No.

THE FEASIBILITY STUDY
ON
BAGHDAD WATER SUPPLY SYSTEM
IMPROVEMENT PROJECT

FINAL REPORT
VOLUME III

SUPPORTING REPORT

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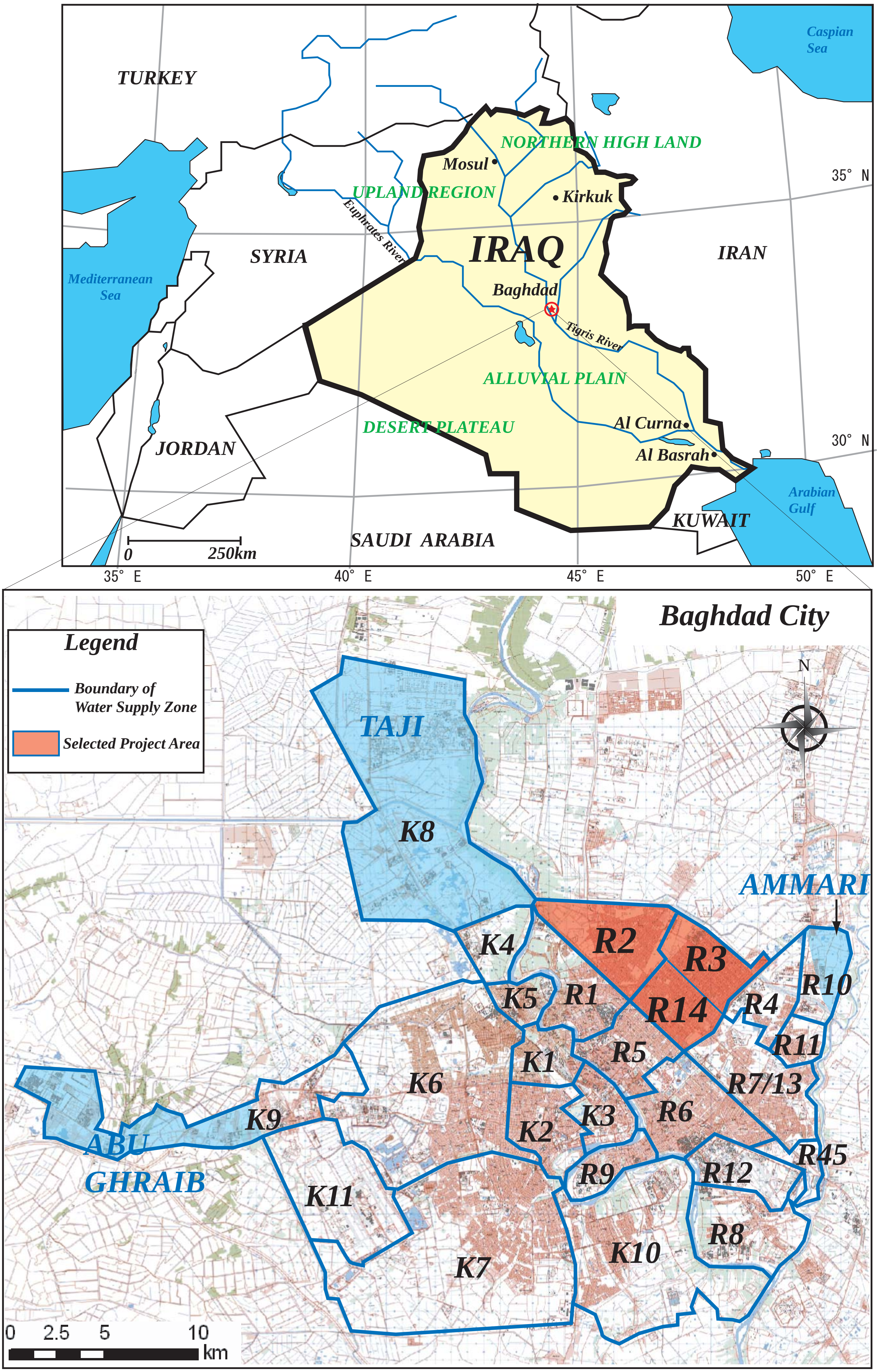

Location Map

ABBREVIATIONS

Organization

BWA	Baghdad Water Authority
CERP	Commander’s Emergency Response Program
COSIT	Iraqi Central Organization for Statistics and Information Technology
CPA	Coalition Provisional Authority
CSO	Central Statistical Organization
EPID	The Environmental Protection and Improvement Directorate
GRD	Gulf Region Division of the U.S. Army Corps of Engineers
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
ILO	International Labor Organization
MOB	Mayoralty of Baghdad
MOCH	Ministry of Construction and Housing
MOE	Ministry of Environment
MOF	Ministry of Finance
MOT	Ministry of Transportation
MPDC	Ministry of Planning & Development Cooperation
MWT	Ministry of Works and Transportation
OPEC	Organization of the Petroleum Exporting Countries
PCO	Project & Contracting Office
UNICEF	United Nations Children’s Fund
USACE	U.S. Army Corps of Engineers
USAID	United States Agency for International Development
WB	The World Bank

Others

ACP	Asbestos Cement Pipe
ADF	Average Daily Flow
ATP	Affordability to Pay
BS	Booster Station
CIP	Cast Iron Pipe
CSO	Central Statistical Organization
CU	Compact Unit
DIP	Ductile Iron Pipe
DMA	District Meter Area
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rete of Return

FIRR	Financial Internal Rate of Return
GDP	Gross Domestic Product
GIS	Geographical Information System
GSP	Galvanized Steel Pipe
IEE	Initial Environmental Examination
LDPE	Low Density Polyethylene Pipe
MDF	Maximum Daily Flow
MIS	Management Information System
NDS	National Development Strategy
ODA	Official Development Assistance
PEP	Polyethylene Pipe
PHF	Peak Hourly Flow
PMT	Project Management Team
PVC	Polyvinyl Chloride Pipe
RPS	Raw Water Pump Station
RWN	Raw Water Network
SCADA	Supervisory Control and Data Acquisition
SDMA	Sub District Meter Area
SR	Service Reservoir
STP	Steel Pipe
UFW	Unaccounted for Water
WCM	Water Consumption Meter
WSZ	Water Supply Zone
WTP	Water Treatment Plant

Units

Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer

Area

cm^2	=	square centimeter
m^2	=	square meter
km^2	=	square kilometer

Volume

cm^3	=	cubic centimeter
m^3	=	cubic meter
l or lit	=	liter
MCM	=	million cubic meter

Weight

mg	=	milligram
g	=	gram
kg	=	kilogram

Time as denominator

/s or /sec	=	per second
/min	=	per minute
/hr.	=	per hour
/d	=	per day
/y	=	per year

Derived measures

lpcd	=	Liter per capita per day
m^3/s	=	Cubic meter per second
m^3/d	=	Cubic meter per day
mg/l	=	milligram per liter

Others

%	=	percent
°C	=	Celsius degrees
ppm	=	parts per million

Currency

JPY	Japanese Yen
US$	US Dollar
ID	Iraq Dinar

Transliterations of Arabic Place Names

9 Nisan	٩ نيسان
Abu Gharib	ابو غريب
Abu Nowas	ابو نواس
Adhamiyah	الاعظمية
Al Salam	السلام
Amin	الأمين
Army Canal	قناة الجيش
Boaitha	البوعيثة
Doura	الدورة
Ekhaa	الاخاء
Fahama	الفحامة
Hamediya	حميدية
Hussian Al Safi	حسن الصافي
Jomhuriya	الجمهورية
Kadhemiyah	الكاظمية
Kamaliya	الكمالية
Kanat	القناة
Karada	الكرادة
Karama	الكرامة
Karkh North	شمال الكرخ
Karkh South	جنوب الكرخ
Karkh	الكرخ
Kasra	الكسرة
Makaseb	المكاسب
Mansour	المنصور
Mendly	مندلي
Montadher	حي المنتظر
Nasser	النصر
New Akad	اكد الجديد
New Ammari	العماري الجديد
New Orfally	أورفلي الجديد
Obaidi	العبيدي
Obour	العبور
Old Akad	اكد القديم
Old Ammari	العماري القديم
Old Orfally	أورفلي القديم
Otaifiya	العطيفية
Jaderiya Bridge	جسرالجادرية
Jaderiya	الجادرية
Qadessia	القادسية
Rasafa	الرصافة
Rashad	الرشاد
Rasheed	الرشيد
Rostamia	الرستمية
Saba Kosour	سبع قصور
Sadr	الصدر
Saidiya	السيدية
Salam	السلام
Salehiya	الصالحية
Senak	السناك
Shaab	الشعب
Shark Dijla	شرق دجلة
Shola	الشعلة
Swaib	صويب
Taji	التاجي
Tal Aswad	تل أسود
Tarik	طارق
Um Al Asafier	ام العصافير
Wahda	الوحدة
Wathba	الوثبة
Zafaraniya	الزعفرانية
Zaiuna	زيونة

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APPENDIX A
HYDRAULIC STUDIES

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HYDRAULIC STUDIES

A.1 Introduction

Hydraulic studies aim at carrying out the preliminary network analysis, not only for the whole water service area of Baghdad Water Authority (BWA), but also for the priority areas consisting of Water Supply Zones (WSZs) R2, R3 and R14, which were selected by the plan formulation as described in the Main Report. The studies consist of four major tasks: 1) creating a simplified hydraulic model of the network, 2) conducting a preliminarily hydraulic analysis of the trunk and distribution mains for the Baghdad water supply system, 3) analyzing the distribution network in WSZs that were selected as priority areas, and 4) recommending improvements for the distribution system in the priority areas.

It is noted that this hydraulic analysis was a preliminary examination since the hydraulic studies were conducted under the conditions of the following issues and risks:

- In general, collection of data and information is most formidable due to the unsatisfactory response from BWA and in consequence it caused a deficit of data and information required for the studies.
- It is supposed that many data, such as maps, drawings and other documents were missing or damaged during the political unrest over the past 15 years.
- The true conditions of the existing water supply facilities are unknown due to lack of data and information about the facilities, such as booster pumps, distribution networks and Compact Units (CUs).
- Especially, the existing conditions of the distribution pipelines, such as length, diameter, material and location, are not able to be correctly comprehended since maps of the distribution network have not been updated.
- Water use and customers are not able to be correctly classified due to lack of data.
- Population and water demand are projected based on the JICA Basic Study Report and USAID Report due to lack of a Baghdad city master plan or water supply master plan.
- Water demand is allocated evenly to each Mahalah in the WSZs since there is no detailed information about land use patterns, population density, family size, type of subscribers or type of buildings.
- It is impossible to grasp exactly the water production, supply, consumption and UFW at present since almost none of the flow meters are functional.
- It is recommended that the hydraulic analysis for the future water supply should be re-examined after formulation of a Baghdad City master plan since the hydraulic analysis was conducted based on the above-mentioned assumptions.

A.2 Hydraulic Model

A.2.1 Basic concepts

The basic concepts for the hydraulic model are briefly described below:

(1) The following studies were used to formulate the model:

- Integrated Study on Improvement of The Baghdad Water Distribution System, The Third Country Training Programme of JICA, March 2005 (JICA Basic Study Report)
- Hydraulic Model Potable Water Distribution System Baghdad Water Authority, USAID, Iraq Infrastructure Reconstruction Program, Phase II Potable Water Sector, January 2006 (USAID Report)

(2) The base map provided by the USAID Report was adopted

(3) The following information regarding physical components of the system is reflected for formulation of the model:

- Water Treatment Plants (WTPs)
- Water Treatment Compact Units (CUs) directly connected to distribution networks
- Transmission Mains
- Service Reservoirs (SRs) and Booster Stations (BSs)
- Distribution Networks (Diameter ≧250mm)
- 2005 Population Served and Water Requirements projected by the JICA Study Team
- Land Use Patterns and WSZs Build-out Year presented by the USAID Report

The typical distribution network consists of the following three hierarchies:

Hierarchy	Range of Pipe Diameters (mm)
1) Distribution Mains	500mm to 1200mm
2) Distribution Sub-mains (Secondary)	300mm to 500mm
3) Distribution Sub-mains (Tertiary)	100mm to 250mm

(4) BWA service ratio is to be 100%.

