

## **VII. POWER SYSTEM STUDY**

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## **VII. POWER SYSTEM STUDY**

### **INTRODUCTION**

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## Introduction

- Power System consists of three major divisions viz. Generation, Transmission and Distribution. Transmission Systems are the links between generating stations and the Distribution systems. Distribution system connects all the loads to transmission lines at substations.
- AC Electrical system was developed in 1885 in US. Until 1917 these systems were usually operated as individual units. With the increase of load and increase in the demand for reliability, interconnection between neighboring systems started growing.
- Interconnections are advantageous economically because fewer machines are required as reserve (reserve capacity) for operation at peak loads and fewer machines running without load (spinning reserve) are required to take care of sudden unexpected increase in load.

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## Introduction

- But inter connections brought many new problems. It increases the amount of current which flows when a short circuit occurs on a system, which requires installation of breakers of higher breaking capacity. The disturbance caused by short circuit on one system may spread to other interconnected system unless proper protection systems are provided at the point of inter connection. Moreover, the synchronous machines of one system must remain in step with the synchronous machines of the other interconnected systems.
- It is thus obvious that for reliable operation of power system all the above are known and addressed. This knowledge is obtained through Power System studies, the parts of which are –
  - 1) Fault Study
  - 2) Load Flow Study and
  - 3) Stability Study

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### FAULT STUDY

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### Fault Study

- When a fault occurs, the immediate current flows (Sub-Transient current) through different element of Power System differs from that flowing a few cycle later (Transient Current) when the circuit breakers are called upon to open and both these currents differ widely from the current under normal operating condition (Steady State Current). Selection of circuit breaker at any particular position depends, apart from nominal steady state current capability, upon –
  - 1) Sub-Transient Current, which the breaker must withstand
  - 2) Transient Current which the breaker must interrupt
- Fault studies determine these currents for various types of faults at various locations of the system. The data obtained from fault calculation is also utilized to determine the settings of the relays.

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### **LOAD FLOW STUDY**

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### **Load Flow Study**

- In an electrical network, the power flow through any element depends upon the difference in magnitude and phase angle of voltage across the element. Thus a change in load or change in voltage owing to alteration in network leads to change in power flow through the element.
- Through this study, voltage, current, active power, reactive power and power factor at various point in the network are determined under various modes of power system operation. Load flow studies are also essential in planning the future development / alteration of the power system.

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### STABILITY STUDY

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### Stability Study

- When a synchronous generator runs in parallel with other generator/s, the power output depends on –
  - i) Magnitude of its generated internal voltage
  - ii) Phase angle of this voltage w.r.t. the generated voltage of the other generator/s
  - iii) Characteristics of the network
- When a change in load occurs, all the generators connected to the system will respond to the change by adjusting the magnitude and or phase angle of the generated voltages. *Voltage stability* is the ability of a power system to maintain steady acceptable voltage magnitude at all buses in the system under normal operating condition and after being subjected to a disturbance.
- The phase angles of the generated voltages depend upon the relative positions of the rotors of the machines. If the phase angle of these generated voltages change constantly and progressively with respect to each other, satisfactory operation would be impossible. Rotor *Angle Stability* is the ability of interconnected synchronous machines to remain in synchronism.

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### SYMMETRICAL THREE PHASE FAULT AT GENERATOR TERMINAL

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### Symmetrical Three Phase Fault at Generator Terminal

- When a short circuit is applied to the terminals of a synchronous generator, the initial resistance to the fault current is offered by the sub-transient reactance ( $X_d''$ ) of the machine. With passage of time (a few cycles), armature reaction comes into play and a new higher resistance is offered by the transient reactance ( $X_d'$ ) of the machine. If the condition is allowed to persist for some more time (a few more cycles), the resistance to the fault current further increases and is offered by synchronous reactance ( $X_d$ ) of the machine.
- From the knowledge of sudden energizing of series RL circuit we know that depending upon the instant of switching, a unidirectional DC component of current is introduced and the total current is the AC component superimposed on the DC component.

$$i = \{V_{\max} / |Z_s|\} \{ \sin(\omega t + \alpha - \theta) - e^{-Rt/L} \sin(\alpha - \theta) \}$$

- Since the voltages of the phases of the three phase machine are displaced by  $120^\circ$  from each other, the short circuit occurs at different points on the voltage wave of each phase. For this reason, the DC component of current is different in each phase. If the DC component of current is removed from each phase, the resulting wave for each phase is as shown below;

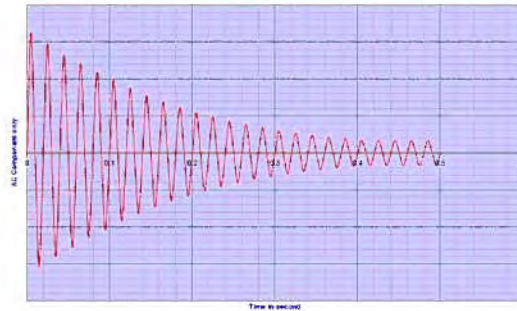
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## Symmetrical Three Phase Fault at Generator Terminal

Short Circuiting of Generator



- From the above it is clear that, short circuiting at generator terminal leads to fault current which diminishes with time. For the first few cycles, the fault current is of maximum value and is called as sub-transient fault current followed by the transient fault current. The fault current continuously diminishes till a stable fault current called as steady state fault current is reached. On the basis of the study objective, relevant reactances and hence relevant fault currents are considered.

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## VII. POWER SYSTEM STUDY

### PER-UNIT SYSTEM

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## Introduction

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- In power systems there are so many different elements such as Motors, Generators and Transformers with very different sizes and nominal values.
- To be able to compare the performances of a big and a small element, per unit system is used.

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## Power System Representation

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- Physical Components in the system are represented by a mathematical model.
- Mathematical models of components are connected in exactly the same way as the physical components to obtain the system representation.
- Various physical components have different ratings or basis.
- It is convenient to obtain the representation with respect to a common basis.

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## Per Unit And Percent Representation

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- The numerical *per unit* value of any quantity is its ratio to the chosen base quantity of the same dimensions.
- Thus a per unit quantity is a normalized quantity with respect to a chosen base value.
- Percent is the per unit quantity multiplied by a 100.

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## Advantages

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- In the per-unit system of representation, device parameters tend to fall in a relatively fixed range, making erroneous values prominent.
- Ideal transformers are eliminated as circuit elements. This results in a large saving in component representation and reduces computational burden.
- The voltage magnitude throughout a given power system is relatively close to unity in the per-unit system for a power system operating normally. This characteristic provides a useful check on the calculations.

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## Base Quantities(1)

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- In power system calculations the nominal voltage of lines and equipment is almost always known, so the voltage is a convenient base value to choose.
- The apparent power (volt-ampere) is usually chosen as a second base. In equipment this quantity is usually known and makes a convenient base.

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## Base Quantities(2)

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- The choice of these two base quantities will automatically fix the base of current, impedance, and admittance.
- In a system study, the volt-ampere base can be selected to be any convenient value such as 100 MVA, 200 MVA, etc.

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## Base Quantities(3)

- The same volt-ampere base is used in all parts of the system. One base voltage in a certain part of the system is selected arbitrarily. All other base voltages must be related to the arbitrarily selected one by the turns ratio of the connecting transformers.

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## Per Unit System(1)

- Power system quantities such as voltage, current and impedance are often expressed in per unit or percent of specified values.
- Per unit quantities are calculated as:

$$\text{Per Unit Value} = \frac{\text{Actual Value}}{\text{Base Value}}$$

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## Per Unit System(2)

### ➤ Per Unit Values

$$S_{pu} = \frac{|S|}{S_{base}} \quad I_{pu} = \frac{|I|}{I_{base}} \quad V_{pu} = \frac{|V|}{V_{base}} \quad Z_{pu} = \frac{|Z|}{Z_{base}}$$

### ➤ Conversion of Per Unit Values

$$Z_{pu} = \frac{|Z|}{Z_{base}} = \frac{S_{base}}{V_{base}^2} |Z|$$

$$|Z| = Z_{base} Z_{pu} = \frac{V_{base}^2}{S_{base}} Z_{pu}$$

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## Per Unit System(3)

➤ Usually, the nominal apparent power (S) and nominal voltage (V) are taken as the base values for power ( $S_{base}$ ) and voltage ( $V_{base}$ ).

➤ The base values for the current ( $I_{base}$ ) and impedance ( $Z_{base}$ ) can be calculated based on the first two base values.

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## Per Unit System(4)

$$Z_{\%} = \frac{Z_{\text{actual}}}{Z_{\text{base}}} \times 100\%$$

- The percent impedance
- e.g. in a synchronous generator with 13.8 kV as its nominal voltage, instead of saying the voltage is 12.42 kV, we say the voltage is 0.9 p.u.

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## Per Unit in 3phase Circuit(1)

- Simplified:
  - Concerns about using phase or line voltages are removed in the per-unit system
  - Actual values of R,  $X_C$  and  $X_L$  for lines, cables, and other electrical equipment typically phase values.
  - It is convenient to work in terms of base VA (base volt-amperes)

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## Per Unit in 3phase Circuit(2)

- Usually, the 3-phase  $S_B$  or  $MVA_B$  and line-to-line  $V_B$  or  $kV_B$  are selected
- $I_B$  and  $Z_B$  dependent on  $S_B$  and  $V_B$

$$S_B = \sqrt{3}V_B I_B \quad V_B = \sqrt{3}I_B Z_B$$

$$I_B = \frac{S_B}{\sqrt{3}V_B}, \quad Z_B = \frac{V_B / \sqrt{3}}{I_B} = \frac{(V_B)^2}{S_B}$$

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## Change of Base(1)

- The impedance of individual generators & transformer, are generally in terms of percent/per unit based on their own ratings.
- Impedance of transmission line in ohmic value
- When pieces of equipment with various different ratings are connected to a system, it is necessary to convert their impedances to a per unit value expressed on the same base.

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## Change of Base(2)

$Z_{pu}^{old}$  be the per unit impedance on the power base  $S_B^{old}$   
& voltage base  $V_B^{old}$

$$Z_{pu}^{old} = \frac{Z_{\Omega}}{Z_B^{old}} = \left( \frac{S_B^{old}}{(V_B^{old})^2} \right) \cdot Z_{\Omega}$$

1

$Z_{pu}^{new}$  be the new per unit impedance on the new power base  $S_B^{new}$   
& new voltage base  $V_B^{new}$

$$Z_{pu}^{new} = \frac{Z_{\Omega}}{Z_B^{new}} = \left( \frac{S_B^{new}}{(V_B^{new})^2} \right) \cdot Z_{\Omega}$$

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## Change of Base(3)

➤ From (1) and (2), the relationship between the old and the new per unit value

$$Z_{pu}^{new} = Z_{pu}^{old} \left( \frac{S_B^{new}}{S_B^{old}} \right) \left( \frac{V_B^{old}}{V_B^{new}} \right)^2$$

➤ If the voltage base are the same,

$$Z_{pu}^{new} = Z_{pu}^{old} \left( \frac{S_B^{new}}{S_B^{old}} \right)$$

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## General Relations Between Circuit Quantities

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*Y-Connection*

$$Z_Y = \frac{V_{LN}}{I_L} = \frac{V_{LL} \angle -30^\circ}{\sqrt{3}} * \frac{\sqrt{3} V_{LL}}{S_{3\phi}} = \frac{V_{LL}^2 \angle -30^\circ}{S_{3\phi}}$$

*Δ-Connection*

$$I_D = \frac{I_L \angle 30^\circ}{\sqrt{3}} = \frac{V_{LL}}{Z_D} = \frac{S_{3\phi} \angle 30^\circ}{3V_{LL}}$$

$$Z_D = \frac{V_{LL}}{I_D} = \frac{\sqrt{3} V_{LL} \angle -30^\circ}{I_L} = \sqrt{3} V_{LL} \angle -30^\circ * \frac{\sqrt{3} V_{LL}}{S_{3\phi}} = \frac{3V_{LL}^2 \angle -30^\circ}{S_{3\phi}}$$

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## Base Conversion

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$$Z_{pu(new)} = Z_{pu(old)} * \frac{MVA_{base(new)}}{MVA_{base(old)}} * \frac{KV_{base(old)}^2}{KV_{base(new)}^2}$$

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## Example One: Base Conversion

- A 50-MVA, 34.5:161 kV transformer with 10% reactance is connected to a power system where all the other impedance values are on a 100 MVA, 34.5 or 161 kV base. The reactance of the transformer under new base is:

$$Z_{pu(new)} = 0.1 * \frac{100}{50} * \frac{KV_{base(old)}^2}{KV_{base(new)}^2} = 0.2$$

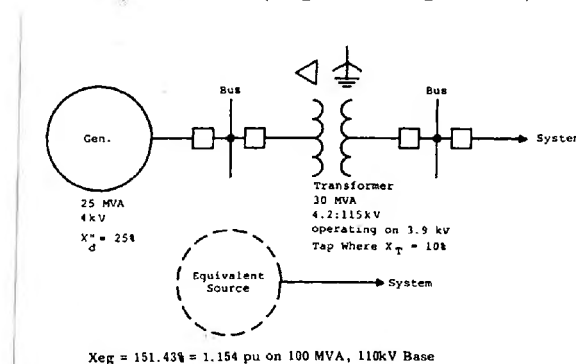
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## Example Two: Base Conversion

- A generator and transformer, as shown below, are to be combined into a single equivalent reactance on a 100 MVA, 110 kV (high voltage side) base.



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## Advantages(1)

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- More meaningful when comparing different voltage levels
- The per unit equivalent impedance of the transformer remains the same when referred to either the primary or the secondary side
- The per unit impedance of a transformer in a three-phase system is the same, regardless the winding connection

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## Advantages(2)

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- Manufacturers usually specify the impedance of the equipment in per unit or percent on the base of its nameplate ratings
- The per unit impedance values of various ratings of equipment lie in a narrow range

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## Advantages(3)

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- Transformer equivalent circuit can be simplified by properly specifying base quantities.
  - Give a clear idea of relative magnitudes of various quantities such as voltage, current, power and impedance.
  - Avoid possibility of making serious calculation error when referring quantities from one side of transformer to the other.

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## Advantages(4)

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- Per-unit impedances of electrical equipment of similar type usually lie within a narrow numerical range when the equipment ratings are used as base values.
  - Manufacturers usually specify the impedances of machines and transformers in per-unit or percent in nameplate rating.

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## Advantages(5)

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- The circuit laws are valid in per unit systems, and the power and voltage equation are simplified since the factor  $\sqrt{3}$  and 3 are eliminated in the per-unit systems.
- Ideal for the computerized analysis and simulation of complex power system problems.

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## **VII. POWER SYSTEM STUDY**

### **CALCULATION OF FAULT CURRENT IN A NETWORK**

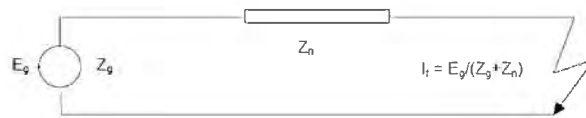
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- When a fault occurs in a network, the fault current is determined by
  - i) the internal emfs of the machines in the system,
  - ii) their impedances and
  - iii) the impedances in the network between the fault and machines.



- Alternatively Fault MVA = Base MVA / PU Impedance.

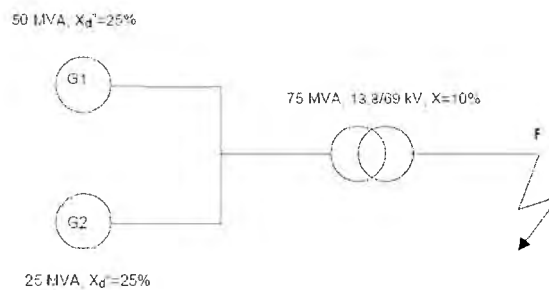
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**Example**

For a network shown below, find the fault current, voltages at primary terminal of the transformer and generator terminals for a three phase symmetrical fault at point F. Also find the contribution of fault current by the generators. Ignore the impedances of the lines.



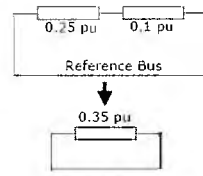
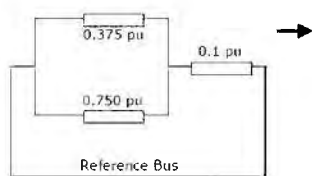
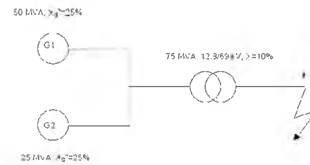
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**Solution**

Let us choose Base MVA = 75  
 The new Per-Unit impedances of the elements on new Base of 75 MVA are as under:  
 $X_{d'}'$  of G1 =  $0.25 * 75/50 = 0.375$  pu  
 $X_{d'}'$  of G2 =  $0.25 * 75/25 = 0.750$  pu  
 $X$  of transformer = 0.1 pu  
 Reactance diagram of the system is as under

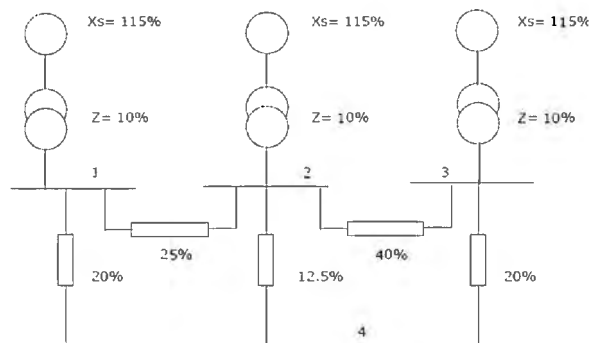


Fault MVA =  $75 / 0.35 = 214$  MVA  
 Fault Current =  $214 * 1000 (\sqrt{3} * 69) = 1.79$  kA

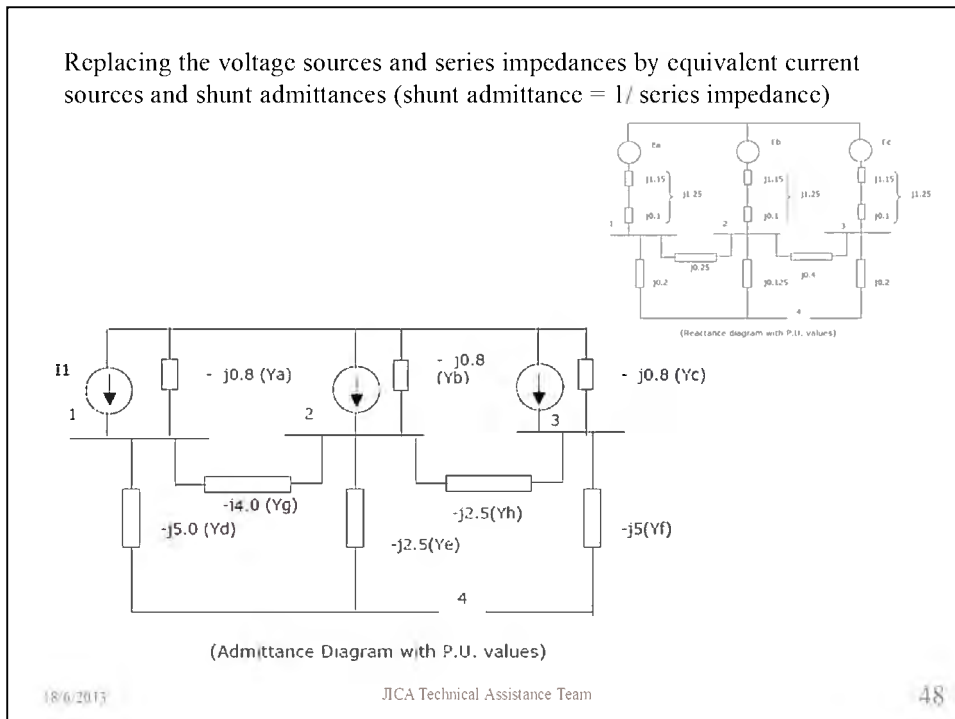
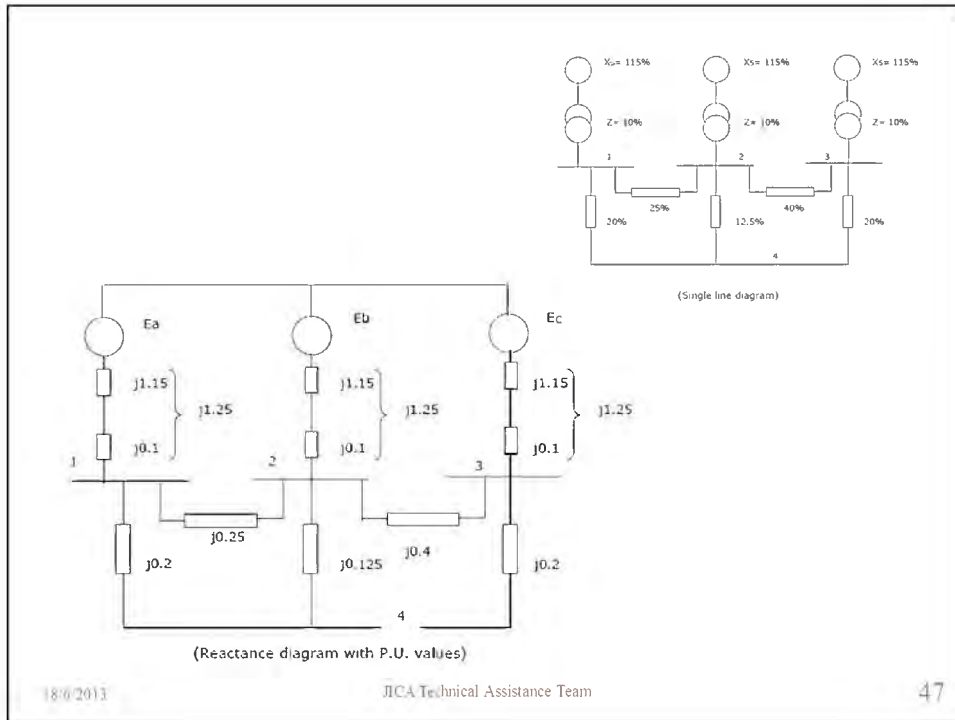
Fault Current =  $E_a / PU Z = 1 / 0.35$  PU  
 Fault Current = 2.857 PU  
 $= 2.875 * \sqrt{3} * 75 * 1000 / 69$   
 $= 1.79$  kA

Fault calculation by the method described so far becomes laborious & time consuming for actual networks which are big & complicated in nature.

Here we will develop methods for formation of network equations.  
 Let us consider the following network (Impedances on same base)



(Single line diagram)



Applying Kirchoff's current law at Bus 1

$$I_1 = V_1 Y_a + (V_1 - V_2) Y_g + (V_1 - V_4) Y_d$$

$$= V_1 (Y_a + Y_g + Y_d) - V_2 Y_g - V_4 Y_d$$

$Y_a + Y_g + Y_d =$  Self admittance of Bus 1 = Sum of all admittances connected to Bus =  $Y_{11}$

-  $Y_g =$  Mutual admittance between Bus 1 & 2 =  $Y_{12}$

-  $Y_d =$  Mutual admittance between Bus 1 & 4 =  $Y_{14}$

0 = Mutual admittance between Bus 1 & 3 =  $Y_{13}$

Hence  $I_1 = Y_{11} V_1 + Y_{12} V_2 + Y_{13} V_3 + Y_{14} V_4$

The general equation in Matrix form is

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$Y_{Bus}$

$I = Y_{bus} V$

Premultiplying both sides by  $Y_{bus}^{-1}$

$$V = Y_{bus}^{-1} I = Z_{bus} I \text{ (as } Y_{bus}^{-1} = Z_{bus} \text{)}$$

In Matrix form,

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix}$$

$Z_{Bus}$

(Admittance Diagram with P.U. values)

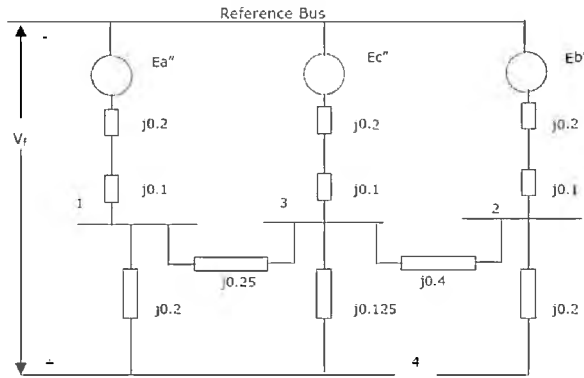
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## VII. POWER SYSTEM STUDY

### USE OF BUS IMPEDANCE MATRIX IN FAULT CALCULATION

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We would now simulate a three phase symmetrical fault at Bus 4 of our network. As our objective is to find out subtransient fault current, we would replace the synchronous reactances of the generator by subtransient reactances and no load generated voltage by sub transient internal voltages of the machines as under. Let the voltage of Bus 4 be  $V_f$

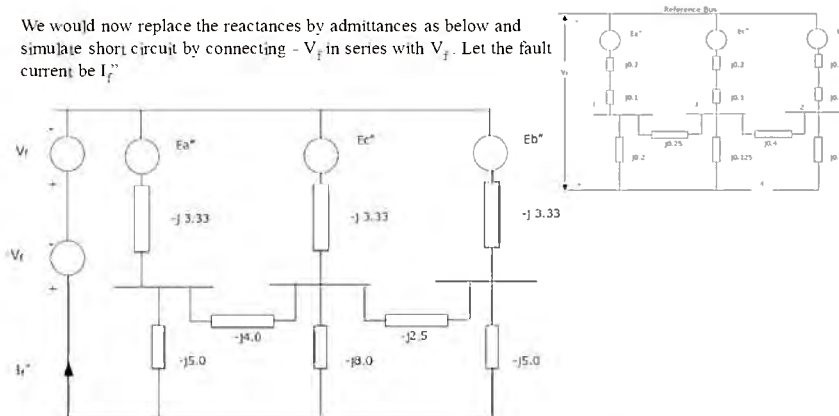


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We would now replace the reactances by admittances as below and simulate short circuit by connecting  $-V_f$  in series with  $V_f$ . Let the fault current be  $I_f''$



If  $E_a''$ ,  $E_b''$ ,  $E_c''$  and  $V_f$  are short circuited, the voltages and currents are due to  $-V_f$  only. The only current entering at Bus 4 is  $-I_f''$

Hence our Matrix equation reduces to

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ I_f'' \end{bmatrix} = \begin{bmatrix} -12.33 & 0 & 4.0 & 5.0 \\ 0 & 10.83 & 2.5 & 5.0 \\ 4.0 & 2.5 & -17.83 & 8.0 \\ 5.0 & 5.0 & 8.0 & -18.0 \end{bmatrix} \begin{bmatrix} V_1'' \\ V_2'' \\ V_3'' \\ -V_f \end{bmatrix}$$

$$(I = Y_{bus} V)$$

Where  $V_1''$ ,  $V_2''$  and  $V_3''$  are the change in voltages due to fault.

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Premultiply both sides by  $Y_{bus}^{-1}$ ,

$$\begin{bmatrix} V_1' \\ V_2' \\ V_3' \\ -V_f \end{bmatrix} = \begin{bmatrix} & & & \\ & Z_{bus} & & \\ & & & \\ & & & \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ -I_f'' \end{bmatrix}$$

Where  $Z_{bus} = \begin{bmatrix} 0.1488 & 0.0651 & 0.0864 & 0.0978 \\ 0.0651 & 0.1554 & 0.0799 & 0.0967 \\ 0.0864 & 0.0798 & 0.1341 & 0.1058 \\ 0.0978 & 0.0967 & 0.1058 & 0.1566 \end{bmatrix}$

$$\begin{bmatrix} V_1' \\ V_2' \\ V_3' \\ -V_f \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ -I_f'' \end{bmatrix}$$

Therefore  $-V_f = Z_{44} X (-I_f'')$

Therefore  $I_f'' = V_f / Z_{44}$ , for our system  $I_f'' = 1.0.1566 = 6.38$  PU

Similarly

$$V_1' = -I_f'' \times Z_{14}, V_2' = -I_f'' \times Z_{24}, V_3' = -I_f'' \times Z_{34}$$

Normally, while studying fault, the network is considered offloaded and the pre-fault voltage of all buses including faulted bus is considered 1 PU

Hence post fault voltage of buses are

$$V_1 = V_f + V_1' = 1 - I_f'' Z_{14} = (1 - 6.38 \times 0.0978) \text{PU} = 0.376 \text{ PU}$$

$$V_2 = V_f + V_2' = 1 - I_f'' Z_{24} = (1 - 6.38 \times 0.0967) \text{PU} = 0.383 \text{ PU}$$

$$V_3 = V_f + V_3' = 1 - I_f'' Z_{34} = (1 - 6.38 \times 0.1058) \text{PU} = 0.324 \text{ PU}$$

$$V_4 = V_f - V_f = 0$$

Current in any part of the network can be found out from the post fault voltages of the buses and relevant element of  $Y_{bus}$ .

Hence the current between Bus 1 & Bus 3 during a fault at Bus 4 =  $(V_1 - V_3) \times Y_{13}$

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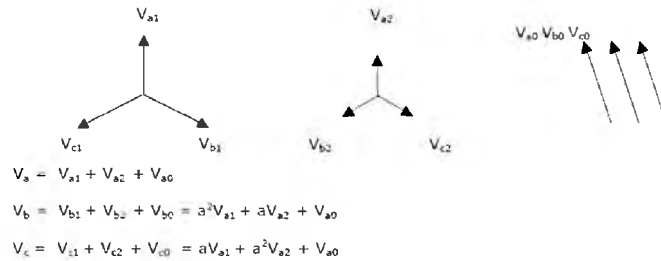
### SYMMETRICAL COMPONENTS

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**Theorem :** Any set of n unbalanced vectors can be resolved to n sets of balanced vectors.



Therefore in Matrix form

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

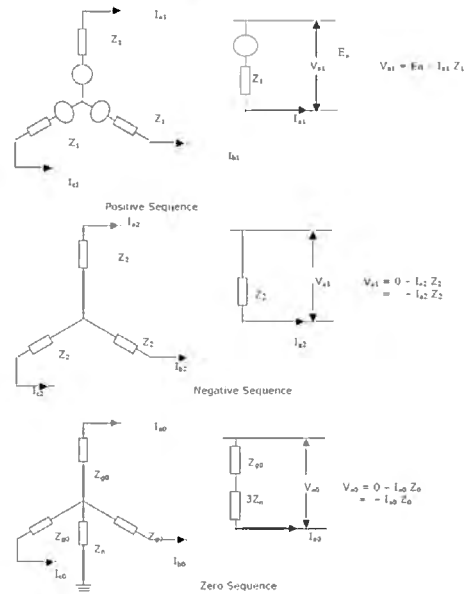
$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

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**Sequence network of unloaded generator**



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**Unsymmetrical faults**

Regardless of type of faults on unloaded generator

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

Single line to ground fault on unloaded generator

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Let us consider that there is a single line to ground fault in phase "a"

Therefore  $V_a = 0, I_b = 0, I_c = 0$

Hence 
$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

Therefore  $I_{a0} = 1/3 I_a, I_{a1} = 1/3 I_a, I_{a2} = 1/3 I_a$

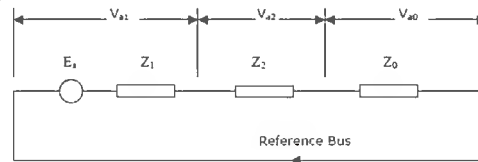
$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

$$V_{a0} = -I_{a2} Z_0, V_{a1} = E_a - I_{a1} Z_1, V_{a2} = -I_{a2} Z_2$$

$$V_{a0} + V_{a1} + V_{a2} = E_a - I_{a1}(Z_0 + Z_1 + Z_2) = V = 0$$

Hence  $I_{a1} = E_a / (Z_0 + Z_1 + Z_2), I_a = 3 I_{a1}$

Hence all the sequence networks are in series for a single line to ground fault.





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on Strengthening Institutional Capacity  
of National Development Agency (ADN)  
in Democratic of Timor-Leste

**-- POWER --**

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## Syllabus

No.	Contents
1	Introduction
2	Power Station (Diesel)
3	Substation
4	Transmission and Distribution System
5	Power System Study
6	<b>Power Flow Analysis</b>
7	Renewable Energy (Photovoltaic Power)
8	Protecting System
9	Power System Operation and Control
10	Others

The contents may be changed depending on conditions.  
I would like to discuss about the contents with Mr. Miguel and YOU.

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## **VIII. POWER FLOW ANALYSIS**

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## **VIII. POWER FLOW ANALYSIS**

### **INTRODUCTION**

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## Introduction

Power systems typically operate under slowly changing conditions which can be analyzed using steady state analysis. Further, transmission systems operate under balanced or near balanced conditions allowing per-phase analysis to be used with a high degree of confidence in the solution. Power flow analysis computationally models these conditions and provides the starting point for most other analyses. For example, the small signal and transient stability effects of a given disturbance are dramatically affected by the “pre-disturbance” operating conditions of the power system. (A disturbance resulting in instability under heavily loaded system conditions may not have any adverse effects under lightly loaded conditions.) Additionally, fault analysis and transient analysis can also be impacted by the “pre-disturbance” operating point of a power system (although, they are usually affected much less than transient stability and small signal stability analysis).

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## The Power Flow Problem

- Power flow analysis is fundamental to the study of power systems forming the basis for other analyses. Power flow analyses play a key role in the planning of additions or expansions to transmission and generation facilities as well as establishing the starting point for many other types of power system analyses. In addition, power flow analysis and many of its extensions are an essential ingredient of the studies performed in power system operations. In this latter case, it is at the heart of contingency analysis and the implementation of real-time monitoring systems.
- The power flow problem (also known as the load flow problem) can be stated as follows:
 

For a given power network, with known complex power loads and some set of specifications or restrictions on power generations and voltages, solve for any unknown bus voltages and unspecified generation and finally for the complex power flow in the network components.
- Additionally, the losses in individual components and the total network as a whole are usually calculated. Furthermore, the system is often checked for component overloads and voltages outside allowable tolerances.

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## Power flow equations

Power flow equations represent the fundamental balancing of power as it flows from the generators to the loads through the transmission network. Both real and reactive power flows play equally important roles in determining the power flow properties of the system. Power flow studies are among the most significant computational studies carried out in power system planning and operations in the industry. Power flow equations allow the computation of the bus voltage magnitudes and their phase angles as well as the transmission line current magnitudes. In actual system operation, both the voltage and current magnitudes need to be maintained within strict tolerances for meeting consumer power quality requirements and for preventing overheating of the transmission lines, respectively.

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## Nonlinear nature

- The difficulty in computing the power flow solutions arises from the fact that the equations are inherently nonlinear because of the balancing of power quantities. Moreover, the large size of the power network implies that power flow studies involve solving a very large number of simultaneous nonlinear equations. Fortunately, the sparse interconnected nature of the power network reflects itself in the computational process, facilitating the computational algorithms.
- Here, we first study a simple power flow problem to gain insight into the nonlinear nature of the power flow equations. We then formulate the power flow problem for the large power system.
- Next, usually like in school, a classical power flow solution method based on the Gauss-Seidel algorithm will be studied. The popular Newton-Raphson algorithm, which is the most commonly used power flow method in the industry today, will be introduced.
- But I will not introduce the algorithm here. I will leave copies of some textbooks, then try to read.

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## VIII. POWER FLOW ANALYSIS

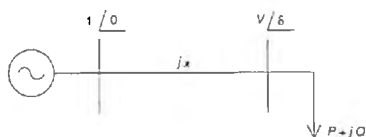
### SIMPLE EXAMPLE OF A POWER FLOW PROBLEM

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Let us consider a single generator delivering the load  $P + jQ$  through the transmission line with the reactance  $x$ . The generator bus voltage is assumed to be at the rated voltage, and it is at 1 per unit (pu). The generator bus angle is defined as the phasor reference, and hence, the generator bus voltage phase angle is set to be zero. The load bus voltage has magnitude  $V$  and phase angle  $\delta$ . Because the line has been assumed to be lossless, note that the generator real power output must be equal to the real power load  $P$ . However, the reactive power output of the generator will be the sum of the reactive load  $Q$  and the reactive power "consumed" by the transmission line reactance  $x$ .



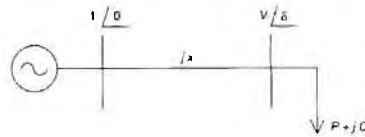
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Let us write down the power flow equations for this problem. Given a loading condition  $P + jQ$ , we want to solve for the unknown variables, namely, the bus voltage magnitude  $V$  and the phase angle  $\delta$ . For simplicity, we will assume that the load is at unity power factor of  $Q = 0$ . The line current phasor  $I$  from the generator bus to the load bus is easily calculated as:

$$I = \frac{V \angle 0 - V \angle \delta}{jx} \quad (1)$$



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Next, the complex power  $S$  delivered to the load bus can be calculated as:

$$S = VI^* = \frac{V \angle (\delta + \pi/2)}{x} - \frac{V^2 \angle (\pi/2)}{x} \quad (2)$$

Therefore, we get the real and reactive power balance equations:

$$P = \frac{-V \sin \delta}{x} \quad \text{and} \quad Q = \frac{-V^2 + V \cos \delta}{x} \quad (3)$$

After setting  $Q = 0$  in equation (3), we can simplify equation (3) into a quadratic equation in  $V^2$  as follows:

$$V^4 - V^2 + x^2 P^2 = 0 \quad (4)$$

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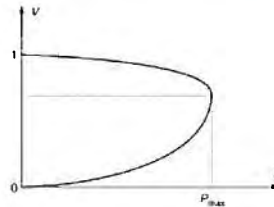
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Therefore, given any real power load  $P$ , the corresponding power flow solution for the bus voltage  $V$  can be solved from equation (4). We note that for nominal load values, there are two solutions for the bus voltage  $V$ , and they are the positive roots of  $V^2$  in the next equation:

$$V^2 = \frac{1 \pm \sqrt{1 - 4x^2 P^2}}{2} \quad (5)$$

Equation (5) implies that there exist two power flow solutions for load values  $P < P_{\max}$  where  $P_{\max} = 1/(2x)$ , and there exist no power-flow solutions for  $P > P_{\max}$ . A qualitative plot of the power flow solutions for the bus voltage  $V$  in terms of different real power loads  $P$  is shown in Figure.

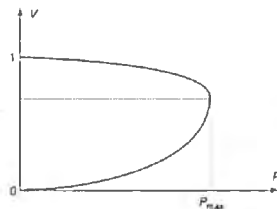


Qualitative Plot of the Power-Flow Solutions

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Qualitative Plot of the Power-Flow Solutions

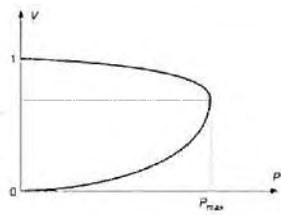
From the plot and from the analysis thus far, we can make the following observations:

1. The dependence of the bus voltage  $V$  on the load  $P$  is very much nonlinear. It has been possible for us to compute the power flow solutions analytically for this simple system. In the large power system with hundreds of generators delivering power to thousands of loads, we have to solve for thousands of bus voltages and their phase angles from large coupled sets of non-linear power flow equations, and the computation is a nontrivial task.

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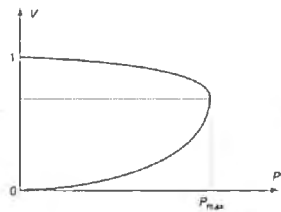
Qualitative Plot of the Power-Flow Solutions

2. Multiple power flow solutions can exist for a specified loading condition. In Figure, there exist two solutions for any load  $P < P_{\max}$ . Among the two solutions, the solution on the upper locus with voltage  $V$  near 1 pu is considered the nominal solution. For the solutions on the lower locus, the bus voltage  $V$  may be unacceptably low for normal operation. The lower voltage solution also requires higher line current to deliver the specified load  $P$ , and the line current values can become unacceptably high. In general, for any specified loading condition, we would like to locate the power flow solution that has the most acceptable values of voltages and currents among the multiple power flow solutions. In this example of a single generator delivering power to a single load, there exist two power flow solutions. In a large power system, there may exist a very large number of possible power flow solutions.

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Qualitative Plot of the Power-Flow Solutions

3. Once the bus voltage  $V$  has been computed from equation (5), the bus voltage phase angle  $\delta$  can be computed from equation (3). Then, the line current phasor  $I$  can be solved from equation (1). Specifically, we would like to ensure that the magnitude of the line current  $I$  stays below the thermal limit of the transmission line for preventing potential damage to the expensive transmission line.

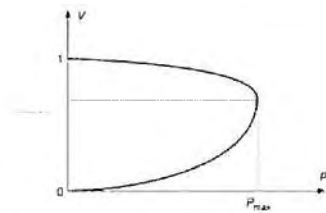
$$(5) \quad V^2 = \frac{1 \pm \sqrt{1 - 4x^2 P^2}}{2}, \quad (3) \quad P = \frac{-V \sin \delta}{x} \text{ and } Q = \frac{-V^2 + V \cos \delta}{x}, \quad (1) \quad I = \frac{1 \angle 0 - V \angle \delta}{jx}$$

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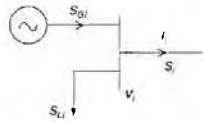


Qualitative Plot of the Power-Flow Solutions

4. Power flow solutions may fail to exist at high loading conditions, such as when  $P > P_{\max}$  in Figure. The loading value  $P_{\max}$  beyond which power flow solutions do not exist is called the static limit in the power literature. Because power flow solutions denote the steady-state operating conditions in our formulation, lack of power flow solutions implies that it is not possible to transfer power from the generator to the load in a steady-state fashion, and the dynamic interactions of the generators and the loads become significant. Operating the power system at loading conditions beyond the static limit may lead to catastrophic failure of the system.

## VIII. POWER FLOW ANALYSIS

### POWER FLOW PROBLEM FORMULATION



Complex Power Balance at Bus i

Here, we will construct the power flow equations in a structured manner using the admittance matrix  $\underline{Y}_{\text{bus}}$  representation of the transmission network. The admittance matrix  $\underline{Y}_{\text{bus}}$  is assumed to be known for the system under consideration. Let us first look at the complex power balance at any bus, say bus i, in the network.

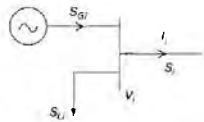
The power balance equation is given by:

$$\underline{S}_i = \underline{V}_i \underline{I}_i^* = \underline{S}_{G_i} - \underline{S}_{L_i}. \quad (6)$$

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Complex Power Balance at Bus i

$$\underline{S}_i = \underline{V}_i \underline{I}_i^* = \underline{S}_{G_i} - \underline{S}_{L_i}. \quad (6)$$

Let us denote the vector of bus voltages as  $\underline{V}_{\text{bus}}$  and the vector of bus injection currents as  $\underline{I}_{\text{bus}}$ . By definition, the admittance matrix  $\underline{Y}_{\text{bus}}$  provides the relationship  $\underline{I}_{\text{bus}} = \underline{Y}_{\text{bus}} \underline{V}_{\text{bus}}$ . Suppose the  $i$ th or  $j$ th entry  $Y_{ij}$  of the  $Y_{\text{bus}}$  matrix has the magnitude  $|Y_{ij}|$  and the phase  $\angle Y_{ij}$ . Then, we can simplify the current injection  $I_i$  as:

$$\underline{I}_i = \sum_j Y_{ij} \underline{V}_j = \sum_j |Y_{ij}| |V_j| \angle (\delta_j + \gamma_{ij}). \quad (7)$$

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Then, combining equations (6) and (7), we get the complex power balance equations for the network as:

$$S_i = S_{G_i} - S_{L_i} = \sum_j Y_{ij} V_i V_j \angle (\delta_i - \delta_j - \gamma_{ij}). \quad (8)$$

Taking the real and imaginary parts of the complex equation (8) gives us the real and reactive power flow equations for the network:

$$P_i = P_{G_i} - P_{L_i} = \sum_j Y_{ij} V_i V_j \cos (\delta_i - \delta_j - \gamma_{ij}). \quad (9)$$

$$Q_i = Q_{G_i} - Q_{L_i} = \sum_j Y_{ij} V_i V_j \sin (\delta_i - \delta_j - \gamma_{ij}). \quad (10)$$

Generally speaking, our objective in this section is to solve for the bus voltage magnitudes  $V_i$  and the phase angles  $\delta_i$  when the power generations and loads are specified. For a power system with  $N$  buses, there are  $2N$  number of power flow equations. At each bus, there are six variables:  $P_{G_i}$ ,  $Q_{G_i}$ ,  $P_{L_i}$ ,  $Q_{L_i}$ ,  $V_i$  and  $\delta_i$ . Depending on the nature of the bus, four of these variables will be specified at each bus, leaving two unknown variables at each bus. We will end up with  $2N$  unknown variables related by  $2N$  equations (9) and (10), and our aim in the rest of this section is to develop algorithms for solving this problem.

Let us consider a purely load bus first, that is, with  $P_{Gi} = Q_{Gi} = 0$ . In this case, the loads  $P_{Li}$  and  $Q_{Li}$  are assumed to be known either from measurements or from load estimates, and the bus voltage variables  $V_i$  and  $\delta_i$  are the unknown variables. Purely load busses with no generation support are called **PQ busses** in power flow studies because both real power injection  $P_i$  and reactive power  $Q_i$  have been specified at these busses.

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Typically, every generator in the system consists of two types of internal controls, one for maintaining the real power output of the generator and the other for regulating the bus voltage magnitude. In power flow studies, we usually assume that both these control mechanisms are operating perfectly and so the real power output  $P_{Gi}$  and  $V_i$  are maintained at their specified values. Again, the load variables  $P_{Li}$  and  $Q_{Li}$  are also assumed to be known. This leaves the generator reactive output  $Q_{Gi}$  and the voltage phase angle  $\delta_i$  as the two unknown variables for the bus. In terms of injections, the real power injection  $P_i$  and the bus voltage  $V_i$  are then the specified variables; thus, the generator busses are normally denoted **PV busses** in power flow studies.

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In reality, the generator voltage control for keeping the bus voltage magnitude at a specified value becomes inactive when the control is pushed to the extremes, such as when the reactive output of the generator becomes either too high or too low. This voltage control limitation of the generator can be represented in power flow studies by keeping track of the reactive output  $Q_{Gi}$ . When the reactive generation  $Q_{Gi}$  becomes larger than a prespecified maximum value of  $Q_{Gi,max}$  or goes lower than a prespecified minimum value  $Q_{Gi,min}$ , the reactive output is assumed to be fixed at the limiting value  $Q_{Gi,max}$  or  $Q_{Gi,min}$ , respectively, and the voltage control is disabled in the formulation; that is, the reactive power  $Q_{Gi}$  becomes a known variable, either at  $Q_{Gi,max}$  or  $Q_{Gi,min}$ , and the voltage  $V_i$  then becomes the unknown variable for bus  $i$ . In power flow terminology, we say that the generator at bus  $i$  has "reached its reactive limits" and, hence, bus  $i$  has changed from a PV bus to a PQ bus. Owing to space limitations, we will not discuss generator reactive limits in any more detail here.

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In addition to PQ busses and PV busses, we also need to introduce the notion of a **slack bus** in the power flow formulation. Note that power conservation demands that the real power generated from all the generators in the network must equal the sum of the total real power loads and the line losses on the transmission network:

$$\sum_i P_{Gi} = \sum_i P_{Li} + \sum_i \sum_j P_{\text{losses}_{ij}} \quad (11)$$

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The line losses associated with any transmission line in turn depend on the line resistance and the line current magnitude. As stated earlier, one of the main objectives of power flow studies is to compute the line currents, and as such, the line current values are not known at the beginning of a power flow computation. Therefore, we do not know the actual values for the line losses in the transmission network. Looking at equation (11), we need to assume that at least one of the variables  $P_{Gi}$  or  $P_{Li}$  should be a free variable for satisfying the real power conservation. Traditionally, we assume that one of the generations is a "slack" variable, and such a generator bus is denoted the slack bus. At the slack bus, we specify both the voltage  $V_i$  and the angle  $\delta_i$ . The power injections  $P_i$  and  $Q_i$  are the unknown variables. Again, by tradition, we set the voltage at slack bus to be the rated voltage or at 1 pu and the phase angle to be at zero.

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## **VIII. POWER FLOW ANALYSIS**

### **ANOTHER APPROACH FOR UNDERSTANDING**

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A two-bus example, shown in Fig. 1, is used to simplify the development of the power-flow equations. The system consists of two busses connected by a transmission line. One can observe that there are six electrical quantities associated with each bus:  $P_D$ ,  $P_G$ ,  $Q_D$ ,  $Q_G$ ,  $|V|$ , and  $\delta$ . This is the most general case, in which each bus is shown to have both generation and demand. In reality, not all busses will have power generation. The impedance diagram of the two-bus system is shown in Fig. 2. The transmission line is represented by a  $\pi$ -model and the synchronous generator is represented by a source behind a synchronous reactance. The loads are assumed to be constant impedance for the sake of representing them on the impedance diagram. Typically, the load is represented by a constant power device, as shown in subsequent figures.

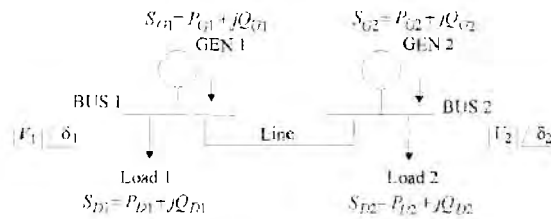


FIG.1 A two-bus power system.

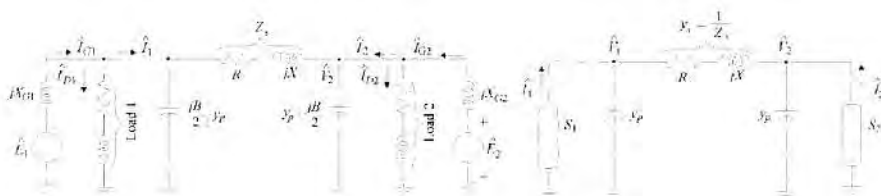


FIG.2 Impedance diagram for the two-bus power system.

FIG.3 Bus powers with transmission line  $\pi$ -model for the two-bus system.

Fig. 3 is the same as Fig. 2 but with the generation and demand bundled together to represent “bus power,” which represents bus power injections. Bus power is defined as

$$S_1 = S_{G1} - S_{D1} = (P_{G1} - P_{D1}) + j(Q_{G1} - Q_{D1}) \quad (1)$$

and

$$S_2 = S_{G2} - S_{D2} = (P_{G2} - P_{D2}) + j(Q_{G2} - Q_{D2}) \quad (2)$$

Also, injected current at bus 1 is

$$\hat{I}_1 = \hat{I}_{s1} - \hat{I}_{l1} \quad (3)$$

and injected current at bus 2 is

$$\hat{I}_2 = \hat{I}_{s2} - \hat{I}_{l2} \quad (4)$$

All quantities are assumed to be per unit. Then, since

$$S_1 = \hat{V}_1 \hat{I}_1^* \Rightarrow P_1 + jQ_1 = \hat{V}_1 \hat{I}_1^* \Rightarrow (P_1 - jQ_1) = \hat{V}_1^* \hat{I}_1 \quad (5)$$

and

$$S_2 = \hat{V}_2 \hat{I}_2^* \Rightarrow P_2 + jQ_2 = \hat{V}_2 \hat{I}_2^* \Rightarrow (P_2 - jQ_2) = \hat{V}_2^* \hat{I}_2 \quad (6)$$

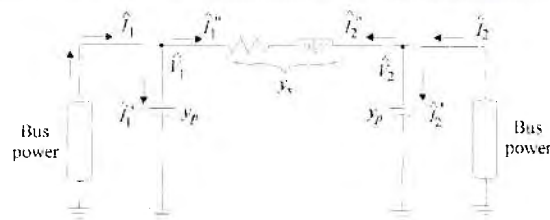


FIG.4 Current flows in the network model.

Let us define current flows in the circuit as shown in Fig. 4. Therefore, at bus 1

$$\begin{aligned} \hat{I}_1 &= \hat{I}_1' + \hat{I}_1'' \\ &= \hat{V}_1 Y_p + (\hat{V}_1 - \hat{V}_2) Y_s \\ \hat{I}_1 &= (Y_p + Y_s) \hat{V}_1 + (-Y_s) \hat{V}_2 \end{aligned} \quad (7)$$

$$\therefore \hat{I}_1 = Y_{11} \hat{V}_1 + Y_{12} \hat{V}_2 \quad (8)$$

where  $Y_{11} \triangleq$  sum of admittances connected at bus 1  $= y_p + y_s$  (9)

$Y_{12} \triangleq$  negative of the admittance between busses 1 and 2  $= -y_s$  (10)



Similarly, at bus 2

$$\begin{aligned} \hat{I}_2 &= \hat{I}'_2 + \hat{I}''_2 \\ &= \hat{V}_2 Y_p + (\hat{V}_2 - \hat{V}_1) Y_x \end{aligned}$$

$$\hat{I}_2 = (-Y_x) \hat{V}_1 + (Y_p + Y_x) \hat{V}_2 \tag{11}$$

$$\hat{I}_2 = Y_{21} \hat{V}_1 + Y_{22} \hat{V}_2 \tag{12}$$

$$Y_{22} \triangleq \text{sum of admittances connected at bus 2} = Y_p + Y_x \tag{13}$$

$$Y_{21} \triangleq \text{negative of the admittance between buses 2 and 1} = -Y_x = Y_{12} \tag{14}$$

Hence, for the two-bus power system, the current injections are

$$\begin{bmatrix} \hat{I}_1 \\ \hat{I}_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} \hat{V}_1 \\ \hat{V}_2 \end{bmatrix} \tag{15}$$

In matrix notation,

$$I_{bus} = Y_{bus} V_{bus} \tag{16}$$

The two-bus system can easily be extended to a larger system. Consider an n-bus system. Fig. 5a shows the connections from bus 1 of this system to all the other busses. Fig. 5b shows the transmission line models. Equations (5) through (16) that were derived for the two-bus system can now be extended to represent the n-bus system. This is shown next.

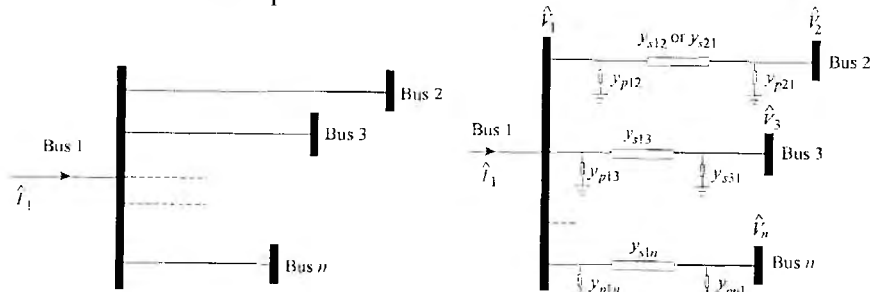


FIG. 5a Extending the analysis to an n-bus system.

FIG. 5b The  $\pi$ -model for the n-bus system.

$$\begin{aligned} \hat{I}_1 &= \hat{V}_1 Y_{p12} + \hat{V}_1 Y_{p13} + \dots + \hat{V}_1 Y_{p1n} + (\hat{V}_1 - \hat{V}_2) Y_{s12} + (\hat{V}_1 - \hat{V}_3) Y_{s13} + \dots + (\hat{V}_1 - \hat{V}_n) Y_{s1n} \\ &= (Y_{p12} + Y_{p13} + \dots + Y_{p1n} + Y_{s12} + Y_{s13} + \dots + Y_{s1n}) \hat{V}_1 - Y_{s12} \hat{V}_2 - Y_{s13} \hat{V}_3 \\ &\quad + \dots - Y_{s1n} \hat{V}_n \quad (17) \\ \hat{I}_1 &= Y_{11} \hat{V}_1 + Y_{12} \hat{V}_2 + Y_{13} \hat{V}_3 + \dots + Y_{1n} \hat{V}_n \quad (18) \end{aligned}$$

where  $Y_{11} = (Y_{p12} + Y_{p13} + \dots + Y_{p1n} + Y_{s12} + Y_{s13} + \dots + Y_{s1n})$  (19)  
 = sum of all admittances connected to bus 1

$$Y_{12} = -Y_{s12}; Y_{13} = -Y_{s13}; Y_{1n} = -Y_{s1n} \quad (20)$$

$$\therefore \hat{I}_1 = \sum_{j=1}^n Y_{1j} \hat{V}_j \quad (21)$$

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Also, extending the power Eq. (5) to an n-bus system,

$$P_1 - jQ_1 = \hat{V}_1^* I_1 = \hat{V}_1^* \sum_{j=1}^n Y_{1j} \hat{V}_j \quad (22)$$

Equation (22) can be written for any generic bus i:

$$P_i - jQ_i = \hat{V}_i^* \sum_{j=1}^n Y_{ij} \hat{V}_j \quad i = 1, 2, \dots, n \quad (23)$$

Equation (23) represents the nonlinear power-flow equations. Equation (15) can also be rewritten for an n-bus system:

$$\begin{bmatrix} \hat{I}_1 \\ \hat{I}_2 \\ \vdots \\ \hat{I}_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1n} \\ Y_{21} & Y_{22} & \dots & Y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{n1} & Y_{n2} & \dots & Y_{nn} \end{bmatrix} \begin{bmatrix} \hat{V}_1 \\ \hat{V}_2 \\ \vdots \\ \hat{V}_n \end{bmatrix} \dots \quad (24)$$

or

$$I_{bus} = Y_{bus} V_{bus} \quad (25)$$

where

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1n} \\ Y_{21} & Y_{22} & \dots & Y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{n1} & Y_{n2} & \dots & Y_{nn} \end{bmatrix} = \text{bus admittance matrix} \quad (26)$$

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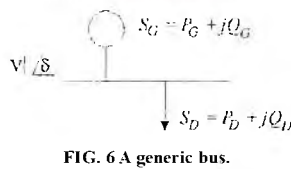


FIG. 6 A generic bus.

TABLE 1 Bus Classifications

Bus classification	Prespecified variables	Unknown variables
Slack or swing	$ V , \delta, P_D, Q_D$	$P_G, Q_G$
Voltage-controlled	$ V , P_G, P_D, Q_D$	$\delta, Q_G$
Load	$P_G, Q_D, P_D, Q_D$	$ V , \delta$

Let us take a generic bus as shown in Fig. 6. As mentioned earlier, each bus has six quantities or variables associated with it. They are  $|V|, \delta, P_G, Q_G, P_D,$  and  $Q_D$ . Assuming that there are  $n$  busses in the system, there would be a total of  $6n$  variables.

