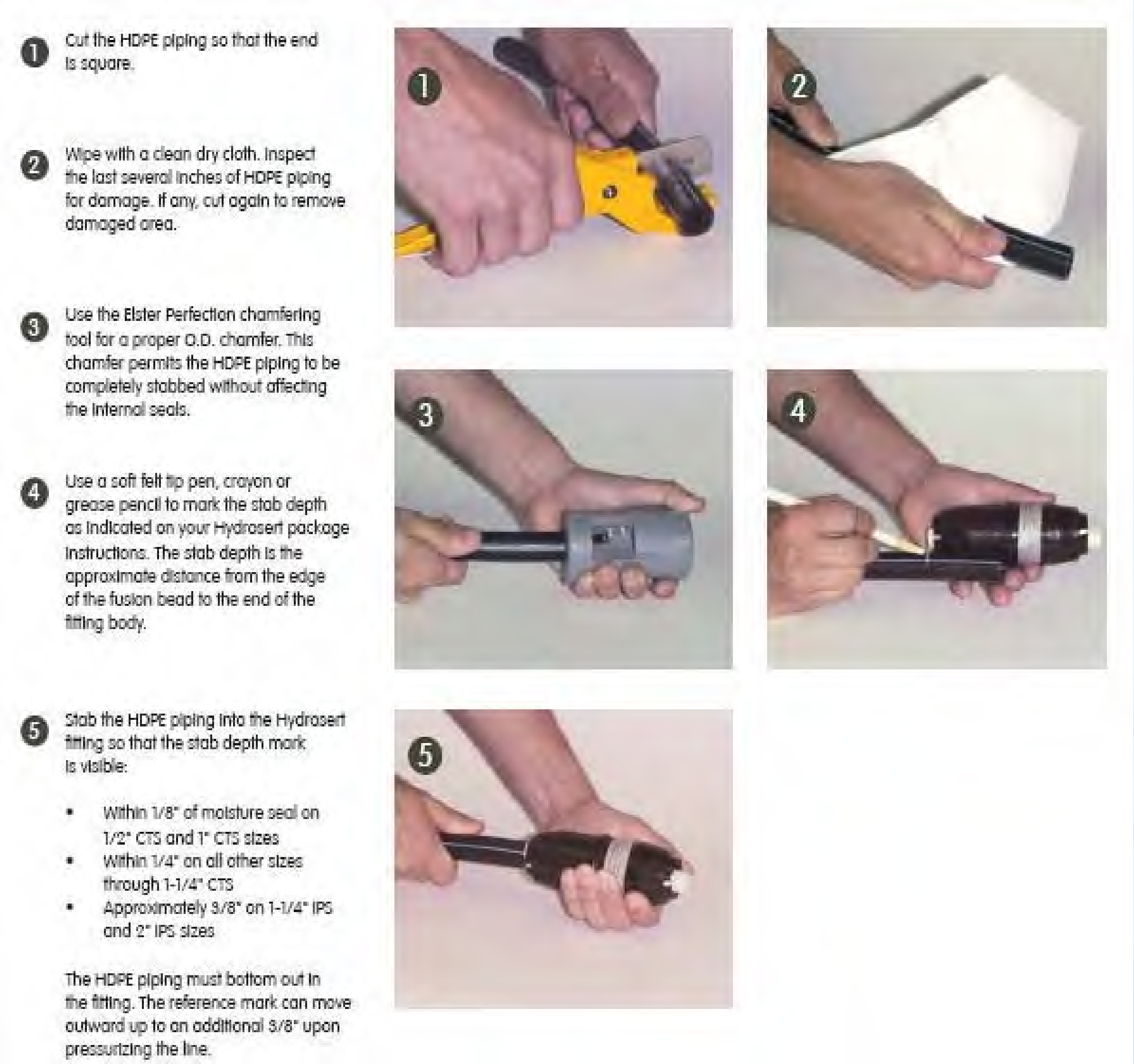


○

* Chapter-4; Pipe Connection

◆ § 4-6 : Threading

Are you check
and inspect
of pipe connection works ?



❶ Cut the HDPE piping so that the end is square.

❷ Wipe with a clean dry cloth. Inspect the last several inches of HDPE piping for damage. If any, cut again to remove damaged area.

❸ Use the Elster Perfection chamfering tool for a proper O.D. chamfer. This chamfer permits the HDPE piping to be completely stabbed without affecting the internal seals.

❹ Use a soft felt tip pen, crayon or grease pencil to mark the stab depth as indicated on your Hydrosert package instructions. The stab depth is the approximate distance from the edge of the fusion bead to the end of the fitting body.

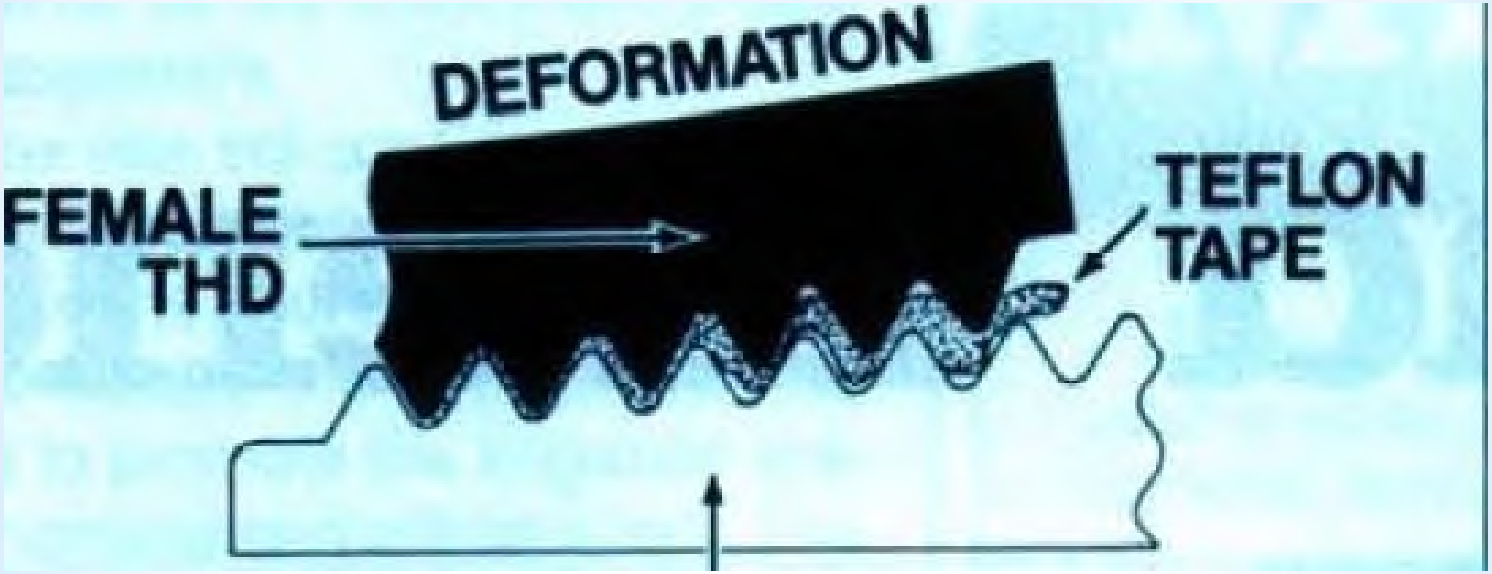
❺ Stab the HDPE piping into the Hydrosert fitting so that the stab depth mark is visible:

- Within 1/8" of moisture seal on 1/2" CTS and 1" CTS sizes
- Within 1/4" on all other sizes through 1-1/4" CTS
- Approximately 3/8" on 1-1/4" IPS and 2" IPS sizes

The HDPE piping must bottom out in the fitting. The reference mark can move outward up to an additional 3/8" upon pressurizing the line.

* Chapter-4; Pipe Connection

◆ § 4-6 : Threading



Teflon tape, when compressed between male and female threads in plastic fillings joints, can cause deformation, leading to leakage and, possibly, to cracked female fittings.

Do not roll (wind) Teflon tape to excess !!

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

Butte welding components

Procedure :

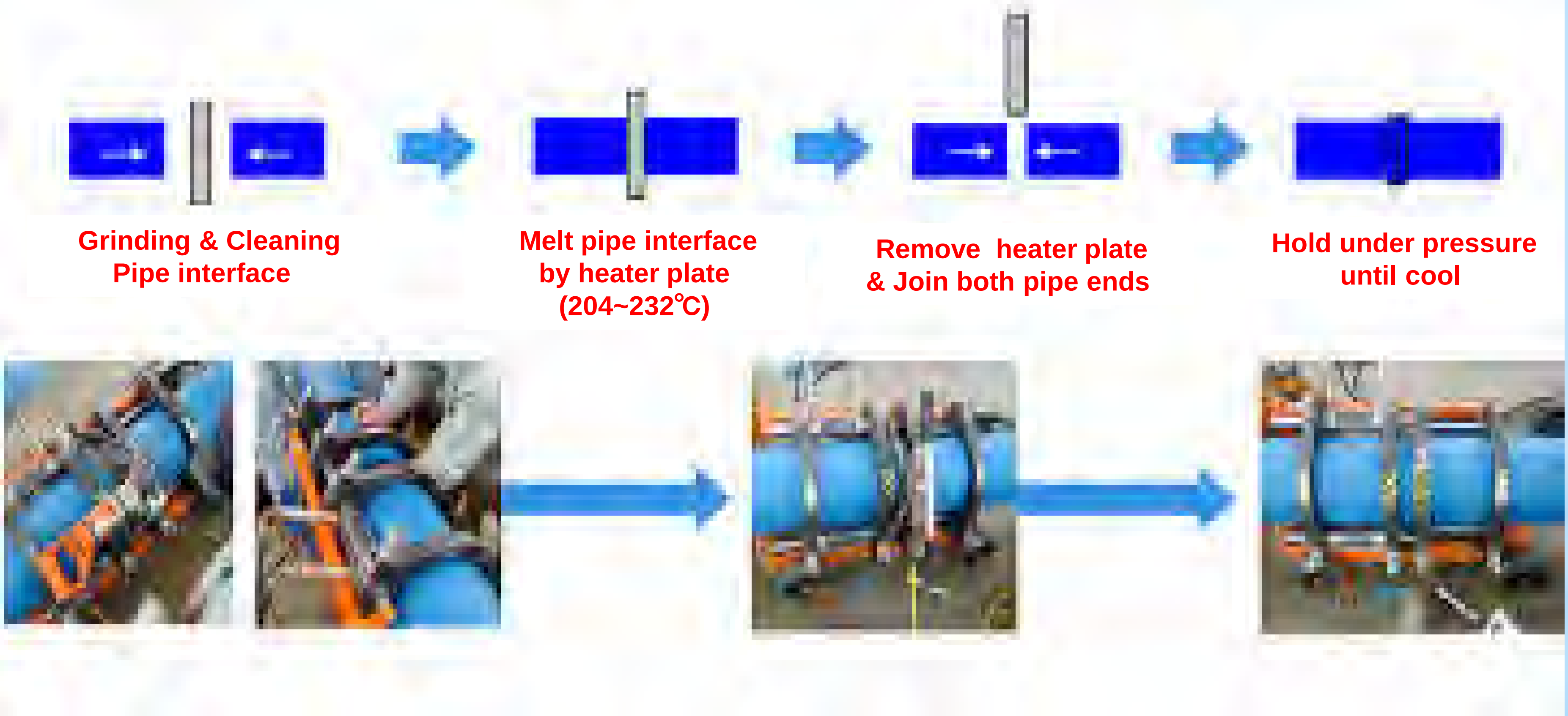
① Clean & Securely fasten the components to be joined.
② Face the pipe ends.
③ Align the pipe profile.
④ Melt the pipe interfaces.
⑤ Join the two profiles together.
⑥ Hold under pressure until coll.
⑦ Visually inspect the joint.

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

5. Join

The maximum recommended time allowed for heater plate removal is indicated below.



Grinding & Cleaning Pipe interface

Melt pipe interface by heater plate (204~232℃)

Remove heater plate & Join both pipe ends

Hold under pressure until cool

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

1. Secure

Clean the inside and outside of the pipe or fitting (components) ends by wiping with a clean, dry cloth or paper towel. Remove all foreign matter.

Align the components in the machine, place them in the clamps, and then close the clamps.

Do not force pipes into alignment against open fusion clamps.

Component ends should protrude past the clamps enough so that facing will be complete.

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

2. Face

Place the facing tool between the component ends, and face them to establish smooth, clean, parallel mating surfaces. Complete facing produces continuous circumferential shavings from both ends. Face until there is minimal distance between the fixed and moveable clamps.

If the machine is equipped with facing stops, face down to the stops. Stop the facer before moving the pipe ends away from the facer. Remove the facing tool, and clear all shavings and pipe chips from the component ends. Do not touch the component ends with your hands after facing.

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

3. Align

Bring the component ends together, check alignment and check for slippage against fusion pressure.

Look for complete contact all around both ends with no detectable gaps, and ODs in high-low alignment.

If necessary, adjust the high side by tightening the high side clamp.

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

4. Melt

Verify that the contact surface of the heating tool is maintaining the correct temperature. Place the heating tool between the component ends, and move the ends against the heating tool. Bring the component ends together under pressure to ensure full contact. The initial contact pressure should be held very briefly and released without breaking contact. Pressure should be reduced when evidence of melt appears on the circumference of the pipe. (204~232 degree Celsius)

Hold the ends against the heating tool **without force** (drag force may be necessary to ensure contact).

Beads of melted PE will form against the heating tool at the component ends. When the proper melt bead size is formed, The proper bead size is dependent upon the size of the component.

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

4. Melt

During heating, the melt bead will expand out flush to the heating tool surface, or may curl slightly away from the surface. If the melt bead curls significantly away from the heating tool surface, unacceptable pressure during heating may have occurred.

Maximum Heater Plate removal Times (for reference)	
Pipe wall thickness	Max. heater removal time
5.1 mm ≦ t < 9.0 mm	8 sec.
9.0 mm ≦ t < 14.0 mm	10 sec.
14.0 mm ≦ t < 30.0 mm	15 sec.
30.0 mm ≦ t < 63.5 mm	20 sec.
63.5 mm ≦ t < 114.0 mm	25 sec.
	* quoted duralite.com

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

5. Join

Immediately after the heating tool is removed, quickly inspect the melted ends, which should be flat, smooth and completely melted. If the melt surfaces are acceptable, immediately and in a continuous motion, bring the ends together and apply the correct joining force.

The correct fusion pressure will form a double bead that is rolled over and contacts the pipe surface. the surface on both ends.

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

6. Hold

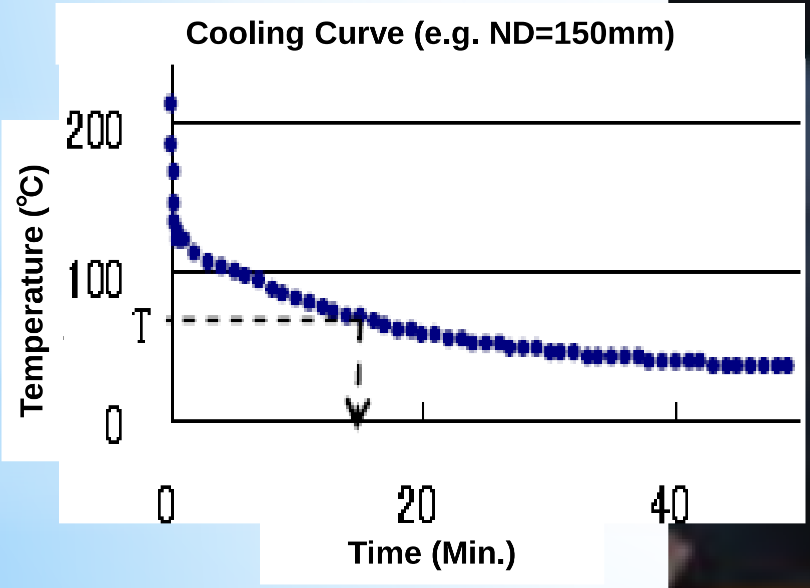
Maintain fusion gauge pressure until the joint is cool.

The joint is cool enough for gentle handling when the double bead is cool to the touch.

Cool for a minimum of 11 minutes per inch of pipe wall.

Do not try to decrease the cooling time by applying water, ice, wet cloths or the like.

Avoid pulling, installation, pressure testing and rough handling for at least an additional 30 minutes.



Cooling Curve (e.g. ND=150mm)

* Chapter-4; Pipe Connection

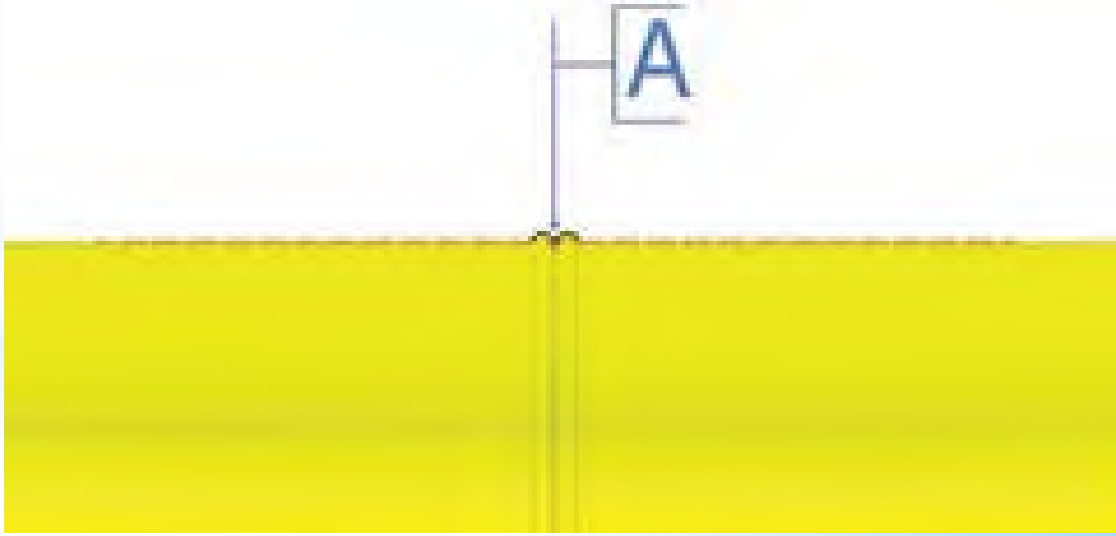
◆ § 4-7 : Butte Welding

7. Inspection

On both sides, the double bead should be rolled over to the surface, and be uniformly rounded and consistent in size all around the joint.

1.

The gap (A) between the two single beads must not be below the fusion surface throughout the entire circumference of the butt joint.

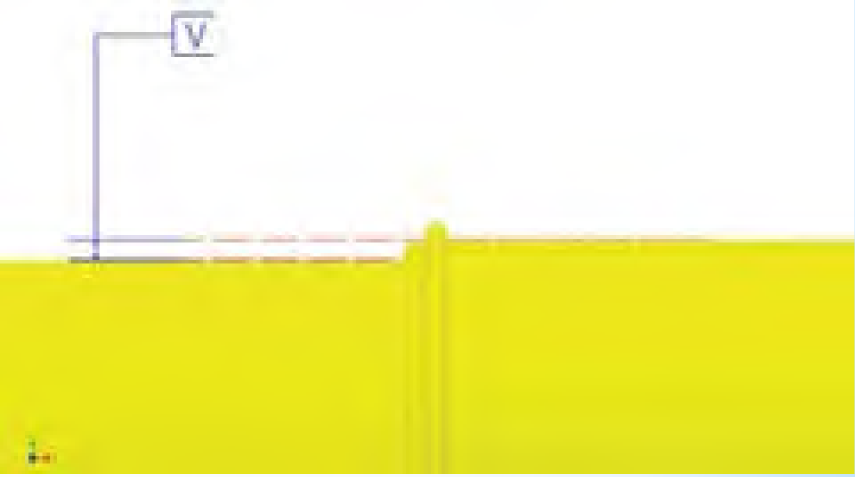


* Chapter-4; Pipe Connection

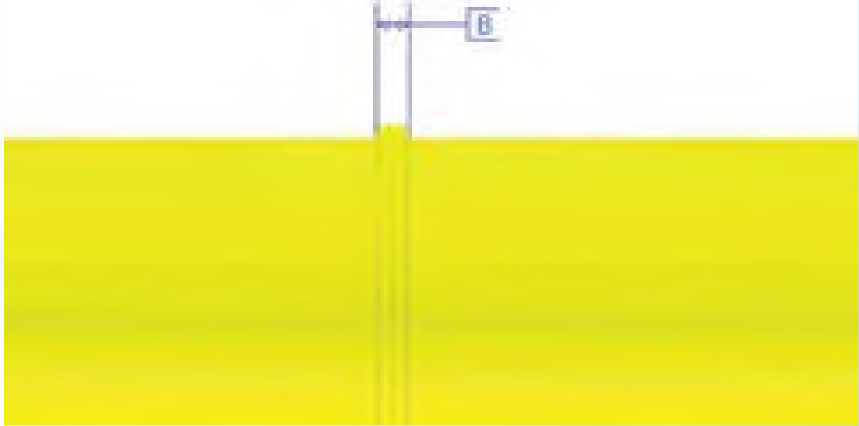
- § 4-7 : Butte Welding

7. Inspection

2.
The displacement (V) between the fused ends must not exceed 10% of the pipe/fitting minimum wall thickness.



3.
Refer to below Table for general guidelines for bead
width, B, for each respective wall thickness.



* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

7. Inspection

Table for general guidelines for bead width, B, for each respective wall thickness.

Approximate Melt Bead Size	
Pipe size (Approximate)	Melt Bead Size
Φ < 40mm	1 ~ 2 mm
40 mm ≦ Φ < 90 mm	2 mm
90 mm ≦ Φ < 225 mm	3 ~ 5 mm
225 mm ≦ Φ < 315 mm	5 ~ 6 mm
Instructions: Determine the wall thickness of the pipe/fitting. Find the wall thickness above. If the exact wall thickness is not shown, use the next lowest wall thickness for determination of bead width.	
* quoted Plastics Pipe Institute ®	

* Chapter-4; Pipe Connection

◆ § 4-7 : Butte Welding

Unacceptable joints

Melt bead too small due to insufficient heat time

Melt bead too large due to excessive heating and/or over pressurization of joint

No! 👎

Misalignment

Incomplete Facing

No! 👎

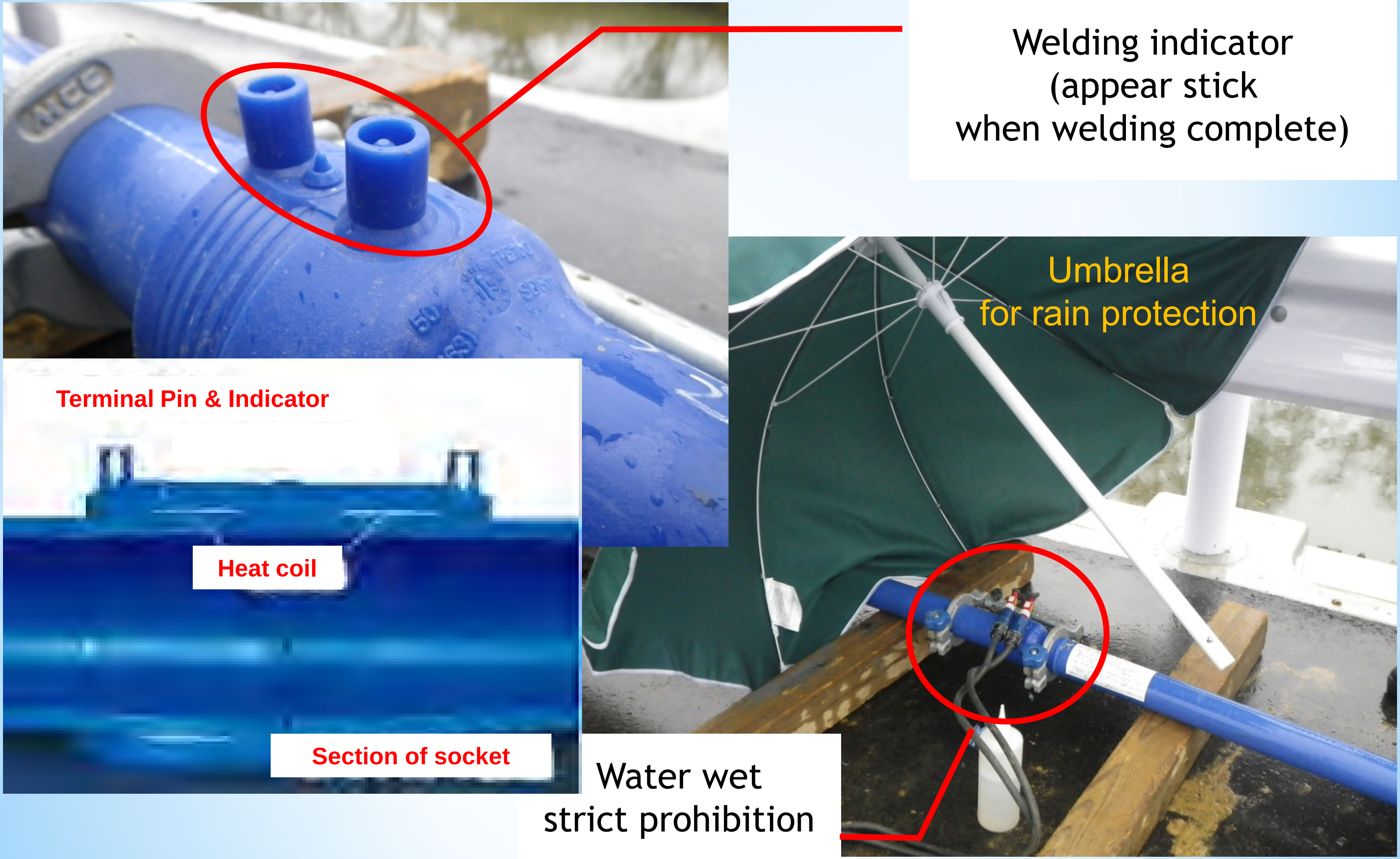
* Chapter-4; Pipe Connection

◆ § 4-8 : Welding of Polypropylene Pipes

DO NOT wet the joint
from rain …etc.
Keep Dry !

* Chapter-4; Pipe Connection

◆ § 4-8 : Welding of Polypropylene Pipes



Welding indicator
(appear stick
when welding complete)

Umbrella
for rain protection

Terminal Pin & Indicator

Heat coil

Section of socket

Water wet
strict prohibition

* Chapter-4; Pipe Connection

◆ § 4-8 : Welding of Polypropylene Pipes

Bar code
of pipe
for welding
information

DO NOT wet the joint
from rain …etc.
Keep Dry !

* Chapter-4; Pipe Connection

◆ § 4-9 : Thrust Block for pipe bend

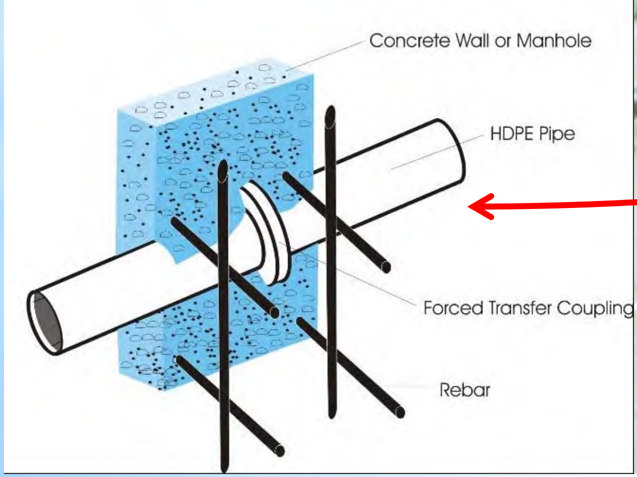
Dimension of the thrust block should be done strictly by technical specifications

* Chapter-4; Pipe Connection

◆ § 4-10 : Pipe layout (Inlet, Outlet, Overflow, Drain) (sample)

Each pipes should be installed right layout and elevation in term of these functions.

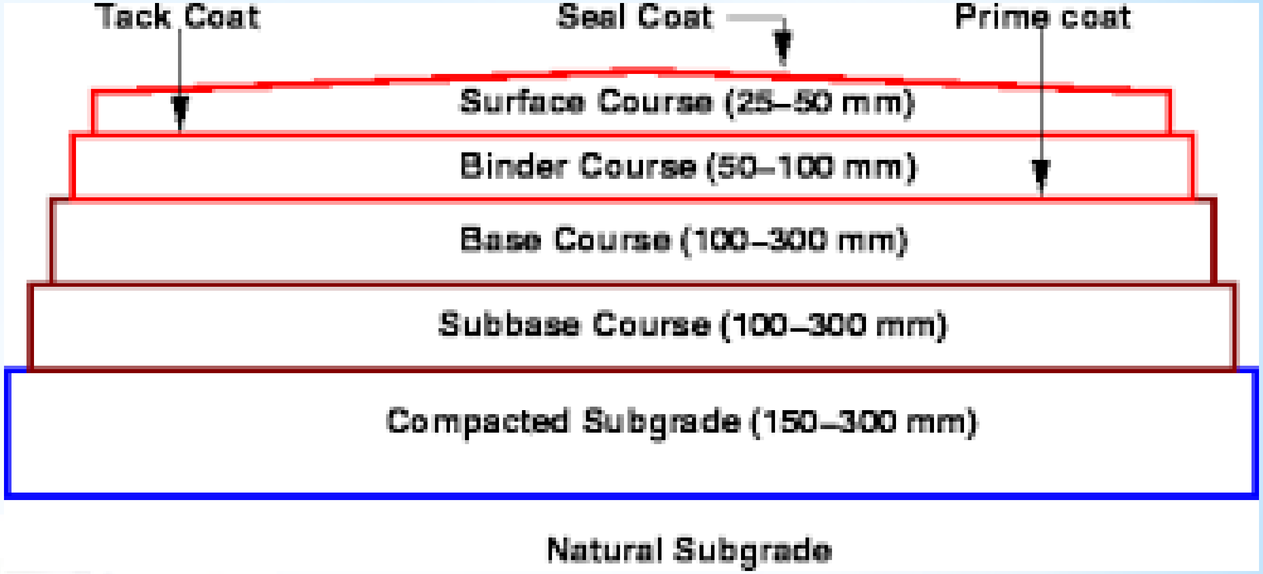
e.g.
- High-High Water Level (= Over Flow Level)
- High water level
- Low Water Level
- Low-Low Water Level
- Drain, Flashing Level

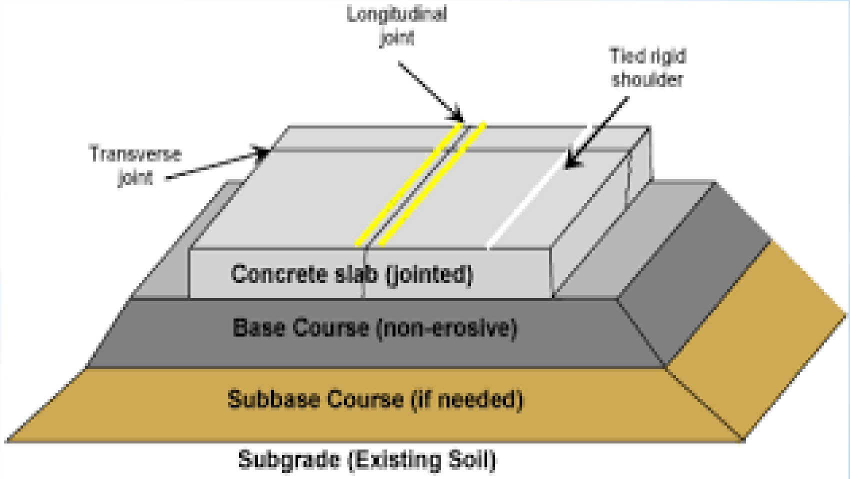


Chapter-4; Pipe Connection

- § 4-11 : **Asphalt** (**Concrete**) pavement of road

Asphalt Pavement





Concrete Pavement

* Chapter-4; Pipe Connection

◆ § 4-11 : Asphalt pavement of road

Good Safety Work !
No good asphalt removal

* Chapter-4; Pipe Connection

◆ § 4-11 :Asphalt pavement of road

* Chapter-4; Pipe Connection

- § 4-11 :Asphalt pavement of road

**Temperature
of
Hot-Mix Asphalt
should be
110℃(Celsius) or more
at site.**

Mar. ~ May 2017

Supplemental Chapters (future recommendations)

The following chapters may be necessary in future
for improvements WASAC activities.

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**
  - **Mixing Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests**
- **Steel Works**
  - **Reinforcement Steel Bar, H-Beam Column & Beam, Bolting, Welding**
- **Mechanical & Electrical Works**
  - **Pump, Valve Gear, Engine, Control Panel, Motor, Grounding**
- **Procedure of quality Inspection**
  - **Order, Indication, Judgement, Grasp whole standards & specification**
- **Schedule Management**
  - **Bar chart & Network scheduling, Productivity Unit & Rate**

Supplemental Chapters (future recommendation)

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**

  Concrete Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests

Ground Reservoir Tank
In West Africa
Actual Concrete Strength = more than 24N/mm2

Supplemental Chapters (future recommendation)

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**

  Mixing Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests

The Quality Inspectors for Form Work, Steel Bar, Concrete are at site during concrete casting with the Chief Engineer.

Concrete Mixer Plants are adopted plural number for the plan of concrete casting and for countermeasure of machine trouble.

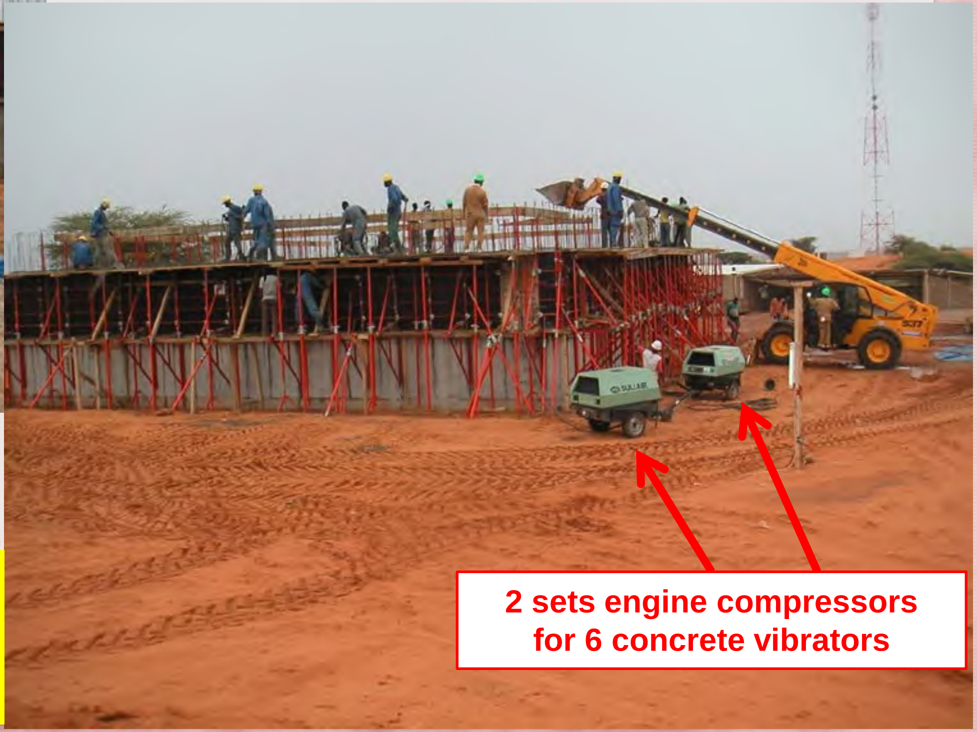
Aggregate is covered by sheet to keep acceptable density for concrete mixing design

Supplemental Chapters (future recommendation)

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**

  Mixing Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests

The Mechanic and Electrician are at site during concrete casting with the Chief & Site Engineers.



2 sets engine compressors for 6 concrete vibrators

Concrete transporter and Vibrator are adopted plural number for the plan of concrete casting and for countermeasure of machine trouble.

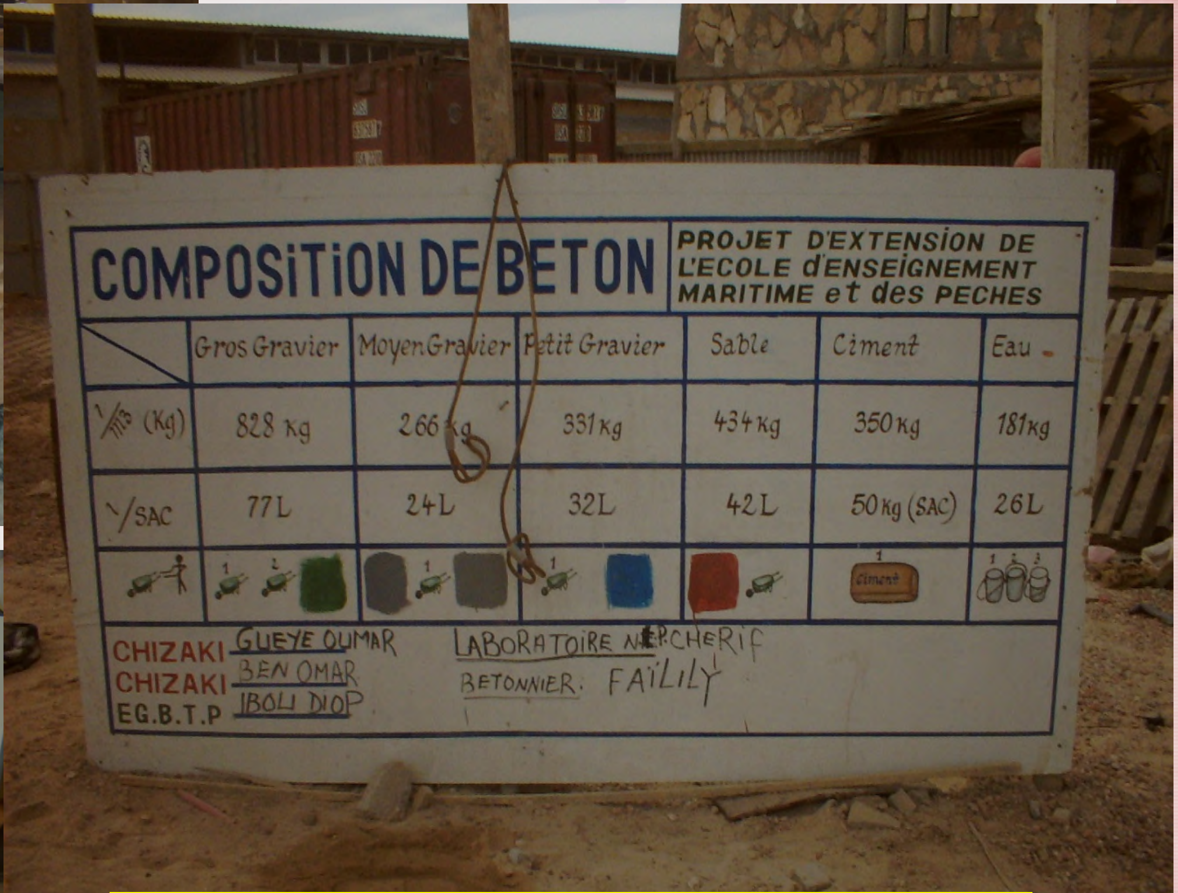
Supplemental Chapters (future recommendation)

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**

  Mixing Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests

Testing of Coase Aggregate

Testing of Slump for workability



COMPOSITION DE BETON

PROJET D'EXTENSION DE L'ECOLE d'ENSEIGNEMENT MARITIME et des PECHES

	Gros Gravier	Moyen Gravier	Petit Gravier	Sable	Ciment	Eau
1/m³ (Kg)	828 kg	266 kg	331 kg	434 kg	350 kg	181 kg
1/SAC	77 L	24 L	32 L	42 L	50 kg (SAC)	26 L
	1 2 🟩	⬛ 1 ⬛	1 🟦	🟥	1 Ciment	1 2 3

CHIZAKI GUEYE OUMAR
CHIZAKI BEN OMAR
EG.B.T.P IBOLI DIOP

LABORATOIRE NEP CHERIF
BETONNIER: FAILILY

Whole workers at site are able to understand concrete proportion and important such as "Daily OJT".