(5) The model was used for analysis of the present condition and for the future plan of the Baghdad water supply system.

(6) The present condition of the Baghdad water supply system was analyzed for the year of 2005.

(7) Target years are to be set at 2014 for the mid-term and 2027 for the long-term.

(8) As for the priority area, only the distribution model was constructed for analysis of the present condition and for the future plan.

(9) The future distribution system was divided into appropriate DMA blocks based on the character and size of the service area in order to alleviate water shortage problems.

A.2.2 Planning Information

(1) Topographic data

The priority areas are located in the northern part of Baghdad City. Total area is about 66 km^2 and population was estimated at 1.5 million in 2005. The elevation varies from 33 m to 37 m above mean sea level as shown in Figure A.2.1. The area slopes down to the south with an inclination of less than 0.1%. The service area is quite flat land with an average slope of about 0.08 %.

(2) Population

BWA population served in the present and in the future are based on the population in Baghdad city and its suburban estimated from the 1997 BWA customer base. The population served in the whole area of Baghdad for the target years is projected below:

Table A.2.1 Population Projections at Target Years

Year	Rasafa Side	Karkh Side	Total
2005	3,105,000	2,490,000	5,595,000
2014	3,843,000	3,120,000	6,963,000
2027	5,330,000	4,223,000	9,553,000

(Source: BWA & JICA Study Team)

In the priority area, the population served for the target years is summarized below:

Table A.2.2 Population Projection for Priority Areas

Year	R2	R3	R14	Total
2005	363,000	658,000	503,000	1,524,000
2014	441,000	820,000	620,000	1,881,000
2027	649,000	1,095,000	828,000	2,572,000

(Source: BWA & JICA Study Team)

(3) Water demand and Allocation

For water demand projections at each target year, the following factors of water use were adopted:

Table A.2.3 Factors of Water Use

Water Use Condition	2005	2014	2027
- Unit Water Consumption (lpcd)	244	280	360
- Planned UFW Ratio (%)	46.4	38.0	25.0
- Peak Day Factor	1.365	1.292	1.250

(Source: BWA & JICA Study Team)

Water requirements in the BWA service area were estimated based on the above-mentioned population and factors below:

Table A.2.4 Water Requirements in BWA Service Area

Description	2005	2014	2027
1. Rasafa Side			
1.1 Average Water Demand ($10^3m^3/d$)	759	1,076	1,919
1.2 Average Daily Requirement ($10^3m^3/d$)	1,416	1,735	2,558
1.3 Max. Daily Requirement ($10^3m^3/d$)	1,933	2,242	3,198
2. Karkh Side			
2.1 Average Water Demand ($10^3m^3/d$)	608	874	1,520
2.2 Average Daily Requirement ($10^3m^3/d$)	1,135	1,409	2,027
2.3 Max. Daily Requirement ($10^3m^3/d$)	1,550	1,820	2,534
3. Total of Baghdad			
3.1 Average Water Demand ($10^3m^3/d$)	1,367	1,949	3,439
3.2 Average Daily Requirement ($10^3m^3/d$)	2,551	3,144	4,585
3.3 Max. Daily Requirement ($10^3m^3/d$)	3,383	4,063	5,732

(Source: BWA & JICA Study Team)

The projected water demands and water requirements of the priority areas are summarized for each WSZ as follows:

Table A.2.5 Water Demand and Requirement Projections for Project Areas

WSZ	2005			2014			2027		
	Water Demand (m^3/d)	Average Daily Requirement (m^3/d)	Maximum Daily Requirement(m^3/d)	Water Demand (m^3/d)	Average Daily Requirement (m^3/d)	Maximum Daily Requirement(m^3/d)	Water Demand (m^3/d)	Average Daily Requirement(m^3/d)	Maximum Daily Requirement(m^3/d)
R2	88,783	165,727	226,218	123,415	199,057	257,182	233,537	311,382	389,228
R3	160,692	299,958	409,443	229,667	370,431	478,597	394,336	525,782	657,227
R14	122,896	229,406	313,139	173,509	279,853	361,570	297,912	397,217	496,521
Total	372,370	695,091	948,800	526,591	849,341	1,097,348	925,785	1,234,381	1,542,976

(Source: BWA and JICA Study Team)

Water demand is allocated to nodes using a simple unit loading method. In this method, the allocated demand should be equal to total demand of each zone divided by the number of nodes for each zone. In preparation for the automated demand allocation, some of the nodes are excluded from selections of demand allocation as follows:

- Nodes located inside pump stations,
- Nodes in the trunk system model that do not connect to the distribution system
- Pipe junctions in WSZs without reservoirs where distribution pipes connect directly to the trunk system,
- Junction points of the reservoirs to be planned in each WSZ.

(4) Data on the water supply facilities

The following data on the eight existing WTPs were input for the hydraulic analysis:

Table A.2.6 Design Water Pressure of WTPs

WTPs Name	Head Pressure (m)
For Karkh Side	
1. Al Karkh WTP	75
2. Al Karama WTP	60
3. Al Qadisiya WTP	60
4. Al Doura WTP	65
For Rasafa Side	
5. Shark Dijla WTP	65
6. Al Wathba WTP	60
7. Al Wahda WTP	50
8. Rasheed WTP	60

(Source: BWA)

The following eight CU-sites from among the existing 16 CU-sites that are connected directly with the distribution network were input for the hydraulic analysis since these eight CUs-sites are supposed to remarkably affect the hydraulic analysis:

Table A.2.7 Design Water Pressure of CU-sites

CU-sites	Head Pressure (m)
1. Al Amin CUs	50
2. Akad 1 CUs	50
3. Akad 2 CUs	50
4. Orfali CUs	50
5. Kamaliya CUs	50
6. Abu Nuaas C.Us	50
7. Al Ubaidi C.Us	50
8. Al Aubor C.Us	50

(Source: BWA)

Service reservoirs (SRs) are considered to have a constant water surface elevation. The water surface elevation is not affected by inflow into or outflow from the reservoir. SRs in the model provide an unlimited supply of water for steady-state simulations. The existing eight SRs with BSs and the II B blending tank of the Shark Dijlah WTP were adopted for hydraulic analysis:

Table A.2.8 Design Water Pressure of SRs

SRs	Head Pressure (m)
For Karkh Side	
1. Taji Reservoir	31
2. North Reservoir	32
3. South Reservoir	32
4. Abu Ghraib Reservoir	32
For Rasafa Side	
5. Al Ubaidy Reservoir	50
6. IIB Reservoir	65
7. Al Rustumia Reservoir	50
8. Al Kamaliya Reservoir	50
9. Al Amin Reservoir	50
(Source: BWA)	

(5) Pipes and nodes

Most of the pipe and valve information was obtained from the SOBEA drawings which were adopted by the USAID Report and were transferred into the model using the geographical features shown on the SOBEA drawings, Baghdad City satellite map and aerial photographs as references. For modelling purposes, a pipe is defined as a circular conduit that: i) has the same diameter and roughness value throughout and ii) extends between two nodes. The pipeline model in the priority area is of ductile iron pipes ranging in diameter from 75mm to 1,600mm.

Water CAD uses nodes to connect pipes, assign elevations to the pipe lines, and assign demands to the System. Water CAD defines nodes as specific points at which an event of interest is occurring. In building the model for the whole area of Baghdad, nodes were placed at the following locations:

- Intersection of pipes,
- Boundary points of the discharge pipe network, and
- Other locations where pressures are important for analysis purposes.

In addition to pipe junctions, model elements, such as service reservoirs with booster pump stations and valves, are also treated as nodes by Water CAD. These nodes are not typically used for allocating water demand in a water distribution system.

A.2.3 Analysis Model and Software

The following models are analyzed using the software program Water CAD:

(1) Trunk Model for BWA Service Area:

- Average Daily Flow: ADF
- Maximum Daily Flow: MDF (1.365 to 1.250 x ADF)
- Peak Hourly Flow: PHF (2.25 x ADF)

(2) Distribution Models for Karkh and Rasafa

- Average Daily Flow: ADF
- Maximum Daily Flow: MDF (1.365 to 1.250 x ADF)
- Peak Hourly Flow: PHF (2.25 x ADF)

(3) Distribution Model for the Priority area (WSZs R2, R3 and R14)

- Average Daily Flow: ADF
- Maximum Daily Flow: MDF (1.365 to 1.250 x ADF)
- Peak Hourly Flow: PHF (2.25 x ADF)

For the hydraulic calculations, the Hazen Williams formula was applied:

$V=0.849 \times Chw \times R_h^{0.63} \times I^{0.54}$

where, Chw: Roughness Coefficient =130

R_h: Hydraulic Radius

I: Hydraulic Gradient

A.2.4 Model Construction

(1) Model Construction for Baghdad City

1) Summary of model construction

Analysis of a water distribution system entails the construction of a hydraulic model which includes transmission mains and major distribution networks from the water treatment plants to the individual WSZs. Input data for the hydraulic model required that water demand figures be developed for each WSZ. The hydraulic model was built using Water CAD and the following factors were considered for the model construction.

- Transmission system: diameters of pipelines range from 500 mm to 2,300 mm and the total length is about 280 km.
- Distribution system: diameters of pipelines range from 250 mm to 500 mm and the total length is about 900 km.
- Number of WTPs: eight WTPs
- Number of CUs: eight CU-sites were included from among 16 CU-sites connected with the network
- Number of Service Reservoirs: eight reservoirs
- Elevation: varying from 32m to 37m above mean sea level.
- Water demand allocation as follows:

Description	2005	2014	2027
1. Distribution System			
1.1 Average Daily Flow: ADF (m^3/s)	29.5	36.4	53.1
1.2 Maximum Daily Flow: MDF (m^3/s)	40.3	47.0	66.3
1.3 Peak Hourly Flow: PHF (m^3/s)	66.4	81.9	119.4
2. Transmission System			
2.1 ADF (m^3/s)	29.5	36.4	53.1
2.2 MDF (m^3/s)	40.3	47.0	66.3
2.3 MDF + PHF (m^3/s)	106.7	128.9	185.7

2) Model construction for the existing trunk main

Model for the existing trunk main was constructed below:

Model Element	Description
Total Pipe Length (km)	280
Range of Pipe Diameters	500mm to 2,300mm
Total Number of Pipes	410
Total Number of Nodes	364
Total Number of CU-sites	8
Total Number of SRs	9
Total Number of WTPs	8

3) Model construction for the existing distribution main

Model construction for the existing distribution main is as follows:

Model Element	Description
Total Pipe Length (km)	900
Range of Pipe Diameters (mm)	250mm to 500mm
Total Number of Pipes	2,765
Total Number of Nodes	2,467 (861 for Karkh, 1,606 for Rasafa)
Total Number of CU-sites	8
Total Number of SRs	9
Total Number of WTPs	8

(2) Model Construction for the Priority Area

1) Summary of model construction

The hydraulic model for the priority area (WSZs R2, R3 and R14) was built using Water CAD and the following factors were considered for the model construction.