The power-flow Eq. (23) can be resolved into the real and reactive parts as follows:

$$\therefore P_i = \text{Real} \left[ \hat{V}_i^* \sum_{j=1}^n Y_{ij} \hat{V}_j \right] \quad i = 1, 2, \dots, n \quad (27)$$

$$Q_i = -\text{Imag} \left[ \hat{V}_i^* \sum_{j=1}^n Y_{ij} \hat{V}_j \right] \quad i = 1, 2, \dots, n \quad (28)$$

Thus, there are  $2n$  equations and  $6n$  variables for the  $n$ -bus system. Since there cannot be a solution in such case,  $4n$  variables have to be prespecified. Based on parameter specifications, we can now classify the busses as shown in Table 1.

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on Strengthening Institutional Capacity  
of National Development Agency (ADN)  
in Democratic of Timor-Leste

**-- POWER --**

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## Syllabus

No.	Contents
1	Introduction
2	Power Station (Diesel)
3	Substation
4	Transmission and Distribution System
5	Power System Study
6	Power Flow Analysis
7	Power System Stability
8	Renewable Energy (Photovoltaic Power)
9	Protecting System
10	Power System Operation and Control
11	Others

Contents may be changed depending on conditions.  
I would like to discuss about the contents with Mr. Miguel and YOU.

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## **IX. POWER SYSTEM STABILITY**

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## **IX. POWER SYSTEM STABILITY**

### **DEFINITION & CLASSIFICATION OF POWER SYSTEM STABILITY**

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## Overview

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- Power system is defined as a network of one or more generating units, loads and power transmission lines including the associated equipments connected to it.
- The stability of a power system is its ability to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium.
- Power system stability problem gets more pronounced in case of interconnection of large power networks.

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## Definition

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Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

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## Need of Stability Classification

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- Stability analysis is easier. Also it leads to proper and effective understanding of different power system instabilities.
  
- Key factors that leads to instability can be easily identified.
  
- Methods can be devised for improving power system stability.

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## Power System Stability Classification

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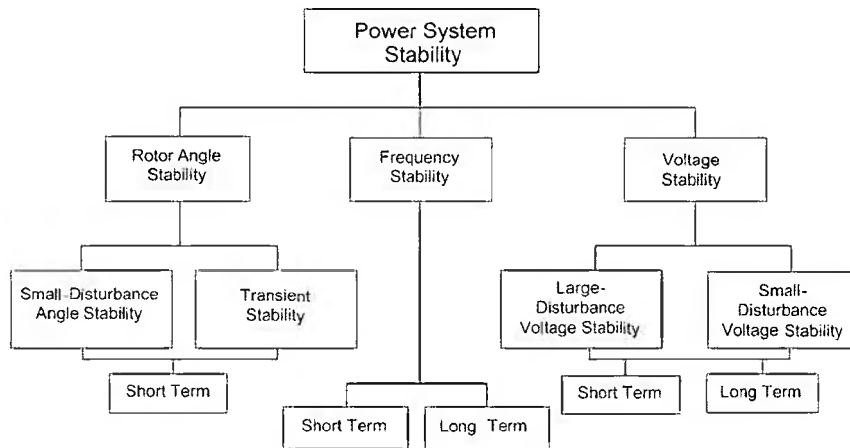
- Rotor angle stability.
  - Small disturbance angle stability.
  - Transient stability.
  
- Voltage stability.
  - Small disturbance voltage stability.
  - Large disturbance voltage stability.
  
- Frequency stability.
  - Short term frequency stability.
  - Long term frequency stability.

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## Stability Classification at a Glance



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## Rotor Angle Stability

- Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance.
- Rotor angle instability occurs due to angular swings of some generators leading to their loss of synchronism with other generators.

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## Rotor Angle Stability(2)

- Depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine.
- At equilibrium, Input mechanical torque equals output electromagnetic torque of each generator. In case of any disturbance the above equality doesn't hold leading to acceleration/ deceleration of rotors of machines.

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## Rotor Angle Stability Classification

- Small Disturbance Rotor Angle Stability:
  - It is the ability of the power system to maintain synchronism under **small disturbances**.
  - Disturbances are considered to be sufficiently small such that the linearization of system equations is permissible for purposes of analysis.
  - The time frame of interest in small-disturbance stability studies is of the order of 10 to 20 seconds following a disturbance.

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## Rotor Angle Stability Classification(2)

- Large Disturbance Rotor Angle Stability:
  - It is the ability of the power system to maintain synchronism under a **severe disturbance**, such as a short circuit on a transmission line.
  - Disturbances are large so that the linearization of system equations is **not permissible** for purposes of analysis.
  - The time frame of interest in small-disturbance stability studies is of the order of 3 to 5 seconds following a disturbance.

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## Voltage Stability

- Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition.
- A system is voltage instable if for at least one bus in the system, the voltage magnitude decreases as reactive power injection is increased.
- Voltage instability results in progressive fall or rise of voltages of some buses.

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## Voltage Stability(2)

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- Large scale effect of voltage instability leads to **Voltage collapse**. It is a process by which the sequence of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system.
  
- The driving force for voltage instability is usually the loads.
  
- Voltage stability problems is also experienced at terminals of HVDC links connected to weak ac systems.

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## Voltage Stability Classification

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- Small Disturbance Voltage Stability:
  - Small-disturbance voltage stability refers to the system's ability to maintain steady voltages when subjected to small disturbances such as incremental changes in system load.
  
  - A combination of both linear and non-linear techniques are used for analysis.

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## Voltage Stability Classification(2)

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- Large Disturbance Voltage Stability:
  - Large-disturbance voltage stability refers to the system's ability to maintain steady voltages following large disturbances such as system faults, loss of generation, or circuit contingencies.
  - The study period of interest may extend from a few seconds to tens of minutes.

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## Frequency Stability

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- Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load.
- Frequency instability leads to tripping of generating units and/or loads.
- Frequency stability may be a short-term phenomenon or a long-term phenomenon.

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## Rotor Angle Stability vs. Voltage Stability

- Rotor angle stability is basically a generator stability while voltage stability means load stability.
- Rotor angle stability is mainly interlinked to real power transfer whereas voltage stability is mainly related to reactive power transfer.

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## **IX. POWER SYSTEM STABILITY**

### **REACTIVE POWER MANAGEMENT,** **VOLTAGE STABILITY AND FACTS** **APPLICATIONS**

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The contents here are general theories.

In general, reactive power is lacking in power system.

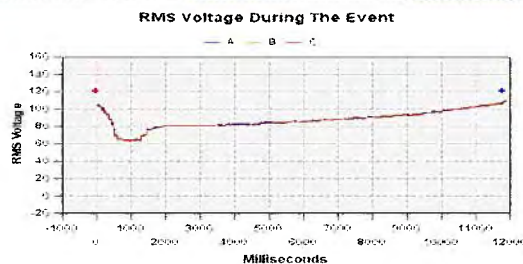
However, in the case of the power system of Timor-Leste, here is excess reactive power.

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## Voltage Profile during Aug 14th Blackout (2003 in the U.S and Canada)



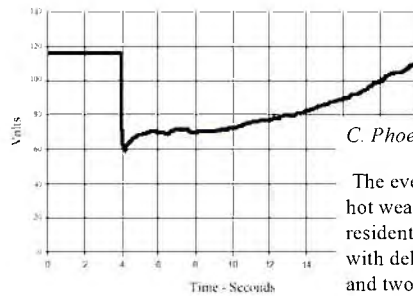
- Voltages decay to almost 60% of normal voltage. This is probably the point that load started dropping off.
- However, the recovery is too slow and generators are not able to maintain frequency during this condition.
- Many generators trip, load shedding goes into effect, and then things just shut down due to a lack of generation.

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## A “Near” Fast Voltage Collapse in Phoenix in 1995



C. Phoenix Area, July 28, 1995 [3]

North American Electric Reliability Council, System Disturbances, Review of Selected 1995 Electric System Disturbances in North America, March 1996.

The event occurred on a Saturday afternoon during very hot weather (44°C, 112°F). Much of the load was residential air conditioning. A 230-kV capacitor bank fault with delayed clearing resulted in loss of five 230-kV lines and two 230/69-kV transformers. About 2100 MW of load was lost. Voltage recovery took up to 20 seconds (Figure 1). Presumably, many residential air conditioners stalled, and then tripped off after some seconds to allow eventual recovery of the remaining power system. Recordings show high reactive power output of area generators during the recovery period. High reactive power output from generators at the nearby Palo Verde nuclear plant was essential for the recovery.

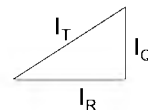
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## Laws of Reactive Physics

- System load is comprised of resistive current (such as lights, space heaters) and reactive current (induction motor reactance, etc.).
- Total current  $I_T$  has two components.
  - $I_R$  resistive current
  - $I_Q$  reactive current
  - $I_T$  is the vector sum of  $I_R$  &  $I_Q$
  - $I_T = I_R + jI_Q$



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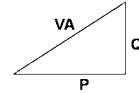
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## Laws of Reactive Physics

- Complex Power called Volt Amperes (“VA”) is comprised of resistive current  $I_R$  and reactive current  $I_Q$  times the voltage.

- “VA” =  $V I_T^* = V (I_R - jI_Q) = P + jQ$



- Power Factor (“PF”) = Cosine of angle between P and “VA”

- $P = \text{“VA”} \times \text{“PF”}$

- System Losses

- $P_{\text{loss}} = I_T^2 R$  (Watts)

- $Q_{\text{loss}} = I_T^2 X$  (VARs)

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## Reactive Physics – VAR loss

- Every component with reactance, X: VAR loss =  $I_T^2 X$
- Z is comprised of resistance R and reactance X
  - On 138kV lines, X = 2 to 5 times larger than R.
  - On 230kV lines, X = 5 to 10 times larger than R.
  - On 500kV lines, X = 25 times larger than R.
  - R decreases when conductor diameter increases. X increases as the required geometry of phase to phase spacing increases.
- VAR loss
  - Increases in proportion to the square of the total current.
  - Is approximately 2 to 25 times larger than Watt loss.

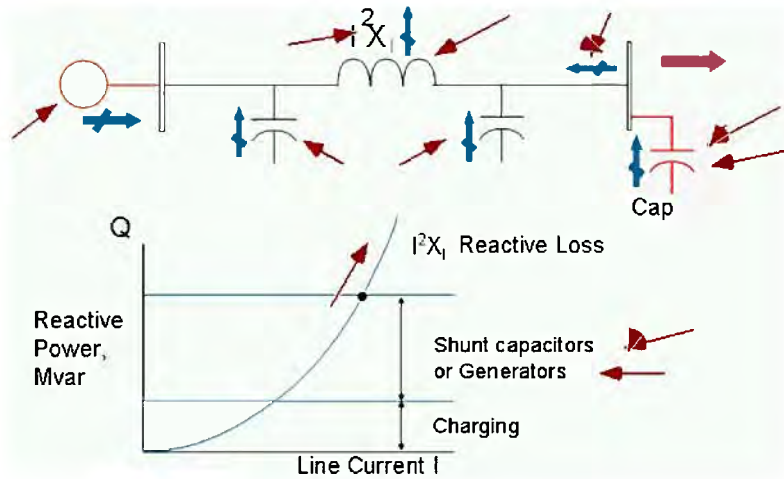
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## Line Charging versus Reactive Demand



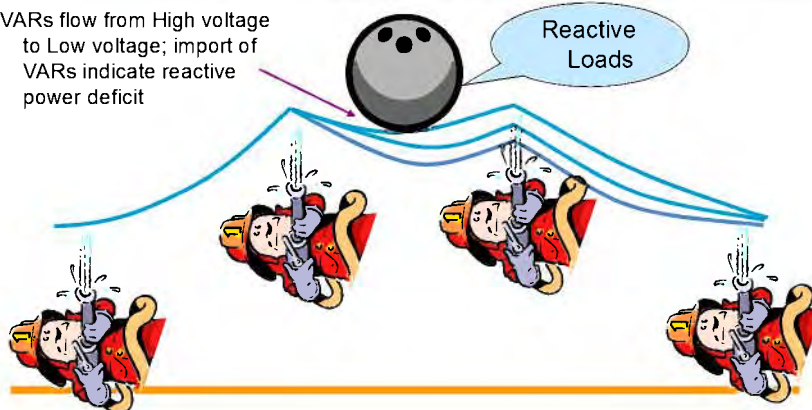
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## Reactive Power for Voltage Support

VARs flow from High voltage to Low voltage; import of VARs indicate reactive power deficit



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## Reactive Power Management/Compensation

What is Reactive Power Compensation?

- Effectively balancing of capacitive and inductive components of a power system to provide sufficient voltage support.
  - Static and dynamic reactive power
- Essential for reliable operation of power system
  - prevention of voltage collapse/blackout

Benefits of Reactive Power Compensation:

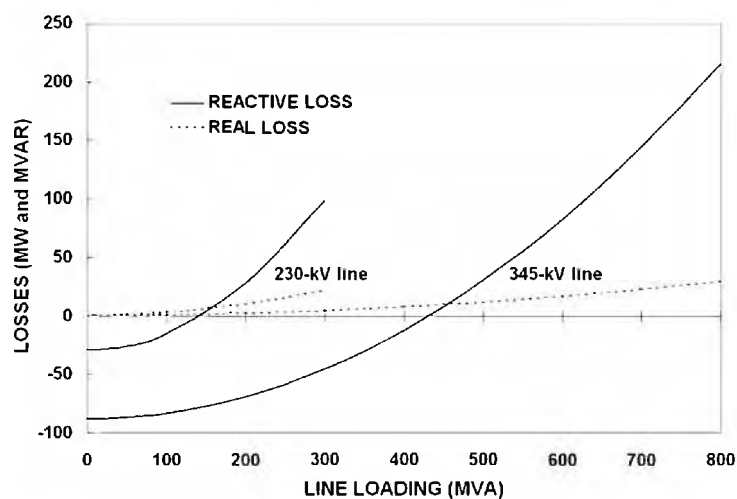
- Improves efficiency of power delivery/reduction of losses.
- Improves utilization of transmission assets/transmission capacity.
- Reduces congestion and increases power transfer capability.
- Enhances grid reliability/security.

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## Transmission Line Real and Reactive Power Losses vs. Line Loading



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## Static and Dynamic VAR Support

- Static Reactive Power Devices
  - Cannot quickly change the reactive power level as long as the voltage level remains constant.
  - Reactive power production level drops when the voltage level drops.
  - Examples include capacitors and inductors.
  
- Dynamic Reactive Power Devices
  - Can quickly change the MVAR level independent of the voltage level.
  - Reactive power production level increases when the voltage level drops.
  - Examples include static VAR compensators (SVC), synchronous condensers, and generators.

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## **IX. POWER SYSTEM STABILITY**

### **VOLTAGE STABILITY**

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## Common Definitions

- **Voltage stability** - ability of a power system to maintain steady voltages at all the buses in the system after disturbance.
- **Voltage collapse** - A condition of a blackout or abnormally low voltages in significant part of the power system.
- **Short term voltage stability** - involves the dynamics of fast acting load components such as induction motors, electronically controlled loads, and HVDC converters.
- **Long term voltage stability** - involves slower acting equipments such as tap-changing transformer, thermostatically controlled loads, and generator limiters.

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## What is Voltage Instability/Collapse?

- A power system undergoes voltage collapse if post-disturbance voltages are below **“acceptable limits”**
  - voltage collapse may be due to voltage or angular instability
- Main factor causing voltage instability is the inability of the power systems to **“maintain a proper balance of reactive power and voltage control”**

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## Voltage Instability/Collapse

- The driving force for voltage instability is usually the load
- The possible outcome of voltage instability:
  - loss of loads
  - loss of integrity of the power system
- Voltage stability timeframe:
  - transient voltage instability: 0 to 10 secs
  - long-term voltage stability: 1 – 10 mins

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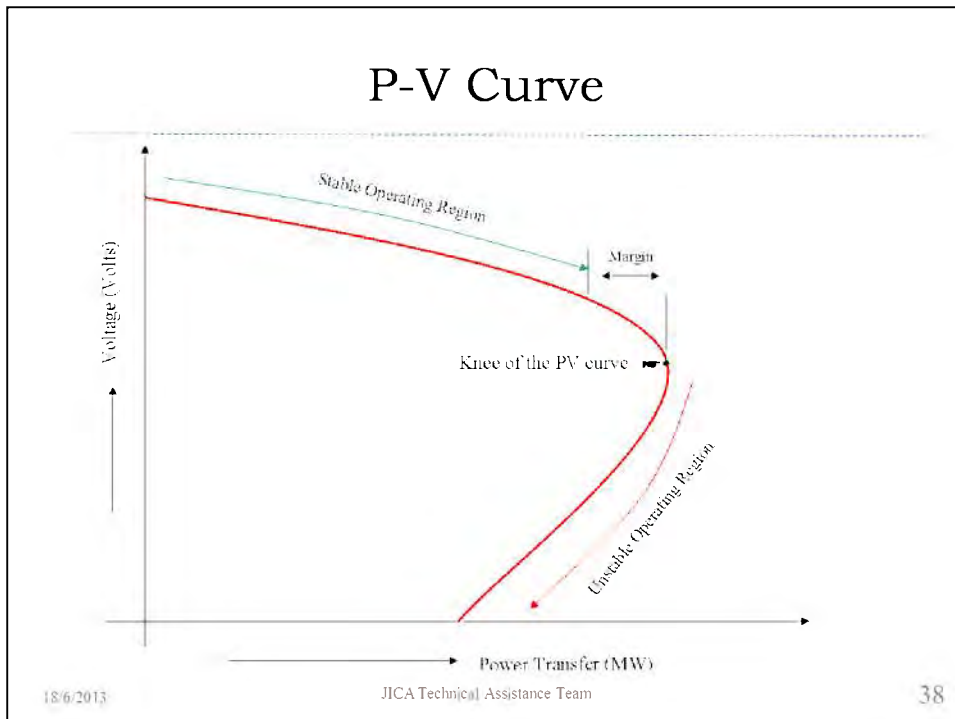
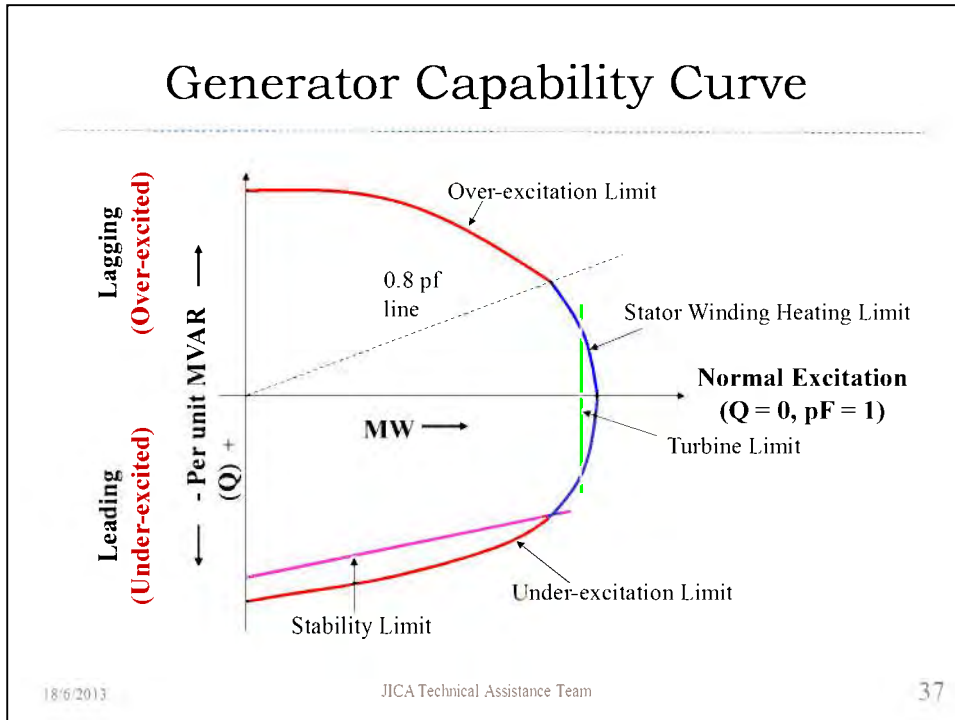
## Voltage stability causes and analysis

- Causes of voltage instability
  - Generators, synchronous condensers, or SVCs reaching reactive power limits
  - Tap-changing transformer action
  - Load recovery dynamics
  - Increase in loading
  - Tripping of heavily loaded lines, generators
- Methods of voltage stability analysis
  - Static analysis methods
    - Algebraic equations, bulk system studies, power flow or continuation power flow methods
  - Dynamic analysis methods
    - Differential as well as algebraic equations. dynamic modeling of power system components required

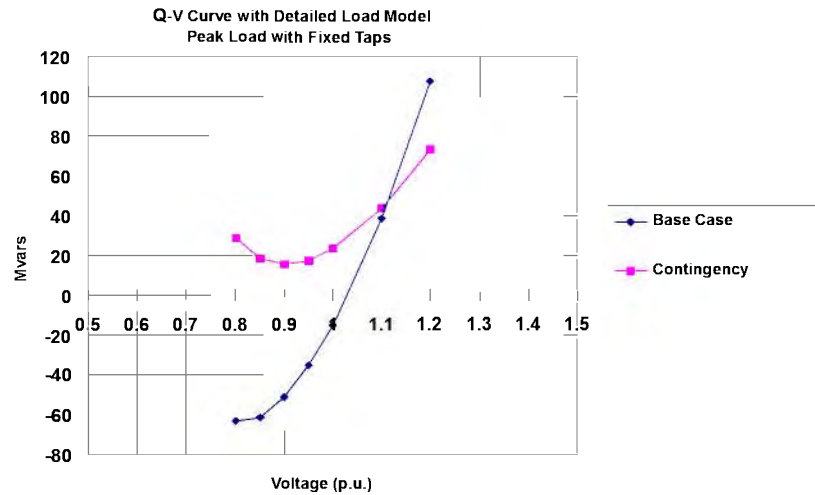
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## Q-V Curve



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## Possible Solutions for Voltage Instability

- Install/Operate Shunt Capacitor Banks
- Add dynamic Shunt Compensation in the form of SVC/STATCOM to mitigate transient voltage dips
- Add Series Compensation on transmission lines in the problem area
- Implement UVLS Scheme
- Construct transmission facilities

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## **IX. POWER SYSTEM STABILITY**

### **FACTS**

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### **What is FACTS?**

- Alternating Current Transmission Systems Incorporating Power Electronic Based and Other Static Controllers to Enhance Controllability and Increase Power Transfer Capability.
  
- power semi-conductor based inverters
- information and control technologies

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## Major FACTS Controllers

- Static VAR Compensator (SVC)
- Static Reactive Compensator (STATCOM)
- Static Series Synchr. Compensator (SSSC)
- Unified Power Flow Controller (UPFC)
- Back-To-Back DC Link (BTB)

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## Static VAR compensator (SVC)

- Variable reactive power source
- Can generate as well as absorb reactive power
- Maximum and minimum limits on reactive power output depends on limiting values of capacitive and inductive susceptances.
- Droop characteristic

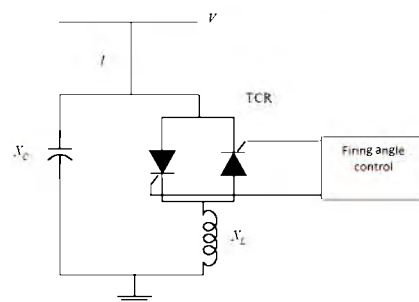


Fig. Schematic diagram of an SVC

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## Static compensator (STATCOM)

- Voltage source converter device
- Alternating voltage source behind a coupling reactance
- Can be operated at its full output current even at very low voltages
- Depending upon manufacturer's design, STATCOMs may have increased transient rating both in inductive as well as capacitive mode of operation

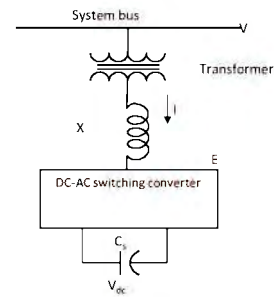


Fig. Schematic diagram of STATCOM

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## Summary

- The increasing need to operate the transmission system at its maximum safe transfer limit has become a primary concern at most utilities
- Reactive power supply or VAR management is an important ingredient in maintaining healthy power system voltages and facilitating power transfers
- Inadequate reactive power supply was a major factor in most of the recent blackouts

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## IX. POWER SYSTEM STABILITY

### ANGLE STABILITY

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## Introduction

Power systems are generally made up of a large interconnection of synchronous machines. In normal operation these machines remain in synchronism with each other, maintaining steady synchronising frequency and constant machine power angle differences between each other. Following a disturbance in a system the frequencies of synchronous machines undergo transient deviations from the synchronous frequency of 50Hz and the machine power angles undergo transient change.

- The category of angle stability can be considered in terms of two main subcategories:
  - 1. **Steady-State/Dynamic:** This form of instability results from the inability to maintain synchronism and/or dampen out system transients and oscillations caused by small system changes, such as continual changes in load and/or generation.
  - 2. **Transient:** This form of instability results from the inability to maintain synchronism after large disturbances such as system faults and/or equipment outages.
- These notes will focus in particular on the transient stability subcategory and on the techniques that can be used to analyse the transient stability of a system following a disturbance.
- The aim of transient stability studies being to determine if the machines in a system will return to a steady synchronised state following a disturbance.

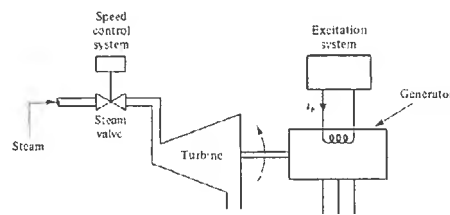
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## The Swing Equation

Consider a generating unit consisting of a three-phase synchronous generator and prime mover, as shown in Figure 1.



**Figure 1** Generating Unit

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The motion of the synchronous generator's rotor is determined by Newton's second law, which is given as:

$$J\alpha_m(t) = T_m(t) - T_e(t) = T_a(t) \quad (1)$$

Where

$J$  = Total moment of inertia of the rotating masses (prime mover and generator) ( $\text{kg}\cdot\text{m}^2$ )

$\alpha_m$  = Rotor angular acceleration ( $\text{rad}/\text{s}^2$ )

$T_m$  = Mechanical torque supplied by the prime mover minus the retarding torque due to mechanical losses (eg. Friction) (Nm)

$T_e$  = Electrical torque, accounting for the total three-phase power output and losses (Nm)

$T_a$  = Net accelerating torque (Nm)

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The machine and electrical torques,  $T_m$  and  $T_e$ , are positive for generator operation.

The rotor angular acceleration is given by

$$\alpha_m(t) = \frac{d\omega_m(t)}{dt} = \frac{d^2\theta_m(t)}{dt^2} \quad (2)$$

$$\omega_m(t) = \frac{d\theta_m(t)}{dt} \quad (3)$$

Where

$\omega_m$  = Rotor angular velocity (rad/s)

$\theta_m$  = Rotor angular position with respect to a stationary axis (rad)

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- In steady state conditions the mechanical torque equals the electrical torque and the accelerating torque is zero. There is no acceleration and the rotor speed is constant at the synchronous velocity.
- When the mechanical torque is more than the electrical torque then the acceleration torque is positive and the speed of the rotor increases.
- When the mechanical torque is less than the electrical torque then the acceleration torque is negative and the speed of the rotor decreases.
- Since we are interested in the rotor speed relative to the synchronous speed it is convenient to measure the rotor angular position with respect to a synchronously rotating axis instead of a stationary one.

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We therefore define

$$\theta_m(t) = \omega_{syn}t + \delta_m(t) \quad (4)$$

Where

$\omega_{syn}$  = Synchronous angular velocity of the rotor, rad/s

$\delta_m$  = Rotor angular position with respect to a synchronously rotating reference

To understand the concept of the synchronously rotating reference axis consider the diagram in Figure 2. In this example the rotor is rotating at half the synchronous speed,  $\omega_{syn}/2$ , such that in the time it takes for the reference axis to rotate  $45^\circ$  the rotor only rotates  $22.5^\circ$  and the rotor angular position with reference to the rotating axis changes from  $-45^\circ$  to  $-67.5^\circ$ .

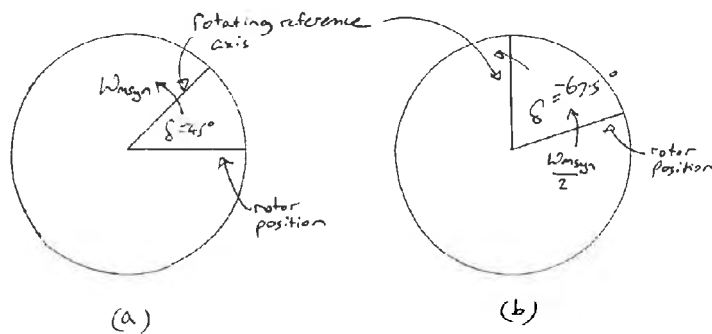


Figure 2 Synchronously rotating reference axis

From (2) and (4), we see that equation (1) can be written as

$$J\omega_m(t) = J \frac{d^2\theta_m(t)}{dt^2} = J \frac{d^2\delta_m(t)}{dt^2} = T_m(t) - T_e(t) = T_a(t) \quad (5)$$

Being that we are analysing a power system we are interested in values of power more than we are in values of torque. It is therefore more convenient to work with expressions of power. Furthermore it is convenient to consider this power in per unit rather than actual units.

Power is equal to the angular velocity times the torque and per unit power can be obtained by dividing by  $S_{rated}$ , so that:

$$\frac{J\omega_m(t)}{S_{rated}} \frac{d^2\delta_m(t)}{dt^2} = \frac{\omega_m(t)T_m(t) - \omega_m(t)T_e(t)}{S_{rated}} = \frac{p_m(t) - p_e(t)}{S_{rated}} = p_{mpu}(t) - p_{epu}(t) \quad (6)$$

$P_{mpu}$  = Mechanical power supplied by the prime mover minus mechanical losses (per unit)

$P_{epu}$  = Electrical power output of generator plus electrical losses (per unit)

We define a constant value known as the normalised inertia constant, or “H” constant.

$$H = \frac{\text{stored kinetic energy at synchronous speed}}{\text{generator voltampere rating}} \quad (7)$$

$$= \frac{\frac{1}{2} J \omega_{syn}^2}{S_{rated}} \quad (\text{joules/VA or per unit-seconds})$$

Equation (6) becomes

$$2H \frac{\omega_m(t)}{\omega_{syn}^2} \frac{d^2\delta_m(t)}{dt^2} = p_{mpu}(t) - p_{epu}(t) = p_{apu}(t) \quad (8)$$

Where  $P_{apu}$  = Accelerating power

We define per-unit rotor angular velocity as:

$$\omega_{pu}(t) = \frac{\omega_m(t)}{\omega_{syn}} \quad (9)$$

Equation (8) becomes

$$\frac{2H}{\omega_{syn}} \omega_{pu}(t) \frac{d^2\delta_m(t)}{dt^2} = p_{mpu}(t) - p_{epu}(t) = p_{apu}(t) \quad (10)$$

When a synchronous generator has  $P$  poles, the synchronous electrical angular velocity,  $\omega_{syn}$ , known more correctly as the synchronous electrical radian frequency, can be related to the synchronous mechanical angular velocity by the following relationship.

$$\omega_{syn} = \frac{P}{2} \omega_{mech} \quad (11)$$

To understand how this relationship arises, consider that the number of mechanical radians in one full revolution of the rotor is  $2\pi$ . If, for instance, a generator has 4 poles (2 pairs), and there are  $2\pi$  electrical radians between poles in a pair then the electrical waveform will go through  $2 * 2\pi = 4\pi$  electrical radians within the same revolution of the rotor.

In general the number of electrical radians in one revolution is the number of mechanical radians times the number of pole pairs (the number of poles divided by two).

The relationship shown in (11) also holds for the electrical angular acceleration  $\alpha(t)$ , the electrical radian frequency  $\omega(t)$ , and the electrical power angle  $\delta$  values.

$$\begin{aligned} \alpha(t) &= \frac{P}{2} \alpha_m(t) \\ \omega(t) &= \frac{P}{2} \omega_m(t) \\ \delta(t) &= \frac{P}{2} \delta_m(t) \end{aligned} \quad (12)$$

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From (9) we see that

$$\omega_{pu}(t) = \frac{\omega_m(t)}{\omega_{mech}} = \frac{\frac{2}{P} \omega(t)}{\frac{2}{P} \omega_{syn}} = \frac{\omega(t)}{\omega_{syn}} \quad (13)$$

Therefore equation (10) can be written in electrical terms rather than mechanical:

$$\frac{2H}{\omega_{syn}} \omega_{pu}(t) \frac{d^2 \delta(t)}{dt^2} = p_{mech}(t) - p_{apu}(t) = p_{apu}(t) \quad (14)$$

This equation is known as the “**SWING-EQUATION**” and is the fundamental equation in determining rotor dynamics in transient stability studies.

The swing equation is non-linear because  $p_{mech}(t)$  is a non-linear function of  $\delta$  and because of the  $\omega_{pu}(t)$  term. The rotor speed, however, does not vary a great deal from the synchronous speed during transients and a value of  $\omega_{pu}(t) \approx 1.0$  is often used in hand calculations.

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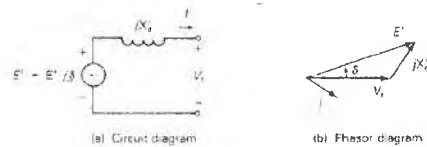


## Electric power equation

In the swing equation the mechanical power from the prime mover,  $P_{ppm}$ , is considered to be constant. This is a reasonable assumption as the conditions in the electrical network can be expected to change before the slower acting control governor can cause the turbine to react.

The electrical power,  $P_{epu}$ , will therefore determine whether the rotor accelerates, decelerates or remains at a constant synchronous speed. Electrical network disturbances resulting from extreme changes in system loading, network faults and circuit breaker operation will cause the generator output to change rapidly and transients will exist.

The synchronous machine is represented in transient stability studies by a transient internal voltage  $E'$  in series with its transient reactance  $X'_d$  as shown in Figure 3.



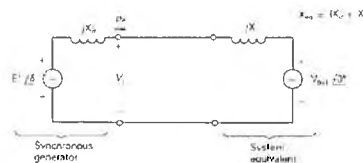
**Figure 3 Simplified synchronous machine model for transient stability studies**

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Generators are normally connected to systems composed of transmission lines, transformers and other machines. When systems are large enough, as they most often are, an “infinite bus” behind a system reactance can represent them. An infinite bus is an ideal voltage source that maintains constant voltage magnitude, phase and frequency. Figure 4 illustrates the connection arrangement of the synchronous generator to the equivalent system.



**Figure 4 Synchronous generator connected to a system equivalent**

The real power delivered from the generator to the infinite bus (and therefore the system) is therefore:

$$P_e = \frac{|E'| |V_{bus}|}{X_{eq}} \sin \delta = P_{max} \sin \delta \quad (15)$$

Where

$$X_{eq} = X'_d + X$$

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## The equal area criterion

A method known as the equal area criterion can be used for a quick prediction of stability. This method determines if a machine maintains its stability after a disturbance by graphical interpretation of the energy stored in the rotating mass. It is, however, restricted to either one machine systems connected to an infinite bus or to two machine systems. More complex and accurate numerical solution of the non-linear swing equation can be performed by computer and is especially applicable to the analysis of multi-machine systems. In these notes we will not focus on this numerical solution method, preferring to look at the simpler equal area method.

Figure 5 shows plots of electrical power  $P_e$  and mechanical power  $P_m$  versus the power angle  $\delta$ . The generating unit illustrated in Figure 5 is initially operating in a steady state and  $P_e = P_m = P_{m0}$  and  $\delta = \delta_0$ .

If a step change in the mechanical power occurs so that it increases to  $P_m = P_{m1}$  at time equals zero. The rotor has inertia and as such the rotor position cannot change instantaneously,  $\delta_m(0-) = \delta_m(0+)$ . As the electrical power angle is related to the rotor position and electrical power is related to the electrical power angle then the electrical power does not change instantaneously,  $\delta(0-) = \delta(0+) = \delta_0$  and  $P_e(0-) = P_e(0+)$ .

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The mechanical and electrical powers will be unbalanced and the accelerating power will act to increase the rotor speed and  $\delta$  will increase. When the angle  $\delta$  reaches the desired value of  $\delta_1$  then the acceleration,  $d^2\delta/dt^2$ , will be zero but as the velocity is above synchronous the angle  $\delta$  will continue to increase and overshoot the target. Once past  $\delta_1$  the electrical power becomes greater than the mechanical power and the rotor decelerates. After reaching a maximum value it begins to swing back towards  $\delta_1$ . If there were no damping present then the angle  $\delta$  would continue to oscillate about the  $\delta_1$  point. Damping, however is present due to mechanical and electrical losses, and  $\delta$  eventually settles down to its final steady state value  $\delta_1$ .

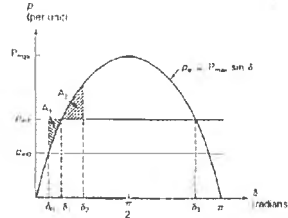


Figure 5 Electrical and Mechanical power versus  $\delta$

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If we consider now the swing equation and assume that  $\omega_{pu}(t) \approx 0.1$  then:

$$\frac{2H}{\omega_{2n}} \frac{d^2\delta}{dt^2} = p_{mpu} - p_{epu} \quad (16)$$

If we multiply both sides by  $d\delta/dt$  and use the identity

$$\frac{d}{dt} \left[ \frac{d\delta}{dt} \right]^2 = 2 \left( \frac{d\delta}{dt} \right) \left( \frac{d^2\delta}{dt^2} \right)$$

Equation (16) becomes

$$\frac{2H}{\omega_{2n}} \left( \frac{d^2\delta}{dt^2} \right) \left( \frac{d\delta}{dt} \right) = \frac{H}{\omega_{2n}} \frac{d}{dt} \left( \frac{d\delta}{dt} \right)^2 = (p_{mpu} - p_{epu}) \left( \frac{d\delta}{dt} \right) \quad (17)$$

Multiplying equation (17) by  $dt$  and integrate from  $\delta_0$  to  $\delta$  we obtain the following expression:

$$\frac{H}{\omega_{2n}} \int_{\delta_0}^{\delta} d \left( \frac{d\delta}{dt} \right)^2 = \int_{\delta_0}^{\delta} (p_{mpu} - p_{epu}) d\delta \quad (18)$$

Or

$$\frac{H}{\omega_{2n}} \left( \frac{d\delta}{dt} \right)^2 \Big|_{\delta_0}^{\delta} = \int_{\delta_0}^{\delta} (p_{mpu} - p_{epu}) d\delta \quad (19)$$

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Note that the above integration begins at  $\delta_0$  and ends at some arbitrary angle  $\delta$ . The value of  $d\delta/dt$  is zero at  $\delta_0$  as the machine is in steady state. The value of  $d\delta/dt$  is also zero at  $\delta$  equal to  $\delta_2$ , as the rotor changes direction back towards  $\delta_1$ . The left hand side of (19) equals zero for  $\delta = \delta_2$  and therefore:

$$\int_{\delta_0}^{\delta_2} (p_{mpu} - p_{epu}) d\delta = 0 \quad (20)$$

If we separate (20) into accelerating and decelerating areas we obtain the following equation:

$$\int_{\delta_0}^{\delta_1} \underbrace{(p_{mpu} - p_{epu}) d\delta}_{\text{area A1}} + \int_{\delta_2}^{\delta_1} \underbrace{(p_{mpu} - p_{epu}) d\delta}_{\text{area A2}} = 0 \quad (21)$$

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Note how the two elements of (21) equate to the areas A1 and A2 shown in Figure 5 and in order for the two equations to be satisfied the two areas must be equal. This is why we call this the “*equal area*” criterion.

In practice, sudden changes in mechanical power do not occur as the time constants associated with the prime mover dynamics are in the order of seconds. However, stability phenomena similar to that described above can also occur from sudden changes in electrical power due to system changes such as system faults.

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## Design methods for improving transient stability

There are a number of design measures that can be implemented to improve the transient stability of a power system:

### 1. Improve the maximum power transfer capability

Improving the maximum power transfer capability of a system means that power can be transferred through alternative un-faulted portions of the network when a fault occurs. The effect of a fault on the system will not be as extreme. The maximum transfer capability of a system can be improved by the following methods:

- a. Implement and use higher system voltage levels (system losses will decrease as current flows will be lower, especially important in cases where line distances are large)
- b. Install additional transmission lines.
- c. Install lines and transformers with smaller reactance values
- d. Install series capacitive transmission line compensation to reduce the overall reactance of lines
- e. Install static VAR compensators and flexible AC transmission systems (FACTS)

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## 2. Implement high speed fault clearing

It is vital to clear faults before the critical clearing time is reached so the quicker a fault is cleared the better.

## 3. Implement high speed re-closure of circuit breakers

As the majority of transmission line short circuits are temporary, re-closure post fault can be beneficial in providing better power transfer capability. Care must be taken in this case to ensure that the re-closing on a permanent fault and any subsequent re-opening will not adversely affect the stability of the system.

## 4. Implement single pole switching

The majority of short circuits are single line to ground and the independent switch out of only the faulted phase means that some power flow can continue across the faulted line. Studies have shown that single line to ground faults are self-clearing even when only the faulted phase is de-energised.

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## 5. Use generators with larger machine inertia and with lower transient reactance

A larger synchronous machine inertia constant (H) results in a reduction in angular acceleration and therefore a slowing down of angular swings. The critical clearing time is increased.

Reducing the machine transient reactance increases the power transfer capability during faults and in the periods post fault.

## 6. Use fast responding, high gain exciters

Modern excitation systems can be designed to act quickly and with high gain in the event of sensing a low terminal voltage during faults. The effect is to increase the generator output during the fault and post fault periods. Critical clearing times are increased.

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### 7. Implement fast valving

Some steam turbines are equipped with fast valving to divert steam flows and rapidly decrease the mechanical output. When a fault occurs near to the generator the electrical power output is reduced and the fast valving acts to balance the mechanical and electrical powers. This provides reduced acceleration and longer critical clearing times.

### 8. Breaking Resistors

In power systems, areas of generation can be temporarily separated from the load areas. When the separation occurs the breaking resistor can be inserted into the generation area for a second or two in order to slow the acceleration.

**Japanese Technical Assistance  
on Strengthening Institutional Capacity  
of National Development Agency (ADN)  
in Democratic of Timor-Leste**

**-- POWER --**

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## Syllabus

No.	Contents
1	Introduction
2	Power Station (Diesel)
3	Substation
4	Transmission and Distribution System
5	Power System Study
6	Power Flow Analysis
7	Power System Stability
8	<b>An Example of Power System Analysis (Using PSS/E)</b>
9	Renewable Energy (Photovoltaic Power)
10	Protecting System
11	Power System Operation and Control
12	Others

The contents may be changed depending on conditions.  
I would like to discuss about the contents with Mr. Miguel and YOU.

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## **X. AN EXAMPLE OF POWER SYSTEM ANALYSIS (USING PSS/E)**

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## **X. AN EXAMPLE OF POWER SYSTEM ANALYSIS (USING PSS/E)**

### **INTRODUCTION TO PSS/E**

**Sorry for the following 6pages looking like advertisements.**

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## Overview

- PSS®E is the premier software tool used by electrical transmission participants world-wide. The probabilistic analyses and advanced dynamics modeling capabilities included in PSS®E provide transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks. PSS®E is the standard Siemens offering for electrical transmission analysis that continues to be the technology of choice in an ever-growing market that exceeds 115 countries.
- Since its introduction in 1976, the **Power System Simulator for Engineering** tool has become the most comprehensive, technically advanced, and widely used commercial program of its type. It is widely recognized as the most fully featured, time-tested and best performing commercial program available.

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## analytical capabilities

- PSS®E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance. It provides the user with the most advanced and proven methods in many technical areas:
  - PSS®E analytical capabilities include:
    - Power flow
    - Contingency analysis
    - Probabilistic contingency
    - Dynamic simulation (including extended term)
    - Short circuit (including IEC 60909).
  - Optional modules provide:
    - Optimal power flow (OPF)
    - Small signal stability analysis (NEVA)
    - Graphical model builder (GMB).

**PSS®E Version 33 released May 2011.**

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## Power flow

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- Fast powerful, and real-world tested system models up to 150,000 buses
- Graphical user interface (GUI)
- User-defined subsystems — subsystems based on areas, owners, zones, bus kV or combinations
- Over 30 years of commercial use and user-suggested enhancements have made

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## Contingency analysis

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When performing a contingency analysis in PSS®E, contingencies can be specified either automatically (e.g., all N-1 contingencies) or by a user-defined list. The result is a comprehensive list of contingencies tested and those that identify violations. The PSS®E Corrective Action feature can then be applied to automatically mitigate contingency violations that then provides a refined list of the most serious violations to be resolved.

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## Probabilistic contingency

Siemens PTI brings you comprehensive transmission probabilistic contingency analysis by enhancing the core state-of-the-art analytical formulations from our PSS®TPLAN software and integrating them into PSS®E. The probabilistic contingency capabilities feature easy configuration, detailed modeling of remedial action schemes, effective identification of voltage collapse conditions, and automatic handling of generation dispatch and load shedding requirements. These combined features provide program users with an all-inclusive tool to evaluate transmission reliability performance in large or small power systems on a deterministic and probabilistic basis.

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## Dynamic simulation

- The dynamic simulation module of PSS®E is a versatile tool to investigate system response to disturbances that cause large and sudden changes in the power system. The dynamic simulation module not only offers a vast library of built-in tested models for modeling different types of equipment, it also offers the capability to create user-defined models of any complexity.
- User models can be developed using Fortran code, or the Graphical Model Builder (GMB) can be used to graphically build and test control block diagrams for use in PSS®E and other PSS® products. An integrated plotting package allows the user to specify comprehensive and customizable plots with the ability to export to several popular graphic formats.

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## X. AN EXAMPLE OF POWER SYSTEM ANALYSIS (USING PSS/E)

### POWER FLOW ANALYSIS USING PSS/E

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## BUSES

- Bus Number: Displays the number assigned to a specific bus (1 through 999997).
- Bus Name: Alphanumeric identifier assigned to bus "#". The name may be up to twelve characters. The bus name may contain any combination of blanks, uppercase letters, numbers and special characters. The bus name is twelve blanks by default.
- Base kV: Bus base voltage; entered in kV.
- Code: Bus type code:
  - 1 - Load bus (no generator boundary condition)
  - 2 - Generator or plant bus (either voltage regulating or fixed Mvar)
  - 3 - Swing bus
  - 4 - Disconnected (isolated) bus
  - 5 - Same as type 1, but located on the boundary of an area in which an equivalent is to be constructed
 Code = 1 by default.
- Voltage (PU): Bus voltage magnitude; entered in per unit, V = 1.0 by default.

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Bus Number	Bus Name	Base kV	CODE	Voltage	Angle
1010	Dili	150	1		
1020	Hera	150	1		
1030	Manatuto	150	1		
1040	Baucau	150	1		
1050	Lospalos	150	1		
1060	Viqueque	150	1		
1070	Same	150	1		
1080	Cassa	150	1		
1090	Suai	150	1		
1100	Maliana	150	1		
1110	Liquica	150	1		
110	Dili	20	1		
120	Hera	15	3	1.00	0.00
130	Manatuto	20	1		
140	Baucau	20	1		
150	Lospalos	20	1		
160	Viqueque	20	1		
170	Same	20	1		
175	Betano	15	2		
180	Cassa	20	1		
190	Suai	20	1		
200	Maliana	20	1		
210	Liquica	20	1		

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## Branches

- From Bus: Branch "from bus" number outside brackets with bus name and bus kV enclosed in brackets.
- To Bus: Branch "to bus" number outside brackets with bus name and bus kV enclosed in brackets.
- Line R (PU): Branch resistance; entered in per unit. A value of R must be entered for each branch.
- Line X (PU): Branch reactance; entered in per unit. A nonzero value of X must be entered for each branch.
- Charging (PU) Total branch charging susceptance (imaginary part of admittance); entered in per unit. B = 0.0 by default.
- Rate A (MVA): First power rating; entered in MVA. Rate A = 0.0 (bypass check for this branch) by default.
- Rate B (MVA): Second power rating; entered in MVA. Rate B = 0.0 by default.
- Rate C (MVA): Third power rating; entered in MVA. Rate C = 0.0 by default.
- Length: Line length; entered in user-selected units.

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➤ Here, line constants were assumed from the standard data of the Kansai Electric Power of Japan.

➤  $R=0.669$ ,  $X=2.1$ ,  $Y=0.0078$  [%/km/cct, 154kV, 1,000MVA base], ACSR, 200mm<sup>2</sup>

➔  $R=0.669 \times 154^2 / 150^2 / 100 = 0.00705$  pu/km/cct

$X=2.1 \times 154^2 / 150^2 \times (50/60) / 100 = 0.018$  pu/km/cct

$Y=0.0078 \times 150^2 / 154^2 \times (50/60) / 100 = 0.000062$  pu/km/cct

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From	From Bus Name	To	To Bus Name	Id	Line R (pu)	Line X (pu)	Charging (pu)	Length[km]
	Dili		Hera	1	0.06922395	0.176742	0.000608778	9.819
	Dili		Hera	2	0.06922395	0.176742	0.000608778	9.819
	Hera		Manatuto	1	0.2883591	0.736236	0.002535924	40.902
	Hera		Manatuto	2	0.2883591	0.736236	0.002535924	40.902
	Manatuto		Baucau		0.36891945	0.941922	0.003244398	52.329
	Baucau		Laspalos		0.44766795	1.142982	0.003936938	63.499
	Baucau		Viqueque		0.30403125	0.77625	0.00267375	43.125
	Loasplos		Viqueque		0.72924495	1.861902	0.006413218	103.439
	Viqueque		Same		0.59554875	1.52055	0.00523745	84.475
	Same		Casa		0.1791264	0.457344	0.001575296	25.408
	Casa		Suai		0.27181275	0.69399	0.00239041	38.555
	Suai		Maliana		0.41019015	1.047294	0.003607346	58.183
	Maliana		Liquica		0.31669305	0.808578	0.002785102	44.921
	Liquica		Dili		0.2736669	0.698724	0.002406716	38.818
					0.00705	0.018	0.000062	1.0

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## Loads

- Bus Number/Name: the bus name
- Id: This is a one, or two, character uppercase, nonblank, alphanumeric load identifier. It is used to distinguish among multiple loads at the same "Bus Number/Name". At buses in which there is a single load present, the ID = 1.
- In-Service: A check mark indicates that a certain load at a "Bus Number/Name" is fully operational. If for any reason a certain load at a "Bus Number/Name" needs to be taken out of service, simply un-check that particular one and click the line above or below to make your changes final.
- Pload (MW): Active power component of constant MVA load; entered in MW.
- Qload (MW): Reactive power component of constant MVA load; entered in MVAR.

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## Assumptions for Load Condition

- The sum of active power load of all Timor Leste is the output value of Hera power plant around 15:00 on June 18, 2013. → 35.4MW
- The value of load above is allocated by the capacity ratio of the distribution substation.
- Power factor of each load is 90 %.

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Bus Number	Bus Name	Id	In Service	Pload (MW)	Qload (Mvar)	Capacity (MVA)
110	Dili		1	10.91	5.28	63
130	Manatuto		1	1.73	0.84	10
140	Baucau		1	5.45	2.64	31.5
150	Lospalos		1	3.46	1.68	20
160	Viqueque		1	1.73	0.84	10
170	Same		1	1.73	0.84	10 (Assumption)
180	Cassa		1	1.73	0.84	10
190	Suai		1	3.46	1.68	20
200	Maliana		1	3.46	1.68	20
210	Liquica		1	1.73	0.84	10

SUM	35.40	17.15	204.5
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Pall	35.40
PF	0.90

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## Machines

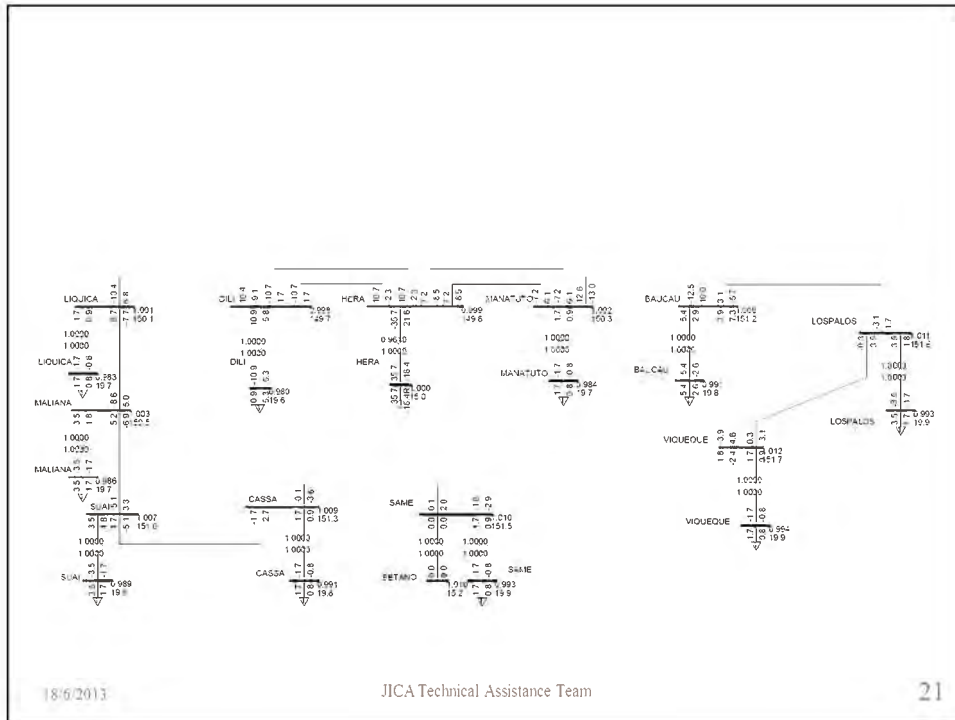
- Bus Number/Name: This displays the Bus Number (where the machine is located) outside of the brackets and displays the bus name as well as the bus voltage in kV inside the brackets.
- Id: This is a one, or two, character uppercase, nonblank, alphanumeric machine identifier. It is used to distinguish among multiple machines at a plant (i.e., at a generator bus). At buses in which there is a single machine present, ID = 1.
- In-Service: A check mark indicates that a certain machine at a "Bus Number/Name" is fully operational. If for any reason a certain machine at a "Bus Number/Name" needs to be taken out of service, simply un-check that particular one and click the line above or below to make your changes final.
- Pgen: This is the active power that the generator is putting out; entered in MW.
- Pmin: This is the minimum active power that the generator can output; entered in MW.
- Pmax: This is the maximum active power that the generator can output; entered in MW.
- Qgen: This is the reactive power that the generator is putting out; entered in MVAR.
- Qmin: This is the minimum reactive power that the generator can output; entered in MVAR.
- Qmax: This is the maximum reactive power that the generator can output; entered in MVAR.

Bus Number	Bus Name	Id	In Service	Pgen (MW)
120	Hera		1	36.0

The value has no meaning because Hera is slack.

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## What we can know from the result

- Loss of active power in the all system 0.3 MW.
- Load of Dili should be larger. It may be 10 MW (30.2-21.4=8.8) larger.