Supplemental Chapters (future recommendation)

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**

  Mixing Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests

**Surface of construction joint of concrete is
chipped and treated
by the water proof material**

Carpenter check
form and supports
during concrete casting.

Supplemental Chapters (future recommendation)

- **Concrete Works (for Reservoir Tank, Valve chamber …etc.)**

Mixing Design, Form work & Scaffolding, Mixing, Casting, Curing, Compression Tests

Water proof mortal coating
In Reservoir Tank

Supplemental Chapters (future recommendation)

- **Steel Works**

  Reinforcement Steel Bar, H-Beam Column & Beam, Bolting, Welding

Quality Test
of
Reinforcement Steel Bars
for Concrete Stricture
(Component, Tension Strength)

Supplemental Chapters (future recommendation)

- **Mechanical & Electrical Works**

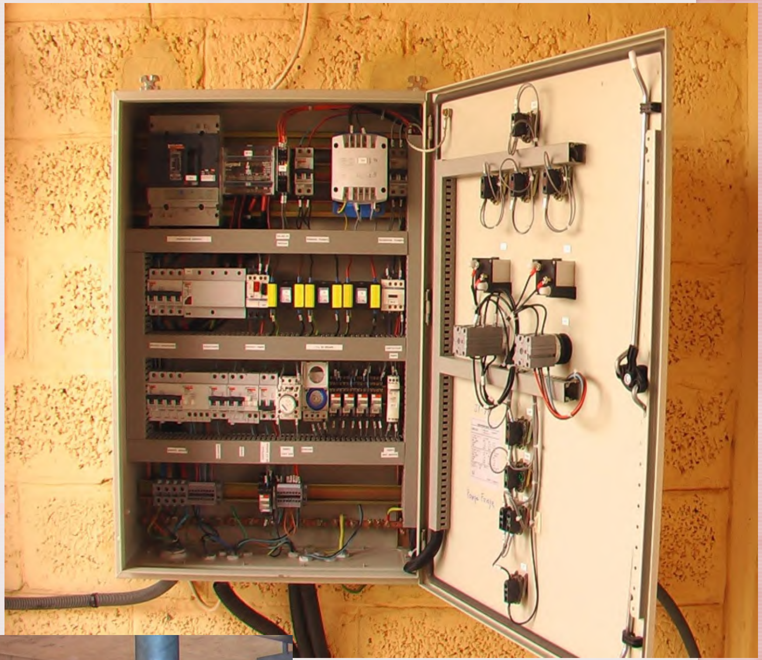
  Pump, Valve Gear, Engine, Control Panel, Motor, Grounding

Mechanic & Electrician check and adjust pump system with technical transfer to the operators such as OJT.

Supplemental Chapters (future recommendation)

◆ Mechanical & Electrical Works

Pump, Valve Gear, Engine, Control Panel, Motor, Grounding



Electrician check and adjust control panel with technical transfer to the operators such as OJT.

Supplemental Chapters (future recommendation)

- **Procedure of quality Inspection**

  Order, Indication, Judgement, Grasp whole standards & specification

Supplemental Chapters (future recommendation)

◆ Procedure of quality Inspection

Order, Indication, Judgement, Grasp whole standards & specification

Inspection of …

- * Reinforcement Steel Bar & Form of Reservoir Tank

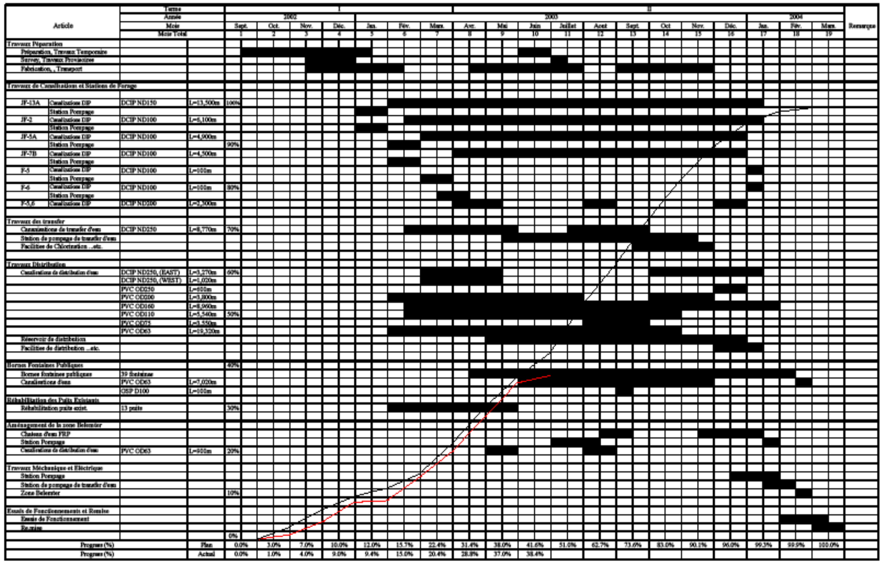
- * Pre – Assembly of Pipes

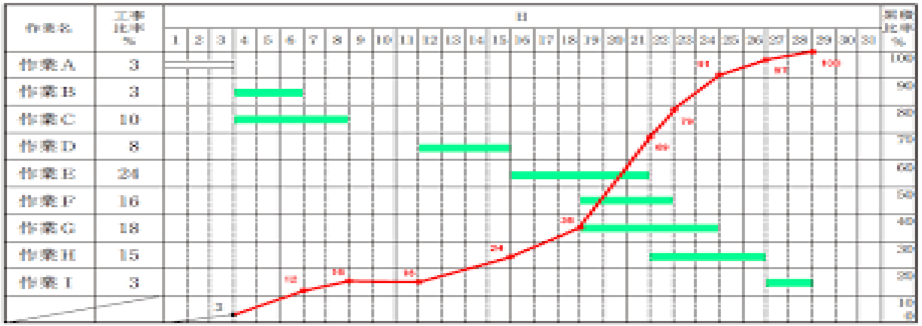
Supplemental Chapters (future recommendation)

- **Schedule Management**

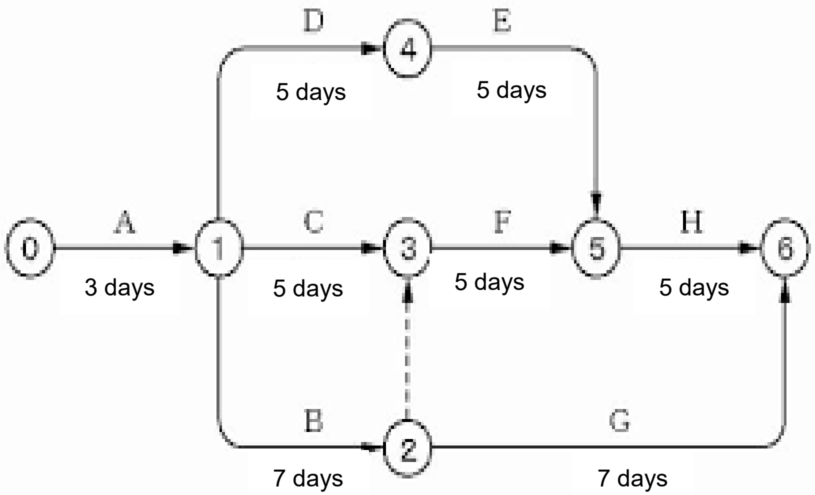
Bar chart & Network scheduling, Productivity Unit & Rate

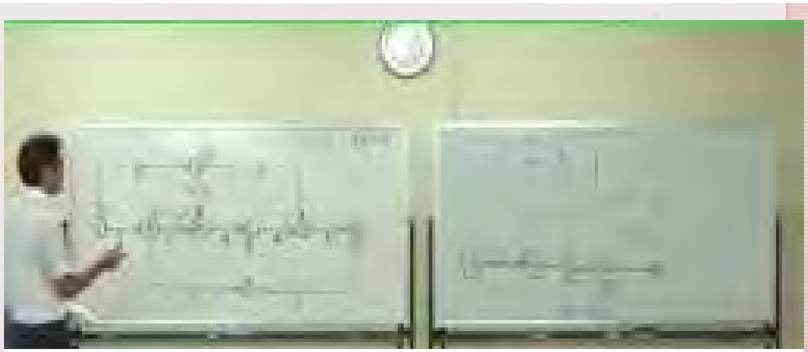
Bar-chart Schedule with progress curve





Network Schedule





Lecture of Network Scheduling

7. Closing Address :

- Mr. Methode Rutagungira (Director of UWSS)
- Mr. Bahige Jean Berschmas (Manager of NRW)
- Mr. Shigeo Otani (Leader of JICA Experts)
- Mr. Masanobu Mayusumi (JICA Observer / Advisor)

Thank you for your time and attention.

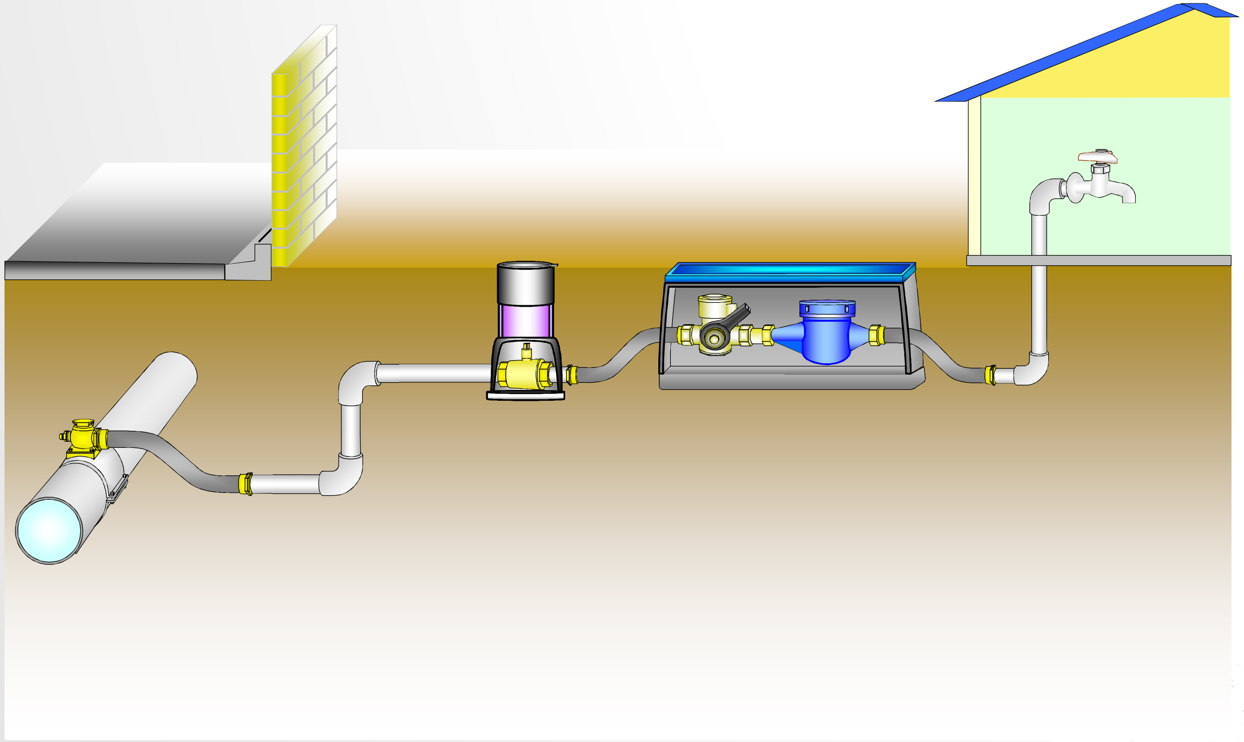
Let’s go back to your fields and do it by your best !

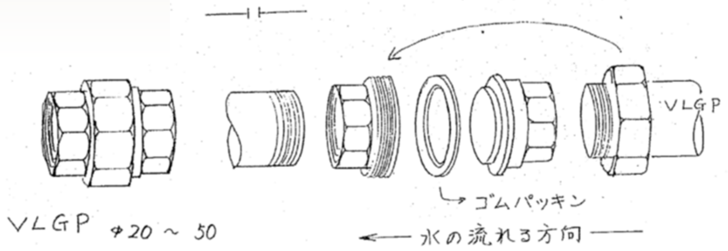
ARIGATO !! MURAKOZE !!

PIPE CONNECTION

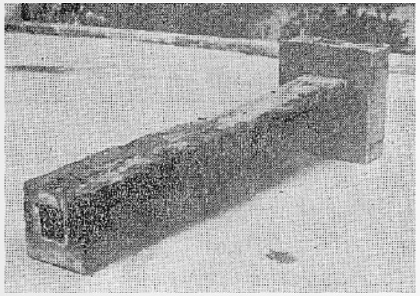
MOMOZONO

Water supply pipe line has so many connection by many material.





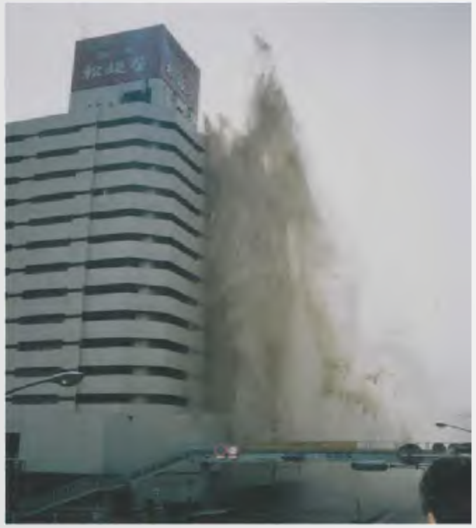
Water supply under pressure is invention !



Yokohama is the first city to supply water under pressure (1887)

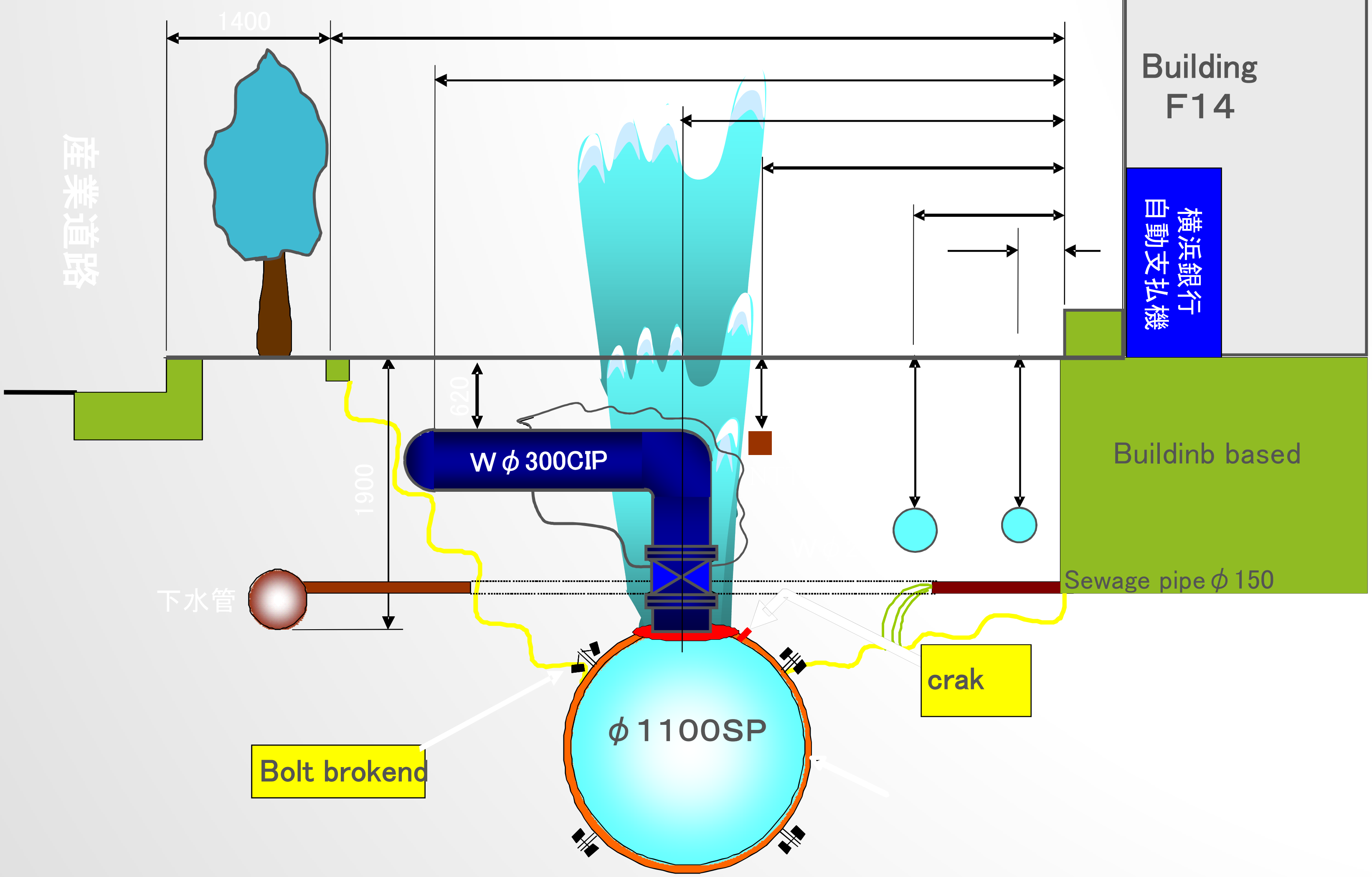
We can drink water everywhere by water pressure!

The connection is weak point in pipe line?



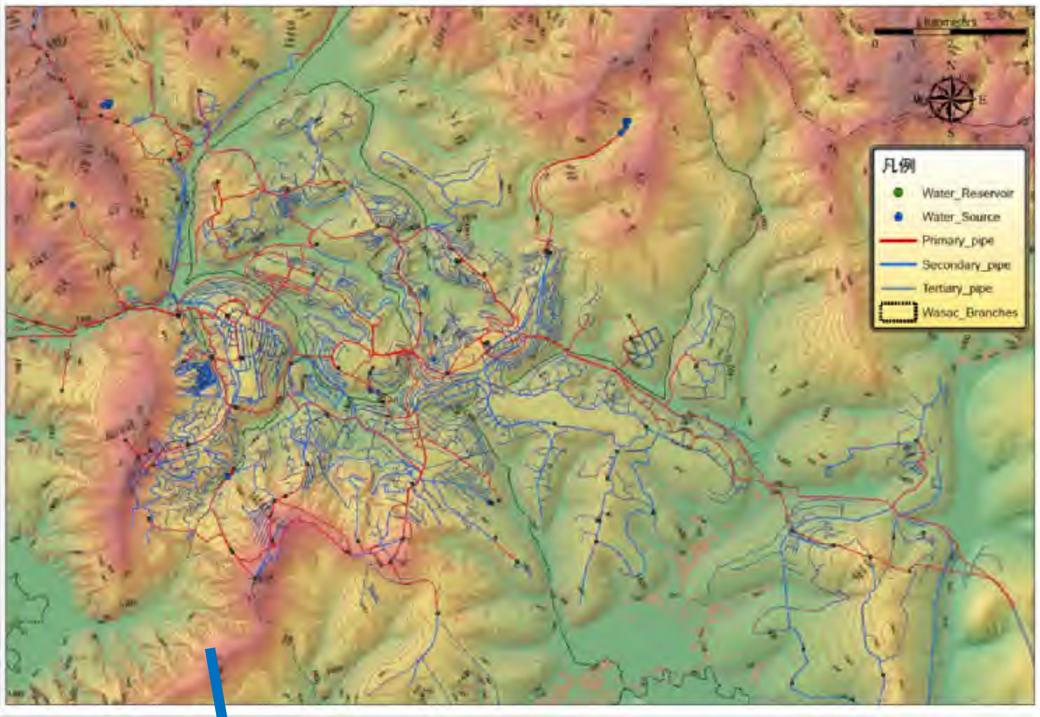
UNDER PRESSURE

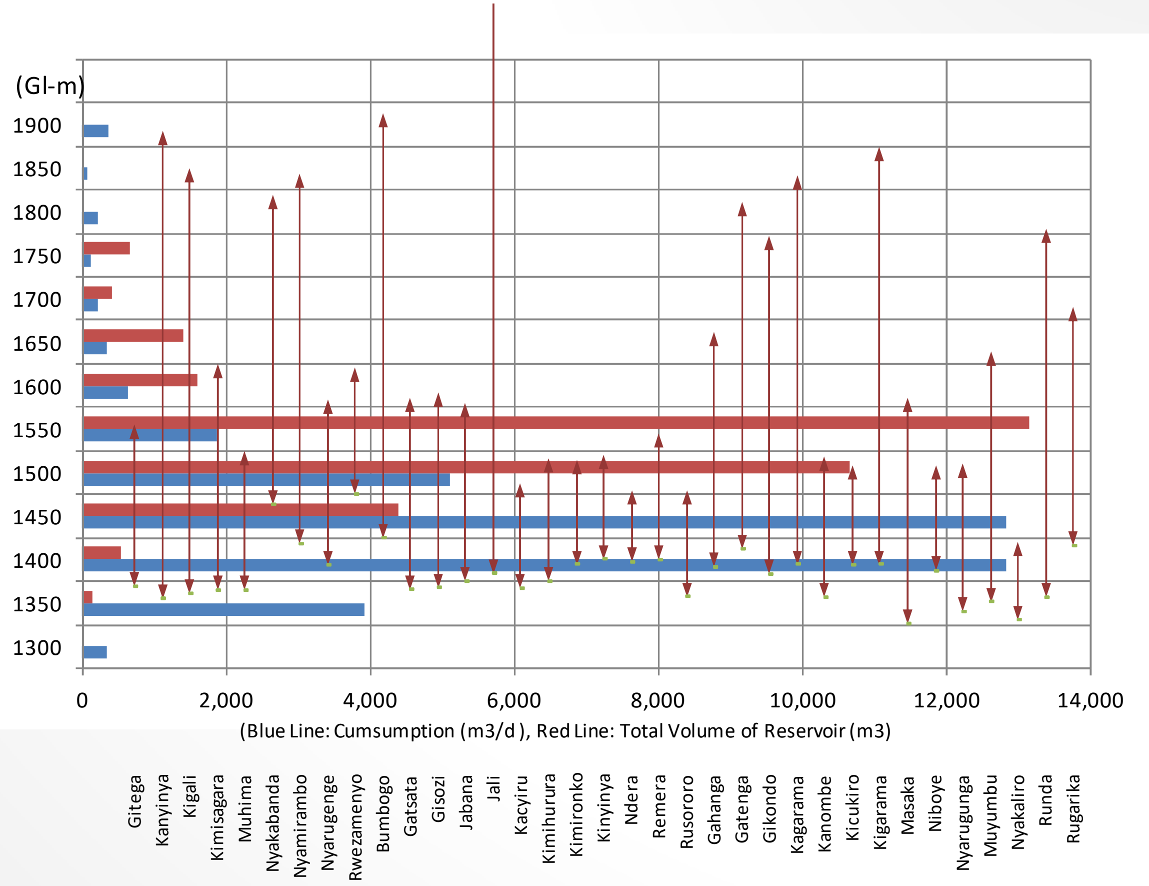
Leakage point drawing




6
5
4
3
2
1

The altitude in Kigali is from 1300m to 1900m





Kigali

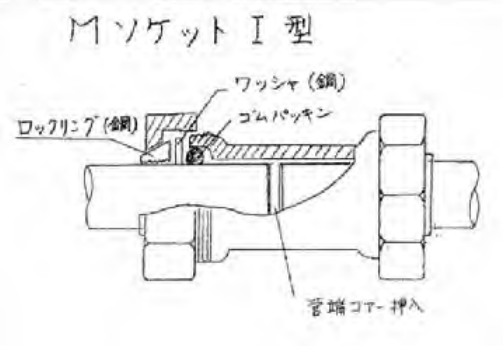
Point1 Seal tape

Seal tape protect that water is going out from pipe, but seal tape support the screw roll!

Point1 Rubber

- Clean up ➡ fit to the correct position ➡ paint the lubricant (oil)

Point2 HDPE/PVC・・・Screw!?



Physicality of material ➡method of the repair

Point3 How to drill the pipe

- How does heated iron rod influence to HDPE pipe?

PE➡ Polyethylene $(-CH_2-CH_2-)$

- HDPE(High Density Polyethylene)

- LDPE(Low Density Polyethylene)

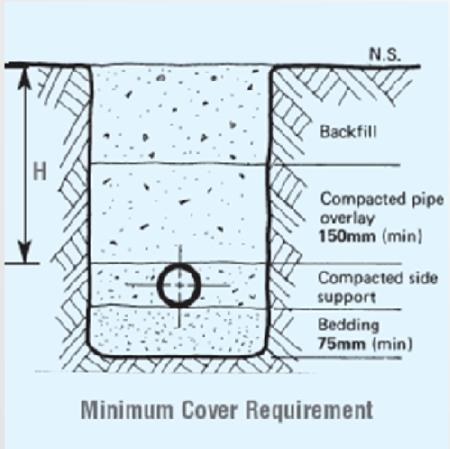
PVC➡ Polyethylene Chloride(Poly Vinyl Cloride) $(\text{-CH}_2\text{-CHCl-})$

- PVC-Hi

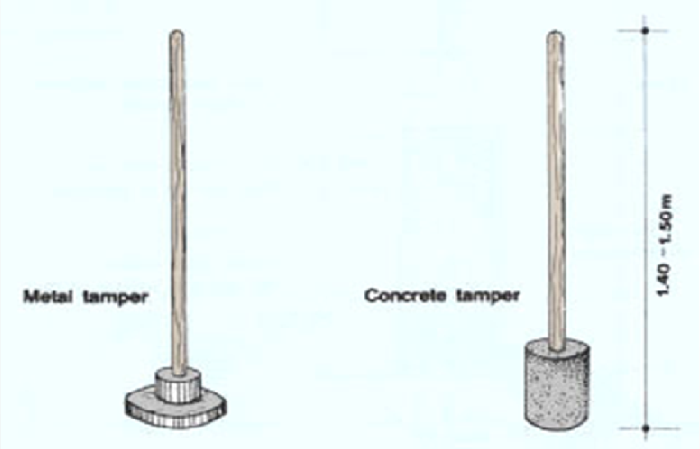
- PVC-U

	Specific weight	Tensile strength	Crushing strength	Bending strength	Heat transfer rate
unit		Kg・ｆ/cm2	Kg・ｆ/cm2	Kg・ｆ/cm2	
HDPE	0.94～0.96	220～380	225	70	10
PVC	1.65	650	850	1080	3.8～4.0

Point5 When you cover soil , what should you take care?



Minimum Cover Requirement



Point 6 Good maintain of equipment leads high quality.

li

Water ✖
Oil ○

PRACTICE

MOMOZONO

PRACTICE 1 PIPE CUTTING

PRACTICE 2 PIPE WELDING PROCEDURE


1.Clean up & Face


2.Align& Melt


3.Join


4.Hold


5.Inspection

PRACTICE 2 PIPE WELDING REMARKS

1.Clean up & Face

- Clean the inside and outside of the pipe
- Do not force pipes into alignment against open fusion clamps
- Remove the facing tool, and clear all shavings and pipe chips from the component ends
- Do not touch the component ends with your hands after facing component ends with you

2.Align

- Look for complete contact all around both ends with no detectable gaps
- Re-face if high-low alignment is adjusted

PRACTICE 2 PIPE WELDING REMARKS

2.Melt

- Heating tool is maintaining the correct temperature (204~232 degree Celsius)
- Pressure should be reduced when evidence of melt appears
- When the proper melt based size is formed , quickly separate the ends and remove the heating tool

Maximum Heater Plate removal Times (for reference)

Pipe wall thickness	Max. heater removal time
5.1 mm ≦ t < 9.0 mm	8 sec.
9.0 mm ≦ t < 14.0 mm	10 sec.
14.0 mm ≦ t < 30.0 mm	15 sec.
30.0 mm ≦ t < 63.5 mm	20 sec.
63.5 mm ≦ t < 114.0 mm	25 sec.

* quoted duralite.com

PRACTICE 2 PIPE WELDING REMARKS

3.Join

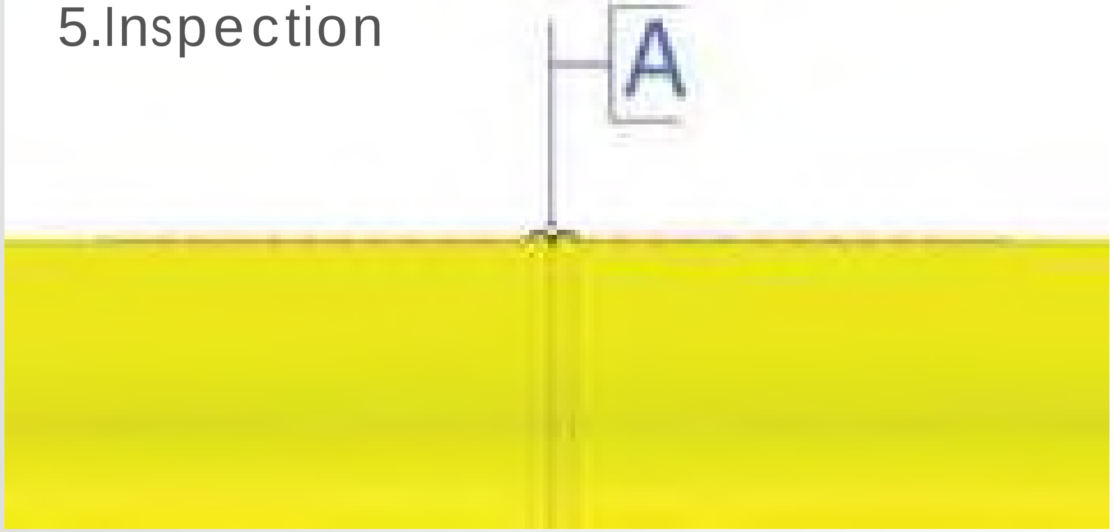
- The correct fusion pressure will form a double bead that is rolled over and contacts the pipe surface
- The fusion force should be held between the pipe ends for approximately 30-90 seconds

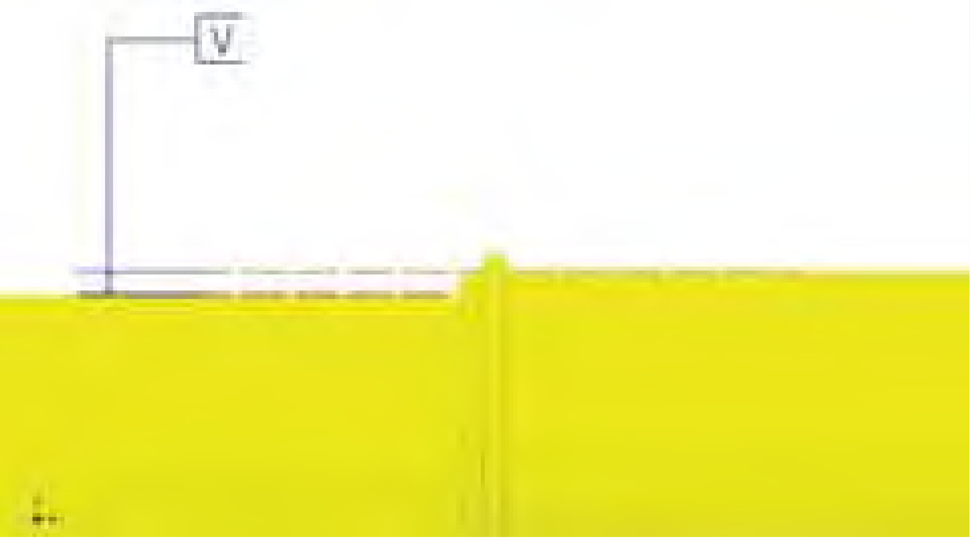
4.Hold

- Maintain fusion gauge pressure until the joint is cool
- Cool for minimum of 11 minutes per inch of pipe wall
- Avoid pulling , installation , pressure testing and rough handing for at least an additional 30 minutes

PRACTICE 2 PIPE WELDING REMARKS

5.Inspection

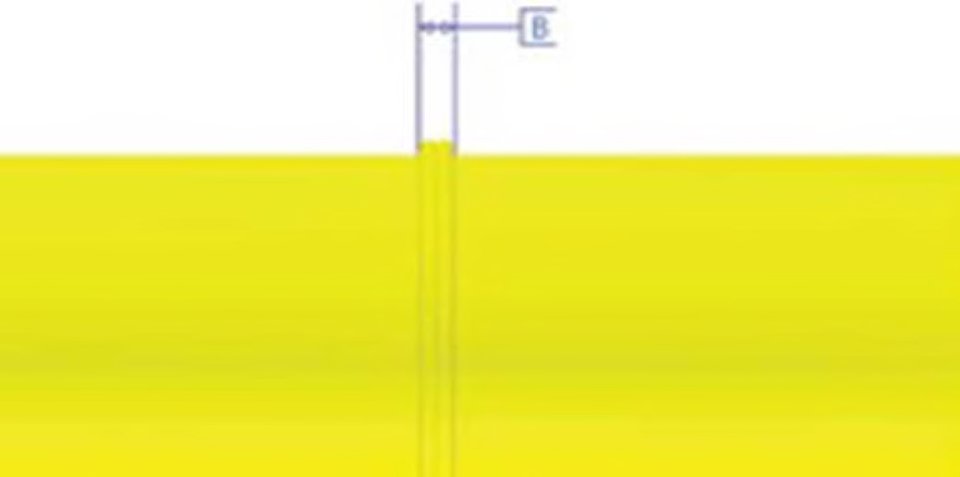




A
The gap (A) between the two single beads
must not be below the fusion surface throughout the entire circumference of the butt joint.

V
The displacement (V) between the fused ends must not exceed 10% of the pipe/fitting minimum wall thickness

PRACTICE 2 PIPE WELDING REMARKS



Approximate Melt Bead Size	
Pipe size (Approximate)	Melt Bead Size
Φ < 40mm	1 - 2 mm
40 mm ≦ Φ < 90 mm	2 mm
90 mm ≦ Φ < 225 mm	3 - 5 mm
225 mm ≦ Φ < 315 mm	5 - 6 mm

Instructions: Determine the wall thickness of the pipe/fitting. Find the wall thickness above. If the exact wall thickness is not shown, use the next lowest wall thickness for determination of bead width.

* quoted Plastics Pipe Institute ®

B

Refer to below Table for general guidelines for bead width, B, for each respective wall thickness.