- The existing distribution system: diameters of pipelines range from 75mm to 1,600mm and the total length is about 1,100 km
- Improved distribution system: diameters of pipelines range from 150 mm to 1,600 mm and the total length is about 1,100 km.
- Case 1 : analyzed for water supply from the Shark Dijlah WTP for WSZs R2, R3 and R14
- Case 2: analyzed for water supply from R2 service reservoir, R3 Sadr WTP and R14 service reservoir for WSZs R2, R3 and R14 respectively.
- Number of CUs: 3 CU-sites for WSZ R3

- Water demand allocation as follows:

WSZ	2005			2014			2027		
	ADF (m^3/s)	MDF (m^3/s)	PHF (m^3/s)	ADF (m^3/s)	MDF (m^3/s)	PHF (m^3/s)	ADF (m^3/s)	MDF (m^3/s)	PHF (m^3/s)
R2	1.9	2.6	4.3	2.3	3.0	5.2	3.6	4.5	8.1
R3	3.5	4.7	7.8	4.3	5.5	9.6	6.1	7.6	13.7
R14	2.7	3.6	6.0	3.2	4.2	7.3	4.6	5.7	10.3
Total	8.1	10.9	18.1	9.8	12.7	22.1	14.3	17.9	32.1

2) Model construction for the existing distribution networks in the priority area:

Model for the existing distribution networks in the priority area: was constructed as below:

Model Element	R2	R3	R14	Total
Total Pipe Length (km)	420	246	451	1,117
Range of Pipe Diameters (mm)	75 to 1,600			
Total Number of Pipes	3,678	1,988	3,808	9,475
Head Pressure of Shark Dijla WTP (m)	65			
Total Number of Nodes	3,266	1,765	3,381	8,412

3) Model construction for improvement of distribution main in the priority area:

Model for improvement of the distribution main in the priority area was constructed for the following two cases:

- Supply from Shark Dijlah WTP:

Model Element	R2	R3	R14	Total
Total Pipe Length (km)	420	246	451	1,117
Range of Pipe Diameters	150 to 1,600			
Total Number of Pipes	3,678	1988	3808	9475
Total Number of Nodes	3,266	1,765	3,381	8,412
Head Pressure of Shark Dijla WTP (m)	65			

- Supply from Service Reservoir or R3 Sadr WTP:

Model Element	R2	R3	R14	Total
Total Pipe Length (km)	420	246	451	1,117
Range of Pipe Diameters	150 to 1,600			
Total Number of Pipes	3,678	1988	3808	9475
Total Number of Nodes	3,266	1,765	3,381	8,412
Head Pressure of R2 SR (m)	50	-	-	-
Head Pressure of R3 Sadr WTP (m)	-	70	-	-
Head Pressure of R14 SR (m)	-	-	60	-

A.3 Hydraulic Analysis

A.3.1 Hydraulic Analysis Execution

Based on the information collected during the data collection efforts, the model development team came to the conclusion that simulation of the current operating condition of Baghdad's water distribution system was not possible. Even if it were, such a model would not be useful for any practical purpose. This is because the current situation in Baghdad is in a major state of change. Major efforts are being expended by many different organizations to correct operational deficiencies at WTPs, reservoirs, and booster pump stations. Power availability is impacting facilities that have no backup generating capacity. Lack of replacement parts affects which equipment is running on any particular day. Control valves that can no longer be operated and that may be jammed in a partially closed position increase the problems of effective operational control. Many treated water pumps are out of service. The remaining pumps have an insufficient supply of water or do not have sufficient delivery capacity to pressurize the system, and, as a result, the control valves have been throttled to keep the pumps within their ranges of recommended operating pressures. The combination of these factors has resulted in extremely low operating pressures throughout the system, especially during the high demand summer periods. This situation is changing and conditions are slowly improving on a day-to-day basis. Rather than current operating conditions, the model presented in this report simulates BWA's potable water distribution system with the assumption that the entire infrastructure incorporated into the model is functional and operating properly.

As more improvements are made and as more accurate information is gathered on the system infrastructure (pipes, valves, pumps, etc.), the model should be updated to more closely simulate the true operating conditions of the system. Unlike an extended-time-simulation model, the development of a single steady-state model that includes both the trunk mains and the distribution networks for the BWA service area does not provide the true hydraulic characteristics of the trunk system nor the results needed to evaluate the carrying capacity of the trunk mains. Two primary reasons for this condition are:

1) For reservoirs having the same water surface elevation, trunk mains will deliver the flow first to the reservoirs having the smallest conveyance head loss from the WTPs. This generally means that the reservoirs closest to the WTPs receive the most inflow. Therefore, the carrying capacity of the trunk mains at the farthest corners of the network and those delivering flow to WSZ reservoirs cannot be evaluated for their capacity to deliver MDFs.

2) WSZs with reservoirs are hydraulically independent from rest of the model. During steady state modelling, the reservoirs in each of the WSZs provide the flow needed to meet the demands of that WSZ (Qd) irrespective of the flow delivered to that WSZ's reservoir (Qt) from the trunk system. When the flow delivered to the reservoir is less than the flow supplied to the distribution system ($Qt < Qd$), the model will simulate a reservoir emptying condition. Similarly the model will simulate a reservoir filling

condition when the influent flow to WSZ reservoir is greater than WSZ's demand (Qt > Qd).

Typically, the flow delivered to the reservoir and flow supplied from the reservoir are not equal (Qt ≠ Qd). Therefore, using the steady state model, the trunk and distribution lines of the BWA potable water system network are modelled separately. For the trunk model, the WSZ reservoirs are replaced by trunk demand nodes in order to evaluate the delivery capacity of the trunk system. Although the distribution model includes the trunk system mains, the distribution model should only be used to evaluate the distribution networks and should not be used to evaluate the hydraulic capacity of the trunk system for the reasons stated above. The per capita demand used for generating the model demands depends on the scenario being modelled (ADF, MDF, and PHF).

A.3.2 Hydraulic Analysis Criteria

A network analysis is the important first step for implementing water supply system improvement including the DMA planning. Results of the hydraulic analysis model are evaluated based on the following criteria:

(1) Flow of hydraulic analysis at each target year

Average Daily Flow (ADF)	Estimation by Unit Water Demand
Maximum Daily Flow (MDF)	1.4 x ADF
Peak Hourly Flow (PHF)	2.25 x ADF

(2) Allowable water pressure

Maximum Water Pressure for Trunk Main	70m
Maximum Water Pressure for Distribution Networks	30m
Minimum Water Pressure for Distribution Networks	10m
Residual Water Pressure at end of service connection	5m

(3) Allowable maximum velocity of pipeline

Trunk Main	less than 3.0 m/s
Distribution Main	less than 2.0 m/s
Distribution Sub-main (Secondary and Tertiary)	less than 1.0 m/s

(4) Head loss gradient evaluation criteria

Head loss gradient Range (m/km)	Evaluation
> 7	To be re-examined
5 to 7	Possibly Inadequate
4 to 5	Limited Acceptable
3 to 4	Acceptable
< 3	Satisfactory

A.3.3 Calibration

The simulation for the whole area of Baghdad was carried out based on the network model using data on the existing water supply facilities from the USAID Report and water demands projected by the JICA Study Team. After the preliminary simulation, the model was calibrated based on updated information and data taken during the study. The following factors were calibrated:

Factor	1st Analysis	Revised Analysis
Peak Day Factor	1.40	1.365 in 2005, 1.292 in 2014, 1.250 in 2027
Coefficient for All Pipes	110	130
Pipe Length for Priority Area (km)	900	1,100
Range of Pipe Diameters for Priority Area (mm)	250mm to 500mm	75mm to 1,600mm

A.3.4 Simulation Results and Recommended Improvements

(1) Simulation Results

The network analysis for the trunk mains in the whole service area and distribution networks in Karkh and Rasafa was carried out using a simplified computer model as shown in Figures A.3.1, A.3.10 and A.3.19 respectively. The specific parameters of the distribution network such as pipe lengths, diameters and elevations were converted into links and nodes of the computer model. Simulation results are presented below:

1) Trunk Mains for Existing Network	
- 2005 (ADF, MDF, PHF)	Figures A.3.1
- 2014 (ADF, MDF, PHF)	Figures A.3.2
- 2027 (ADF, MDF, PHF)	Figures A.3.3
2) Distribution Networks for Existing Network in Karkh Side	
- 2005 (ADF, MDF, PHF)	Figures A.3.4
- 2014 (ADF, MDF, PHF)	Figures A.3.5
- 2027 (ADF, MDF, PHF)	Figures A.3.6
3) Distribution Networks for Existing Network in Rasafa Side	
- 2005 (ADF, MDF, PHF)	Figures A.3.7
- 2014 (ADF, MDF, PHF)	Figures A.3.8
- 2027 (ADF, MDF, PHF)	Figures A.3.9
4) Distribution Networks for Existing Network in Priority Area	(Calibrated)
- 2014 (MDF) in R2, R3 & R14 from Shark Dijlah WTP	Figures A.3.10
- 2014 (MDF) in R2, R3 & R14 from SR or Sadr WTP	Figures A.3.11
5) Distribution Networks for Improved Network in WSZ R2	(Calibrated)
Supply from Shark Dijlah WTP	
- 2005 (ADF, MDF, PHF)	Figures A.3.12
- 2014 (ADF, MDF, PHF)	Figures A.3.13
- 2027 (ADF, MDF, PHF)	Figures A.3.14
Supply from R2 service reservoir	
- 2005 (ADF, MDF, PHF)	Figures A.3.15
- 2014 (ADF, MDF, PHF)	Figures A.3.16
- 2027 (ADF, MDF, PHF)	Figures A.3.17
6) Distribution Networks for Improved Network in WSZ R3	(Calibrated)

Supply from Shark Dijlah WTP - 2005 (ADF, MDF, PHF) - 2014 (ADF, MDF, PHF) - 2027 (ADF, MDF, PHF)	 Figures A.3.18 Figures A.3.19 Figures A.3.20
Supply from R3 Sadr WTP - 2005 (ADF, MDF, PHF) - 2014 (ADF, MDF, PHF) - 2027 (ADF, MDF, PHF)	 Figures A.3.21 Figures A.3.22 Figures A.3.23
7) Distribution Networks for Improved Network in WSZ R14 Supply from Shark Dijlah WTP - 2005 (ADF, MDF, PHF) - 2014 (ADF, MDF, PHF) - 2027 (ADF, MDF, PHF)	(Calibrated) Figures A.3.24 Figures A.3.25 Figures A.3.26
Supply from R14 service reservoir - 2005 (ADF, MDF, PHF) - 2014 (ADF, MDF, PHF) - 2027 (ADF, MDF, PHF)	 Figures A.3.27 Figures A.3.28 Figures A.3.29

Results of the analysis suggest changing the network to incorporate and re-group block R2 to neighbouring R3 and R14 zones (see Figure A.3.19). These changes require installation of connecting pipes and isolation valves between R2 and R3. Some regions in R3 and R14 zones are having low pressure problems due to insufficient pipe capacity. Several pipes need to be replaced with larger diameter mains. The results of flow analysis indicate that the instantaneous maximum flow velocity in most pipelines of the zones R3 and R14 is more than 2.0 m/s, while in the distribution main for R2 it is less than 2.0 m/s. In the zones R3 and R14, water pressure in water mains varies from 10 m to 28 m and in R2 water pressure of more than 30 m is estimated. Minimum water pressures in R3, analyzed at the sub mains, are between 0 m and 10 m. These figures do not meet BWA's minimum criteria of 10 m. Head loss gradient in R2 is acceptable at less than 3 m, while in the zones R3 and R14 it is mostly more than 4 m. Head loss gradient of the main connected between R2 and R3 is in a critical condition with a head loss of more than 7 m. Results of the analysis suggest changing the network to incorporate and re-group large block R2 to neighbouring R3 zone (see Figure A.3.19).

(2) Summary of Simulation Results for the Existing Trunk and Distribution System in Baghdad

1) Trunk System

This section identifies some of the potential problem areas to help focus BWA's efforts to take advantage of the model to identify alternatives that can improve the hydraulics in BWA's drinking water system. Various alternative solutions available to reduce head loss and/or increase pressures should be evaluated for each of these areas before identifying an alternative for implementation. This evaluation also helps in understanding the impact of a particular alternative on the rest of the system and some alternatives could improve the conditions in other identified areas of concern.

The trunk line delivering flow to IIB reservoir has inadequate pressure to deliver the flow required despite satisfactory head loss gradient. This condition reduces the flow delivered to IIB reservoir which will impact the drinking water supplies available for distribution in Rasafa area. Alternatives should be evaluated to boost pressure in this line to ensure adequate flow is delivered to IIB reservoir

Head loss gradient in trunk lines supplying drinking water to WSZs R1 and R2 from IIB reservoir is high (> 5m/km) through these two lines. Reinforcement of these lines or construction of a perimeter trunk system around the outside of the city to relieve the demand carried by these pipes should be considered.