Bus Number	Bus Name	Id	In Service	Load (MW)	Load (Mvar)	Capacity (MVA)
110	Dili		1	24.43	11.83	63
130	Manatuto		1	0.75	0.37	10
140	Baucau		1	2.38	1.15	31.5
150	Lospalos		1	1.51	0.73	20
160	Viqueque		1	0.75	0.37	10
170	Same		1	0.75	0.37	10
180	Cassa		1	0.75	0.37	10
190	Suai		1	1.51	0.73	20
200	Maliana		1	1.51	0.73	20
210	Liquica		1	0.75	0.37	10
SUM				35.10	17.00	141.5
Pall				35.10	10.67	
PF					0.90	

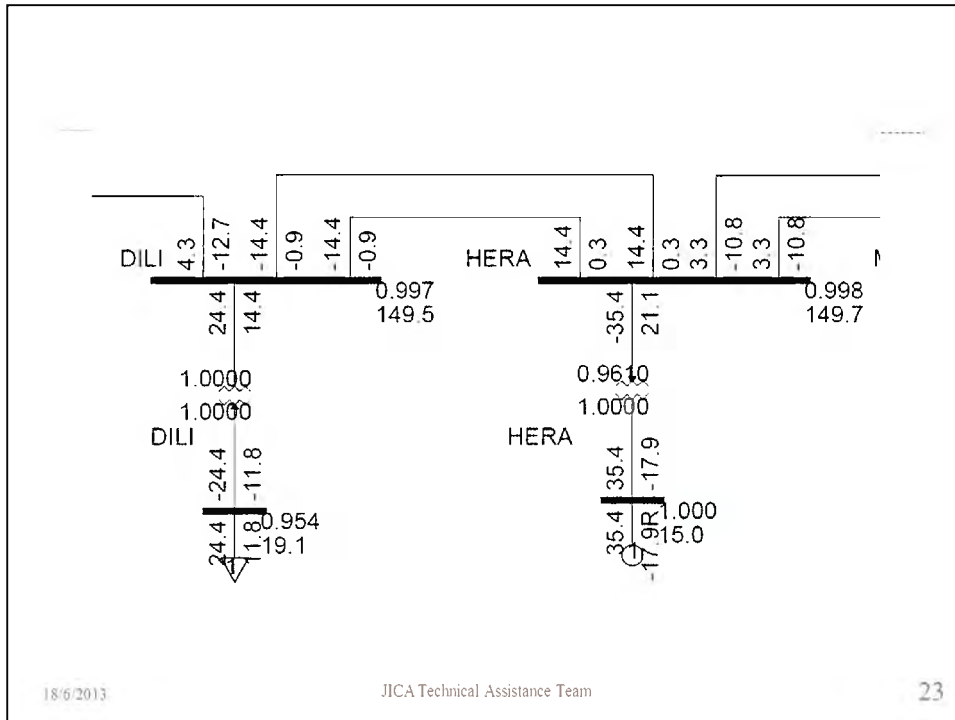
+8.8

Pall-load of Dili

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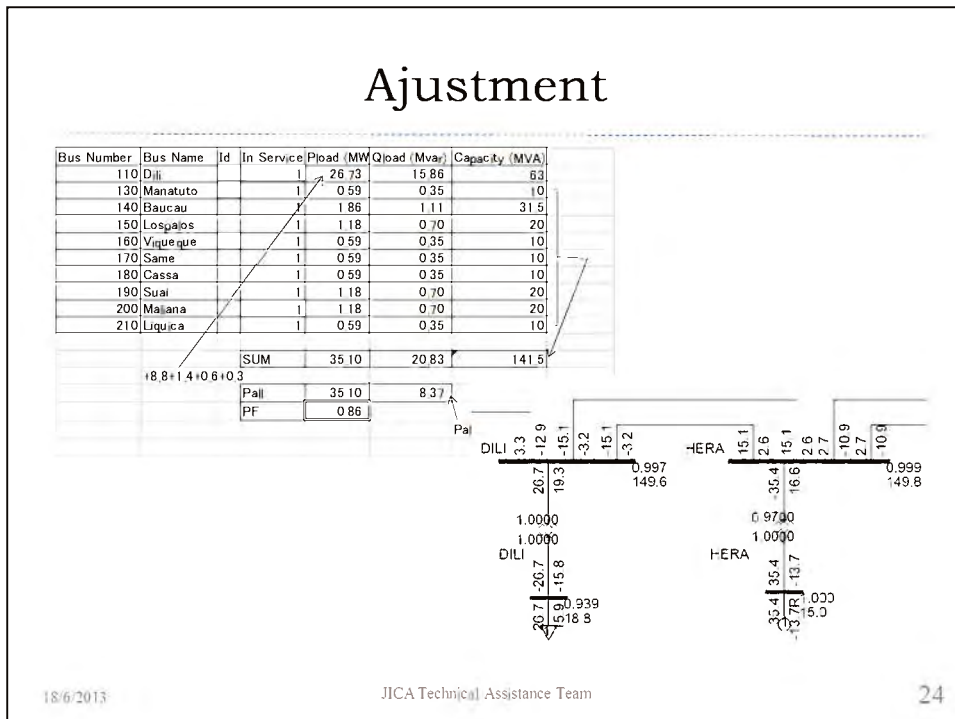
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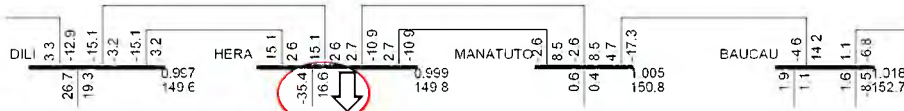
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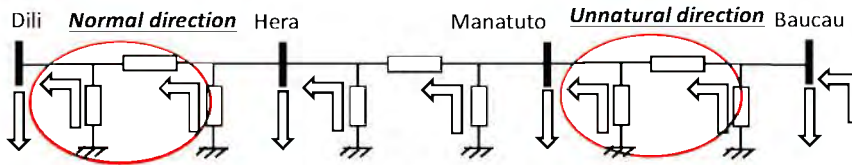


## The reason of Leading Power Factor Operation



- The very low consumption of power
- Long distance of the lines

### The Reactive Power Flow

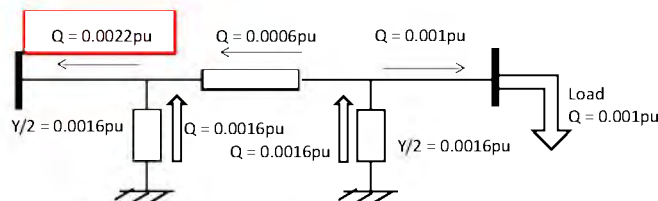


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- Charging of the line (Y) between Manatuto and Baucau (52km) is 0.0032pu (150kV, 1,000MVAbase).
- $Y/2 = 0.0016$
- If bus voltage is 1.0 pu, reactive power,  $Q=0.0016pu$  is generated.
- On the other hand, for example, the reactive power load of Baucau is 1.0Mvar (0.001pu).
- Therefore,  $0.0016+0.0006 = 0.0022pu = 2.2MVar$  is not consumed and flow to generators. The loss of transmission line is ignored.



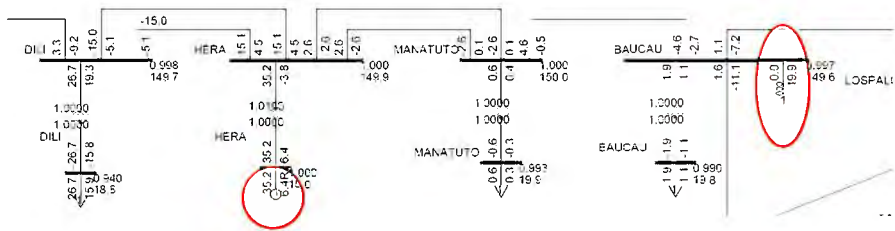
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## Countermeasure

- One of countermeasures is installing of a shunt reactor in the north-east area.



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on Strengthening Institutional Capacity  
of National Development Agency (ADN)  
in Democratic of Timor-Leste**

**-- POWER --**

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## Syllabus

No.	Contents
1	Introduction
2	Power Station (Diesel)
3	Substation
4	Transmission and Distribution System
5	Power System Study
6	Power Flow Analysis
7	Power System Stability
8	An Example of Power System Analysis (Using PSS/E)
9	<b>How to Use the Result of Power System Analysis</b>
10	Renewable Energy (Photovoltaic Power)
11	Protecting System
12	Power System Operation and Control
13	Others

The contents may be changed depending on conditions.  
I would like to discuss about the contents with Mr. Miguel and YOU.

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## **XI. HOW TO USE THE RESULT OF POWER SYSTEM ANALYSIS**

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### Overview

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- This materials explains how the results of power system analysis (Transmission System Studies) are used in actuality by introducing the material, 'An Overview of Transmission System Studies' (REA BULLETIN 1724E-202) published by UNITED STATES DEPARTMENT OF AGRICULTURE

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## 1. INTRODUCTION:

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- Recent trends in power system complexity, energy conservation and economic performance of REA-financed projects reinforce the need for careful system planning for transmission facilities. Planning studies generally involve the modeling of these facilities in order that system performance can be conveniently observed and evaluated.

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## 2. PURPOSE:

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- The purpose of this bulletin is to outline the system studies that should be considered to support design criteria for REA-financed transmission facilities from 34.5 through 765 kilovolts (kV).
- Presented in Section 3 is a list of transmission system studies for various facility applications that should be considered. Section 4 contains the input data required to perform each study. A flow chart is presented in Section 5 that relates the interdependency of each study to the overall system planning concept. Section 6 contains a detailed explanation of each study.

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### 3. SYSTEM STUDY APPLICABILITY:

- Table 1 represents a list of the type transmission system studies and requirements to support REA related financing arrangements for projects from 34.5 kV through 765 kV. These system studies should be considered in conjunction with the long range system and financial planning requirements. This list of studies is not necessarily complete nor is it listed in any order of priority. Each study should be completed or considered as required in Table 1 for the specific facility in question in order that system performance can be evaluated. (Refer to Sections 5 and 6 of this bulletin for a detailed description of each study.)

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- The column numbers in the table refer to the following studies:

- 1) Facility Feasibility
- 2) Load Flow
- 3) Reactive Compensation
- 4) Stability
- 5) Subsynchronous Resonance
- 6) Statistical Line Design
- 7) Short Circuit
- 8) Insulation Coordination
- 9) Corona and Radio Interference
- 10) Electrostatic and Electromagnetic
- 11) Transmission Facility Economics

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➤ Symbols used in Table 1 are defined as follows:

- An "X" indicates study should be performed and submitted to REA in conjunction with a request for REA action on financing arrangements.
- A "Y" indicates study should be performed and submitted to REA with the project design information.
- A "Z" indicates study should be performed but not submitted for review unless requested by REA.
- An "O" indicates it may be advisable to have study performed depending on system complexity. REA should be informed whether or not study will be completed at which time the borrower will be informed if REA desires to review results.
- No mark indicates the study is not generally applicable.

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#### 4. INPUT DATA REQUIREMENTS:

- Prior to developing system models for each planning study, data must be developed:
- (1) to permit mathematical simulation of the real system,
  - (2) to aid in the analysis of system performance related to equipment performance, and
  - (3) to provide constraints so that system improvements can be made.
- A brief description of such input data will now be presented for generators, transformers, lines and loads.

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## 4.1 Generators:

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- For steady-state analysis, generators are represented in terms of the real and reactive power to the system. Conversely, for transient performance, system studies may require full representation of the electrical and mechanical characteristics of each generator.

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## 4.2 Transformers:

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- Most system studies require information about core and winding loss resistances, leakage reactances, turns ratios at available taps, and automatic tap-changing limits.

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## analytical capabilities

- PSS®E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance. It provides the user with the most advanced and proven methods in many technical areas:
  - PSS®E analytical capabilities include:
    - Power flow
    - Contingency analysis
    - Probabilistic contingency
    - Dynamic simulation (including extended term)
    - Short circuit (including IEC 60909).
  - Optional modules provide:
    - Optimal power flow (OPF)
    - Small signal stability analysis (NEVA)
    - Graphical model builder (GMB).

**PSS®E Version 33 released May 2011.**

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## 4.3 Transmission Lines:

- Transmission lines are generally represented by single phase models with equivalent series impedances (resistance-inductance combinations) between line terminals and equivalent shunt admittances at each terminal. For a balanced three-phase transmission system the manner in which a single phase is represented should depend on the line length and accuracy required. In selecting a model, it is usual to classify transmission lines as short, medium, or long. There is no definite length that can be stipulated to divide short and long line analysis. For the majority of the cases, a sufficient degree of accuracy may be obtained by the short line model on lines up to 50 miles (80 kilometers). The degree of accuracy varies with line length and configuration and also with conductor diameter and spacing.

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## 4.4 Loads:

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- In load flow studies, loads are usually represented by constant real and reactive power flow requirements. For stability studies, large motor loads are characterized by induction motor equivalent electrical circuits.

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## 4.5 Miscellaneous:

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- Input data are also developed in order to determine relay settings in terms of loading limits. Transient and dynamic stability studies require knowledge of relay and breaker times and operating sequences. Outage rates and durations for all major equipment are also necessary for developing reliability data.

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## 5. SYSTEM STUDY FLOW CHART:

- The following is a list of system studies that should be considered to support the design criteria along with a system study flow chart that relates each study to the overall planning concept. These studies are listed in Section 3 and are repeated below for convenience:
  - 1) Facility Feasibility
  - 2) Load Flow
  - 3) Reactive Compensation
  - 4) Stability
  - 5) Subsynchronous Resonance (SSR)
  - 6) Statistical Line Design
  - 7) Short Circuit
  - 8) Insulation Coordination
  - 9) Corona and Radio Interference
  - 10) Electrostatic and Electromagnetic
  - 11) Transmission Facility Economics
- SSR, item 5, primarily may occur when series compensation is employed. Statistical Line Design Parameters, item 6, are presented in the 1993 edition of the National Electrical Safety Code (NESC) for EHV transmission lines.

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- A system study flow chart is shown in Figure 1. The facility feasibility study yields information pertaining to voltage level, system capacity, conductor type, and the approximate location of transmission circuits. Once a basic plan is established, a more complete transmission system study is used in order to perform detailed load flow and stability studies. The results of load flow studies help determine the adequacy of the design with regard to acceptable voltage, phase angle, impedance, and power flow variations. Reactive compensation studies utilize information from load flow studies to establish optimum types of reactive (var) sources. Similarly, results from stability studies may show several alternatives to achieve stability before equipment characteristics are specified. After the load flow and stability studies, then possible switching over-voltage problems are investigated via a statistical line design study since these voltages influence line and apparatus insulation levels.

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- Other statistical line design investigations include lightning, contamination, and flashover strength studies to yield an optimum insulation system for the transmission facility. Short circuit studies are then performed to assure proper selection of protective relays and circuit breaker interrupting characteristics. Similarly, insulation coordination studies are necessary to assure proper protection of facilities against system over-voltage (internal-switching surges and external-lightning strokes).

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- Extra-high-voltage (EHV) investigations that concern environmental and safety factors are corona, radio interference, electrostatic (E/S) and electromagnetic (E/M) studies. Finally, transmission facility economic studies should be considered that include tower, conductor, hardware, equipment, and right-of-way trade-off cost analyses.

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## 6. DISCUSSION OF INDIVIDUAL SYSTEM STUDIES:

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- This section gives additional details about each type of study.

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### 6.1 Facility Feasibility:

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- Facility feasibility studies include load and rating requirements, system voltage, surge impedance loading and system capacity.

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## 6.1.1 Load Requirements :

- The foundation of any system planning study is a determination of the load to be served which should be compatible with an approved Power Requirements Study (7 CFR 1710, Subpart E). This load is viewed in terms of magnitude; daily and seasonal variation; area distribution; behavior characteristics with voltage and frequency variations; and reliability requirements. In addition to requiring full knowledge of the existing load and its characteristics, the planning process calls for the careful projection of load growth. In general, loads are projected for the entire system as well as for each region and each major existing and future substation.

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## 6.1.2 Rating Requirements :

- Besides their use in operating the system under abnormal conditions, this type of study is essential to the system planning function.
- Each type of electrical equipment has a thermal rating which varies as a function of load cycle, ambient, loss of life, sun exposure, etc. Most utilities develop ratings similar to the following:
  - 1) Normal (continuous)
  - 2) Emergency - 4 hours, 8 hours, 24 hours
  - 3) Emergency - 1 month, 6 months
- These ratings are used for both planning continuous loads and contingency loads. They also assist in planning for the different equipment loading characteristics in summer and winter.

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### 6.1.3 System Voltage :

- Transmission system voltages below the extra-high-voltage (EHV) level are between 34.5 and 230 kilovolts (kV). The nominal EHV levels in the United States are 345, 500 and 765 kV.
- If a transmission facility is to be developed economically, voltage steps should be neither too large nor too small. In general, a 230 kV transmission system will find it is most economical to stay at 230 kV until load growth requirements dictate 500 kV as a economical level. Similarly, 345 kV systems will probably bypass 500 kV in favor of 765 kV when load growth requirements dictate a higher voltage level.

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### 6.1.4 Surge Impedance Loading :

- Surge impedance loading (SIL) is a convenient indicator of comparing the approximate load-carrying capability of transmission lines of different voltages. SIL is the load that the line will carry when each phase is terminated in an impedance of:

$$Z_o = \frac{Z_L}{Y_C} \quad \text{Eq. 1}$$

(formula is squared)

where:

$Z_o$  = surge impedance, in ohms

$Z_L$  = series line impedance, in ohms per unit length

$Y_C$  = shunt line admittance, in ohms per unit length

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- The SIL, in megawatts (MW), is a function of the magnitude of  $Z_0$  (or  $Z_0$ ) and the square of the voltage as shown in the following equation:

$$\text{SIL} = \frac{V^2}{Z_0} \quad \text{Eq. 2}$$

where:

$V$  = root mean squared (RMS) line-to-line voltage, in kilovolts (kV).

- While SIL gives a general idea of the relative loading capability of a line, it is usual to load lines less than 300 miles (480 kilometers) above the SIL. Conversely, because of stability limitations, it is usual to load lines greater than 300 miles (480 kilometers) below the SIL unless capacitor compensation is employed. Computer-generated SIL tables of REA transmission structures and lines are presented in REA Bulletin 1724E-201, "Electrical Characteristics of REA AC Transmission Line Designs."

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## 6.1.5 Transmission Line Capacity :

- The capacity of a transmission line is dependent on the operating voltage, heating limit, economic limit, and stability limit.

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### 6.1.5.1 Heating Limit

- Because of power losses, the current flowing in any conductor results in a temperature rise, and if permitted to reach the annealing point, the conductor may be damaged. However, before the annealing point is reached, vertical clearance requirements may be the limiting factor. The load required to create this condition, normally called the heating limit, will vary considerably, depending on the ambient temperature, wind velocity, conductor type and surface condition. (As the heating limit is approached, vertical clearances are generally reduced due to additional sag.) A newly installed aluminum conductor steel reinforced (ACSR) or all aluminum conductor (AAC) has a lower heating limit than a conductor which is weathered and turned dark. The heating limit is not normally a determining factor on long transmission lines unless the conductor is small and loaded beyond the economic limit; on short lines the heating limit is normally reached before the stability limit.

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### 6.1.5.2 Economic Limit

- The determination of the most economical conductor size is complex because of the many variables involved. These variables include: (1) rate of load growth, (2) change in geographical distribution and kinds of loads, (3) cost of right-of-way, (4) location of new power supply points, (5) load factor, (6) emergency service, and (7) continuity of service. For system voltages well below the EHV range, conductor sizes can generally be chosen satisfactorily by the application of Kelvin's Law; i.e., the most economical size of conductor is that for which the investment charges are equal to the cost of energy losses.

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- However, the application of this law to EHV transmission lines will not generally result in the selection of the optimum conductor size. This is because Kelvin's Law does not reflect the change in supporting structures with changes in conductor size, and also does not include the transformer capacity. A complete cost analysis should account for all effects that result from changes in conductor size and circuit loading. These include: (1) total annual fixed cost of the complete transmission line as a function of conductor size, (2) annual cost of power losses, (3) annual cost of reactive (var) supply needed to support the receiving-end voltage, and (4) an annual cost of terminals and transformer capacity required at the sending and receiving ends.

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### 6.1.5.3 Stability Limit

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- Another factor which may influence line capacity is the stability or power limit. Stability is that attribute of the system which enables it to develop restoring forces equal to or greater than disturbing forces. Steady-state stability is a condition which exists in a power system when there are no sudden disturbances on the system. Transient stability is a condition which exists if, after a sudden disturbance has taken place, the system regains equilibrium. The transient limit is usually lower and of greater importance than the steady-state limit. For relatively long lines, series capacitors or autotransformers may be used to decrease the effective line reactance and therefore increase the stability limit (Section 6.3.1.).

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- A good "rule of thumb" relationship for obtaining the approximate steady-state capability of a transmission circuit between two terminals is as follows:

$$P_{\max} = 0.75 V^2 / M \quad \text{Eq. 3}$$

where:

$P_{\max}$  = Maximum transferred power, in megawatts (MW)

$V$  = RMS line-to-line voltage, in kilovolts (kV)

$M$  = Distance between terminals, in miles.

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## 6.2 Load Flow:

- Once facility feasibility studies are performed, a thorough check of the transmission system plan is made with load flow study programs. System planners confirm the adequacy of the proposed transmission network, considering line loadings, bus voltages and reactive (var) supplies. Cases are run as specified by the system planner under normal and outage contingency conditions along with the reliability criteria for each load region. A base case study provides a reference to determine the emergency and future loadings of facilities.
- The base case utilizes information corresponding to normal operating conditions. Such a case serves as a comparison to other system conditions that need to be studied. A first contingency case is also recommended since as a general minimum contingency situation, the system should perform with a single facility out of service.

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- Once a base case is established, one or more changes can be introduced to determine variations in system performance. These changes may include any combination of the following:
- a) Take any line or bus out of service;
  - b) Add loads to any or all buses and lines;
  - c) Change regulated bus voltages and phase angles;
  - d) Add or delete new interconnecting lines;
  - e) Add new generation to any bus;
  - f) Change transformer taps;
  - g) Increase conductor size of any line;
  - h) Control reactive (var) power flow;
  - i) Increase or decrease transformer capacity;
  - j) Take any bulk substation transformer out of service.

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- The performance of the system as indicated by several load flow cases is properly reproduced only within the limits established by the system planner. Each case represents power flows and voltages which would exist on the system if all input data such as loads and generation were precisely reproduced. Although the load flow study results might never duplicate actual system conditions, they are meaningful primarily because the mathematical model can be tested beyond the acceptable performance range of the real system, thus better identifying limiting conditions. An example of a typical digital load flow study is shown in Appendix A.

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- Load flow programs presently used automatically take into account the voltage regulating capability of synchronous condensers and transformers, while maintaining designated generation schedules as well as net interchange among interconnected systems. Specified changes in system facilities and methods of operation are automatically calculated for a number of cases in sequence.
  - The required input data for load flow programs generally include: (1) bus designations, (2) line and transformer impedances, (3) real and reactive (var) power flows for each load, (4) generator power output, (5) voltage schedules and reactive (var) power flow limits of generators, synchronous condensers and switched capacitors, (6) tie-line designations, and (7) system interchange information.

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- Printed output includes the (1) calculated voltage magnitude and phase angle at each bus, (2) transformer, capacitor and reactor data, (3) real and reactive (var) power flows for each line and transformer, (4) net system interchange and tie-line power flows and (5) a record of system changes. Special output features are available or can be developed to aid the planner in the analysis of the system. Examples include lists of facilities loaded beyond preestablished limits, and lists of buses where the voltage is below desirable levels.

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## 6.3 Reactive Compensation:

- Reactive (var) compensation studies utilize information from load flow studies to establish optimum types and sizes of reactive (var) sources. There are two basic types of system compensation: (1) series compensation, in terms of impedance, is used to reduce a transmission line's effective reactance, and (2) shunt compensation, in terms of reactive power, is used to reduce the magnitude of reactive (var) power that flows in the network.

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### 6.3.1 Series Reactive Compensation :

- Inductive reactance of transmission lines is one of the most important parameters limiting power flow capability. The insertion of capacitive reactance in series with the line's inductive reactance decreases the line impedance. This helps to increase the transmission system capability requirements. Series compensation effectively increases the transmission line capacity. This reduces the need for higher transmission voltages or greater number of circuits. (When series compensation is used, a subsynchronous resonance (SSR) study should be performed.) When applying series capacitors on EHV systems (345-765 kV), it is important that they do not introduce undue limitations on the flexibility of future system development. The location of series capacitors along the line has a significant effect on the voltage profile, and power losses. For compensation less than 50 percent, it is usually advantageous to locate the capacitors at the midpoint of the line to improve the voltage profile. Unfortunately, this may not be economically practical unless a substation exists near the midpoint of the line.

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### 6.3.2 Shunt Reactive Compensation:

- As transmission voltages and line lengths increase, the capacitive charging currents from EHV lines also increase. These currents can cause undesirable overvoltages on generators and transformers, as well as increase power losses. In order to reduce the capacitive charging currents, shunt reactors are utilized to minimize the overvoltages during lightly loaded, switching or transient conditions. Shunt reactors may be either switched or directly connected at the transmission line terminals or to the tertiary windings of autotransformers. Tertiary shunt reactors can be switched as system reactive power requirements and voltages vary whereas permanently connected line shunt reactors cannot be separated from the line during switching operations.

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### 6.4 Stability:

- The starting point of stability studies is the steady-state conditions (determined by the load flow study) immediately before the system disturbance under investigation occurs. Information which can be derived from a steady-state stability study includes the rotor or stability phase angle, real and reactive (var) power flow, bus voltage and system frequency. Transient (first swing) and dynamic (multiple swing) studies are generally performed either on analog devices or a digital computer.

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## 6.4.1 Transient Stability :

- Generally, a transient stability program utilizes initial voltages and power flows obtained from the load flow program and converts the system to that required for the analysis of transient phenomena. For specified fault conditions and switching operations, the program calculates synchronous and induction machine electrical and mechanical torques, speeds, rotor torque angles, currents, and system voltages. In addition, some programs calculate currents and impedances of selected lines and simulate the automatic operation of impedance-type relays during severe systems oscillations. Switching operations and fault conditions are automatically simulated in sequence to represent the occurrence and clearing of faults.

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- Input data required depend upon the complexity of the machine representation desired. For the simplest representation, the data required for a synchronous machine is the real and reactive (var) power, stator resistance, transient reactance, and inertia constant. A more detailed representation requires the characteristics of the turbine governor system and generator excitation system, and the detailed reactance, time constants, and magnetic saturation parameters associated with the machine. For most modern studies, the more detailed machine representation is utilized to provide a better understanding of system performance. For an induction machine, the real power, rotor, stator and magnetizing impedances, and the load speed-torque relationships are usually required.

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## 6.4.2 Dynamic Stability :

- Transient stability studies are generally limited to the analysis of performance within one or two seconds after the fault. It is also important in many cases to simulate subsequent redistribution of power flows according to system inertias and governor characteristics. These dynamic stability conditions generally are important after the sudden loss of large units or generating plants, or a large concentration of load. A number of computer programs for dynamic simulation are available that take into account large system models and accurately represent the dynamic response of loads such as induction motors.

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## 6.4.3 Results From Studies :

- Transient studies can help determine: (1) need for faster protective relay system, (2) system operating and design weaknesses, (3) desirability of fast valving, and (4) initial heavy loading of key transmission facilities. Dynamic studies generally simulate system performance during the period following sudden loss of generation or load. These studies can aid in system design by determining: (1) high speed excitation performance, (2) effect of load shedding, and (3) potential system cascading effects.

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#### 6.4.4 Methods to Improve Stability :

- Presented below are several methods which may be employed to improve system stability.

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#### Conventional Remedies

- The most common remedy for improving power-system stability is to speed up the protective system and to increase the amount of transmission capacity. At this point in time, improving relay and breaker clearing times is difficult due to technological and economic considerations (state-of-the-art circuit breakers generally interrupt currents when the ac wave passes through current zero). The time interval between adjacent current zeros on an ac power system is determined by the power-system frequency and generally cannot be changed by the circuit breaker designer. Also, most present day protective relay methods depend on the determination of direction, distance, or impedance parameters that inherently require a certain minimum amount of measurement time for accurate results.

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## Fast Valving

- A source of power system instability is the excess energy supplied by the prime mover during the disturbance. If this energy is reduced or made equal to the energy needed by the generator during the disturbance, the generator acceleration problem is also reduced. Valves on modern large generating stations are usually very heavy and if the fast valving process is to be effective, the valve must be operated in a very short time. In several cases, whether the generator will remain stable is determined in less than a second. Thus, the energy input from the turbine must be changed very rapidly.

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## Breaker Selection and Relay Protection

- A stuck breaker on a close in three-phase fault may cause loss of synchronism resulting in instability problems. The use of power circuit breakers (PCB), whose poles can be operated individually, is an approach to prevent this condition. If each of the poles can trip independently, there is less probability that more than one of the poles will be stuck. Thus, a three-phase fault can be converted to a single-phase fault in normal relaying time. If the PCB fails to trip because it did not receive the trip signal from protective relays, the preceding method is invalid. For this situation, the installation of the PCB with individual poles will not provide any benefits. The most common method is the use of "stuck breaker" schemes employing overcurrent relays and high speed timers. In this situation the stuck breaker scheme is timed to clear the adjacent breakers within the maximum clearing time. The primary relay scheme must be sped up accordingly.

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## System Damping

- System damping is a method of providing restoring forces in order to decrease undesired oscillations or large system swings. Generally, it is difficult to apply fast valving and braking resistors in such a way that there will be negligible system swings after the fault is cleared. In the more usual case where such controls are not used, the swings may be sufficient to cause loss of synchronism after the fault is cleared. Swings that cause loss of synchronism, loss of load, or large voltage excursions, should be controlled to reduce them to acceptable proportions. Damping restores equilibrium between the generator input and output so that minimum power is available for acceleration or deceleration. Two forms of system damping are insertion of a dc tie between two ac lines and load shedding.

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- A dc tie between two ac lines provides a solution to the stability problem since no phase synchronization exists between the ac lines. The dc tie has characteristics that are suited for the damping function. HVDC controls can be arranged so that the power flow over the dc lines is independent of the conditions existing on the ac lines. Thus, it becomes possible to have the dc tie surge power in accordance with the operating needs of the interconnecting ac systems. Besides high costs, difficulties may be experienced in the practical design of control circuits that develop the intelligence necessary to control the dc line.

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- 
- Load shedding is another form of system damping. Generally, load shedding relays are installed to disconnect load when there is insufficient generation to maintain normal system frequency. This is a related system problem that is brought about because generator synchronism is lost for other reasons. Voltage reduction is another form of load shedding. This method is complicated by the necessity for extremely high speed underfrequency relays. Because of their sensitivity they often false-trip and cause start-up problems.

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## 6.5 Subsynchronous Resonance:

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- Subsynchronous resonance (SSR) occurs when the natural frequencies associated with the mechanical torques of synchronous machines are close to those imposed by the connecting networks. Steady-state SSR involves spontaneous oscillations that are either sustained or slowly increased in magnitude with time. Transient SSR generally refers to transient torques on the generator shaft resulting from oscillating currents in the electrical network caused by faults or switching operations. The study of SSR requires two phases: (1) stability analysis to insure that oscillations cannot build up during normal operation, and (2) the simulation of switching operations and faults to insure that associated torques do not exceed shaft stress limits. Results from SSR investigations yield the probability of occurrence of SSR in the system. Corrective measures required to reduce SSR are the use of filters to block currents at SSR frequencies and the use of other design techniques besides series compensation to meet system stability requirements.

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- Transmission systems containing series compensation may exhibit subsynchronous resonance at frequencies below 60 Hz. Thus, currents at subsynchronous frequencies may be amplified by synchronous machines causing undesirable oscillations and potential stability problems. The buildup or decay of these currents is dependent on the series resistance and loading levels of the transmission system.

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## 6.6 Statistical Line Design:

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- The main objectives of overvoltage, short circuit, and insulation coordination investigations are to (1) set criteria for transmission line electrical design, (2) establish ratings of surge arresters and other protective devices, and (3) specify equipment insulation levels. These three investigations will now be discussed.
  - Line design studies include switching surge evaluations, lightning performance, and contamination and flashover performance. All these factors influence transmission line and apparatus insulation levels. For transmission voltages between 34.5 and 230 kV, line insulation studies may not be necessary if insulation requirements are specified as in REA Bulletin 1724E-200.

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## 6.6.1 Switching Surge Evaluation :

- One severe overvoltage which the transmission facility must withstand is the switching surge. Switching surges are produced by switching of apparatus such as circuit breakers and disconnecting switches. These overvoltages appear across the line and station insulation, both phase-to-ground and phase-to-phase. Together with lightning and contaminated considerations they determine the required line insulation levels. Switching surge requirements are also used in insulation coordination studies for substation equipment (Section 6.8).

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- Insulation strength characteristics (which vary with such statistical data as wind, precipitation, and air density) are utilized in the switching surge evaluation. Other factors which affect the insulation system are breaker insertion resistors, line length, configuration, and loading. These parameters determine the waveshape and magnitude of switching surge which, in turn, influence the insulation flashover strength characteristic. Studies on the transient network analyzer (TNA) are an excellent starting point for determination of system insulation based on switching surge performance. These TNA studies may include the following statistical parameter evaluations:

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- a. Probability of proper circuit breaker operation
  - b. Probability that an insulator string will swing to a certain position.
  - c. Probability that weather factors will reduce flashover voltage performance across insulators and gaps.
  - d. Probability that a voltage surge will exceed the critical flashover voltage rating of an insulator string.

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- 
- As noted above, switching surge performance is determined primarily by the line insulation. The number of insulators is selected so that the probability of flashover from switching surges does not exceed design specifications. In general, for transmission voltages below EHV (34.5-230 kV), switching surges do not limit the tower insulation design since the insulation strength increases in proportion to the phase-to-structure clearance. At EHV levels (345-765 kV) the air gap begins to saturate and switching surge line performance may become the limiting factor in the choice of tower dimensions and clearances.

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## 6.6.2 Lightning Performance :

- Besides switching surge studies, a second major consideration in designing transmission lines is lightning performance. Analytically, the lightning problem is extremely complicated being a function of many lightning statistics such as stroke current amplitude, rise times, hit probabilities and frequency of occurrence. (Thunderstorm-day activity is shown on the Isokeraunic map. From the map data, a relative comparison is made of thunderstorm activity in each area.)

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- Lightning evaluation of transmission facilities includes consideration of storm incidence in the area, tower height and configuration, and insulator string length. Overhead ground wires (OHGW) are usually used to shield phase conductors from direct strokes. The number and location of OHGWs are major factors in estimating the number of shielding failures. In addition to OHGWs, a combination of line insulation and tower footing resistance parameters are used to minimize lightning flashovers across a transmission line.

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- 
- To obtain an accurate estimate of lightning performance of a proposed line design, transient network analyzers (TNA), digital computers and system modeling methods are employed to determine such parameters as the trip-out rate. Surge arrester ratings for transmission system applications are normally based on data from TNA studies. The resultant transient overvoltages from these studies are statistical in nature and are combined with insulation strength probability studies to estimate lightning flashover performance.

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### 6.6.3 Contamination Performance :

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- The third major line design study is contamination performance of transmission line insulation. Unlike switching surge and lightning studies, which estimate transient performance, contamination studies relate to the 60 Hz or fundamental frequency performance.
- Results from contamination studies yield flashover insulation levels of (1) air gaps at extreme swing angles and (2) contaminated insulator strings. Both of these levels are based on statistical parameter such as geographical location and transmission system configuration (such as tower size and geometry).

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## 6.7 Short Circuit:

- The principal purposes of short circuit studies are listed below:
- a. Provide information for proper selection of protective relays to establish system performance requirements and settings.
  - b. Provide information for proper selection of circuit breaker interrupting requirements.
  - c. Evaluate voltages during faulted conditions which would affect insulation coordination and the application of surge arresters.
  - d. Design the type and capability of grounding systems.
  - e. Establish the electromechanical forces to be withstood by system facilities.
  - f. Provide data for a variety of network calculations during the process of planning and designing the system.

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- A variety of computer programs have been developed for performing short circuit studies. Some are designed specifically to facilitate relay studies, while others provide information primarily used in planning. All represent the system by symmetrical component equivalent reactances of various facilities. The programs generally calculate for each bus of a specified system the total three-phase and line-to-ground bus faults, including effects of zero-sequence mutual impedances. Also specified are the three-phase and line-to-ground fault contributions for each line or transformer connected to the faulted bus.

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- Input data required include bus identification, positive and zero-sequence impedances of lines and transformers, and transient and subtransient reactances of synchronous machines.
  - The printed output includes all bus faults and line contributions for three-phase and line-to-ground faults for both normal and switched conditions. This allows quick identification of the breaker duties under the worst conditions, and provides data in a form usable for evaluation purposes. In addition, a variety of printouts of currents and voltages can be specified in any combination for every faulted bus.

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## 6.8 Insulation Coordination:

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- Insulation coordination is defined as the protection of electrical systems and apparatus from harmful overvoltages by the correlation of characteristics of protective devices and the equipment being protected.
- To coordinate insulation and protective devices, impulse voltage levels are defined in terms of both BIL (basic impulse insulation level) and BSL (basic switching surge level).

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- 
- Insulation coordination is defined as the protection of electrical systems and apparatus from harmful overvoltages by the correlation of characteristics of protective devices and the equipment being protected. To coordinate insulation and protective devices, impulse voltage levels are defined in terms of both BIL (basic impulse insulation level) and BSL (basic switching surge level).

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- Similarly, the BSL describes the equipment's ability to withstand switching surges. The standard BSL waveform is 250/2500 which is a wave that has a front time of 250 microseconds and reaches half magnitude at 2500 microseconds.
  - Results from insulation coordination studies yield the expected stress requirements on the system equipment. Other outputs include BIL and BSL performance, arrester selection, and system operating constraints for a given or assumed overvoltage, lightning, waveshape and insulation strength characteristics.

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## 6.9 Corona and Radio Interference :

- Radio and television noise or electromagnetic interference (EMI), and audible interference are rapidly becoming controlling factors in the design and planning of transmission systems, especially at EHV and UHV. Two of the most reported environmental effects caused by transmission facilities operating at EHV and UHV (345 kV and above) are corona noise interference and voltage induction. (See Section 6.10)

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- Electrical discharges due to either corona or gap sparkover are the basic sources of radio and audible noise (AN) interference. The pulses caused by these discharges are injected into the transmission line phase conductors or other conducting components which may act as a radiating antenna or transmission media.
- Thus, EMI from the transmission lines is caused either by complete electrical discharges across small gaps or by partial electrical discharges such as corona.

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- Gap-type noise sources can occur in the following transmission line components:
  - a. Insulators that are dirty, cracked or loose,
  - b. Splices,
  - c. Tie wires,
  - d. Between hardware parts (clamps, brackets, insulator pins, crossarm braces, and guy wires),
  - e. At small gaps between ground wires and hardware parts,
  - f. With electrical apparatus that is either defective, damaged, improperly designed, or improperly installed (such as corroded or loose fuse elements, transformer insulation failure, noisy contacts in relays, meters and regulators).
- These gap-type noise sources can be located by equipment that traces EMI such as broadcast radio sets and battery operated portable television receivers. Noise sources can be electrically short circuited or minimized by improving the bonding between adjacent conducting parts or by tightening loose connections.

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- At EHV and UHV corona (an electrical discharge through ionized air) is generally the main source of noise interference. Corona is formed when voltage gradients are above the critical gradient. For a specified operating voltage, conductor contamination is the main cause of corona. However, conductor surface burrs and scratches, and weather (rain, snow, and humidity) cause an increase in corona effects. Other corona byproducts are power loss in conductors and ozone production (a chemical reaction of the corona discharge). Thus, transmission line corona is a source of radio interference (RI) and audible noise (AN) at EHV and UHV. The measure of corona depends on existing ambient conditions prior to line construction and also on the level of noise from the energized line. For RI, the ambient conditions consist of the received signal strength and background noise level. The quality of reception during ambient conditions depends on the ratio of these two components and is called the ambient signal-to-noise ratio (ASNR). RI, resulting from transmission line corona, depends on the ratio of the received signal strength and the noise level produced by the line. This is referred to as the interference signal-to-noise ratio (SNR). The comparison of ASNR and SNR is a measure of the corona produced by a line at any one location. If both the ASNR and SNR levels are high, reception quality will also be high.

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## 6.10 Electrostatic and Electromagnetic :

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- At EHV and UHV the medical and biological concerns due to electric field gradients and the electrostatic (E/S) and electromagnetic (E/M) coupling between overhead transmission lines and conductive objects should be considered.

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### 6.10.1 Medical and Biological :

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- Medical and biological studies deal with the direct physiological effects on humans, animals, and plants subjected to strong electric field. The magnitude of
- electric field strength (or voltage gradient) at ground level is
- usually used in medical studies to determine permissible field
- strength limits for people and animals near energized
- transmission lines.

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## 6.10.2 Induced Voltage :

- Electrostatically induced voltages are possible when a conductive object insulated from ground is in the vicinity of alternating current overhead lines. Similarly, electromagnetic induction effects are possible when transmission line phase conductors carrying fault currents cause induced voltages at the open ends of an insufficiently grounded r the E/S case, a steady-state shock current magnitude of five milliamperes is considered as the "let-go" level in the 1993 edition of the National Electrical Safety Code (NESC). Other practical considerations may dictate that the shock current magnitude be kept below the one milliampere "threshold of perception" level. For the E/M case, object grounding intervals are based on transient current levels through a person or animal.
- Results from E/S and E/M studies help determine the grounding requirements for stationary metallic objects (fences and buildings) and insulated conductive vehicles.

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## 6.11 Transmission Facility Economics :

- The last system study discussed is that of transmission facility economics. Several of the factors that should be considered in an economic study include tower, conductor, accessory, and right-of-way costs. While all these factors enter into a study of transmission costs, two basic elements that are of significant importance are (1) the load-carrying capability of lines in terms of voltage and distance, and (2) the associated equipment, particularly transformers and switchgear. Related to both transmission capability and cost is a third element; an evaluation of the economics of intermediate switching stations. Some of the questions that should be answered in a transmission facility economic study are the following:

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- a. What diameter of conductor is necessary to reduce radio interference and corona loss to acceptable levels?
  - b. What line insulation is necessary?
  - c. What should the BIL of the station equipment be?
  - d. How much load can be safely associated with a transmission circuit?
  - e. What is the economic comparison with lower voltage transmission or even high voltage direct current (HVDC) transmission for some installations?
  - f. What should the electrostatic and electromagnetic requirements be to minimize the effects of voltage induction and field gradients on humans, animals, and plants near overhead lines?

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## 7. CONCLUSIONS:

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- In conclusion, an overview of eleven system studies is presented to support REA-financed transmission facilities from 34.5 to 765 kV. These studies are not necessarily complete nor are they listed in any order of priority. Each study should be considered for the specific facility in question in order that system performance can be observed and evaluated.

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## **ANNEX-9**

### **CLASSROOM LESSON ON WATER SUPPLY**

## Design of Rural Water Supply System

### Lesson 1 Introduction

- WB's Rural Water Supply Manuals
- Water System Design Process
- Outline of Water Supply System

## RURAL WATER SUPPLY MANUALS

February 2012

The World Bank Office Manila

**Volume I: DESIGN MANUAL**

**Volume II: CONSTRUCTION  
SUPERVISION MANUAL**

**Volume III: OPERATION AND  
MAINTENANCE MANUAL**



## **RURAL WATER SYSTEM DESIGN PROCESS**

### **1. Service Level**

### **2. Water Demand Projections**

### **3. Facilities Designs**

#### 4. Capital Investment and O&M Costs

#### 5. Tariff Design

#### 6. Design Iteration

#### 7. Plans and Design Specifications

### **1. Service Level**

– The decision on service level or levels that the utility would provide should be based on a consultation process among the stakeholders.

### **2. Water Demand Projections**

– It is necessary to determine the design horizon for which the facilities will be designed, and project the population to be served annually over this horizon, the unit consumptions, and expected non-revenue water.

### **3. Facilities Designs**



#### 4. Capital Investment and O&M Costs

–The planner/designer will have to estimate the O&M costs based on the details of the proposed system, its water source, and facilities.

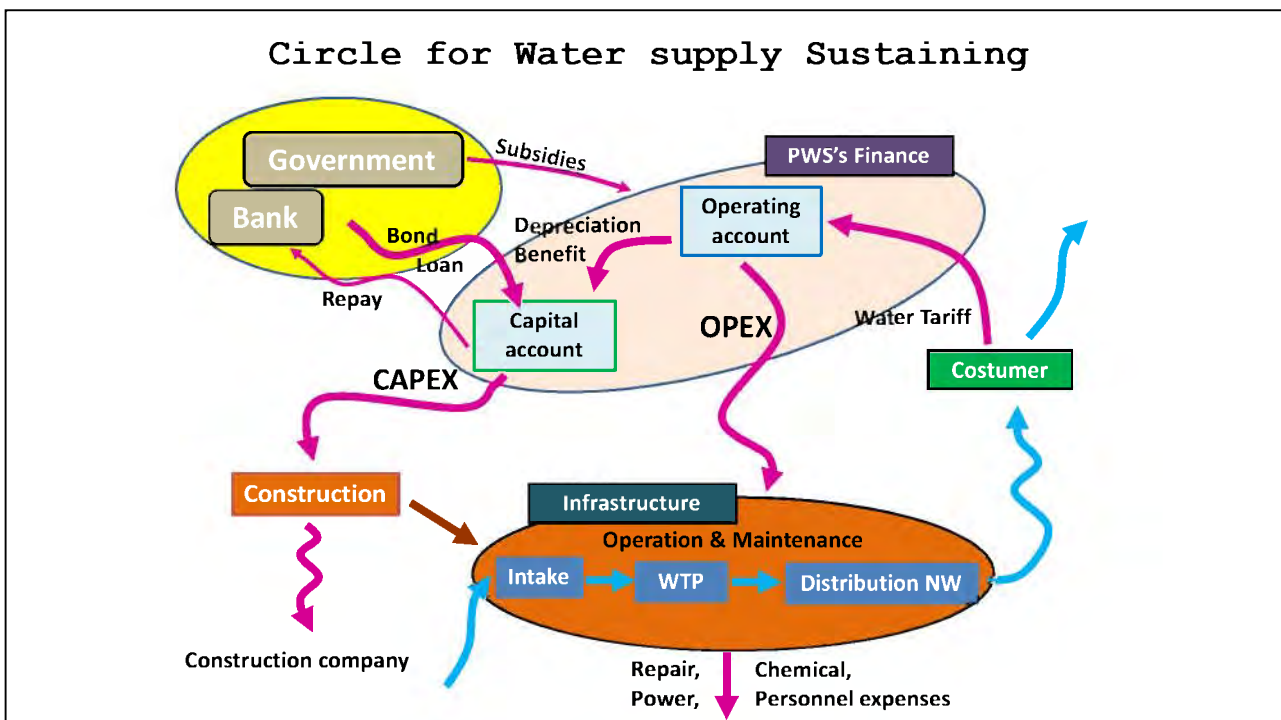
#### 5. Tariff Design

#### 6. Design Iteration

– Before plans are finalized, there is need to confirm if the facility, as proposed, meets the social criteria of affordability and acceptance.

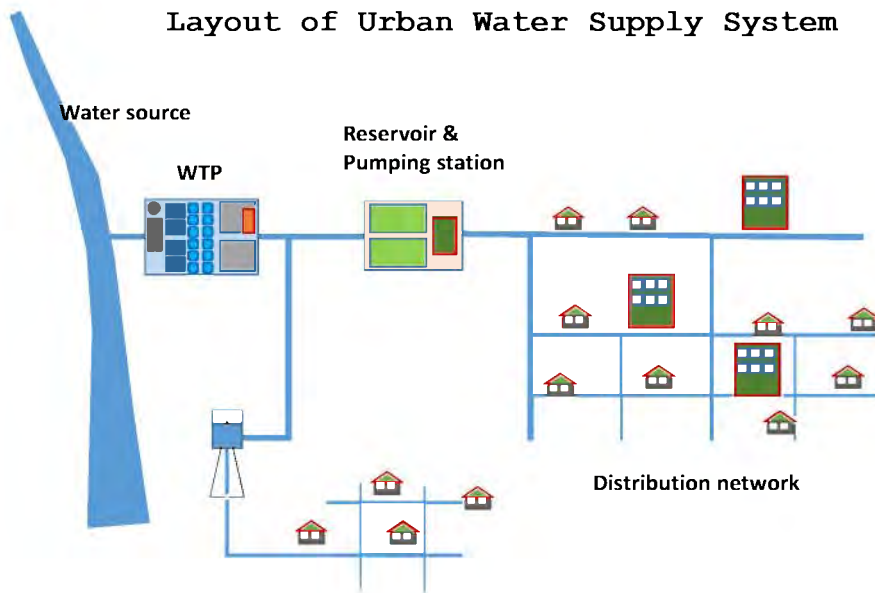
#### 7. Plans and Design Specifications

– Once all the agreements, design parameters, and assumptions are established, the detailed plans have to be prepared by professional engineers to ensure a well-balanced system that will fulfill its objectives, and to provide a detailed guide for the construction of the facilities.



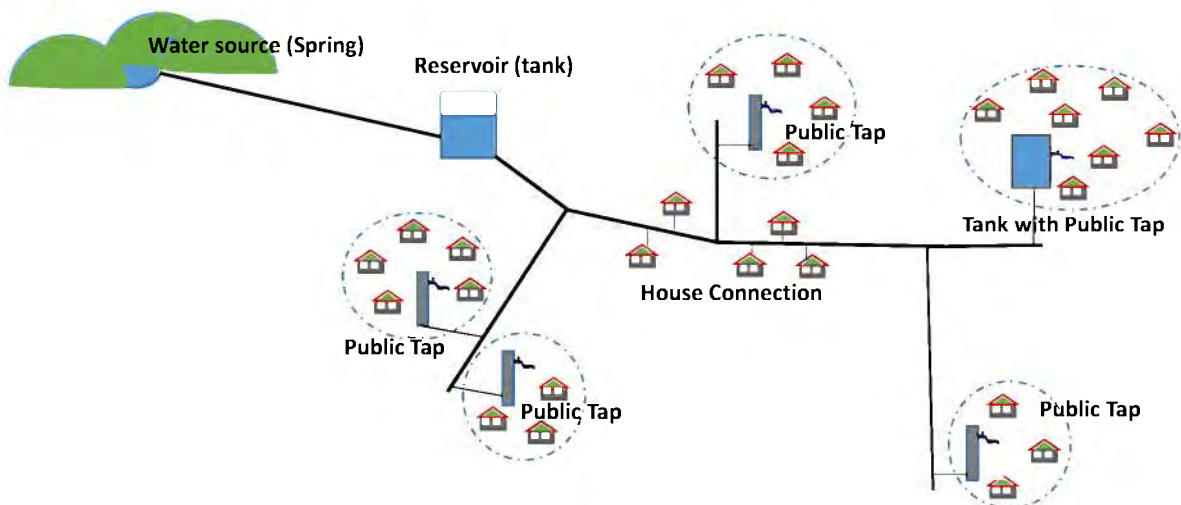
## OUTLINE OF WATER SUPPLY SYSTEM

### Layout of Urban Water Supply System



### 3. Facilities Designs

### Layout of Rural Water Supply System



**Component of Rural Water Supply System**

1. Water source and Intake facilities
2. Transmission main
3. Water treatment plant
4. Reservoir (Tank)
5. Distribution mains
6. Public taps or (and) Service pipe

## Lesson 2 Water Demand

- Service Level Definitions
- Design Period
- Design Population
- Water Consumptions
- Non-Revenue Water (NRW)
- Water Demand

### 1. Service Level

Per Capita Water Consumption = ?

Public Tap or House Connection ?

- Multi-tap in house  
100 l/c/d

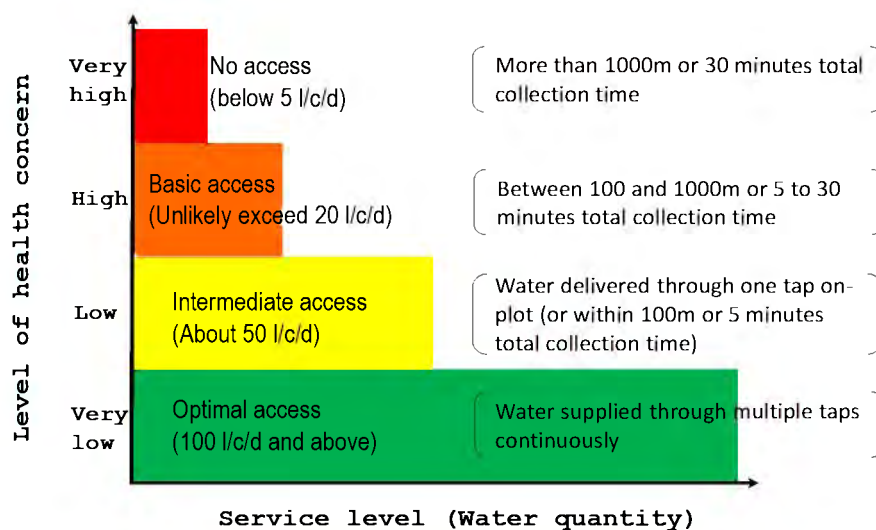


→ 50m (2.5min)  
50 l/c/d

→ 50m – 500m (2.5min - 15min)  
20 l/c/d

→ 500m (15min)  
Below 5 l/c/d

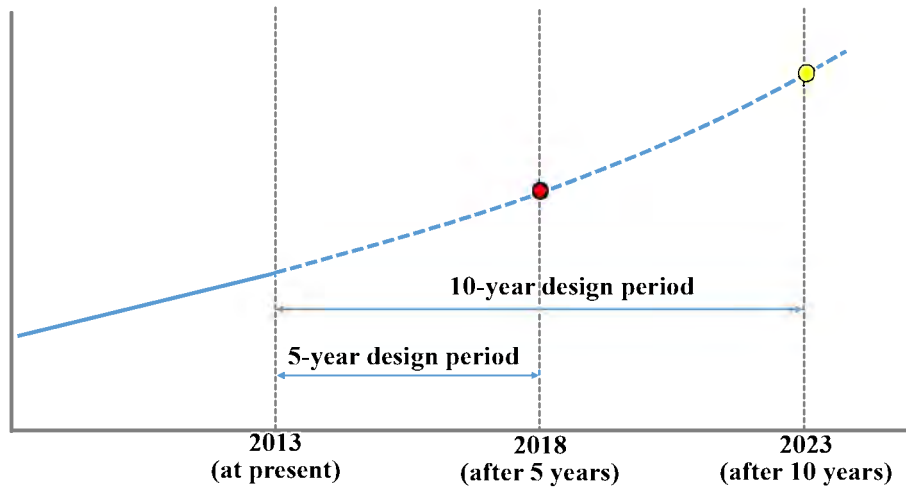
## Domestic Water Quantity and Health



## Summary of requirement for water service level to promote health

Service level	Access measure	Needs met	Level of health concern
No access (quantity collected often below 5 l/c/d)	More than 1000m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practiced at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – hand washing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on plot (or within 100m or 5 minutes total collection time)	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

## 2. Design Period



	<b>Advantages</b>	<b>Disadvantages</b>
<b>Five-year design period</b>	Low initial capital cost.	Need for new capital outlays after five (5) years to upgrade system capacity.
<b>Ten-year design period</b>	The water system facilities are capable of meeting the demand over a longer period.	The higher initial capital cost.

### 3. Design Population

#### 2 ways of projecting the design population

- ◆ Estimate the population that can be served by the sources.
- ◆ Project the community population, and determine the potential service area and the served population.

$$CP(2023) = CP(2013) \times (1+r)^n$$

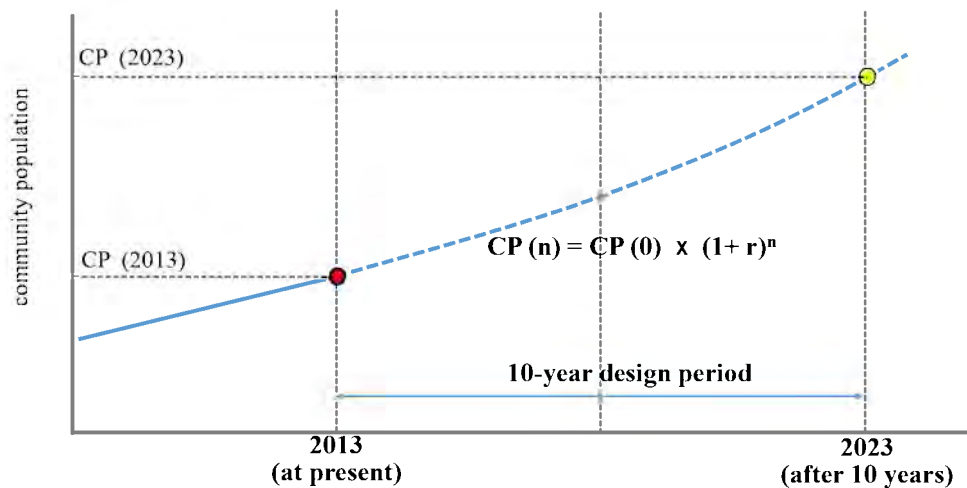
herein

CP (2023) = projected Community Population at 2023

CP (2013) = Community Population at present (2013)

r = yearly growth rate

n = design period (here 10years)



#### 4. Water consumption

In rural areas:

Water consumption is generally limited to domestic uses.

- **drinking**
  - **cooking**
  - **cleaning**
  - **washing**
  - **bathing**
- } 30 - 60 lpcd

Institutional Connections: 1.0 m<sup>3</sup>/d

Commercial Connections: 0.8 m<sup>3</sup>/d

#### 5. Non Revenue Water (NRW)

$$\text{NRW (\%)} = \frac{\text{Amount of NRW}}{\text{System input volume}} \times 100 (\%)$$

**NRW**

Leakage

Illegal use

**System input volume**

Amount of produced water or distributed water



## 6. Water Demand

### Water demand:

Summation of all the consumptions to determine the capacity needed from the source/s.

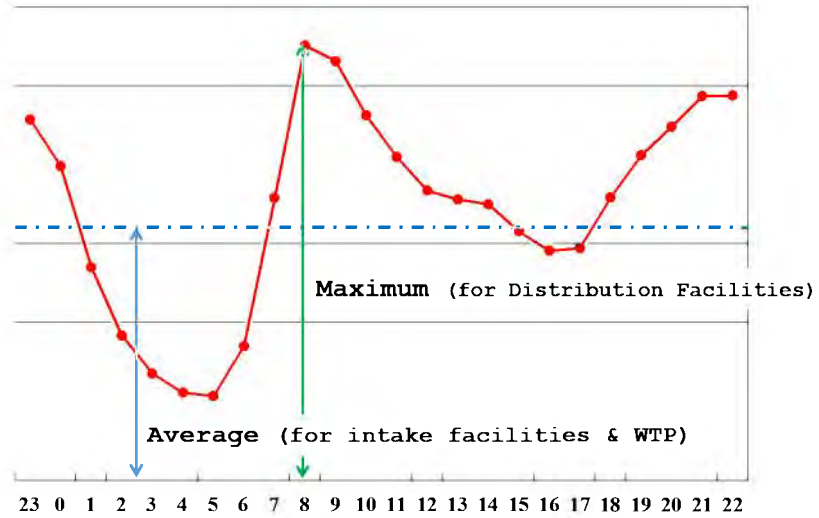
$$\text{Water demand} = \text{Total Consumption} + \text{NRW}$$

$$\left( \begin{array}{l} \text{Domestic uses} \\ \text{Institutional uses} \\ \text{Commercial uses} \end{array} \right)$$

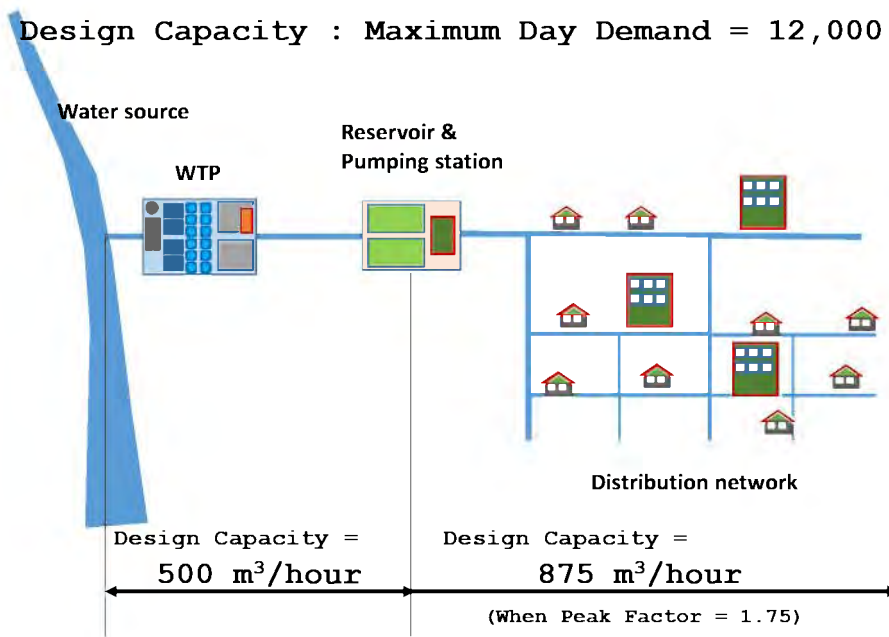
## Demand Variations and Demand Factors

- **Minimum day demand:**  
The minimum amount of water required in a single day over a year.
- **Average day demand:**  
The average of the daily water requirement spread in a year.
- **Maximum day demand:**  
The maximum amount of water required in a single day over a year.
- **Peak hour demand:**  
The highest hourly demand in a day.