PRACTICE 2 PIPE WELDING REMARKS

Unacceptable joints

Melt bead too small due to insufficient heat time

Melt bead too large due to excessive heating and/or over pressurization of joint

No! 👎

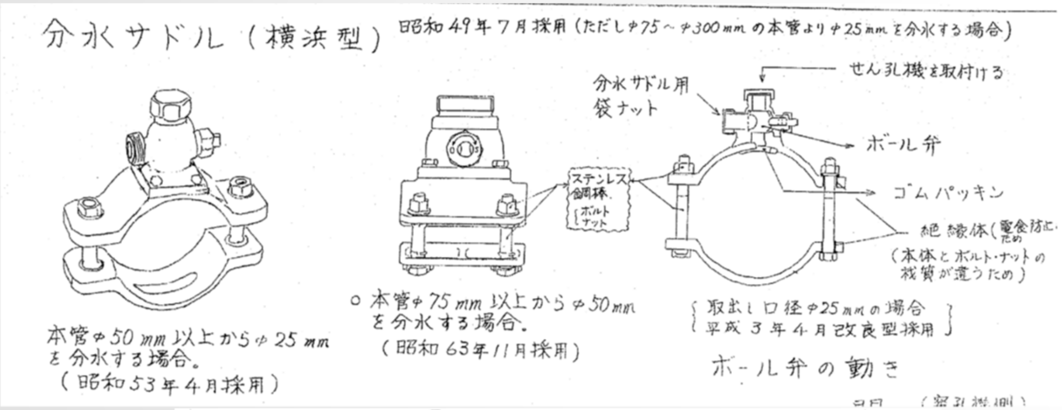
Misalignment

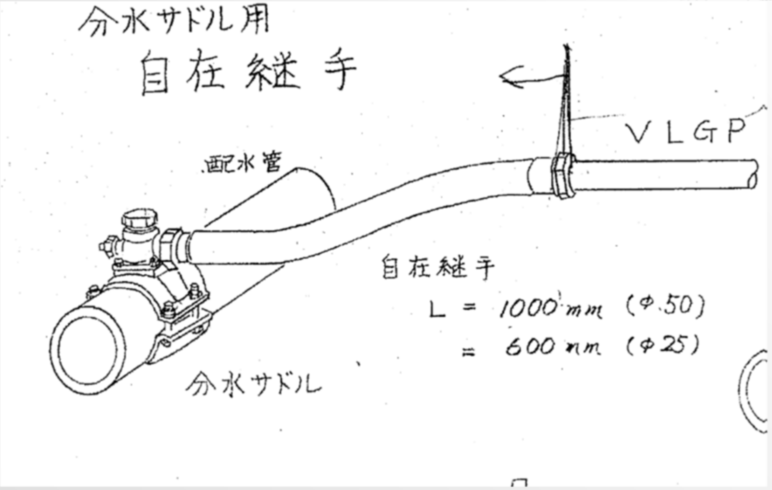
Incomplete Facing

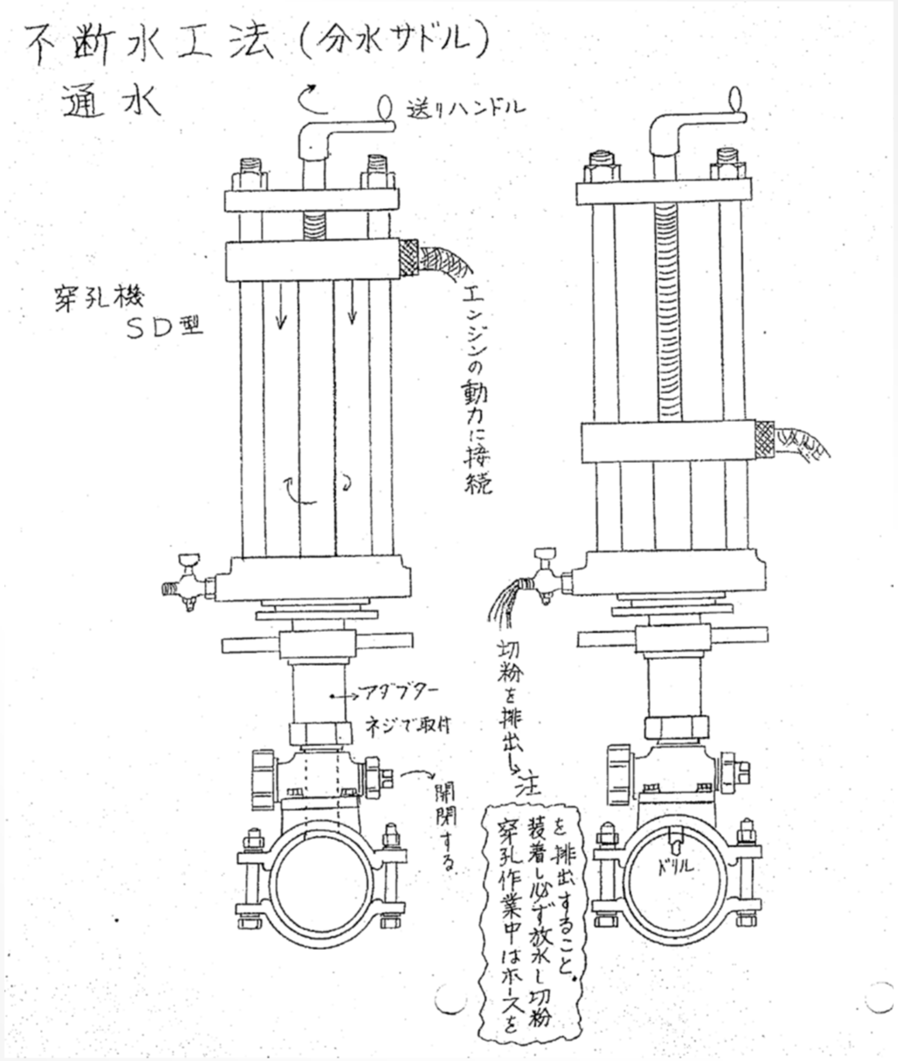
No! 👎

PRACTICE 3 DRILLING

TYPE OF YOKOHAMA





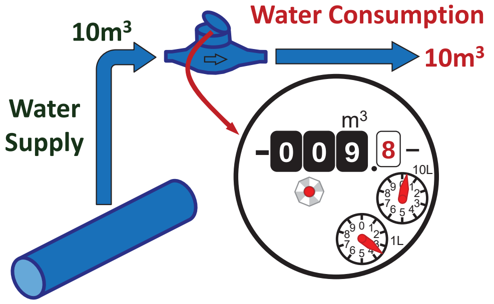


Water Meter

CHIAKI SUZUKI, JICA EXPERT

Water Meter Insensitiveness / Meter Error

 # Where WASAC's water disappeared?

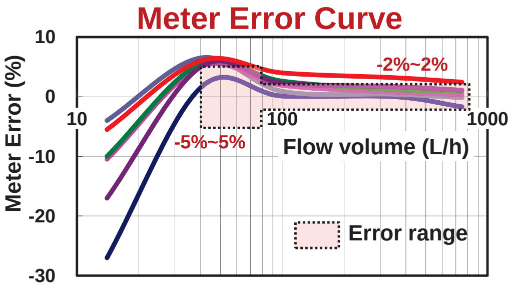


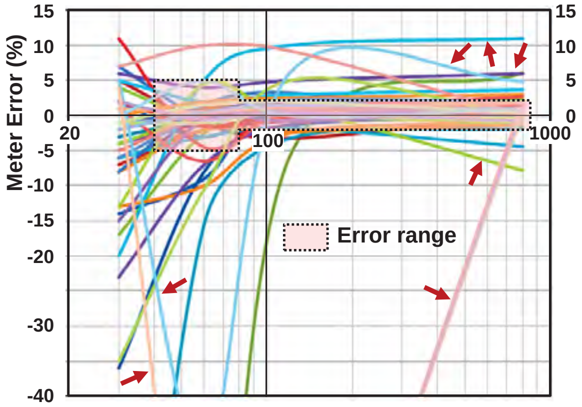
Water meter error

$$= \frac{9.8 - 10.0}{10.0} = -2.0\%$$

NRW

Water Meter Insensitiveness / Meter Error

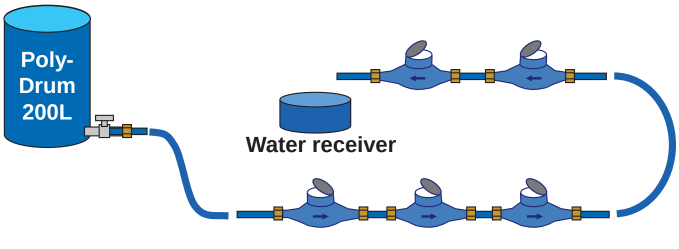




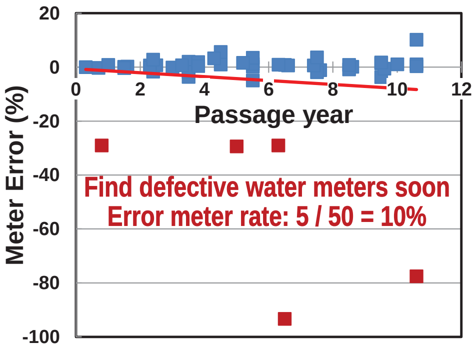
Water Meter Insensitiveness / Meter Error

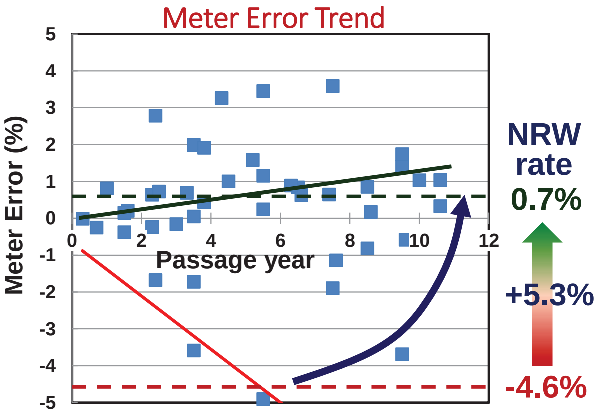
WASAC Meter Test Laboratory

If Up country branch does not have a test bench, try to create by yourself!



Water Meter Insensitiveness / Meter Error





Permissive error of ISO4064

Flow examination must be following points		
Between Q1～(Q1×1.1)	Between Q2～(Q2×1.1)	Between (Q3×0.9)～Q3

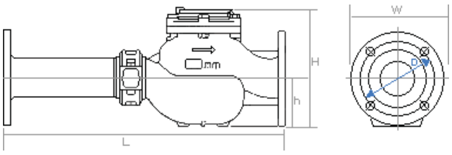
Meter designation and permanent flowrate (Q3)

- Designated according to the permanent flowrate Q3 and ratio of Q3 to the minimum flowrate Q1
- Measuring range (Q3/Q1) will be 80, 100, 125, 160, etc.
- Q4/Q3 = 1.25 and Q2/Q1 = 1.6
- Maximum permissible error in service: twice the maximum permissible errors
- Maximum permissible error, 5% for lower range and 2% for higher range

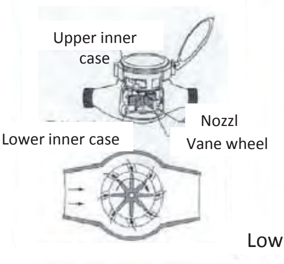
---

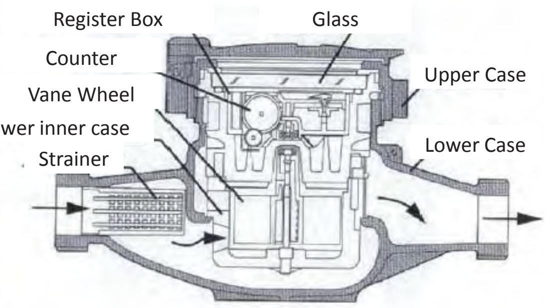
Water Meter Types

- **Inferential type (Velocity type)**
- **Positive displacement (Volumetric)**
- Electromagnetic
- Ultra-sonic
- Waltsman
- Etc.

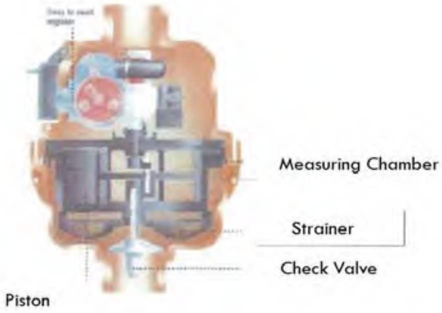


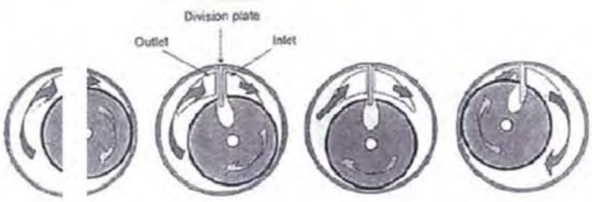
Vane Wheel Water Meter
- (Dry dial multi-jet)

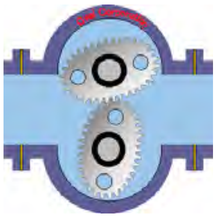




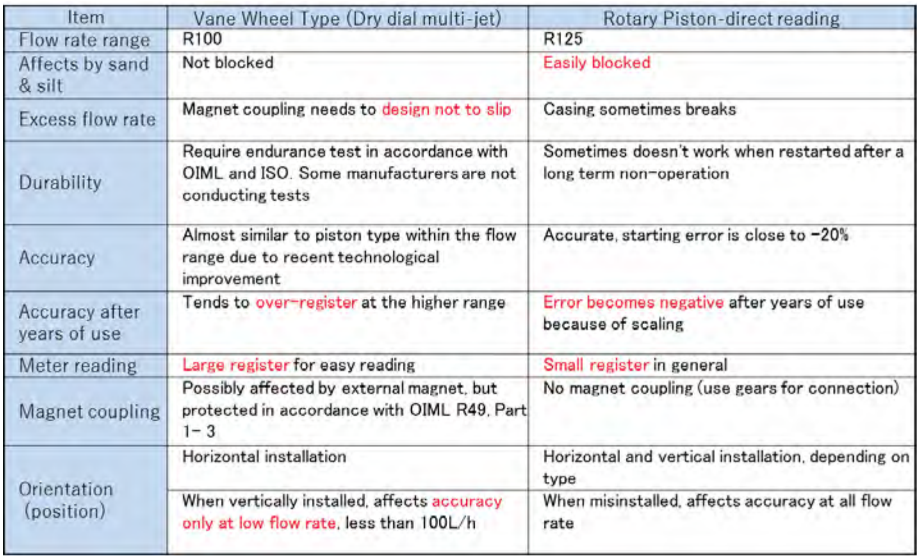
Rotary Piston Water Meter
- Positive displacement







Comparison of Vane Wheel with Rotary Piston Water Meters



Item	Vane Wheel Type (Dry dial multi-jet)	Rotary Piston-direct reading
Flow rate range	R100	R125
Affects by sand & silt	Not blocked	Easily blocked
Excess flow rate	Magnet coupling needs to design not to slip	Casing sometimes breaks
Durability	Require endurance test in accordance with OIML and ISO. Some manufacturers are not conducting tests	Sometimes doesn't work when restarted after a long term non-operation
Accuracy	Almost similar to piston type within the flow range due to recent technological improvement	Accurate, starting error is close to −20%
Accuracy after years of use	Tends to over-register at the higher range	Error becomes negative after years of use because of scaling
Meter reading	Large register for easy reading	Small register in general
Magnet coupling	Possibly affected by external magnet, but protected in accordance with OIML R49, Part 1- 3	No magnet coupling (use gears for connection)
Orientation (position)	Horizontal installation	Horizontal and vertical installation, depending on type
	When vertically installed, affects accuracy only at low flow rate, less than 100L/h	When misinstalled, affects accuracy at all flow rate

---

How to install the water meter

Surrounding of the water meter

- Water temperature
- Surrounding temperature
- Water pressure
- Vibration
- Water quality
- Magnetism

How to install the water meter

- **Water temperature**

- More than 0.1˚C, Less than 30˚C

- **Surrounding temperature**

- More than 5˚C, less than 55˚C

- **Water pressure**

- In the range between 0.15 to 1MPa

- **Fluctuation of the pressure**

- Reduce the fluctuation. Water hammer does not exceed 1.5MPa

---

How to install the water meter

- **Water quality**

- Install the strainer or filter before the meter

- Electromagnetic flowmeter keeps the electrical conductivity if maker designated

- pH balance

- **Vibration and Magnetism**

- Exclude cause of vibration

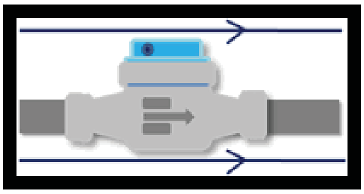
- Exclude ferromagnetic

- **Location of meter**

- Light place

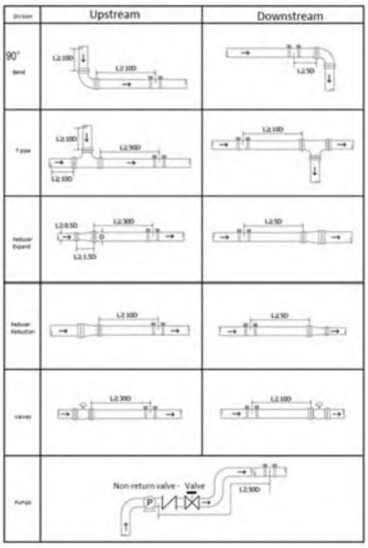
How to install the water meter

Installation



- Easy to read
- Install under level of the tap
- Install is level and check the direction of flow
- More than 10D to the upstream, More than 5D to the downstream
- Install the non-return valve to the downstream
- Install the valve to the upstream
- Prevent of microcell corrosion

How to install the water meter



- **How to install the electromagnetic flow meter**

- 90˚ Bend pipe
- T pipe
- Reducer (Expand)
- Reducer (Reduction)
- Valves
- Pumps and others

CONTACT

CHIAKI SUZUKI
Suzuki-c@yokohamawater.co.jp

METER READINGS GENERAL

Desire KAYIRU

INTRODUCTION

- The commercial directorate manages the operations of all the commercial aspects of WASAC includes the branches and monitors the company in the facility of sufficient and quality services to its customers.
- The effective of services delivery, WASAC have now 20 branches in the country with 183 CFOs who each one provide the service to satisfy the customers

Roles of CFOs to improve services in Wasac

- ❑ To run and make an utility company perform the services delivery and financial viability of the company CFOs should be accountable and responsible to provide a good image of the company
- ❑ CFOs should comply their duties , to well take readings, bill timely the customers and provide the invoices on time; In additional duties they should:
- ➢ Sensitised to Increase the number of new connections
- ➢ Increase water sales;
- ➢ Increase revenue collection;
- ➢ Improve revenue collection efficiency;
- ➢ Reduce water Commercial losses;
- ➢ Increase customer satisfaction and reduce Customer complaints;
- ➢ Metering efficiency;
- ➢ Public Awareness and communication
- ➢ Etc..

Billing Management

- ❑ All Customers should be well billed timely on monthly basis;

Condition:

- CFOs should make sure If customer exist or no, then checks customer status

If customer status is valid for billing then put the readings in the system

for Comparison of current reading with previous reading

The Current reading should be >= Previous reading

New Tarrif

ICYICIRO CY' ABAFATABUGUZI	AMAZI AKORESHWA KU KWEZI (m^3)	IGICIRO GISHYA HATABARIWEMO TVA
		(FRW/m^3)
AMAVOMERO RUSANGE	HATITAWE KU NGANO Y'AMAZI	323
INGO & IBIGO	0 – 5	323
INGO & IBIGO	6 – 20	331
INGO & IBIGO	21 – 50	413
INGO & IBIGO	51 – 100	736
INGO & IBIGO	101 & BEYOND	847
INGANDA	HATITAWE KU NGANO Y'AMAZI	736

Categories of Wasac customers

We have 10 categories of customers

0. Diplomate
1. Particulars
2. Public services
3. Palatal
4. Agent state
5. Commercial
6. Industries
7. Collectivities
8. Publics Tapes
9. WASAC

Billing Calculation

- How to make a bill?
- **(A) Consumption=Current readings-Previous Readings**
- **(B) Charge=Consumption*tariff**
- **(C) Regulatory fees(RF)=Charge*0.3%**

. **(D) VAT (18%)=[(Charge+meter rent)*18%]**

Total bill =Charge+RF+100+VAT or (B+ C+100+ D)

Payment Model

- **All Payment of services provided by WASAC should be done through the Banks**
- **Bill payment is done in two option:**
- **Through Banks and online**

1. Online payment With:

- ✓ MTN
- ✓ AIRTEL

2. <u>BANKS</u>

- ✓ BK
- ✓ COGEBANK
- ✓ ECOBANK
- ✓ GTBANK
- ✓ I&M BANK
- ✓ BPR

WASAC
Water & Sanitation Corporation
Dignifying life

Payment Model

How to Check Water Bill on Website

Go to www.wasac.rw

Go to the Important links "right side" , click on Check and pay your bill

Enter your POC "Point of Connection" or Customer Number NB: 9 Digital

You will get your Balance

Click on Unpaid Invoices then you will see all your unpaid Invoices

on Payments History, you will see your payments history

WASAC
Water & Sanitation Corporation
Dignifying life

Payment Model

How to Pay Water Bill on Mobile Money

Check your outstanding balance and pay your water bill instantly with MTN Mobile Money.

How to Pay:

- ❖ Dial *182#
- ❖ Choose pay bill
- ❖ Go to Water
- ❖ Enter Account Number
- ❖ Enter MM PIN
- ❖ Confirm the details and dial * 1 to continue

Payment Model (ContS)

- ❖Enter the amount you wish to pay
- ❖ Enter your Mobile Money PIN to confirm payment

Customer receives a notification message How much does it cost? The transaction fee for all amounts is 300rwf.

KEY OF SUCCESS

Customer Field officer's
BEHAVIOUR

Vis a vis to the Customer…

Thank you for your attention!

DEFINITION & USE
WORKING PRINCIPLE
METER CONDITIONS: HOW TO JUDGE WHETHER THEY ARE NORMAL OR NOT?

BY: FELICIEN NIRINGIYIMANA
HEAD OF METER MANAGEMENT SERVICES

DEFINITION & USE

- (a)The **water meter** is a device for measuring and registering the quantity of water that passes through a pipe or other outlet.
- (b) The **water meter** is a device which is used to measure the volume of water used by residential and commercial buildings that are supplied with water by a public water supply system(ex.WASAC ltd in RWANDA);
- They can also be used at a well, water source or water system to determine the flow of water via a specific portion of the system.

TYPES OF METERS BASING ON CONSUMPTION

- 1. Domestic meters
- Are the water meters that are used for small houses /small consumers

WATER METERS ARE DIVIDED INTO TWO CATEGORIES BASING TO THE CONSUMPTION

1.Domestic water meter

2. Industrial water meters

INDUSTRIAL METERS

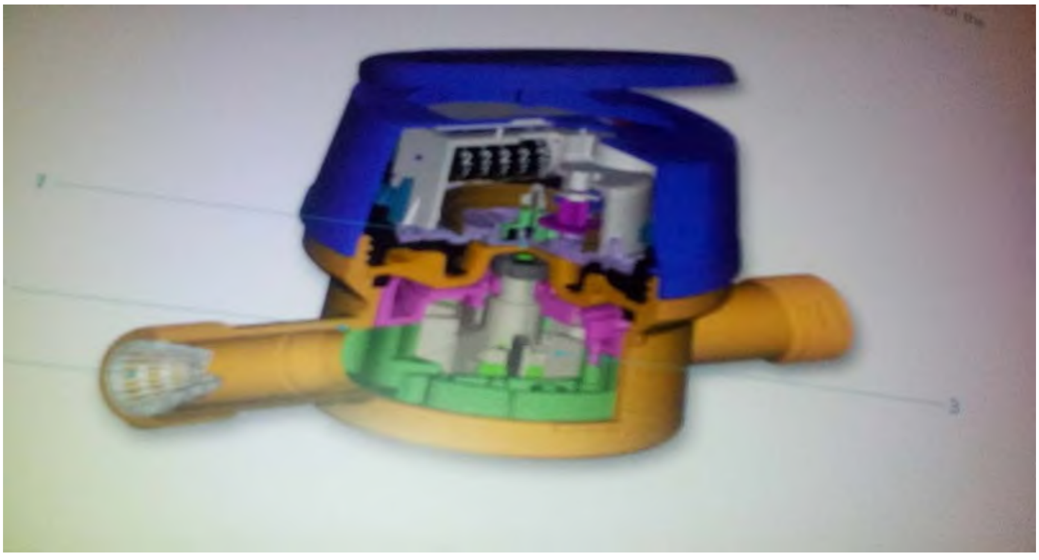
- Are the water meters that are used for big consumers like hospitals , big industries, WTP,……

WORKING PRINCIPLE FOR MECHANICAL METERS

The mechanical meter has two main components, the **hydraulic part** that receive the water flow to be measured and **the register part** that displays the received and measured water volume.

- The Flow coming from inlet, is diverted by a specially shaped injector(2),this flow is injected to the turbine(3) and is rotated.

WORKING PRINCIPLE FOR MECHANICAL METERS



METER CONDITIONS

How to judge whether they are
Normal or not?

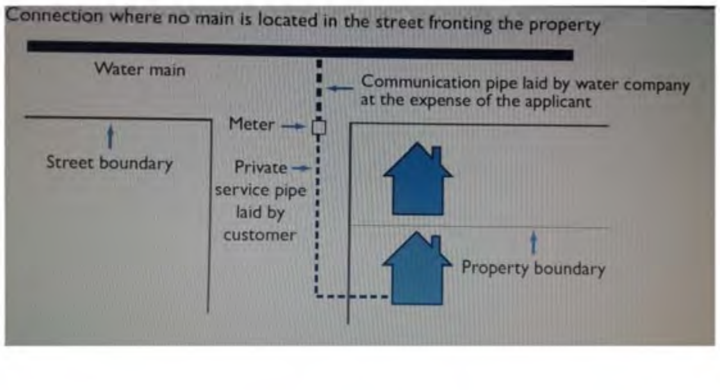
- This will be done in open conversation

- Only **<u>one</u>** fact will show you that the meter has worked/is working in normal condition.
- Which one??? ''**CHANGE OF INDEX**''
- Example: Last reading=130m3;Curent reading=138m3;Cons=8m3

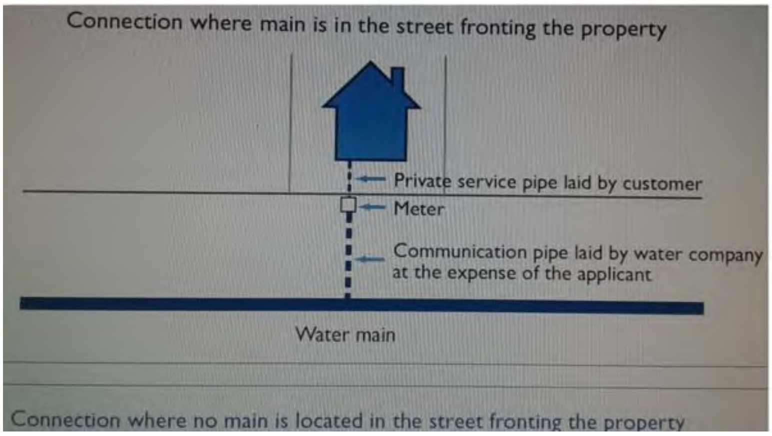
THANK YOU FOR YOUR ATTENTION!!

STANTARD SERVICE CONNECTION & MAIN PIPES INSTALLATION

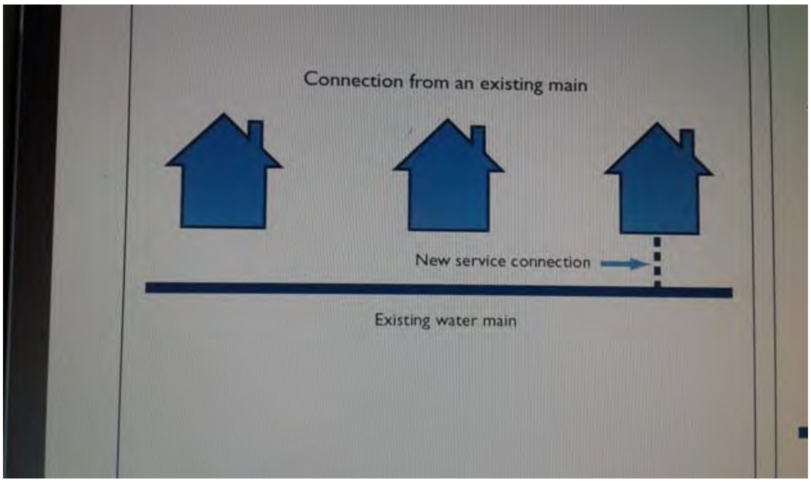
Connection where no main is located in the street fronting the property



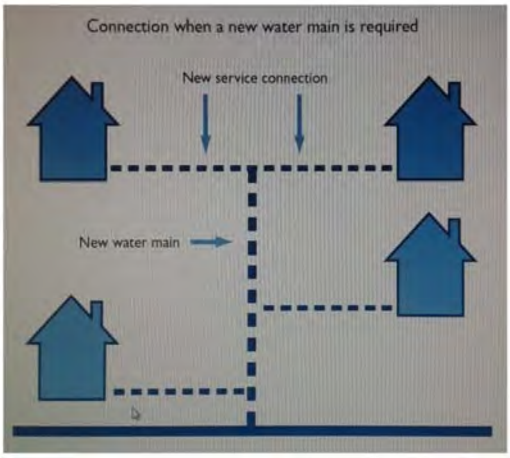
Connection where main is in the street fronting the property



Connection from an existing main

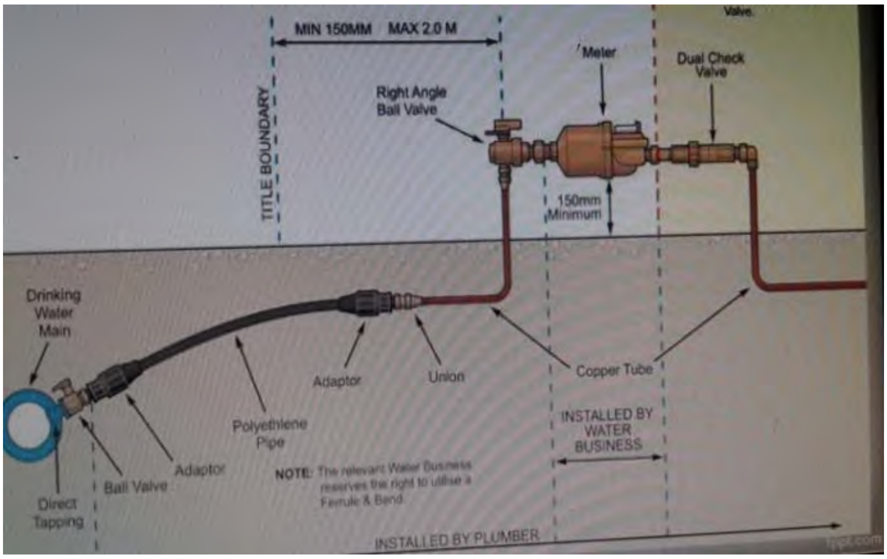


Connection when a new water main is required



STANDARD HOUSE CONNECTION

Screwed clamp, Valve, Union, socket, PE pipe

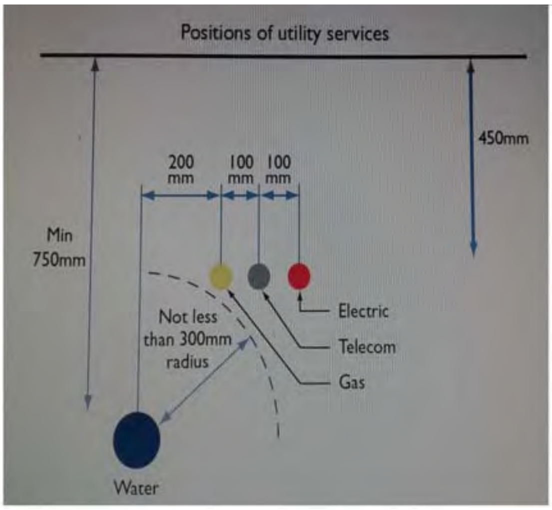


NOTE: The relevant Water Business reserves the right to utilise a Ferrule & Bend.

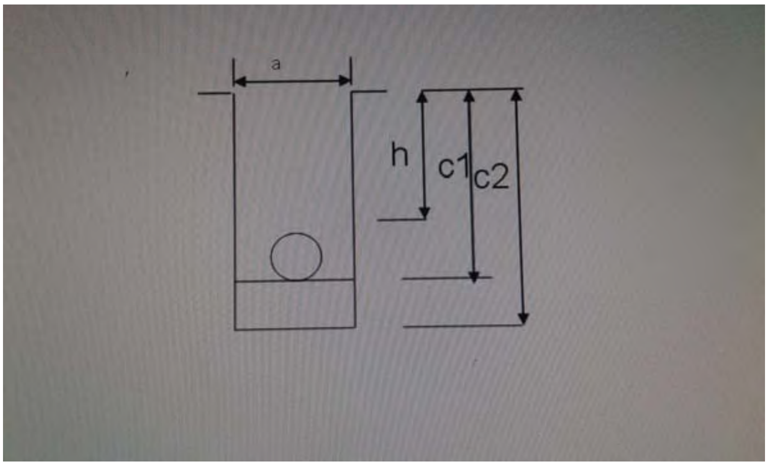
Connection done at Bumbogo-Gishaka village

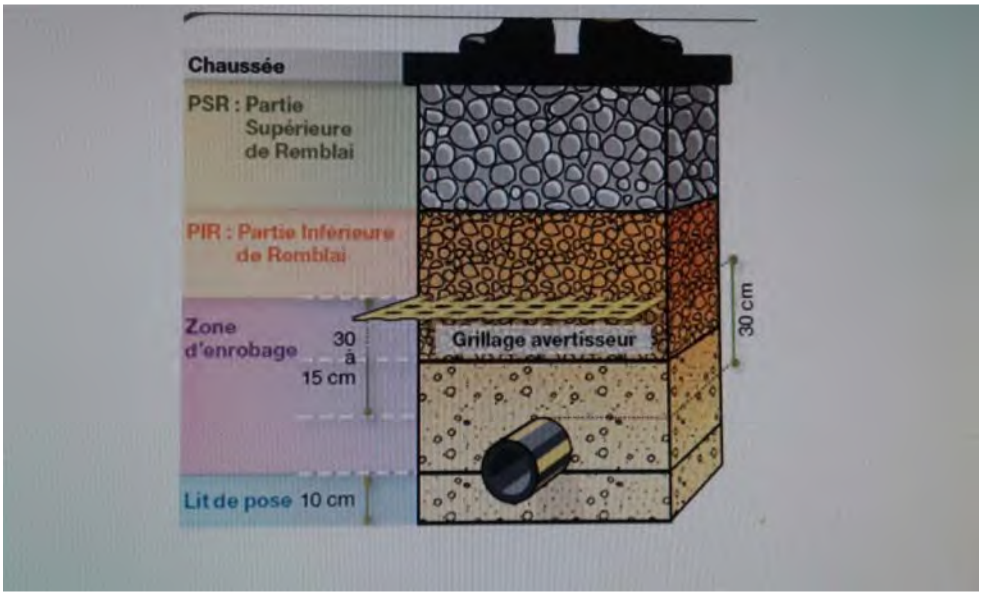
Not accepted

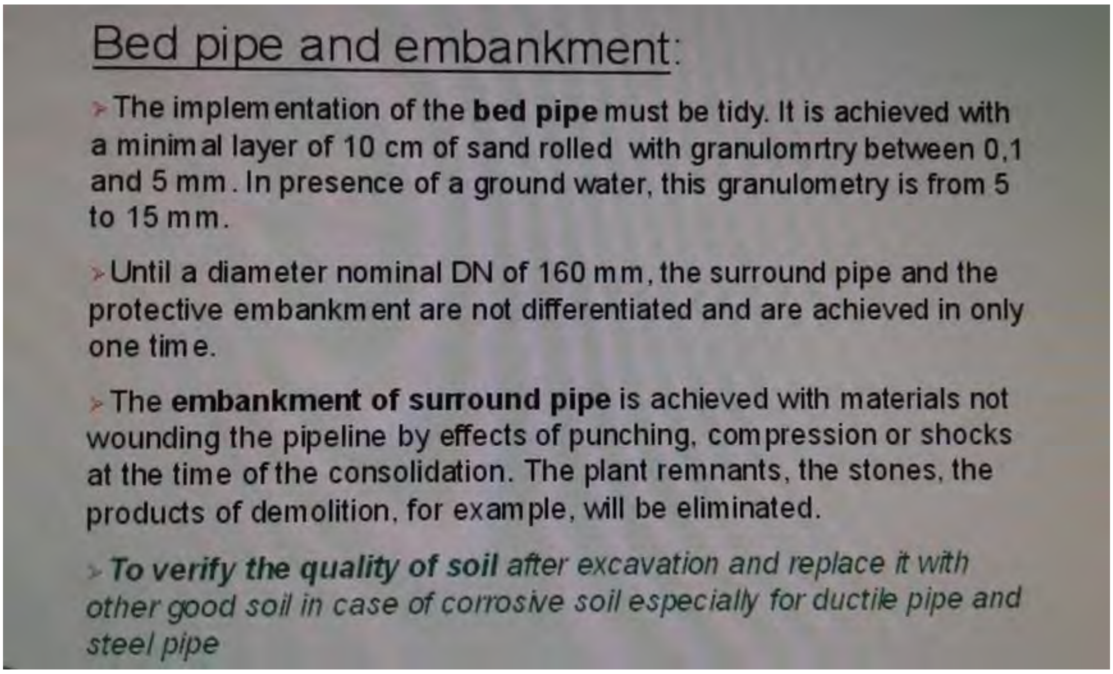
Position of water utility services



STANDARD OF EXCAVATION AND INSTALLATION OF MAIN PIPES

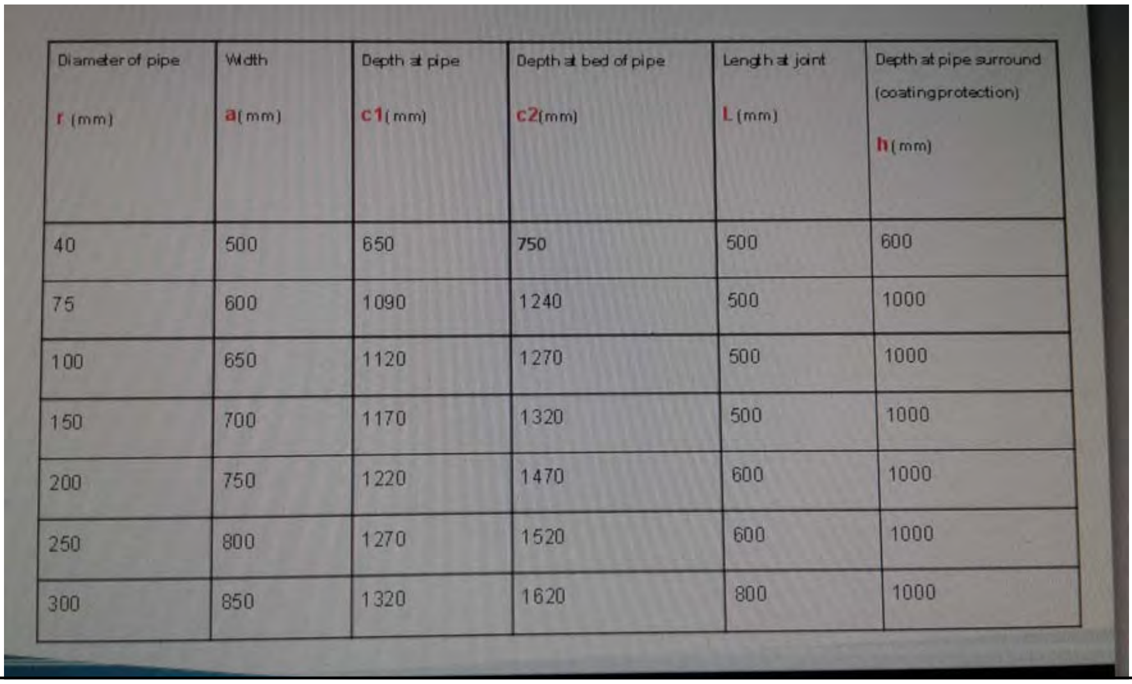




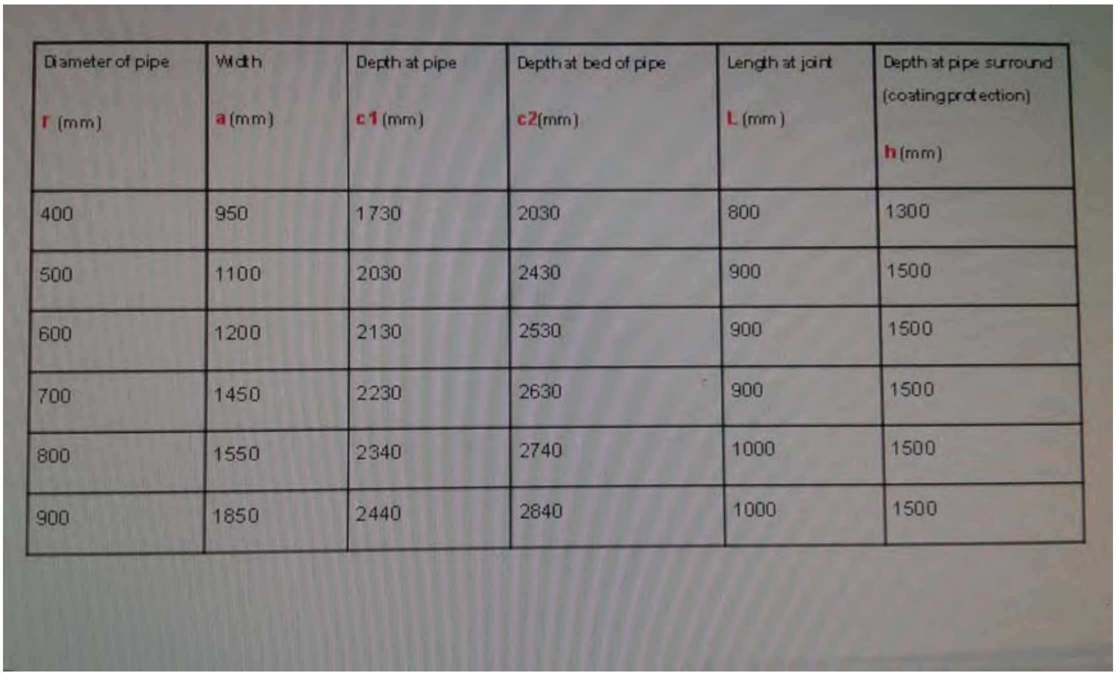


Bed pipe and embankment:

- The implementation of the **bed pipe** must be tidy. It is achieved with a minimal layer of 10 cm of sand rolled with granulomrtry between 0,1 and 5 mm. In presence of a ground water, this granulometry is from 5 to 15 mm.
- Until a diameter nominal DN of 160 mm, the surround pipe and the protective embankment are not differentiated and are achieved in only one time.
- The **embankment of surround pipe** is achieved with materials not wounding the pipeline by effects of punching, compression or shocks at the time of the consolidation. The plant remnants, the stones, the products of demolition, for example, will be eliminated.
- ***To verify the quality of soil*** *after excavation and replace it with other good soil in case of corrosive soil especially for ductile pipe and steel pipe*



Diameter of pipe r (mm)	Width a (mm)	Depth at pipe c1 (mm)	Depth at bed of pipe c2 (mm)	Length at joint L (mm)	Depth at pipe surround (coating protection) h (mm)
40	500	650	750	500	600
75	600	1090	1240	500	1000
100	650	1120	1270	500	1000
150	700	1170	1320	500	1000
200	750	1220	1470	600	1000
250	800	1270	1520	600	1000
300	850	1320	1620	800	1000



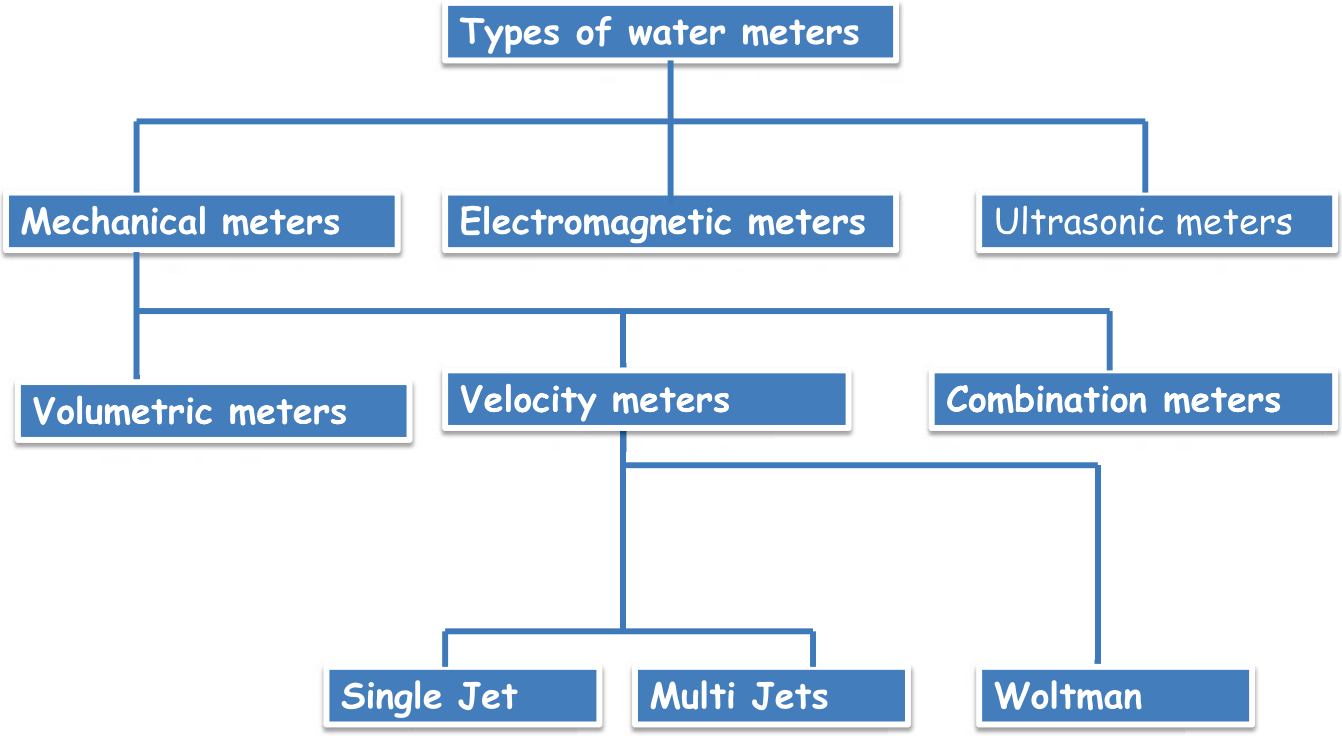
Diameter of pipe r (mm)	Width a (mm)	Depth at pipe c1 (mm)	Depth at bed of pipe c2(mm)	Length at joint L (mm)	Depth at pipe surround (coating protection) h (mm)
400	950	1730	2030	800	1300
500	1100	2030	2430	900	1500
600	1200	2130	2530	900	1500
700	1450	2230	2630	900	1500
800	1550	2340	2740	1000	1500
900	1850	2440	2840	1000	1500

OPERATION AND MAINTENANCE POLICY (cfr WASAC Procedure manual page 31)

- Water distribution activities shall be implemented in different WASAC branches under coordination of Water Operation Services based at Head Quarter.
- The Water Distribution Services based at HQ will be responsible of Operation and maintenance of the main forwarding infrastructures above to Ø200mm while the pipelines below or equal to Ø200mm shall be under responsibility of branches. For any other particular case, the branch should seek for assistance from the water operation services.

THANK YOU

Different types of meters



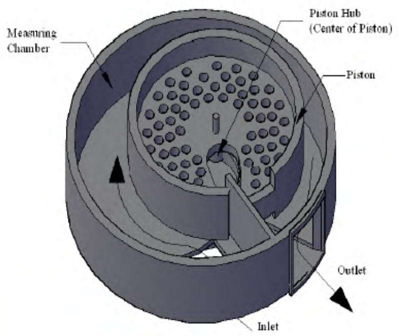
Types of water meters

- Mechanical meters
  - Volumetric meters
  - Velocity meters
    - Single Jet
    - Multi Jets
    - Woltman
  - Combination meters
- Electromagnetic meters
- Ultrasonic meters

Different types of meters

I. Mechanical meters

I.1. Volumetric meters

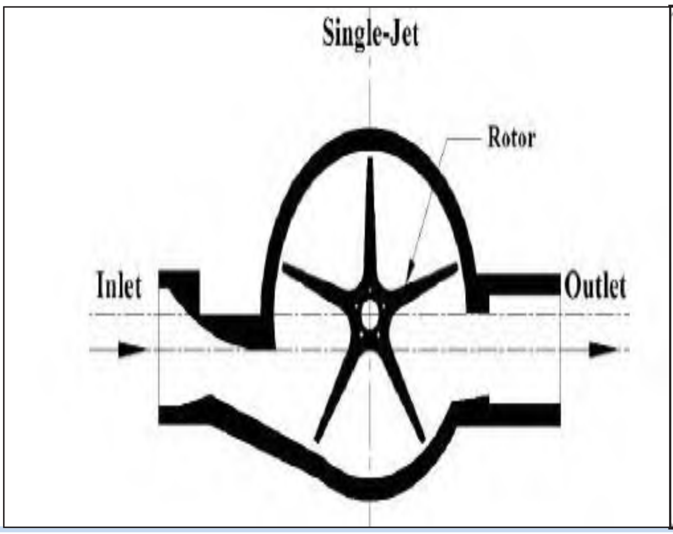


Different types of meters

Mechanical meters

I.2. Velocity meters

I.2.1.Single Jet

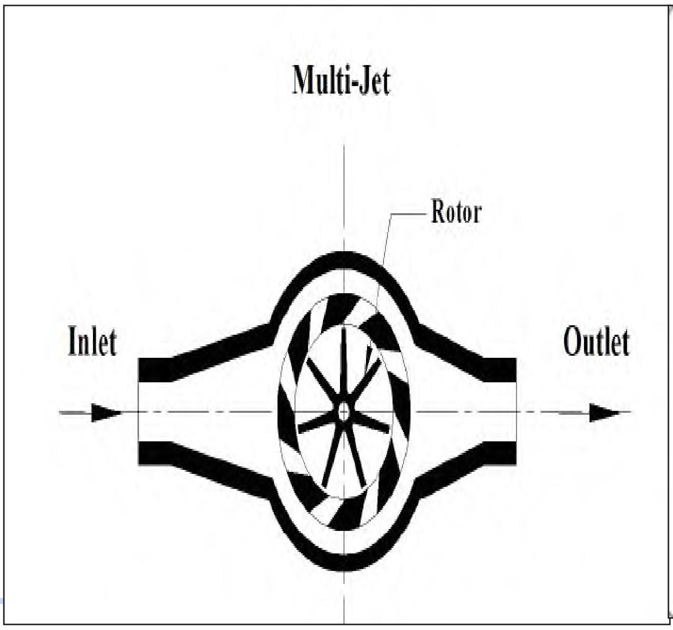


Different types of meters

Mechanical meters

I.2. Velocity meters

I.2.2.Multijet Jet

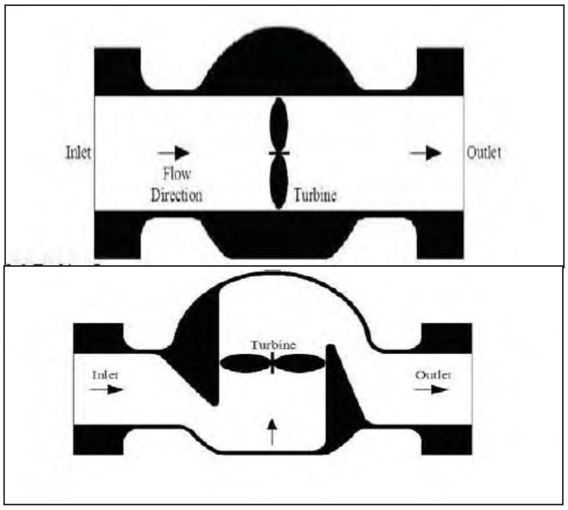


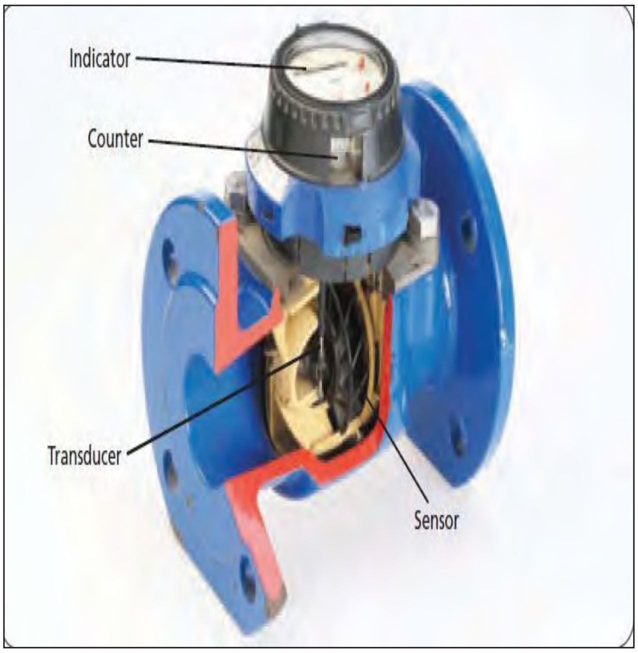
Different types of meters

Mechanical meters

I.2. Velocity meters

I.2.3.WOLMAN

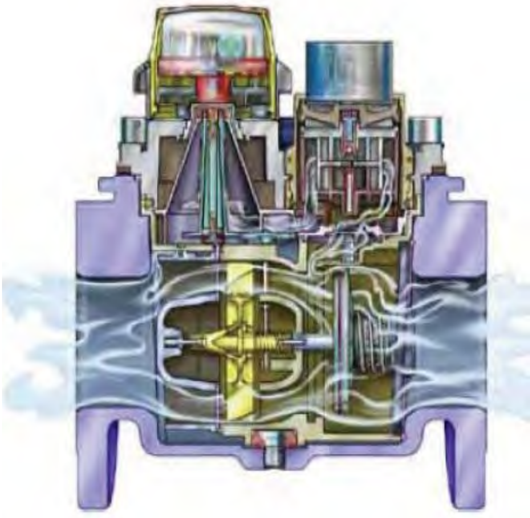




Different types of meters

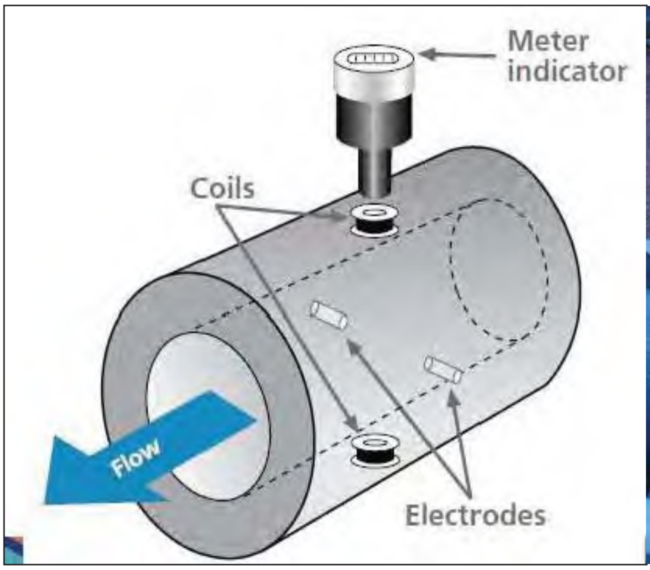
Mechanical meters

I.3.Combination meters



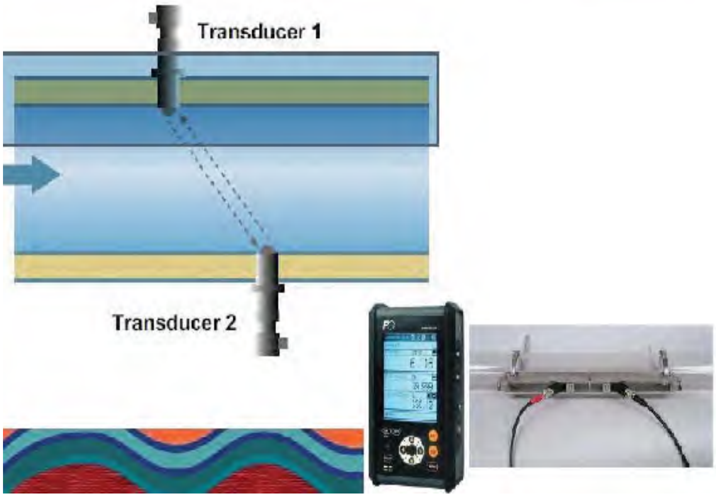
Different types of meters

II. Electromagnetic meters



Different types of meters

III. Ultrasonic meters



Different types of meters

IV. Prepaid meters ??? In WASAC

WELCOME

CUSTOMER FOCUS PROGRAMME

Presenter

Felix Gatanazi

INTRODUCTION

- Name
- Position
- Experience

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Dignifying life

Programme Objectives

- Seek ways and means of improving performance to enhance service delivery
- Establish and alleviate problems hindering efficient service delivery
- Identify potential and practical ideas necessary in boosting

  performance

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Programme Objectives

- Come up with a specially designed organizational programme for different client groups.
- Maximize utilization of available resources and personalities for our organizations.
- Create a friendlier environment where skills can be shared to create better understanding and cooperation.

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Key Goals

We should understand :

- Ourselves as Customer Relationship Management staff.
- The people who seek our services
- The opportunities in promoting our products and services in Rwanda & beyond.

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Dignifying life

Key to Success in Customer Care

We must have thorough knowledge of :

- Customer needs
- Customer expectations
- Customer attitude

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Dignifying life

Who is a customer/client?

- This is a person whom we provide a service
- It is a person who pays for the service
- It is a person who compliments our service
- It is the person who keeps us in business
- It is the person who pays your salary!

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Who are our customers?

Internal customers

- Colleagues in the next door department
- Colleagues in other branches / offices
- Colleagues at ……………………….

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Who frequents our offices?

External Customers

- Fellow citizens
- Foreigners
- Prospective clients
- Competitors
- Government / regulatory authorities
- Prospective investors – local & international

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Customer Relations Strategy

- What drives them to do business with you?
- Given an internal support area, would your customers opt to deal with you?
- How do you need to do to effectively address clients needs & expectations?
- What do your clients desire when they encounter you & your products/services? - *Water*

Factors for Service delivery Success

- Strong **internal** partnerships.
- Accurate collection of info from employees at all levels.
- Employ CRM tools that are customer and employee friendly.
- Don’t go high tech while low tech would do.

Definition of quality.

- Quality is what the customer considers value for his money
- Quality is the positive attribute that goes beyond the expectations of the customer
- Quality is what the customer says it is!
- It can never be decided by the service provider ; it would be suspect & not objective

Issues to Emphasize

- Being ahead of the customer needs
- Making our customers positively & consciously aware of what we are doing for them
- Ensuring that customers are genuinely gratified other than merely satisfied
- Beware of too much customer praises!

Customer care : issues to avoid

- Service should never become the norm and cease to be noticed
- Never take quality for granted
- Never violate accepted standards…clients notice nasty behavior most often
- Never deliver service unconsciously
- It is imprudent to engage the client in any argument…..the customer is our king!

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The Excellent Servant Key Characteristics

- Excellent product / service knowledge
- Positive, cheerful and goal-oriented or result oriented
- Extremely confident and is an optimist
- Risk taker ; comfortable in awkward situations when trying something new ideas

---

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The Excellent Servant Key Characteristics

- Dominates the listening while the client dominates the talking
- Highly disciplined with high degree of self control
- Provides solutions to problems
- Deals honestly and objectively
- Pleasant, patient and easy-going

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Dignifying life

The Excellent Servant Key Characteristics

- Strategic thinker, seeks solutions well in advance
- Embraces an attitude of gratitude all the time
- Builds relationships
- Always calls people by their names

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Why customer care?

- Ensure our clients get value for their money.
- Safeguard our market share/revenue
- Get a competitive edge for growth / expansion of market share

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Human relations
Why do we need them?

- To build greater self confidence
- To cement our relations with other people
- Human relations enhance communication skills
- To develop skills that portray us as leaders
- To manage stress and worry…enables you stay more focused and set smart goals.

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Strengthening relations

- Don't criticize, condemn or complain
- Give honest, sincere appreciation
- Arouse in the other person an eager want
- Become genuinely interested in other people
- Smile
- Call people by their names
- Be an excellent listener

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Changing Attitude & Behavior

- Begin with praise & honest appreciation
- Talk about your own mistakes before criticizing others
- Ask questions instead of giving direct orders
- Praise the slightest improvement & praise every improvement
- Use encouragement, make the fault seem easy to correct
- Let the other person save face

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Dignifying life

Tools for encouraging complaints

- Stamped and addressed card supplied at the point of sale
- Customer service desk at point of sale
- Approach by our personnel to check satisfaction
- Complaint forms, suggestion box, …

Importance of Feedback

- Positive feedback assures us that we are on track – the customer is genuinely gratified

Negative feedback helps us :

- Assess our current position
- Improve on areas highlighted
- Evaluate the service and identify gaps
- identify areas that need extra effort
- Plan for the future

Turn Complaints into Income!

- List five commonest client complaints.
- Analyze each complaint and establish the root cause.
- Determine the cost of doing nothing.
- Finally, determine the potential profit opportunity.

Tyranny of the urgent

Crisis Deadlines Meetings Repairs	Planning Clarifying Values Relationships Vision Process Improvement
Phone calls Interruptions Mail Reports Drop-ins	Junk mail Some calls Pleasure activities Trivia

---

Factors Influencing Customer Care

- Initial contact
- Follow up process
- Clear specification of service features
- Advance notice of any deviation
- Clear invoicing
- Easy access to the service provider for assistance
- All staff must be polite & helpful.

Setting Standards

- Time required to answer a phone call
- Time to respond to a letter or fax
- Time required to resolve a problem
- Frequency of management visits to customers
- Anticipated time between breakdowns

Setting Standards

- Mean time to repair (MTTR)
- Frequency at which sites should be inspected for safety, cleanliness, or other relevant factors
- Length of queues (eg: Disconnection period)
- Response time to request for service (eg: as in Client charter)

Thank You!

We thank you for your participation, your determination to serve better and the spirit to excel.

The training is over, the challenge is to practice the skills acquired.

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Water & Sanitation Corporation
Dignifying life

METER READINGS GENERAL

Desire KAYIRU

INTRODUCTION

- The commercial directorate manages the operations of all the commercial aspects of WASAC includes the branches and monitors the company in the facility of sufficient and quality services to its customers.

- The effective of services delivery, WASAC have now 20 branches in the country with 183 CFOs who each one provide the service to satisfy the customers

Roles of CFOs to improve services in Wasac

- To run and make an utility company perform the services delivery and financial viability of the company CFOs should be accountable and responsible to provide a good image of the company
- CFOs should comply their duties , to well take readings, bill timely the customers and provide the invoices on time; In additional duties they should:
- Sensitised to Increase the number of new connections
- Increase water sales;
- Increase revenue collection;
- Improve revenue collection efficiency;
- Reduce water Commercial losses;
- Increase customer satisfaction and reduce Customer complaints;
- Metering efficiency;
- Public Awareness and communication
- Etc..

Billing Management

- ☐ All Customers should be well billed timely on monthly basis;

Condition:

- CFOs should make sure If customer exist or no, then checks customer status

If customer status is valid for billing then put the readings in the system

for Comparison of current reading with previous reading

The Current reading should be >= Previous reading

New Tarrif

ICYICIRO CY' ABAFATABUGUZI	AMAZI AKORESHWA KU KWEZI (m^3)	IGICIRO GISHYA HATABARIWEMO TVA
		(FRW/m^3)
AMAVOMERO RUSANGE	HATITAWE KU NGANO Y'AMAZI	323
INGO & IBIGO	0 – 5	323
INGO & IBIGO	6 – 20	331
INGO & IBIGO	21 – 50	413
INGO & IBIGO	51 – 100	736
INGO & IBIGO	101 & BEYOND	847
INGANDA	HATITAWE KU NGANO Y'AMAZI	736

Categories of Wasac customers

We have 10 categories of customers

0. Diplomate
1. Particulars
2. Public services
3. Palatal
4. Agent state
5. Commercial
6. Industries
7. Collectivities
8. Publics Tapes
9. WASAC

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Dignifying life

Billing Calculation

- How to make a bill?
- **(A) Consumption=Current readings-Previous Readings**
- **(B) Charge=Consumption*tariff**
- **(C) Regulatory fees(RF)=Charge*0.3%**
- **(D) VAT (18%)=[(Charge+meter rent)*18%]**

Total bill =Charge+RF+100+VAT or (B+ C+100+ D)

Payment Model

- **All Payment of services provided by WASAC should be done through the Banks**
- **Bill payment is done in two option:**
- **Through Banks and online**

1. Online payment With:

✓ MTN
✓ AIRTEL

2. <u>BANKS</u>

✓ BK
✓ COGEBANK
✓ ECOBANK
✓ GTBANK
✓ I&M BANK
✓ BPR

Payment Model

How to Check Water Bill on Website

Go to www.wasac.rw

Go to the Important links "right side" , click on Check and pay your bill

Enter your POC "Point of Connection" or Customer Number NB: 9 Digital

You will get your Balance

Click on Unpaid Invoices then you will see all your unpaid Invoices

on Payments History, you will see your payments history

Payment Model

How to Pay Water Bill on Mobile Money

Check your outstanding balance and pay your water bill instantly with MTN Mobile Money.

How to Pay:

- Dial *182#
- Choose pay bill
- Go to Water
- Enter Account Number
- Enter MM PIN
- Confirm the details and dial * 1 to continue

Payment Model (ContS)

- Enter the amount you wish to pay
- Enter your Mobile Money PIN to confirm payment

Customer receives a notification message How much does it cost? The transaction fee for all amounts is 300rwf.

KEY OF SUCCESS

Customer Field officer’s BEHAVIOUR

Vis a vis to the Customer…

Thank you for your attention!

DEFINITION & USE

WORKING PRINCIPLE

METER CONDITIONS: HOW TO JUDGE WHETHER THEY ARE NORMAL OR NOT?

BY: FELICIEN NIRINGIYIMANA
HEAD OF METER MANAGEMENT SERVICES

DEFINITION & USE

- (a)The **water meter** is a device for measuring and registering the quantity of water that passes through a pipe or other outlet.
- (b) The **water meter** is a device which is used to measure the volume of water used by residential and commercial buildings that are supplied with water by a public water supply system(ex.WASAC ltd in RWANDA);
- They can also be used at a well, water source or water system to determine the flow of water via a specific portion of the system.

TYPES OF METERS BASING ON CONSUMPTION

- 1. Domestic meters
- Are the water meters that are used for small houses /small consumers

WATER METERS ARE DIVIDED INTO TWO CATEGORIES BASING TO THE CONSUMPTION

1.Domestic water meter

2. Industrial water meters

INDUSTRIAL METERS

- Are the water meters that are used for big consumers like hospitals , big industries, WTP,……

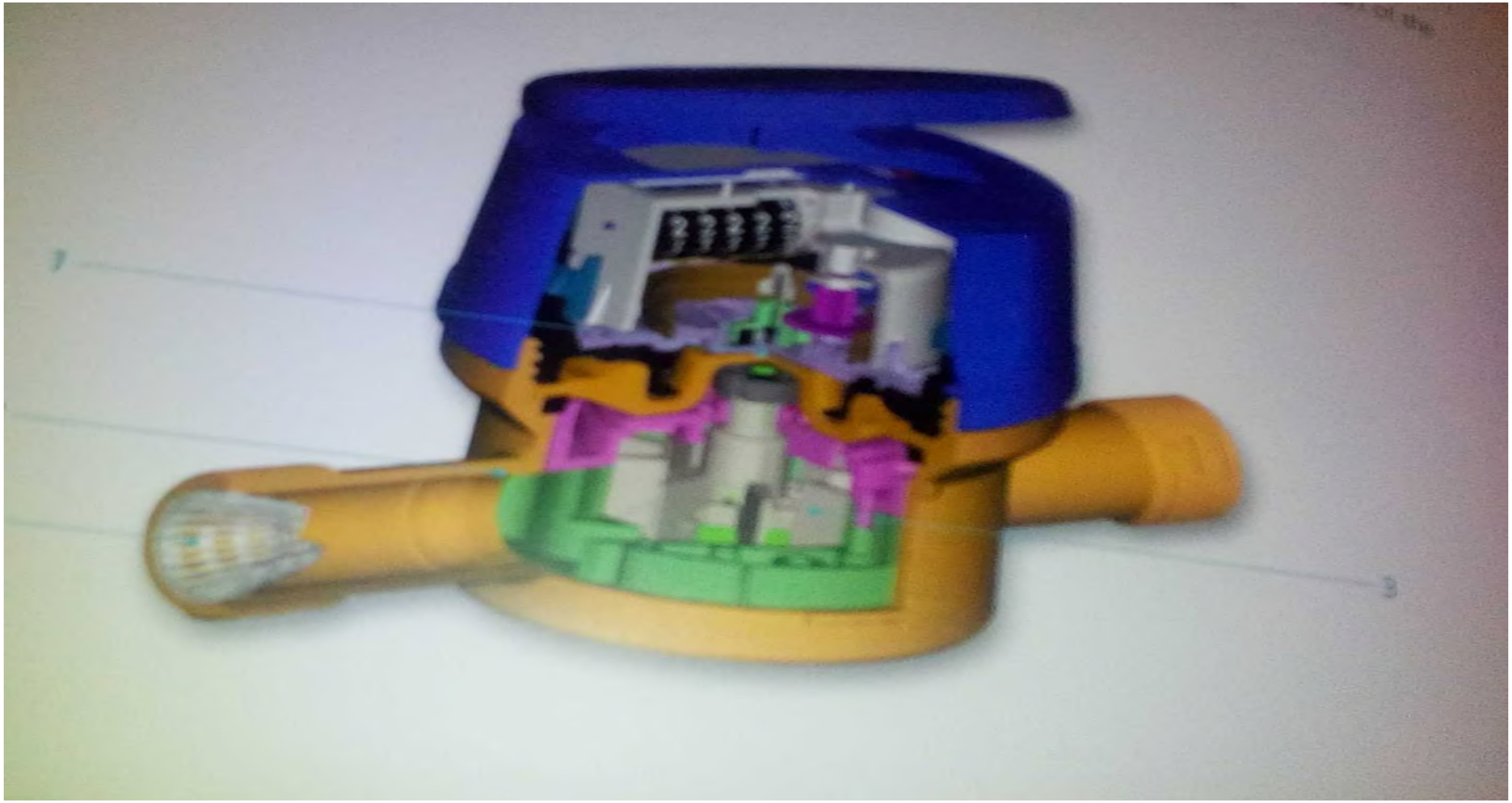

m3
090025549
SENSUS

WORKING PRINCIPLE FOR MECHANICAL METERS

The mechanical meter has two main components, the **hydraulic part** that receive the water flow to be measured and **the register part** that displays the received and measured water volume.

- The Flow coming from inlet, is diverted by a specially shaped injector(2),this flow is injected to the turbine(3) and is rotated.

WORKING PRINCIPLE FOR MECHANICAL METERS



METER CONDITIONS

How to judge whether they are

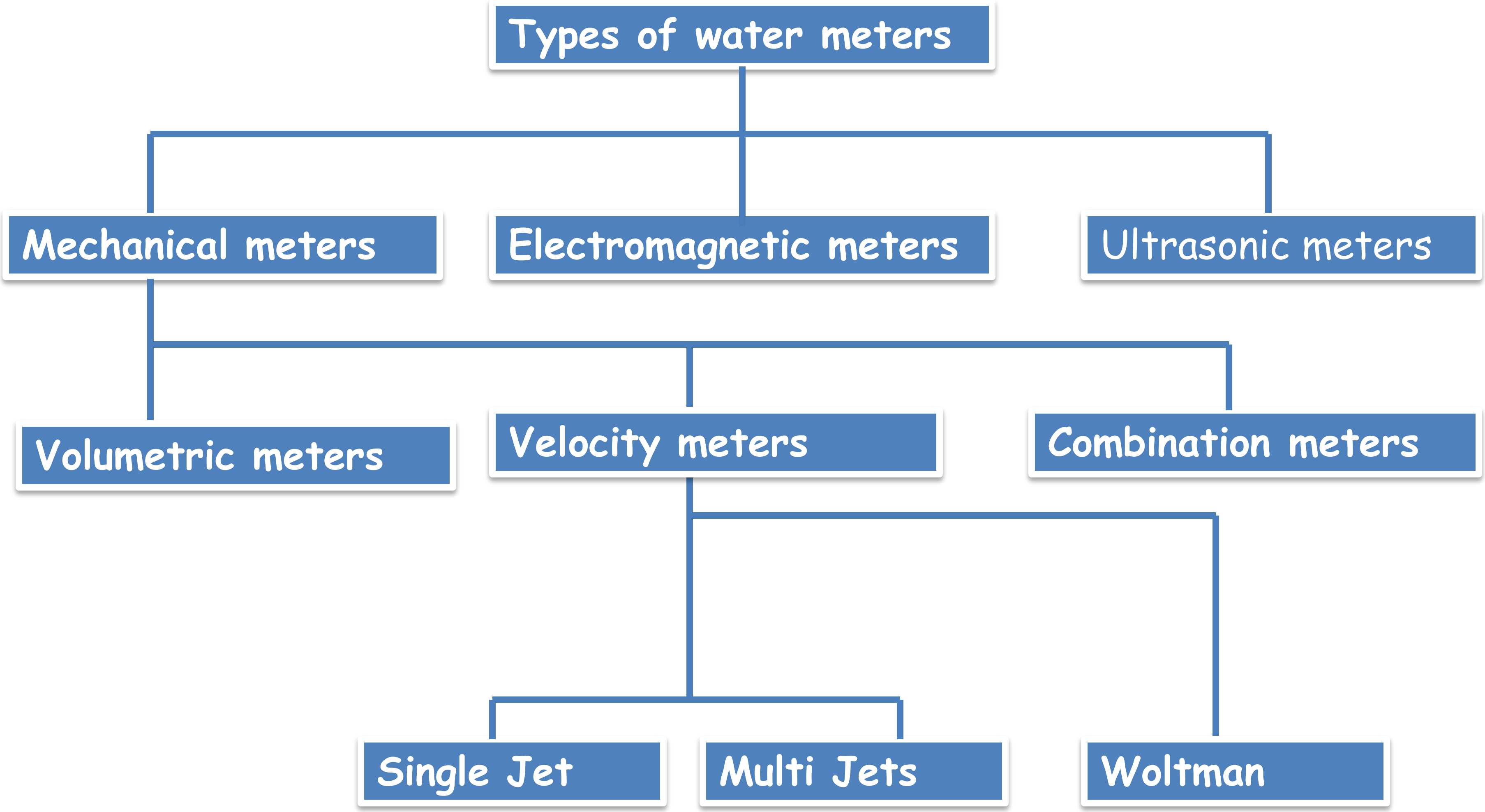
Normal or not?

- This will be done in open conversation

- Only **one** fact will show you that the meter has worked/is working in normal condition.
- Which one??? ‘’**CHANGE OF INDEX’’**
- Example: Last reading=130m3;Curent reading=138m3;Cons=8m3

THANK YOU FOR YOUR ATTENTION!!