2) Karkh side

MODEL	SCENARIO	RESULTS
1. Trunk System		Almost all trunk mains are sufficient
2. Distribution System	2005 ADF	All zones can receive water at acceptable pressures
	2005 MDF	Southern part of K10 and some parts in the north west of K1 and K6 have inadequate pressure with less than 10 m
	2005 PHF	Water can not be delivered to K10 and inadequate pressure in the NE of K7
	2014 ADF	only inadequate pressure in K6 and the north of K7
	2014 MDF	Inadequate pressure in K10,K6 and the north east of K7
	2014 PHF	Water can not be delivered to K10 and the north of K6 and K4 and S of K3
	2027 ADF	Water can not be delivered to k10 and inadequate pressure in K6 and k2
	2027 MDF	Water can not be delivered to k10 and inadequate pressure in K6, the north east of K7 and E of K9
	2027 PHF	Water can not be delivered to k10 K8,K4, the south east of K3 and parts of K6 and K7

3) Rasafa side

MODEL	SCENARIO	RESULTS
1. Trunk System		Some trunk mains for R3, R7/13, R10 are not sufficient
2. Distribution system	2005 ADF	Delivery pressure is limited acceptable in the north of R3.
	2005 MDF	Delivery pressure is Unacceptable in the north east and middle of R3 and Inadequate in the south west part of R3
	2005 PDF	Delivery pressures in R3 and R14 are unacceptable. Pressure in R2, R5, the north east of R9 and parts of R4 are Inadequate.
	2014 ADF	Delivery pressure in R3 is inadequate.
	2014 MDF	Delivery pressures in R3 and NE of R10 are unacceptable and pressure in R14 is inadequate.
	2014 PHF	Delivery pressure in R2, R14, R3, R5, and the north east of R9 are unacceptable and pressure in the middle of R9 and R6, and the south east of R9 are inadequate
	2027 ADF	Delivery pressure in R3 and the north east of R10 are unacceptable. Pressures in the zones in the north east of R2 and R14 are inadequate
	2027 MDF	Water can not be delivered in zones R3,R14, the north east of R2, and the north east of R10 and the delivery pressures are inadequate in zones R2,R5 and north east of R9,R7/13
	2027 PHF	Water cannot be delivered to all zones, excepting the north east of R6 and the south west of R7/13

(3) Hydraulic Analysis Results and Recommendations

The results of the hydraulic analysis and recommendations are summarized below:

- For present and future average daily flow, distribution networks on the Karkh side are sufficient; however, they are not sufficient on the Rasafa side, especially in R3 and R14.
- For future peak hourly flow, almost all distribution networks will be in a critical condition with more than 7 m/km of head loss gradient.
- For the present peak hourly flow, in the Karkh side zones K1, K5, K6, K10 and in the Rasafa side zones R1, R2, R3, R14, R7/13, R4, R5, R6, R11 are in a critical condition with more than 7 m/km of head loss.
- Changing the network to incorporate and re-group large block R2 to neighboring R3 zone is recommended.
- These changes require the installation of connecting pipes and isolation valves between R2 and R3.
- Several pipes of the existing trunk and distribution networks capacity in R3 and R14 need to be improved since some networks in the zones are having low pressure problems due to insufficient pipe capacity.
- The instantaneous maximum flow velocity in most pipelines of zones R3 and R14 is more than 2.0 m/s, while in the distribution mains of R2 it is less than 2.0 m/s.
- In zones R3 and R14 water pressure in the distribution mains varies from 10 m to 28 m and in R2 water pressure of higher than 30 m is estimated.
- Minimum water pressures in R3, as analyzed at the sub mains consisting of secondary and tertiary, are between 0 m and 10 m. These figures do not meet BWA's minimum criteria of 10 m.
- Head loss gradient in R2 is acceptable at less than 3 m, while in zones R3 and R14 it is mostly more than 4 m.
- Head loss gradient of the mains connecting between R2 and R3 are in a critical condition with more than 7 m head loss.
- Results suggest that WSZs on the Rasafa side should be improved urgently by means of improvement of the distribution network to provide proper pipe capacity and also a service reservoir at each WSZ is recommended.

N
W E
S

Bench Marck

32.23 Elevation No.

Service Reservoir Boundary

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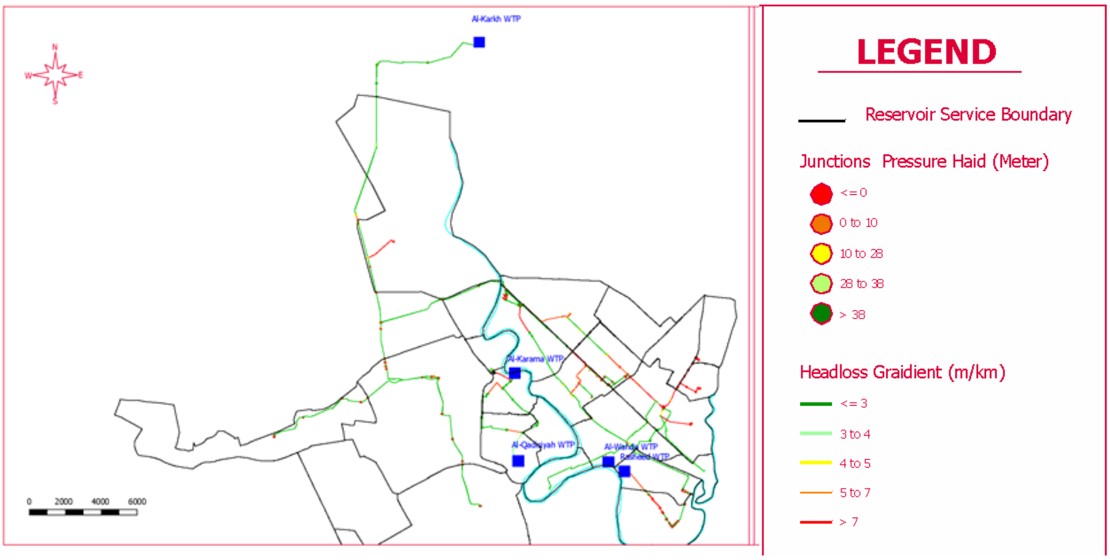
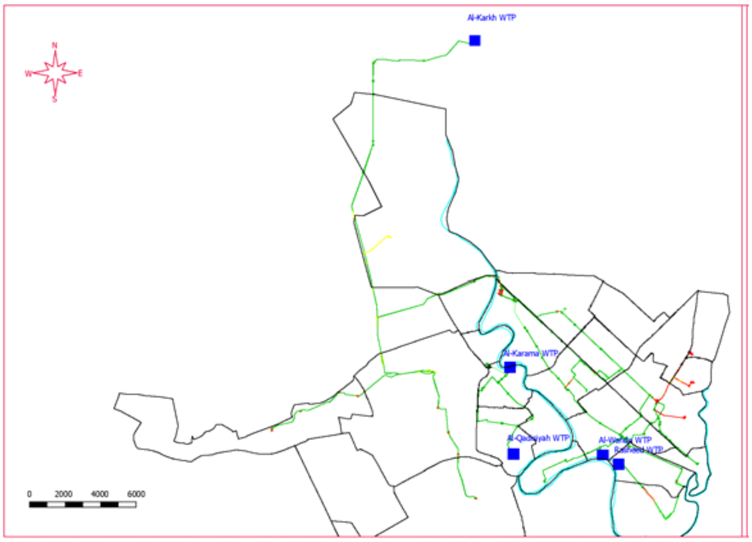
			Scale: As-Shown	Date:	Figure A.2.1

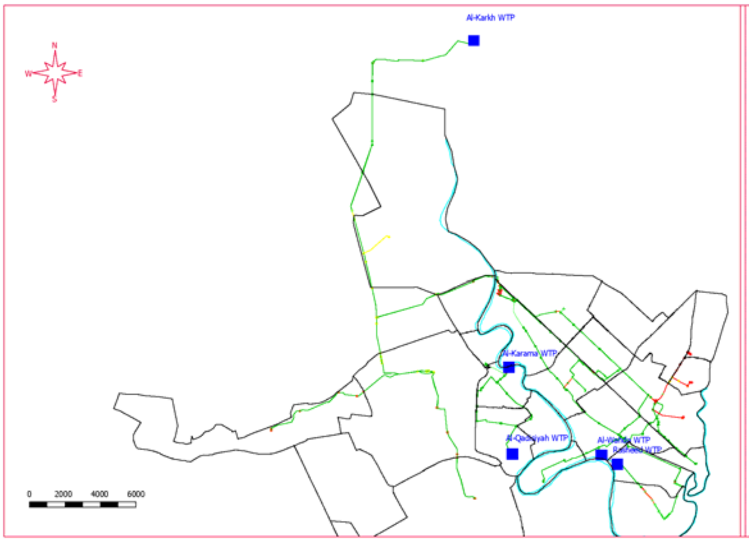
2005-ADF



2005-MDF



2005-PHF



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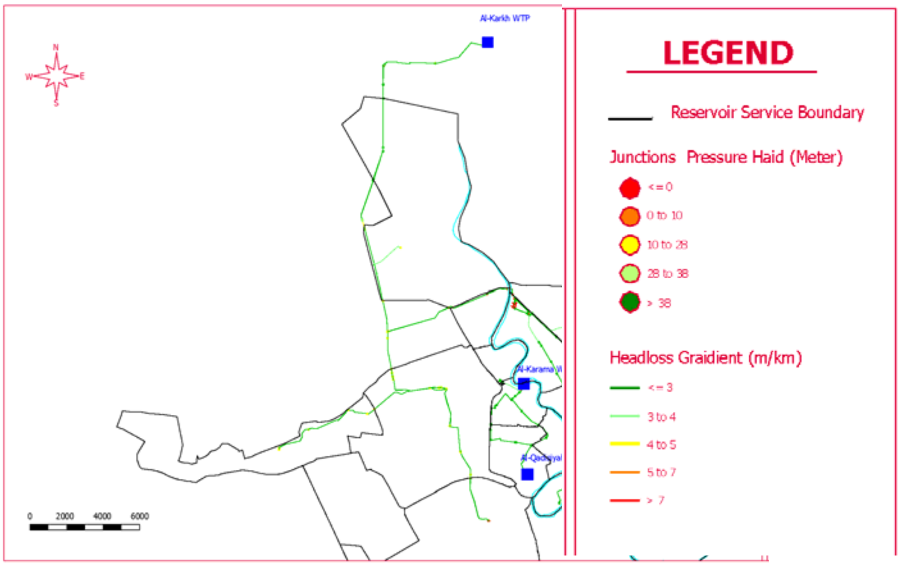
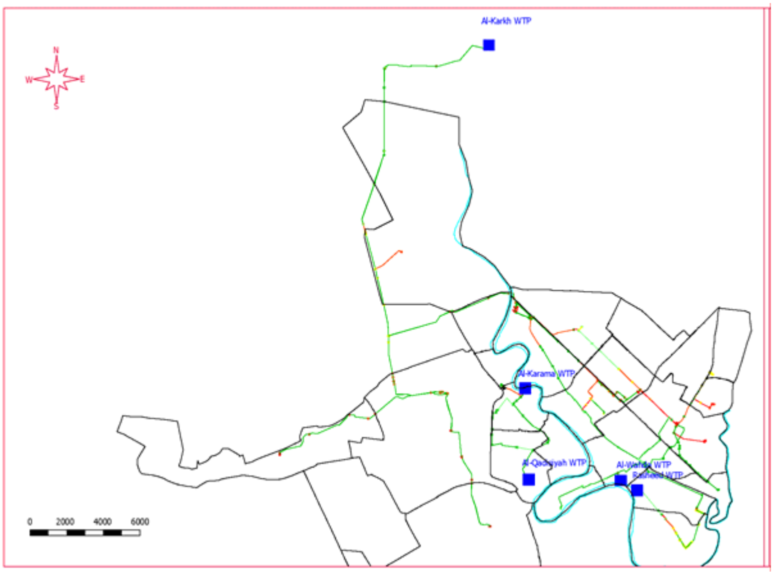
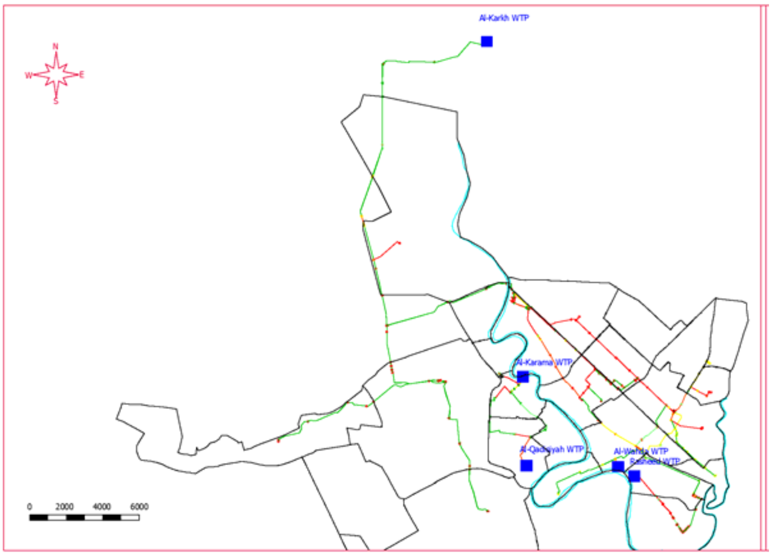
2014-ADF