### Peak Hour Demand in Maximum Day



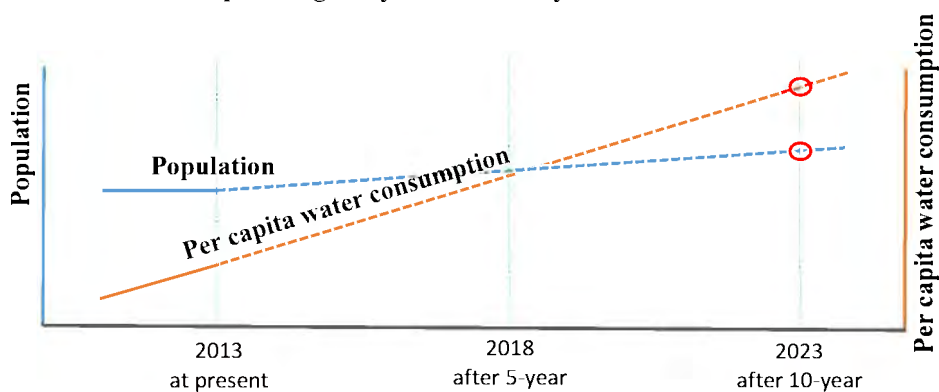
Design Capacity : Maximum Day Demand = 12,000 m<sup>3</sup>/day



**Water Demand = Per capita water consumption x Population + NRW**

**Water Demand Projections = Water Demand at Targeted year**

example: Targeted year = after 10 years



## Water Demand for Design of Facilities

### Example: Community A

Households (HHs) = 100, average 1 HH = 6 persons

Total served Population =  $100 \times 6 = 600$

Average Water demand =  $600 \times 50 \text{ lpcd} = 30,000 \text{ l/d}$

NRW (Leakage ratio) = 15 %

Distributed amount including Leakage

=  $30,000 \text{ l/d} / (1 - 0.15) / 86400 \text{ sec/d} = 0.41 \text{ l/sec}$

Maximum Water demand

= Average Water demand (including NRW)  $\times 1.30$

=  $0.41 \text{ l/sec} \times 1.30 = 0.53 \text{ l/sec}$

**Reference** Multi-Village Pooling Project in Indonesia  
**Handbook for Community-Based Water Supply Organizations**  
 October 2011

## Estimating Quantity of Water Demand

### Guiding Principles in Estimation

The Ministry of Public Works Regulation 18/2007 suggests that the projection of water needs be done for a planning period of 15 years, in 5-year intervals. It is necessary to make assumptions on how many additional customers will be served during each interval of the planning period.

- Different components of the system will need to be expanded/developed during the 5 years, according to the following portion of the projected demand:
  - Water intake – 130% of the volume of total water needs for the day
  - Water treatment – 120% of the volume of total water needs for the day
  - Water distribution – 100% of the volume of total water needs for the peak hour of the day
- For the water distribution system, the demand for water should be based on the volume required during peak hours, not just the average during the day. ‘Peak hours’ refers to the hours of the day during which the volume of water utilization is highest because of simultaneous use. The actual hours when demand is highest should be observed by the water provider, but usually these are during the following times: 06.00- 09.00, 12.00-14.00 and 17.00-19.00

### Customer Profiles (1)

Type of Customers	Total Number of Customers	Average Consumption	Annual Consumption	% of Total Annual Water Consumption
1. House connections	300 households x 4 persons = <b>1,200 persons</b>	50 liters per capita per day x 365 days	21,900 m <sup>3</sup>	85%
2. Stand pipes	2 standpipes x 20 households x 4 persons = <b>120 persons</b>	20 liters per capita per day x 365 days	876 m <sup>3</sup>	4%
3. Water-using businesses, including restaurants, laundry and clinics	2 establishments x 10 visitors = <b>20 visitors</b>	100 liters per visitor per day x 365 days	730 m <sup>3</sup>	3%
4. Non-water using businesses, such as offices	2 establishments x 10 employees = <b>20 employees</b>	20 liters per employee per day x 20 days x 12 months	96 m <sup>3</sup>	0.5%

### Customer Profiles (2)

5. School	1 elementary school x 6 levels x 35 students = 210 students	20 liters per student per day x 20 days x 10 months	840 m <sup>3</sup>	3.3%
6. Mosque	1 mosque x 210 visitors per week / 7 days = 30 visitors	20 liters per visitor per day x 365 days	219 m <sup>3</sup>	.09%
7. Public Market	1 market x 20 stalls = 20 stalls	200 liters per stall per day x 2 days x 12 months	96 m <sup>3</sup>	.05%
8. Livestock - cow	40 heads	30 liters per head per day x 365 days	438 m <sup>3</sup>	1.7%
9. Livestock - goat	40 heads	20 liters per head per day x 365 days	292 m <sup>3</sup>	1.1%
<b>Total Annual Water Consumption</b>			<b>25,487 m<sup>3</sup></b>	<b>100%</b>

### Customer Profiles (3)

<i>Additional Provision for:</i>				
10. Fire fighting, system flushing and other public uses			1,275 m <sup>3</sup>	5% of 25,487 m <sup>3</sup>
11. Water losses			5,100 m <sup>3</sup>	20% of 25,487 m <sup>3</sup>
<b>Total Water Needs</b>			<b>31,862 m<sup>3</sup></b>	



## **Lesson 3: Water Sources**

### **1. Classification of Water Sources**

### **2. Source Capacity Measurements**

### **3. Source Water Protection**

## **1. Classification of Water Sources**

- ◆ Rain Water
- ◆ Springs
- ◆ Infiltration Wells  
(Riverbed Water)
- ◆ Groundwater
- ◆ Surface Water

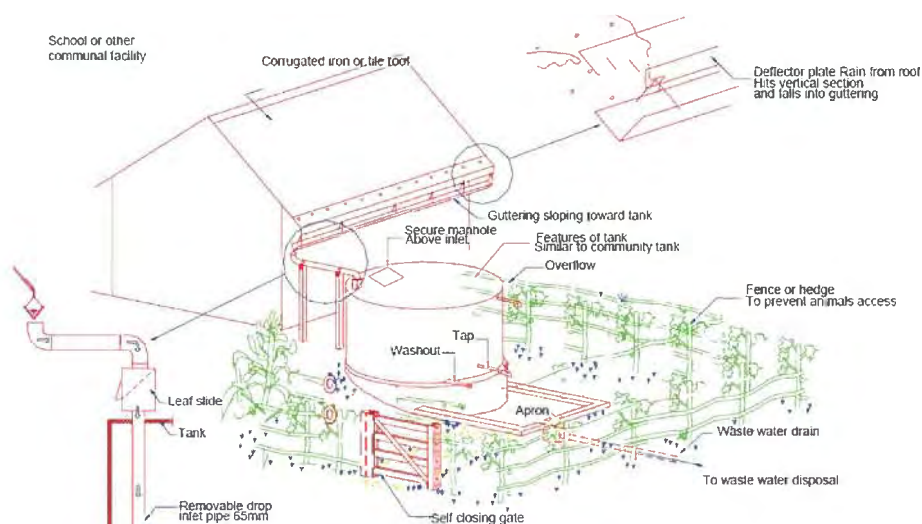


### Selecting Sources of Raw Water

Characteristics and Factors to Consider	Spring	Ground Water (Well)	Surface (Ponds, lakes, river, etc.)
<b>Water Quality</b>	Usually moderately satisfactory	Usually satisfactory	Usually less than satisfactory
<b>Source of Pollution and Prevention</b>	Local infiltration of waste, such as from animals grazing around the spring. Fencing off the spring area and protecting the spring with a spring box.	Seepage into the ground, such as from nearby septic tanks or dumpsites. Locating wells at least 10 meters away from a septic tank.	Distributed across the area of the water body from point and non-point sources. General prohibitions or regulated discharge of pollutants into the water.
<b>Treatment</b>	Needs filtration and sedimentation to separate off sand/soil particles. Likely to need disinfection.	Likely to need disinfection	Likely to need sedimentation, filtration and disinfection at the minimum. May need other treatment process.
<b>Skills to Manage Production</b>	Low	Moderate	Moderate to high
<b>Use of Energy to Draw</b>	Naturally surfacing; gravity.	Pumping required to draw water.	Diversion to intake usually does not require pumping
<b>Main Flow of Flood</b>	Important to locate parts of the collection structure (e.g. inlet chamber) away from the flow of the flood.		Important to locate parts of the collection structure (e.g. inlet chamber) away from the flow of the flood.

Multi-Village Pooling Project in Indonesia Handbook for Community-Based Water Supply Organizations

## (1) Rain Water



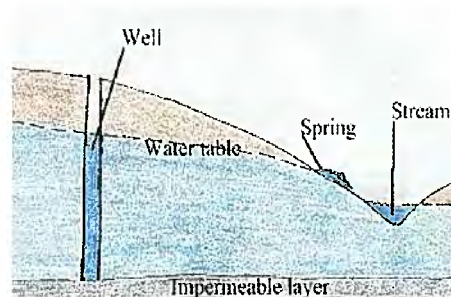
**Standard Rain Catchment Design**

## (2) Springs

### Outcrops of groundwater

(ex. appear as- )

- small water holes
- wet spots at the foot of hills



### To obtain satisfactory water

- Eliminate surface water intrusion
- Prevent animals from gaining access to the spring
- No immediate upstream settlements

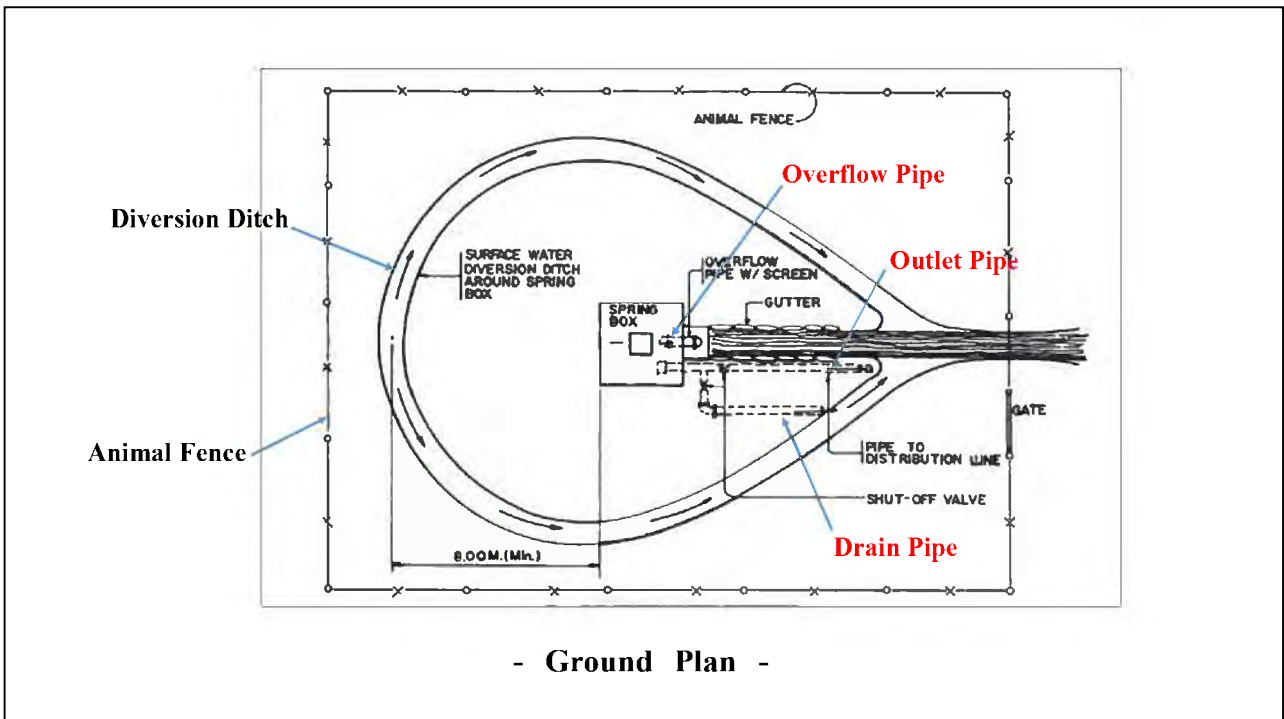
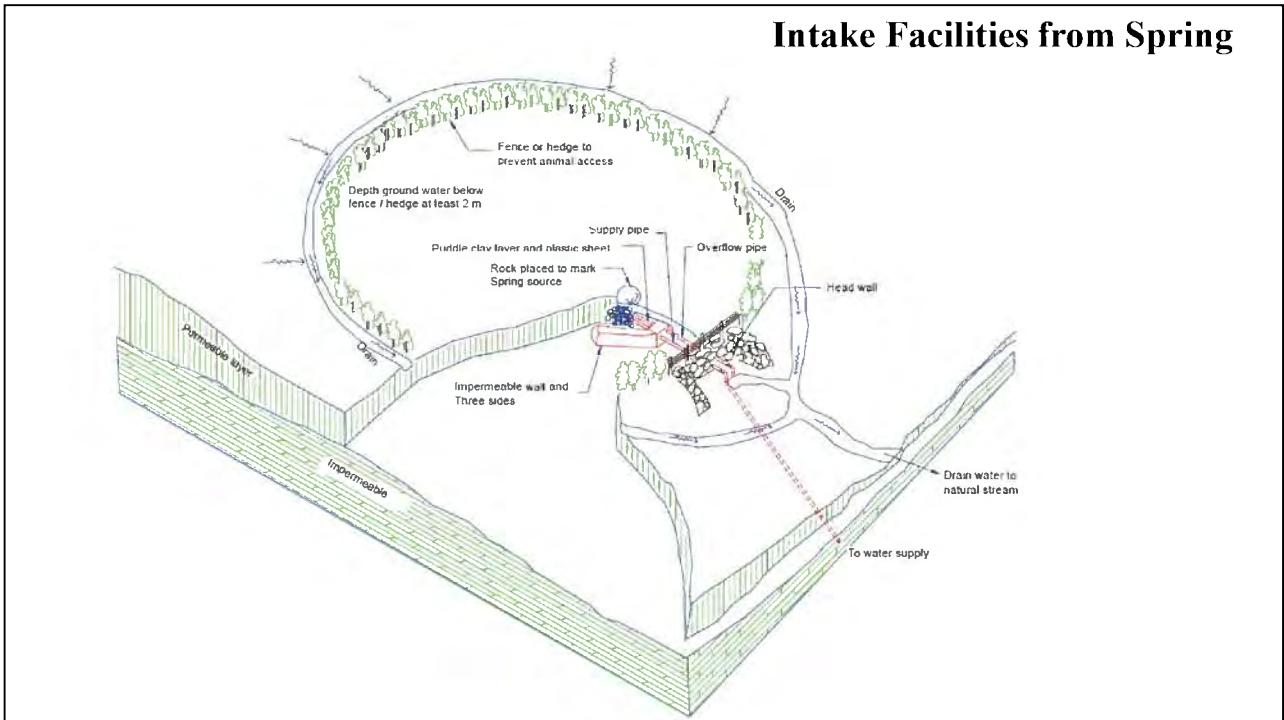
## Springs should

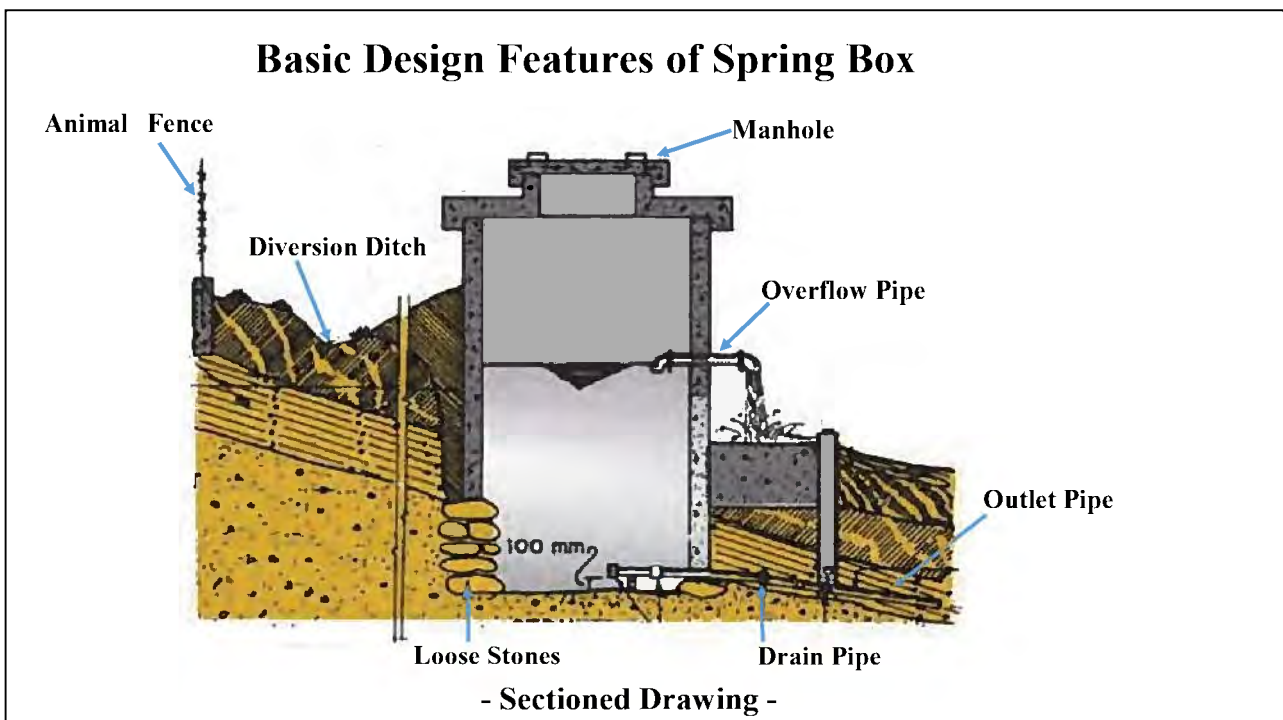
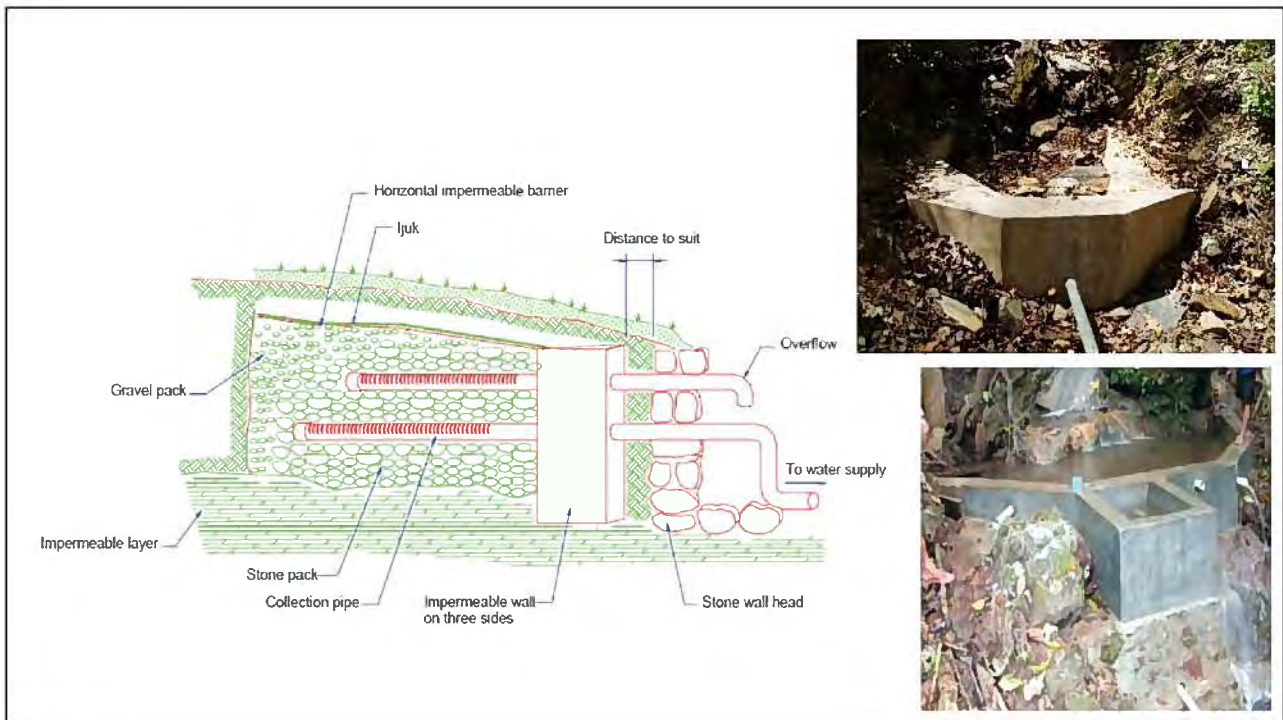
- be protected from surface-water pollution
- have a watertight cover
- be obtained by gravity flow
- have inspection manholes

(should be locked)



### Intake Facilities from Spring

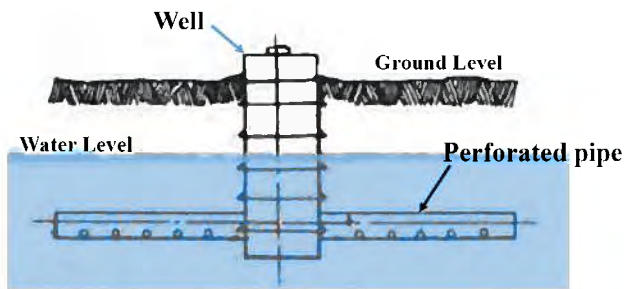
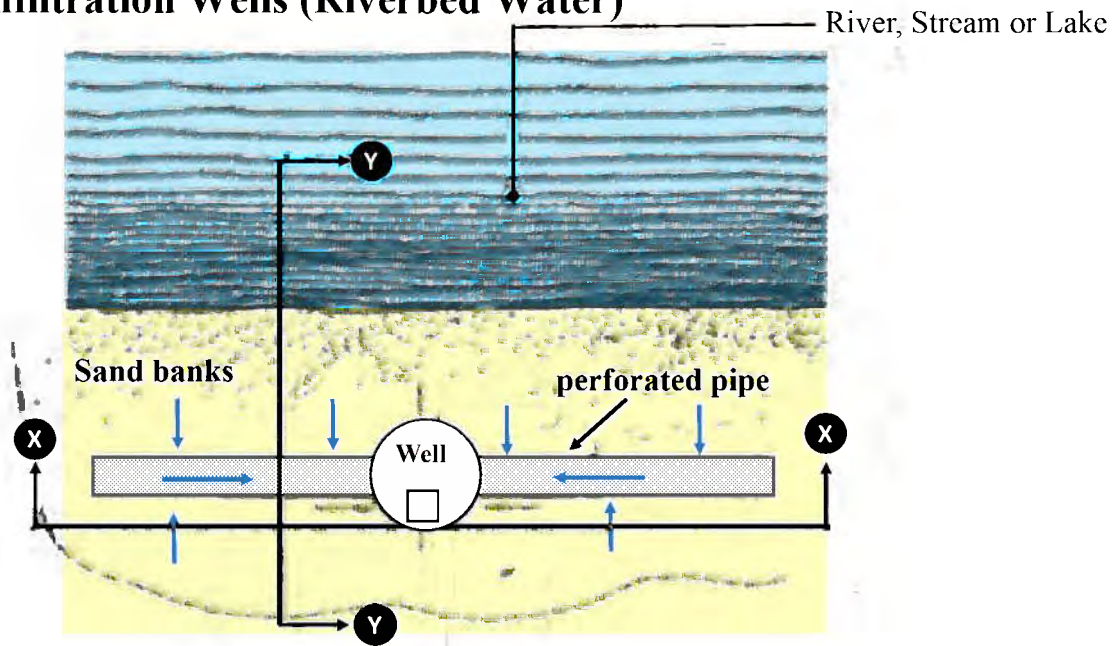




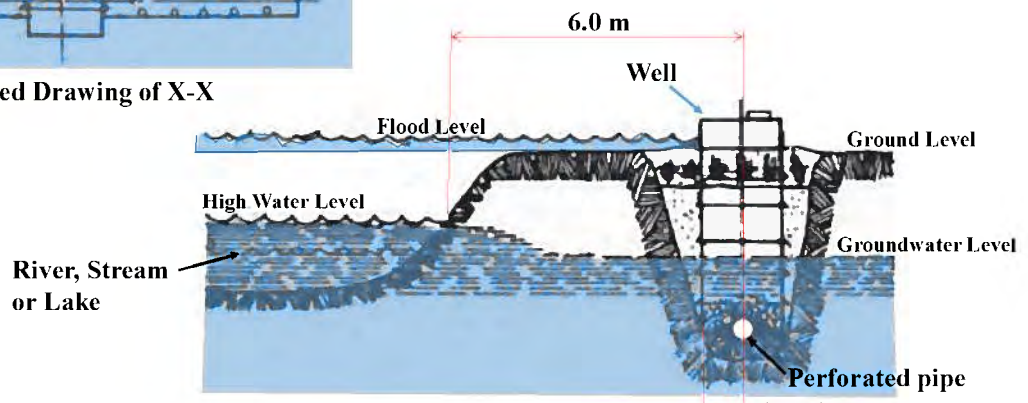




**(3) Infiltration Wells (Riverbed Water)**



Sectioned Drawing of X-X



Sectioned Drawing of Y-Y

## (4) Groundwater

### Classification of Wells Based on Aquifer Tapped

#### 1. Shallow Wells

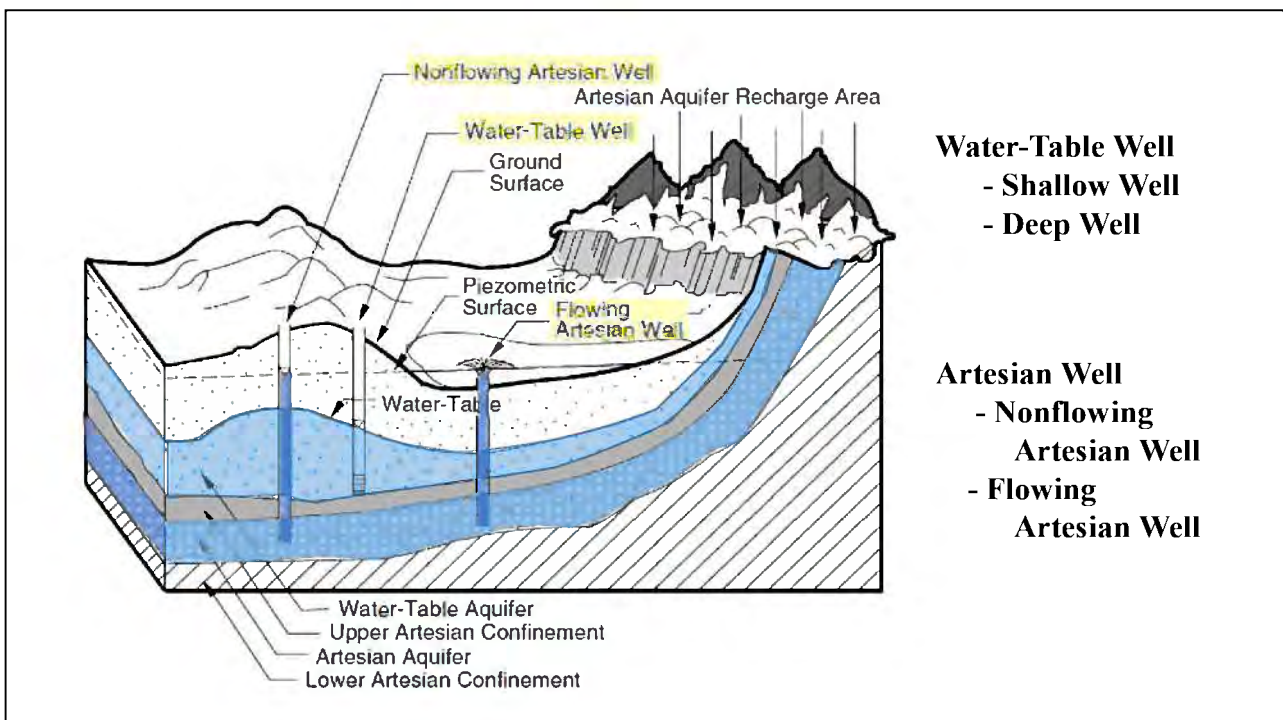
- less than 20 meters deep
- great dependence on seasonal rainfalls

#### 2. Deep Wells

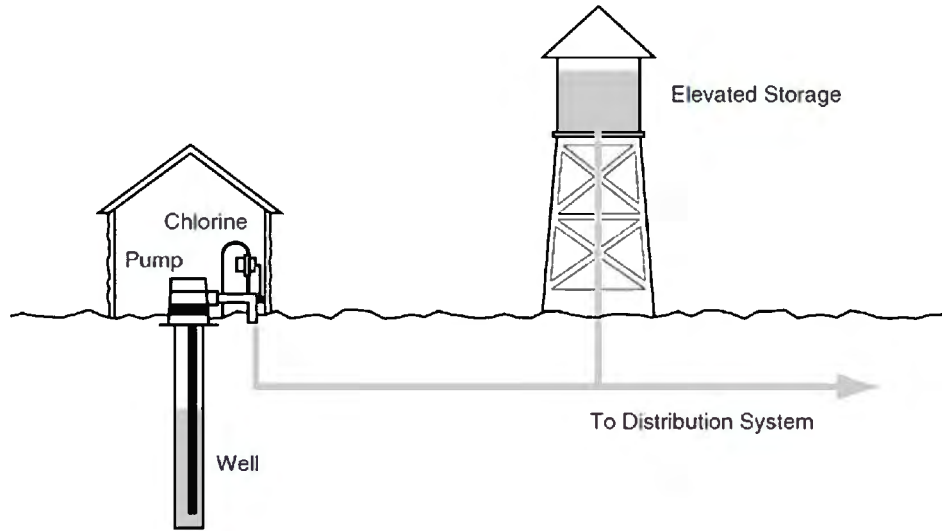
- over 20 meters deep
- not confined by an overlying impermeable layer

#### 3. Artesian Wells

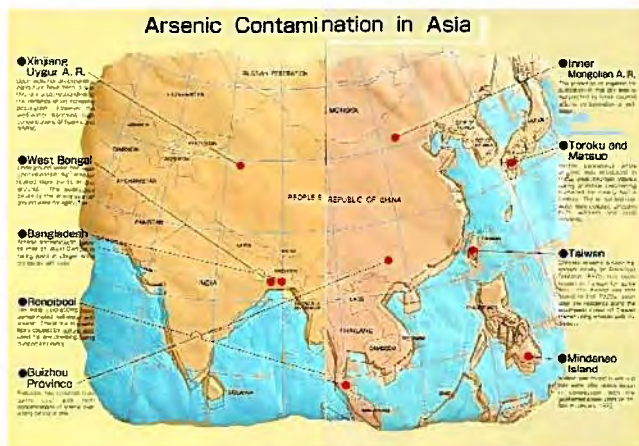
- from an aquifer confined between less permeable materials (clay, rock)



### Simple Well System



### Arsenic Problem



### **(5) Surface Water**

- include water from streams, rivers, lakes, ponds, seas and oceans
- contains organic and inorganic minerals
- needs expensive water treatment
- should be avoided for rural water supplies

## **2. Source Capacity Measurements**

### Measurements of Discharge

- a. Volumetric Method
- b. Flow Method using V-Notch Weir
- c. Rough Flow-Rate Method

### a. Volumetric Method

**Data:**

Volume of oil drum used : 200 liters  
 Number of drums used : 1  
 Time to fill the drum : 30 seconds

**Required:** Well yield

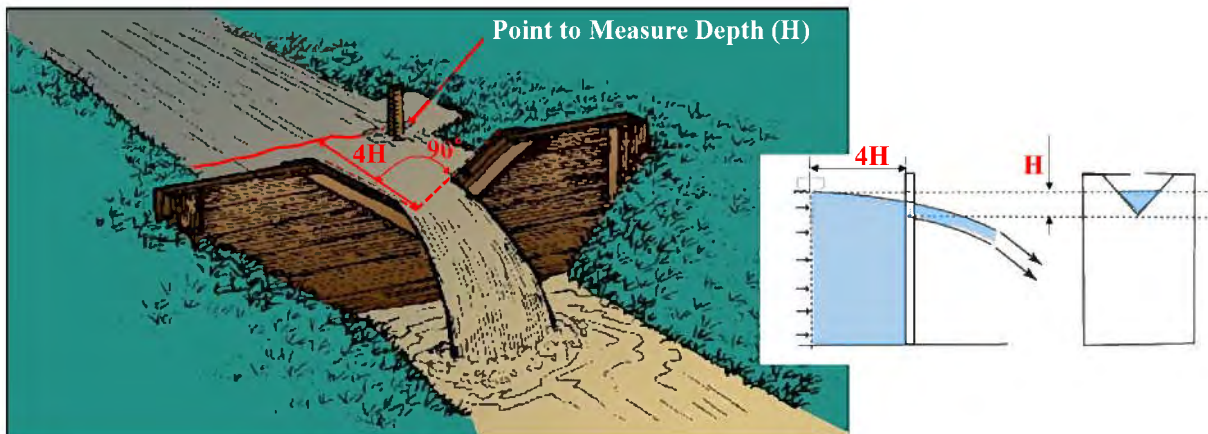
1. Calculate the total volume of water collected, V

$$V = \text{Volume of container used} = 200 \text{ liters}$$

2. Calculate the yield of well, Q

$$Q = \frac{\text{Volume of water collected}}{\text{time in seconds}} = \frac{200 \text{ l}}{30 \text{ s}} = 6.67 \text{ lps}$$

### b. Flow Method using V-Notch Weir



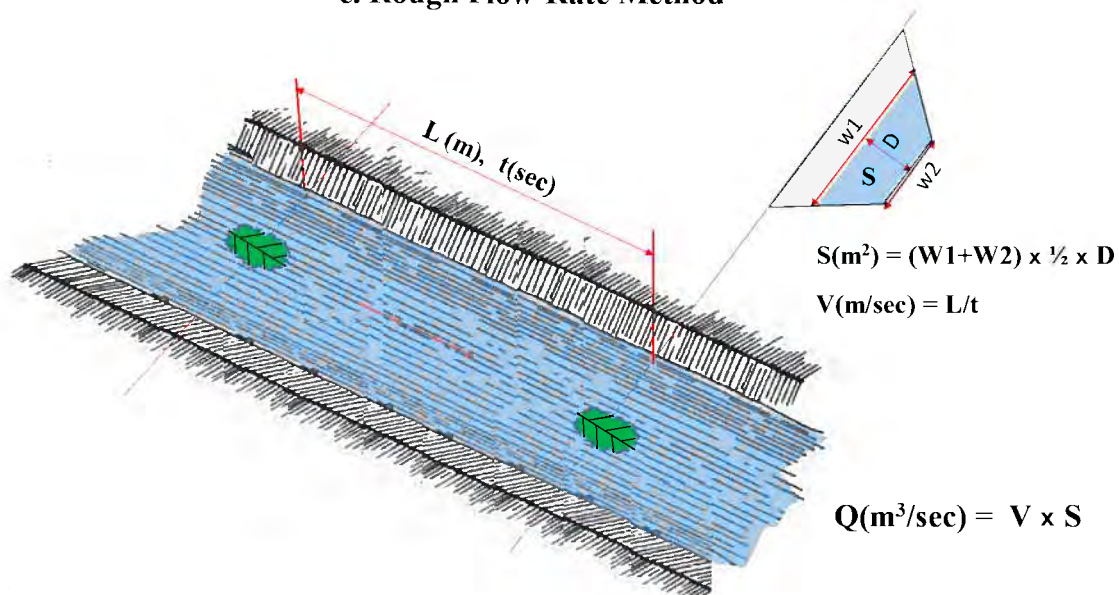
$$60^\circ : Q = 0.008 \times H^{2.5}$$

$$90^\circ : Q = 0.0138 \times H^{2.5}$$

$$Q : \text{l/sec}, H : \text{cm}$$



### c. Rough Flow-Rate Method



## 3. Source Water Protection

In any drinking water system, protecting source water is a critical step towards avoiding drinking water contamination. Protected watersheds will improve the quality of the source water.

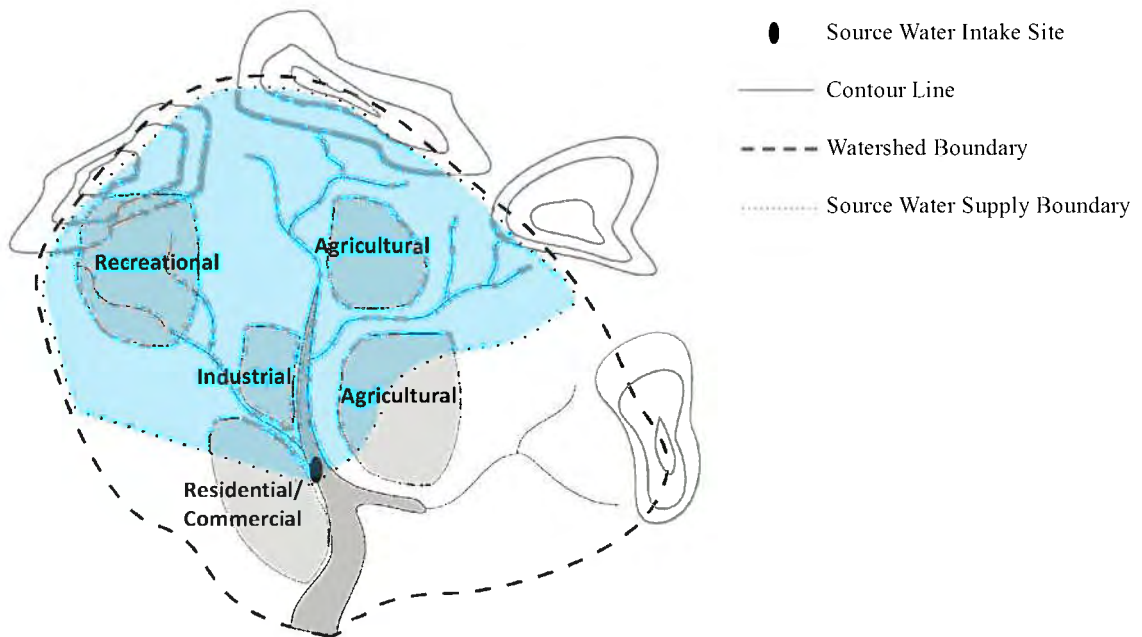
**When the water source have been polluted, there are several option:**

- (1) To change the water source**
- (2) To install a suitable water treatment system**
- (3) To remove the polluting source**

### Main Pollution Sources

Pollution Source	Possible Contaminants
Solid waste landfill	Heavy metals, chloride, sodium, wide variety of organic & inorganic compounds
Liquid waste storage ponds	Heavy metals, solvents and brines
Septic tanks/leach fields	Organic solvents, nitrates, sulfates and microbiological contaminants
Agricultural activities	Nitrates, herbicides and pesticides
Infiltration of urban runoff	Inorganic compounds, heavy metals and petroleum products

### Generalized land-use overlay with watershed delineation map



## Lesson 4 Water Treatment

*Water treatment ideally should be avoided.*

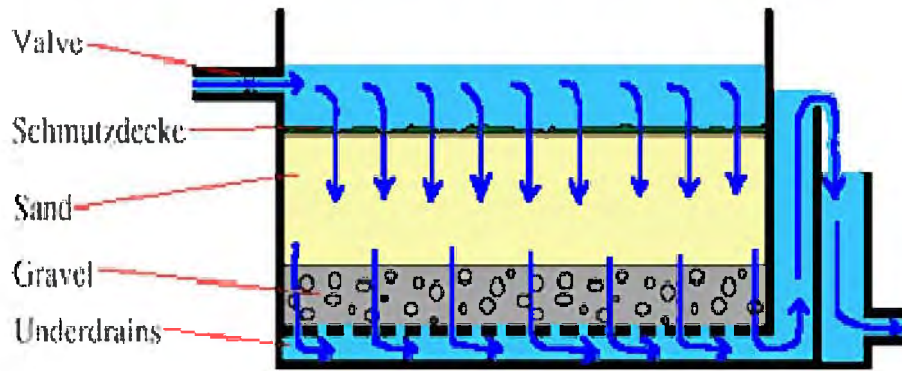
*It is best to select sources with good water quality at the outset to reduce facility and operation costs.*

- **Slow Sand Filtration**
- **Rapid Sand Filtration**
- **Disinfection**
- **Altona Case**

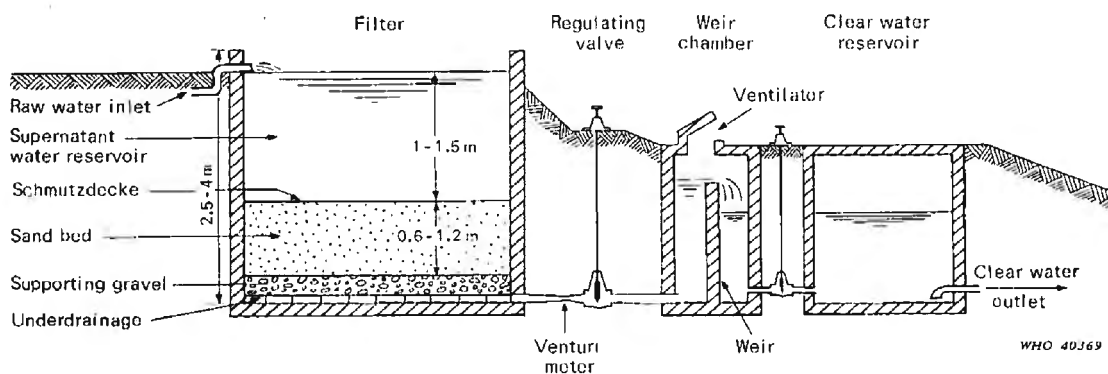
### Slow Sand Filtration vs Rapid Sand Filtration

<b>Filtration rate:</b>	<b>4 - 6 m/day</b>	<b>120 – 150 m/day</b>
<b>Turbidity</b> : (Raw Water)	<b>under 20 ntu</b>	<b>under 1000 – 2000 ntu</b>
<b>Pre-treatment:</b>	<b>none / Sedimentation</b>	<b>Coagulation, flocculation, Sedimentation</b>

### Slow Sand Filter



### Slow Sand Filtration



## Altona Case: Cholera outbreak in Hamburg, Germany in 1892



- Large outbreak of Cholera in Hamburg
- 17,000 cases; 8,600 deaths
- Very few cases in neighborhoods served by Altona's filtered water supply
- Hamburg's sewers were upstream from Altona's intake!

## Rapid Sand Filtration

Coagulation and Flocculation

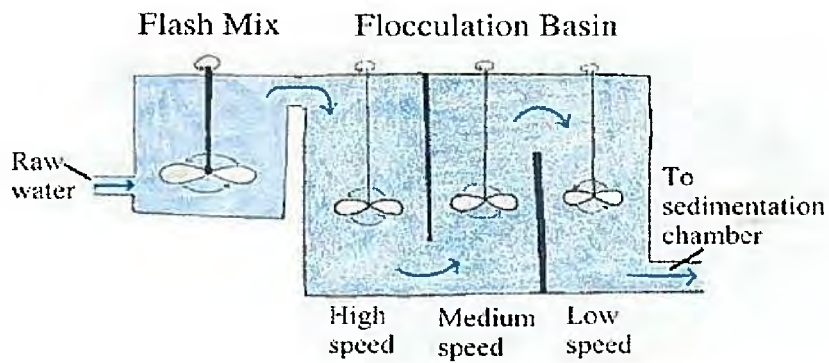


Sedimentation



Rapid Sand Filter

## Coagulation and Flocculation

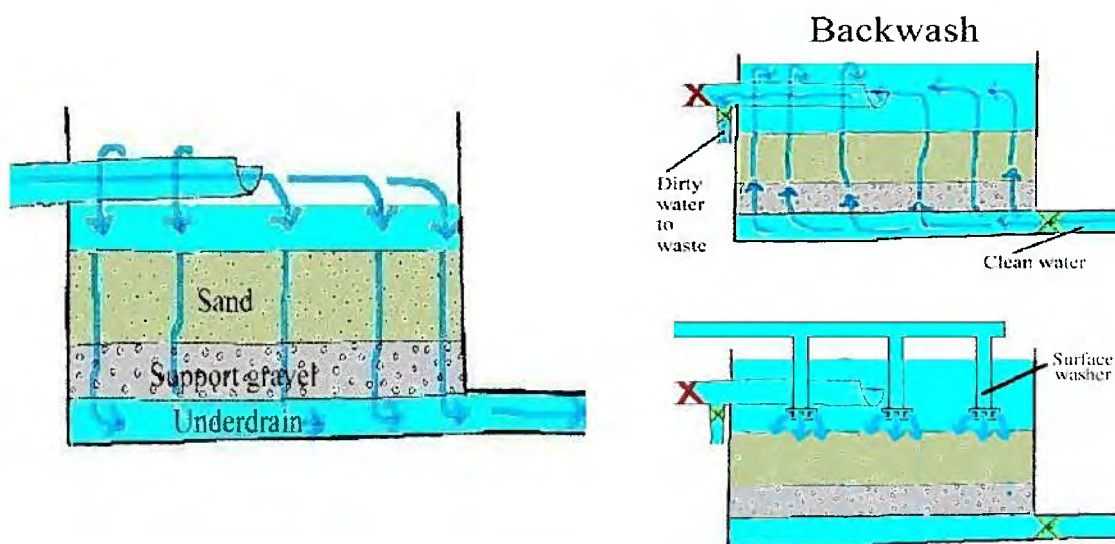


## Sedimentation





## Rapid Sand Filter

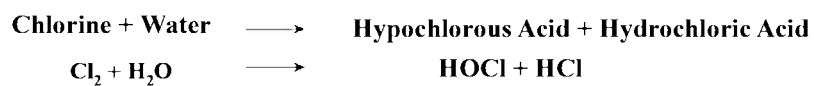


## Disinfection

1. **Water disinfection: the removal, deactivation or killing of pathogenic microorganisms.**
2. **To ensure that drinking water is free from disease-causing microorganisms.**

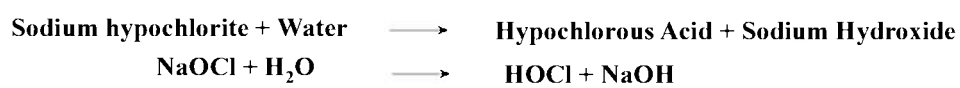
Disinfection is often universally employed by water distribution systems, even when water at the source is deemed already potable – as a precautionary measure to control the spread of waterborne diseases.

## Chlorine Gas

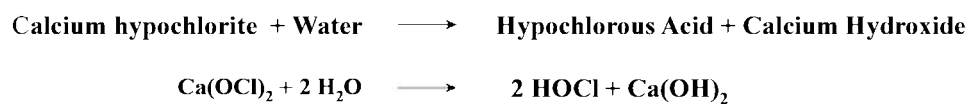


## Hypochlorites

**Sodium hypochlorite (NaOCl)**



**Calcium hypochlorite (Ca(OCl)<sup>2</sup>)**





## **Lesson 5 Transmission and Distribution Systems**

- Transmission and Distribution System
- Pipeline Hydraulics
- Pipeline Design Criteria
- Pipeline Materials Selection
- Appurtenances for Transmission and Distribution Mains
- Reservoir (Tank)
- Public Faucets/Service Connections

### **1. Transmission & Distribution System**

#### **(1) Through gravity flow**

This is the ideal set-up when the location of the water source is at a considerably higher elevation than the area to be served.

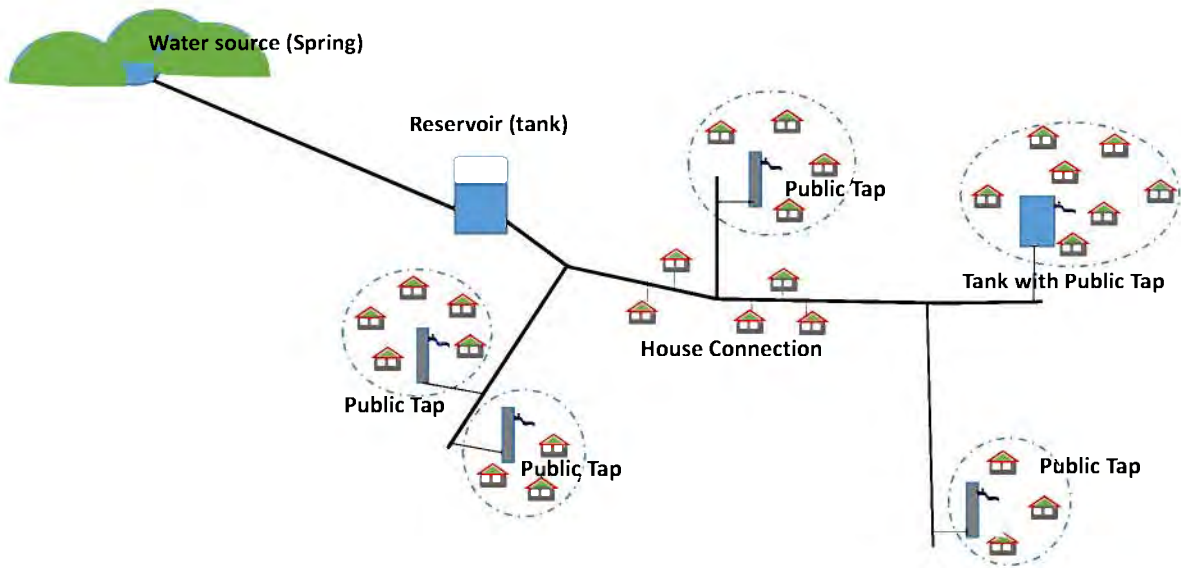
#### **(2) Through pumping with storage**

Water is either (a) pumped to a distribution pipe network, then to consumers, with excess water going to a storage tank, or (b) pumped to a storage tank first, then water is distributed by gravity from the tank to the consumers.

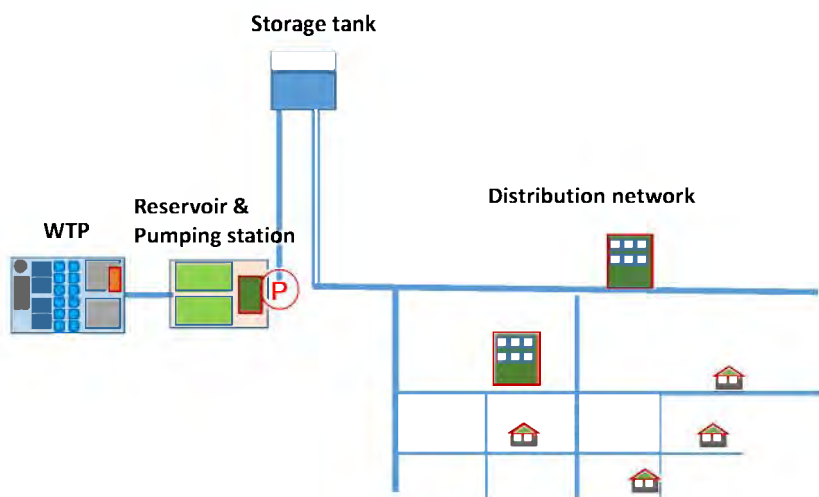
#### **(3) Through direct pumping to the distribution system**

Water is pumped directly from the source to the distribution system to the consumers.