Different types of meters



Types of water meters

Mechanical meters

Electromagnetic meters

Ultrasonic meters

Volumetric meters

Velocity meters

Combination meters

Single Jet

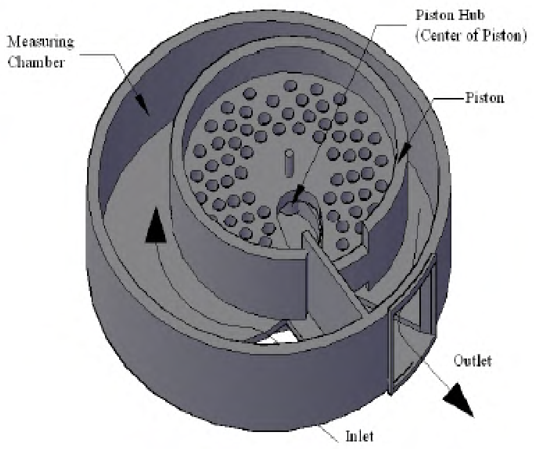
Multi Jets

Woltman

Different types of meters

I. Mechanical meters

I.1. Volumetric meters

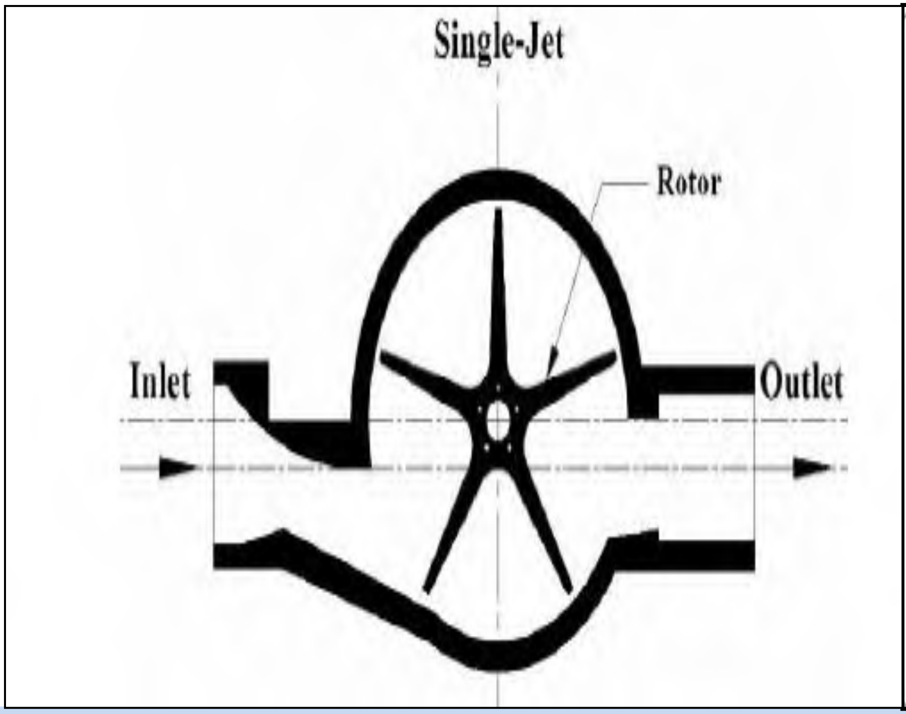


Different types of meters

Mechanical meters

I.2. Velocity meters

I.2.1.Single Jet

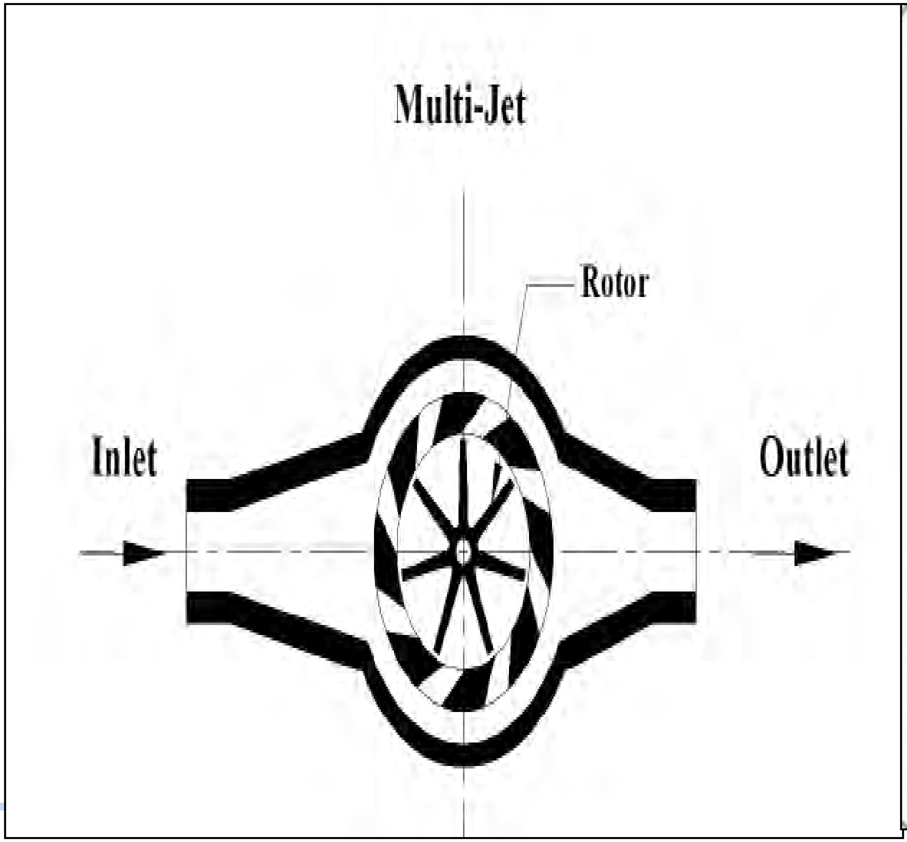


Different types of meters

Mechanical meters

I.2. Velocity meters

I.2.2.Multijet Jet

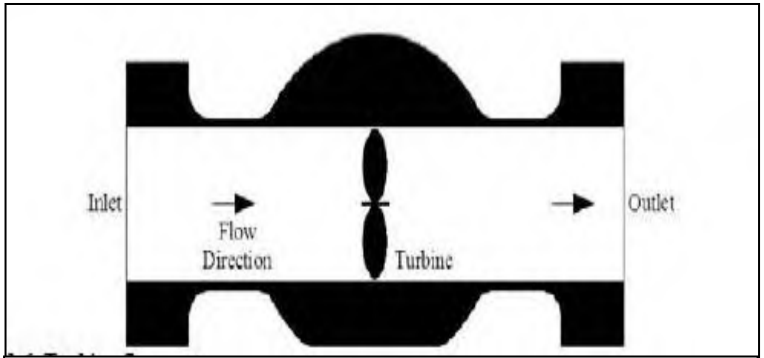


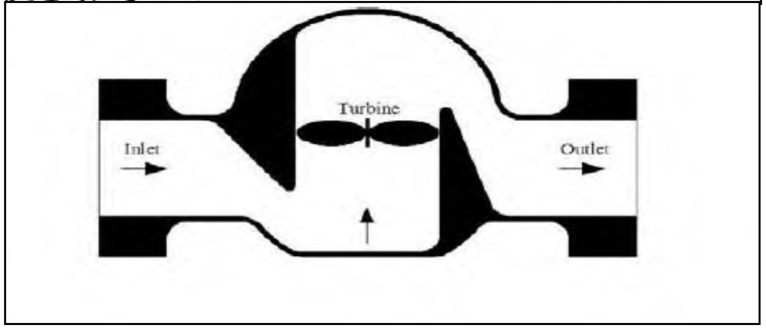
Different types of meters

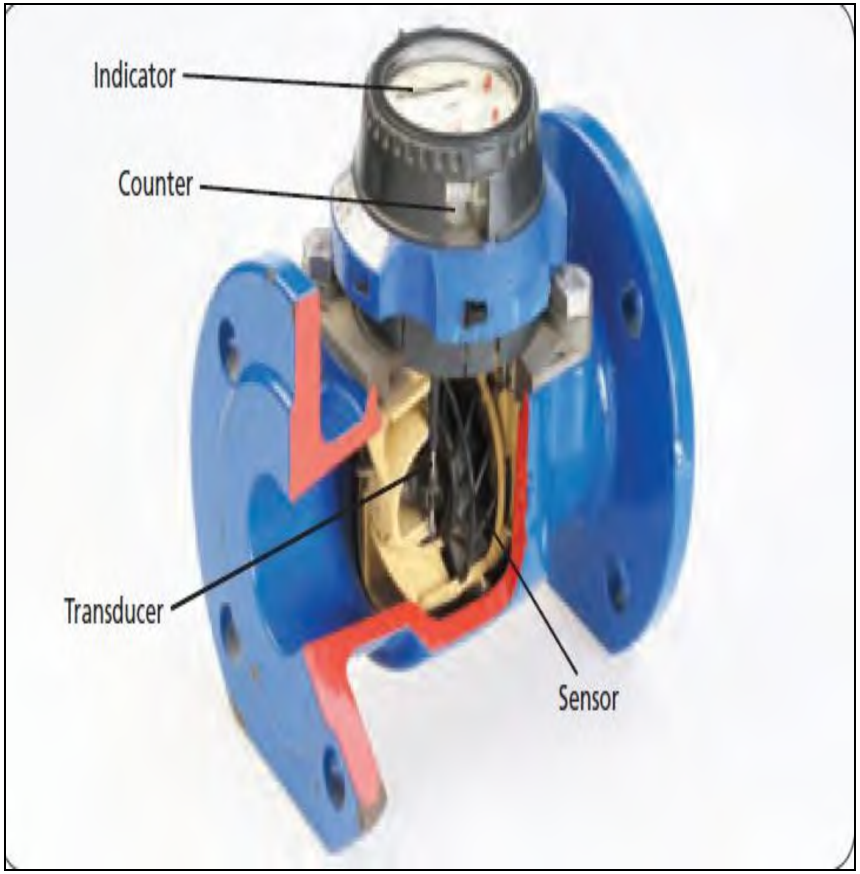
Mechanical meters

I.2. Velocity meters

I.2.3.WOLMAN



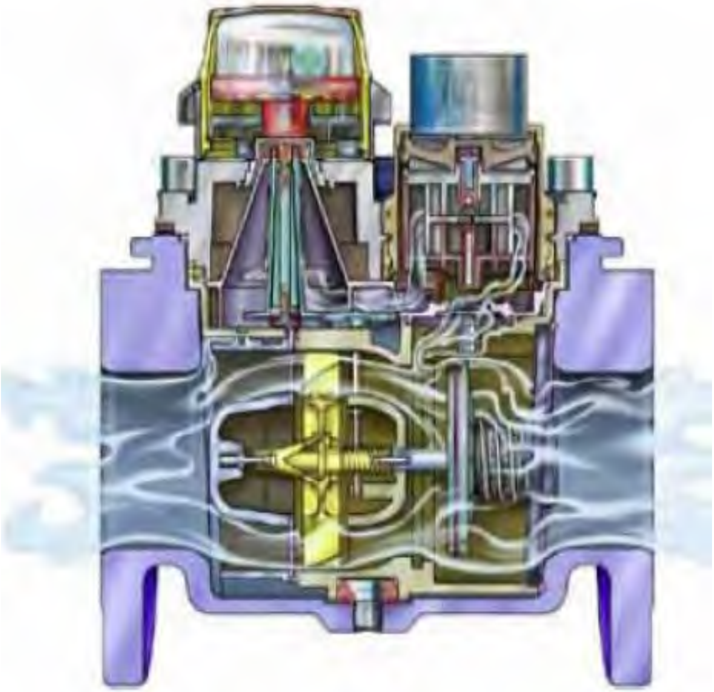




Different types of meters

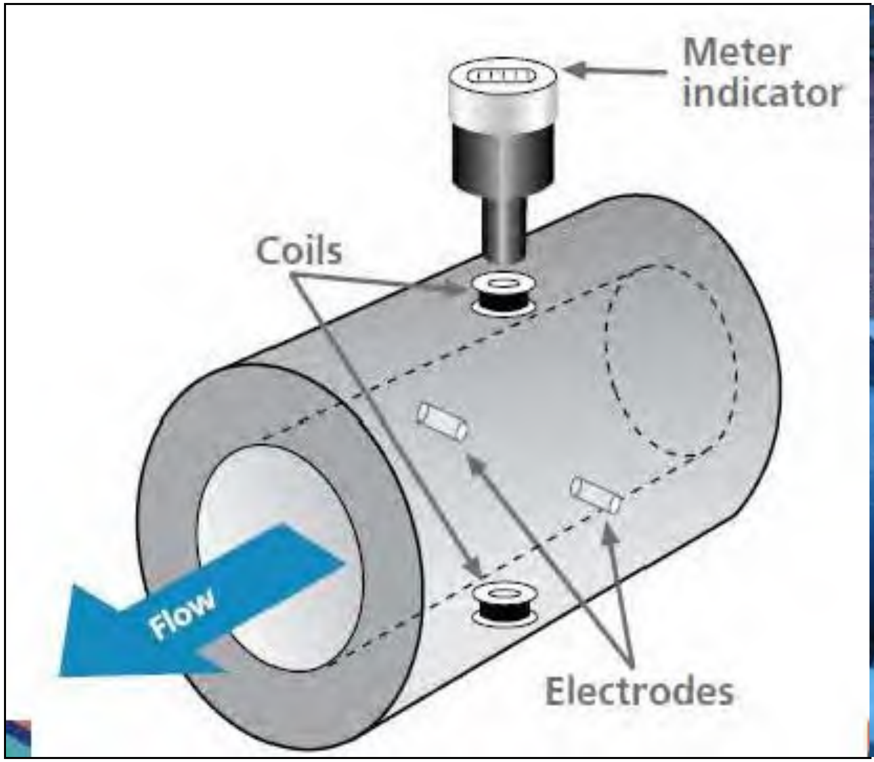
Mechanical meters

I.3.Combination meters



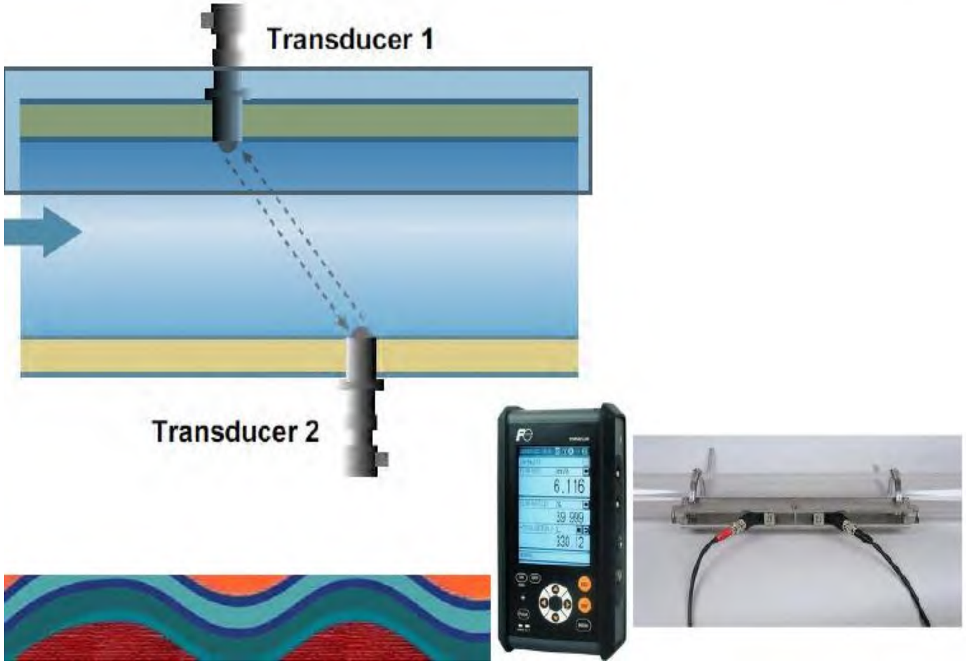
Different types of meters

II. Electromagnetic meters



Different types of meters

III. Ultrasonic meters

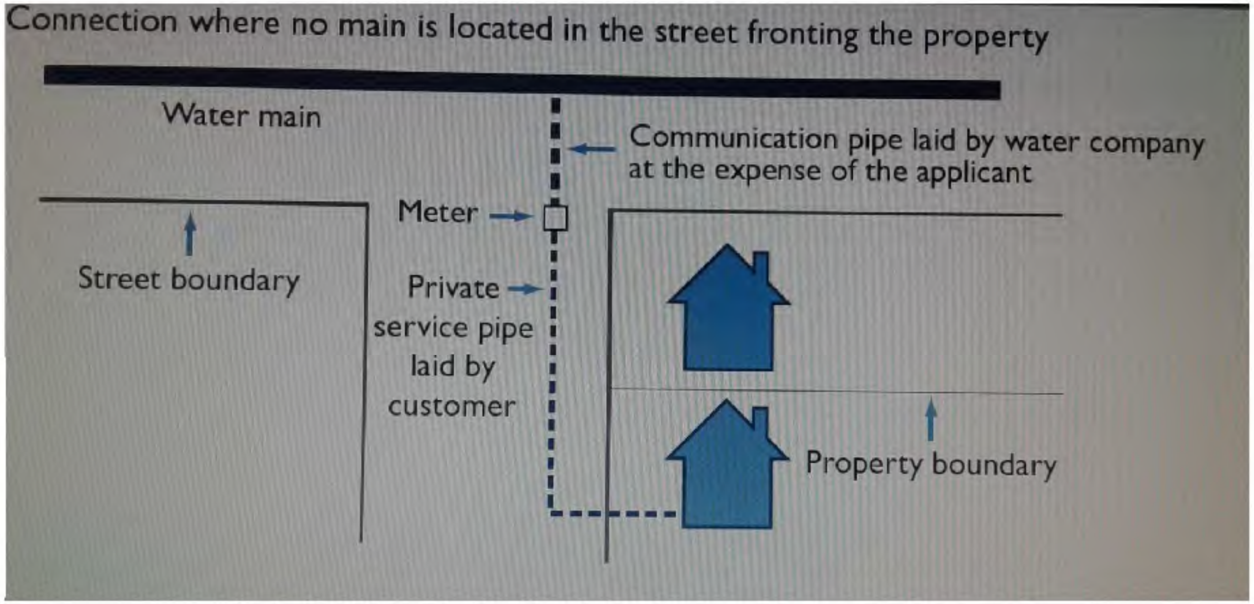


Different types of meters

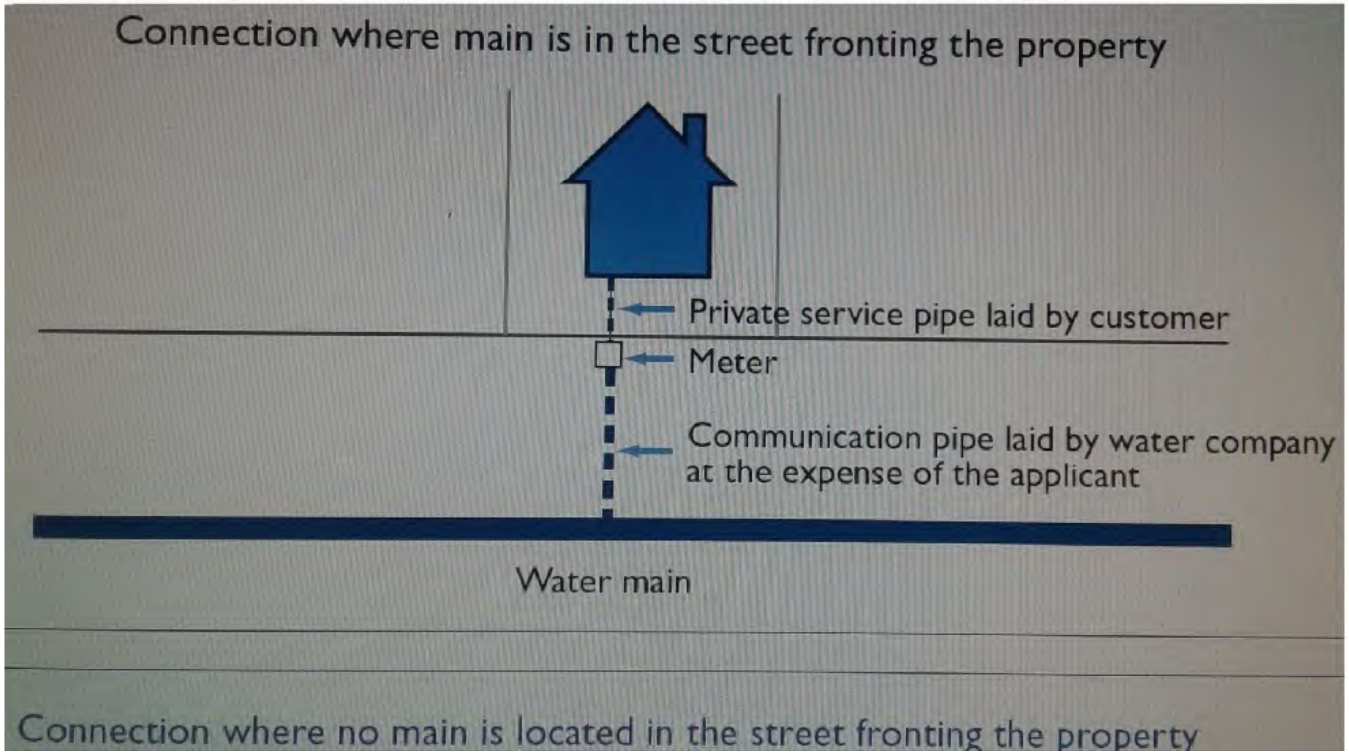
IV. Prepaid meters ??? In WASAC

STANTARD SERVICE CONNECTION & MAIN PIPES INSTALLATION

Connection where no main is located in the street fronting the property



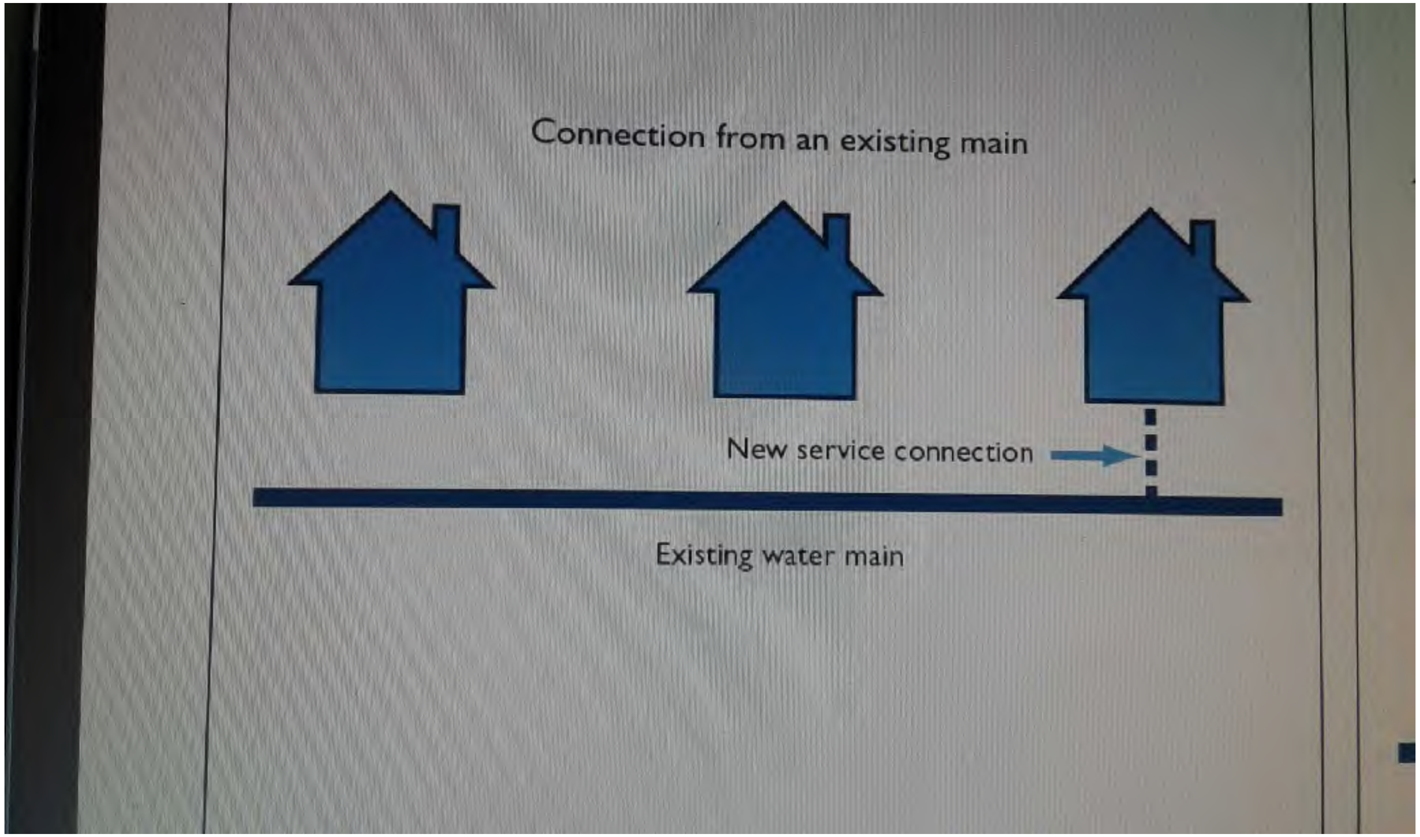
Connection where main is in the street fronting the property



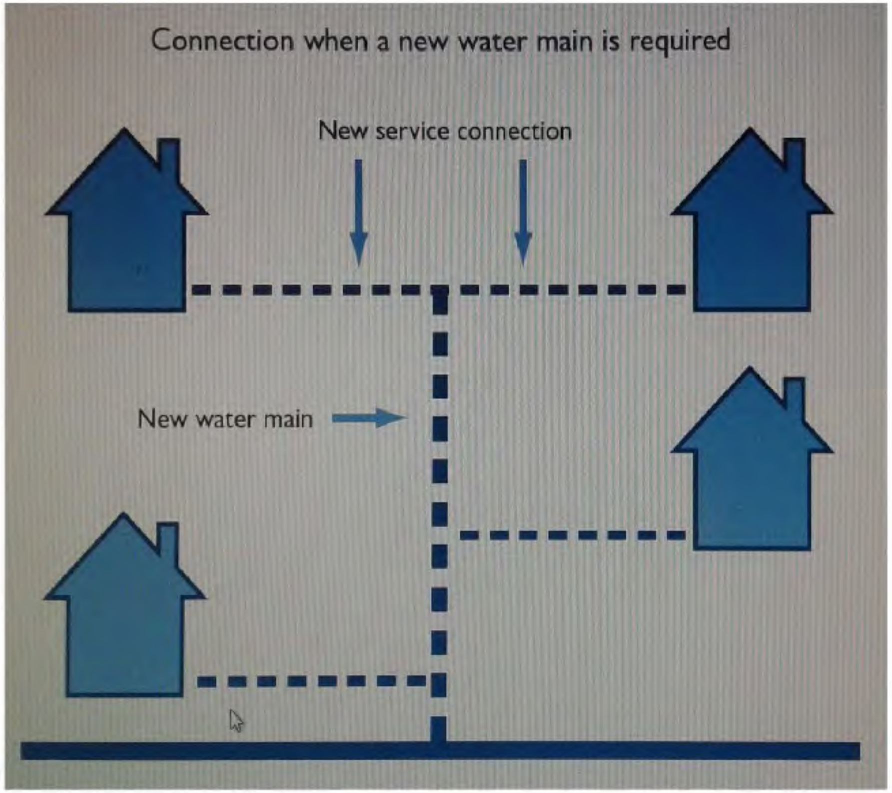
Connection where main is in the street fronting the property

Connection where no main is located in the street fronting the property

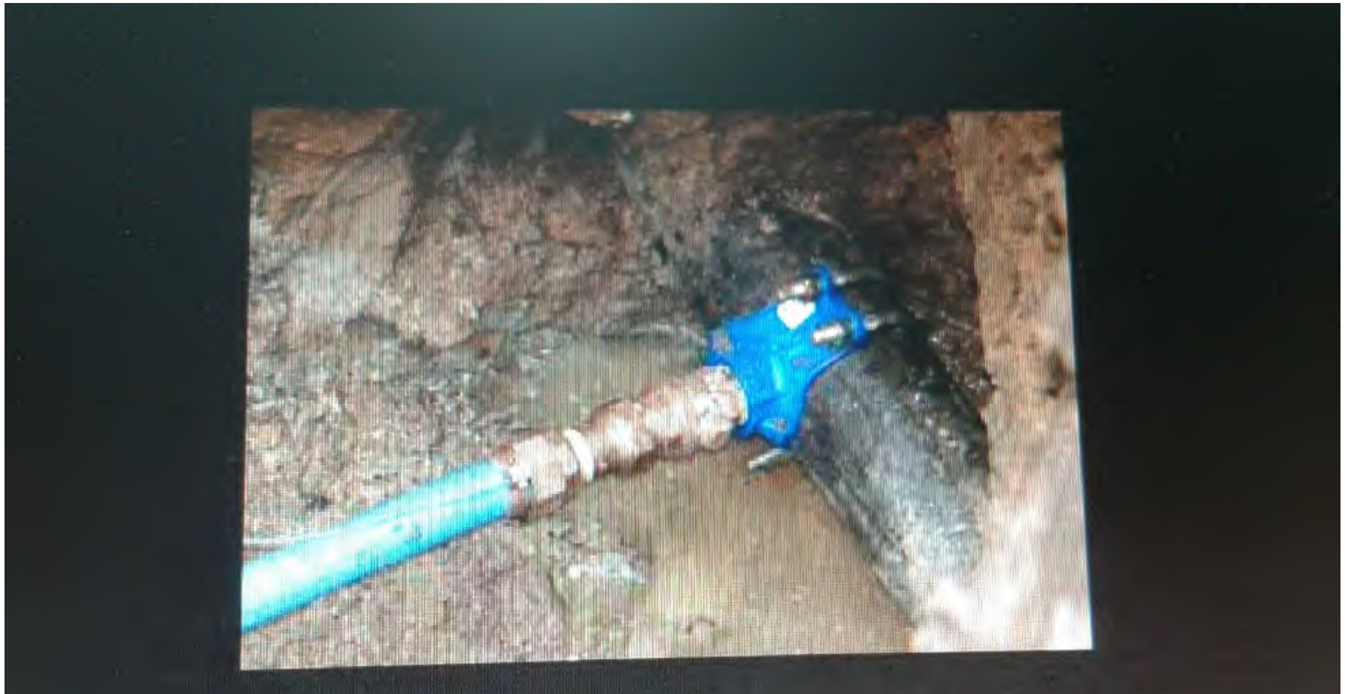
Connection from an existing main



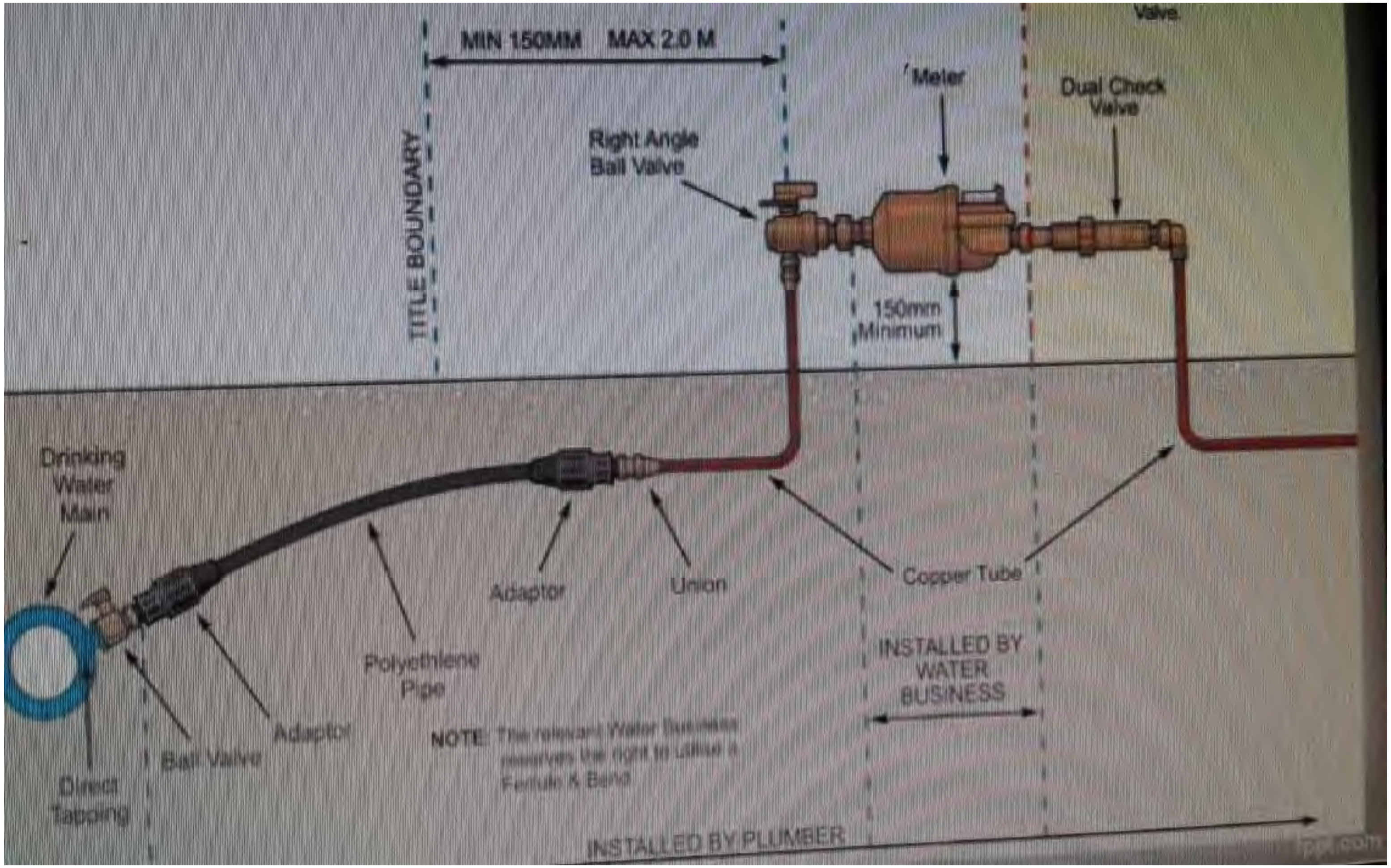
Connection when a new water main is required



STANDARD HOUSE CONNECTION



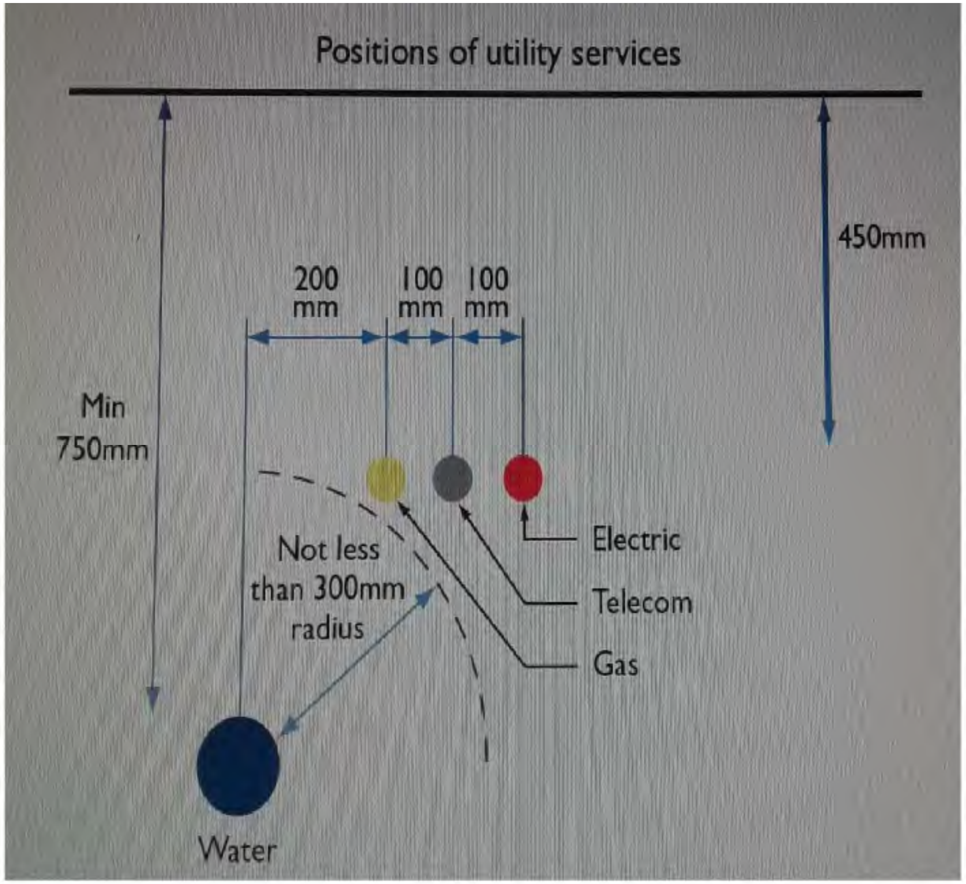
Screwed clamp, Valve, Union, socket, PE pipe


Valve.
MIN 150MM MAX 2.0 M
TITLE BOUNDARY
Meter
Dual Check Valve
Right Angle Ball Valve
150mm Minimum
Drinking Water Main
Adaptor
Union
Copper Tube
Polyethlene Pipe
INSTALLED BY WATER BUSINESS
Adaptor
Ball Valve
Direct Tapping
NOTE: The relevant Water Business reserves the right to utilise a Ferrule & Bend
INSTALLED BY PLUMBER