2014-MDF

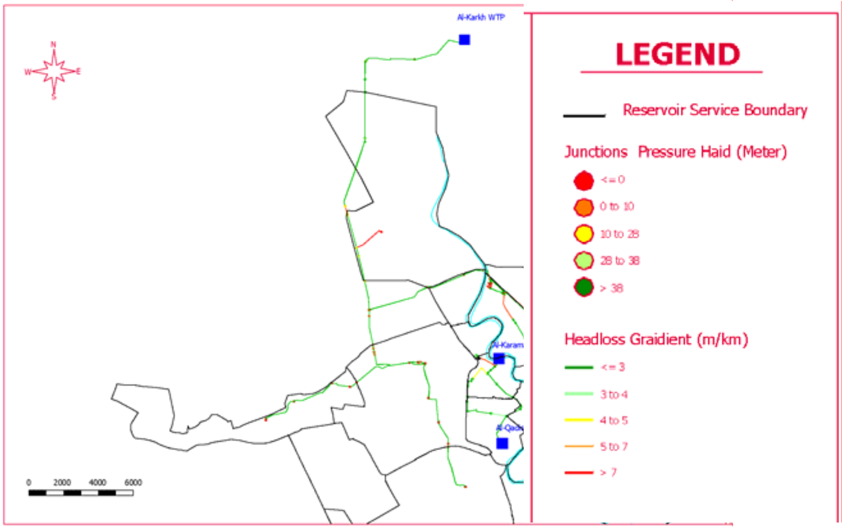


2014-PHF

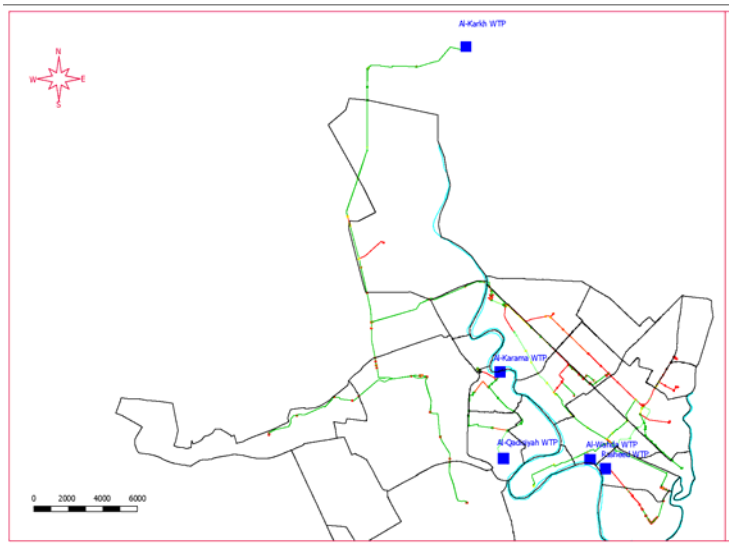


JICA **Japan International Cooperation Agency**	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. **Tokyo Engineering Consultants Co.,Ltd.**	**Title** TRUNK MAIN FOR EXISTING NETWORK 2014 – (ADF, MDF, PHF) **Figure** Figure A.3.2

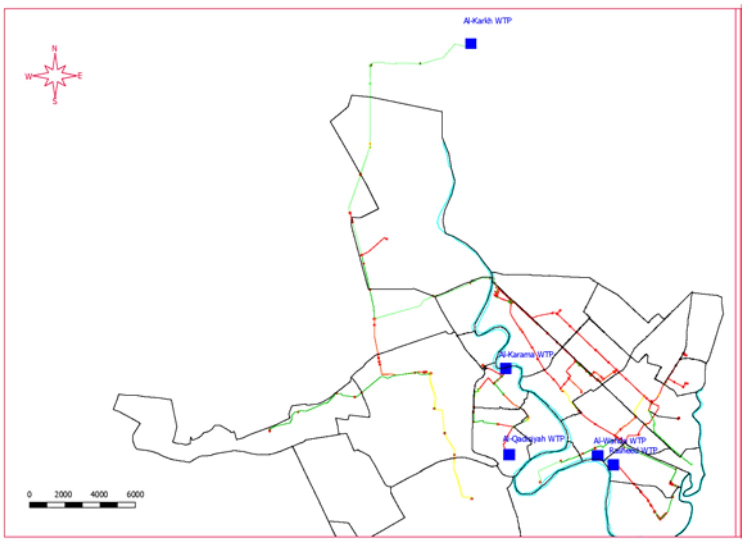
2027-ADF



2027-MDF

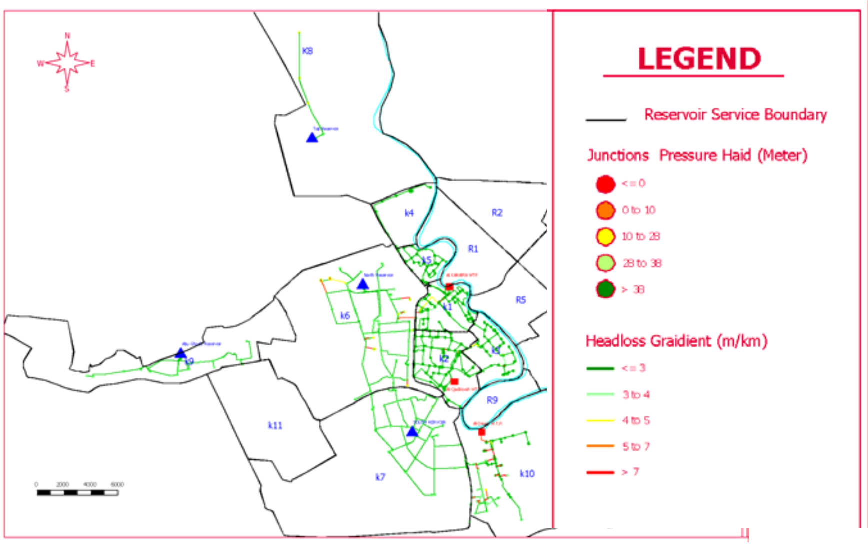


2027-PHF

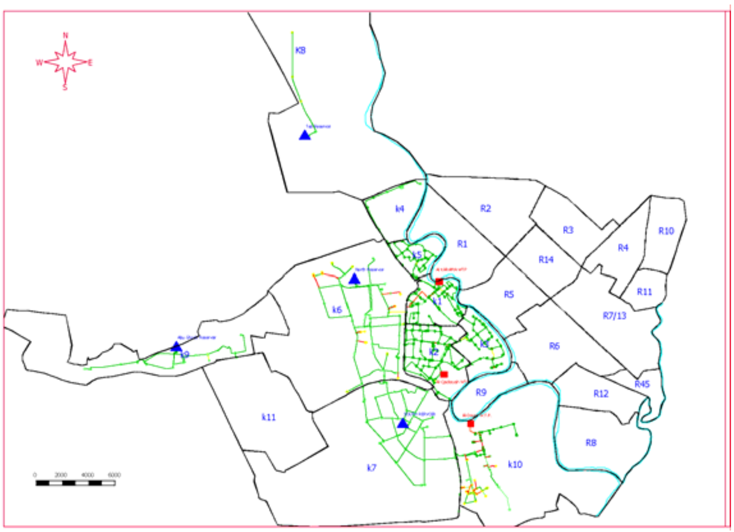


JICA **Japan International Cooperation Agency**	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. **Tokyo Engineering Consultants Co.,Ltd.**	**Title** TRUNK MAIN FOR EXISTING NETWORK 2027 – (ADF, MDF, PHF) **Figure** Figure A.3.3