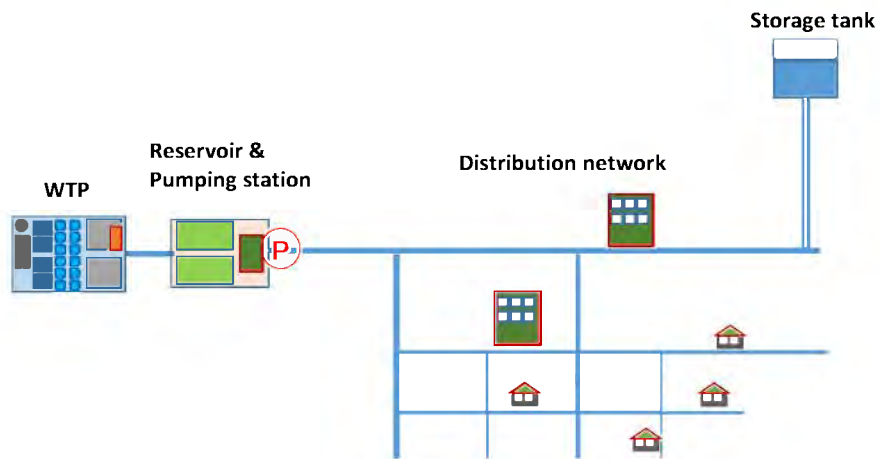
(1) Distribution by gravity



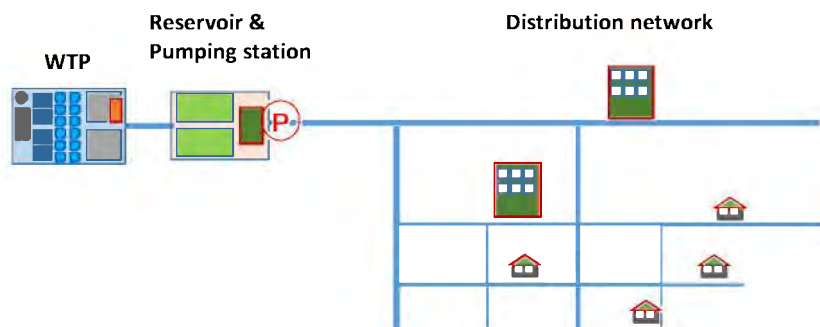
(2) Distribution by pump with storage



(2) Distribution by pump with storage

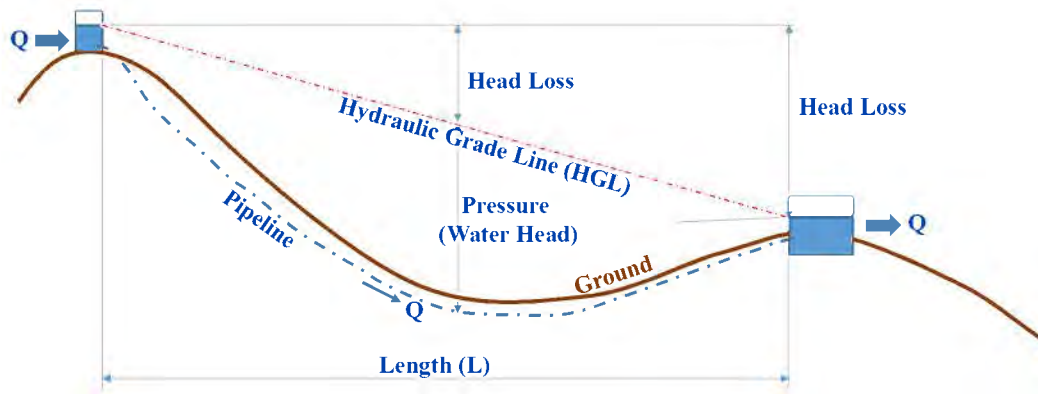


(3) Distribution by pump



## 2. PIPELINE HYDRAULICS

- (1) Pressure (= Water Head)
- (2) Head Losses
- (3) Hydraulic Grade Line (HGL)



### Hazen–Williams Formula

- Darcy-Weisbach formula
- **Hazen-Williams formula**
- Mannings formula
- Combined Darcy-Weisback and Colebrook-White equation.

$$Q = 0.25783C \cdot (D/1000)^{2.63} \cdot (h/L)^{0.54} \cdot 1000$$

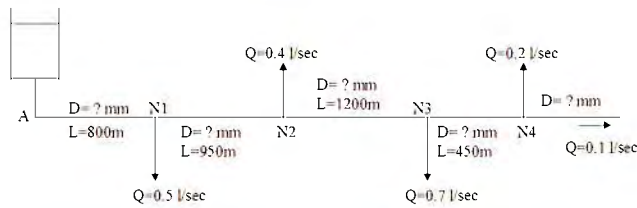
$$D = 1.6258C^{-0.38} \cdot (Q/1000)^{0.38} \cdot (h/L)^{-0.205} \cdot 1000$$

$$h = 10.666C^{-1.85} \cdot (D/1000)^{-4.87} \cdot (Q/1000)^{1.85} \cdot L$$

$$C = (Q/1000) / (D/1000)^{2.63} / (h/L)^{0.54} / 0.27853$$

- h: Head Loss (m)
- C: Flow (Roughness) coefficient
- D: Pipe diameter (m)
- Q: Flow rate (m<sup>3</sup>/s)
- L: Pipe Length (m)

## Practice



Node	GL(m)	Qflow	Qout	h(m)	L(m)	C	D (mm)	R-Head
A	45		-	-	-	-	-	20.00
N1	30		0.5		800	120		
N2	25		0.4		950	120		
N3	20		0.7		1200	120		
N4	20		0.2		450	120		

### 3. Pipeline Design Criteria

1. Minimum pressure at the remotest end of the system = 3 m
2. Maximum velocity of flow in pipes
  - a. Transmission Line = 3.0 m/s
  - b. Distribution Line = 1.5 m/s
3. Minimum velocity of flow in pipes = 0.40 m/s
4. Demand Factor: varies from 0.3 (minimum demand) to 3.0 (peak-demand)
5. Allowable head loss: minimum = 0.50 m/1,000 m, maximum = 10 m/1,000 m
6. Allowable pressure: minimum = 3 m, maximum = 70 m

#### 4. Pipeline Materials Selection

Parameters	GI	PVC	PE
Crushing strength versus superimposed loads in trench	Excellent	Fair	Poor
Burst strength versus internal pressure	Excellent	Good	Good
Durability	Fair	Excellent	Excellent
Resistance to corrosion	Poor	Excellent	Excellent
Flow capacity	Fair	Excellent	Excellent
Resistance to external mechanical injury	Excellent	Fair	Fair
Ease of installation	Easy	Must be handled gently. Must be buried	
Pipe Cost	High	Low	Low
Cost per fitting	Low	High	High
Number of fittings	High	High	High

NWRC RWS Volume I, Design Manual

#### Comparison of Pipe materials

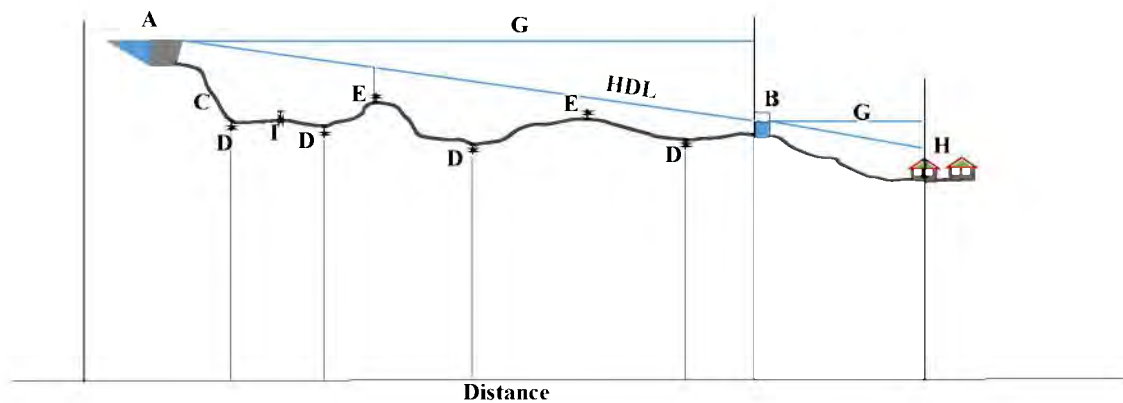
Material Property	DI	PVC	HDPE
Tensile strength	60,000 psi	7,000 psi	3,200 psi
Corrosion resistance (int)	Good – w/cement lining	Excellent	Excellent
UV resistance	Excellent	Gradual strength decline	Yes - w/carbon black
Diameter range	3" - 64"	4" - 12" (C900) 14" - 48" (C905)	4" - 63"
Type of joints	Push-on or mechanical	Push-on or mechanical	Heat fused
Need for special bedding for typical installations	No	Yes	No
Anticipated service life	100 years	50 - 100 years	50 years

EPA 816-D-09-001 November 2009

## 5. Appurtenances for Transmission and Distribution Mains

### (1) Valves

- a. Isolation Valves
- b. Directional Valves
- c. Altitude Valves
- d. Air Release Valves and Vacuum Breaking Valves
- e. Pressure Reducing Valves



**A = Intake structure**  
**B = Storage reservoir**  
**C = Pipeline**  
**D = Blow-off valve**  
**E = Air valve**

**HDL = Hydraulic grade line**  
**G = Static head**  
**H = Rural town or Village**  
**I = Sectioning valve**  
 (every 1.5 km)

## (2) Fittings

### a. To connect the same type and size of pipe:

Union  
Coupling

### b. To connect two pipes of different sizes:

Reducers

### c. To change the direction of flow:

Elbow  
Tee  
Cross

### d. To stop the flow:

Caps, plugs and blind flanges

## 6. Reservoir (Tank)

### Capacity

#### (1) $Cr = (1/4) (ADD)$

where:

Cr = Reservoir capacity in liters

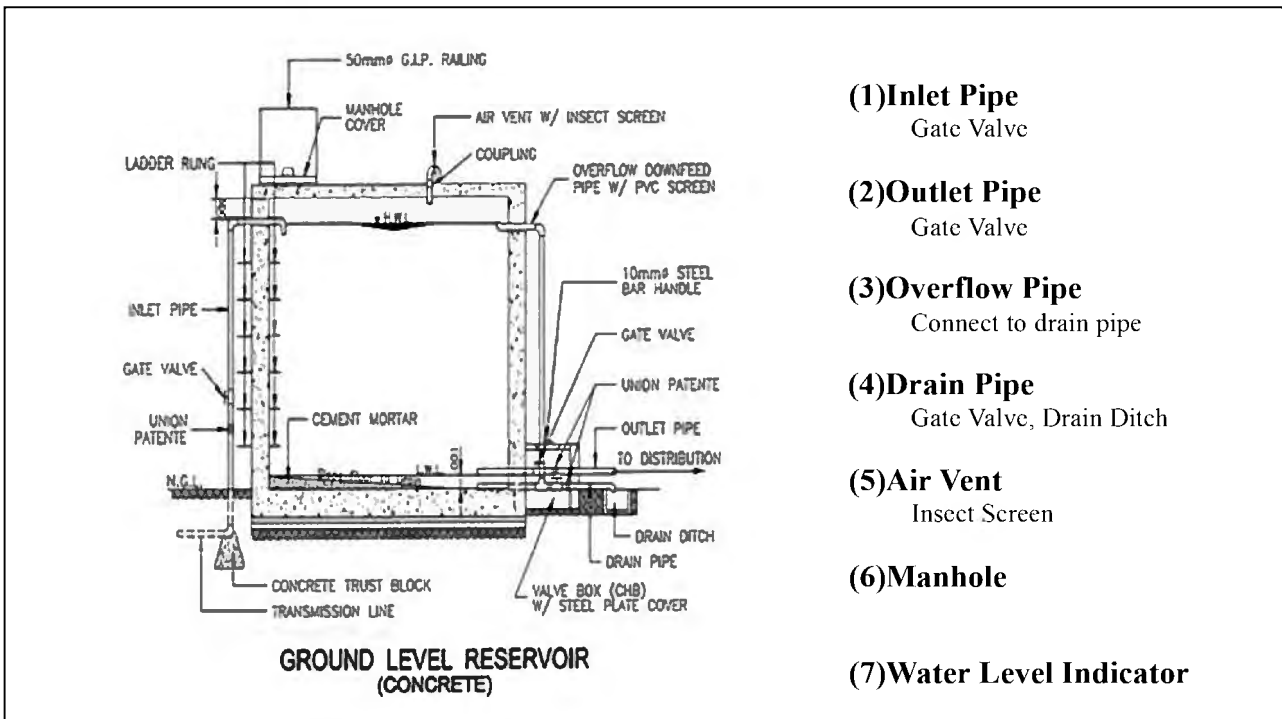
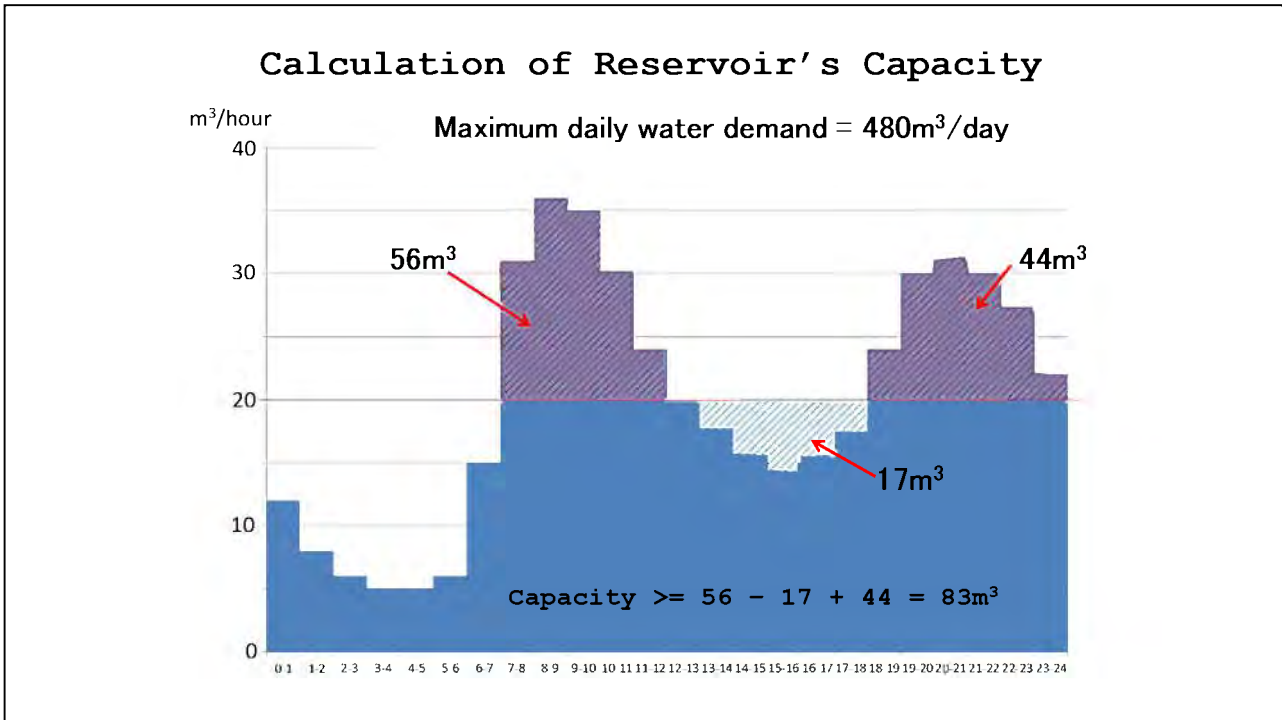
ADD = Average day demand in liters per day

#### (2) To calculate from hourly demand of MDD

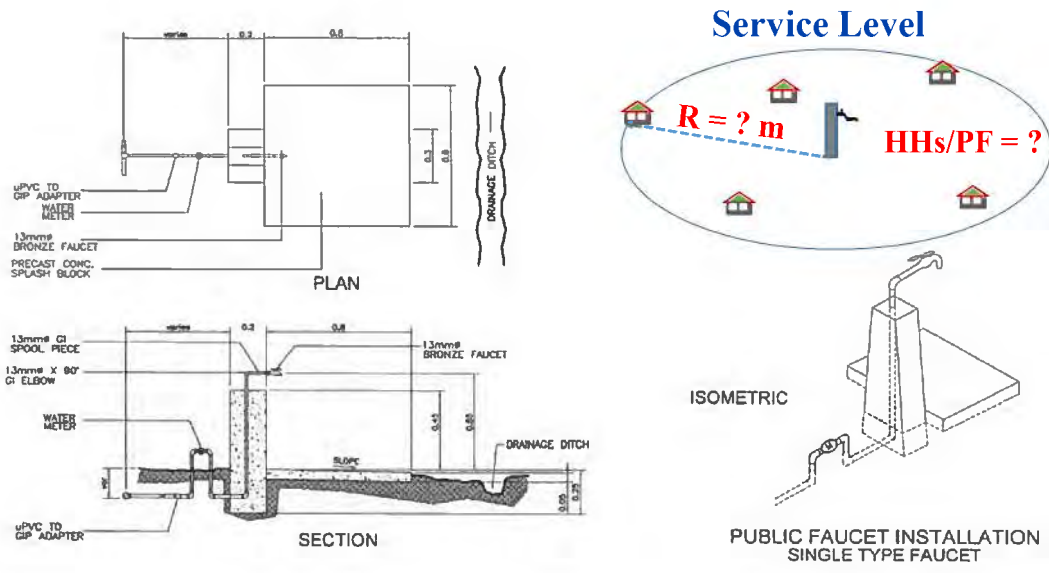
where:

MDD = Maximum day demand





## 6. Public Faucets/Service Connections



## Service Level

Per Capita Water Consumption = ?

Public Tap or House Connection ?

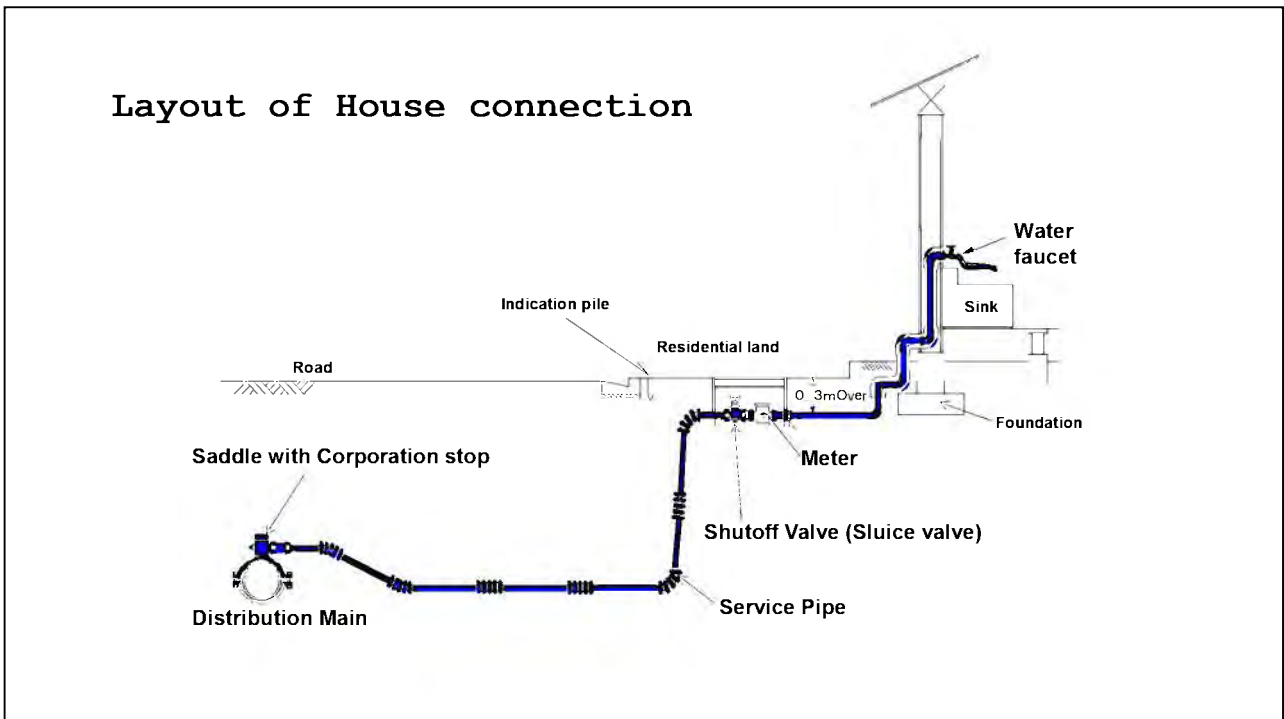
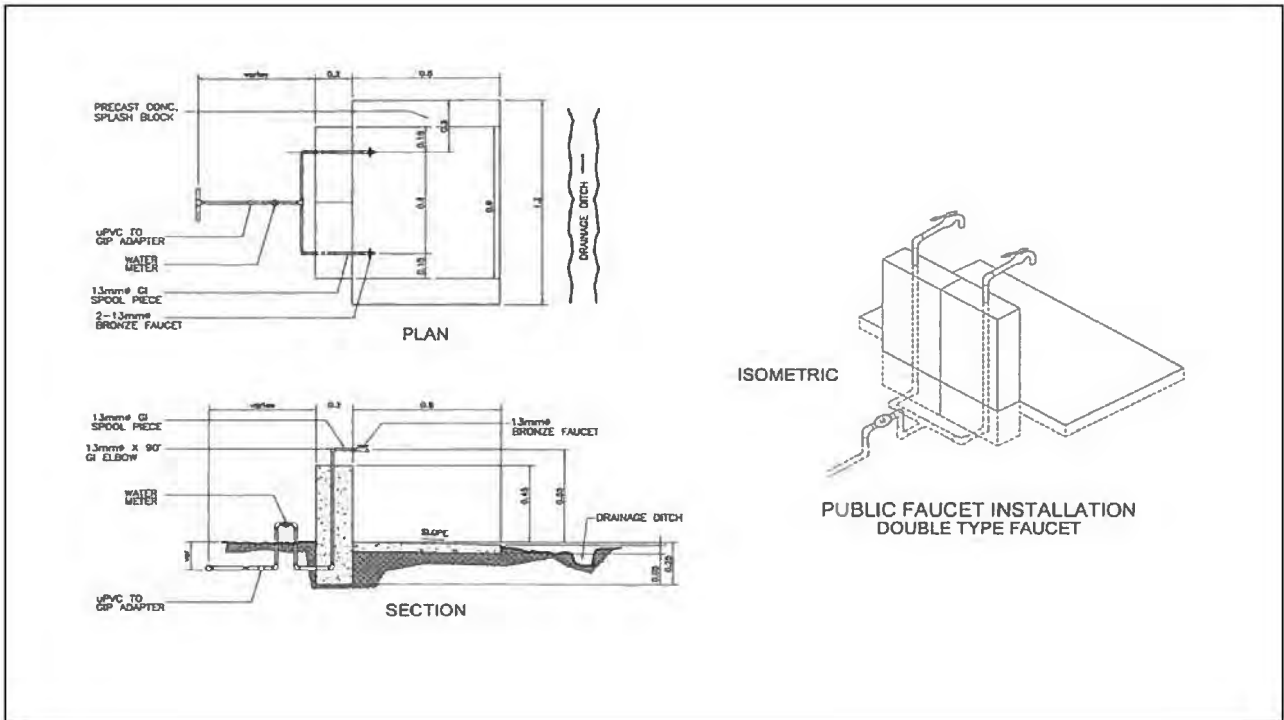
- Multi-tap in house  
100 l/c/d



→ 50m (2.5min)  
50 l/c/d

→ 50m – 500m (2.5min - 15min)  
20 l/c/d

→ 500m (15min)  
Below 5 l/c/d

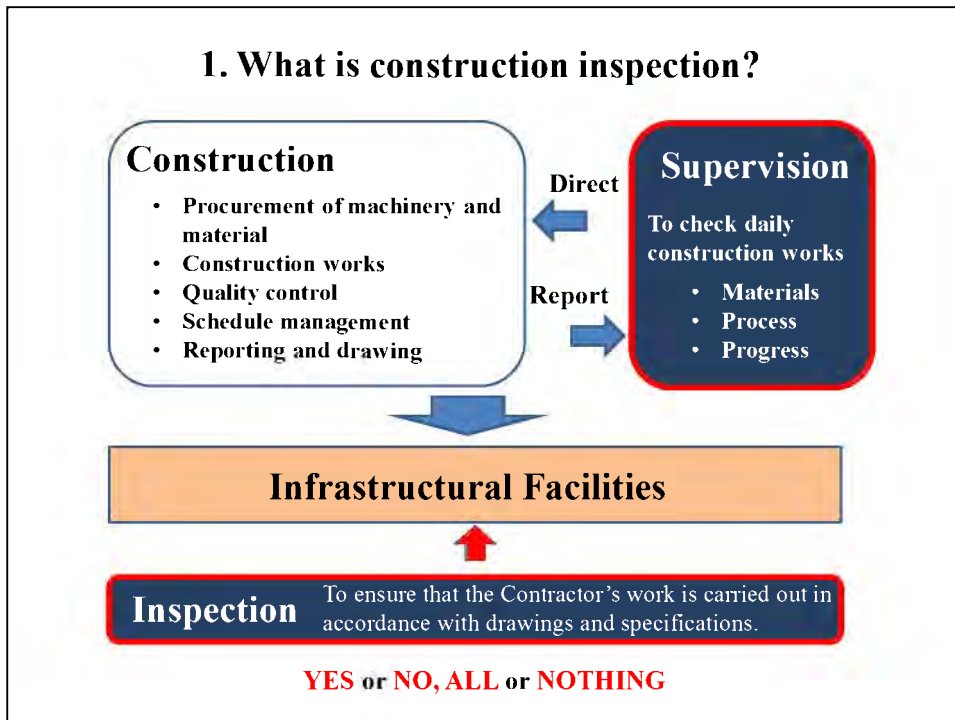


## **PART II**

# **Inspection for Rural Water Supply Project**

## **Lesson 6 Construction Inspection**

- **What is construction inspection?**
- **Inspection procedures**
- **Check points**



DISCUSSION

**What is/are necessary to secure good quality of infrastructure ?**

Ability of Construction Company

or

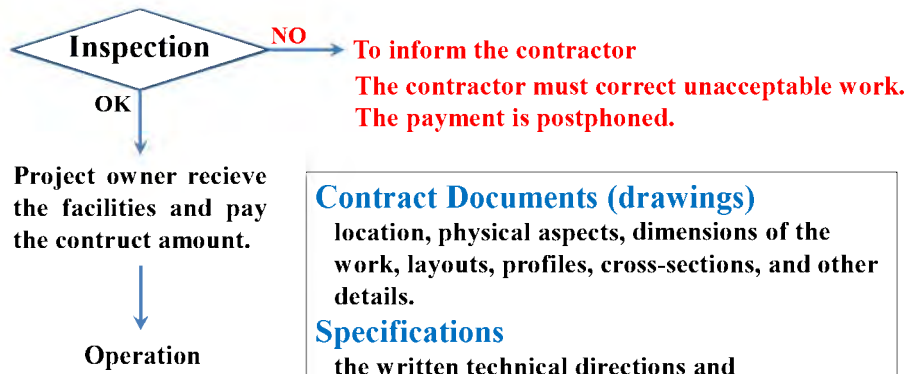
Supervision

or

Inspection

## Inspection is

To ensure that the Contractor's work is carried out in accordance with contract documents and specifications of the project.



## Construction Inspector's Job Description

In general the inspection personnel must ensure the following items:

- a. All material and workmanship are in accordance with the specifications and the acceptable good practice.
- b. The quality control testing of material is at an acceptable level of workmanship.
- c. All works are to be in accordance with the level, alignment, dimension, and cross-sections as specified in construction drawings and specifications.

## 2. Inspection procedures

### Pre-Inspection

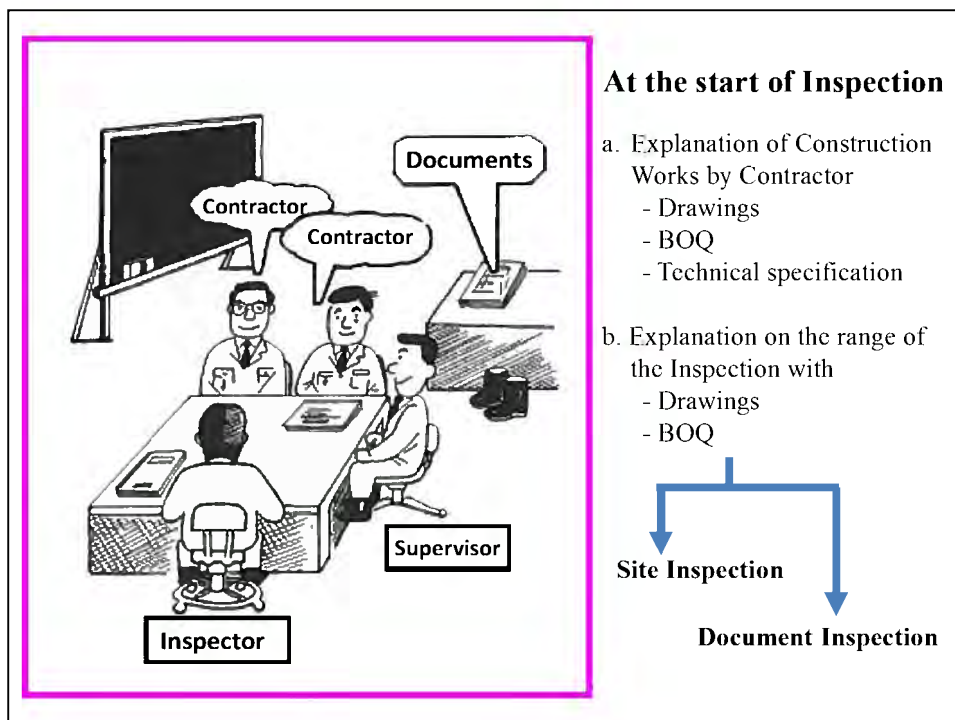
1. To receive all the plans, approved drawings, specifications, and other documents pertaining to the assigned project.

### Beginning of Inspection

2. To be explained about the outline of the whole construction works and the range of the inspection using drawings and BOQ by the Contractor.

### Inspection

3. To start the site inspection or the document inspection.



## 2-1. Site Inspection

Intermediate inspection and Completion inspection

- (1) To measure the dimensions of facilities, and check whether the measurements meet with the drawings.
- (2) To check the materials about the amount and qualities.
  - On-site examination of materials
  - Count the amount at site
  - Documents of quality guarantee and examination
  - Statements of delivery
- (3) To check the external appearance by watching
  - Workmanship
  - Situations under the construction

## 2-2. Document Inspection

- (1) Confirmation of Documents submitted
  - 1) Contract Document: the contract amount and payment conditions
  - 2) Bill of Quantities showing unit prices and quantities
  - 3) Description of changes, alteration or variations, if any
  - 4) Site Inspection Report by KDD
  - 5) Digital data of BOQ
- (2) Confirmation of Payment conditions
- (3) Calculation in billing sheets
- (4) Confirmation of completed works in BOQ, drawings and photos**
- (5) Confirmation of work schedule
- (6) Confirmation of inspection result by KDD

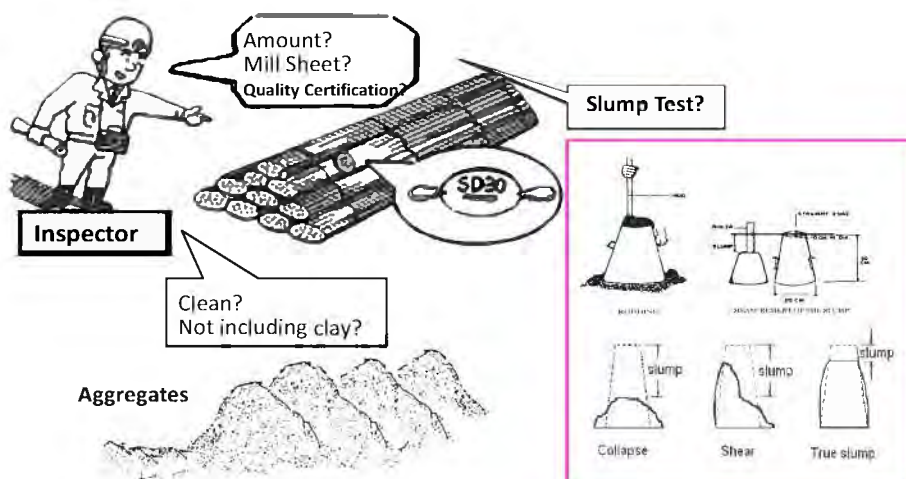


### 3. Check points

1. To check the materials
2. To check the Processes
3. To measure the dimensions of facilities
4. To check the external appearance
5. To check the BOQ
6. To check the construction photos
7. Examples of check points

#### 3-1. To check the materials

To check the materials about the amount and qualities.



## **GUIDELINES IN PRODUCING GOOD CONCRETE**

### **1. Using the Right Materials**

- Portland Cement
- Aggregate (Gravel & Sand)
- Water
- Admixtures

### **2. Obtaining the Right Mix Proportions**

### **3. Controlling the Proportion and Mixing Method**

- A homogeneous mixture
- Uniform batches

### **4. Placing**

### **5. Curing**

- To prevent freshly poured concrete from drying out too quickly

## **CONCRETE INSPECTION**

The Inspector necessarily must refer to the design drawings and specifications, to ensure that these are complied with, and to keep a record that shall cover the following:

- 1. Quality and proportions of concrete materials and strength of concrete;**
- 2. Construction and removal of forms and shoring;**
- 3. Placing of reinforcements;**
- 4. Mixing, placing and curing of concrete;**
- 5. Sequence of erection and connection of walls; and**
- 6. General progress of work.**

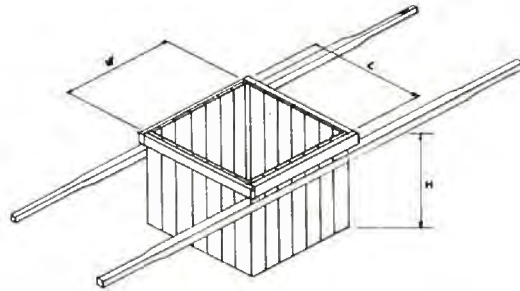
### Fine Aggregates or Sand - Removing Clay and Silt -

Clay and silt present in excessive quantities can be detected by conducting the following test:

1. Fill a quart jar (1.14 liter) or Erlenmeyer flask with sand to a depth of 5.0 cm (2 inches);
2. Add water until the jar or flask is 3/4 full;
3. Shake the contents for about one minute with the last few shakes in a sidewise direction;
4. Allow the jar to stand for 30 minutes;
5. Observe the top of the sand. If there is more than 3.2 mm layer of sediment, the sand where the sample was taken is unsuitable for construction purposes. However, the aggregates in question can be used after washing and removing the undesirable materials.

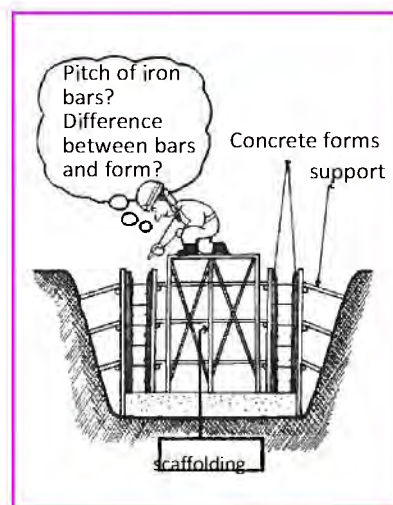
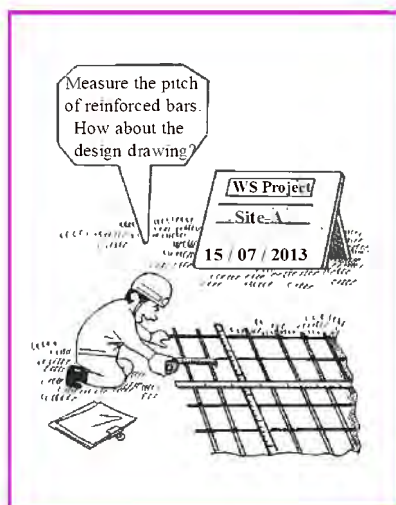
### Typical concrete mixes and their uses

Class	Typical Concrete Mixes ( volume proportions)				Quantity of Materials per m <sup>3</sup> of Concrete				Usage
	Cement	Water	Sand	Gravel	Cement	Sand	Gravel		
					bags	m <sup>3</sup>	m <sup>3</sup>	m <sup>3</sup>	
AA	1	0.7 – 1.0	1.5	3.0	10.4	0.294	0.44	0.88	Foundation
A	1	0.7 – 1.0	2.0	4.0	7.9	0.223	0.45	0.9	Beams & Slabs
B	1	0.7 – 1.0	2.5	5.0	6.5	0.184	0.46	0.92	Columns
C	1	0.7 – 1.0	3.0	6.0	5.5	0.156	0.47	0.94	Flooring on fill, and pavements
D	1	0.7 – 1.0	3.5	7.0	4.8	0.136	0.48	0.96	Big Mass Footings



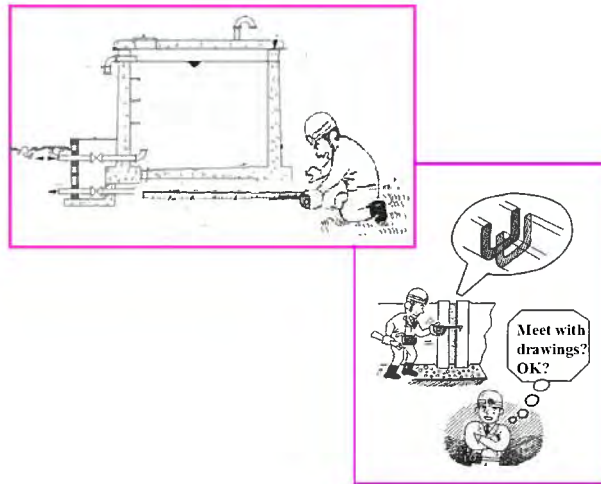
Capacity (m <sup>3</sup> )	Inside Measurements		
	Length (m)	Width (m)	Height (m)
0.10	0.4	0.4	0.63
0.20	0.6	0.6	0.56
0.30	0.8	0.8	0.47

### 3-2. To check the Processes



### 3-3. To measure the dimensions of facilities

To measure the dimensions of facilities, and check whether the measurements meet with the drawings.



### 3-4. To check the external appearance



Cold Joints

Nobuaki Otsuki, Junji Yokokura and Takahiro Nishida  
Actual Technological Levels of Concrete in Developing Countries  
- Concrete Problems in the World-

### Bad Examples



Trace of Bubble



Lackof corner

### 3-5. To check the BOQ

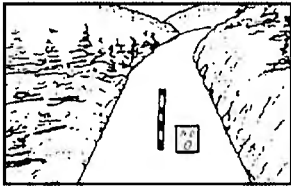
Item	Shape/ Spec.	unit	Quantity			Remarks
			Contract	Execution	Execution Rate (%)	
Pipe Laying	D 50 mm	m	1,500	1,350		
Concrete Tank	2 x3 x2.5		1	1		RC
Excavation	0.4 x 0.3	m3	180	162		0.12m3/m

### 3-6. To check the construction photos

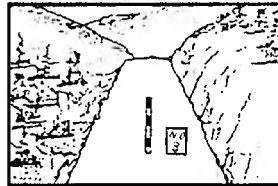
1. Photos of pre-construction photos and the completion
2. Photos of under-constructing (building methods)
3. Photos of using materials
4. Photos of material qualities (material testing)
5. Photos of facilities dimensions photos

#### Pre-Construction

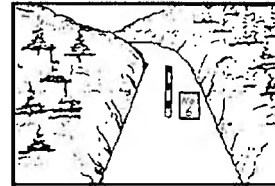
No.0 ~ No.3



No.3 ~ No.5

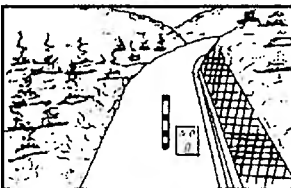


No.5 ~ No.6

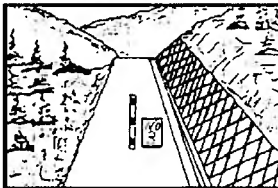


#### Post-Construction

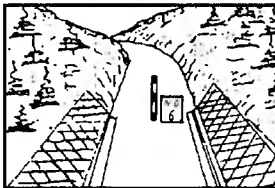
No.0 ~ No.3

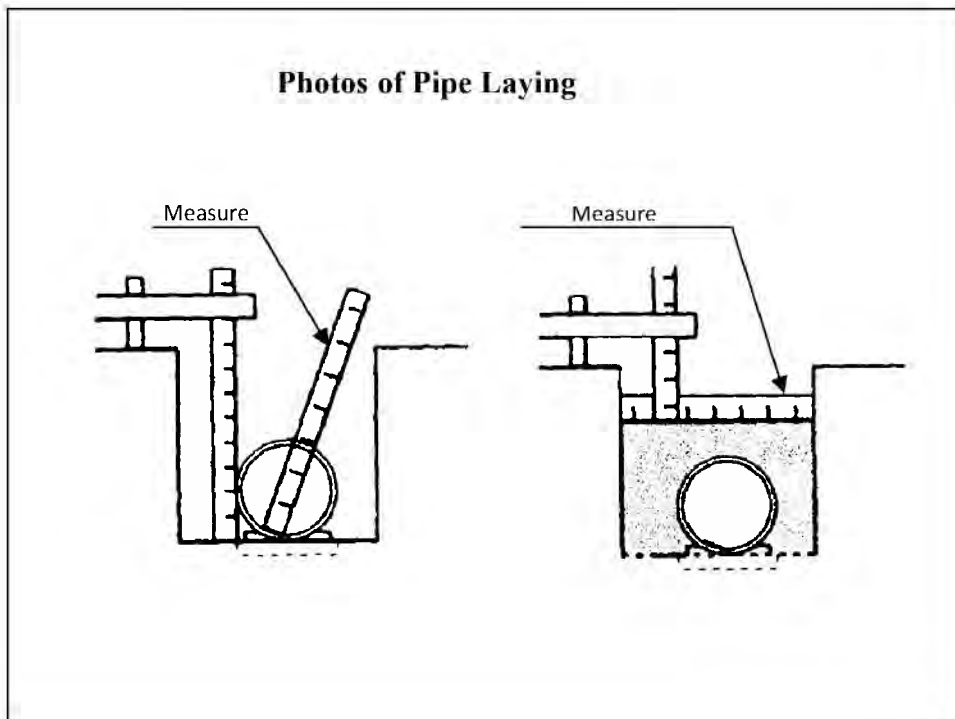
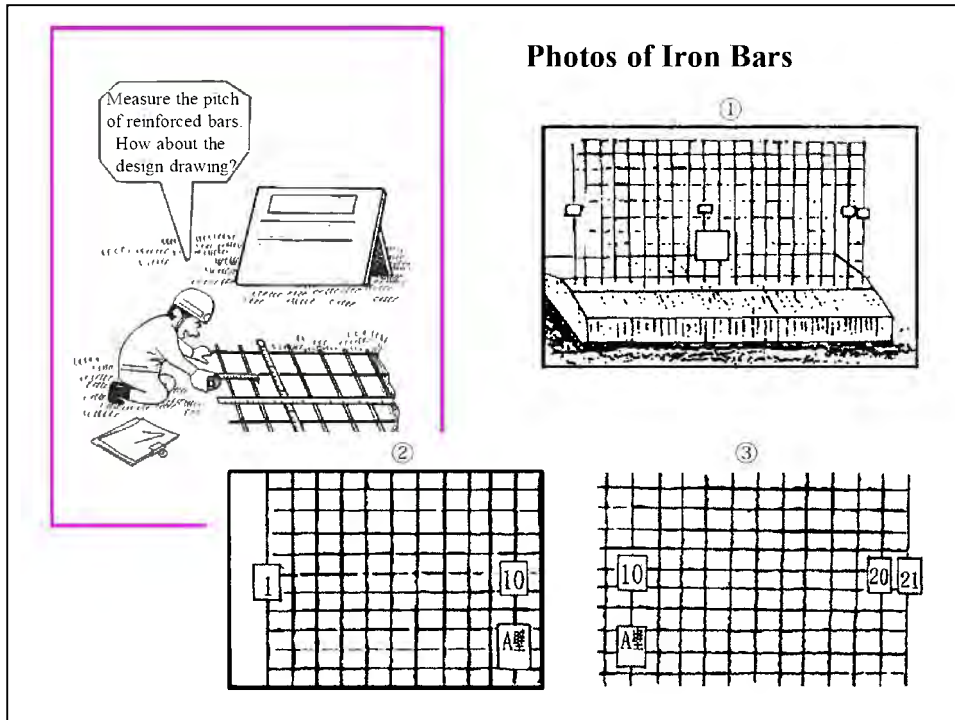


No.3 ~ No.5



No.5 ~ No.6



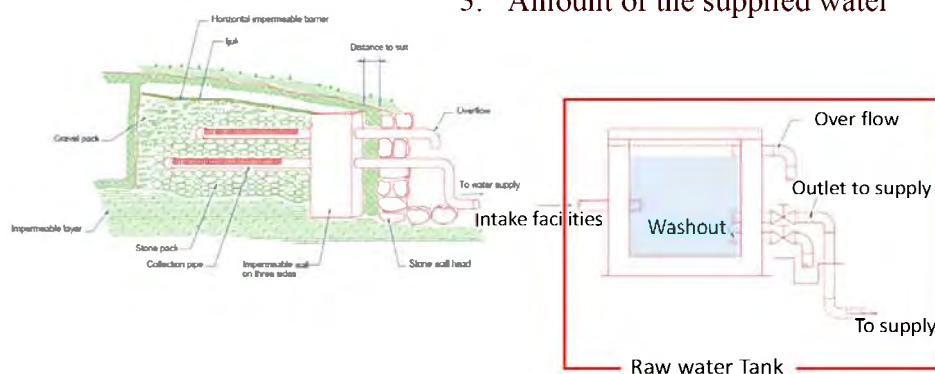


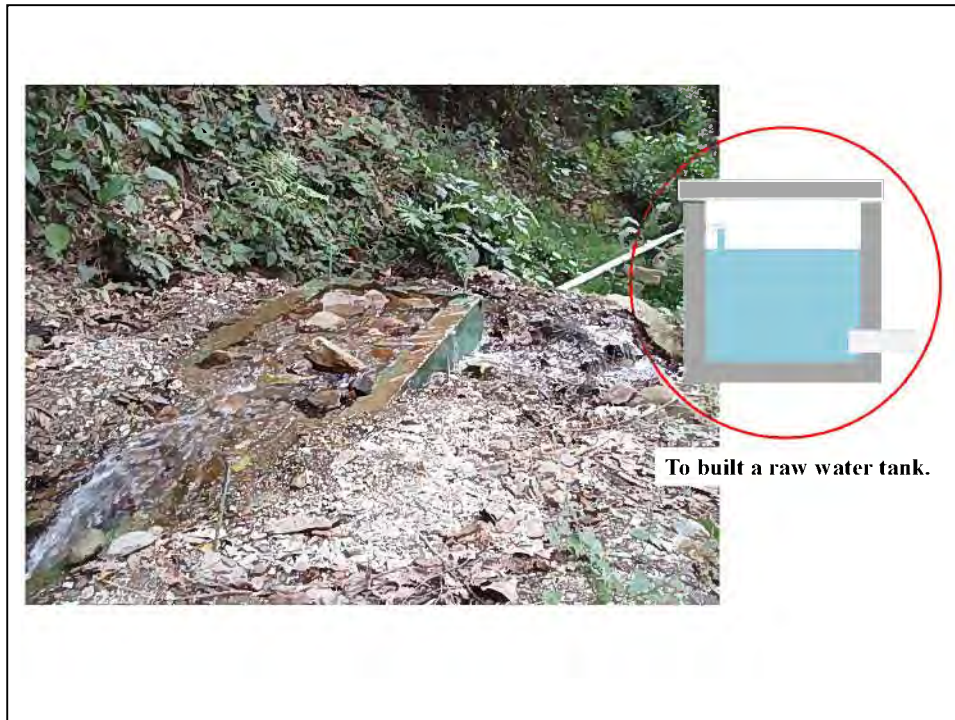


### 3-7. Examples of check points

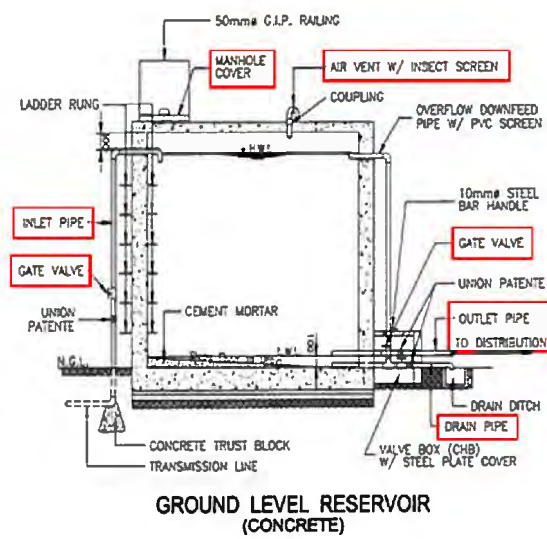
#### Water Source and Intake Facilities

1. Water quantity of the source
2. Water quality of the source
3. Amount of the supplied water

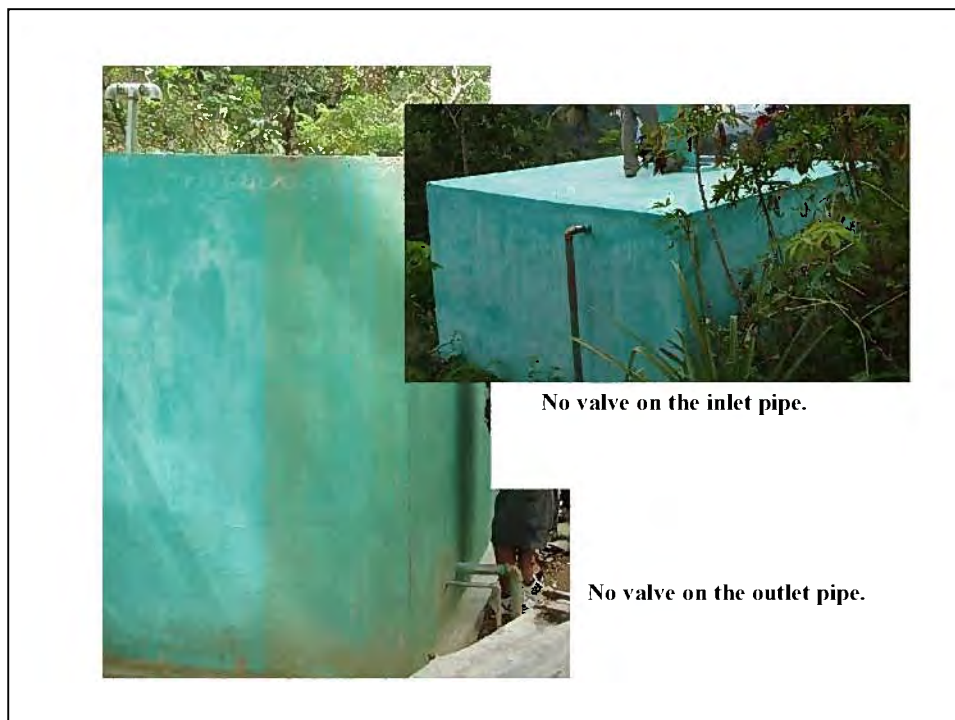




### Reinforced Concrete Reservoir



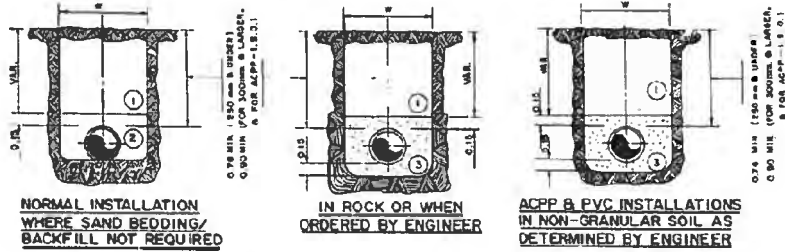
- (1) Inlet Pipe & Valve
- (2) Outlet Pipe & Valve
- (3) Overflow Pipe
- (4) Drain Pipe & Valve
- (5) Air Vent
- (6) Manhole
- (7) Water Level Indicator



### **Points of Pipeline Inspection**

- 1. Materials**
- 2. Length and Diameter**
- 3. Excavation and Pipe Laying**
- 4. Pipeline Profile**
- 5. Appurtenances for Pipeline**
- 6. Thrust Blocks and Anchors**

## Excavation and Pipe Laying

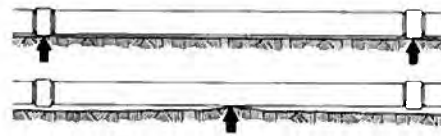


- ① Compacted selected native material backfill.
- ② Compacted selected native material in 0.15 m layers.
- ③ Approved sand bedding & backfill hand placed & compacted.

**Right**



**Wrong**



## Incorrect Pipe connection and Bending

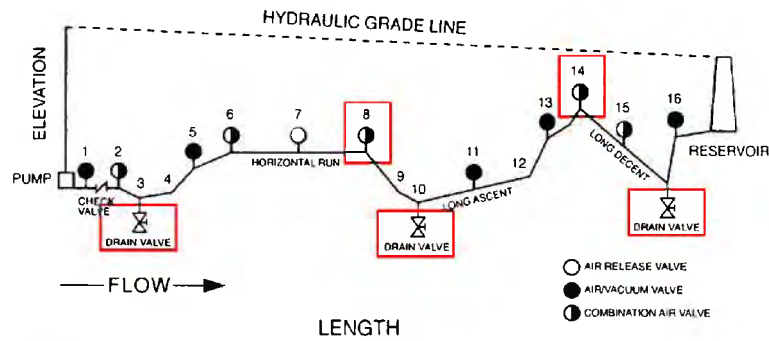


To make clear which is the main line and which are the branches.



To use a bend joint (22½).

### Sample Pipeline Profile Illustrating Valve Locations



NO.	DESCRIPTION	RECOMMENDED TYPES	NO.	DESCRIPTION	RECOMMENDED TYPES
1	Pump Discharge	Air/Vacuum for Pumps	9	Decrease Downslope	No Valve Required
2	Incr. Downslope	Combination	10	Low Point	No Valve Required
3	Low Point	No Valve Required	11	Long Ascent	Air/Vac or Combination
4	Increase Upslope	No Valve Required	12	Increase Upslope	No Valve Required
5	Decrease Upslope	Air/Vac or Combination	13	Decrease Upslope	Air/Vac or Combination
6	Beginning Horizontal	Combination	14	High Point	Combination
7	Horizontal	Air/Rel or Combination	15	Long Descent	Air Release or Combination
8	End Horizontal	Combination	16	Decrease Upslope	Air/Vac or Combination

### Air Valve Locations Along a Pipeline

Air valves are installed on a pipeline to exhaust air and admit to prevent vacuum conditions and air-related surges. The AWWA Steel Pipe Manual recommends Air Valves at the following points along a pipeline.

- 1. High Points:** Combination Air Valve
- 2. Long Horizontal Runs:** Air Release or Combination Valve at 380 to 760 m intervals.
- 3. Long Descents:** Combination Valve at 380 to 760 m intervals.
- 4. Long Ascents:** Air/Vacuum Valve at 380 to 760 m intervals.
- 5. Decrease in an Up Slope:** Air/Vacuum Valve
- 6. Increase in a Down Slope:** Combination Air Valve

From "Theory, Application, and Sizing of Air Valves"  
(Val-Matic Valve and Manufacturing Corporation)



**Air Release Valves**

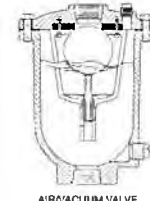
The valve has a small precision orifice to release air under pressure continuously during pipeline operation.



AIR RELEASE VALVE

**Air/Vacuum Valves**

An Air/Vacuum Valves is installed downstream of pumps and at high points to exhaust large volumes of air during pump start-up and pipeline filling. The valve also will admit large volumes of air to prevent a vacuum condition from occurring in the pipeline and to allow for draining.