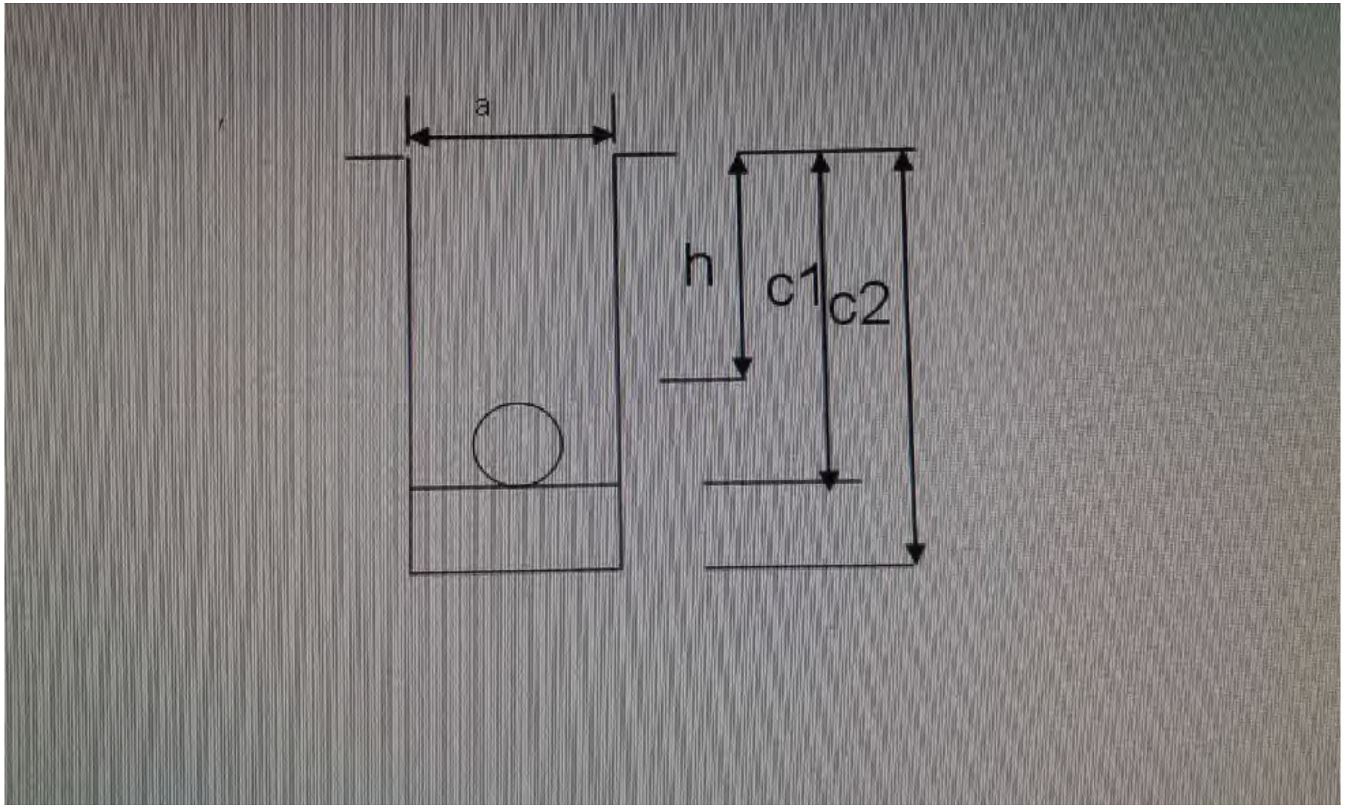

Connection done at Bumbogo-Gishaka village

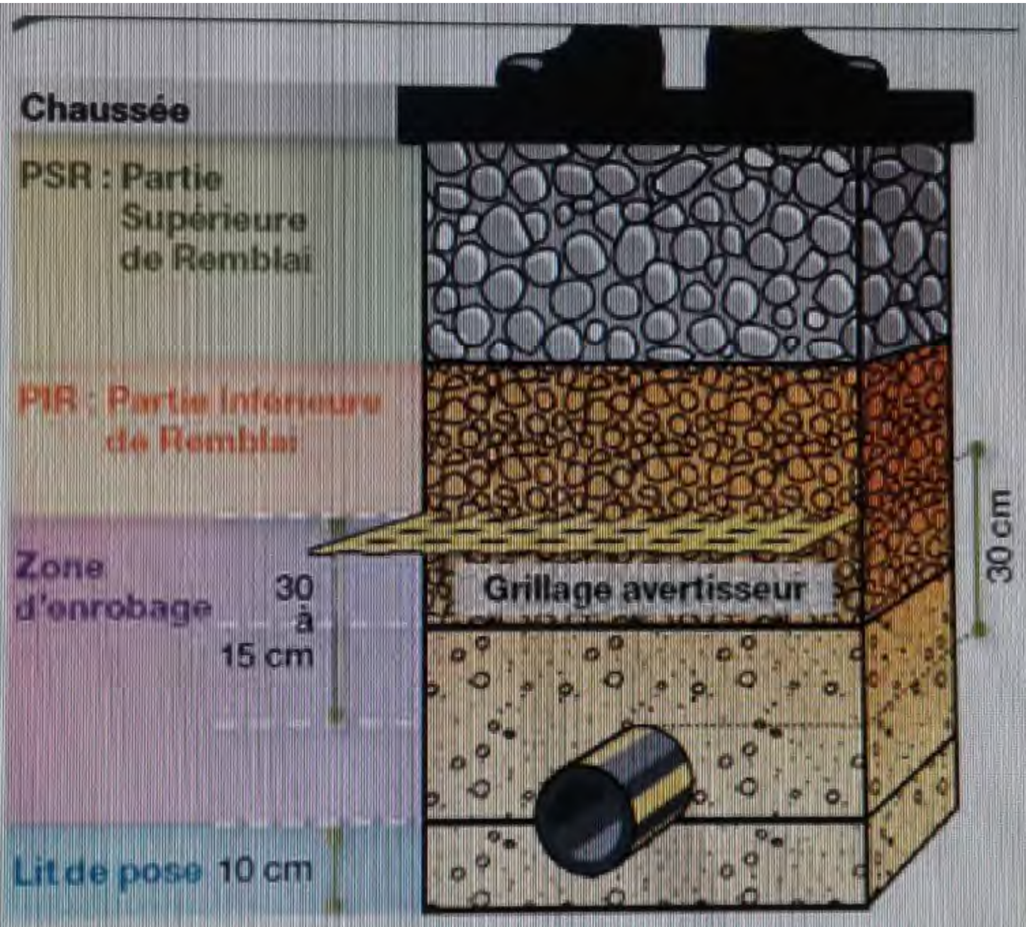
22
Not accepted

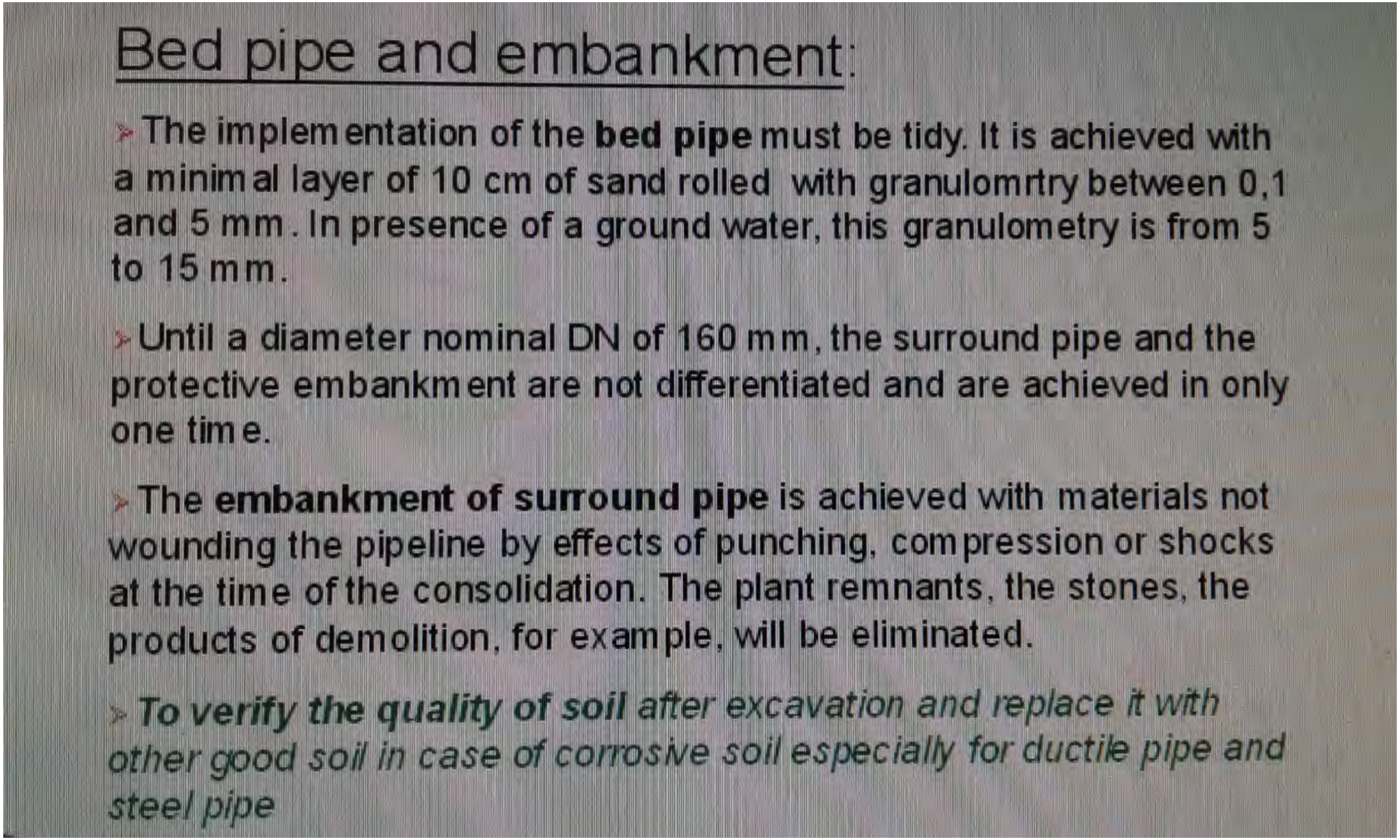
Position of water utility services



STANDARD OF EXCAVATION AND INSTALLATION OF MAIN PIPES

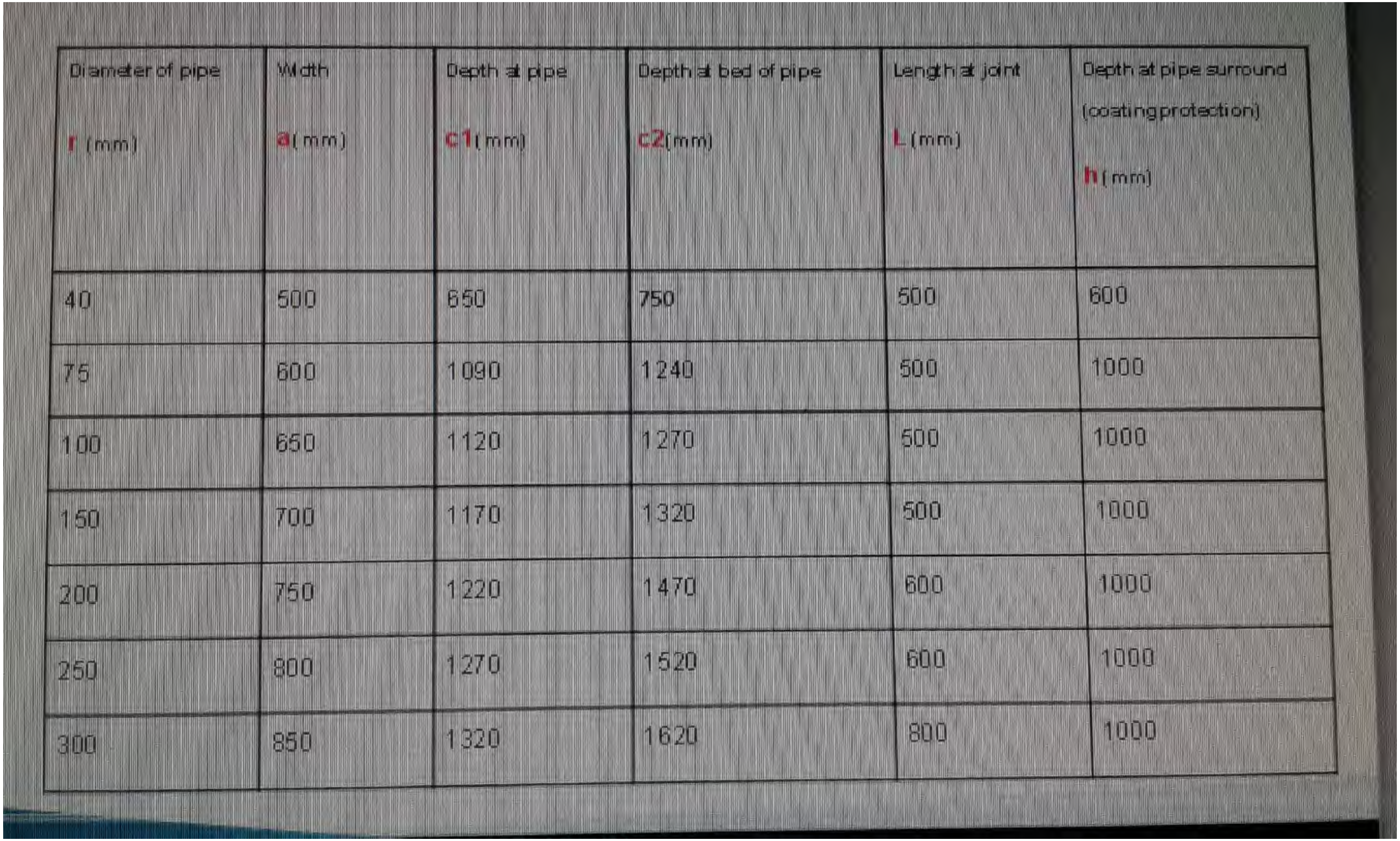



Chaussée
PSR : Partie Supérieure de Remblai
PIR : Partie Inférieure de Remblai
Zone d'enrobage
30 à 15 cm
Grillage avertisseur
30 cm
Lit de pose 10 cm

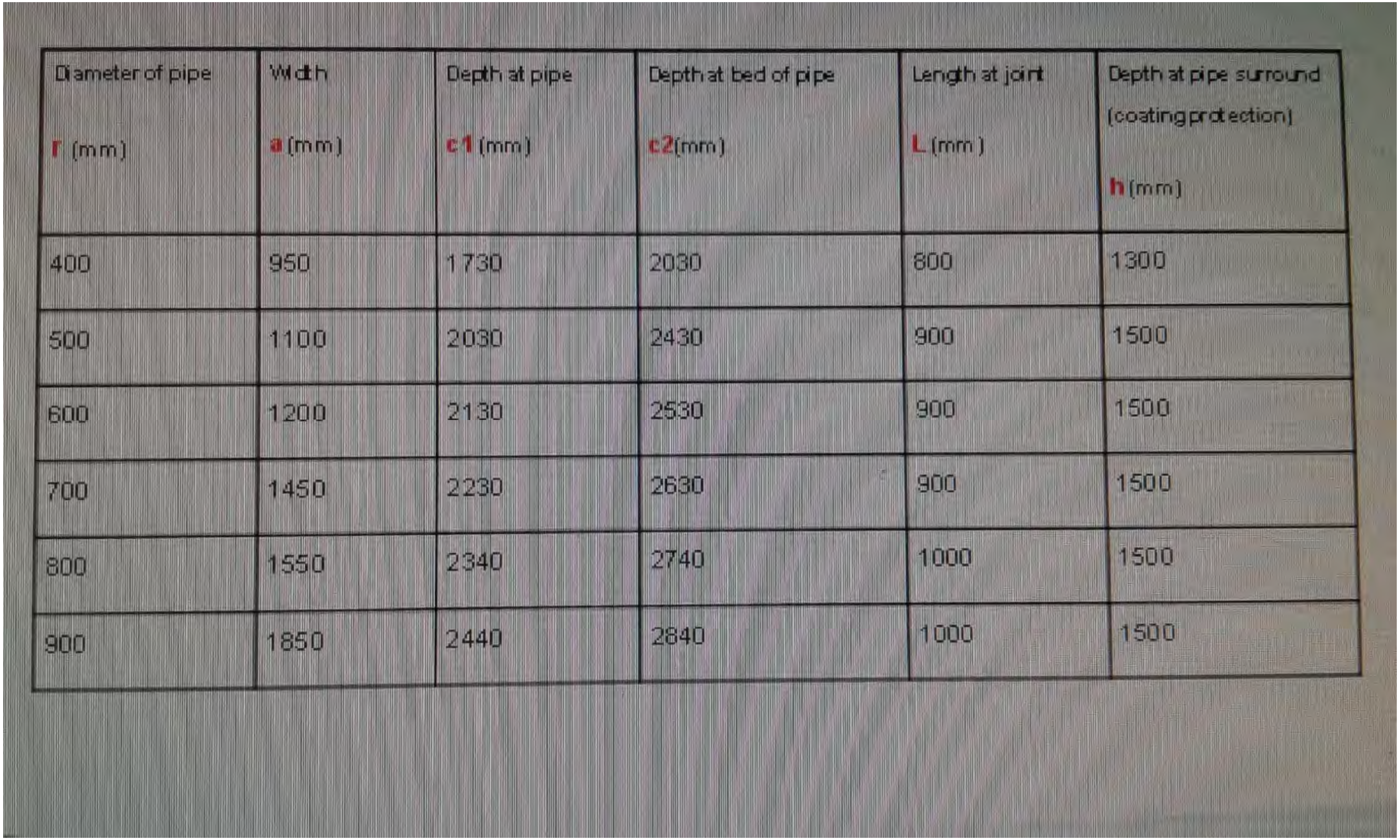


Bed pipe and embankment:

- The implementation of the **bed pipe** must be tidy. It is achieved with a minimal layer of 10 cm of sand rolled with granulomrtry between 0,1 and 5 mm. In presence of a ground water, this granulometry is from 5 to 15 mm.
- Until a diameter nominal DN of 160 mm, the surround pipe and the protective embankment are not differentiated and are achieved in only one time.
- The **embankment of surround pipe** is achieved with materials not wounding the pipeline by effects of punching, compression or shocks at the time of the consolidation. The plant remnants, the stones, the products of demolition, for example, will be eliminated.
- ***To verify the quality of soil*** *after excavation and replace it with other good soil in case of corrosive soil especially for ductile pipe and steel pipe*



Diameter of pipe r (mm)	Width a (mm)	Depth at pipe c1 (mm)	Depth at bed of pipe c2 (mm)	Length at joint L (mm)	Depth at pipe surround (coating protection) h (mm)
40	500	650	750	500	600
75	600	1090	1240	500	1000
100	650	1120	1270	500	1000
150	700	1170	1320	500	1000
200	750	1220	1470	600	1000
250	800	1270	1520	600	1000
300	850	1320	1620	800	1000



Diameter of pipe **r** (mm)	Width **a** (mm)	Depth at pipe **c1** (mm)	Depth at bed of pipe **c2**(mm)	Length at joint **L** (mm)	Depth at pipe surround (coating protection) **h** (mm)
400	950	1730	2030	800	1300
500	1100	2030	2430	900	1500
600	1200	2130	2530	900	1500
700	1450	2230	2630	900	1500
800	1550	2340	2740	1000	1500
900	1850	2440	2840	1000	1500

OPERATION AND MAINTENANCE POLICY (cfr WASAC Procedure manual page 31)

- Water distribution activities shall be implemented in different WASAC branches under coordination of Water Operation Services based at Head Quarter.

- The Water Distribution Services based at HQ will be responsible of Operation and maintenance of the main forwarding infrastructures above to Ø200mm while the pipelines below or equal to Ø200mm shall be under responsibility of branches. For any other particular case, the branch should seek for assistance from the water operation services.

THANK YOU

WASAC
Water & Sanitation Corporation
Dignifying life

WELCOME

CUSTOMER FOCUS PROGRAMME

Presenter
Felix Gatanazi

WASAC
Water & Sanitation Corporation
Dignifying life

INTRODUCTION

- Name
- Position
- Experience

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- Identify potential and practical ideas necessary in boosting

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- Ourselves as Customer Relationship Management staff.

- The people who seek our services

- The opportunities in promoting our products and services in Rwanda & beyond.

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Key to Success in Customer Care

We must have thorough knowledge of :

- Customer needs
- Customer expectations
- Customer attitude

Who is a customer/client?

- This is a person whom we provide a service
- It is a person who pays for the service
- It is a person who compliments our service
- It is the person who keeps us in business
- It is the person who pays your salary!

Who are our customers?

Internal customers

- Colleagues in the next door department
- Colleagues in other branches / offices
- Colleagues at ……………………….

Who frequents our offices?

External Customers

- Fellow citizens
- Foreigners
- Prospective clients
- Competitors
- Government / regulatory authorities
- Prospective investors – local & international

Customer Relations Strategy

- What drives them to do business with you?
- Given an internal support area, would your customers opt to deal with you?
- How do you need to do to effectively address clients needs & expectations?
- What do your clients desire when they encounter you & your products/services? - *Water*

Factors for Service delivery Success

- Strong **internal** partnerships.

- Accurate collection of info from employees at all levels.
- Employ CRM tools that are customer and employee friendly.

- Don’t go high tech while low tech would do.

Definition of quality.

- Quality is what the customer considers value for his money
- Quality is the positive attribute that goes beyond the expectations of the customer
- Quality is what the customer says it is!
- It can never be decided by the service provider ; it would be suspect & not objective

Issues to Emphasize

- Being ahead of the customer needs
- Making our customers positively & consciously aware of what we are doing for them
- Ensuring that customers are genuinely gratified other than merely satisfied
- Beware of too much customer praises!

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Customer care : issues to avoid

- Service should never become the norm and cease to be noticed
- Never take quality for granted
- Never violate accepted standards…clients notice nasty behavior most often
- Never deliver service unconsciously
- It is imprudent to engage the client in any argument…..the customer is our king!

The Excellent Servant Key Characteristics

- Excellent product / service knowledge

- Positive, cheerful and goal-oriented or result oriented

- Extremely confident and is an optimist

- Risk taker ; comfortable in awkward situations when trying something new ideas

The Excellent Servant Key Characteristics

- Dominates the listening while the client dominates the talking
- Highly disciplined with high degree of self control
- Provides solutions to problems
- Deals honestly and objectively
- Pleasant, patient and easy-going

The Excellent Servant Key Characteristics

- Strategic thinker, seeks solutions well in advance
- Embraces an attitude of gratitude all the time
- Builds relationships
- Always calls people by their names

Why customer care?

- Ensure our clients get value for their money.
- Safeguard our market share/revenue
- Get a competitive edge for growth / expansion of market share

Human relations
Why do we need them?

- To build greater self confidence
- To cement our relations with other people
- Human relations enhance communication skills
- To develop skills that portray us as leaders
- To manage stress and worry…enables you stay more focused and set smart goals.

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Strengthening relations

- Don’t criticize, condemn or complain
- Give honest, sincere appreciation
- Arouse in the other person an eager want
- Become genuinely interested in other people
- Smile
- Call people by their names
- Be an excellent listener

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Changing Attitude & Behavior

- Begin with praise & honest appreciation
- Talk about your own mistakes before criticizing others
- Ask questions instead of giving direct orders
- Praise the slightest improvement & praise every improvement
- Use encouragement, make the fault seem easy to correct
- Let the other person save face

Tools for encouraging complaints

- Stamped and addressed card supplied at the point of sale
- Customer service desk at point of sale
- Approach by our personnel to check satisfaction
- Complaint forms, suggestion box, …

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Importance of Feedback

- Positive feedback assures us that we are on track – the customer is genuinely gratified

Negative feedback helps us :

- Assess our current position
- Improve on areas highlighted
- Evaluate the service and identify gaps
- identify areas that need extra effort
- Plan for the future

Turn Complaints into Income!

- List five commonest client complaints.
- Analyze each complaint and establish the root cause.
- Determine the cost of doing nothing.
- Finally, determine the potential profit opportunity.

Tyranny of the urgent

Crisis Deadlines Meetings Repairs	Planning Clarifying Values Relationships Vision Process Improvement
Phone calls Interruptions Mail Reports Drop-ins	Junk mail Some calls Pleasure activities Trivia

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Factors Influencing Customer Care

- Initial contact
- Follow up process
- Clear specification of service features
- Advance notice of any deviation
- Clear invoicing
- Easy access to the service provider for assistance
- All staff must be polite & helpful.

Setting Standards

- Time required to answer a phone call
- Time to respond to a letter or fax
- Time required to resolve a problem
- Frequency of management visits to customers
- Anticipated time between breakdowns

Setting Standards

- Mean time to repair (MTTR)
- Frequency at which sites should be inspected for safety, cleanliness, or other relevant factors
- Length of queues (eg: Disconnection period)
- Response time to request for service (eg: as in Client charter)

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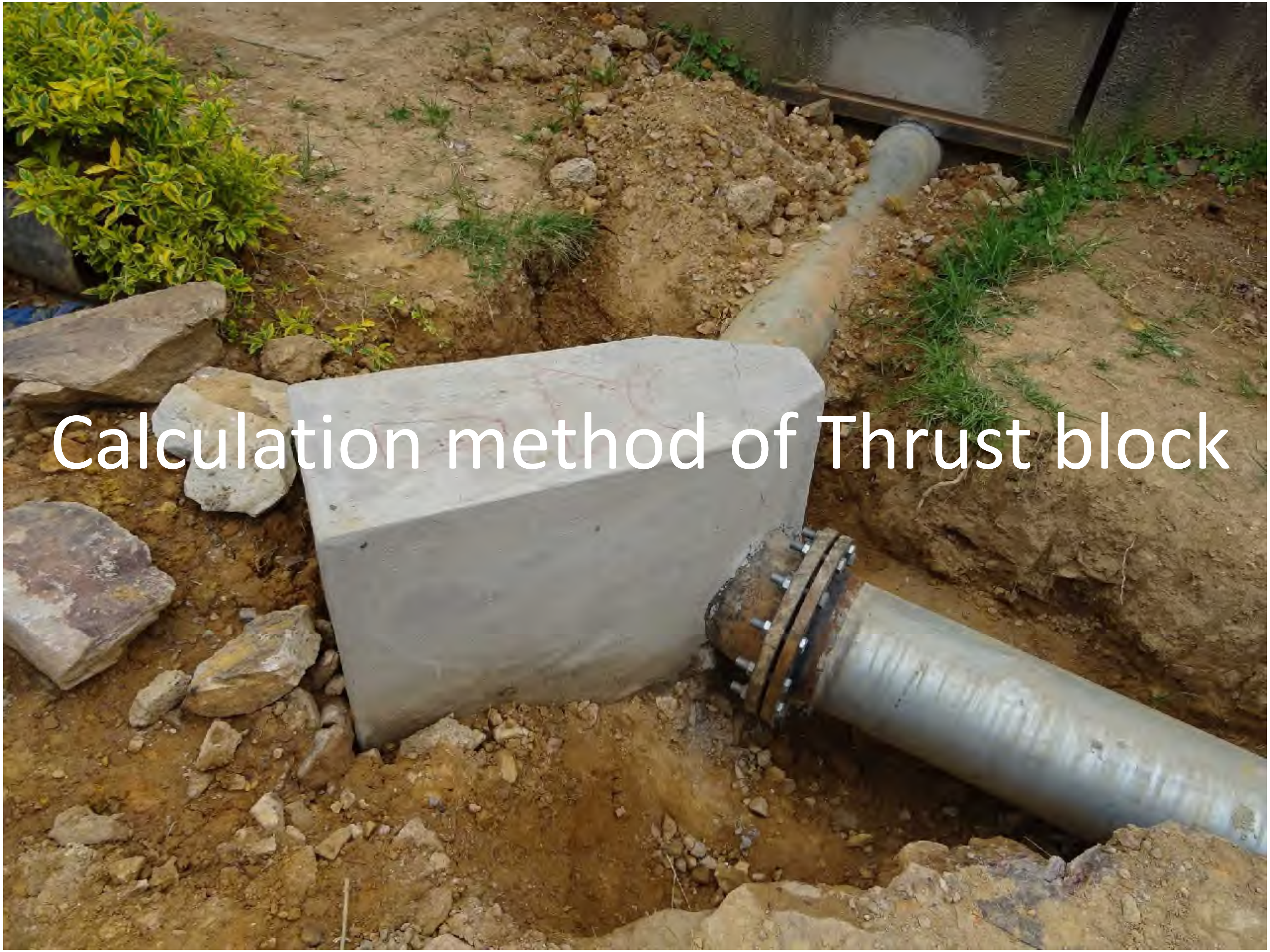
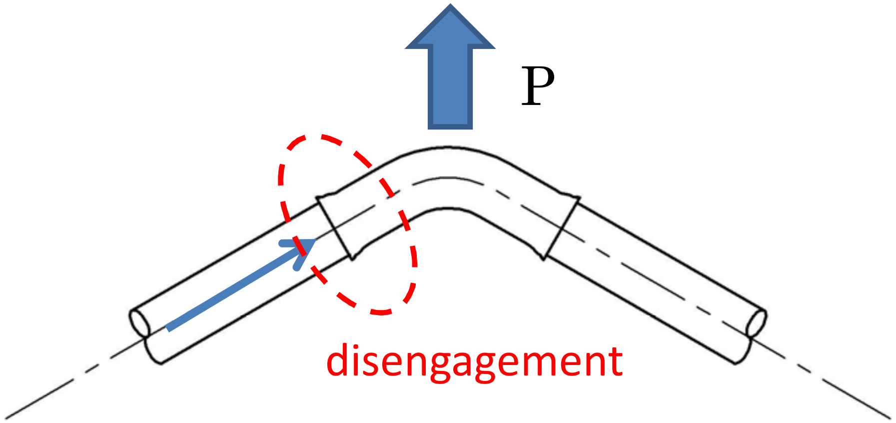
Thank You!

We thank you for your participation, your determination to serve better and the spirit to excel.

The training is over, the challenge is to practice the skills acquired.

Calculation method of Thrust block





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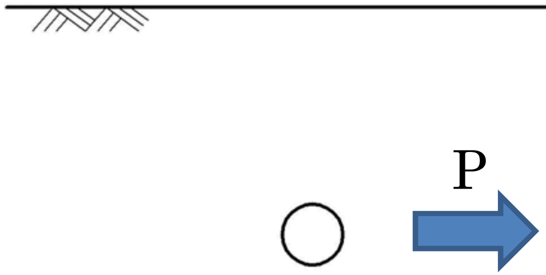
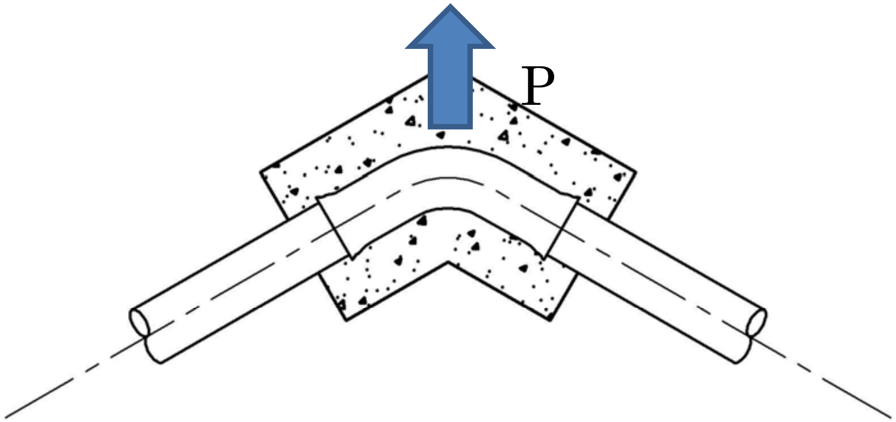


Section

P: Thrust Force of Bending Point
(force of outside direction)



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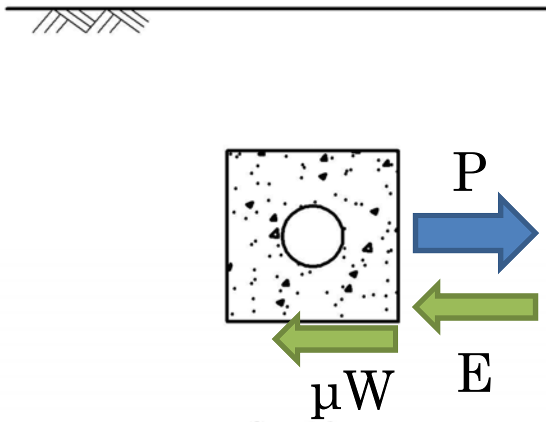


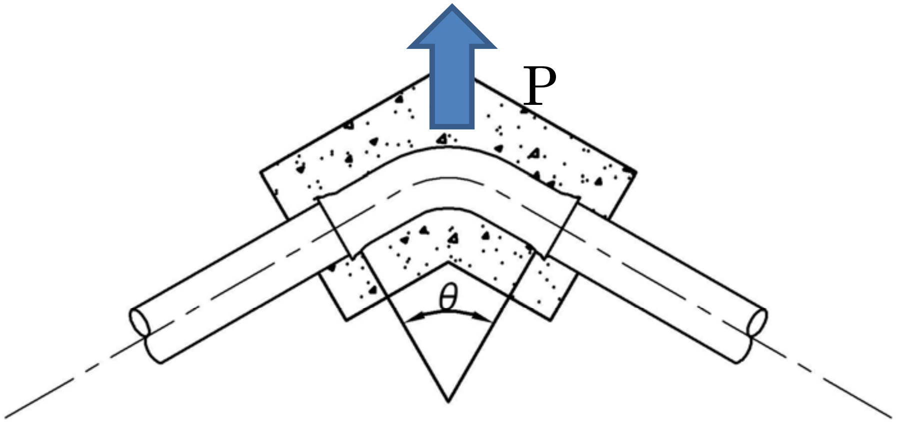
Section

P: Thrust Force of Bending Point
(force of outside direction)

E: Passive Earth Resistance Force of
Back of Concrete

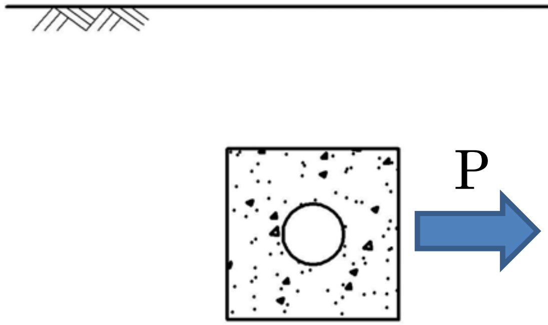
μW: Friction Resistance Force within
Bottom of Soil

$$P < \mu W + E$$



Plan

$$P=2pA\times\sin\theta/2$$



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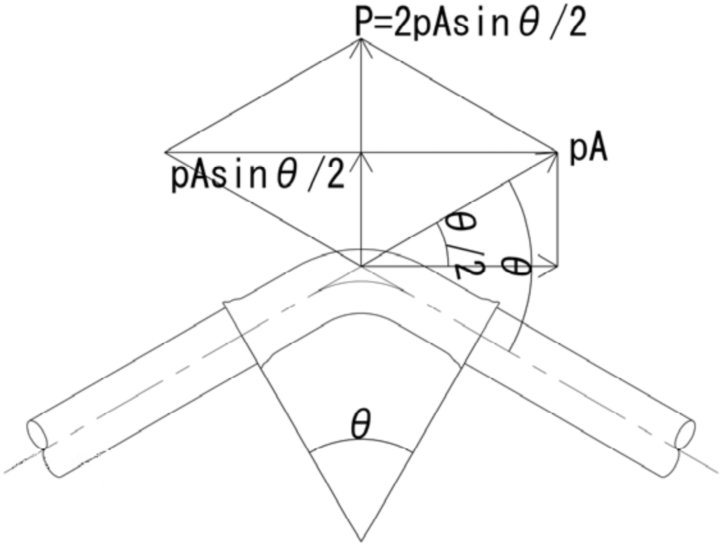

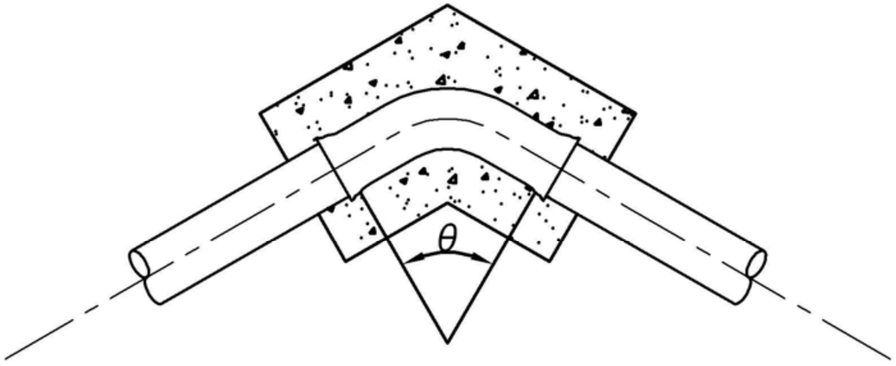

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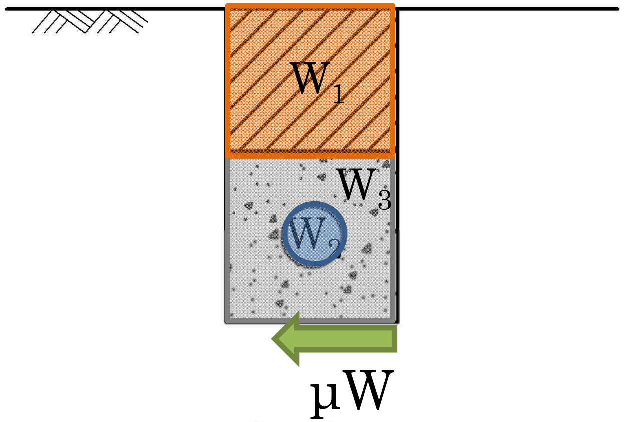


Section

$$\mu W=\mu(W_1+W_2+W_3)$$

W:Total Wight against Bottom of Concrete

W_1:Load from Soil

W_2:Load from Water and Pipe

W_3:Load from Concrete

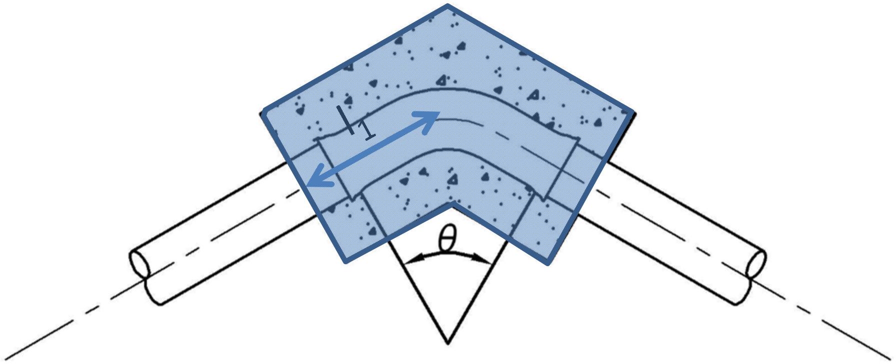
μ:Coefficient of Frictional Resistance within Concrete and Soil

μ:Coefficient of Frictional Resistance within Concrete and Soil

Coefficient of Frictional Resistance within Concrete and Soil

Type of the soil	Coefficient of Frictional	Type of the soil	Coefficient of Frictional
Compaction	0.50	Gravel	0.60
Soil of muddy	0.33	Clay	0.20～0.50
Small Cobble stone	0.60	Dry sand	0.50
Cobble stone	0.50	Norumal sand or wet sand	0.20～0.33

【Reference:The Design Criteria for Water Supply Facilities 2012 P509 Table-7.7.1】



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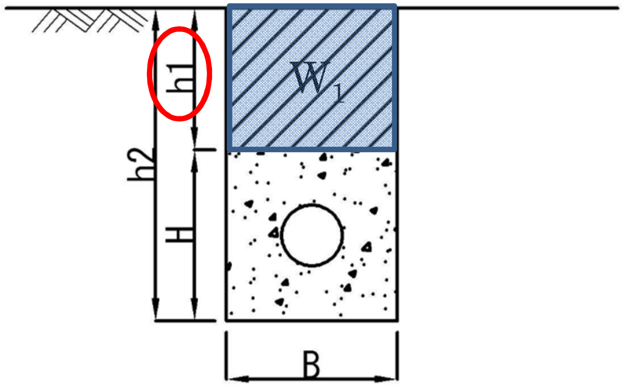


Section

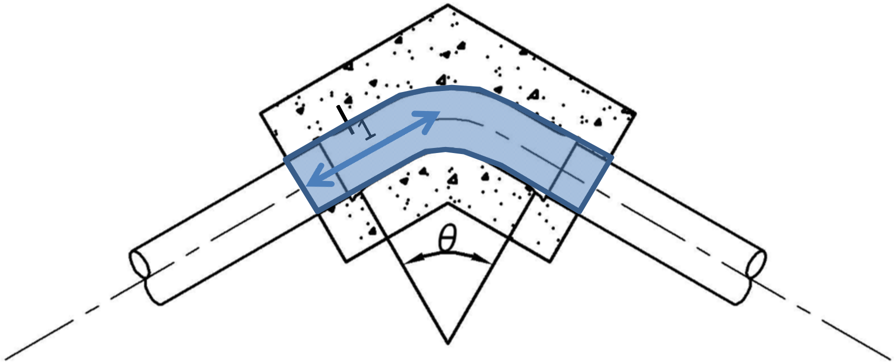
W_1:Load from Soil

$$\boxed{W_1=2\times l_1\times B\times h_1\times \gamma s}$$

γs: Unit Weight of Soil

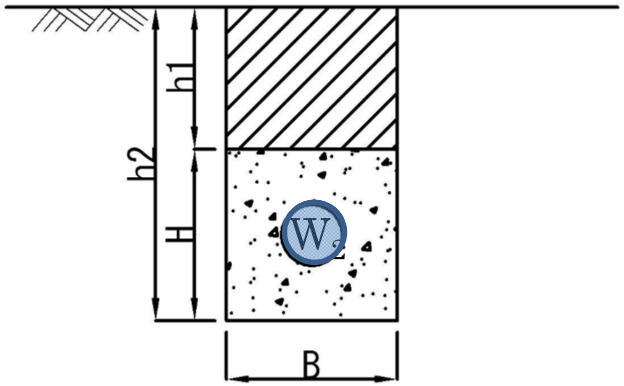
Unit Weight of Soil

Type	Condition	Unit weight
Norumal sand	Dry	14.0
	Including the water	16.0
Sand	Dry	16.0
	Including the water	18.0
Clay mingling sand	Dry	20.0
	Including the water	15.0
	saturated with water	19.0
Clay	Dry	16.0
	Including the water	20.0
	saturated with water	-
Silt		17.0