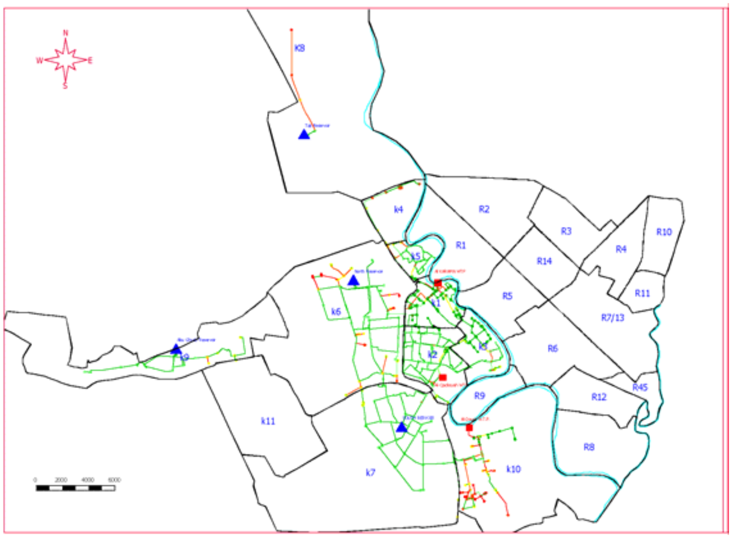
2005-ADF



2005-MDF



2005-PHF



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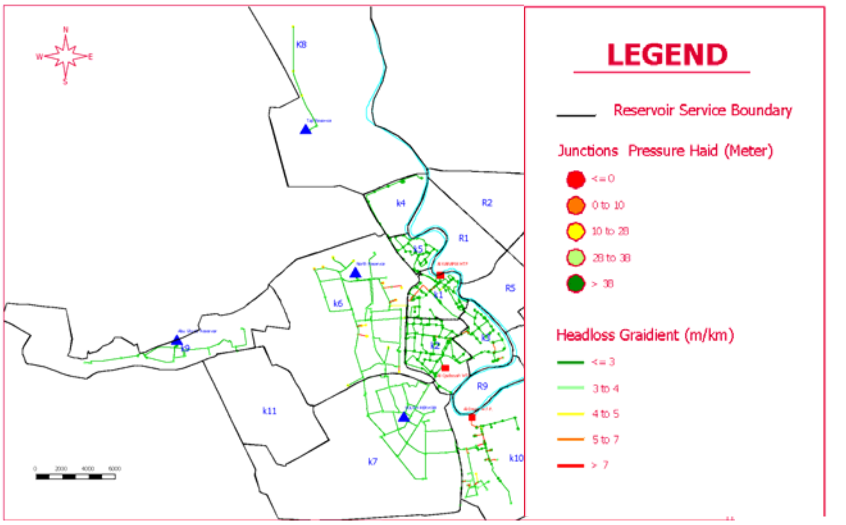
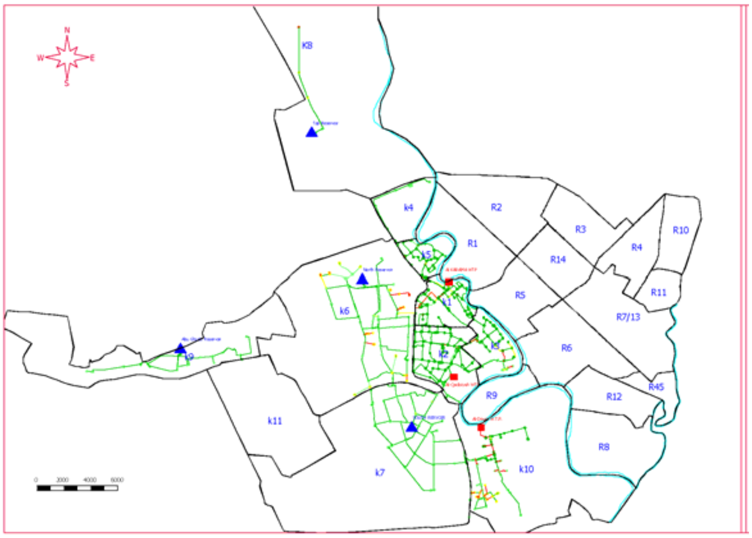
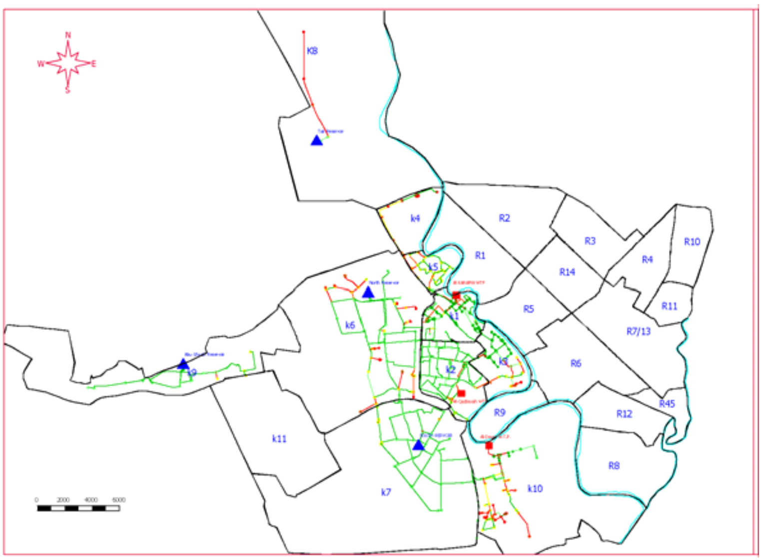
2014-ADF



2014-MDF



2014-PHF



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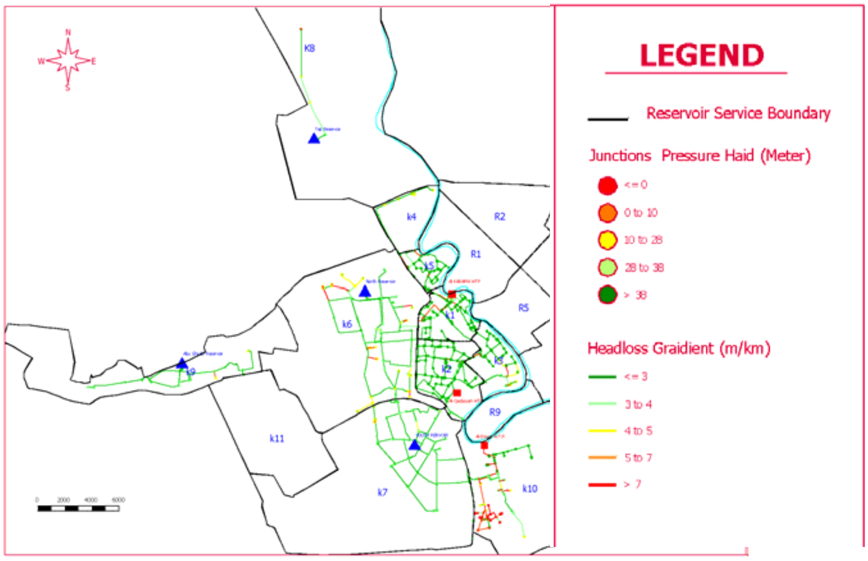
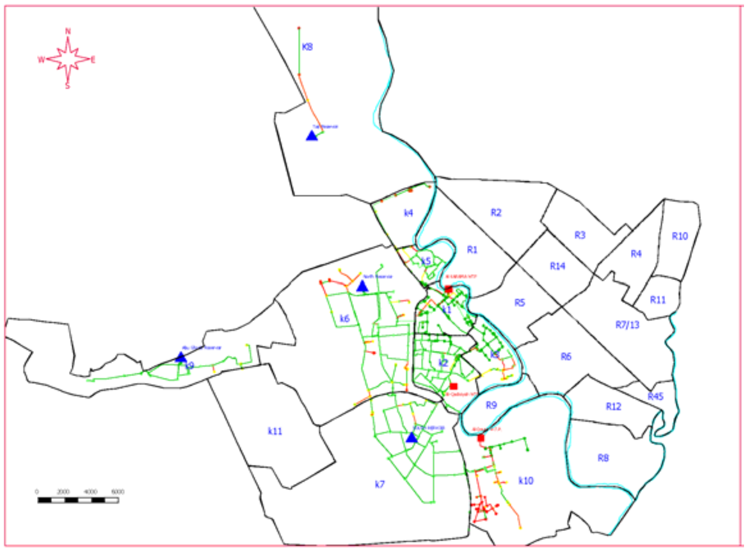
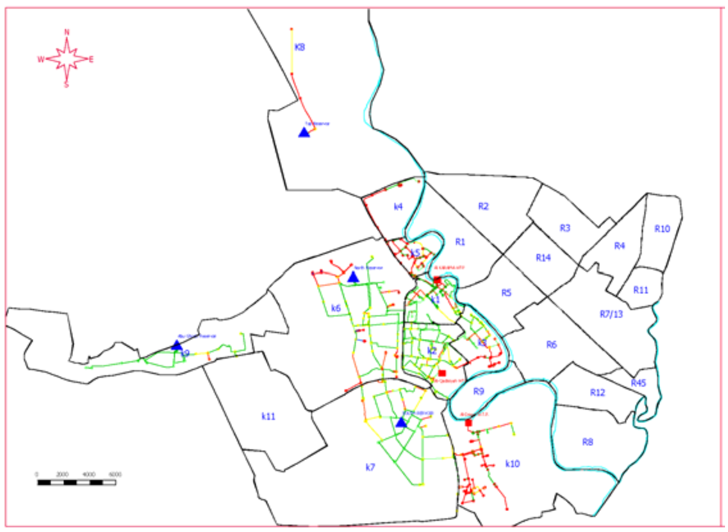
2027-ADF



2027-MDF



2027-PHF



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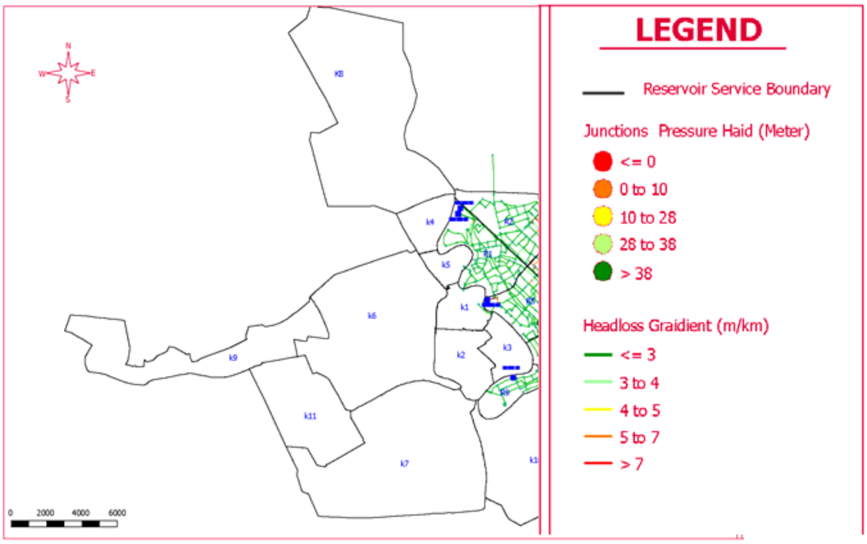
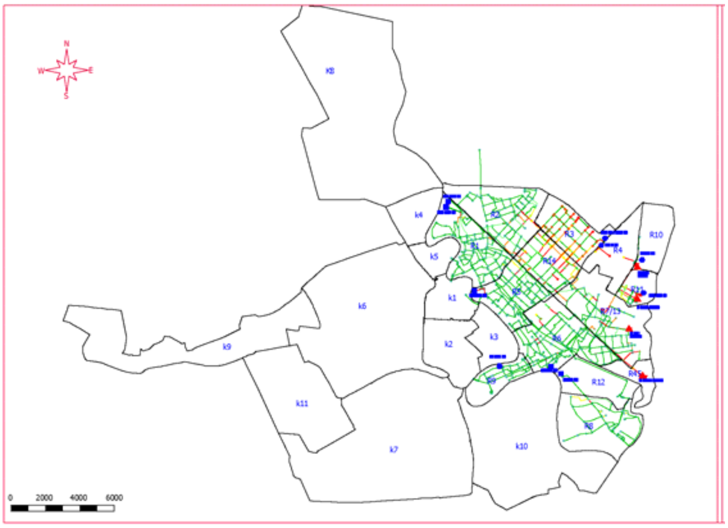
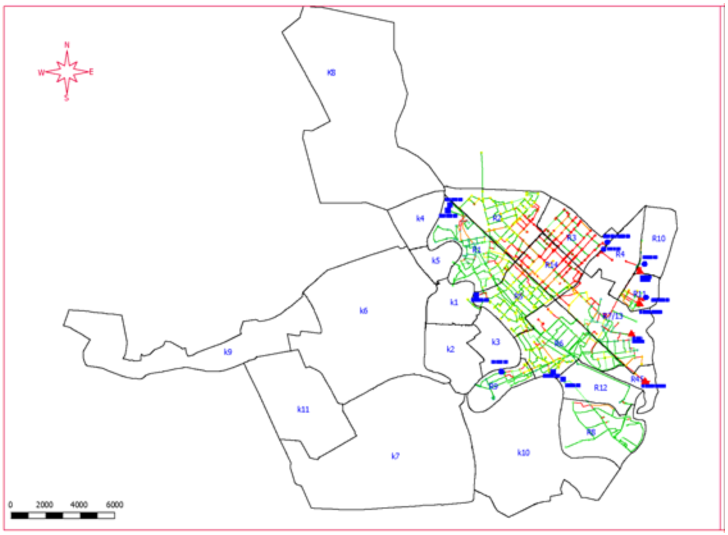
2005-ADF