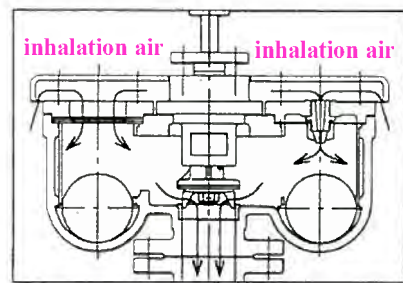
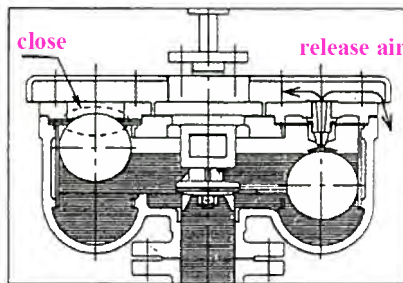
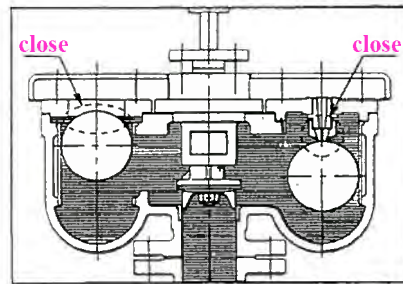
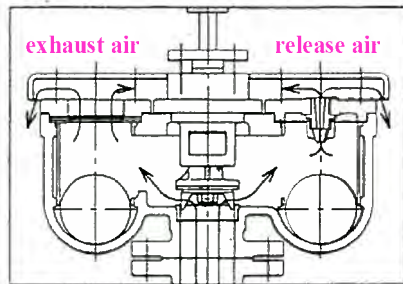
AIR/VACUUM VALVE

**Combination Air Valves**

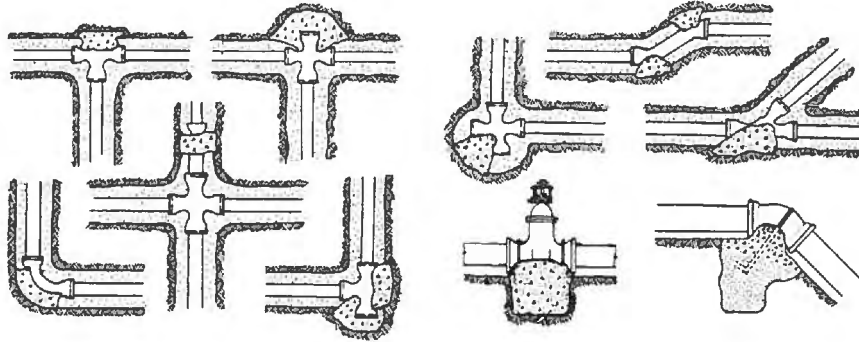
The Combination Air Valve combines the functions of both the Air/Vacuum and Air Release Valves and is an excellent choice for high points. A Combination Valve contains both a small release orifice and a large air/vacuum port in one assembly/



SINGLE BODY COMBINATION



### Thrust Blocks & Anchors



THRUST BLOCKS and ANCHORS

## **ANNEX-10**

### **CASE STUDY ON WATER SUPPLY**



## Design of Rural water supply : Case Study (1)

1. Service Area and Water Demand
2. Water Source
3. Transmission Main
4. Reservoir (Tank)
5. Distribution Main
6. Stand Pipe

PDID	CHECKLIST C-3-1 (1/4)			Verified by	Approved by
Type of Project	Water Supply – spring/river bed water	Objective	Planning and Design		
Contract/Project No		Date of Submission	/ / 201 ( dd / mm . yyyy )		
Project Name		Stage	Verification of Draft Contract Documents		
Implementing Agency					
Check Item	Check Point	Date Checked	Tick	Remarks	
Project concept	Is the project proposed in accordance with Government Strategy (rural and urban water supply development strategy)?				
Coordination	Was all coordination made between the relevant agencies?				
Project area	Are data/information available, including: <input type="checkbox"/> number of present population and households, <input type="checkbox"/> major income sources, <input type="checkbox"/> development history of the villages/towns, <input type="checkbox"/> rainfalls?				
	Are the area frequently affected by natural disaster like <input type="checkbox"/> floods or <input type="checkbox"/> landslides?				
Project target	Target year: _____				
	Number of households to be served: _____				

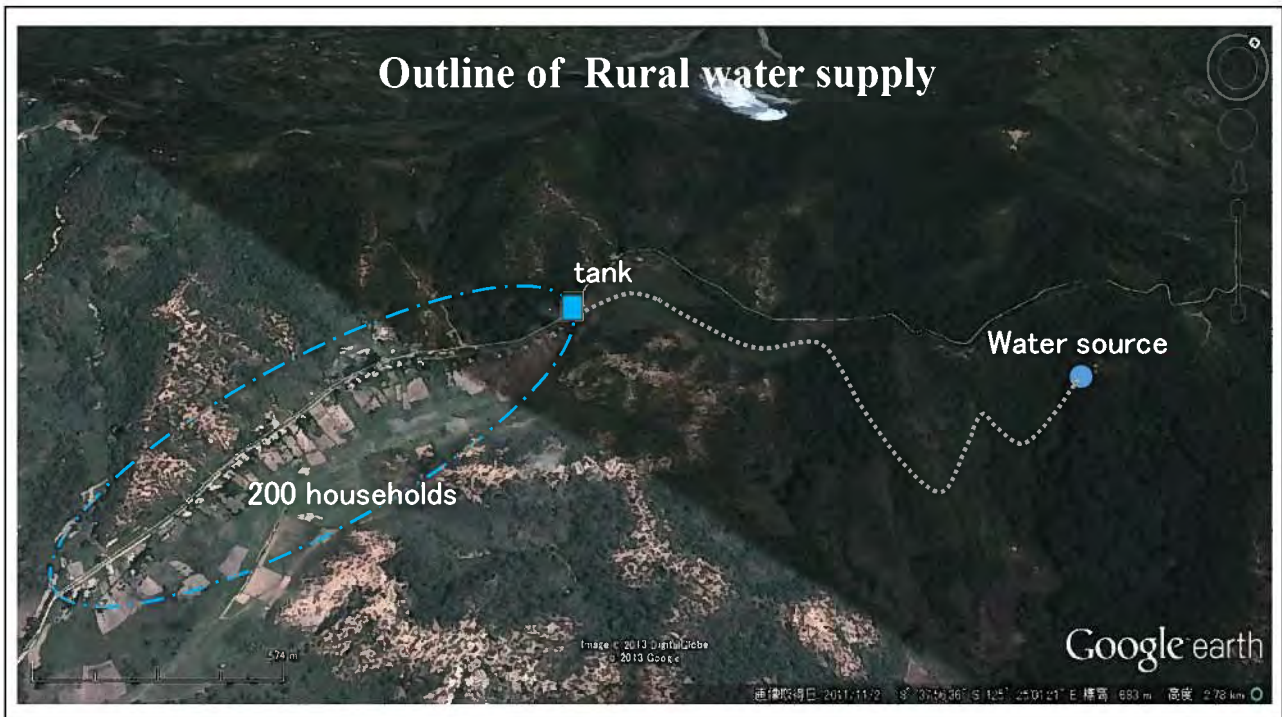
PDID		CHECKLIST C-3-1 (2/4)		Verified by	Approved by
Type of Project	Water Supply - spring/river bed water	Objective	Planning and Design		
Check Item	Check Point	Date Checked	Tick	Remarks	
Existing condition	Are data available on:				
	<input type="checkbox"/> What are the present water sources for people's daily lives?				
	<input type="checkbox"/> What are their major problems ( <input type="checkbox"/> quantity, <input type="checkbox"/> quality, <input type="checkbox"/> distance)?				
Planned water source	<input type="checkbox"/> What are health condition of the people? (morbidity rate of water borne diseases)				
	Is water source sufficient in quantity and quality? Quantity: _____ L/sec, Quality: <input type="checkbox"/> turbid, <input type="checkbox"/> not turbid			See Annex: Planned water source No.1	
	Is its yield stable throughout the year? <input type="checkbox"/> yes, <input type="checkbox"/> no				
	Is gravity flow system applied for water transmission? <input type="checkbox"/> yes, <input type="checkbox"/> no				
Future water demand	Is catchment area of the source sufficient? <input type="checkbox"/> yes, <input type="checkbox"/> no			See Annex: Planned water source No.4	
	Supply water to the people via <input type="checkbox"/> house taps or <input type="checkbox"/> public taps?				
	Design value of unit water consumption per capita per day: _____ L/c/d				
	Is calculation for future water demand by the service population made or not? <input type="checkbox"/> yes, <input type="checkbox"/> no				

PDID		CHECKLIST C-3-1 (3/4)		Verified by	Approved by
Type of Project	Water Supply - spring/river bed water	Objective	Planning and Design		
Check Item	Check Point	Date Checked	Tick	Remarks	
Pipeline design	Is pipe diameter estimated using pipe flow formula with variables of distance, height and flow rate? <input type="checkbox"/> yes, <input type="checkbox"/> no			See Annex: Pipeline design No.1	
	Are drawings of hydraulic profile based on field survey attached? <input type="checkbox"/> yes, <input type="checkbox"/> no			See Annex: Pipeline design No.2	
	Are pipe accessories such as gate valves, air valves, wash-outs properly designed? <input type="checkbox"/> yes, <input type="checkbox"/> no			See Annex: Pipeline design No.3	
Service reservoir design	Is the reservoir equipped with <input type="checkbox"/> inlet valves, <input type="checkbox"/> outlet valves, <input type="checkbox"/> drain pipes, <input type="checkbox"/> overflow pipes, <input type="checkbox"/> air ventilator.			See Annex: Service reservoir design No.1	
	Is concrete structure with reinforcement bars normally designed: <input type="checkbox"/> yes, <input type="checkbox"/> no				
Public taps	Number of faucets equipped at a tap: _____ faucets				
	Number of households to be served by one tap: _____ households				
	Are concrete apron properly designed: <input type="checkbox"/> yes, <input type="checkbox"/> no				
	Are drain pipes equipped at the concrete apron: <input type="checkbox"/> yes, <input type="checkbox"/> no				

PDID	CHECKLIST C-3-1 (4/4)			Verified by	Approved by
Type of Project	Water Supply - spring/river bed water	Objective	Planning and Design		

Check Item	Check Point	Date Checked	Tick	Remarks
Operation & maintenance after construction	Is water user committee planned to organize in the village/town: <input type="checkbox"/> yes, <input type="checkbox"/> no			
	Is an operation plan (cleaning, valve control, etc.) prepared: <input type="checkbox"/> yes, <input type="checkbox"/> no			
	Will fixed amount of fees for O&M be collected from the households: US\$ _____ /month/household			
People's awareness	Do people have an awareness to pay for O&M fees: <input type="checkbox"/> yes, <input type="checkbox"/> no			
	Do people have a willingness to be serviced: _____ households out of _____ households			



## 1. Service Area and Water Demand

### (1) Service Area

### (2) Water Demand

Households (HHs) = 200, average 1 HH = 6 persons

Total served Population = 200 × 6 = 1,200 persons

Average Water demand = 1,200 × [ a ] lpcd = [ b ] l/d

NRW (Leakage ratio) = 15 %

Distributed amount including Leakage

= [ b ] l/d / (1 - 0.15) / 86400 sec/d = [ c ] l/sec

Maximum Water demand

= Average Water demand (including NRW) × 1.30

= [ c ] l/sec × 1.30 = [ d ] l/sec

quote from Multi-Village Pooling Project in Indonesia  
Handbook for Community-Based Water Supply Organizations

## 2. Water Source

### Flow Measurement Using Volumetric Method

**Volumetric Method:** Suitable for point source flows, i.e. the flow of water localized

**You will need** : 1. Water container with a known volume  
2. Stop watch  
3. Pen and paper to note down the results

**Steps**

1. Place the container at the point of flow
2. Record the time it takes to fill up
3. Repeat a few times for best results
4. Calculate the Quantity of Flow with the formula below for each trial
5. Take the average Quantity of Flow for all trials

**Formula**  $Q = V / T$

Q : quantity of flow

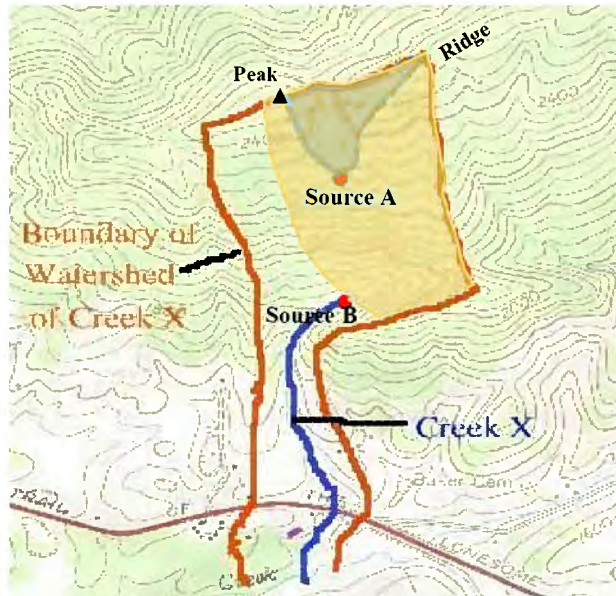
V : volume of container (in liters)

T : time it takes to fill up the container (in seconds)

**Water Source = 1.5 L/sec**



**(Catchment Area)**



**Catchment Area**

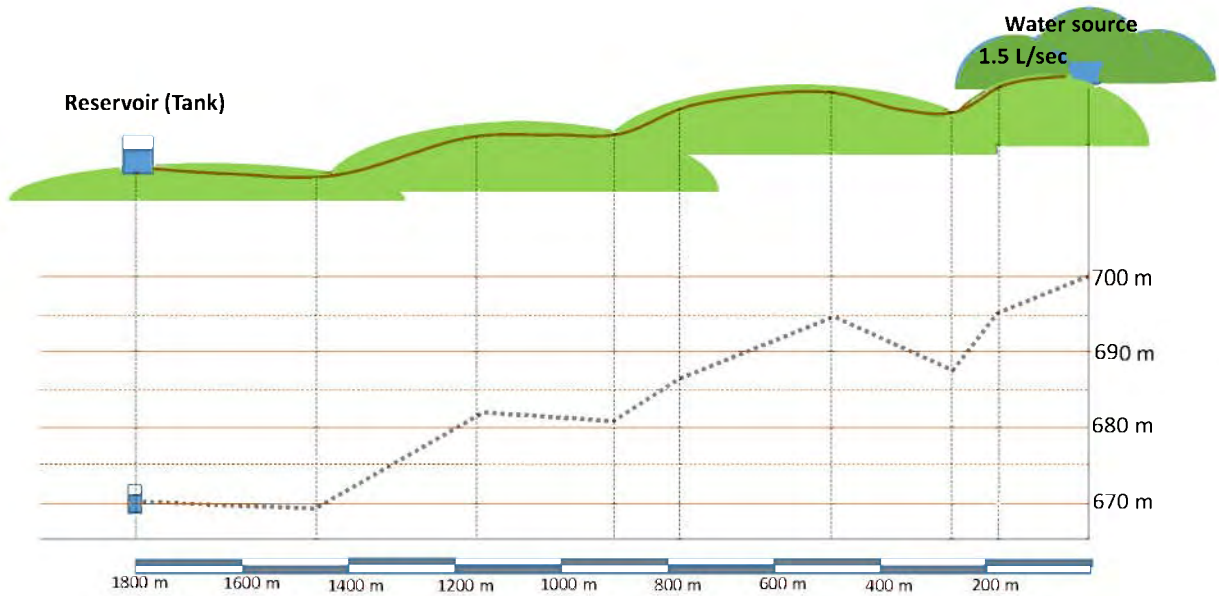
**Source A:**



**Source B:**



**3. Transmission Main**





## 4. Reservoir (Tank)

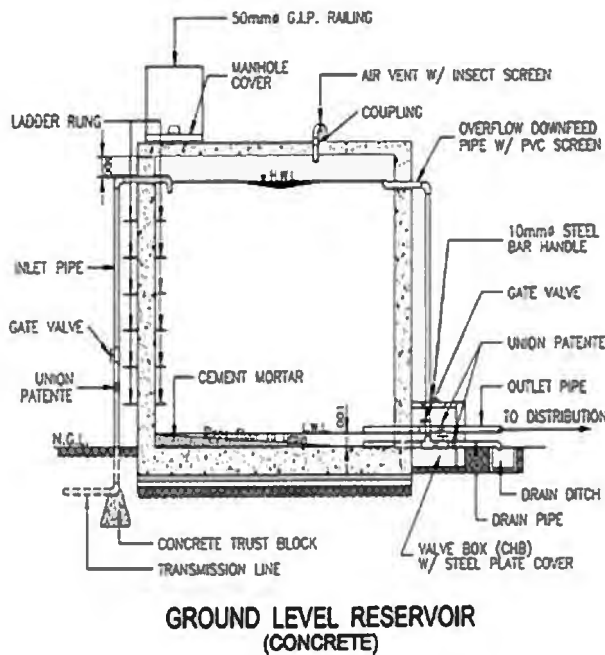
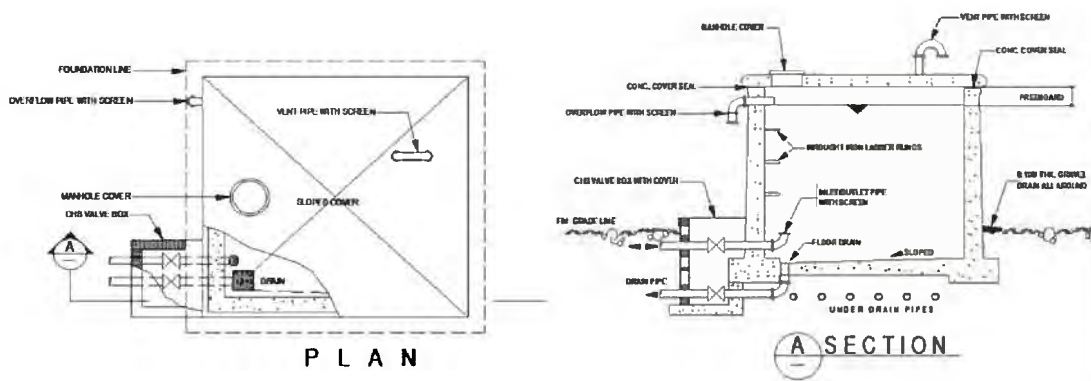
### Capacity

$$Cr = (1/4) (ADD)$$

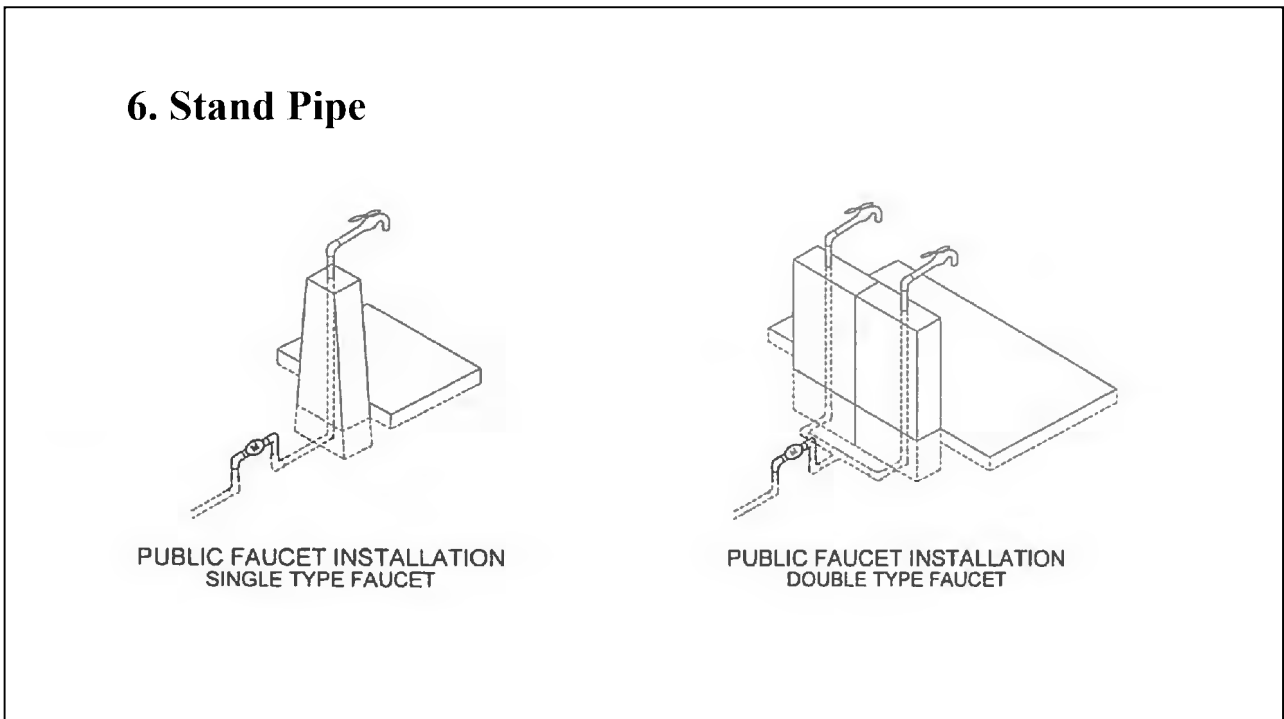
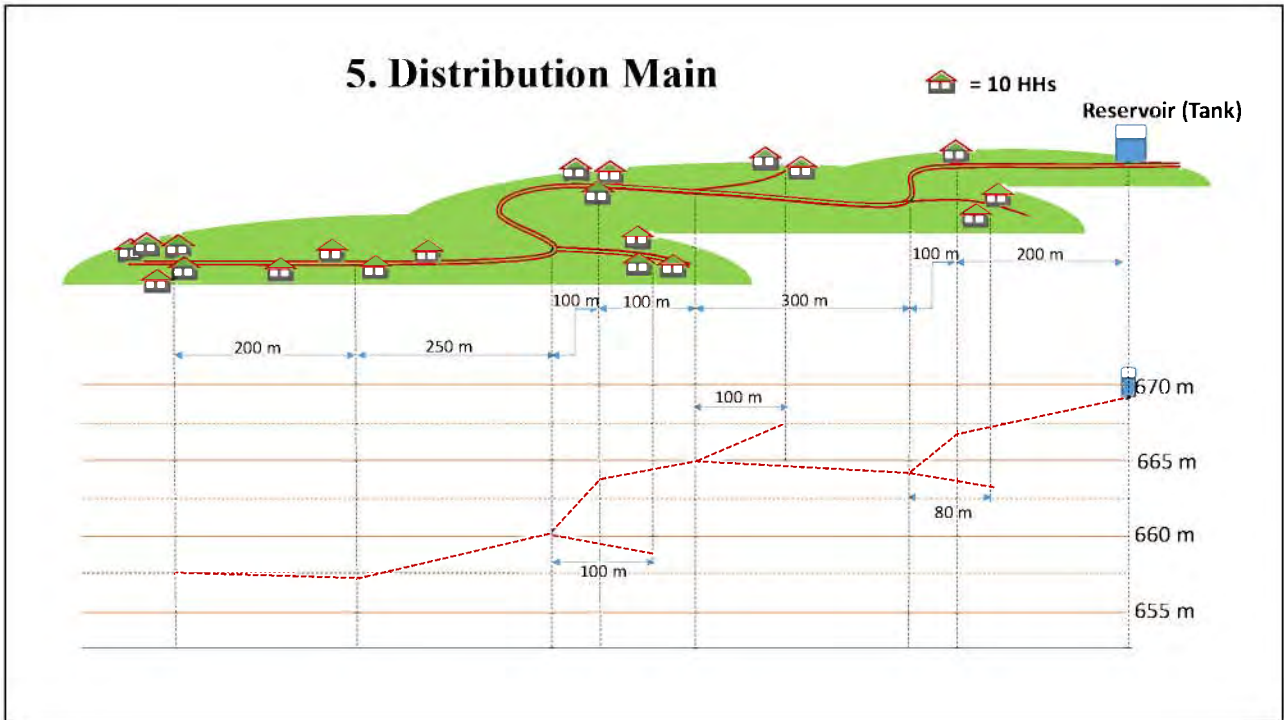
where:

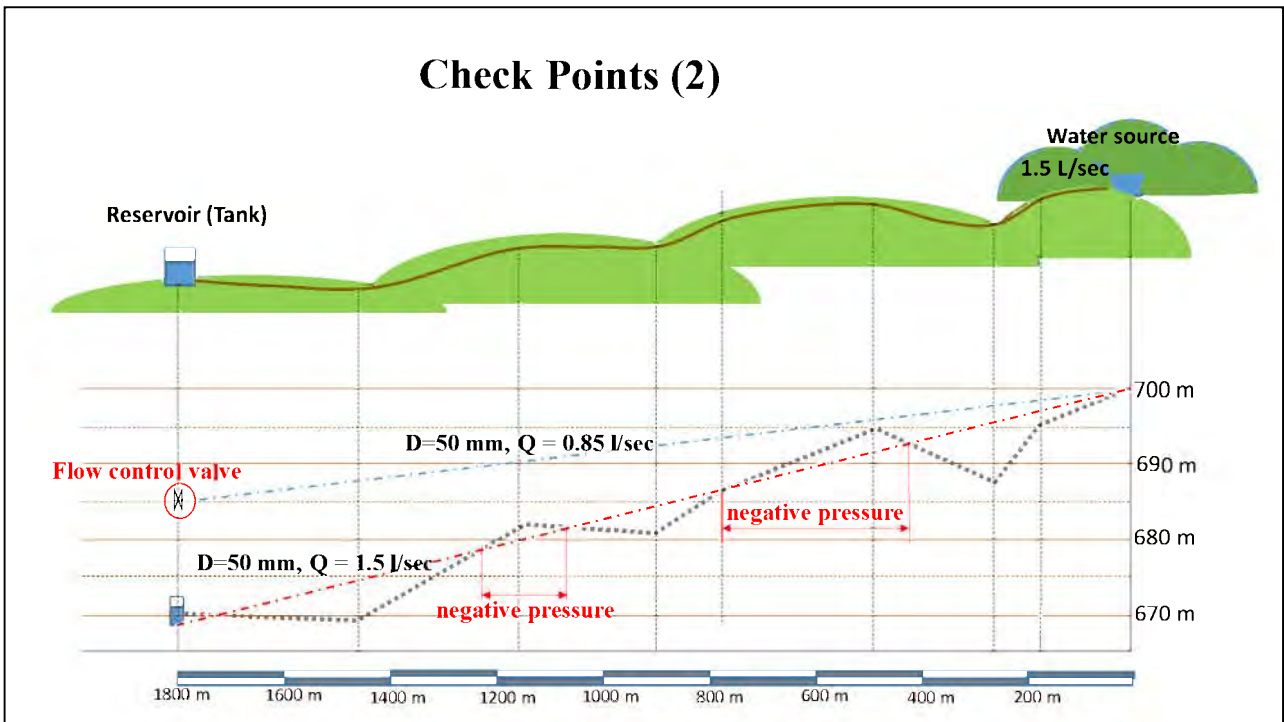
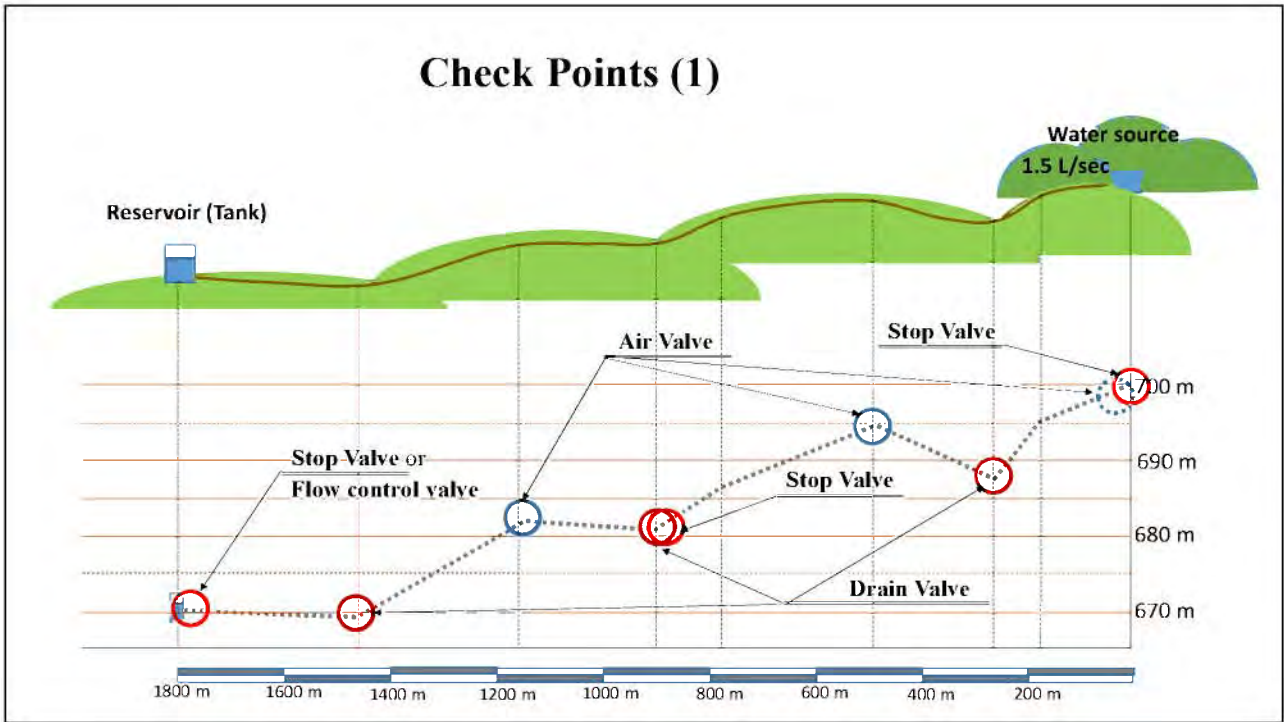
Cr = Reservoir capacity in liters

ADD = Average day demand in liters per day



- (1) Inlet Pipe  
Gate Valve
- (2) Outlet Pipe  
Gate Valve
- (3) Overflow Pipe  
Connect to drain pipe
- (4) Drain Pipe  
Gate Valve, Drain Ditch
- (5) Air Vent  
Insect Screen
- (6) Manhole
- (7) Water Level Indicator





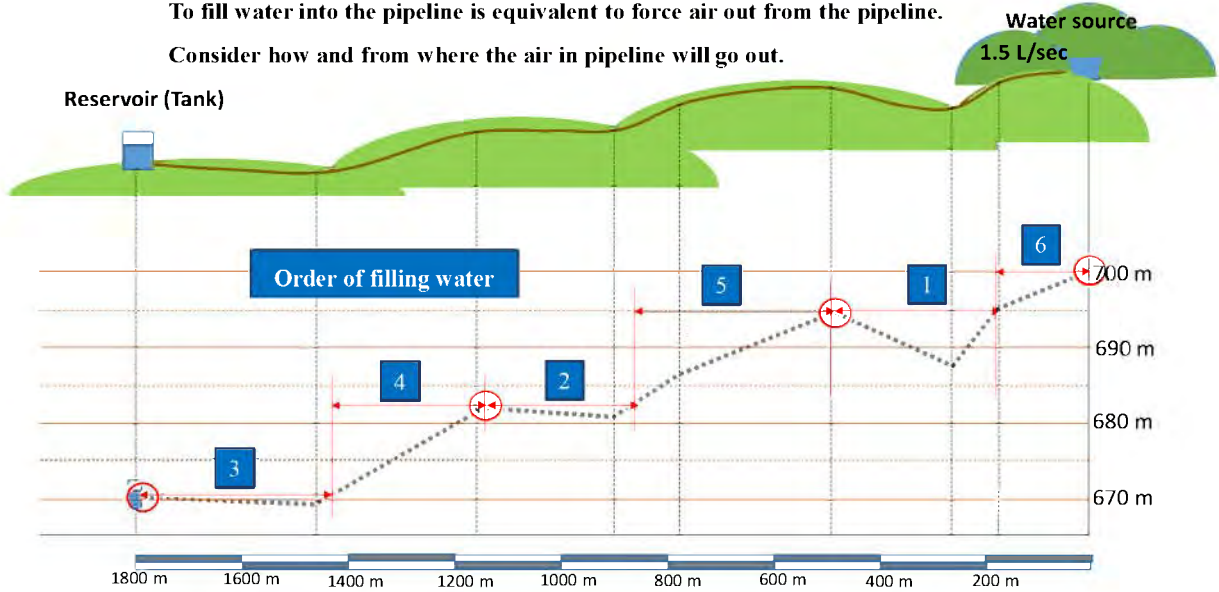


Knowhow: filling of water

## How to fill water into the pipeline after construction

To fill water into the pipeline is equivalent to force air out from the pipeline.

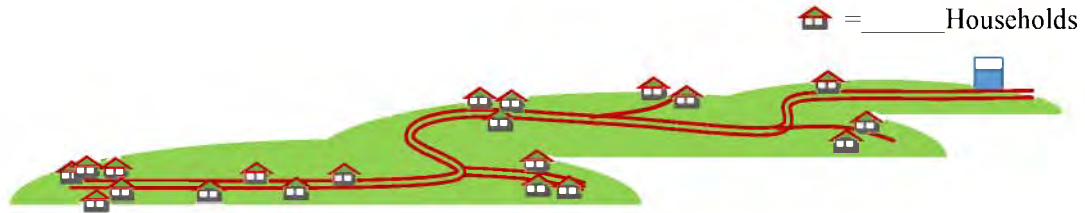
Consider how and from where the air in pipeline will go out.



## WORKSHEET : Design of Rural Water Supply - Case Study (1) –

### 1. Project area

Number of present population and households



Present population = \_\_\_\_\_ HHs x \_\_\_\_\_ Persons/HH

HH: Household

### 2. Project target

Target year: \_\_\_\_\_

Number of households to be served: \_\_\_\_\_

Number of population to be served: \_\_\_\_\_

### 3. Planned water source

a. Is water source sufficient in quantity and quality?

a-1. Quantity: \_\_\_\_\_ L/sec

a-2. Quality :  turbid,  not turbid

b. Is its yield stable throughout the year?  yes,  no

c. Is its yield stable throughout the year?  yes,  no

d. Catchment area of the source: \_\_\_\_\_ m length x \_\_\_\_\_ m width

### 4. Future water demand

a. How to supply water to the people

house connection  public taps

b. Design value of unit water consumption per capita per day: \_\_\_\_\_ L/c/d

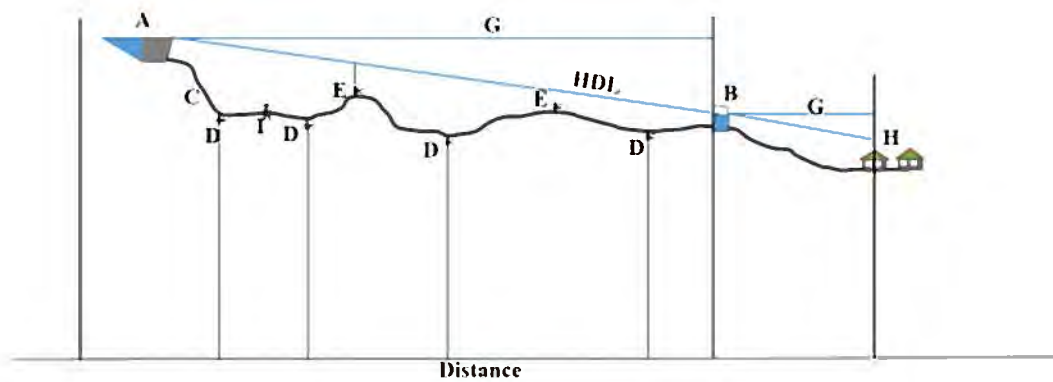
c. Is calculation for future water demand by the service population made or not?

yes,  no

### 5. Pipeline design

a. Are pipe accessories such as gate valves, air valves, wash-outs properly designed?

- yes,  no



- A = Intake structure
- B = Storage reservoir
- C = Pipeline
- D = Blow-off valve
- E = Air valve
- HDL = Hydraulic grade line
- G = Static head
- H = Rural town or Village
- I = Sectioning valve (every 1.5 km)

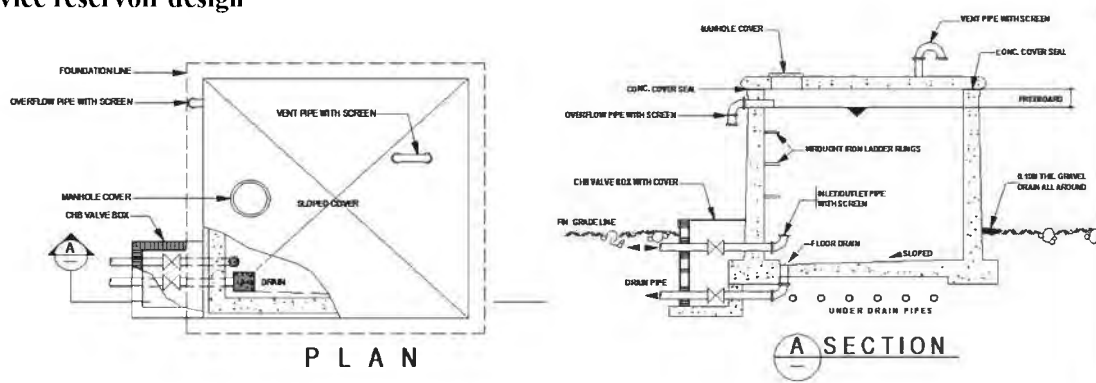
b. Are drawings of pipe-laying attached?

- yes,  no

c. Are hydraulic grade (water heads) calculated? (example: calculated by EPANET)

- yes,  no

### 6. Service reservoir design



a. Is the capacity of reservoir sufficient? \_\_\_\_\_ m<sup>3</sup>

$$Cr = (1/4) (ADD)$$

where:

Cr = Reservoir capacity in liters

ADD = Average day demand in liters per day

b. Is the reservoir equipped with

- inlet valves,  outlet valves,  drain pipes,  overflow pipes,
- air ventilator.

c. Is concrete structure with reinforcement bars normally designed:

- yes,  no

### 7. Public taps

a. Number of faucets equipped at a public stand: \_\_\_\_\_ faucets

b. Number of households to be served by a public stand: \_\_\_\_\_ households

c. Are concrete apron properly designed:

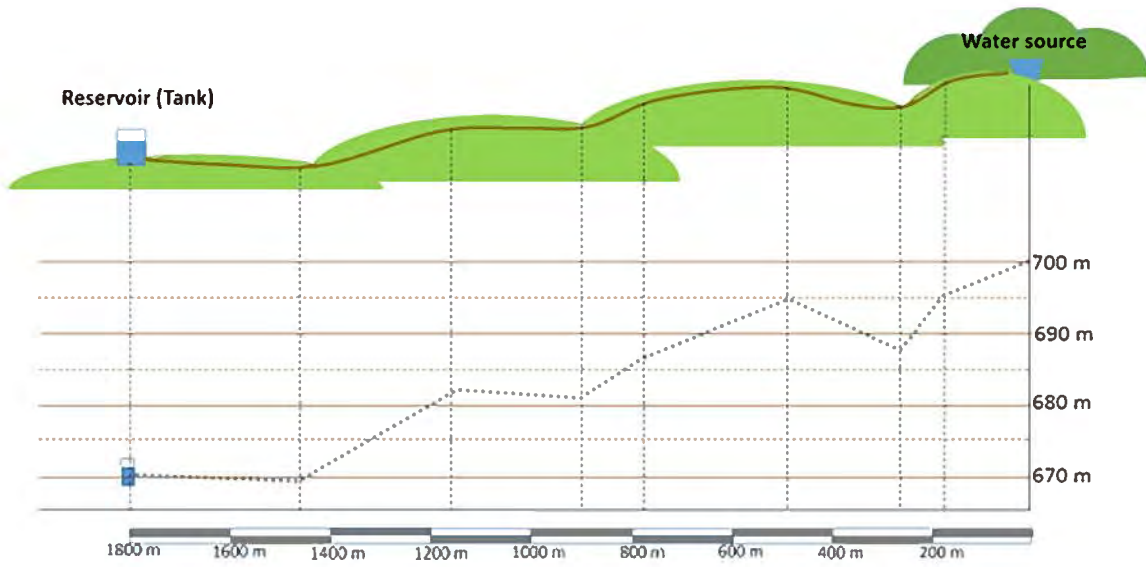
- yes,  no

d. Are drain pipes equipped at the concrete apron:

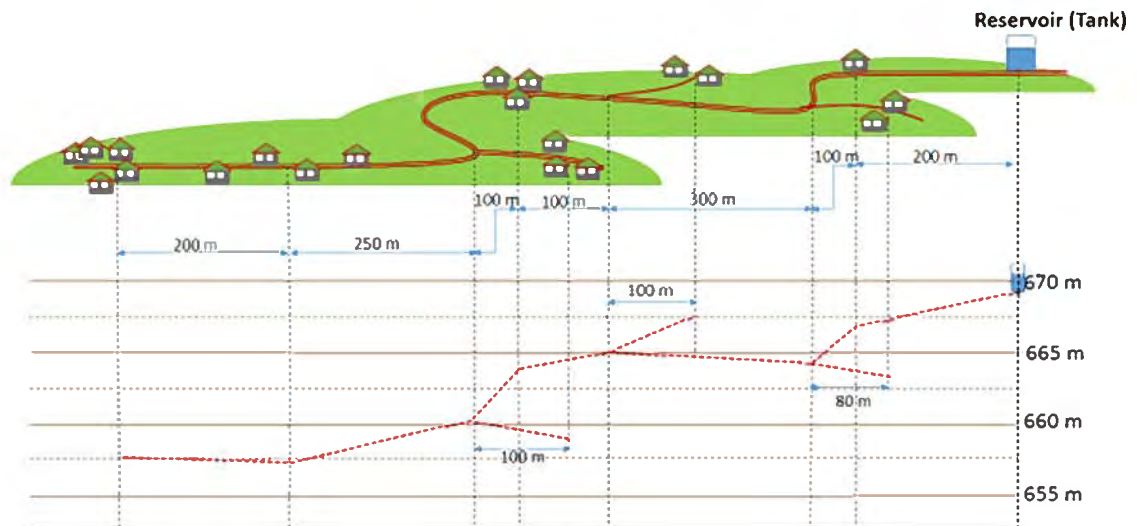
- yes,  no

## Hydraulic calculation

### 1. Transmission pipe



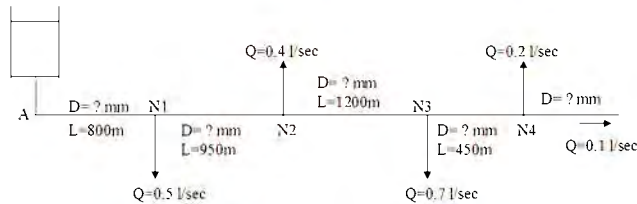
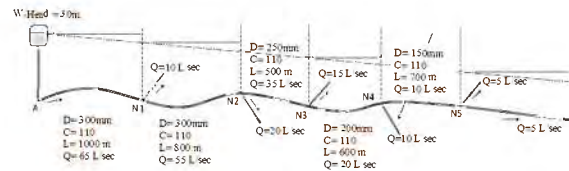
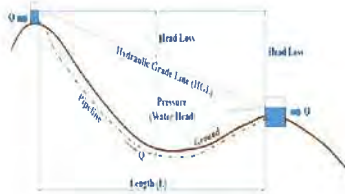
### 2. Distribution Pipes



## **ANNEX-11**

### **PIPECAL ON WATER SUPPLY**

## How to use PIPECAL



### Hazen-Williams Formula

- Darcy-Weisbach formula
- **Hazen-Williams formula**
- Mannings formula
- Combined Darcy-Weisback and Colebrook-White equation.

$$Q = 0.25783C \cdot (D/1000)^{2.63} \cdot (h/L)^{0.54} \cdot 1000$$

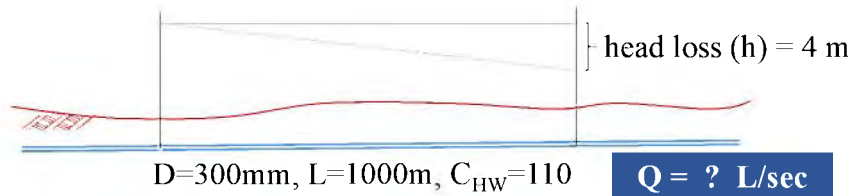
$$D = 1.6258C^{-0.38} \cdot (Q/1000)^{0.38} \cdot (h/L)^{-0.205} \cdot 1000$$

$$h = 10.666C^{-1.85} \cdot (D/1000)^{-4.87} \cdot (Q/1000)^{1.85} \cdot L$$

$$C = (Q/1000) / (D/1000)^{2.63} / (h/L)^{0.54} / 0.27853$$

- h: Head Loss (m)  
 C: Flow (Roughness) coefficient  
 D: Pipe diameter (mm)  
 Q: Flow rate (l/s)  
 L: Pipe Length (m)

**1. To Calculate the flow rate (Q)**



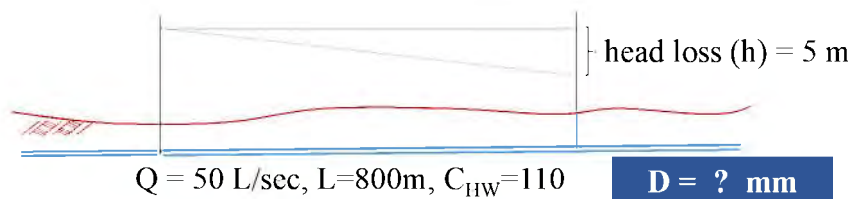
$$Q = 0.25783C \cdot (D/1000)^{2.63} \cdot (h/L)^{0.54} \cdot 1000$$

D(mm)= ?	h(m)= ?	L(m)= ?	C= ?	Q (l/sec)
300	4	1000	110	

Input

Output

**2. To calculate pipe-diameter (D)**



$$D = 1.6258C^{-0.38} \cdot (Q/1000)^{0.38} \cdot (h/L)^{-0.205} \cdot 1000$$

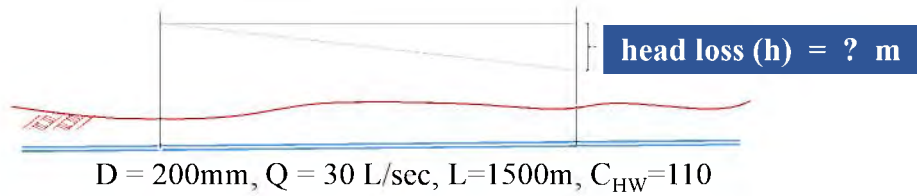
Q(l/sec)=?	h(m)= ?	L(m)= ?	C= ?	D (mm)
50	5	800	110	

Input

Output



**3. To calculate the head-loss (h)**



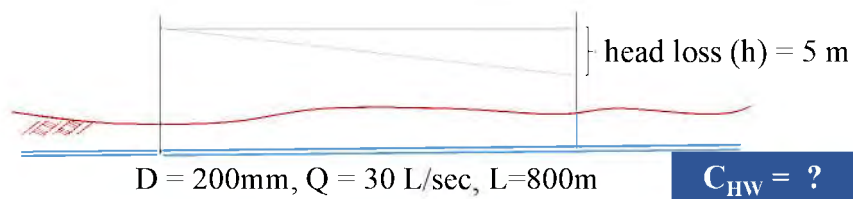
$$h = 10.666C^{-1.85} \cdot (D/1000)^{-4.87} \cdot (Q/1000)^{1.85} \cdot L$$

Q(l/sec)=?	D(mm)= ?	L(m)= ?	C= ?	h (m)
30	200	1500	110	

Input

Output

**4. To calculate the flow coefficient**



$$C = (Q/1000) / (D/1000)^{2.63} / (h/L)^{0.54} / 0.27853$$

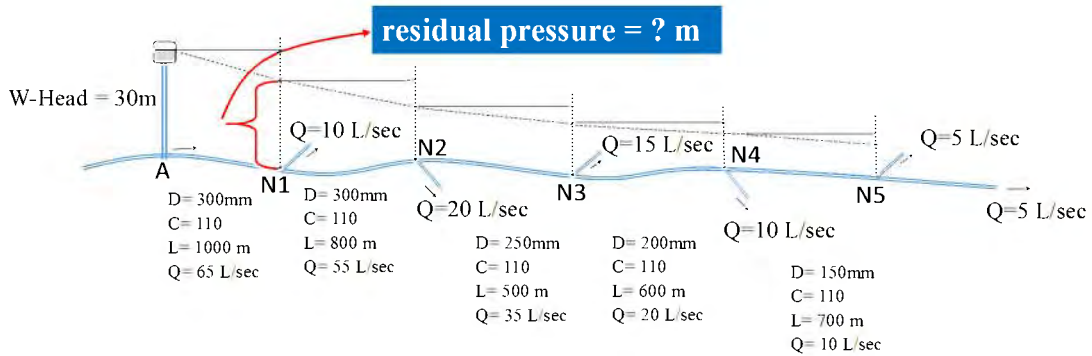
Q(l/sec)=?	D(mm)= ?	h(m)= ?	L(m)= ?	C
30	200	5	800	

Input

Output

### 5. Hydraulics of a pipeline with branches

5-1. To calculate the residual pressure at each node of a pipeline



Node	GL(m)	Qout	W-Head	Pipeline	D(mm)	L(m)	C	Qflow	loss (m)
A	GLA= 10	-	30.00		-	-	-	-	-
Node- 1	GL1= 10	10	WH1	A - N1	300	1000	110	65	h1
Node- 2	GL2= 12	20	WH2	N1 - N2	300	800	110	55	h2
Node- 3	GL3= 8	15	WH3	N2 - N3	250	500	110	35	h3
Node- 4	GL4= 7	10	WH4	N3 - N4	200	600	110	20	h4
Node- 5	GL5= 5	5	WH5	N4 - N5	150	700	110	10	h5
To Down	-	5	-	N5 -	100	-	-	5	-

Step -2: To calculate

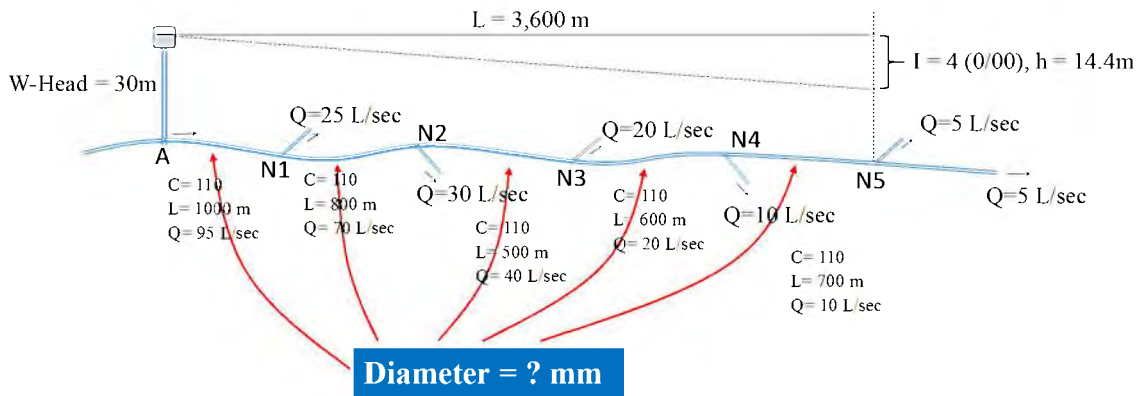
$$WH1 = GLA + WHA - GL1 - h1$$

$$WH2 = GL1 + WH1 - GL2 - h2$$

$$WH3 = GL2 + WH2 - GL3 - h3$$

Step -1: To calculate using PIPECAL

5-2. To calculate the efficient diameter of each section



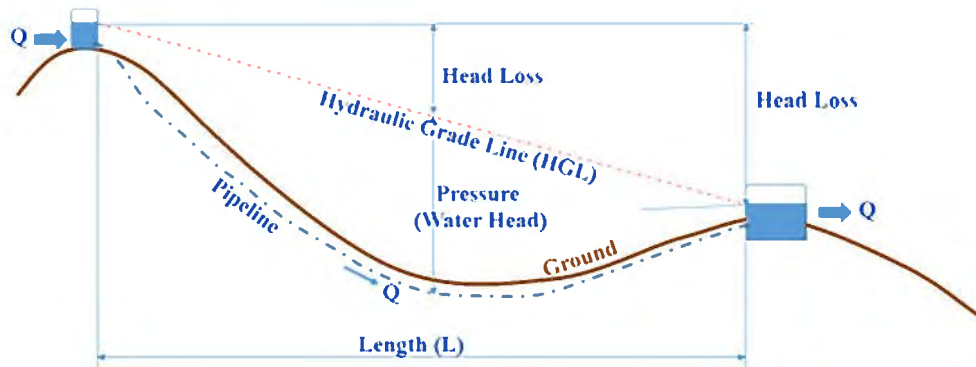
Node	GL(m)	Qout	W-Head	Pipeline	D(mm)	L(m)	C	Qflow	I(0/00)	loss (m)
A	10	-	30.00		-	-	-	-	-	-
Node- 1	10	25	26.0	A - N1		1000	110	95	4	4.0
Node- 2	12	30	20.8	N1 - N2		800	110	70	4	3.2
Node- 3	8	20	22.8	N2 - N3		500	110	40	4	2.0
Node- 4	7	10	21.4	N3 - N4		600	110	20	4	2.4
Node- 5	5	5	20.6	N4 - N5		700	110	10	4	2.8
To Down	-	5	-	N5		-	-	5	-	-

To calculate

## Basic Hydraulics for Water Supply Engineers

The flow in a water main has some relation with roughness of pipe inside (friction). As a result of the friction loss, the difference of water heads between at an upper-point and at the lower point occurs.

Several formulas are used to calculate the flow in a water main by applying a roughness or friction coefficient as a factor.



### 1. Hydraulic Formulas

There are several formulas on pressured pipeline hydraulics, which express the relation between flow rate and head loss. They are shown below. A well-known formula is Hazen-Williams Formula.

#### a. Hazen-Williams Formula

$$Q = 0.25783C \cdot (D/1000)^{2.63} \cdot (h/L)^{0.54} \cdot 1000$$

$$D = 1.6258C^{-0.38} \cdot (Q/1000)^{0.38} \cdot (h/L)^{-0.205} \cdot 1000$$

$$h = 10.666C^{-1.85} \cdot (D/1000)^{-4.87} \cdot (Q/1000)^{1.85} \cdot L$$

$$C = 3.9503(Q/1000) \cdot (D/1000)^{-2.63} \cdot (h/L)^{-0.54}$$

#### b. Takakuwa Formula

$$Q = C \cdot (D/1000)^{2.495} \cdot (h/L)^{0.512} \cdot 1000$$

$$D = C^{-0.401} \cdot (Q/1000)^{0.401} \cdot (h/L)^{-0.205} \cdot 1000$$

$$h = C^{-1.952} \cdot (D/1000)^{-4.87} \cdot (Q/1000)^{1.952} \cdot L$$

$$C = (Q/1000) \cdot (D/1000)^{-2.495} \cdot (h/L)^{-0.512}$$

#### c. Manning Formula

$$Q = 0.31168C \cdot (D/1000)^{2.667} \cdot (h/L)^{0.5} \cdot 1000$$

$$D = 1.566C^{-0.375} \cdot (Q/1000)^{0.375} \cdot (h/L)^{-0.1875} \cdot 1000$$

$$h = 10.294C^{-2} \cdot (D/1000)^{-5.33333} \cdot (Q/1000)^2 \cdot L$$

$$C = 3.2084(Q/1000) \cdot (D/1000)^{-2.6667} \cdot (h/L)^{-0.5}$$

The comparison of flow-coefficient between Hazen-Williams Formula, Takakuwa Formula and Manning Formula: at D=250mm, Q=40 L/sec

Hazen-Williams	80	90	100	110	120	130	140
Takakuwa	19.5	21.8	24.1	26.4	28.6	30.9	33.1
Manning	60.6	67.5	74.4	81.3	88.1	94.9	101.6

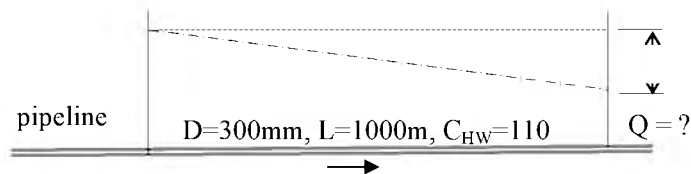
## 2. Calculation of Using MS-Excel (Spreadsheet Software)

Calculations of pipeline hydraulics can be done easily by using a spreadsheet software such as MS-Excel. Followings are examples of pipeline calculation. In these examples Hazen-Williams Formula are used.

### 2-1. Calculation of a simple pipeline hydraulics (using Sheet 'Simple-Pipeline' of Excel file "PIPE-CAL.xlsx")

(1) To Calculate the flow rate (using Formula-1 of Sheet 'Simple-Pipeline')

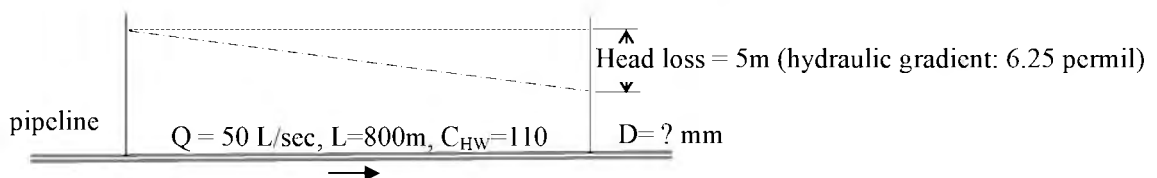
This is an example how to get the flow rate (Q) when pipe diameter (D), pipe length (L), head loss (h) and flow coefficient ( $C_{HW}$ ) are given.



$$\begin{aligned}
 Q &= 0.25783 C_{HW} \cdot (D/1000)^{2.63} \cdot (h/L)^{0.54} \cdot 1000 \\
 &= 0.25783 \times 110 \times (0.3)^{2.63} \times (0.004)^{0.54} \times 1000 \\
 &= 65.5 \text{ L/sec}
 \end{aligned}$$

(2) To calculate the pipe-diameter (using Formula-2 of Sheet 'Simple-Pipeline')

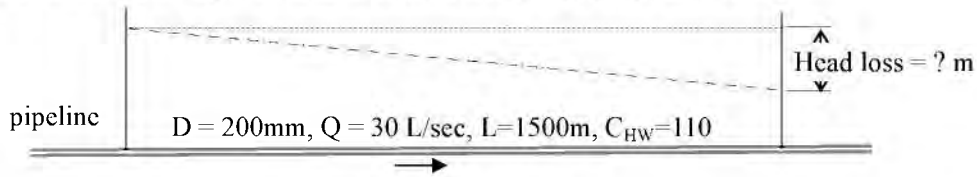
This is an example how to get the pipe-diameter (D) when Q, L, h,  $C_{HW}$  are given.



$$\begin{aligned}
 D &= 1.6258 C_{HW}^{-0.38} \cdot (Q/1000)^{0.38} \cdot (h/L)^{-0.205} \cdot 1000 \\
 &= 1.6258 \times (110)^{-0.38} \times (0.05)^{0.38} \times (0.00625)^{-0.205} \times 1000 \\
 &= 247 \text{ mm} \quad (\Rightarrow 250 \text{ mm})
 \end{aligned}$$

(3) To calculate the head-loss (using Formula-3 of Sheet 'Simple-Pipeline' )

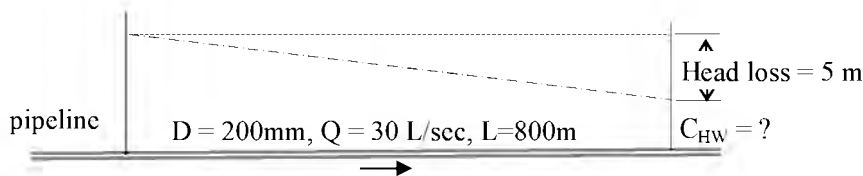
This is an example how to get the head-loss (h) when Q, D, L, C<sub>HW</sub> are given.



$$\begin{aligned}
 h &= 10.666C_{HW}^{-1.85} \cdot (D/1000)^{-4.87} \cdot (Q/1000)^{1.85} \cdot L \\
 &= 10.666 \times (110)^{-1.85} \times (0.2)^{-4.87} \times (0.030)^{1.85} \times 1500 \\
 &= 10.33 \text{ m}
 \end{aligned}$$

(4) To calculate the flow coefficient (using Formula-4 of Sheet 'Simple-Pipeline' )

This is an example how to get the flow coefficient (C<sub>HW</sub>) when Q, D, L, h are given.

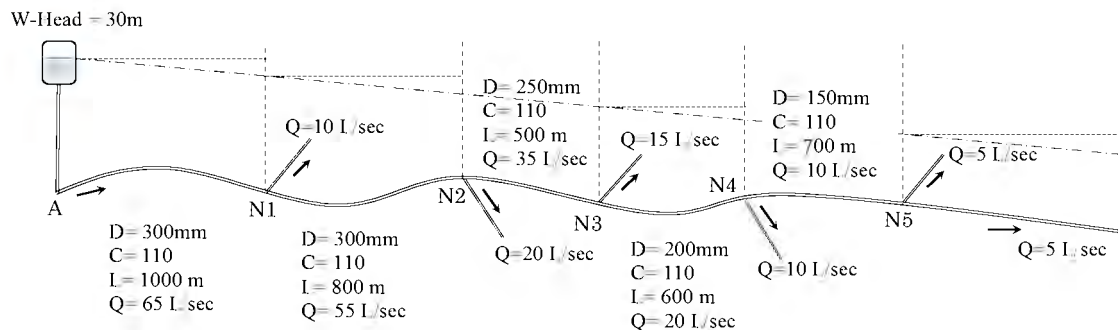


$$\begin{aligned}
 C &= 3.9503(Q/1000) \cdot (D/1000)^{-2.63} \cdot (h/L)^{0.54} \\
 &= 3.9503 \times (0.03) \times (0.2)^{-2.63} \times (5/800)^{0.54} \\
 &= 115
 \end{aligned}$$

## 2-2. Hydraulics of a pipeline with branches (using Sheet 'with Branch' of Excel file "PIPECAL.xls")

(1) To calculate the residual pressure at each node of a pipeline with several branches (using case-1 of Sheet 'with Branch').

This is an example how to get the head loss (h) between each two nodes and the water head (w-H) at each node when water head at the base (A in here), GL of nodes, water amount discharged from the nodes (consumption), pipe diameters (D), pipe lengths (L), and flow coefficients (C<sub>HW</sub>) are given.

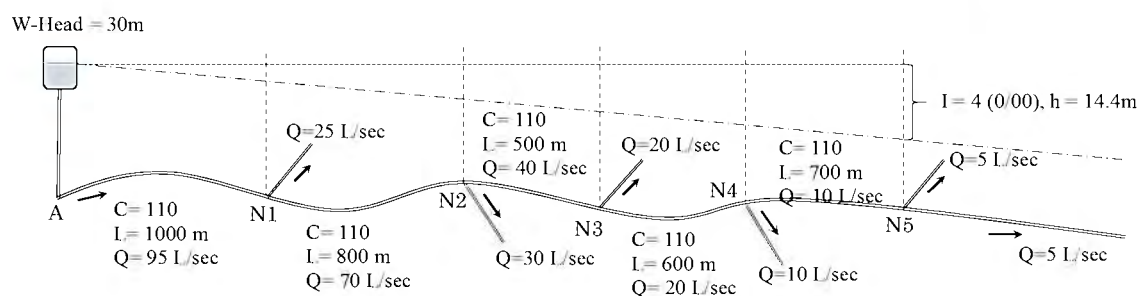


Put the given data into the table of case-1 of Sheet 'with Branch'. You will get the answer at column 'W-head' and column 'loss(m)' of the same table.

Node	GI (m)	Qout	W-Head	Pipeline	D(mm)	L(m)	C	Qflow	loss (m)
A	10	-	30.00		-	-	-	-	-
Node- 1	10	10	<b>26.00</b>	A - N1	300	1000	110	65	<b>4.00</b>
Node- 2	12	20	<b>21.65</b>	N1 - N2	300	800	110	55	<b>2.35</b>
Node- 3	8	15	<b>24.10</b>	N2 - N3	250	500	110	35	<b>1.55</b>
Node- 4	7	10	<b>23.15</b>	N3 - N4	200	600	110	20	<b>1.95</b>
Node- 5	5	5	<b>22.59</b>	N4 - N5	150	700	110	10	<b>2.56</b>
To Down	-	5	-	N5 -	100	-	-	5	-

(2) To calculate the efficient diameter of each section of a pipeline with several branches (using case-2 of Sheet 'with Branch').

This is an example how to decide the pipe diameters (D) of each section when water head at the base (A in here), GL of nodes, water amount discharged from the nodes (consumption), pipe lengths (L), and flow coefficients ( $C_{HW}$ ) are given. You have to assume the reasonable pipeline hydrau-gradient ( $h/L$ ).



Put the given data into the table of case-2 of Sheet 'with Branch'. you will get the answer at column 'D(mm)' of the same table.

Node	GI (m)	Qout	W-Head	Pipeline	D(mm)	L (m)	C	Qflow	I(0/00)	loss (m)
A	10	-	30.00		-	-	-	-	-	-
Node- 1	10	25	26.0	A - N1	<b>345.5</b>	1000	110	95	4	4.0
Node- 2	12	30	20.8	N1 - N2	<b>307.6</b>	800	110	70	4	3.2
Node- 3	8	20	22.8	N2 - N3	<b>248.7</b>	500	110	40	4	2.0
Node- 4	7	10	21.4	N3 - N4	<b>191.1</b>	600	110	20	4	2.4
Node- 5	5	5	20.6	N4 - N5	<b>146.9</b>	700	110	10	4	2.8
To Down	-	5	-	N5 -	-	-	-	5		-

## **ANNEX-12**

### **EPANET ON WATER SUPPLY**



### at the beginning “Why EPANET, but not EPANET”

1. EPANET is a worldwide used free software introduced in:

“**RURAL WATER SUPPLY DESIGN MANUAL**” published by World Bank Manila Office

“Among the current software available in the internet and from proprietary sources, the EPANET is highly recommended. EPANET is public domain software developed by the US Environmental Protection Agency that can be downloaded free on the internet.”

“**Handbook for Community-Based Water Supply Organizations**” published by Ministry of Public Works, Indonesia

“There are now available computer supported design systems, such as ‘**EPANET**,’ a public domain software developed by the US Environmental Protection Authority, to help hydraulic analysis and modeling.”