Plan

W_2:Load from Water and Pipe

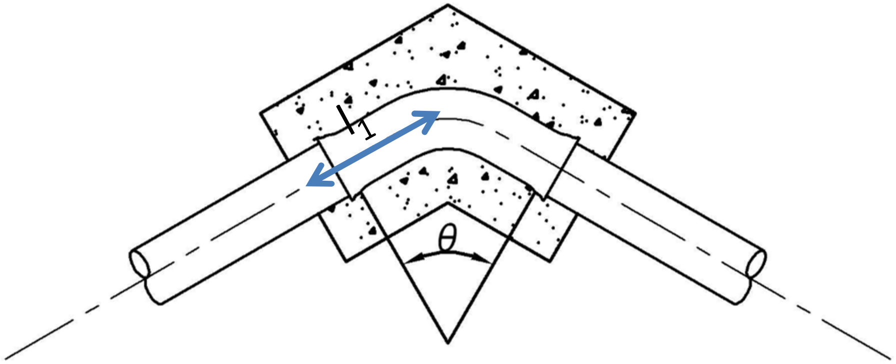


Section

$$\boxed{W_2=Wp+\pi/4\times D^2\times 2\times l_1\times \gamma w}$$

Wp:Weight of Pipe
γw: Unit weight of Water

W_3:Load from Concrete



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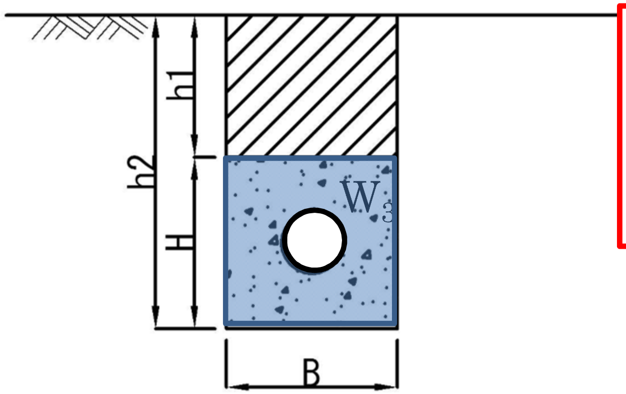
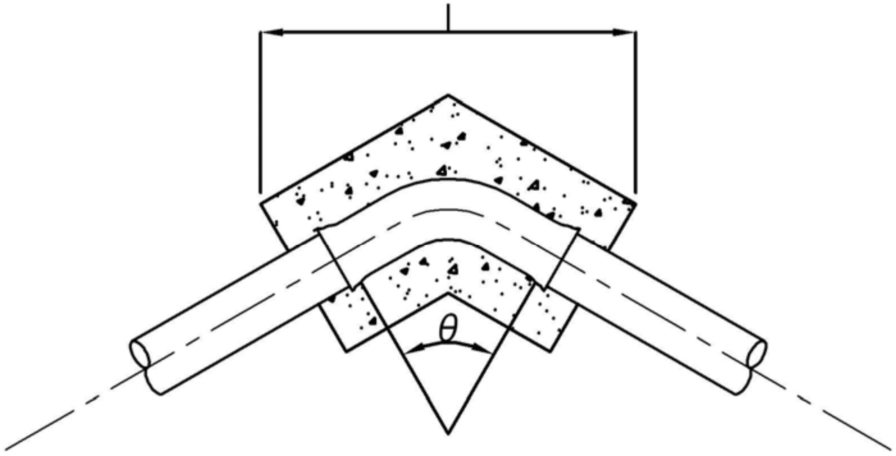


Section

$$W_3=\{2\times l_1(B\times H-\pi/4\times D_2{}^2)\}\times \gamma c$$

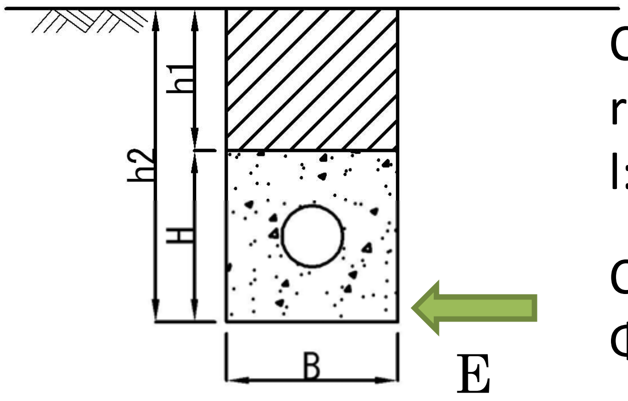
D_2:External Diameter

γc: Unit weight of Concrete



Plan

$$E=1/2Ce\times r\times(h_2{}^2-h_1{}^2)\times l$$



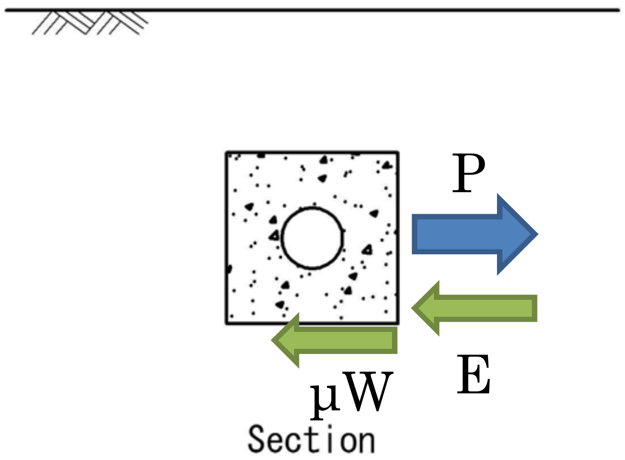
Section

Ce:Coefficient of Passive Earth Resistance Force
r:Unit Weight of Soil(kN/m^3)
l:Length of Projection of back of Concrete (m)

Ce=tan2(45° +Φ/2)
Φ：Internal Friction Angle of Soil(°)

Internal Friction Angle

Type	Condition	Internal friction
Norumal sand	Dry	30～40
	Including the water	45
Sand	Dry	30～35
	Including the water	40
Clay mingling sand	Dry	20～25
	Including the water	40～45
	saturated with water	20～25
Clay	Dry	40～45
	Including the water	20～25
	saturated with water	14～20
Silt		10～20

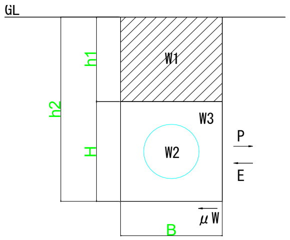


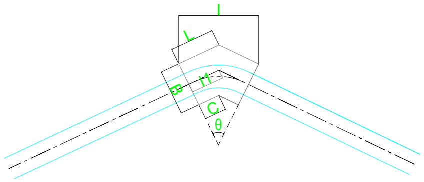
R:Total Resistance Force of Thrust Block

$R=\mu W+E$

$Sr=R/P > 1.5$ (JAPAN STANDARD)

Sr:Safety Rate





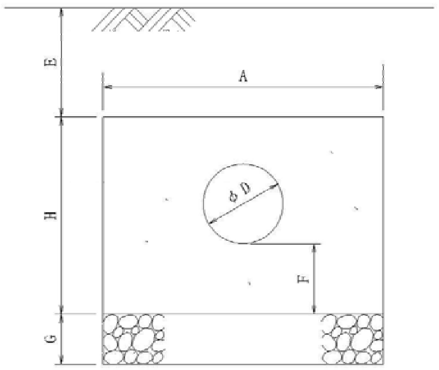
	Unit	PN40				
Bent : θ	°	90.00	45.00	22.50	11.25	2.50
Nominal Diameter : D	m	0.600	0.600	0.600	0.600	0.600
External Diameter : D2	m	0.635	0.635	0.635	0.635	0.635
Depth of Pipe Head from ground	m	1.00	1.00	1.00	1.00	1.00
Internal Pressure : p	kN/m2	4000	4000	4000	4000	4000
Coefficient of Frictional Resistance within Concrete and Soil : μ		0.50	0.50	0.50	0.50	0.50
Unit Weight of Soil : γs	kN/m3	16.00	16.00	16.00	16.00	16.00
Internal Friction Angle of Soil : φ	°	30.00	30.00	30.00	30.00	30.00
Unit weight of Water : γw	kN/m3	9.80	9.80	9.80	9.80	9.80
Unit Weight of Pipe	kN/m	1.67	1.67	1.67	1.67	1.67
Unit Weight of Concrete : γc	kN/m3	23.00	23.00	23.00	23.00	23.00
B	m	2.70	2.70	1.20	1.20	1.20
H	m	3.50	2.30	2.00	1.20	1.20
l1	m	2.20	2.20	2.40	1.90	0.50
L	m	3.55	2.76	2.52	1.96	0.51
h1	m	0.80	0.80	0.32	0.72	0.72
h2	m	4.30	3.10	2.32	1.92	1.92
C	m	0.85	1.64	2.28	1.84	0.49
Friction Resistance Force within Bottom of Pipe and Soil μW=μ*W		547.94	383.99	140.39	83.78	22.05
Passive Earth Resistance Force of Back of Concrete E=1/2*Ce*γs*(h2^2-h1^2)*l		2150.76	1097.57	626.23	296.47	78.00
Thrust Force of Bending Point (force of outside direction) P=2*p*A*SIN(θ/2)	kN	1791.48	969.54	494.27	248.33	55.27
Cross Section Area of Pipe A=D2^2*π/4	m2	0.32	0.32	0.32	0.32	0.32
Total Wight against Bottom of Concrete W=W1+W2+W3	kN	1095.88	767.99	280.79	167.57	44.10
Load from Soil W1=2*l1*B*γs*h1	kN	152.06	152.06	29.49	52.53	13.82
Load from Water and Pipe W2=(Wp+π/4*D^2*2*l1*γw)	kN	19.52	19.52	21.30	16.86	4.44
Load from Concrete W3=2*l1*(B*H-π/4*D2^2)*γc	kN	924.29	596.40	230.00	98.18	25.84
Length of Projection of back of Concrete l=2*L*COS(θ/2)	m	5.02	5.10	4.94	3.90	1.03
Coefficient of Passive Earth Resistance Force Ce=TAN(45+Φ/2)^2		3.00	3.00	3.00	3.00	3.00
Unit Weight of Pipe Wp=Unit Weight of Pipe*l1*2	t	7.33	7.33	8.00	6.33	1.67
Total Resistance Force of Thrust Block R=μW+E	kN	2698.70	1481.56	766.63	380.26	100.05
Safety Rate Sf=R/P		1.51	1.53	1.55	1.53	1.81
More than Safty Tate x 1.5 is OK		OK	OK	OK	OK	OK
Bearing Force of Ground for Supporting Thrust block σ=W/B*l1	kN/m2	92.25	64.65	48.75	36.75	36.75
Volume of Thrust Block	m3	41.58	27.32	11.52	5.47	1.44
Volume of Pipe (deduction)	m3	1.39	1.39	1.52	1.20	0.32
Volume of Concrete	m3	40.19	25.93	10.00	4.27	1.12
Aggregate (t=20cm)	m3	2.38	2.38	1.15	0.91	0.24
Formwork	m2	49.07	32.03	23.37	11.37	4.65

参考図

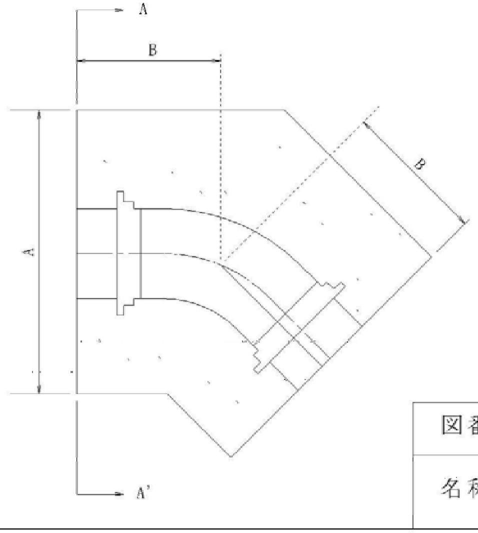
材料及び寸法表

呼び径 D mm	管頂土被り m	設計水圧 MPa	A m	B m	H m	E m	F m	G m	一体化拘束長 m	Co打設量 m³	型枠面積 m²	砕石 m³
300	0.80	1.30	0.85	1.40	0.70	0.61	0.19	0.15		1.44	5.11	0.36
			0.85	0.40	0.70	0.61	0.19		6.00	0.41	2.31	0.10
400	1.50		0.95	0.40	1.90	1.00	0.97			1.33	6.65	0.11
500			1.05	0.60	2.00	1.00	0.97			2.26	9.00	0.19
600			1.15	0.80	2.15	1.00	1.02			3.46	11.83	0.28
			1.15	0.20	1.05	1.29	0.21		6.00	0.36	3.26	0.07
700			1.30	1.05	2.25	1.00	1.02			5.26	15.30	0.41
			1.10	0.30	1.20	1.27	0.23		6.00	0.54	4.08	0.10
300	0.80	1.00	0.85	0.65	1.05	0.50	0.43	0.15		1.05	4.52	0.17
400	1.50		0.95	0.40	1.55	1.00	0.62			1.06	5.43	0.11
500			1.05	0.60	1.70	1.00	0.67			1.88	7.65	0.19
600			1.15	0.80	1.80	1.00	0.67			2.81	9.90	0.28
700			1.30	1.05	1.85	1.00	0.62			4.16	12.58	0.41

A-A’ 断面図



平 面 図



図番	2－3	平成	18
名称	曲管防護コンクリート工図 （45° HB）		

Attachment 4: Handover letter of the Equipment Procured in the Project

Equipment List for Handover

Item	Output	Equipment	Description	Quantity	Procured by	Date of Handover	Letter No
1	2	Equipment and materials for training on pipe repairing and service connection	Pipes, piping materials and tools	1 set	Consultant	2019/2/28	1
2		Leak detection equipment	Ultrasonic flow meter, leak detector, etc.	1 set	JICA	2019/2/28	1
3		Survey equipment	Portable GPS receiver, test meter, etc.	1 set	Consultant	2019/2/28	1
4	3	Equipment for establishing Pilot DMA	Customer meters, mechanical flow meter, valves, etc.	1 set	Consultant	2019/2/28	1
5		Chambers for the Pilot Project	3 locations in Area 1 1 location in Area 2	1 set	Consultant	2019/2/28	1
6		PRV piping materials	Pipe connectors for PRV installation	1 set	Consultant	2019/2/28	1
7		Materials for service pipe replacement	PVC and deformed pipes	1 set	Consultant	2019/2/28	1
8	1	Materials for distribution reservoir management	PRV 12sets, Float valves 10sets, pipes and piping material	1 Unit	Consultant	2020/11/26	3
9		Materials for pressure control	Pipes and piping material for Bypass	1 Unit	Consultant	2020/11/26	3
10		Portable test meters	DN15, 26sets	1 Unit	Consultant	2020/5/21	2
11		Water Level Sensor and Datalogger for Water Level	Water Level Sensor, Datalogger	3 sets	Consultant	2020/11/26	3

Item	Output	Equipment	Description	Quantity	Procured by	Date of Handover	Letter No
		Sensor					
12		Pressure sensor and Datalogger for Water Level Sensor	Pressure sensor, Logger, Data Collector	3 sets	Consultant	2020/11/26	3
13	Covid-19 response activities	Engine Pump and Water Meter for Covid-19 response activities	Pump (DN80mm, 55m3/hr, H20m), Meter(Waltman type, DN50mm, PN16)	23 sets	Consultant	2021/11/19	4
14		Procurement material for Reduction Intermittent Water	Pipe and fittings for network repair	1 Unit	Consultant	2021/11/19	4
15			Service pipe	1 Unit	Consultant	2021/11/19	4
16			FV	1 Unit	Consultant	2021/11/19	4
17	4	Equipment for hydraulic isolation of 4 Branches and development of the monitoring systems	Chambers for the monitoring system	23 places	Consultant	2019/2/28	1
18			Equipment for monitoring system (Flowmeter etc.)	1 Unit	JICA	Guarantee Period until Sept. 2022	-
19			Monitoring systems (facility)	1 Unit	JICA		-
20	—	Equipment for project operation	Vehicle (minibus)	1 Unit	JICA	Returned to JICA 2021/11/26	-
			Vehicle (pickup)	1 Unit	JICA		-
			Multifunctional photocopier	1 set	Consultant	2019/2/28	-4

レター①

WASAC
Water & Sanitation Corporation

"Dignifying Life"

Kigali, 28 FEB 2019

No 11.07.024/836/19/DUWSS - CEO/dn

To: Mr. MARUO Shin
Chief Representative
JICA Rwanda Office

Dear sir,

Re: Receipt of Equipment & Materials from JICA

We are pleased to inform you that we have received the equipment and materials herewith attached from JICA in the project for **"Strengthening Non-Revenue Water Control in Kigali City Water Network 'based** on the Record of Discussions signed on March 30, 2016 between WASAC and JICA.

The received equipment and materials are for:

- Leak Detection Equipment
- Equipment for survey
- Equipment for training work on pipe repair and service pipe connection, and Equipment for pilot project (Ruyenzi and Kadobogo)
- Pipes and related Fittings for service pipe replacement in Kadobogo.
- PRV Fittings in Pilot area (Ruyenzi & Kadobogo)

We should take responsibility of the security, care and maintenance of equipment and keep them in good condition.
In addition, we would like to utilize them effectively even after the project.

Sincerely,

Eng. Aimé MUZOLA

Chief Executive Officer

Attachment: List of Equipment & materials

WASAC
Water & Sanitation Corporation

"Dignifying Life"

Kigali, 28 FEB 2019 **No 11.07.024/837/19/DUWSS - CEO/dn**

To: Mr. MARUO Shin
Chief Representative
JICA Rwanda Office

Dear sir,

Re: Receipt of Manholes constructed by JICA

We are pleased to inform you that we have received the manholes (Chambers) for Kigali water network isolation, constructed by JICA in the project for **"Strengthening Non-Revenue Water Control in Kigali City Water Network '**based on the Record of Discussions signed on March 30, 2016 between WASAC and JICA.

The received manholes are for:

- Chambers (4) for Pilots areas (Ruyenzi & Kadobogo)
- Chambers (23) for Equipment Monitoring System

We would ensure the security responsibility and utilize all manholes and maintaining them in good condition.
In addition, we would like to use them effectively even after the project.

Sincerely,

Eng. Aimé MUZOLA

Chief Executive Officer

Attachment: Construction report

Attachment:

List of Equipment & Materials

Leak Detection Equipment

PROJECT FOR STRENGTHENING NON-REVENUE WATER CONTROL IN KIGALI CITY WATER NETWORK
Hand Over Equipment for Leak Detection (Procured by JICA)

Equipment Name	Production Serial Number	CODE	Qty	Total Price/RWF	Unity Price (Yen)	Total price (Yen)
Equipment for Leak Detection						
Ultrasonic Flowmeter (Portable Type)	2398	JL1- JL6	6	13,247,148	1,742,000	10,452,000
Flow & Pressure Data Logger	42803	JL7- JL12	6	2,699,620	355,000	2,130,000
Correlation Leak Detector	000642	JL-13- JL15	3	11,726,236	1,542,000	4,626,000
Water Leak Detector	008698	JL16- JL 18	3	2,174,905	286,000	858,000
Non-Metal Detector	01/TS2954L1INT/01	JL19- JL 21	3	539,924	866,000	2,598,000
Metal Detector	007162	JL22- JL24	3	585,551	77,000	231,000
Iron Pipe, Cable Detector	002110	JL25-JL27	3	1,984,791	261,000	783,000
Time integral water leakage detector(FSB-8D / FSJ-1)	17048389 / 16040279	JL28-JL 30	3	1,984,791	216,000	648,000
Leak Sound Detection Bar	-	JL31- JL39	9	68,441	9,000	81,000
Range Finder	-	JL40-JL45	3	70,722	9,300	27,900
Boring Bar	-	JL43- JL 45	3	182,510	24,000	72,000
Hammer Drill	-	JL46-JL48	3	760,456	100,000	300,000
Hexagonal Bit	-	JL49-JL63	15	76,046	10,000	150,000
Generator	-	JL64-JL 66	3	1,148,289	151,000	453,000
Laptop Computer	CK0PG92	JL67-JL69	3	1,551,331	204,000	612,000
TOTAL(Leak Detection Equipments)				**38,800,760**		**24,021,900**

Date; 23th January 2019

For WASAC

PREPARED BY:

23/01/2019

Mr. NTAMUTURANO Desire
Head of Leak Detection and Pressure Management

VERIFIED BY:

Mr. BAHIGE Jean Berchmas
NRW Manager

APPROUVED BY:

Mr: RUTAGUNGIRA Methode

Director of Urban Water and Sanitation Services

For JICA

Mr. ITANGISHAKA Vedaste
Assistant / NRW project

Mr. SHIGEO Otani
Chief Adviser of NRW
and JICA Expert team

Item No.	Description	Model/Specifications	Q'ty	unit	Unit price	amount
3	Correlation Leak Detector	LC-2500	3	set	1,542,000	4,626,000
4	Water Leak Detector	HG-10AII	3	set	286,000	858,000
5	Plastic Water Pipe Locator(Receiver)	RD-500	3	set	866,000	2,598,000
	Plastic Water Pipe Locator(Transmitter)	RD-500	3	set		(included in No.5)
6	Metal Detector	F-90M	3	set	77,000	231,000
7	Iron Pipe, Cable Detector	PL-1000	3	set	261,000	783,000
9	Leak Sound Detection Bar	LSP-1.5	9	set	9,000	81,000
10	Range Finder	B-20S	3	set	9,300	27,900
11	Boring Bar	Boring Bar 1.0m	3	set	24,000	72,000
12	Hammer Drill	PR-38E(E)	3	set	100,000	300,000
	step-down transformer	CVD-20 (incl. plug WF-6320)	3	set		(included in No.12)
13	Hexagonal Bit	HEXLL 19.0x800	15	set	10,000	150,000
14	Generator	SH6500EX-R	3	set	151,000	453,000
15	Laptop Computer	Latitude Rugged 5414	3	set	204,000	612,000
	optical mouse	MS116	3	set		(included in No.15)
			EX-GO-DOWN			10,791,900
			FREIGHT			330,100
			INSURANCE PREMIUM			21,318
			CIP RWANDA			**JPY 11,143,318**

平成29年6月27日

様式6

輸送日程報告カード （[✓ 予定]・ 確定・ 到着確認）

株式会社
会社名：HELICOM CORPORATION,INC
代表取締役
担当者名：足立 出光

案件名	ルワンダ国キガリ市無収水対策強化プロジェクト（ロット2）向け機材
公示番号	GE1603
主な機材名	相関式漏水探知機 他
機材入庫年月日	平成29年6月12日
貨物個数	別添のとおり
内容量及び重量	別添のとおり
仕向地	ルワンダ国キガリ国際空港
輸送契約内容	a. 海上輸送のみ（陸揚保税地域搬入までの輸送契約） b. 内陸輸送を含む輸送契約 [✓ c. その他]
貨物海上保険付保日数	① 90日（aの通常ケース） ② 150日（bの通常ケース） [✓ ③ その他（30）日（cの場合）]
B/L番号	未定
B/L発行日	未定
船会社の現地代理店名又は内陸輸送業者名及び所在地/TEL	Air France KLM Cargo Kigali Office Kigali International Airport Cargo Terminal KN 5 Rd, Kigali, Rwanda Phone +250788304411

	予定	確定	到着確認
船積港	成田空港		
船会社	KLMオランダ航空		
船名	KL862		
出港日	平成29年6月30日		
陸揚港	ルワンダ国キガリ国際空港		
陸揚港着港日	平成29年7月3日		
内陸輸送ルート	－		
内陸輸送後の最終到着場所	Water and Sanitation Corporation KN 4 AV 8 CENTENARY HOUSE P.O.BOX 2331 Kigali – RWANDA TEL：+250-(0)788-181-427		
内陸輸送後の最終到着日	－		
保険付保期限（仕向港荷揚げ後30日の日付）	平成29年8月2日		

機材番号	名　称（日本語）	仕　様	数 量	単位	荷姿（段ボール等）	単重量(kg)	@サイズ(cm)		
	名　称（英　語）				個口数	総重量(Kg)	総容積(M3)		
3	相関式漏水探知器	LC-2500	3	set	3	20	80	45	38
	Correlation Leak Detector					60	0.410		
4	音聴式漏水探知器	HG-10AII	3	set	1	17	80	45	38
	Water Leak Detector					17	0.137		
5	非金属管探知機(受信機)	RD-500	3	set	3	1.8	132	25	12.5
						5.4	0.0412		
	非金属管探知機(送信機)	RD-500	3	set	3	1.0	30	38	69
						3.0	0.0786		
6	金属探知器	F-90M	3	set	1	10	71	36.5	45
	Metal Detector					10	0.117		
7	金属管探知機	PL-1000	3	set	1	20	71	36.5	45
	Iron Pipe, Cable Detector				1	10	76	44	24
						30	0.197		
9	音聴棒　(1.5m)	LSP-1.5	9	set	1	7	165	18	18
	Leak Sound Detection Bar					7	0.053		
10	距離計	B-20S	3	set	1	1.0	41.5	22	7
	Range Finder					3.2	0.02176		
11	ﾎﾞｰﾘﾝｸﾞﾊﾞｰ 1.0m	ボーリングバー 1.0m	3	set	3	5	170	5	5
	Boring Bar					15	0.013		
12	ハンマードリル	PR-38E(E)	3	set	3	12.0	53	17	38
	Hammer Drill					36.0	0.103		
	ダウントランス	CVD-20	3	set	3	17	37	31	30
	step-down transformer	ﾌﾟﾗｸﾞ WF-6320含む				51	0.103		
13	ハンマードリル用ビット	HEXLL 19.0x800	15	set	1	1.0	87	10	4
	Hexagonal Bit					15.0	0.010		
14	発電機	SH6500EX-R	3	set	3	79.9	73	57	53
	Generator					239.7	0.708		
15	ラップトップコンピュータ	Latitude Rugged 5414	2	set	1	4.3	60	38	24
	Laptop Computer					8.6	0.05472		
	ラップトップコンピュータ×1　光学マウス×3	Latitude Rugged 5414	1	set	1	5.0	60	38	24
	Laptop Computer×1　optical mouse ×3	MS116	3			5.7	0.05472		

074 | NRT | 56689883

074-56689883

Not negotiable

Air Waybill

Issued by **KLM-ROYAL DUTCH AIRLINES**
P.O.BOX 7700, 1117 ZL SCHIPHOL AIRPORT, THE NETHERLANDS

Copies 1, 2 and 3 of this Air Waybill are originals and have the same validity.

Shipper's Name and Address
HELICOM CORPORATION INC ON BEHALF OF JICA
3-30-27 OHAMA-CHO, AMAGASAKI-SHI,
HYOGO-KEN JAPAN
PHONE : +81-3-5575-2421 FAX : +81-3-5575-2423

Shipper's Account Number

Consignee's Name and Address
WATER AND SANITATION CORPORATION
KN 4 AV 8 CENTENARY HOUSE
P.O.BOX 2331 KIGALI - RWANDA
TEL. : +250-(0)788-181-427

Consignee's Account Number

Issuing Carrier's Agent Name and City
KAMIGUMI AIR SERVICE CO.,LTD.
TOKYO,JAPAN

Accounting Information
1. JICA RWANDA OFFICE
IMMEUBLE EBENEZER BOULEVARD DE L'UMUGANDA,
KACYIRU KIGALI, RWANDA
B.P. 6878, KACYIRU, KIGALI, RWANDA**

Agent's IATA Code: 16-3 1527/0016

Account No.

Airport of Departure (Addr. of First Carrier) and Requested Routing: NARITA AIRPORT,JAPAN

Reference Number

Optional Shipping Information

To	By First Carrier	Routing and Destination	to	by	to	by	Currency	Chgs Code	WT/VAL PPD	WT/VAL COLL	Other PPD	Other COLL	Declared Value for Carriage	Declared Value for Customs
HEL	KL		KGL	KL			JPY		X		X		N.V.D.	

Airport of Destination	Requested Flight/Date		Amount of Insurance
KIGALI, RWANDA (KGL)	KL862/30	KL537/03	-

INSURANCE - If carrier offers insurance and such insurance is requested in accordance with the conditions thereof, indicate amount to be insured in figures in box marked Amount of Insurance.

Handling Information
**TEL : +250-(0)788-301-731, +250-(0)788-301-732, +250-(0)788-301-723
2. SAME AS CONSIGNEE

SCI

No. of Pieces RCP	Gross Weight	kg lb	Rate Class	Commodity Item No.	Chargeable Weight	Rate / Charge	Total	Nature and Quantity of Goods (incl. Dimensions or Volume)
4	585.0	K	Q		657.0	2,350	1,543,950	EQUIPMENT FOR PROJECT FOR STRENGTHENING NON-REVENUE WATER CONTROL IN KIGALI CITY WATER NETWORK LOT 2 FREIGHT:PREPAID INVOICE NO:HCRW-2017-2 TOTAL:4 PACKAGES ONLY M'MENT : 3.941 M3

MARKS. Water and Sanitation Corporation
JICA (IN DIA)
Kigali, Rwanda
INVOICE NO: HCRW-2017-2
C/No. 1/4~4/4

SIDE MARK(in RED)
TECHNICAL COOPERATION BY THE
GOVERNMENT OF JAPAN

	Prepaid	Collect
Weight Charge	1,543,950	
Valuation Charge		
Tax		
Total other Charges Due Agent		
Total other Charges Due Carrier	38,106	
Total prepaid / Total collect	1,582,056	
Currency Conversion Rates / cc Charges in Dest. Currency		
For Carriers Use only at Destination / Charges at Destination / Total collect Charges		

Other Charges
MY 35,478
SCI 2,628

Shipper certifies that the particulars on the face hereof are correct and that insofar as any part of the consignment contains dangerous goods, such part is properly described by name and is in proper condition for carriage by air according to the applicable Dangerous Goods Regulations.

Signature of Shipper or his Agent

29.Jun.2017 TOKYO,JAPAN S.KOHAMA

Executed on (date) at (place) Signature of Issuing Carrier or its Agent

074-56689883

PRINTED IN JAPAN

Copy 9 - (For Sales Agent)

HELICOM CORPORATION INC
3-30-27 OHAMA-CHO, AMAGASAKI-SHI,
HYOGO-KEN
JAPAN
PHONE : +81-3-5575-2421
FAX : +81-3-5575-2423

INVOICE

INVOICE NO : HCRW-2017-2 **DATE : June 26, 2017**

CONSIGNEE

Water and Sanitation Corporation
KN 4 AV 8 CENTENARY HOUSE
P.O.BOX 2331 Kigali - RWANDA
TEL : +250-(0)788-181-427

CASE MARK (SHIPPING MARKS)

Water and Sanitation Corporation
JICA
Kigali, RWANDA
INVOICE NO : HCRW-2017-2
C/No. 1/4~4/4

SIDE MARK : (in RED)
TECHNICAL COOPERATION BY THE
GOVERNMENT OF JAPAN

NOTIFY PARTY

1. JICA Rwanda Office
Immeuble EBENEZER Boulevard de l'Umuganda,
Kacyiru Kigali, Rwanda
B.P. 6878, Kacyiru, Kigali, Rwanda
TEL : +250-(0)788-301-731, +250-(0)788-301-732, +250-(0)788-301-723

2. same as consignee

SHIPPED PER AIRCRAFT

SAILNG ON OR ABOUT June 30, 2017

FROM Narita, Japan

VIA Amsterdam, Netherlands

TO Kigali, Rwanda

SHIPPER
HELICOM CORPORATION INC on behalf of JICA

TERMS OF PAYMENT
No Payment
- No Commerical Value -

DESCRIPTION OF GOODS	QUANTITY		UNIT PRICE	AMOUNT
Equipment for Project for Strengthening Non-Revenue Water control in Kigali City Water Network Lot 2				
Details are as per attached sheet	1	lot		JPY10,791,900
Total:	1 Lot		EX-GO-DOWN	JPY10,791,900
			FREIGHT	JPY330,100
			INSURANCE PREMIUM	JPY21,318
			CIP Kigali	JPY11,143,318

"The above mentioned equipment is to be donated under Technical Cooperation by the Government of Japan."

HELICOM CORPORATION INC

Idemitsu Adachi
Managing Director

HELICOM CORPORATION INC
3-30-27 OHAMA-CHO, AMAGASAKI-SHI,
HYOGO-KEN
JAPAN
PHONE : +81-3-5575-2421
FAX : +81-3-5575-2423

PACKING LIST

INVOICE NO : HCRW-2017-2

DATE : June 26, 2017

CONSIGNEE

Water and Sanitation Corporation
KN 4 AV 8 CENTENARY HOUSE
P.O.BOX 2331 Kigali - RWANDA
TEL : +250-(0)788-181-427

CASE MARK (SHIPPING MARKS)

Water and Sanitation Corporation
JICA
Kigali, RWANDA
INVOICE NO : HCRW-2017-2
C/No. 1/4~4/4

SIDE MARK : (In RED)
TECHNICAL COOPERATION BY THE
GOVERNMENT OF JAPAN

NOTIFY PARTY

1. JICA Rwanda Office
Immeuble EBENEZER Boulevard de l'Umuganda,
Kacyiru Kigali, Rwanda
B.P. 6878, Kacyiru, Kigali, Rwanda
TEL : +250-(0)788-301-731, +250-(0)788-301-732, +250-(0)788-301-723

2. same as consignee

SHIPPED PER AIRCRAFT	**SAILNG ON OR ABOUT** June 30, 2017
FROM Narita, Japan	**VIA** Amsterdam, Netherlands
TO Kigali, Rwanda	

SHIPPER
HELICOM CORPORATION INC on behalf of JICA

TERMS OF PAYMENT
No Payment
- No Commerical Value -

DESCRIPTION OF GOODS	QUANTITY		Net weight	Gross weight	M3
Equipment for Project for Strengthening Non-Revenue Water control in Kigali City Water Network Lot 2					
Details are as per attached sheet	1	lot	506.6 kgs	585 kgs	3.941 M3
Total:	1 Lot				

"The above mentioned equipment is to be donated under Technical Cooperation by the Government of Japan."

HELICOM CORPORATION INC

Idemitsu Adachi
Managing Director

C/No.	Item No.	Description	Model / Part No.	Q'ty	N/Weight	G/Weight	M'Ment
1/4							
	10	Range Finder	B-20S	3	3.2	128	0.658
	12	Hammer Drill	PR-38E(E)	3	36		
		step-down transformer	CVD-20 (incl. plug WF-6320)	3	51		
	13	Hexagonal Bit	HEXLL 19.0x800	15	15		
	15	Laptop Computer	Latitude Rugged 5414	2	8.6		
		Laptop Computer	Latitude Rugged 5414	1	5.7		
		optical mouse	MS116	3			
2/4							
	3	Correlation Leak Detector	LC-2500	3	60	159	1.644
	4	Water Leak Detector	HG-10AII	3	17		
	5	Plastic Water Pipe Locator（Receiver)	RD-500	3	5.4		
	6	Metal Detector	F-90M	3	10		
	7	Iron Pipe, Cable Detector	PL-1000	3	30		
3/4							
	5	Plastic Water Pipe Locator（Transmitter)	RD-500	3	3	48	0.488
	9	Leak Sound Detection Bar	LSP-1.5	9	7		
	11	Boring Bar	Boring Bar 1.0m	3	15		
4/4	14	Generator	SH6500EX-R	3	239.7	250	1.151
		total			506.6	585.0	3.941

MS&AD
Mitsui Sumitomo Insurance

ORIGINAL

Mitsui Sumitomo Insurance Company, Limited

MARINE CARGO POLICY

Head Office : 9, Kanda-Surugadai, 3Chome, Chiyoda-ku, Tokyo, 101-8011, Japan

This is to certify that this Company insure under the below Open/Provisional Policy, if any, as follows:

Assured(s),etc.
JAPAN INTERNATIONAL COOPERATION AGENCY

Open Policy No. NOP-112467

Invoice No. HCRW-2017-2

POLICY
No. 117-1020373684

Amount insured(Valued at the same as Amount Insured.)
CARGO
¥11,144,000.-

Claim,if any,payable at/in
TOKYO

THIS COMPANY'S HEAD OFFICE

Conditions IN CASE THE VARIATION IN CONDITIONS IS ALL RISKS(A/R), W.A., OR F.P.A. WITHOUT DATE, THOSE SHALL BE DEEMED TO READ AS INSTITUTE CARGO CLAUSES (A), (B) OR (C) 1/1/09 RESPECTIVELY.

ALL RISKS
SPECIAL CLAUSE FOR JICA SHIPMENT (30 DAYS)
WAIVER OF SUBROGATION CLAUSE
ALL OTHER TERMS & CONDITIONS ARE SUBJECT TO THE OPEN POLICY NO. NOP-112467

Local Vessel or Conveyance
ANY CONVEYANCE

From(interior port or place of loading)
INTERIOR PLACE IN JAPAN

Ship or Vessel
AIRCRAFT

Voyage: at and from
NARITA

Sailing on or about
JUN. 30, 2017

Voyage: to/via
AMSTERDAM

Thence to
KIGALI/INTERIOR PLACE IN RWANDA BY LAND CONVEYANCE

Goods and Merchandises
Mark(s) and Number(s) as per Invoice No. specified above.

TECHNICAL EQUIPMENT OF J.I.C.A.
WATER CONTROL IN KIGALI CITY WATER NETWORK LOT 2
TOTAL: 1 LOT

Co-insurance Clause
It is hereby understood and agreed that this Policy is issued by Mitsui Sumitomo Insurance Co., Ltd. on behalf of Co-Insurers who are severally and not jointly liable for their individual subscription hereon. Mitsui Sumitomo Insurance Co., Ltd. shall on behalf of Co-insurers receive premium, make payment of claims and administer all matters relating to this Policy.