2005-MDF



2005-PHF



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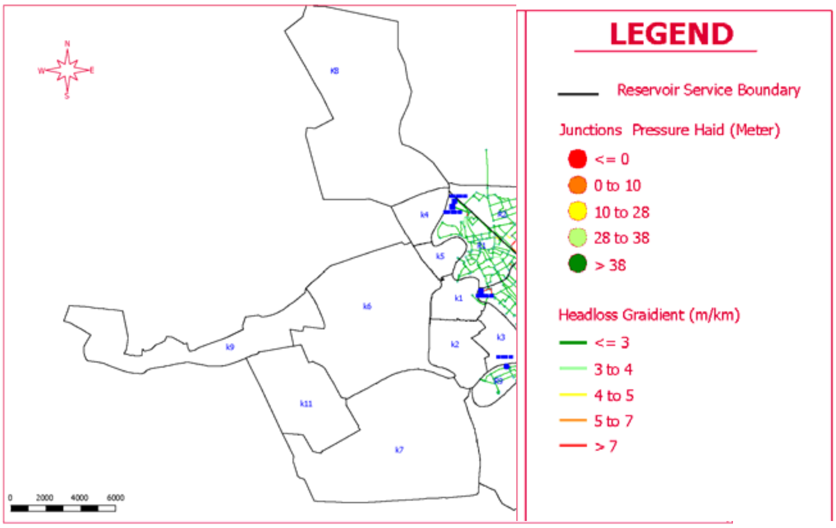
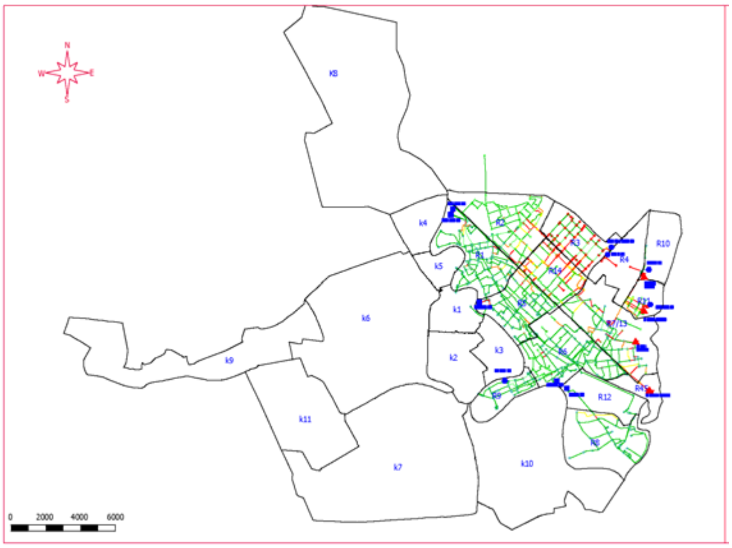
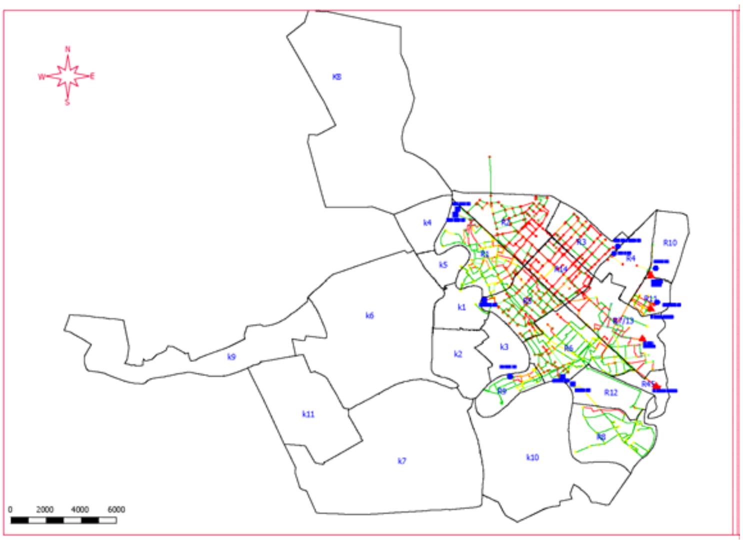
2014-ADF



2014-MDF

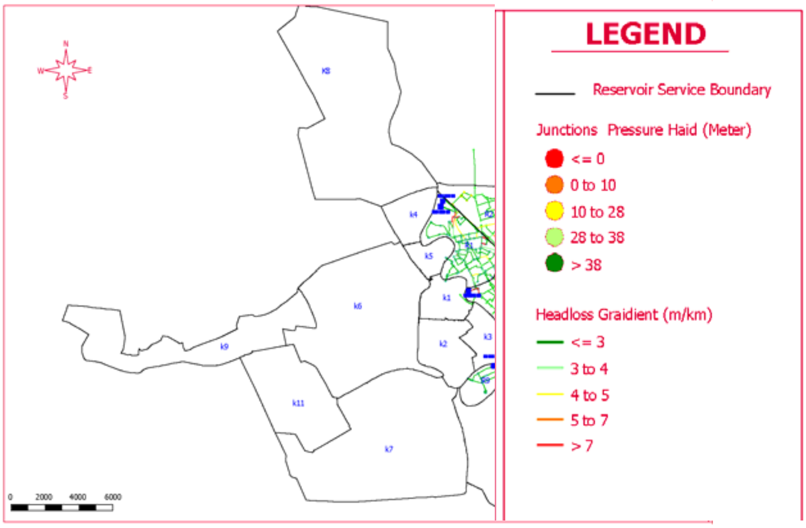


2014-PHF

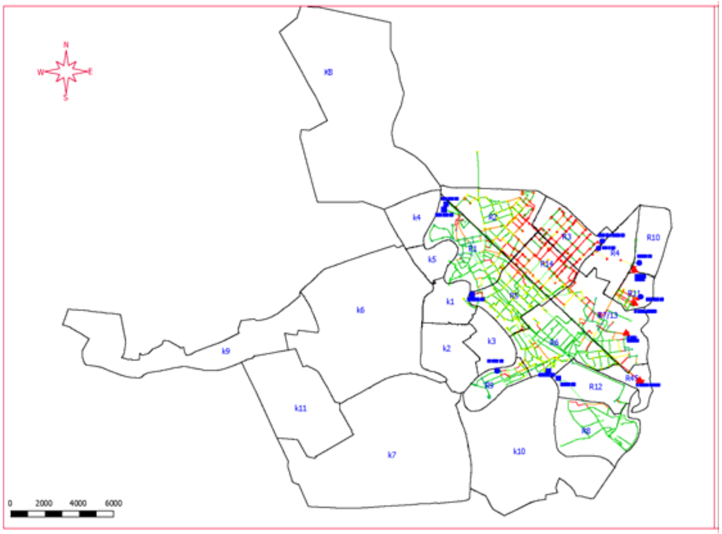


Japan International Cooperation Agency	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. **Tokyo Engineering Consultants Co.,Ltd.**	**Title** DISTRIBUTION NETWORK FOR EXISTING NETWORK IN RASAFA SIDE 2014 – (ADF, MDF, PHF) **Figure** Figure A.3.8

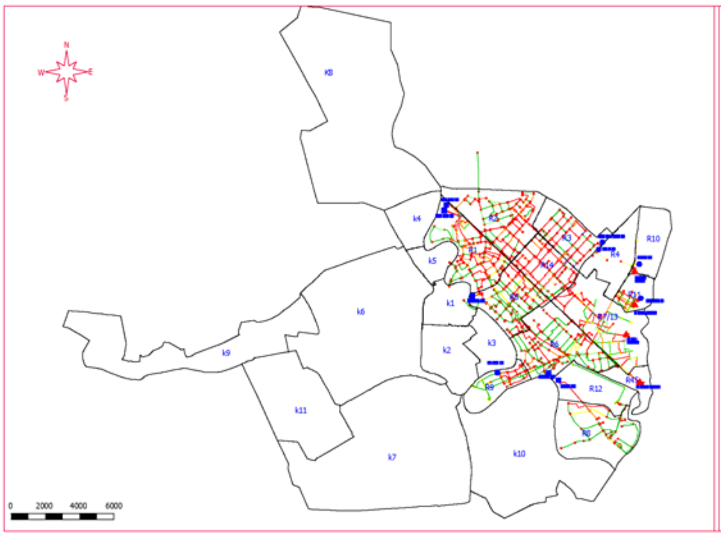
2027-ADF



2027-MDF



2027-PHF



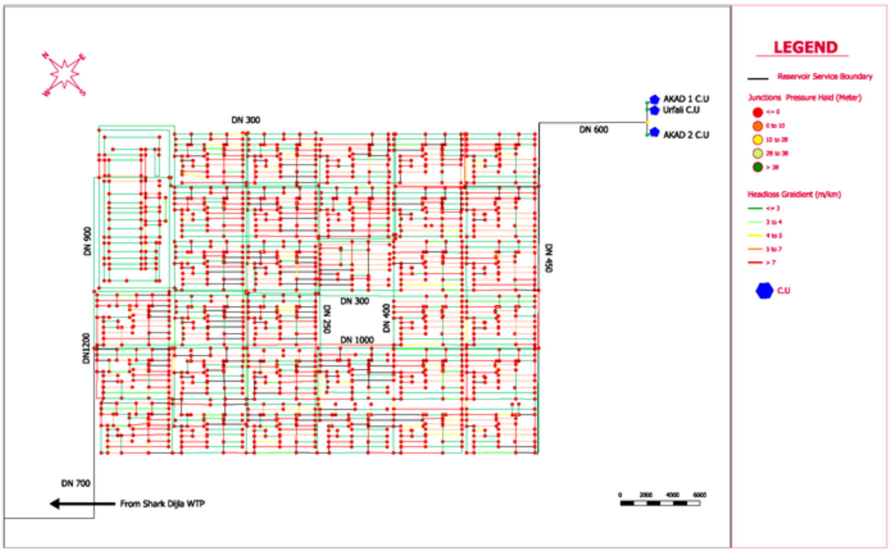
Japan International Cooperation Agency	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. Tokyo Engineering Consultants Co.,Ltd.	**Title** DISTRIBUTION NETWORK FOR EXISTING NETWORK IN RASAFA SIDE 2027 – (ADF, MDF, PHF) **Figure** Figure A.3.9

2014-MDF

in R2

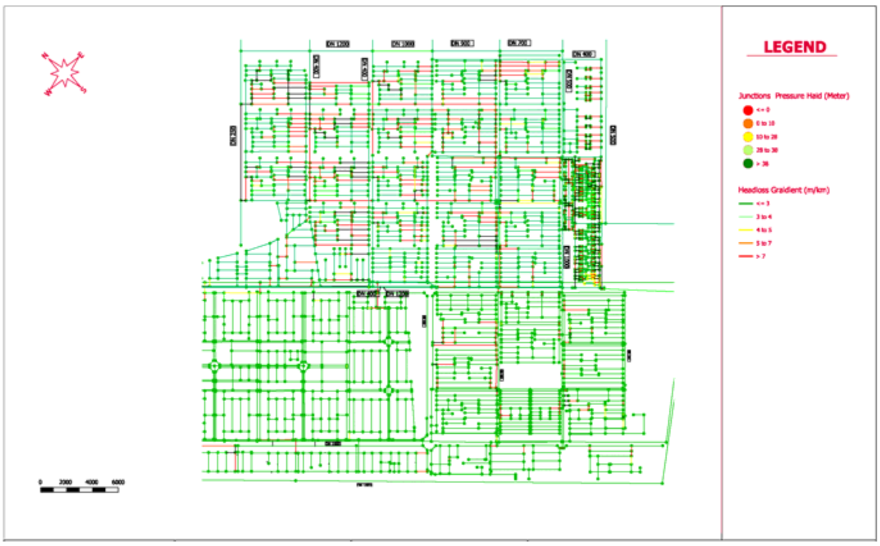
2014-MDF

in R3



2014-MDF

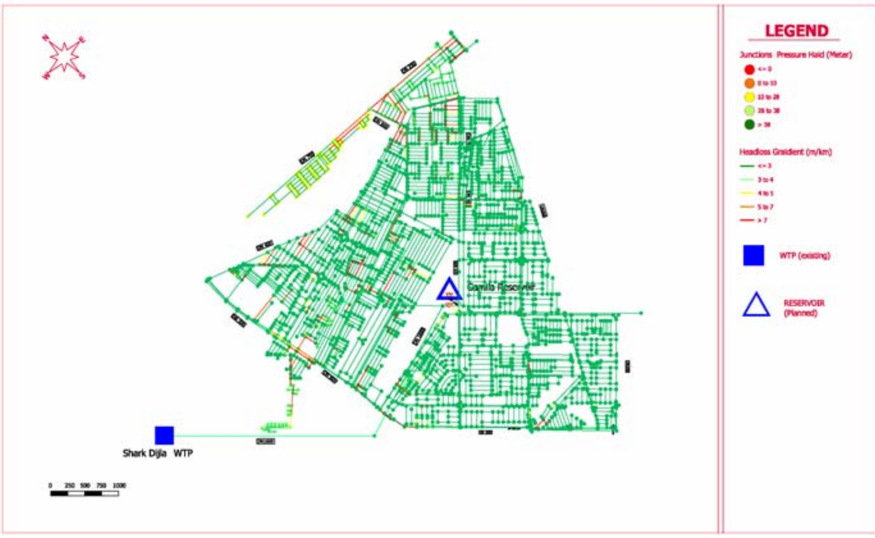
in R14



Japan International Cooperation Agency	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. **Tokyo Engineering Consultants Co.,Ltd.**	**Title** DISTRIBUTION NETWORK FOR EXISTING NETWORK IN PRIORITY AREA 2014 – (MDF) IN R2,R3,R14FROM SHARK DIJLA WTP **Figure** Figure A.3.10