2. Hydraulics of pipeline is one of core components in a small water supply system.

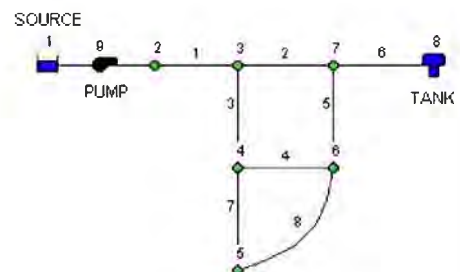
- ◆ Water source (intake) facilities
- ◆ Transmission and Distribution pipelines
- ◆ Storage tank (Reservoir)
- ◆ Public tap

But pipelines must be designed one by one, there is not a reference drawings to be quoted from the other projects.

3. **But**, EPANET is not the best tool in all cases. Excel (PIPECAL) is sometimes better than EPANET. Case by case.

## How to use EPANET

1. What is EPANET
2. Installing EPANET
3. Steps for EPANET Analysis
4. Practice



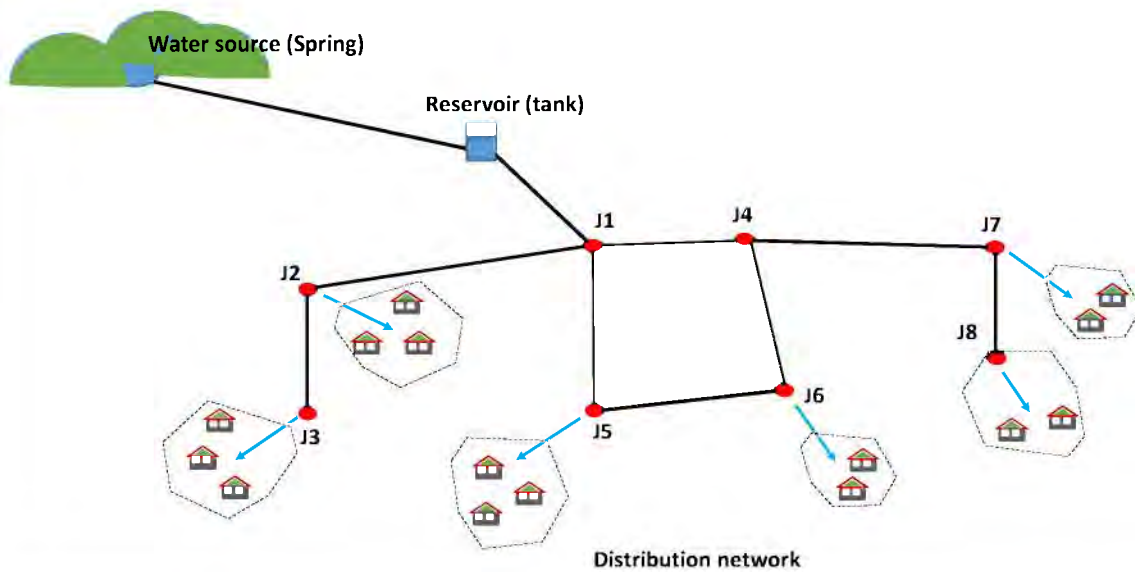
# What is EPANET

Provided by the U.S. Environmental Protection Agency (EPA)

EPANET: A computer program for simulation of  
(1) Hydraulic  
(2) Water quality behavior  
within pressurized pipe networks

Network: pipes, nodes (pipe junctions), pumps,  
valves, storage tanks, reservoirs

## Layout of Water Supply System



## Steps for EPANET Analysis

One typically carries out the following steps when using EPANET to model a water distribution system:

1. Open EPANET 2.0 Program
2. Set-Up a New Projects
3. Create the Project Scenario
4. Analyze the Network
5. View Results of Analysis

### 1. Open EPANET 2.0 Program

- To Run EPANET program, simply select this item off of the Start Menu
- Select EPANET 2.0 from the submenu
- Click to Run:

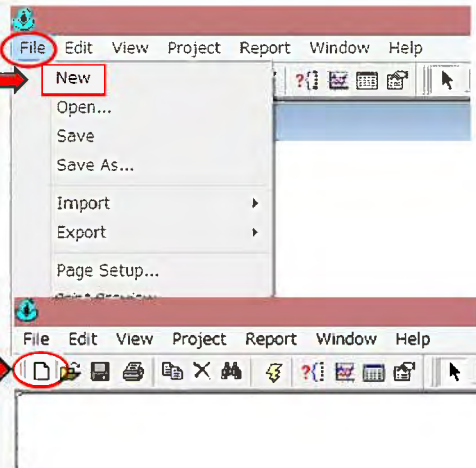


## 2. Set up a New Project

- a. Create a New Project
- b. Set Project Preferences
- c. Set Project Defaults
- d. Set Map Options

### a. Create a New Project

- From Main Toolbars select: **File >> New**
- A new, unnamed project is created with all options set to default values



- Or, click **New Project** from Standard Toolbars
- Prompted to save the existing project before the new project is created

### b. Set Project Preferences: File>>Preferences

- From Main Toolbars
- select: File >> Preferences

- Formats Preferences

### b. Set Project Preferences: File>>Preferences

- General Preferences

- Lastly, Press Select below Temporary Directory
- Browse for the c:\temp directory and press **OK** to accept the default directory

### c. Set Project Defaults: Project>>Defaults

▪ From General Toolbar select: Project >> Defaults

▪ ID Labels Defaults

Object	ID Prefix
Junctions	J
Reservoirs	R
Tanks	T
Pipes	P
Pumps	
Valves	
Patterns	
Curves	
ID Increment	1

Save as defaults for all new projects

OK Cancel Help

### c. Set Project Defaults: Project>>Defaults

▪ Properties Defaults

- Make sure Auto Length is off
- For Pipe Diameter = 50
- For Pipe Roughness = 120

▪ Hydraulics Defaults

- Select appropriate flow units >> LPS
- Select headloss formula >> H-W

Property Default Value

Node Elevation	0
Tank Diameter	50
Tank Height	20
Pipe Length	100
Auto Length	Off
Pipe Diameter	50
Pipe Roughness	120

Save as defaults for all new projects

OK Cancel Help

Option Default Value

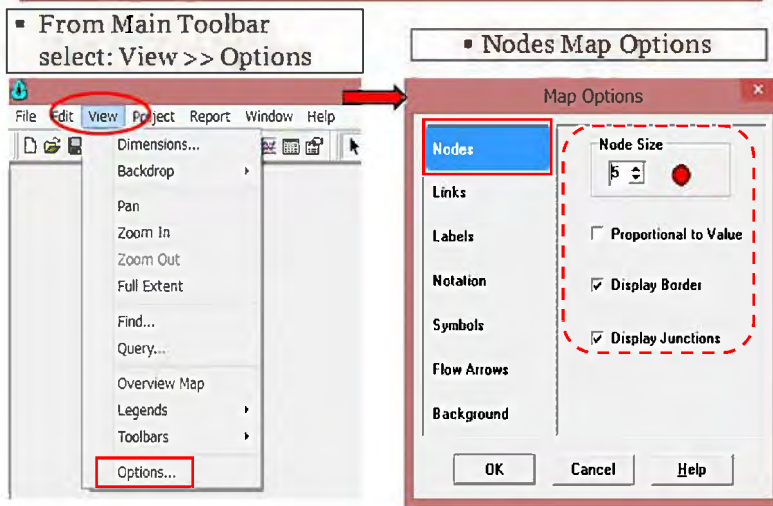
Flow Units	LPS
Headloss Formula	H,W
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	1.0

Save as defaults for all new projects

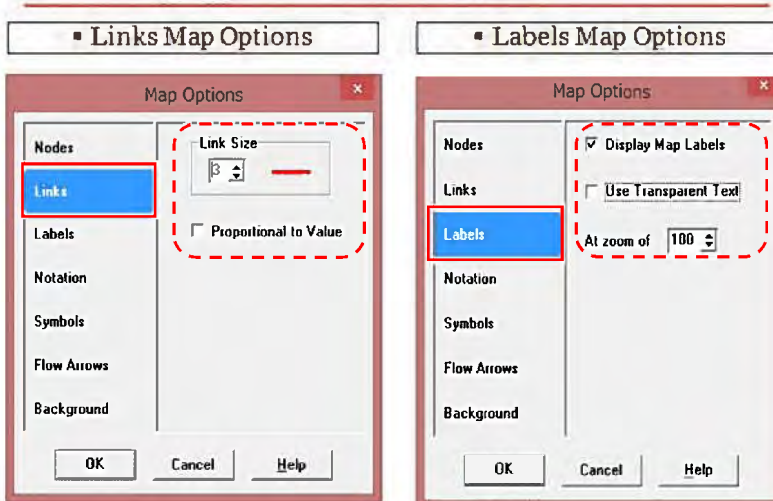
OK Cancel Help



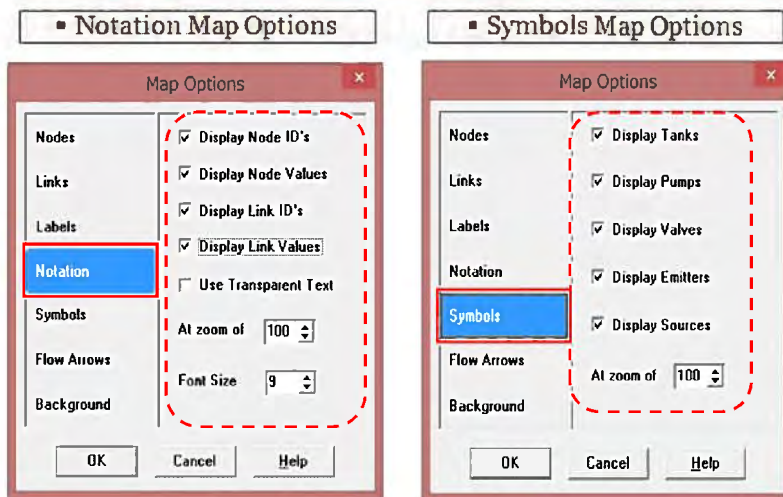
### c. Set Map Options: View>>Options



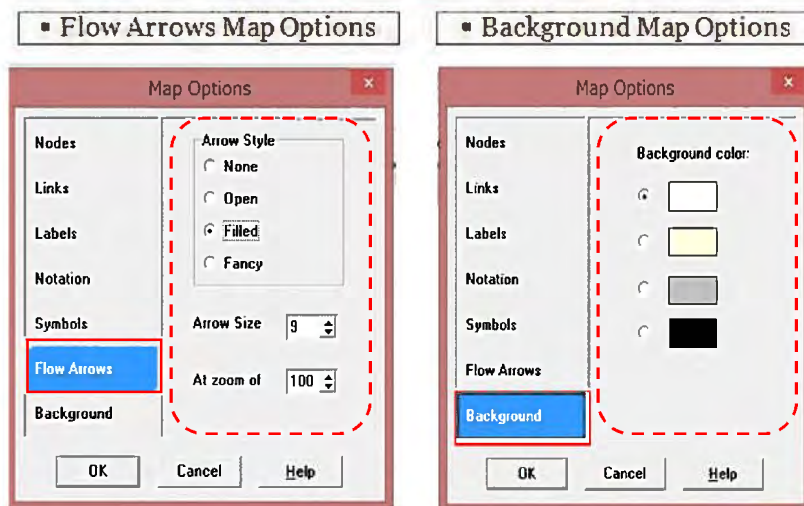
### c. Set Map Options: View>>Options



**c. Set Map Options: View>>Options**



**c. Set Map Options: View>>Options**




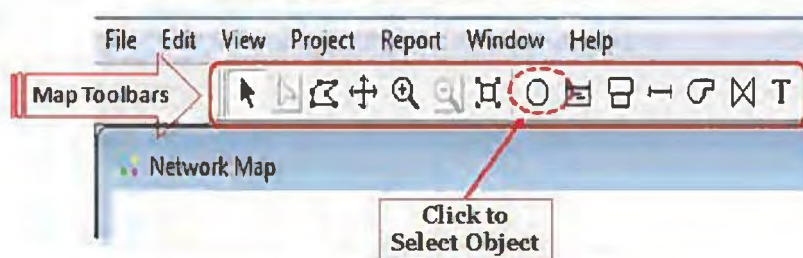


### 3. Create the Project Scenario

- a. Draw the Network
  - Nodes (including reservoirs, tanks)
  - Pipes connecting nodes
  - Pumps
  - Control Valves
- b. Specify Network Properties
  - Nodes {demands, elevations}
  - Pipe properties {L, D, C}
  - Pump Curves {H vs. Q}
- c. Run a Simulation
  - Single period (snapshot) Analysis
- d. Saving and Opening a Project
  - Save As a Project
  - Open a Project

#### a. Draw the network


- We are now ready to begin drawing our network by making use of Buttons contained on the Map Toolbar shown below.
  - Use Object Selection Button 

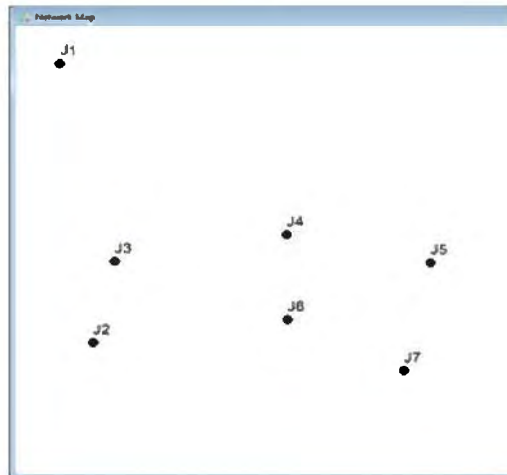


- If the Map Toolbars are not visible then select:  
**View >> Toolbars >> Map**

## a. Draw the network


### ▪ Adding Junctions

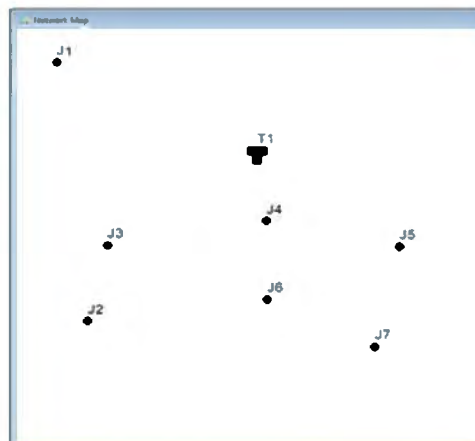
- First, we will add the junction nodes.
- Click the **Junction button**  and then click on the map at the locations of nodes 1 through 7,
- ALWAYS start a project by putting at least two (2) junctions on the map. You can add all junctions at this time, or add additional junctions later.



## a. Draw the network


### ▪ Adding Tank

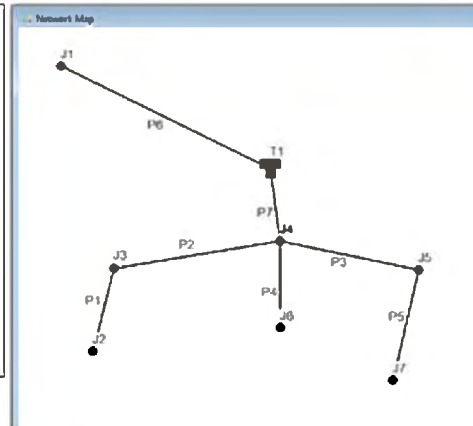
- Finally, add the tank by clicking the **Tank button**  and clicking the map where the tank is located,
- At this point the Network Map should look something like the drawing in attached figure.



## a. Draw the network


### ▪ Adding Links

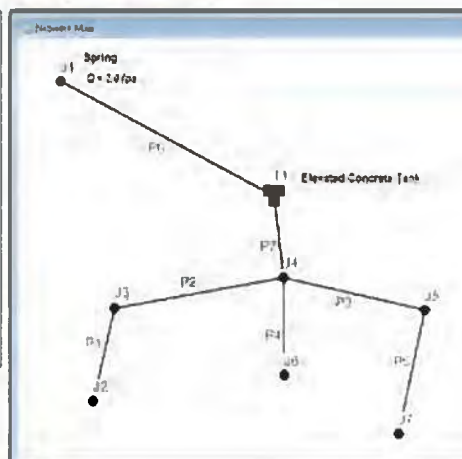
- Next we will add the pipes. Let's begin with Pipe 1 connecting J2 to J3
- First click the Pipe button  on the Map Toolbar
- Then click the mouse on J2 on the map and then on J3
- Repeat this procedure for Pipes P2 through P7



## a. Draw the network

### ▪ Adding Labels

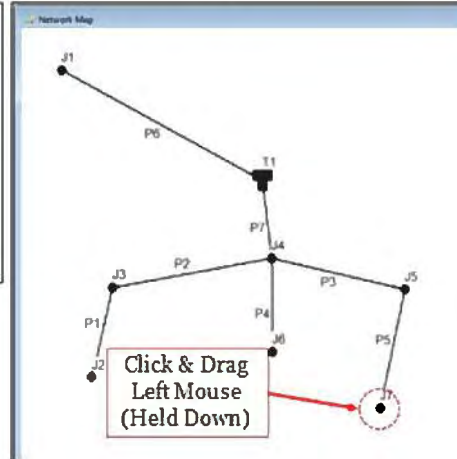
- Next we will label the spring and tank
- Select the Text button  on the Map Toolbar and click somewhere close to the spring (Node J1)
- An edit box will appear. Type in the word "Spring" and then hit the Enter key.
- Click next to the Tank and enter its label.




## a. Draw the network

### ▪ Moving an Object

- If the Nodes are out of position you can move them around by clicking the node to select it
- Drag it with the left mouse button held down to its new position
- Labels can be repositioned in similar procedure



## b. Specify Network Properties

- Editing an Object is Adding Information to:
  - Links
  - Nodes
- To select an object on the map using the Select Object button:
  - Click the Select Object button  (Arrow) on the Map Toolbar
  - Double-Click the mouse over the desired object on the map
- To select an object using the Browser:
  - Select the type of object from the Object listbox of the Database Browser
  - Select the desired object from the Item listbox

## b. Specify Network Properties

### Editing Junction Properties:

- The nodes in our example network are assumed to have the following properties:



Network Table - Nodes

Node ID	HHs	Pop1	PF	NRW (%)	Water Demand (lps)		Elevation
					ADD	MDD	m
Junc J1	Spring Source				-2.50		40
Junc J2	14	77	3	30%	0.076	0.099	10
Junc J3	35	193	7	30%	0.191	0.248	11
Junc J4	53	292	11	30%	0.290	0.377	13
Junc J5	67	369	13	30%	0.366	0.476	14
Junc J6	32	176	6	30%	0.175	0.228	12
Junc J7	35	193	7	30%	0.191	0.248	13
Tank1							
<b>Total</b>	<b>236</b>	<b>1300</b>	<b>47</b>		<b>1.289</b>	<b>1.676</b>	

## b. Specify Network Properties

The screenshot shows the EPANET interface. On the left, a network map has a junction node circled in red with a callout box that says 'Double-click to Edit'. An arrow labeled 'Input Data' points from the map to the 'Junction Property Editor' window in the center. This window displays a table of properties for 'Junction J3', with 'Elevation' and 'Base Demand' highlighted by a red dashed box. To the right, the 'Data Browser' window is open, showing a list of nodes with a callout box 'Double-click to Edit' pointing to a node in the list and another callout box 'Click to Edit' pointing to a specific property in the table.

## b. Specify Network Properties

### ▪ Editing Tank Property:

- The Tank in our example network is assumed to have the following properties:

**Tank Node Data :** **T1**

Tank Bottom Elev. :	<b>18.00</b>
Initial Level :	<b>3.50</b>
Minimum Level :	<b>0.10</b>
Maximum Level :	<b>3.60</b>
Diameter :	<b>4.20</b>

*Input Data* →

## b. Specify Network Properties

The screenshot shows the EPANET interface with the Tank Property Editor dialog box open for Tank T1. The dialog box lists various properties such as Tank ID, X-Coordinate, Y-Coordinate, Description, Elevation, Initial Level, Minimum Level, Maximum Level, Diameter, Minimum Volume, Volume Curve, Massy Model, Reaction Coeff., Initial Quality, Source Quality, and Net Inflow. The 'Elevation' property is highlighted with a red dashed box. A red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. Another red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A third red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A fourth red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A fifth red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A sixth red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A seventh red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A eighth red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A ninth red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A tenth red arrow points from the 'Elevation' property in the dialog box to the 'Elevation' property in the 'Data Browser' on the right. A 'Double-click to Edit' callout points to the tank node in the network diagram. A 'Click to Edit' callout points to the tank node in the network diagram. An 'Input Data' callout points to the tank node in the network diagram.

## b. Specify Network Properties

### ▪ Editing Pipe Properties:

- The Pipes in our example network are assumed to have the following properties:



Length    Diameter    Roughness

Network Table - Links

Link ID	Node Number		Length m	Diameter mm	"C"
	From	To			
Pipe P1	J2	J3	200	50	120
Pipe P2	J3	J4	300	75	120
Pipe P3	J4	J5	250	75	120
Pipe P4	J4	J6	200	75	120
Pipe P5	J5	J7	250	50	120
Pipe P6	J1	T1	3000	100	120
Pipe P7	T1	J4	30	100	120


## b. Specify Network Properties

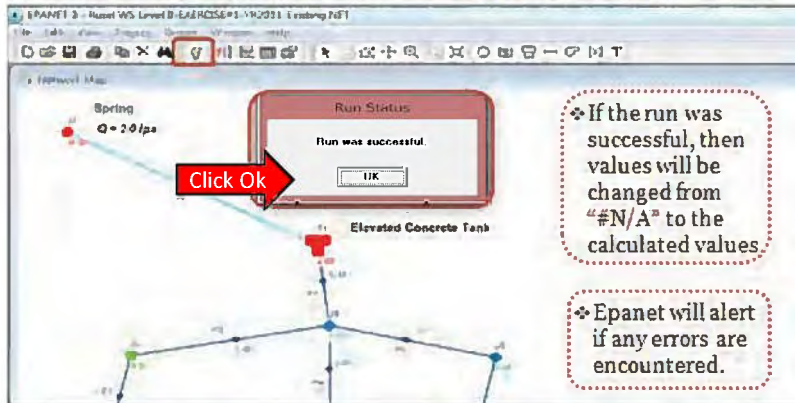
The screenshot shows the EPANET interface. On the left, a network diagram has a pipe highlighted with a red circle and a callout box that says "Double-click to Edit". In the center, the "Pipe Property Editor" window is open for "Pipe P4". It lists various properties: Pipe ID (P4), Start Node (J4), End Node (J3), Description, Tag, Length (200), Diameter (50), Roughness (120), Loss Coeff. (0), Initial Status (Open), Bulk Coeff., Wall Coeff., Flow (N/A), Velocity (N/A), Wet Headloss (N/A), Friction Factor (N/A), Reaction Rate (N/A), and Quality (N/A). A red dashed box highlights the Length, Diameter, and Roughness fields. An "Input Data" arrow points from the table above to these fields. On the right, the "Data Browser" window shows a list of pipes (P1-P7) with a red circle around Pipe P4 and a callout box that says "Click to Edit". Another callout box above it says "Double-click to Edit" pointing to the pipe list.



### c. Run a Simulation

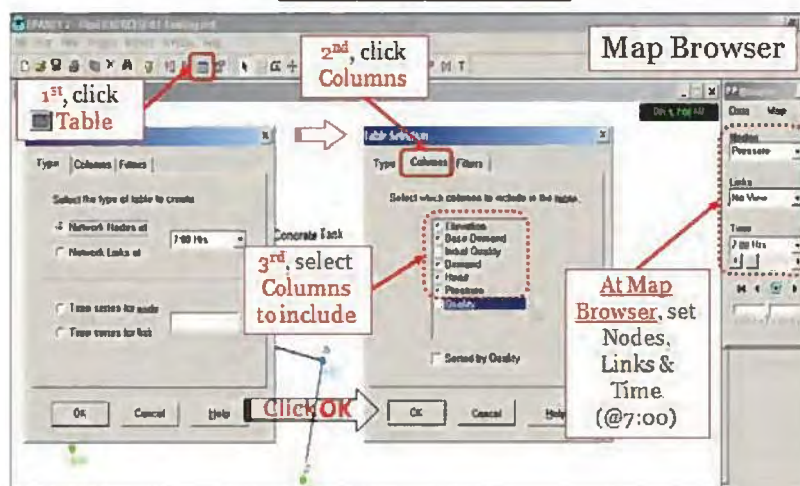
- Run a Single period (steady-state) Analysis

- You now have enough information to run a Single Period (or steady-state) hydraulic analysis
- To run the analysis select Project >> Run Analysis (or click the  button)



### c. View Results

- View Results - Tables



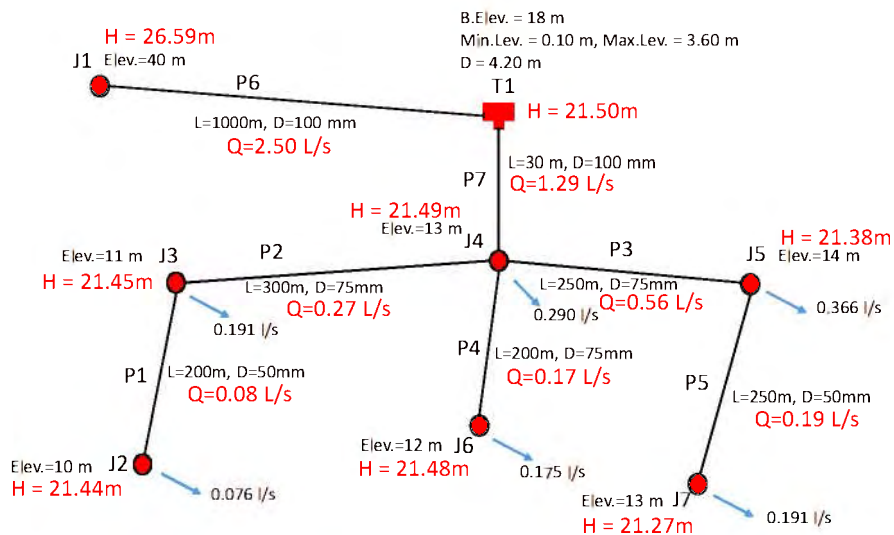


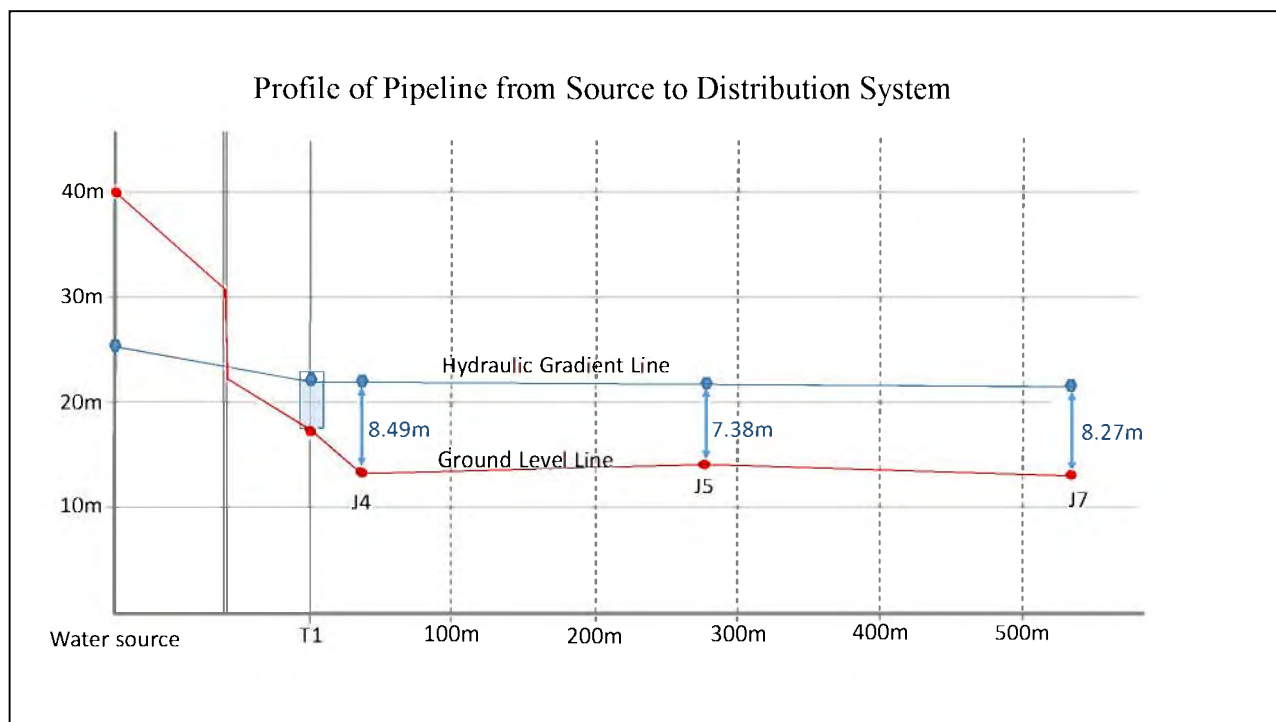
### c. View Results: Tables

- EPANET allows you to view selected project data and analysis results in a tabular format
- Tables can be printed, copied to the Windows clipboard, or saved as a data file or Windows metafile
- Network Link sign on flow (+/-) is relative to the way the pipe (link) was initially drawn on the network map

Node ID	Elevation m	Base Demand	Demand LPS	Head m	Pressure m
Junc J2	10	0.071	0.14	19.90	9.90
Junc J3	11	0.179	0.36	19.95	8.95
Junc J4	13	0.270	0.54	20.71	7.71
Junc J5	14	0.342	0.68	20.37	6.37
Junc J1	40	-2.00	-2.00	34.42	-5.58
Junc J7	13	0.179	0.36	20.03	7.03
Junc J6	12	0.163	0.33	20.40	8.40
Tank T1	18	N/A	-0.41	20.76	2.76

### Results of Calculation



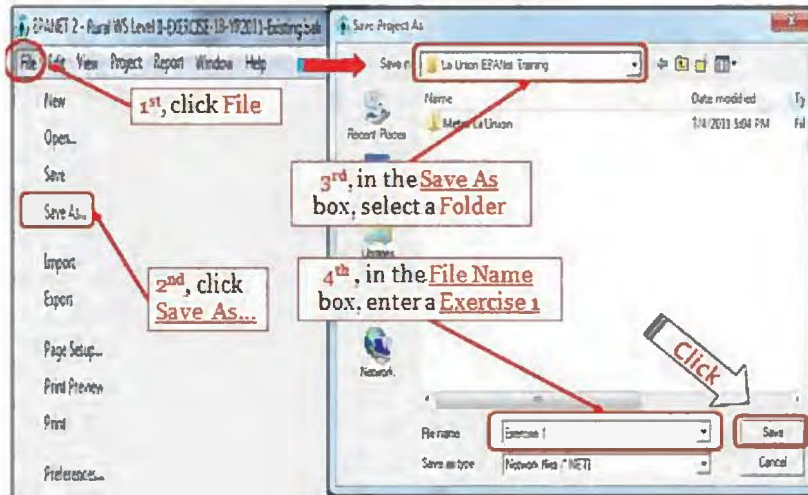


#### d. Saving & Opening Project

- 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 **Exercise 1**. (An extension of **“.net”** will be added to the file name if one is not supplied)
  3. Click **Save** 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.

### d. Saving & Opening Project

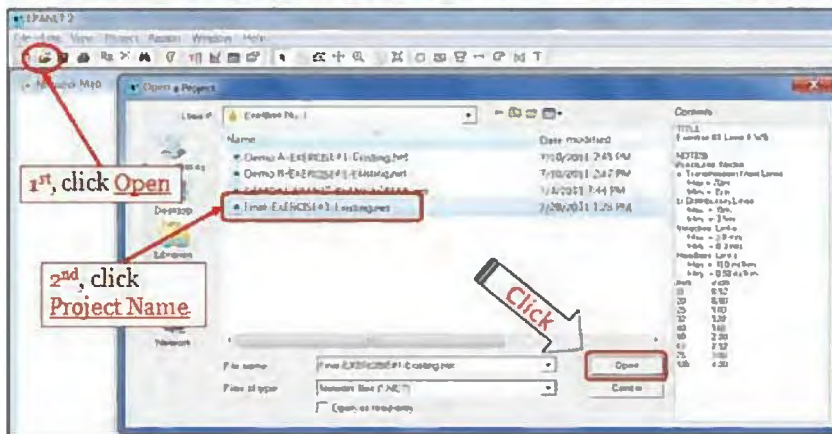
#### ▪ Saving As a Project

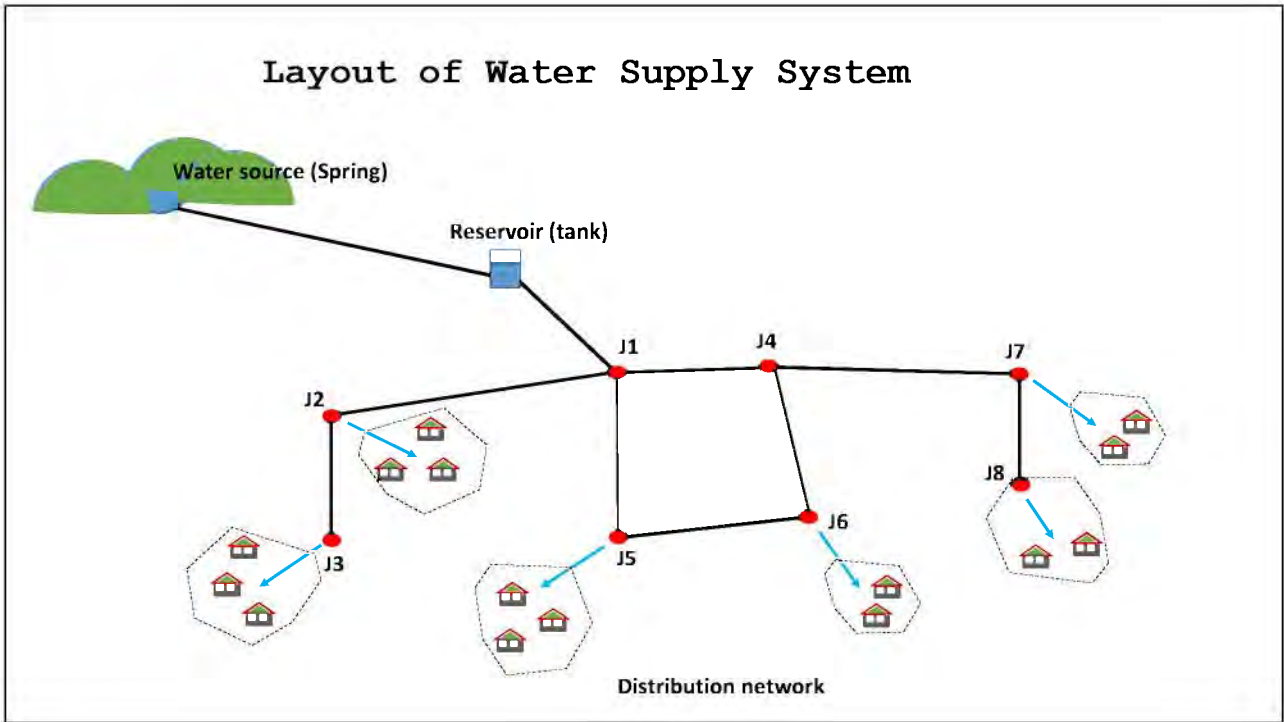


### d. Saving & Opening Project

#### ▪ Opening a Project

- To open our project at some later time, select the Open command from the File menu (File>>Open), or click the Open button [O] from the map toolbar.





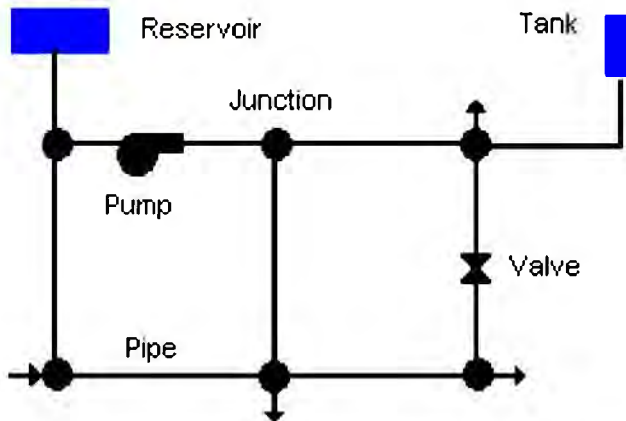
### Practice of EPANET

No	Diameter (mm)	Length (m)
P1		50
P2		200
P3		250
P4		100
P5		150
P6		130
P7		175
P8		330
P9		150

No	Q (l/sec)	Elevation (m)
R1		30
J1	0.00	22
J2	0.17	20
J3	0.12	16
J4	0.00	20
J5	0.31	18
J6	0.40	15
J7	0.34	18
J8	0.16	14

## Physical Components



Physical Components in a Water Distribution System

Junctions  
Reservoirs  
Tanks  
Pipes  
Pumps  
Valves

## 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.

## 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.

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.

## 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.

## 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).

Computed outputs for pipes include:

- flow rate
- velocity
- headloss

## Practices of EPANET

Analyze the distribution systems below by EPANET. Modify the system (pipe diameter etc.) when there are something wrong in a result of EPANET.

### Timor Leste Rural Water Supply Guideline (DENSA of MPW): Standards of GFC design

1. Max static Pressure in network:  $\leq 100\text{m}$  unless topographical constraints
2. Minimum static pressure in network: 5 – 10m
3. max-min static pressure at taps: 5 – 15m
4. Diameter between intake and sedimentation tank:  $\geq 50\text{mm}$
5. Diameter between tanks: Per hydraulic calculation
6. Diameter at tap stands: 3/4inch GS
7. Velocity of pipe in diameter (min – max)
  - (1) 20 – 40mm: 0.3 – 2m/sec
  - (2) 50 – 75mm: 1 – 3m/sec

### Practice-1

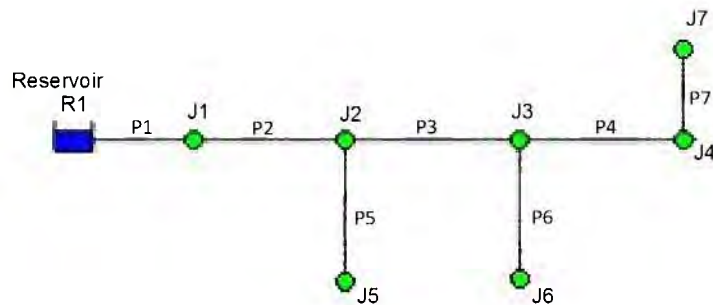


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
R1	100	0.00
J1	85	0.09
J2	82	0.00
J3	78	0.00
J4	77	0.00
J5	82	0.10
J6	78	0.07
J7	76	0.05

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
P1	450	50	120
P2	350	50	120
P3	400	50	120
P4	250	50	120
P5	40	20	120
P6	25	20	120
P7	50	20	120



## Practice-2

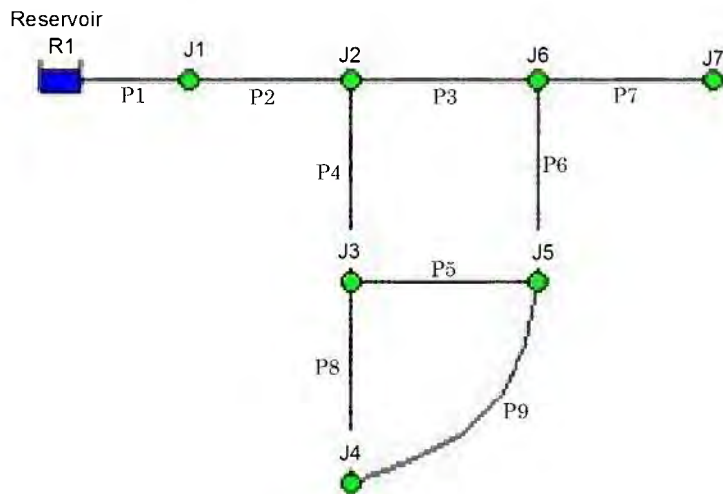


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
R1	100	0.00
J1	86	0.09
J2	77	0.09
J3	68	0.13
J4	58	0.05
J5	70	0.10
J6	75	0.07
J7	80	0.05

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
P1	450	50	120
P2	350	50	120
P3	400	50	120
P4	250	40	120
P5	400	40	120
P6	250	40	120
P7	500	40	120
P8	350	40	120
P9	800	40	120

### Practice-3

Analyze the case of Practice-2 with a time pattern below into consideration.

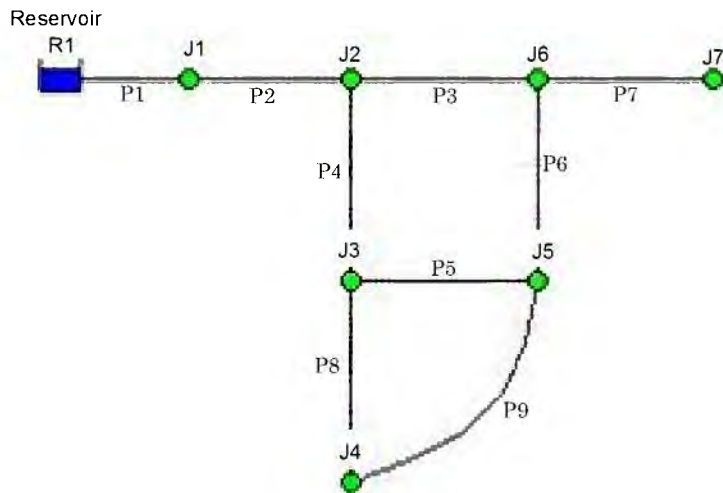


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
R1	100	0.00
J1	86	0.09
J2	77	0.09
J3	68	0.13
J4	58	0.05
J5	70	0.10
J6	75	0.07
J7	80	0.05

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
P1	450	50	120
P2	350	50	120
P3	400	50	120
P4	250	40	120
P5	400	40	120
P6	250	40	120
P7	500	40	120
P8	350	40	120
P9	800	40	120

Table 3: Time Pattern

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
Time Factor	0.60	0.40	0.30	0.25	0.25	0.30	0.75	1.55	1.80	1.75	1.50	1.20
Time	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
Time Factor	1.00	0.90	0.80	0.75	0.80	0.90	1.20	1.50	1.55	1.50	1.35	1.10

### EPANET 2 USERS MANUAL P.21-P.23

#### 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).

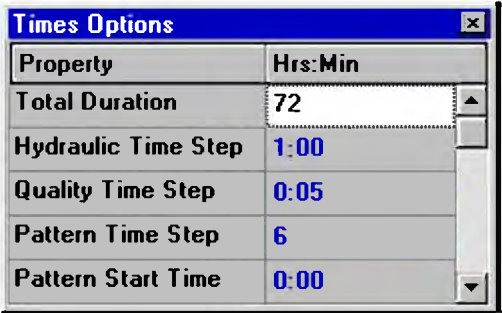



Figure 2.8 Times Options

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.

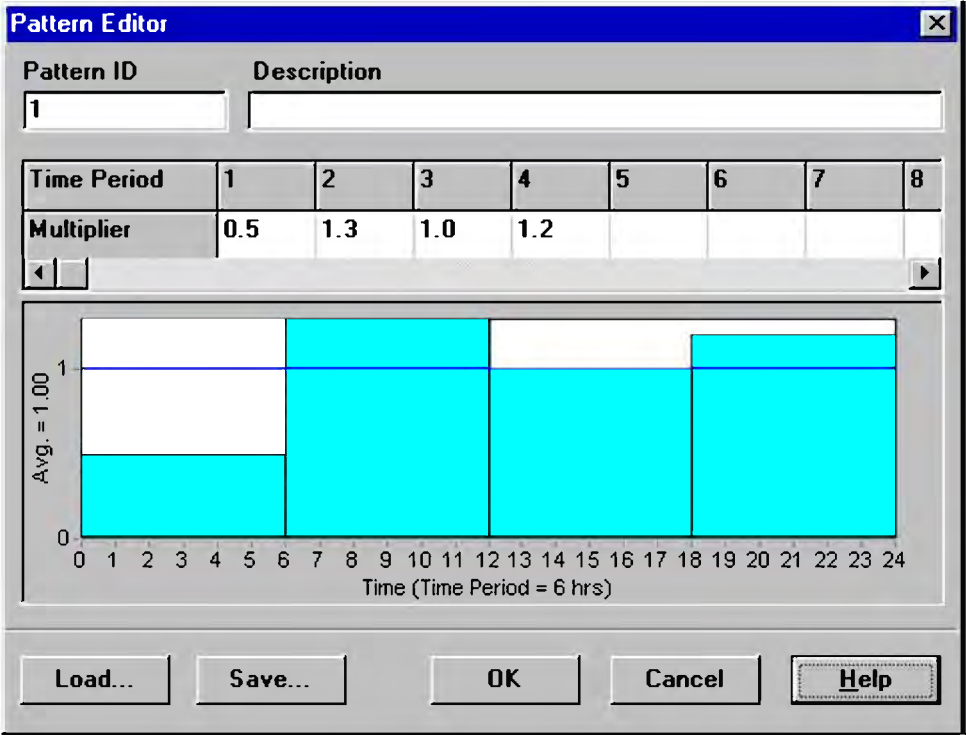






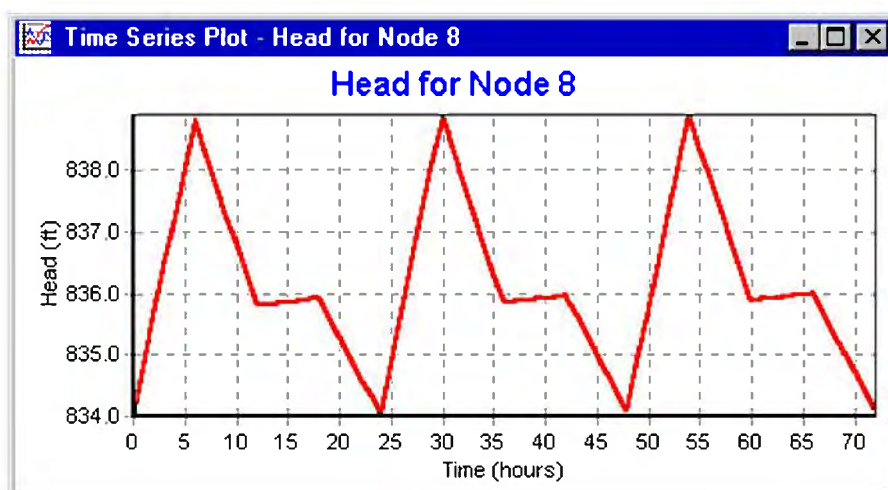
Figure 2.9 Pattern Editor

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

### Practice-4

Analyze the system distributed by a pump.

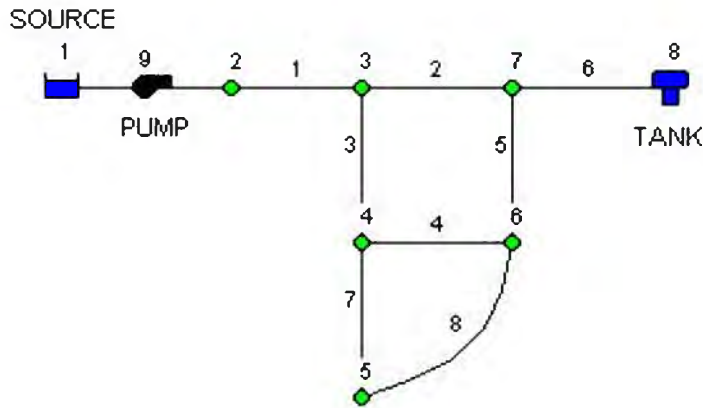


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
1	100	0.00
2	100	0.00
3	103	9.46
4	100	9.46
5	85	12.62
6	100	9.46
7	100	0.00
8	140	0.00

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
1	900	350	100
2	1,500	300	100
3	1,500	200	100
4	1,500	200	100
5	1,500	200	100
6	2,100	250	100
7	1,500	150	100
8	2,200	150	100

Node 8: The tank (Node 8) has a 18-m diameter, a 1.5-m water level, and a maximum level of 6 m.


Link 9: The pump (Link 9) can deliver 46 m of head at a flow of 38 L/sec.

$$\text{Head} = 60.00 - 0.0097 [\text{Flow}]^2.00$$

### EPANET 2 USERS MANUAL P.19

#### 2.5 Setting Object Properties

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.

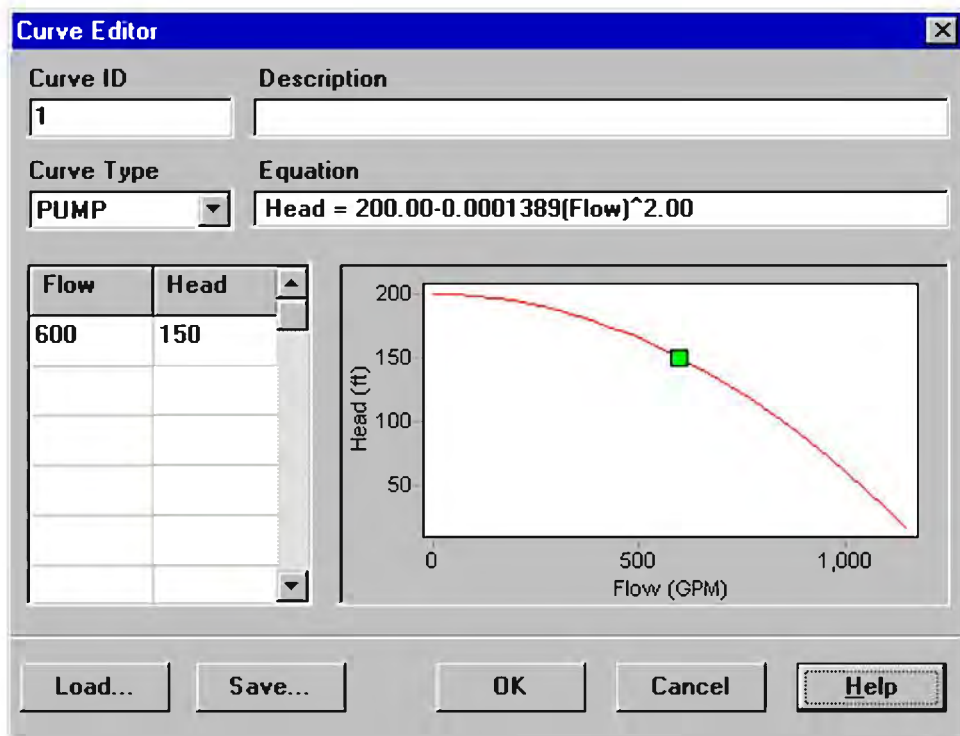


Figure 2.6 Curve Editor

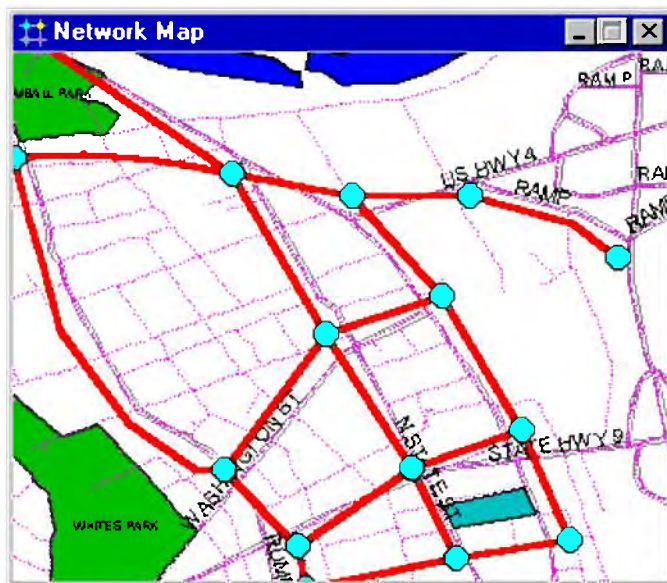
### Practice-5

Draw pipe network on a backdrop map.

## EPANET 2 USERS MANUAL P.85 – P.86

### 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 lose resolution when rescaled. 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 save 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.



### at the beginning “Why EPANET, but not EPANET”

1. EPANET is a worldwide used free software introduced in:

“**RURAL WATER SUPPLY DESIGN MANUAL**” published by World Bank Manila Office

“Among the current software available in the internet and from proprietary sources, the EPANET is highly recommended. EPANET is public domain software developed by the US Environmental Protection Agency that can be downloaded free on the internet.”

“**Handbook for Community-Based Water Supply Organizations**” published by Ministry of Public Works, Indonesia

“There are now available computer supported design systems, such as ‘**EPANET**,’ a public domain software developed by the US Environmental Protection Authority, to help hydraulic analysis and modeling.”

2. Hydraulics of pipeline is one of core components in a small water supply system.

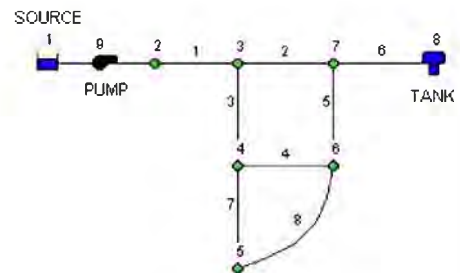
- ◆ Water source (intake) facilities
- ◆ Transmission and Distribution pipelines
- ◆ Storage tank (Reservoir)
- ◆ Public tap

But pipelines must be designed one by one, there is not a reference drawings to be quoted from the other projects.

3. **But**, EPANET is not the best tool in all cases. Excel (PIPECAL) is sometimes better than EPANET. Case by case.