CO-INSURANCE	
MITSUI SUMITOMO	90.000%
TOKIO & NICHIDO	5.000%
SJNK	5.000%

Including risks of War and Strikes

Place and Date signed in
TOKYO JUN. 28, 2017

No.of Pol.
2

AFG-67 799
8TYY

JIC- JIC-

IMPORTANT

PROCEDURE IN THE EVENT OF LOSS OR DAMAGE FOR WHICH UNDERWRITERS MAY BE LIABLE

LIABILITY OF CARRIERS, BAILEES OR OTHER THIRD PARTIES

It is the duty of the Assured and their Agents, in all cases, to take such measures as may be reasonable for the purpose of averting or minimising a loss and to ensure that all rights against Carriers, Bailees or other third parties are properly preserved and exercised. In particular, the Assured or their Agents are required:-

1. To claim immediately on the Carriers, Port Authorities or other Bailees for any missing packages.
2. In no circumstances, except under written protest, to give clean receipts where goods are in doubtful condition.
3. When delivery is made by Container, to ensure that the Container and its seals are examined immediately by their responsible official.
   If the Container is delivered damaged or with seals broken or missing or with seals other than as stated in the shipping documents, to clause the delivery receipt accordingly and retain all defective or irregular seals for subsequent identification.
4. To apply immediately for survey by Carriers' or other Bailees' Representatives if any loss or damage be apparent and claim on the Carriers or other Bailees for any actual loss or damage found at such survey.
5. To give notice in writing to the Carriers or other Bailees within 3 days of delivery if the loss or damage was not apparent at the time of taking delivery.

NOTE:The Consignees or their Agents are recommended to make themselves familiar with the Regulations of the Port Authorities at the port of discharge.

DOCUMENTATION OF CLAIMS

To enable claims to be dealt with promptly, the Assured or their Agents are advised to submit all available supporting documents without delay, including when applicable :-

1. Original policy of insurance.
2. Original or certified copy of shipping invoices, together with shipping specification and/or weight notes.
3. Original or certified copy of Bill of Lading and/or other contract of carriage.
4. Survey report or other documentary evidence to show the extent of the loss or damage.
5. Landing account and weight notes at port of discharge and final destination.
6. Correspondence exchanged with the Carriers and other Parties regarding their liability for the loss or damage.

In the event of loss or damage which may involve a claim under this insurance, no claim shall be paid unless immediate notice of such loss or damage has been given to and a Survey Report obtained from this Company's Office or Agents specified in this Policy.

This insurance is subject to the goods insured being carried under deck, unless otherwise agreed.

The following wording shall be deleted and replaced with the wording (*) printed right in cases of Institute Cargo Clauses dated 1/1/63 being applied.
Institute Cargo Clauses 1/1/09 shall be applied unless otherwise specified above.

Notwithstanding anything contained herein or attached hereto to the contrary, this insurance is understood and agreed to be subject to English law and practice only as to liability for and settlement of any and all claims.
This insurance does not cover any loss or damage to the property which at the time of happening of such loss or damage is insured by or would but for the existence of this Policy be insured by any fire or other insurance policy or policies except in respect of any excess beyond the amount which would have been payable under the fire or other insurance policy or policies had this insurance not been effected.
We, Mitsui Sumitomo Insurance Company, Limited, hereby agree, in consideration of the payment to us by or on behalf of the Assured of the premium as arranged, to insure against loss damage liability or expense to the extent and in the manner herein provided.
In Witness whereof,
I the Undersigned of Mitsui Sumitomo Insurance Company, Limited, on behalf of the said Company have subscribed My Name in the place specified as above to the policies, the issued numbers thereof being specified above, of the same tenor and date, one of which being accomplished, the others to be void, as of the date specified as above.

Subject to the following Clauses (as far as applicable):-
Following Institute Clauses issued by the International Underwriters Association of London
Institute Cargo Clauses 1/1/63 specified above
Institute War Clauses (Cargo) 1/1/80
Institute Strikes Riots and Civil Commotions Clauses 1/1/63
Institute Cargo Clauses 1/1/82 or 1/1/09 specified above
Institute War Clauses (Cargo) 1/1/82 or 1/1/09
Institute Strikes Clauses (Cargo) 1/1/82 or 1/1/09
Institute Air Cargo Clauses (All Risks)(excluding sendings by Post) 15/6/65
Institute War Clauses (Air Cargo)(excluding sendings by Post) 1/1/80
Institute Cargo Clauses (Air)(excluding sendings by Post) 1/1/82 or 1/1/09
Institute War Clauses (Air Cargo)(excluding sendings by Post) 1/1/82 or 1/1/09
Institute Strikes Clauses (Air Cargo) 1/1/82 or 1/1/09
Institute War Clauses for the insurance of sendings by Post 1/3/80
Institute War Clauses (sendings by Post) 1/1/82 or 1/3/09
Institute Dangerous Drugs Clause (applicable with Institute Cargo Clauses 1/1/63)
Institute Replacement Clause (applicable to Machinery)
Institute Radioactive Contamination, Chemical, Biological, Bio-Chemical and Electromagnetic Weapons Exclusion Clause
[illegible] and Malicious Damage Clause (applicable with Institute Cargo Clauses (B) or (C))
Label Clause (applicable to Labelled Goods)
Grounding Clause (applicable with Institute Cargo Clauses 1/1/63)
Other Insurance Clause
Under Deck or On Deck Clause
Cargo ISM Endorsement
Termination of Transit Clause (Terrorism)
Sanction Limitation and Exclusion Clause
Mail and Parcel Post Clause (applicable to sendings by Post)
Post Clause (applicable to sendings by Post)
Duty Clause (applicable when duty is separately insured)
Special Clause for Through Transport by Vessel and Aircraft
Special Clause for Institute Cargo Clauses (C) 1/1/09
Special Clause for Institute War Clauses
Special Clause for Residual Property
Benefit of Insurance Clause

(*)Be it known that

Name (s) of Assured (s), etc. as specified above
as well in his or their own Name, as for and in the Name and Names of all and every other Person or Persons to whom the same doth, may, or shall appertain, in part or in all, do make Assurance, and hereby cause himself or themselves and them and every of them, to be Insured, lost or not lost, at and from as specified above upon Goods and Merchandises as specified above in the good Ship or Vessel called the as specified above whereof is Master, for this present Voyage
or whosoever else shall go for Master in the said Vessel, or by whatsoever other Name or Names the said Vessel, or the Master thereof, is or shall be named or called:- BEGINNING the Adventure upon the said Goods and Merchandises from the loading thereof on board the said Ship, and so to continue and endure, until the said Goods and Merchandises shall have arrived at as specified above and until the same be there discharged and safely landed. And it shall be lawful for the said Vessel, in this Voyage, to proceed and sail to, and touch and stay at any Ports or Places whatsoever, (within the limits of the above Voyage) for necessary Provisions, Assistance or Repairs, without prejudice to this Insurance: the said Goods and Merchandises laden thereon for so much as concerns the Assured, are and shall be valued at as specified above
Touching the Adventures and Perils which the said Mitsui Sumitomo Insurance Company, Limited, themselves are content to bear, and to take upon them in this Voyage: they are of the Seas, Men-of-War, Fire, Enemies, Pirates, Rovers, Thieves, Jettisons, Letters of Mart and Counter-Mart, Surprisals, Takings at Sea, Arrests, Restraints and Detainments of all Kings, Princes, and People, of what Nation, Condition, or Quality soever, Barratry of the Master and Mariners, and of all other Perils, Losses, and Misfortunes that have or shall come to the Hurt, Detriment, or Damage of the said Goods and Merchandises, or any part thereof,
and in case of any Loss or Misfortune, it shall be lawful for the Assured, his or their Factors, Servants, or Assigns, to sue, labour, and travel for, in and about the Defence, Safeguard and Recovery of the said Goods and Merchandises, or any part thereof, without prejudice to this Insurance: to the Charges whereof the said Company will contribute. It is expressly declared and agreed that no acts of the Insurer or Insured in recovering, saving, or preserving the property insured, shall be considered as a waiver or acceptance of abandonment. AND it is agreed that this Writing or Policy of Insurance shall be of as much Force and Virtue as the surest Writing or Policy of Insurance made in LONDON. And so the said Mitsui Sumitomo Insurance Company, Limited, are contented, and do hereby promise and bind themselves to the Assured, his or their Executors, Administrators, or Assigns, for the true Performance of the Premises: confessing themselves paid the Consideration due unto them for this Insurance, at and after the rate of as arranged Per cent.
. Corn, Fish, Salt, Fruit, Flour and Seed are warranted free from Average, unless General, or the Ship be stranded, sunk or burnt; Sugar, Tobacco, Hemp, Flax, Hides and Skins are warranted free from Average under Five per cent. and all other Goods are warranted free from Average under Three percent., unless General, or the Ship be stranded, sunk or burnt.
This insurance is understood and agreed to be subject to English law and usage as to liability for and settlement of any and all claims.
In Witness whereof, I the Undersigned of Mitsui Sumitomo Insurance Company, Limited, on behalf of the said Company, have subscribed my Name in as specified above to as specified above Policies of the same tenor and date, one of which being accomplished, the others to be void, as of the date specified above.

For Mitsui Sumitomo Insurance Company, Limited

(AUTHORIZED SIGNATORY)

Wording of the clauses applied (other than the same printed on the front or in the attached sheet) can be seen at the Website (http://www.ms-ins.com/cargo/) or available from this Company upon request.

Item No.	Description	Model/Specifications	Q'ty	unit	Unit price	amount
1	Ultrasonic Flowmeter	UFP-20	6	set	1,742,000	10,452,000
		large sensor UFP-20	6	set		(included in No.1)
2	Flow & Pressure Data Logger	Textlog Multi	6	set	355,000	2,130,000
8	Time integral water leakage detector	FSB-8D FSJ-1	3	set	216,000	648,000
			EX-GO-DOWN			13,230,000
			FREIGHT			570,000
			INSURANCE PREMIUM			26,451
			CIP RWANDA			JPY 13,826,451

MS&AD
Mitsui Sumitomo Insurance

ORIGINAL

Mitsui Sumitomo Insurance Company, Limited

MARINE CARGO POLICY

Head Office : 9, Kanda-Surugadai, 3Chome, Chiyoda-ku, Tokyo, 101-8011, Japan

This is to certify that this Company insure under the below Open/Provisional Policy, if any, as follows:

Assured(s),etc.
JAPAN INTERNATIONAL COOPERATION AGENCY

Open Policy No. NOP-112467

Invoice No. HCRW-2017-2

POLICY
No. 117-1020373684

Amount Insured(Valued at the same as Amount Insured.)
CARGO
¥11,144,000.-

Claim, if any, payable at/in
TOKYO

THIS COMPANY'S HEAD OFFICE

Conditions [illegible]

ALL RISKS
SPECIAL CLAUSE FOR JICA SHIPMENT (30 DAYS)
WAIVER OF SUBROGATION CLAUSE
ALL OTHER TERMS & CONDITIONS ARE SUBJECT
TO THE OPEN POLICY NO. NOP-112467

Local Vessel or Conveyance	From(interior port or place of loading)	
ANY CONVEYANCE	INTERIOR PLACE IN JAPAN	
Ship or Vessel	**Voyage: at and from**	**Sailing on or about**
AIRCRAFT	NARITA	JUN. 30, 2017
Voyage: to/via	**Thence to**	
AMSTERDAM	KIGALI/INTERIOR PLACE IN RWANDA BY LAND CONVEYANCE	

Goods and Merchandises
Mark(s) and Number(s) as per Invoice No. specified above.

TECHNICAL EQUIPMENT OF J.I.C.A.
WATER CONTROL IN KIGALI CITY WATER NETWORK LOT 2
TOTAL: 1 LOT

Co-Insurance Clause
It is hereby understood and agreed that this Policy is issued by Mitsui Sumitomo Insurance Co., Ltd. on behalf of Co-Insurers who are severally and not jointly liable for their individual subscription hereon. Mitsui Sumitomo Insurance Co., Ltd. shall on behalf of Co-Insurers receive premium, make payment of claims and administer all matters relating to this Policy.

CO-INSURANCE

MITSUI SUMITOMO	90.000%
TOKIO & NICHIDO	5.000%
SJNK	5.000%

Including risks of War and Strikes

Subject to the following Clauses (as far as applicable)-
Following Institute Clauses issued by the International Underwriters Association of London
Institute Cargo Clauses 1/1/63 specified above
Institute War Clauses (Cargo) 1/1/80
Institute Strikes Riots and Civil Commotions Clauses 1/1/63
Institute Cargo Clauses 1/1/82 or 1/1/09 specified above
Institute War Clauses (Cargo) 1/1/82 or 1/1/09
Institute Strikes Clauses (Cargo) 1/1/82 or 1/1/09
Institute Air Cargo Clauses (All Risks)(excluding sendings by Post) 15/6/65
Institute War Clauses (Air Cargo)(excluding sendings by Post) 1/1/80
Institute Cargo Clauses (Air)(excluding sendings by Post) 1/1/82 or 1/1/09
Institute War Clauses (Air Cargo)(excluding sendings by Post) 1/1/82 or 1/1/09
Institute Strikes Clauses (Air Cargo) 1/1/82 or 1/1/09
Institute War Clauses for the insurance of sendings by Post 1/1/80
Institute War Clauses (sendings by Post) 1/1/82 or 1/1/09
Institute Dangerous Drugs Clause (applicable with Institute Cargo Clauses 1/1/63)
Institute Replacement Clause (applicable to Machinery)
Institute Radioactive Contamination, Chemical, Biological, Bio-Chemical and Electromagnetic Weapons Exclusion Clause
Piracy and Malicious Damage Clause (applicable with Institute Cargo Clauses (B) or (C))
Label Clause (applicable to Labelled Goods)
Grounding Clause (applicable with Institute Cargo Clauses 1/1/63)
Other Insurance Clause
Under Deck or On Deck Clause
Cargo ISM Endorsement
Termination of Transit Clause (Terrorism)
Sanction Limitation and Exclusion Clause
Mail and Parcel Post Clause (applicable to sendings by Post)
Post Clause (applicable to sendings by Post)
Duty Clause (applicable when duty is separately insured)
Special Clause for Through Transport by Vessel and Aircraft
Special Clause for Institute Cargo Clauses (C) 1/1/09
Special Clause for Institute War Clauses
Special Clause for Residual Property
Benefit of Insurance Clause

Place and Date signed in		No. of Pol.		
TOKYO	JUN. 28, 2017	2	AFG-67 799 8TYY	JIC- JIC-

IMPORTANT

PROCEDURE IN THE EVENT OF LOSS OR DAMAGE FOR WHICH UNDERWRITERS MAY BE LIABLE

LIABILITY OF CARRIERS, BAILEES OR OTHER THIRD PARTIES

It is the duty of the Assured and their Agents, in all cases, to take such measures as may be reasonable for the purpose of averting or minimising a loss and to ensure that all rights against Carriers, Bailees or other third parties are properly preserved and exercised. In particular, the Assured or their Agents are required:-

1. To claim immediately on the Carriers, Port Authorities or other Bailees for any missing packages.
2. In no circumstances, except under written protest, to give clean receipts where goods are in doubtful condition.
3. When delivery is made by Container, to ensure that the Container and its seals are examined immediately by their responsible official.
   If the Container is delivered damaged or with seals broken or missing or with seals other than as stated in the shipping documents, to clause the delivery receipt accordingly and retain all defective or irregular seals for subsequent identification.
4. To apply immediately for survey by Carriers' or other Bailees' Representatives if any loss or damage be apparent and claim on the Carriers or other Bailees for any actual loss or damage found at such survey.
5. To give notice in writing to the Carriers or other Bailees within 3 days of delivery if the loss or damage was not apparent at the time of taking delivery.

NOTE:The Consignees or their Agents are recommended to make themselves familiar with the Regulations of the Port Authorities at the port of discharge.

DOCUMENTATION OF CLAIMS

To enable claims to be dealt with promptly, the Assured or their Agents are advised to submit all available supporting documents without delay, including when applicable :-

1. Original policy of insurance.
2. Original or certified copy of shipping invoices, together with shipping specification and/or weight notes.
3. Original or certified copy of Bill of Lading and/or other contract of carriage.
4. Survey report or other documentary evidence to show the extent of the loss or damage.
5. Landingaccount and weight notes at port of discharge and final destination.
6. Correspondence exchanged with the Carriers and other Parties regarding their liability for the loss or damage.

In the event of loss or damage which may involve a claim under this insurance, no claim shall be paid unless immediate notice of such loss or damage has been given to and a Survey Report obtained from this Company's Office or Agents specified in this Policy.

This insurance is subject to the goods insured being carried under deck, unless otherwise agreed.

The following wording shall be deleted and replaced with the wording (*) printed right in cases of Institute Cargo Clauses dated 1/1/63 being applied.
Institute Cargo Clauses 1/1/09 shall be applied unless otherwise specified above.

Notwithstanding anything contained herein or attached hereto to the contrary, this insurance is understood and agreed to be subject to English law and practice only as to liability for and settlement of any and all claims.
This insurance does not cover any loss or damage to the property which at the time of happening of such loss or damage is insured by or would but for the existence of this Policy be insured by any fire or other insurance policy or policies except in respect of any excess beyond the amount which would have been payable under the fire or other insurance policy or policies had this insurance not been effected.
We, Mitsui Sumitomo Insurance Company, Limited, hereby agree, in consideration of the payment to us by or on behalf of the Assured of the premium as arranged, to insure against loss damage liability or expense to the extent and in the manner herein provided.
In Witness whereof,
I the Undersigned of Mitsui Sumitomo Insurance Company, Limited, on behalf of the said Company have subscribed My Name in the place specified as above to the policies, the issued numbers thereof being specified above, of the same tenor and date, one of which being accomplished, the others to be void, as of the date specified as above.

(*) Be it known that

Name (s) of Assured (s), etc. as specified above as well in his or their own Name, as for and in the Name and Names of all and every other Person or Persons to whom the same doth, may, or shall appertain, in part or in all, do make Insurance, and hereby cause himself or themselves and them and every of them, to be Insured, lost or not lost, at and from as specified above upon Goods and Merchandises as specified above in the good Ship or Vessel called the as specified above whereof is Master, for this present Voyage

or whosoever else shall go for Master in the said Vessel, or by whatsoever other Name or Names the said Vessel, or the Master thereof, is or shall be named or called;- BEGINNING the Adventure upon the said Goods and Merchandises from the loading thereof on board the said Ship, and so to continue and endure, until the said Goods and Merchandises shall have arrived at as specified above and until the same be there discharged and safely landed. And it shall be lawful for the said Vessel, in this Voyage, to proceed and sail to, and touch and stay at any Ports or Places whatsoever, (within the limits of the above Voyage) for necessary Provisions, Assistance or Repairs, without prejudice to this Insurance the said Goods and Merchandises laden thereon for so much as concerns the Assured, are and shall be valued at as specified above

Touching the Adventures and Perils which the said Mitsui Sumitomo Insurance Company, Limited, themselves are content to bear, and to take upon them in this Voyage; they are of the Seas, Men-of-War, Fire, Enemies, Pirates, Rovers, Thieves, Jettisons, Letters of Mart and Counter-Mart, Surprisals, Takings at Sea, Arrests, Restraints and Detainments of all Kings, Princes, and People, of what Nation, Condition, or Quality soever, Barratry of the Master and Mariners, and of all other Perils, Losses, and Misfortunes that have or shall come to the Hurt, Detriment, or Damage of the said Goods and Merchandises, or any part thereof;
and in case of any Loss or Misfortune, it shall be lawful for the Assured, his or their Factors, Servants, or Assigns, to sue, labour, and travel for, in and about the Defence, Safeguard and Recovery of the said Goods and Merchandises, or any part thereof, without prejudice to this Insurance; to the Charges whereof the said Company will contribute. It is expressly declared and agreed that no acts of the Insurer or Assured in recovering, saving, or preserving the property insured, shall be considered as a waiver or acceptance of abandonment. AND it is agreed that this Writing or Policy of Assurance shall be of as much Force and Virtue as the surest Writing or Policy of Assurance made in LONDON. And so the said Mitsui Sumitomo Insurance Company, Limited, are contented, and do hereby promise and bind themselves to the Assured, his or their Executors, Administrators, or Assigns, for the true Performance of the Premises; confessing themselves paid the Consideration due unto them for this Insurance, at and after the rate of as arranged Per cent.
N.B. Corn, Fish, Salt, Fruit, Flour and Seed are warranted free from Average, unless General, or the Ship be stranded, sunk or burnt; Sugar, Tobacco, Hemp, Flax, Hides and Skins are warranted free from Average under Five per cent. and all other Goods are warranted free from Average under Three percent., unless General, or the Ship be stranded, sunk or burnt.
This insurance is understood and agreed to be subject to English law and usage as to liability for and settlement of any and all claims.
In Witness whereof, I the Undersigned of Mitsui Sumitomo Insurance Company, Limited, on behalf of the said Company, have subscribed my Name in as specified above to as specified above Policies of the same tenor and date, one of which being accomplished, the others to be void, as of the date specified above.

For Mitsui Sumitomo Insurance Company, Limited

(AUTHORIZED SIGNATORY)

Wording of the clauses applied (other than the same printed on the front or in the attached sheet) can be seen at the Website (http://www.ms-ins.com/cargo/) or available from this Company upon request.

平成29年6月27日

様式6

輸送日程報告カード　（[✓ 予定]・ 確定・ 到着確認）

株式会社
会社名：HELICOM CORPORATION INC.
代表取締役
担当者名：足立 出光

案件名	ルワンダ国キガリ市無収水対策強化プロジェクト（ロット1）向け機材
公示番号	GE1603
主な機材名	超音波流量計 他
機材入庫年月日	平成29年6月12日
貨物個数	別添のとおり
内容量及び重量	別添のとおり
仕向地	ルワンダ国キガリ国際空港
輸送契約内容	a. 海上輸送のみ（陸揚保税地域搬入までの輸送契約） b. 内陸輸送を含む輸送契約 [✓ c.] その他
貨物海上保険付保日数	① 90日（aの通常ケース）　② 150日（bの通常ケース）　[✓ ③] その他（30）日（cの場合）
B/L番号	未定
B/L発行日	未定
船会社の現地代理店名又は内陸輸送業者名及び所在地/TEL	Air France KLM Cargo Kigali Office Kigali International Airport Cargo Terminal KN 5 Rd, Kigali, Rwanda Phone +250788304411

	予定	確定	到着確認
船積港	成田空港		
船会社	KLMオランダ航空		
船名	KL862		
出港日	平成29年6月30日		
陸揚港	ルワンダ国キガリ国際空港		
陸揚港着港日	平成29年7月3日		
内陸輸送ルート	-		
内陸輸送後の最終到着場所	Water and Sanitation Corporation KN 4 AV 8 CENTENARY HOUSE P.O.BOX 2331 Kigali - RWANDA TEL：+250-(0)788-181-427		
内陸輸送後の最終到着日	-		
保険付保期限（仕向港荷揚げ後30日の日付）	平成29年8月2日		

074 | NRT | 56689905

074-56689905

Shipper's Name and Address

HELICOM CORPORATION INC ON BEHALF OF JICA
3-30-27 OHAMA-CHO, AMAGASAKI-SHI,
HYOGO-KEN JAPAN
PHONE : +81-3-5575-2421 FAX : +81-3-5575-2423

Shipper's Account Number

Not negotiable

Air Waybill

Issued by KLM-ROYAL DUTCH AIRLINES

P.O.BOX 7700, 1117 ZL SCHIPHOL AIRPORT, THE NETHERLANDS

Copies 1, 2 and 3 of this Air Waybill are originals and have the same validity.

Consignee's Name and Address

WATER AND SANITATION CORPORATION
KN 4 AV, 8 CENTENARY HOUSE
P.O.BOX 2331 KIGALI - RWANDA
TEL : +250-(0)788-181-427

Consignee's Account Number

Issuing Carrier's Agent Name and City

KAMIGUMI AIR SERVICE CO.,LTD.
TOKYO,JAPAN

Accounting Information

1. JICA RWANDA OFFICE
IMMEUBLE EBENEZER BOULEVARD DE L'UMUGANDA,
KACYIRU KIGALI, RWANDA
B.P. 6878, KACYIRU, KIGALI, RWANDA**

Agent's IATA Code 16-3 1527/0016

Account No.

Airport of Departure (Addr. of First Carrier) and Requested Routing

NARITA AIRPORT,JAPAN

Reference Number

Optional Shipping Information

To	By First Carrier	Routing and Destination	to	by	to	by	Currency	CHGS Code	WT/VAL PPD	WT/VAL COLL	Other PPD	Other COLL	Declared Value for Carriage	Declared Value for Customs
HEL		KL	KGL	KL			JPY		X		X		N.V.D.	

Airport of Destination	Requested Flight/Date		Amount of Insurance
KIGALI RWANDA (KGL)	KL862/30	KL537/03	

INSURANCE - If carrier offers insurance and such insurance is requested in accordance with the conditions thereof, indicate amount to be insured in figures in box marked Amount of Insurance.

Handling Information

**TEL : +250-(0)788-301-731, +250-(0)788-301-732, +250-(0)788-301-723
2. SAME AS CONSIGNEE

SCI

No. of Pieces RCP	Gross Weight	kg lb	Rate Class Commodity Item No.	Chargeable Weight	Rate / Charge	Total	Nature and Quantity of Goods (incl. Dimensions or Volume)
2	240.0	K	Q	449.5	2,350	1,056,325	EQUIPMENT FOR PROJECT FOR STRENGTHENING NON-REVENUE WATER CONTROL IN KIGALI CITY WATER NETWORK LOT 1 FREIGHT:PREPAID INVOICE NO:HCRW-2017-1 TOTAL:2 PACKAGES ONLY M'MENT : 2.696 M3

MARKS: Water and Sanitation Corporation
JICA (IN DIA)
Kigali, Rwanda
INVOICE NO: HORW-2017-1
C/No.1/2~2/2

SIDE MARK:(in RED)

TECHNICAL COOPERATION BY THE

GOVERNMENT OF JAPAN

Prepaid	Weight Charge	Collect
1,056,325		

Valuation Charge

Tax

Total other Charges Due Agent

Total other Charges Due Carrier 26,071

Other Charges

MY 24,273
SCI 1,798

Shipper certifies that the particulars on the face hereof are correct and that insofar as any part of the consignment contains dangerous goods, such part is properly described by name and is in proper condition for carriage by air according to the applicable Dangerous Goods Regulations.

Signature of Shipper or his Agent

Total prepaid	Total collect
1,082,396	

Currency Conversion Rates	cc Charges in Dest. Currency

29.Jun.2017 TOKYO,JAPAN S.KOHAMA

Skohama

Executed on (date) at (place) Signature of Issuing Carrier or its Agent

For Carriers Use only at Destination	Charges at Destination	Total collect Charges

074-56689905

Copy 9 - (For Sales Agent)

PRINTED IN JAPAN

TOPPAN FORMS CO.,LTD 0031500 01/00 IATA International Air Transport Association CASS Japan

C/No.	Item No.	Description	Model / Part No.	Q'ty	N/Weight	G/Weight	M'Ment
1/2							
	1	Ultrasonic Flowmeter	UFP-20	6	154.2	184	1.532
			large sensor UFP-20	3	10.8		
2/2							
	1	Ultrasonic Flowmeter	large sensor UFP-20	3	10.8	56	1.164
	2	Flow & Pressure Data Logger	Textlog Multi	6	27		
	8	Time integral water leakage detector	FSB-8DFSJ-1	3			
		total			202.8	240.0	2.696

MS&AD
Mitsui Sumitomo Insurance

ORIGINAL

Mitsui Sumitomo Insurance Company, Limited

MARINE CARGO POLICY

Head Office : 9, Kanda-Surugadai, 3Chome, Chiyoda-ku, Tokyo, 101-8011, Japan

This is to certify that this Company insure under the below Open/Provisional Policy, if any, as follows:

Assured(s),etc.
JAPAN INTERNATIONAL COOPERATION AGENCY

Open Policy No. NOP-112467

Invoice No. HCRW-2017-1

POLICY
No. 117-1020373817

Amount Insured(Valued at the same as Amount Insured.)
CARGO
¥13,827,000.-

Claim, if any, payable at/in
TOKYO

THIS COMPANY'S HEAD OFFICE

Conditions IN CASE THE WORDING IN CONDITIONS IS ALL RISKS/W.A., F.P.A. WITHOUT DATE, THERE SHALL BE DEEMED TO READ AS INSTITUTE CARGO CLAUSES (A), (B) OR (C) 1/1/09 RESPECTIVELY.

ALL RISKS
SPECIAL CLAUSE FOR JICA SHIPMENT (30 DAYS)
WAIVER OF SUBROGATION CLAUSE
ALL OTHER TERMS & CONDITIONS ARE SUBJECT TO THE OPEN POLICY NO. NOP-112467

Local Vessel or Conveyance
ANY CONVEYANCE

From(interior port or place of loading)
INTERIOR PLACE IN JAPAN

Ship or Vessel
AIRCRAFT

Voyage: at and from
NARITA

Sailing on or about
JUN. 30, 2017

Voyage: to/via
AMSTERDAM

Thence to
KIGALI/INTERIOR PLACE IN RWANDA BY LAND CONVEYANCE

Goods and Merchandises
Mark(s) and Number(s) as per Invoice No. specified above.

TECHNICAL EQUIPMENT OF J.I.C.A.
WATER CONTROL IN KIGALI CITY WATER NETWORK LOT 1
TOTAL: 1 LOT

Co-Insurance Clause
It is hereby understood and agreed that this Policy is issued by Mitsui Sumitomo Insurance Co., Ltd. on behalf of Co-insurers who are severally and not jointly liable for their individual subscription hereon. Mitsui Sumitomo Insurance Co., Ltd. shall on behalf of Co-insurers receive premium, make payment of claims and administer all matters relating to this Policy.

CO-INSURANCE

MITSUI SUMITOMO	90.000%
TOKIO & NICHIDO	5.000%
SJNK	5.000%

Including risks of War and Strikes

Place and Date signed in
TOKYO JUN. 28, 2017

No. of Pol.
2

AFG-67 799
8TYY

JIC- JIC-

IMPORTANT

PROCEDURE IN THE EVENT OF LOSS OR DAMAGE FOR WHICH UNDERWRITERS MAY BE LIABLE

LIABILITY OF CARRIERS, BAILEES OR OTHER THIRD PARTIES

It is the duty of the Assured and their Agents, in all cases, to take such measures as may be reasonable for the purpose of averting or minimising a loss and to ensure that all rights against Carriers, Bailees or other third parties are properly preserved and exercised. In particular, the Assured or their Agents are required:-

1. To claim immediately on the Carriers, Port Authorities or other Bailees for any missing packages.
2. In no circumstances, except under written protest, to give clean receipts where goods are in doubtful condition.
3. When delivery is made by Container, to ensure that the Container and its seals are examined immediately by their responsible official.
   If the Container is delivered damaged or with seals broken or missing or with seals other than as stated in the shipping documents, to clause the delivery receipt accordingly and retain all defective or irregular seals for subsequent identification.
4. To apply immediately for survey by Carriers' or other Bailees' Representatives if any loss or damage be apparent and claim on the Carriers or other Bailees for any actual loss or damage found at such survey.
5. To give notice in writing to the Carriers or other Bailees within 3 days of delivery if the loss or damage was not apparent at the time of taking delivery.

NOTE:The Consignees or their Agents are recommended to make themselves familiar with the Regulations of the Port Authorities at the port of discharge.

DOCUMENTATION OF CLAIMS

To enable claims to be dealt with promptly, the Assured or their Agents are advised to submit all available supporting documents without delay, including when applicable :-

1. Original policy of insurance.
2. Original or certified copy of shipping invoices, together with shipping specification and/or weight notes.
3. Original or certified copy of Bill of Lading and/or other contract of carriage.
4. Survey report or other documentary evidence to show the extent of the loss or damage.
5. Landingaccount and weight notes at port of discharge and final destination.
6. Correspondence exchanged with the Carriers and other Parties regarding their liability for the loss or damage.

In the event of loss or damage which may involve a claim under this insurance, no claim shall be paid unless immediate notice of such loss or damage has been given to and a Survey Report obtained from this Company's Office or Agents specified in this Policy.

This insurance is subject to the goods insured being carried under deck, unless otherwise agreed.

The following wording shall be deleted and replaced with the wording (*) printed right in cases of Institute Cargo Clauses dated 1/1/63 being applied. Institute Cargo Clauses 1/1/09 shall be applied unless otherwise specified above.

Notwithstanding anything contained herein or attached hereto to the contrary, this insurance is understood and agreed to be subject to English law and practice only as to liability for and settlement of any and all claims.

This insurance does not cover any loss or damage to the property which at the time of happening of such loss or damage is insured by or would but for the existence of this Policy be insured by any fire or other insurance policy or policies except in respect of any excess beyond the amount which would have been payable under the fire or other insurance policy or policies had this insurance not been effected.

We, Mitsui Sumitomo Insurance Company, Limited, hereby agree, in consideration of the payment to us by or on behalf of the Assured of the premium as arranged, to insure against loss damage liability or expense to the extent and in the manner herein provided.

In Witness whereof,
I the Undersigned of Mitsui Sumitomo Insurance Company, Limited, on behalf of the said Company have subscribed My Name in the place specified as above to the policies, the issued numbers thereof being specified above, of the same tenor and date, one of which being accomplished, the others to be void, as of the date specified as above.

Subject to the following Clauses (as far as applicable):-
Following Institute Clauses issued by the International Underwriters Association of London
- Institute Cargo Clauses 1/1/63 specified above
- Institute War Clauses (Cargo) 11/3/09
- Institute Strikes Riots and Civil Commotions Clauses 1/1/63
- Institute Cargo Clauses 1/1/82 or 1/1/09 specified above
- Institute War Clauses (Cargo) 1/1/82 or 1/1/09
- Institute Strikes Clauses (Cargo) 1/1/82 or 1/1/09
- Institute Air Cargo Clauses (All Risks) (excluding sendings by Post) 15/6/65
- Institute War Clauses (Air Cargo) (excluding sendings by Post) 11/3/80
- Institute Cargo Clauses (Air) (excluding sendings by Post) 1/1/82 or 1/1/09
- Institute War Clauses (Air Cargo) (excluding sendings by Post) 1/1/82 or 1/1/09
- Institute Strikes Clauses (Air Cargo) 1/1/82 or 1/1/09
- Institute War Clauses for the insurance of sendings by Post 11/3/80
- Institute War Clauses (sendings by Post) 1/1/82 or 1/1/09
- Institute Dangerous Drugs Clause (applicable with Institute Cargo Clauses 1/1/63)
- Institute Replacement Clause (applicable to Machinery)
- Institute Radioactive Contamination, Chemical, Biological, Bio-Chemical and Electromagnetic Weapons Exclusion Clause

Piracy and Malicious Damage Clause (applicable with Institute Cargo Clauses (B) or (C))
Label Clause (applicable to Labelled Goods)
Grounding Clause (applicable with Institute Cargo Clauses 1/1/63)
Other Insurance Clause
Under Deck or On Deck Clause
Cargo ISM Endorsement
Termination of Transit Clause (Terrorism)
Sanction Limitation and Exclusion Clause
Mail and Parcel Post Clause (applicable to sendings by Post)
Post Clause (applicable to sendings by Post)
Duty Clause (applicable when duty is separately insured)
Special Clause for Through Transport by Vessel and Aircraft
Special Clause for Institute Cargo Clauses (C) 1/1/09
Special Clause for Institute War Clauses
Special Clause for Residual Property
Benefit of Insurance Clause

(*) Be it known that

Name (s) of Assured (s), etc. as specified above as well in his or their own Name, as for and in the Name and Names of all and every other Person or Persons to whom the same doth, may, or shall appertain, in part or in all, do make Insurance, and hereby cause himself or themselves and them and every of them, to be Insured, lost or not lost, at and from as specified above upon Goods and Merchandises as specified above in the good Ship or Vessel called the as specified above whereof is Master, for this present Voyage

or whosoever else shall go for Master in the said Vessel, or by whatsoever other Name or Names the said Vessel, or the Master thereof, is or shall be named or called:- BEGINNING the Adventure upon the said Goods and Merchandises from the loading thereof on board the said Ship, and so to continue and endure, until the said Goods and Merchandises shall have arrived at as specified above and until the same be there discharged and safely landed. And it shall be lawful for the said Vessel, in this Voyage, to proceed and sail to, and touch and stay at any Ports or Places whatsoever, (within the limits of the above Voyage) for necessary Provisions, Assistance or Repairs, without prejudice to this Insurance: the said Goods and Merchandises laden thereon for so much as concerns the Assured, are and shall be valued at as specified above

Touching the Adventures and Perils which the said Mitsui Sumitomo Insurance Company, Limited, themselves are content to bear, and to take upon them in this Voyage; they are of the Seas, Men-of-War, Fire, Enemies, Pirates, Rovers, Thieves, Jettisons, Letters of Mart and Counter-Mart, Surprisals, Takings at Sea, Arrests, Restraints and Detainments of all Kings, Princes, and People, of what Nation, Condition, or Quality soever, Barratry of the Master and Mariners, and of all other Perils, Losses, and Misfortunes that have or shall come to the Hurt, Detriment, or Damage of the said Goods and Merchandises, or any part thereof;

and in case of any Loss or Misfortune, it shall be lawful for the Assured, his or their Factors, Servants, or Assigns, to sue, labour, and travel for, in and about the Defence, Safeguard and Recovery of the said Goods and Merchandises, or any part thereof, without prejudice to this Insurance; to the Charges whereof the said Company will contribute. It is expressly declared and agreed that no acts of the Insurer or Insured in recovering, saving, or preserving the property insured, shall be considered as a waiver or acceptance of abandonment. AND it is agreed that this Writing or Policy of Assurance shall be of as much Force and Virtue as the surest Writing or Policy of Assurance made in LONDON. And so the said Mitsui Sumitomo Insurance Company, Limited, are contented, and do hereby promise and bind themselves to the Assured, his or their Executors, Administrators, or Assigns, for the true Performance of the Premises; confessing themselves paid the Consideration due unto them for this Insurance, at and after the rate of as arranged Per cent

N.B. Corn, Fish, Salt, Fruit, Flour and Seed are warranted free from Average, unless General, or the Ship be stranded, sunk or burnt; Sugar, Tobacco, Hemp, Flax, Hides and Skins are warranted free from Average under Five per cent and all other Goods are warranted free from Average under Three percent., unless General, or the Ship be stranded, sunk or burnt.

This insurance is understood and agreed to be subject to English law and usage as to liability for and settlement of any and all claims.

In Witness whereof, I the Undersigned of Mitsui Sumitomo Insurance Company, Limited, on behalf of the said Company, have subscribed my Name in as specified above to as specified above Policies of the same tenor and date, one of which being accomplished, the others to be void, as of the date specified above.

For Mitsui Sumitomo Insurance Company, Limited

(AUTHORIZED SIGNATORY)

Wording of the clauses applied (other than the same printed on the front or in the attached sheet) can be seen at the Website (http://www.ms-ins.com/cargo/) or available from this Company upon request.