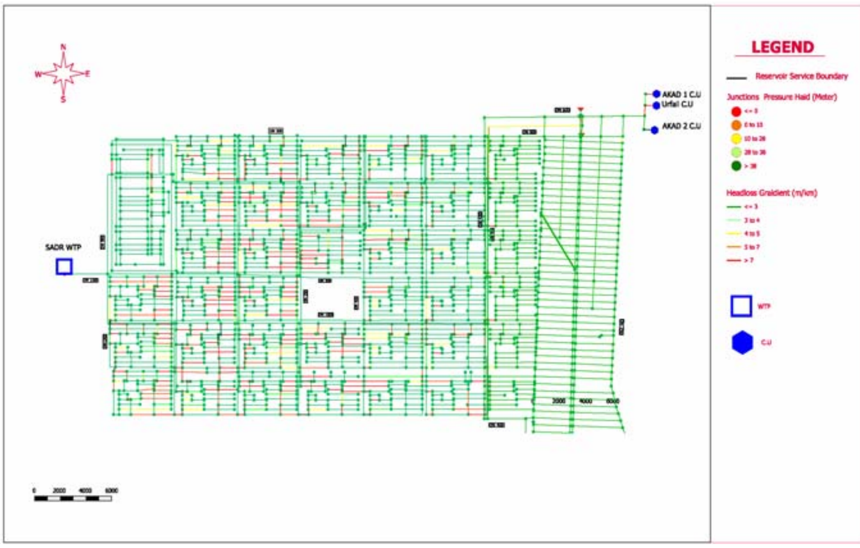
2014-MDF

in R2



2014-MDF

in R3

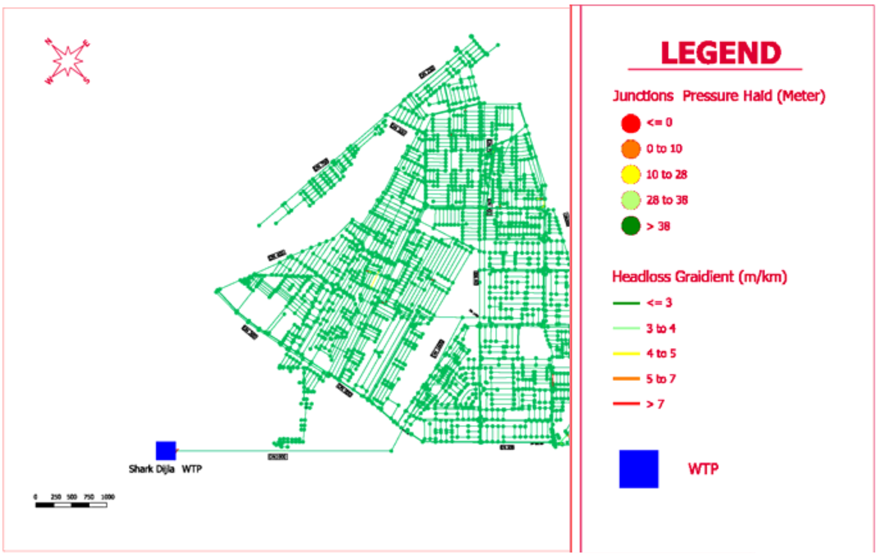


2014-MDF

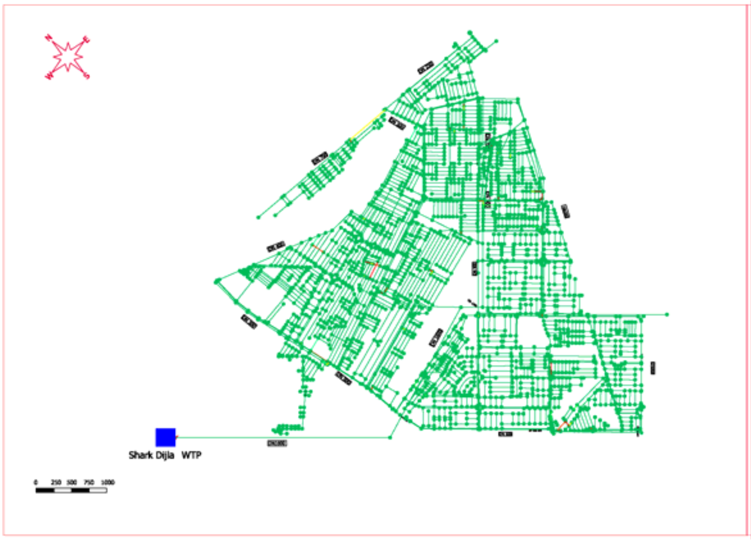
in R14

Japan International Cooperation Agency	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. Tokyo Engineering Consultants Co.,Ltd.	**Title** DISTRIBUTION NETWORK FOR EXISTING NETWORK IN PRIORITY AREA 2014 – (MDF) IN R2,R3,R14FROM SR OR SADR WTP **Figure** Figure A.3.11

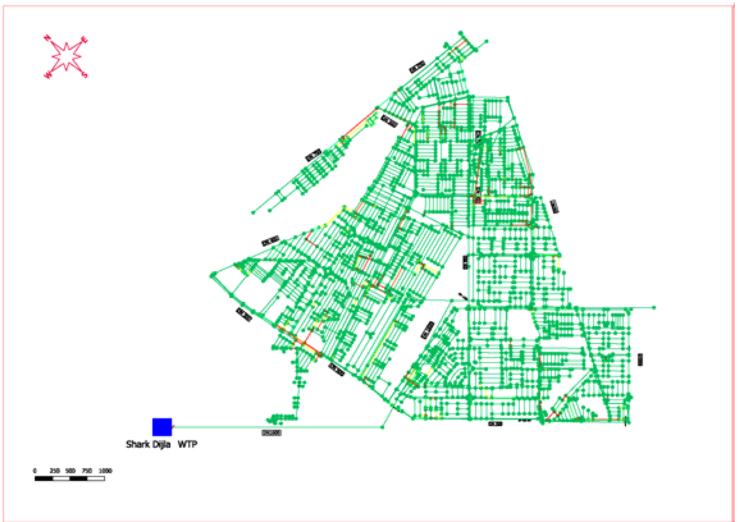
2005-ADF



2005-MDF

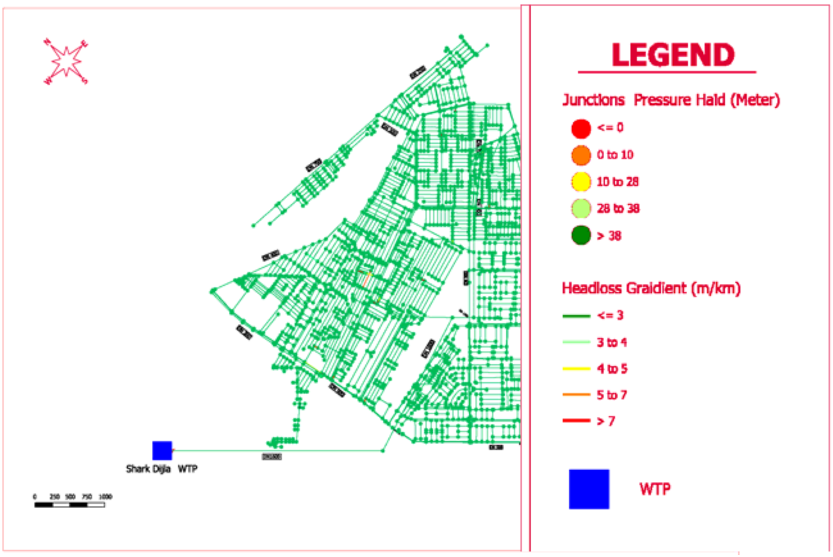


2005-PHF

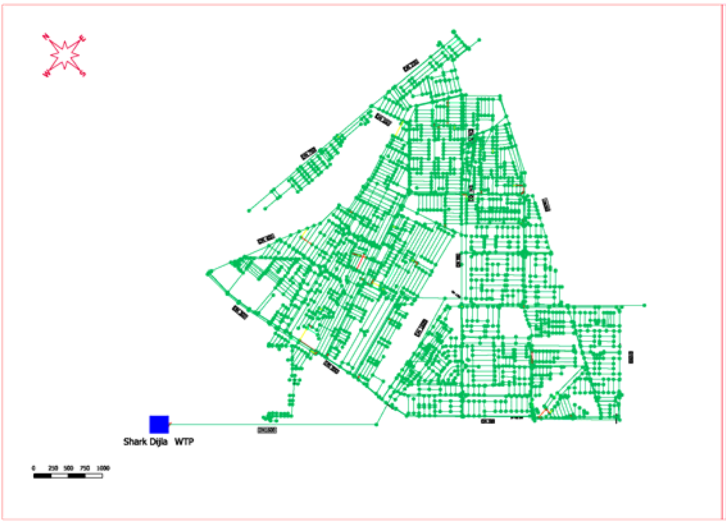


Japan International Cooperation Agency	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. **Tokyo Engineering Consultants Co.,Ltd.**	**Title** DISTRIBUTION NETWORK FOR IMPROVED NETWORK IN WSZ R2 SUPPLY FROM SHARK DIJLAH WTP -2005(ADF, MDF, PHF) **Figure** Figure A.3.12

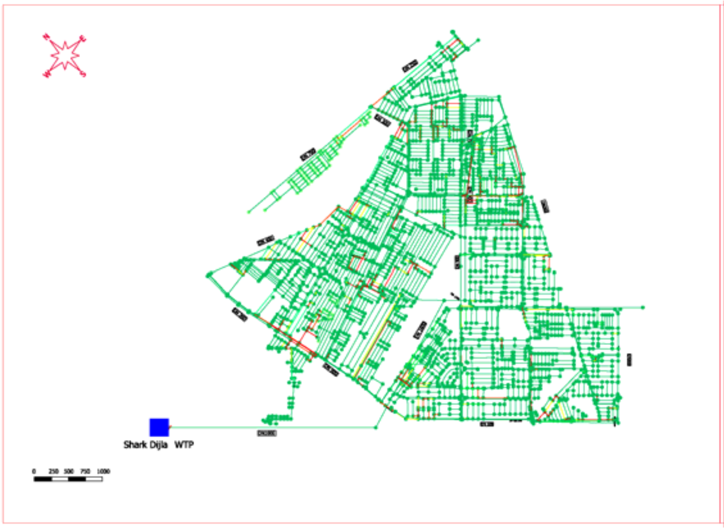
2014-ADF



2014-MDF



2014-PHF



Japan International Cooperation Agency	The Feasibility Study on Baghdad Water Supply System Improvement Project in the Republic of Iraq	NIPPON KOEI CO.,LTD. **Tokyo Engineering Consultants Co.,Ltd.**	**Title** DISTRIBUTION NETWORK FOR IMPROVED NETWORK IN WSZ R2 SUPPLY FROM SHARK DIJLAH WTP -2014 (ADF, MDF, PHF) **Figure** Figure A.3.13