## How to use EPANET

1. What is EPANET
2. Installing EPANET
3. Steps for EPANET Analysis
4. Practice



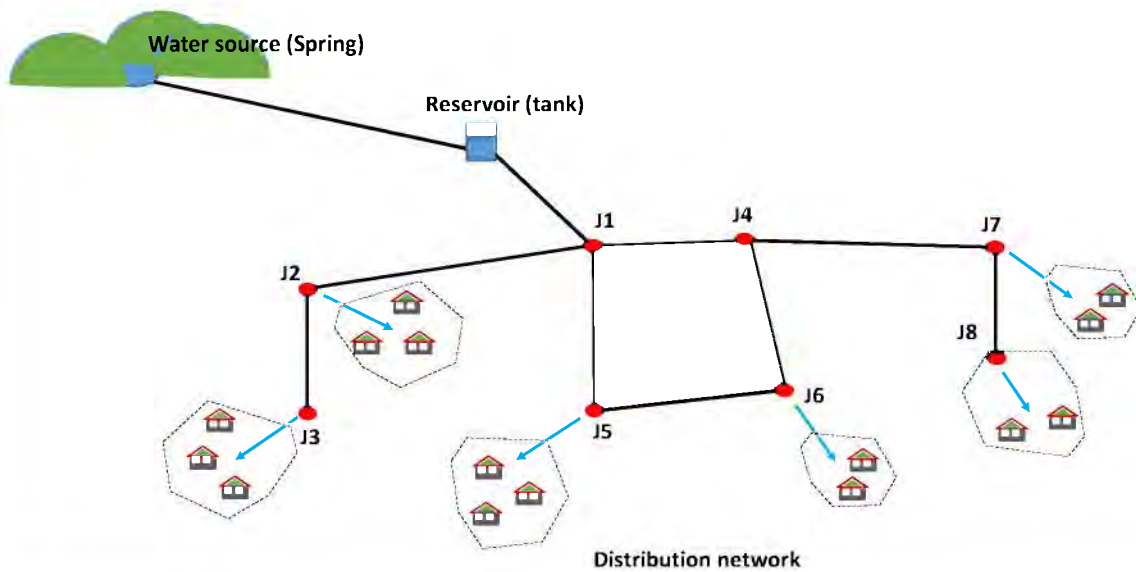
# What is EPANET

Provided by the U.S. Environmental Protection Agency (EPA)

EPANET: A computer program for simulation of  
(1) Hydraulic  
(2) Water quality behavior  
within pressurized pipe networks

Network: pipes, nodes (pipe junctions), pumps,  
valves, storage tanks, reservoirs

## Layout of Water Supply System



## Steps for EPANET Analysis

One typically carries out the following steps when using EPANET to model a water distribution system:

1. Open EPANET 2.0 Program
2. Set-Up a New Projects
3. Create the Project Scenario
4. Analyze the Network
5. View Results of Analysis

### 1. Open EPANET 2.0 Program

- To Run EPANET program, simply select this item off of the Start Menu
- Select EPANET 2.0 from the submenu
- Click to Run:



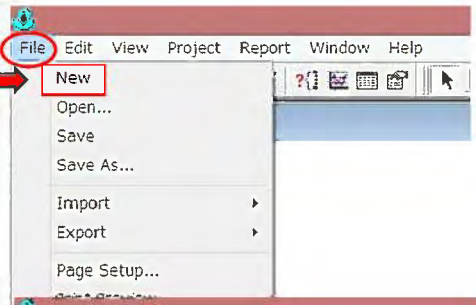
## 2. Set up a New Project

---

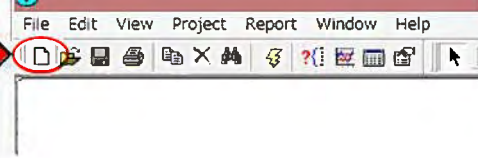
- a. Create a New Project
- b. Set Project Preferences
- c. Set Project Defaults
- d. Set Map Options

### a. Create a New Project

- From Main Toolbars select: **File >> New**
- A new, unnamed project is created with all options set to default values



- Or, click **New Project** from Standard Toolbars
- Prompted to save the existing project before the new project is created



### b. Set Project Preferences: File>>Preferences

- From Main Toolbars  
select: File >> Preferences

- Formats Preferences

### b. Set Project Preferences: File>>Preferences

- General Preferences

- Lastly, Press Select below Temporary Directory
- Browse for the c:\temp directory and press **OK** to accept the default directory

### c. Set Project Defaults: Project>>Defaults

▪ From General Toolbar select: Project >> Defaults

▪ ID Labels Defaults

Object	ID Prefix
Junctions	J
Reservoirs	R
Tanks	T
Pipes	P
Pumps	
Valves	
Patterns	
Curves	
ID Increment	1

Save as defaults for all new projects

OK Cancel Help

### c. Set Project Defaults: Project>>Defaults

▪ Properties Defaults

- Make sure Auto Length is off
- For Pipe Diameter = 50
- For Pipe Roughness = 120

▪ Hydraulics Defaults

- Select appropriate flow units >> LPS
- Select headloss formula >> H-W

Property Default Value

Node Elevation	0
Tank Diameter	50
Tank Height	20
Pipe Length	100
Auto Length	Off
Pipe Diameter	50
Pipe Roughness	120

Save as defaults for all new projects

OK Cancel Help

Option Default Value

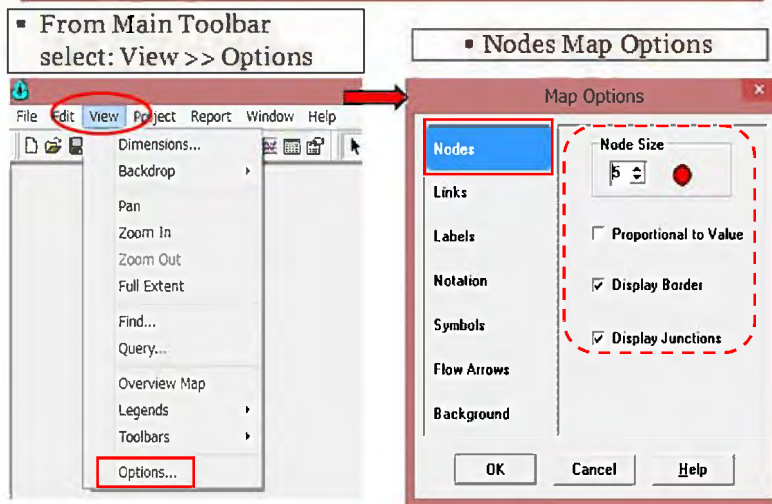
Flow Units	LPS
Headloss Formula	H,W
Specific Gravity	1
Relative Viscosity	1
Maximum Trials	40
Accuracy	0.001
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	1.0

Save as defaults for all new projects

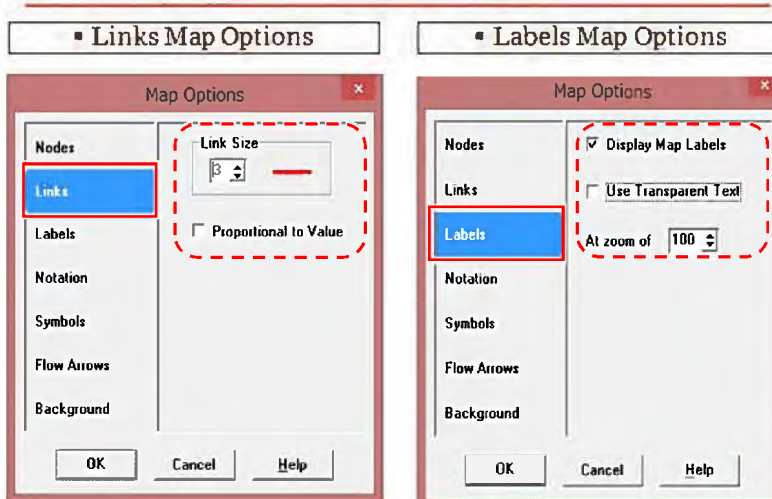
OK Cancel Help



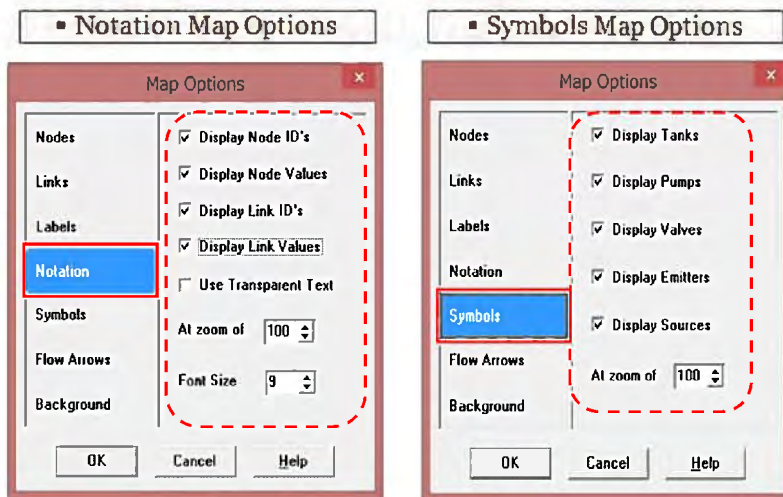
### c. Set Map Options: View>>Options



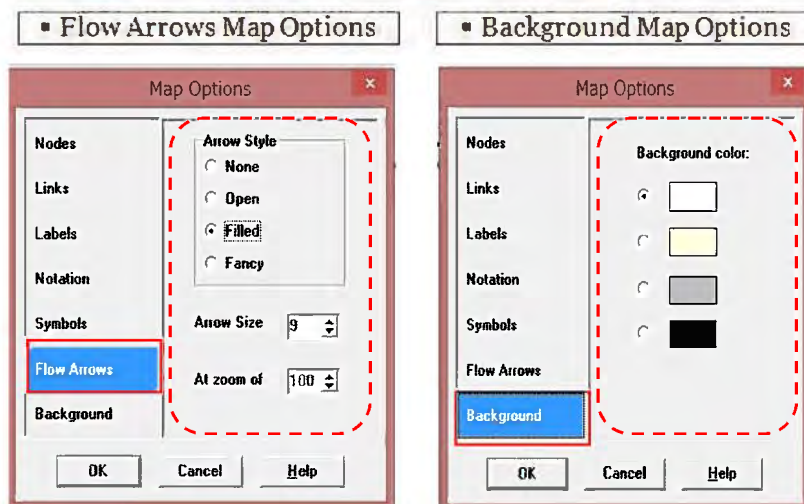
### c. Set Map Options: View>>Options



### c. Set Map Options: View>>Options



### c. Set Map Options: View>>Options




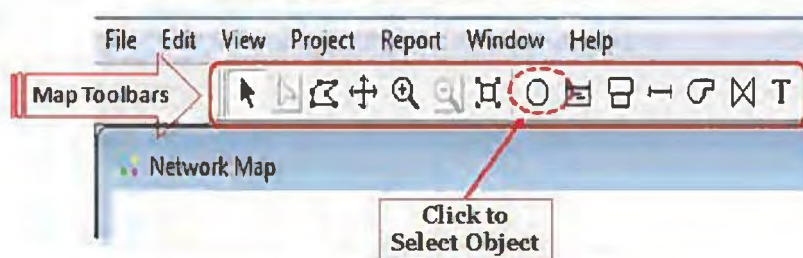


### 3. Create the Project Scenario

- a. Draw the Network
  - Nodes (including reservoirs, tanks)
  - Pipes connecting nodes
  - Pumps
  - Control Valves
- b. Specify Network Properties
  - Nodes {demands, elevations}
  - Pipe properties {L, D, C}
  - Pump Curves {H vs. Q}
- c. Run a Simulation
  - Single period (snapshot) Analysis
- d. Saving and Opening a Project
  - Save As a Project
  - Open a Project

#### a. Draw the network


- We are now ready to begin drawing our network by making use of Buttons contained on the Map Toolbar shown below.
  - Use Object Selection Button 

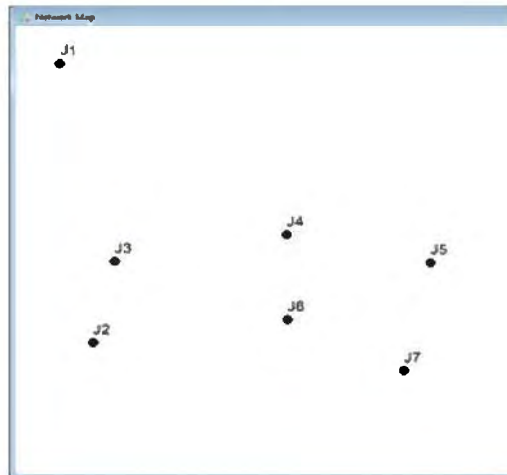


- If the Map Toolbars are not visible then select:  
**View >> Toolbars >> Map**

## a. Draw the network


### ▪ Adding Junctions

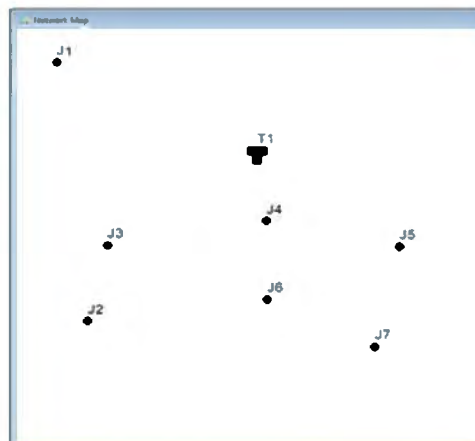
- First, we will add the junction nodes.
- Click the **Junction button**  and then click on the map at the locations of nodes 1 through 7,
- Always start a project by putting at least two (2) junctions on the map. You can add all junctions at this time, or add additional junctions later.



## a. Draw the network


### ▪ Adding Tank

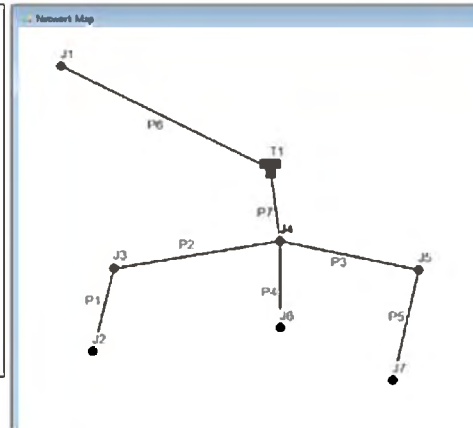
- Finally, add the tank by clicking the **Tank button**  and clicking the map where the tank is located,
- At this point the Network Map should look something like the drawing in attached figure.



## a. Draw the network


### ▪ Adding Links

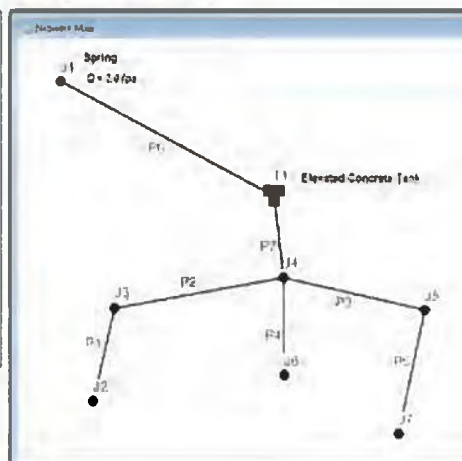
- Next we will add the pipes. Let's begin with Pipe 1 connecting J2 to J3
- First click the Pipe button  on the Map Toolbar
- Then click the mouse on J2 on the map and then on J3
- Repeat this procedure for Pipes P2 through P7



## a. Draw the network

### ▪ Adding Labels

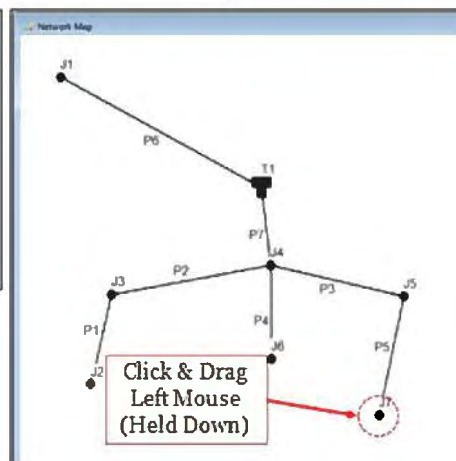
- Next we will label the spring and tank
- Select the Text button  on the Map Toolbar and click somewhere close to the spring (Node J1)
- An edit box will appear. Type in the word "Spring" and then hit the Enter key.
- Click next to the Tank and enter its label.




## a. Draw the network

### ▪ Moving an Object

- If the Nodes are out of position you can move them around by clicking the node to select it
- Drag it with the left mouse button held down to its new position
- Labels can be repositioned in similar procedure



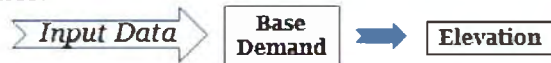
## b. Specify Network Properties

- Editing an Object is Adding Information to:
  - Links
  - Nodes
- To select an object on the map using the Select Object button:
  - Click the Select Object button  (Arrow) on the Map Toolbar
  - Double-Click the mouse over the desired object on the map
- To select an object using the Browser:
  - Select the type of object from the Object listbox of the Database Browser
  - Select the desired object from the Item listbox

## b. Specify Network Properties

### Editing Junction Properties:

- The nodes in our example network are assumed to have the following properties:



Network Table - Nodes

Node ID	HHs	Pop1	PF	NRW (%)	Water Demand (lps)		Elevation
					ADD	MDD	m
Junc J1	Spring Source				-2.50		40
Junc J2	14	77	3	30%	0.076	0.099	10
Junc J3	35	193	7	30%	0.191	0.248	11
Junc J4	53	292	11	30%	0.290	0.377	13
Junc J5	67	369	13	30%	0.366	0.476	14
Junc J6	32	176	6	30%	0.175	0.228	12
Junc J7	35	193	7	30%	0.191	0.248	13
Tank1							
Total	236	1300	47		1.289	1.676	

## b. Specify Network Properties

The screenshot shows the EPANET interface. On the left, a network map has a junction node circled in red with a callout box that says 'Double-click to Edit'. An arrow labeled 'Input Data' points from the map to the 'Junction Property Editor' window. The editor window shows a table of properties for 'Junction J3':

Property	Value
Junction ID	J3
X Coordinate	-2505.94
Y Coordinate	7271.73
Description	
Tag	
Elevation	11
Base Demand	0.191
Demand Pattern	
Demand Categories	1
Emitter Code	
Initial Quality	
Source Quality	
Actual Demand	N/A
Total Head	N/A
Pressure	N/A
Quality	N/A

On the right, the 'Data Browser' window is open, showing a list of nodes. A callout box says 'Double-click to Edit' pointing to a node in the list, and another callout box says 'Click to Edit' pointing to a specific property in the list.

## b. Specify Network Properties

### ▪ Editing Tank Property:

- The Tank in our example network is assumed to have the following properties:

**Tank Node Data : T1**

Property	Value
Tank Bottom Elev. :	18.00
Initial Level :	3.50
Minimum Level :	0.10
Maximum Level :	3.60
Diameter :	4.20

Input Data →

## b. Specify Network Properties

The screenshot shows the EPANET interface with the Tank Property Editor dialog box for Tank T1. The dialog box contains the following properties and values:

Property	Value
Tank ID	T1
X Coordinate	437.50
Y Coordinate	915.00
Description	
Tag	
Elevation	18
Initial Level	3.5
Minimum Level	0.1
Maximum Level	3.6
Diameter	4.2
Minimum Volume	
Volume Curve	
Mixing Model	Misc
Mixing Fraction	
Reaction Coeff.	
Initial Quality	
Source Quality	
Net Inflow	N/A

Annotations in the screenshot include:

- Double-click to Edit:** Points to the tank node in the network diagram.
- Click to Edit:** Points to the 'Elevation' field in the Tank Property Editor dialog.
- Double-click to Edit:** Points to the 'Tank T1' entry in the Data Browser.
- Input Data:** An arrow points to the tank node in the diagram.

## b. Specify Network Properties

### ▪ Editing Pipe Properties:

- The Pipes in our example network are assumed to have the following properties:



Length    Diameter    Roughness

Network Table - Links

Link ID	Node Number		Length m	Diameter mm	"C"
	From	To			
Pipe P1	J2	J3	200	50	120
Pipe P2	J3	J4	300	75	120
Pipe P3	J4	J5	250	75	120
Pipe P4	J4	J6	200	75	120
Pipe P5	J5	J7	250	50	120
Pipe P6	J1	T1	3000	100	120
Pipe P7	T1	J4	30	100	120


## b. Specify Network Properties

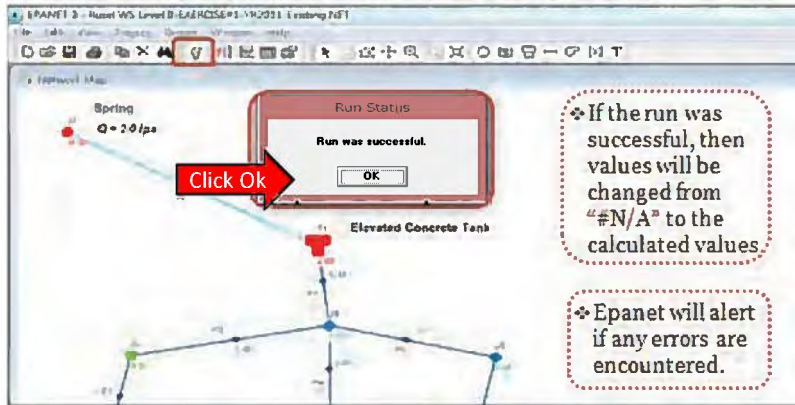
The screenshot shows the EPANET interface. On the left, a network diagram has a pipe highlighted with a red circle and an arrow pointing to it with the text "Double-click to Edit". In the center, the "Pipe Property Editor" window is open for "Pipe P4". It lists various properties: Pipe ID (P4), Start Node (J4), End Node (J6), Description (J4), Length (200), Diameter (50), Roughness (120), Loss Coeff. (0), Initial Status (Open), Wall Coeff., Fee (N/A), Velocity (N/A), Bell Headloss (N/A), Friction Factor (N/A), Reaction Rate (N/A), and Quality (N/A). A red dashed box highlights the Length, Diameter, and Roughness fields. An arrow labeled "Input Data" points to this box. On the right, the "Data Browser" window shows a list of pipes (P1-P7) with a red circle around Pipe P4 and an arrow pointing to it with the text "Double-click to Edit". Below it, another arrow points to Pipe P4 with the text "Click to Edit".



### c. Run a Simulation

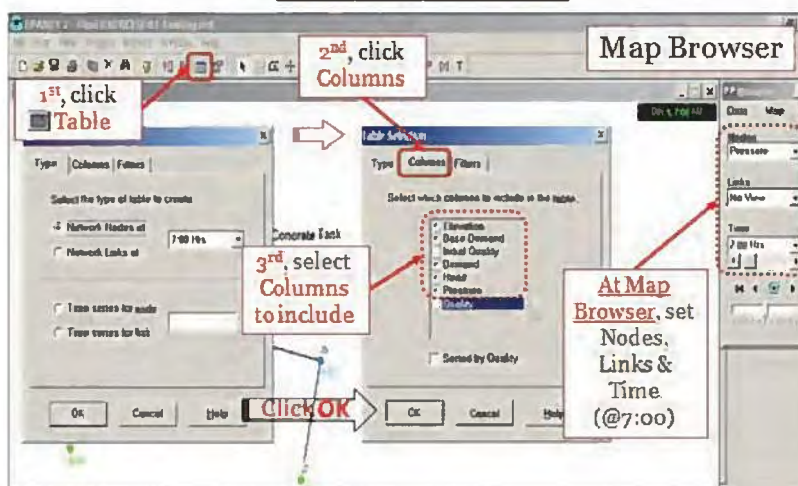
- Run a Single period (steady-state) Analysis

- You now have enough information to run a Single Period (or steady-state) hydraulic analysis
- To run the analysis select Project >> Run Analysis (or click the  button)



### c. View Results

- View Results - Tables



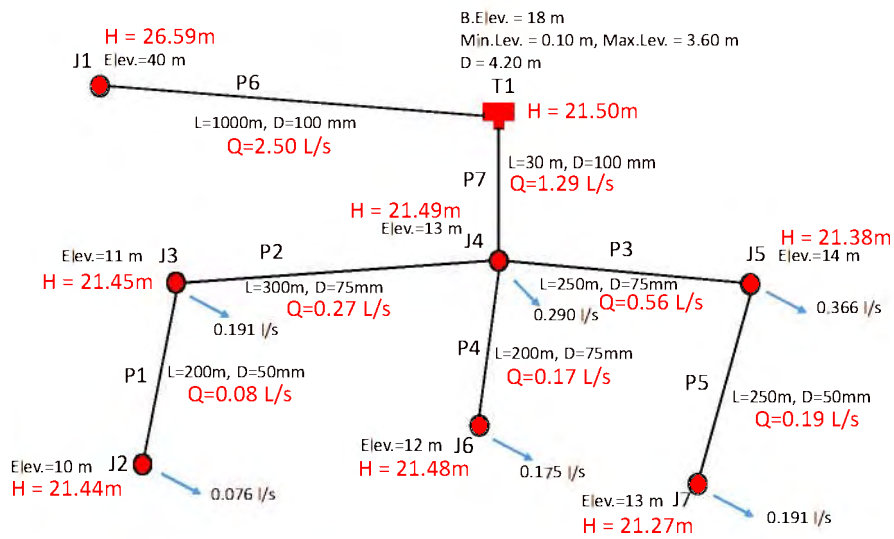


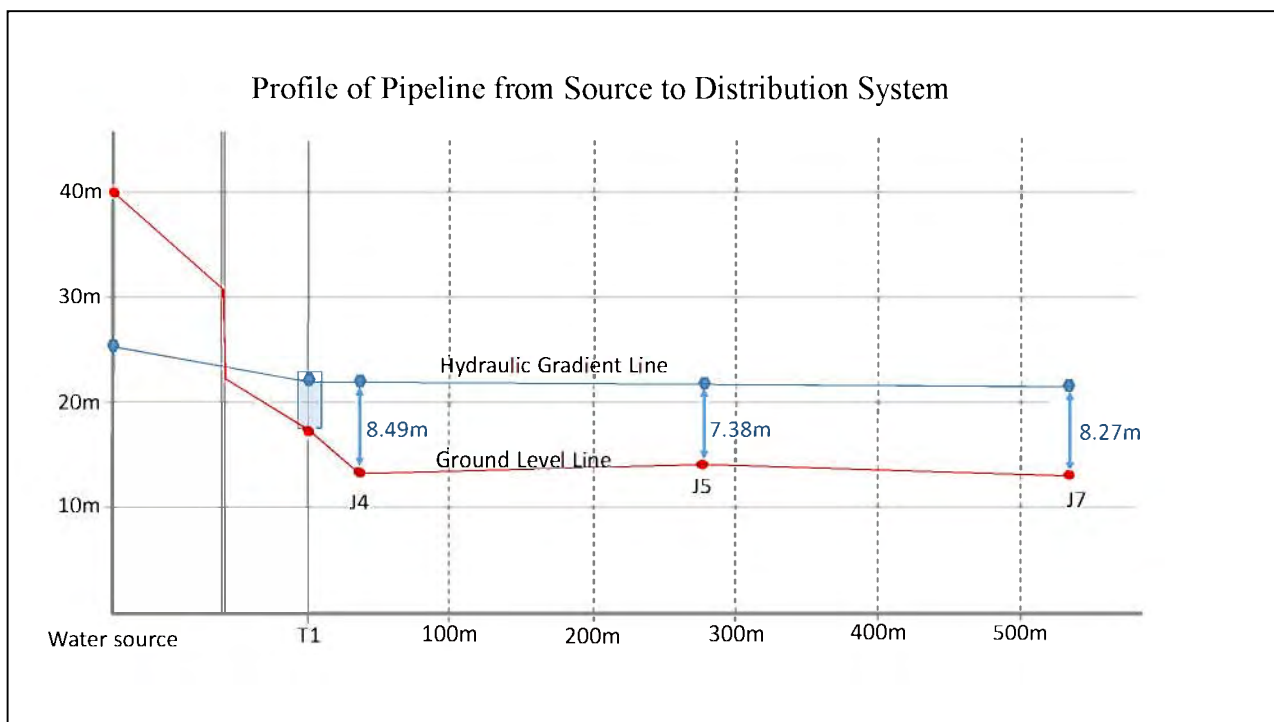
### c. View Results: Tables

- EPANET allows you to view selected project data and analysis results in a tabular format
- Tables can be printed, copied to the Windows clipboard, or saved as a data file or Windows metafile
- Network Link sign on flow (+/-) is relative to the way the pipe (link) was initially drawn on the network map

Node ID	Elevation m	Base Demand	Demand LPS	Head m	Pressure m
Junc J2	10	0.071	0.14	19.90	9.90
Junc J3	11	0.179	0.36	19.95	8.95
Junc J4	13	0.270	0.54	20.71	7.71
Junc J5	14	0.342	0.68	20.37	6.37
Junc J1	40	-2.00	-2.00	34.42	-5.58
Junc J7	13	0.179	0.36	20.03	7.03
Junc J6	12	0.163	0.33	20.40	8.40
Tank T1	18	N/A	-0.41	20.76	2.76

### Results of Calculation



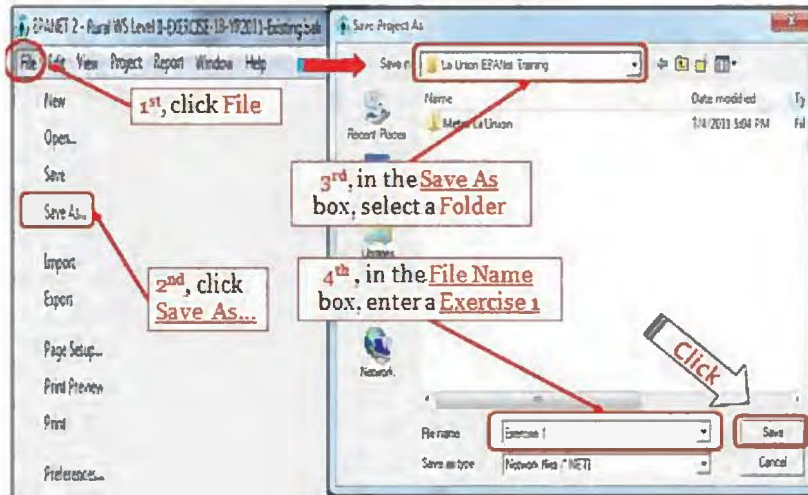


#### d. Saving & Opening Project

- 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 **Exercise 1**. (An extension of **“.net”** will be added to the file name if one is not supplied)
  3. Click **Save** 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.

### d. Saving & Opening Project

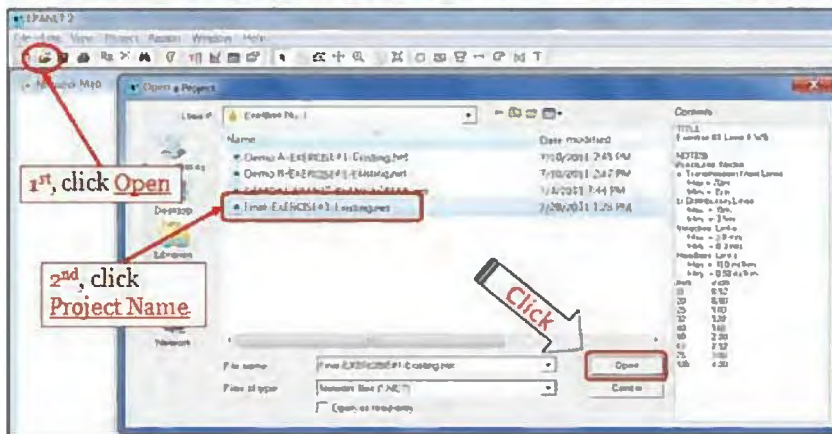
#### ▪ Saving As a Project

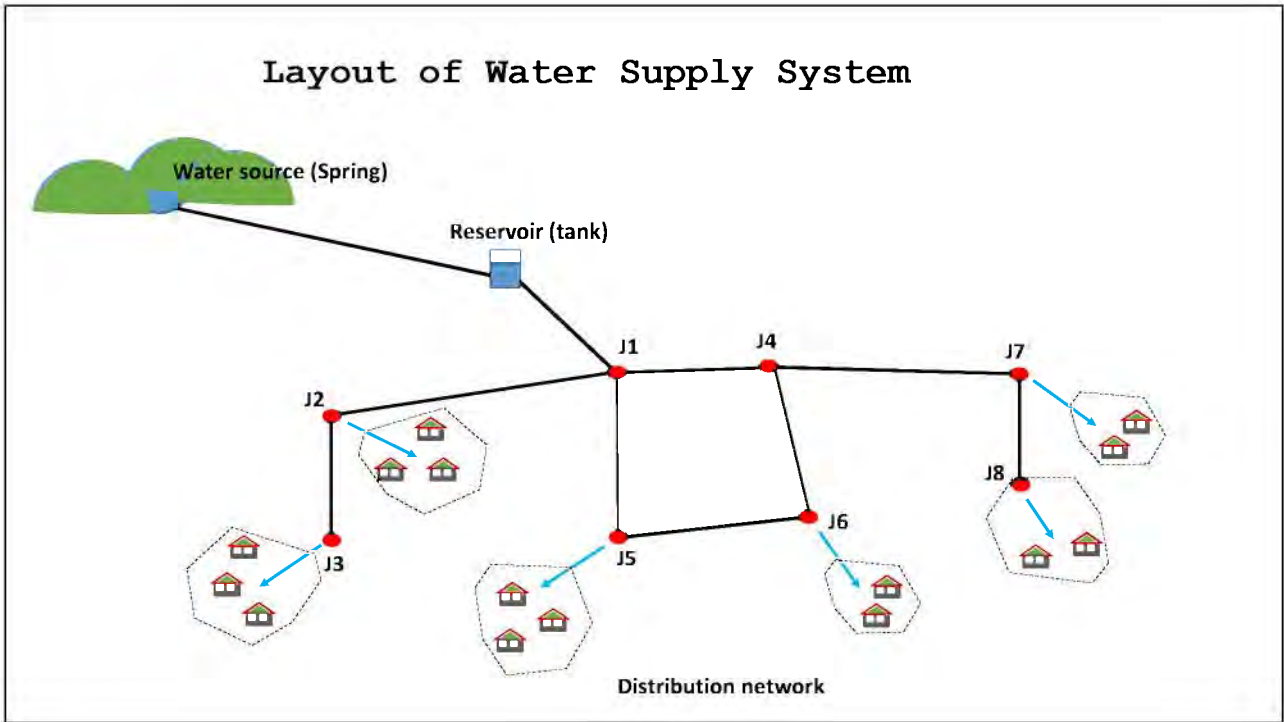


### d. Saving & Opening Project

#### ▪ Opening a Project

- To open our project at some later time, select the Open command from the File menu (File>>Open), or click the Open button [O] from the map toolbar.





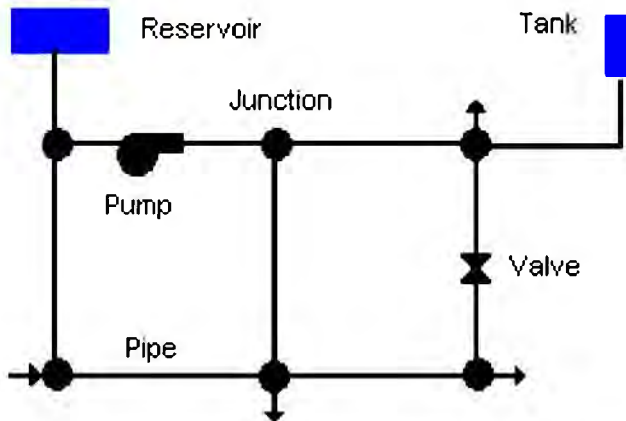
### Practice of EPANET

No	Diameter (mm)	Length (m)
P1		50
P2		200
P3		250
P4		100
P5		150
P6		130
P7		175
P8		330
P9		150

No	Q (l/sec)	Elevation (m)
R1		30
J1	0.00	22
J2	0.17	20
J3	0.12	16
J4	0.00	20
J5	0.31	18
J6	0.40	15
J7	0.34	18
J8	0.16	14

## Physical Components



Physical Components in a Water Distribution System

Junctions  
Reservoirs  
Tanks  
Pipes  
Pumps  
Valves

## 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.

## 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.

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.

## 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.

## 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).

Computed outputs for pipes include:

- flow rate
- velocity
- headloss

## Practices of EPANET

Analyze the distribution systems below by EPANET. Modify the system (pipe diameter etc.) when there are something wrong in a result of EPANET.

### Timor Leste Rural Water Supply Guideline (DENSA of MPW): Standards of GFC design

1. Max static Pressure in network:  $\leq 100\text{m}$  unless topographical constraints
2. Minimum static pressure in network: 5 – 10m
3. max-min static pressure at taps: 5 – 15m
4. Diameter between intake and sedimentation tank:  $\geq 50\text{mm}$
5. Diameter between tanks: Per hydraulic calculation
6. Diameter at tap stands: 3/4inch GS
7. Velocity of pipe in diameter (min – max)
  - (1) 20 – 40mm: 0.3 – 2m/sec
  - (2) 50 – 75mm: 1 – 3m/sec

### Practice-1

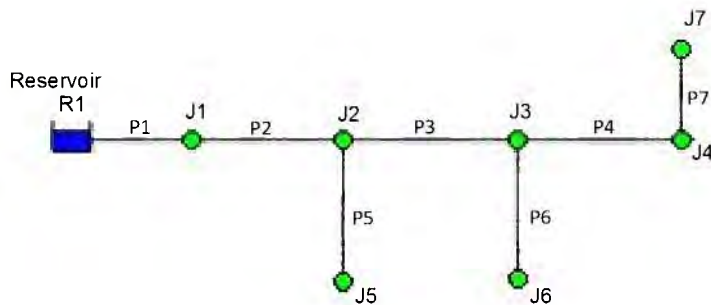


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
R1	100	0.00
J1	85	0.09
J2	82	0.00
J3	78	0.00
J4	77	0.00
J5	82	0.10
J6	78	0.07
J7	76	0.05

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
P1	450	50	120
P2	350	50	120
P3	400	50	120
P4	250	50	120
P5	40	20	120
P6	25	20	120
P7	50	20	120



## Practice-2

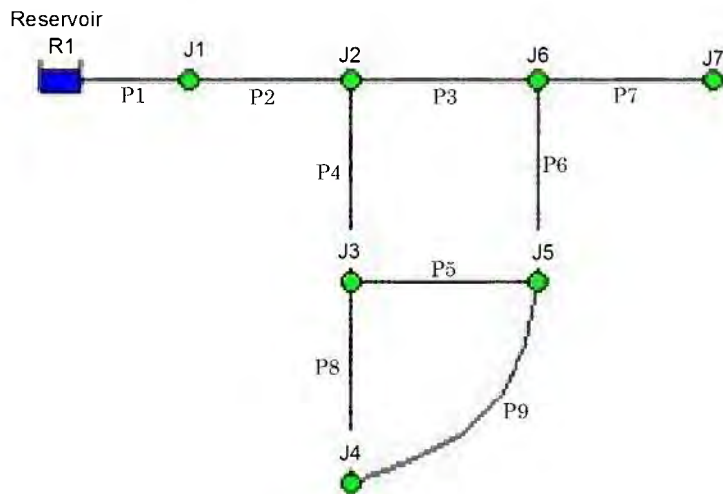


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
R1	100	0.00
J1	86	0.09
J2	77	0.09
J3	68	0.13
J4	58	0.05
J5	70	0.10
J6	75	0.07
J7	80	0.05

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
P1	450	50	120
P2	350	50	120
P3	400	50	120
P4	250	40	120
P5	400	40	120
P6	250	40	120
P7	500	40	120
P8	350	40	120
P9	800	40	120

### Practice-3

Analyze the case of Practice-2 with a time pattern below into consideration.

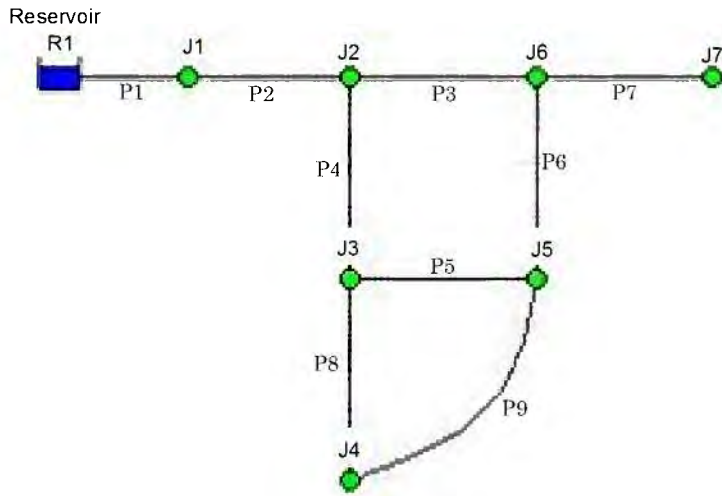


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
R1	100	0.00
J1	86	0.09
J2	77	0.09
J3	68	0.13
J4	58	0.05
J5	70	0.10
J6	75	0.07
J7	80	0.05

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
P1	450	50	120
P2	350	50	120
P3	400	50	120
P4	250	40	120
P5	400	40	120
P6	250	40	120
P7	500	40	120
P8	350	40	120
P9	800	40	120

Table 3: Time Pattern

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
Time Factor	0.60	0.40	0.30	0.25	0.25	0.30	0.75	1.55	1.80	1.75	1.50	1.20
Time	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
Time Factor	1.00	0.90	0.80	0.75	0.80	0.90	1.20	1.50	1.55	1.50	1.35	1.10

### EPANET 2 USERS MANUAL P.21-P.23

#### 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).

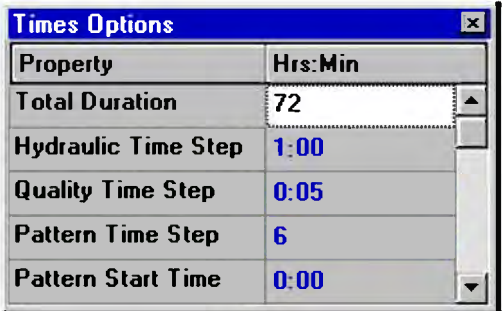



Figure 2.8 Times Options

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.

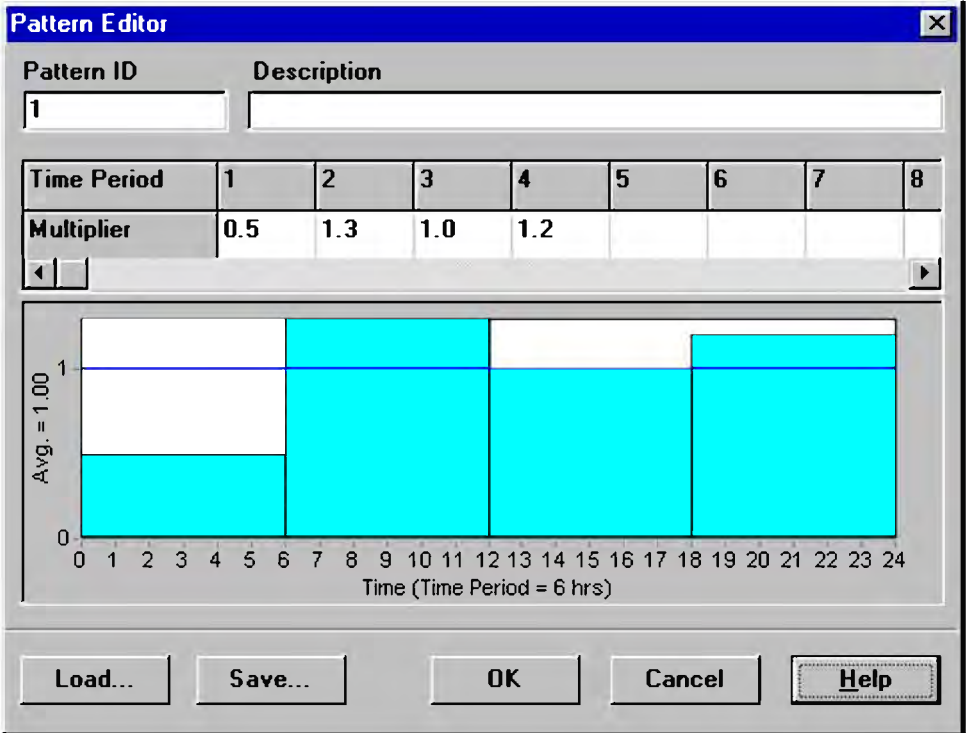






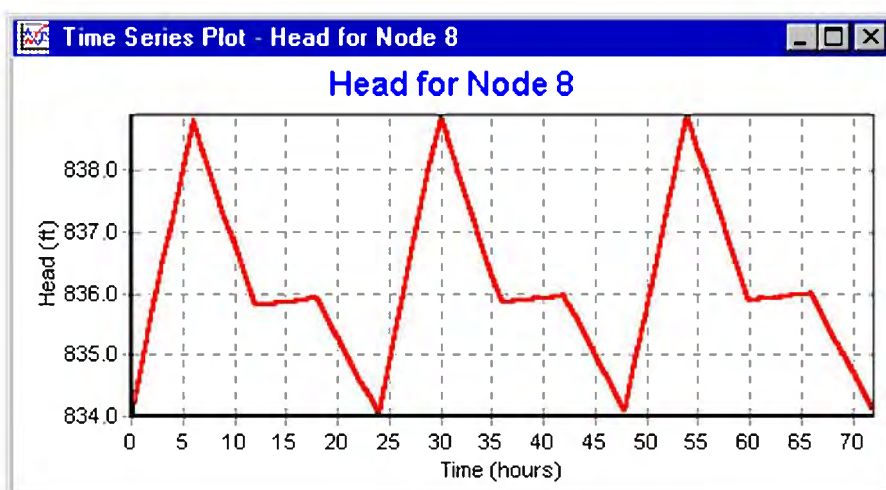
Figure 2.9 Pattern Editor

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

### Practice-4

Analyze the system distributed by a pump.

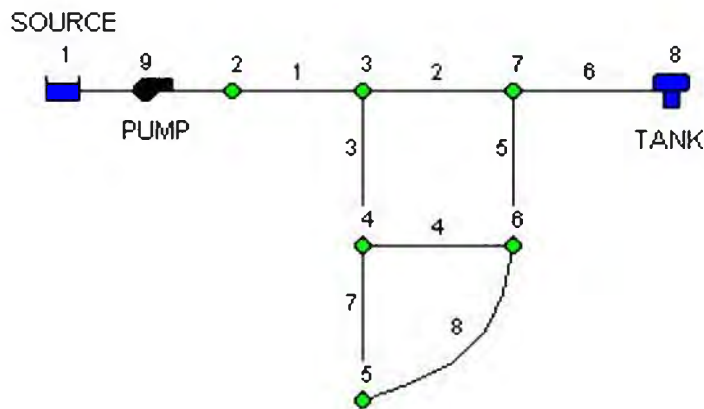


Table 1: Network Node Properties

Node	Elevation (m)	Demand (L/s)
1	100	0.00
2	100	0.00
3	103	9.46
4	100	9.46
5	85	12.62
6	100	9.46
7	100	0.00
8	140	0.00

Table 2: Network Pipe Properties

Pipe	Length (m)	Diameter (mm)	C
1	900	350	100
2	1,500	300	100
3	1,500	200	100
4	1,500	200	100
5	1,500	200	100
6	2,100	250	100
7	1,500	150	100
8	2,200	150	100

Node 8: The tank (Node 8) has a 18-m diameter, a 1.5-m water level, and a maximum level of 6 m.


Link 9: The pump (Link 9) can deliver 46 m of head at a flow of 38 L/sec.

$$\text{Head} = 60.00 - 0.0097 [\text{Flow}]^2.00$$

### EPANET 2 USERS MANUAL P.19

#### 2.5 Setting Object Properties

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.

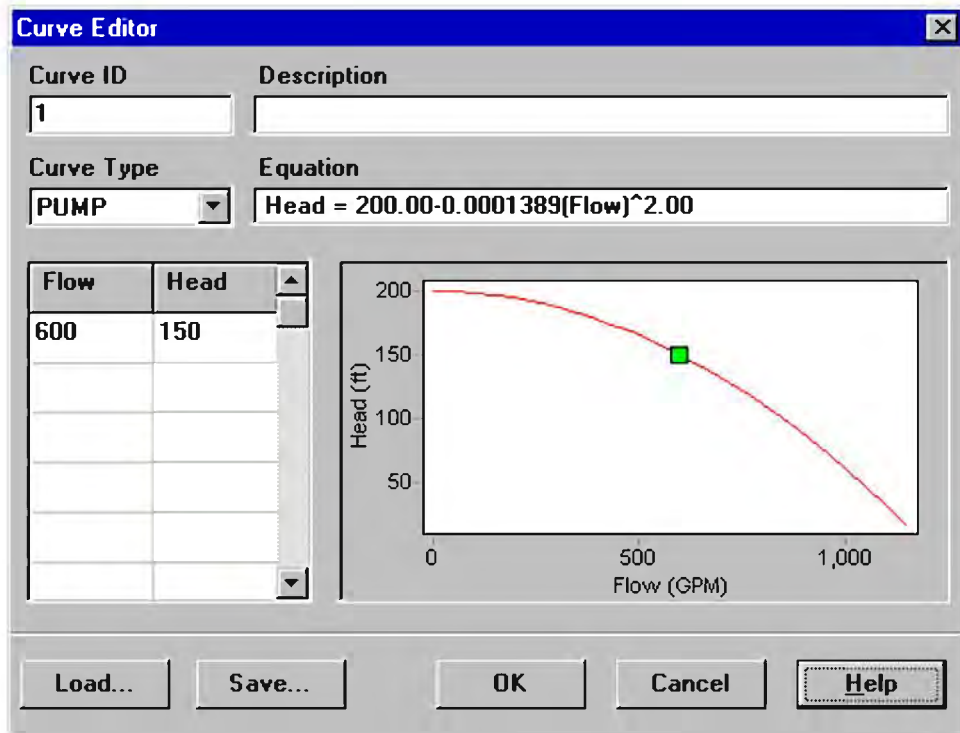


Figure 2.6 Curve Editor

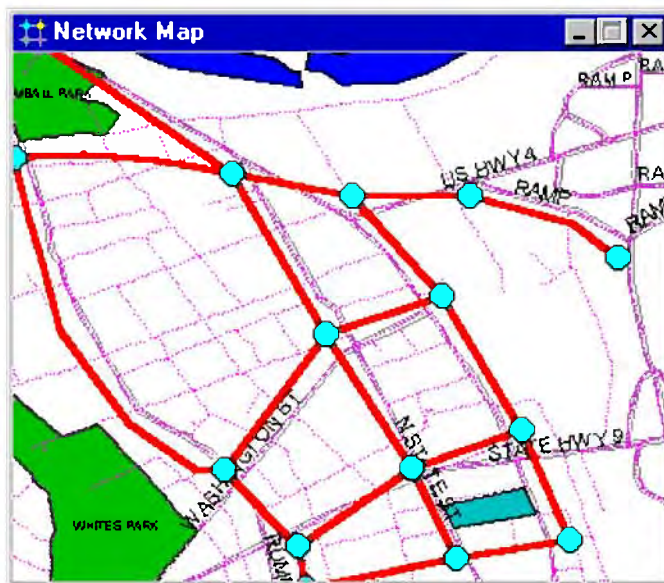
### Practice-5

Draw pipe network on a backdrop map.

## EPANET 2 USERS MANUAL P.85 – P.86

### 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 lose resolution when rescaled. 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 save 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.



## **ANNEX-13**

### **SHORT REPORT ON WATER SUPPLY**

# Inspection Summary of MDG Suco Projects

Prepared by JICA Engineer

May 2013

## 1. Site Visit Schedule

JICA Water Supply Engineer accompanied by ADN Engineer has visited MDG Suco project sites in the period from 7 May to 10 May 2013. Table below outlines schedules of the site visit by the engineers.

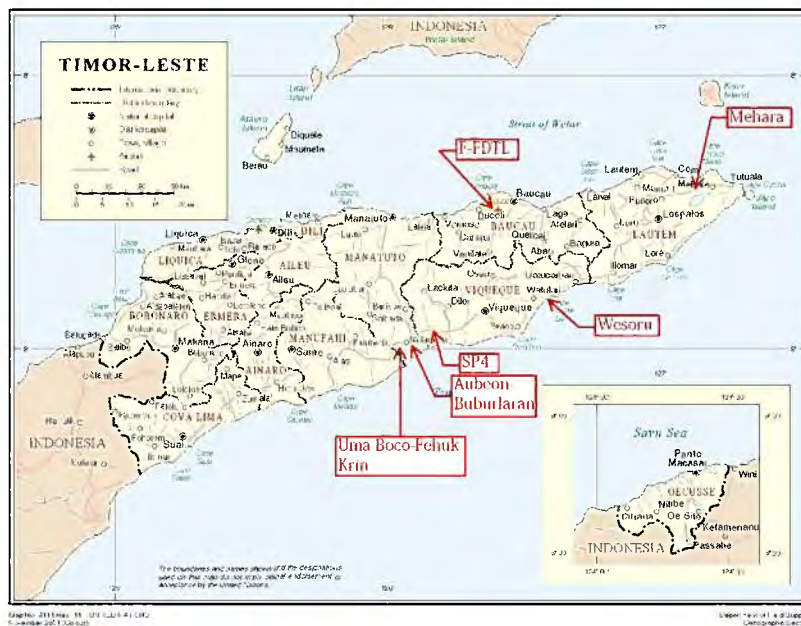
Table - Site Visit Schedule

Date	Move		Activities
	From	To	
7 May (Tue)	Dili	Lospalos	Visit Mehara project site
	Lospalos	Baucau	Stay at Baucau ADN office
8 May (Wed)	Baucau	Viqueque	Visit Wesoru project site
			Stay at Viqueque ADN office
9 May (Thu)	Viqueque	Manatuto	Visit Natarbora project sites
	Manatuto	Viqueque	Visit SP4 project site
	Viqueque	Baucau	Stay at Baucau ADN office
10 May (Fri)	ADN office	F-FDTL	Visit F-FDTL office, meeting with Commando, visiting project site and Aubaka spring.
	Baucau	Dili	Return to Dili

## 2. Project Location

MDG Suco projects, in general, are located in rural area of each district, far from its district center. The majority of residents to be settled in the planned houses are mainly farmers. They currently live in traditional sago-leaves roofed huts. Number of houses to be constructed ranges from 50 units to 300 units in one Suco Project, depending on needs of the people.

Fig – Project Site in Districts; Baucau, Lautem, Viqueque and Manatuto



### 3. Progress and Findings

Project progress as of May 2013 and major findings by ADN & JICA Engineers are summarized in a table below.

Table – Project Progress and Engineer Observation

District	Sub-district	Suco/Aideia	Number of Houses	Progress				Problems Observed	Action/Suggestion Made
				Houses	Drainage	Road	Sanitation		
Baucau	Baucau	F-FDTL	200	Completed	Not yet	Not yet	Not yet	1. There exists leakage on the existing raw water main, causing water shortage at FDTL. 2. Suco leader rejects additional supply to MIDG Suco area through a branch from the main.	1. Leak repair is required. 2. Dialogue with the society is necessary to solve water right issue.
				Completed	Under construction	Under construction	Not yet	1. Sands utilized for concrete contain a lot of silts and clays, evaluated not appropriate. 2. It requires borehole construction to supply water to the area.	1. Immediate replacement ordered by Engineer. 2. Engineer ordered Contractor to propose borehole sites, design and schedule.
Lautem	Tutuula	Mehara	150	Completed	Completed	Completed	Not yet	1. Boreholes are not in operation because of a lack of fund. 2. Water supply to the project site is not determined.	1.&2. DNSA shall provide budget to operate the borehole to supply water to the public, including MIDG Suco area. Coordination between DNSA and the Society is required.
				Completed	Completed	Completed	Not yet	1. Stagnant water are observed in drainage channels. 2. Existing borehole is not functioning because of lack of pump and its accessories.	1. Immediate amendment of base concrete ordered by Engineer. 2. As the existing borehole is a possible water source to the project site, Engineer ordered the Contractor to propose newly installation of pumps and tanks with necessary pipeworks and public taps.
Manatuto	Natarbora	Uma Boco-Fehuk Krin	126	Completed	Completed	Completed	Not yet	1. Well construction is under way.	1. Works shall be continued.
				Completed	Completed (Repair)	Completed (Repair)	Not yet	1. Project site suffers from frequent flood. 2. Subsurface of the area consists of mostly soft clay. 3. It requires borehole construction to supply water to the area.	1. Drainage channel provision shall be started first before initiation of house construction to improve work performance. 2. Carefull attention shall be paid to site clearance and refill. 3. Engineer ordered Contractor to propose newly construction of boreholes.
Viqueque	Luca	SP4	52	Completed	Completed	Completed	Not yet		
				Under construction	Under preparation	Under preparation	Not yet		
	Watuari	Wesoru	364	Under construction	Under preparation	Under preparation	Not yet		
			979						

Note: Engineer means ADN engineer responsible for MIDG Suco projects in Baucau, Lautem, Viqueque and Manatuto.

4. Photographs (7 May – 10 May, 2013)



[Mehara] -1. Roads & Channels under Construction



[Mehara] – 2. Drainage Channels under Construction



[Mehara] – 3. Sands Sampled by Engineer (Replacement directed by Engineer)



[Mehara] – 4. Proposed Site for Boring



[Wesoru] – 1. Construction newly Started in April



[Wesoru] – 2. Foundation with Reinforcement





[Wesoru] – 3. Backhoe for Earthwork



[Wesoru] – 4. Existing Well near the Project Site (9m depth in operation)



[Aubeon-Buburlaran] – 1. Stagnant Rain Water in Drainage Channel (Immediate repair ordered by ADN Engineer)



[Aubeon-Buburlaran] – 2. Existing Handpump Well (Made in Japan)



[Aubeon-Buburlaran] – 3. Existing Borehole without Pump set (Considered as possible source)



[Aubeon-Buburlaran] – 4. Earthworks not completed (Backfill observed insufficient)





[Uma Boco-Fehuk Krin] – 1. Completed 126 House Units (while water has not been provided yet)



[Uma Boco-Fehuk Krin] – 2. Borehole Constructed by USAID in 2010 (62m in depth, not in operation because of a lack of gov. budget for operation)



[Uma Boco-Fehuk Krin] – 3. Ground Storage Reservoir No.1 to the Town(20m<sup>3</sup> x 2 basins)



[Uma Boco-Fehuk Krin] – 4. Storage Reservoir No.2 located on a hill (50m<sup>3</sup> x 2 basins), high enough to supply water to the project site by gravity



[SP4] – 1. Overview of Project Site



[SP4] – 2. Dug Well under Construction





[SP4] – 3. Excavated Silt and Sand of the Dug Well Bottom Layer



[Natarbora] - Meeting with Suco Leader on Possible MDG Suco Project



[F-FDTL] – 1. Leaks from the Bottom of the Reservoir newly Constructed



[F-FDTL] – 2. 200 Houses Completed



[F-FDTL] – 3. Aubaka Spring Located inside Forest, (Suco leader reluctant to visit the spring)



[F-FDTL] – 4. Existing Raw Water Transmission to F-FDTL (4km x 3" in diameter, GSP)





# Attachment (Drawings)

1. Mehara, Lautem district

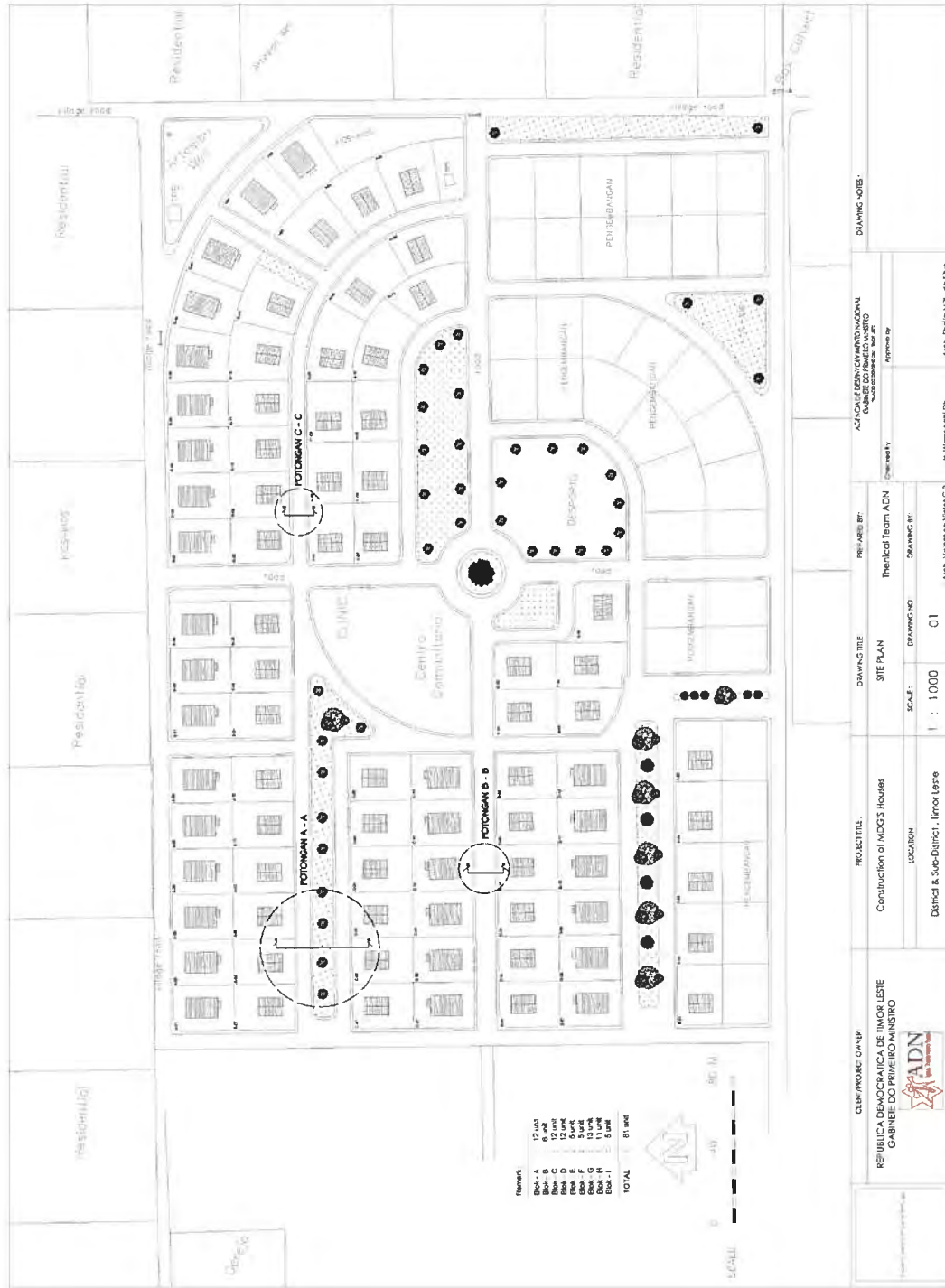


2. Wesoru, Viqueque district

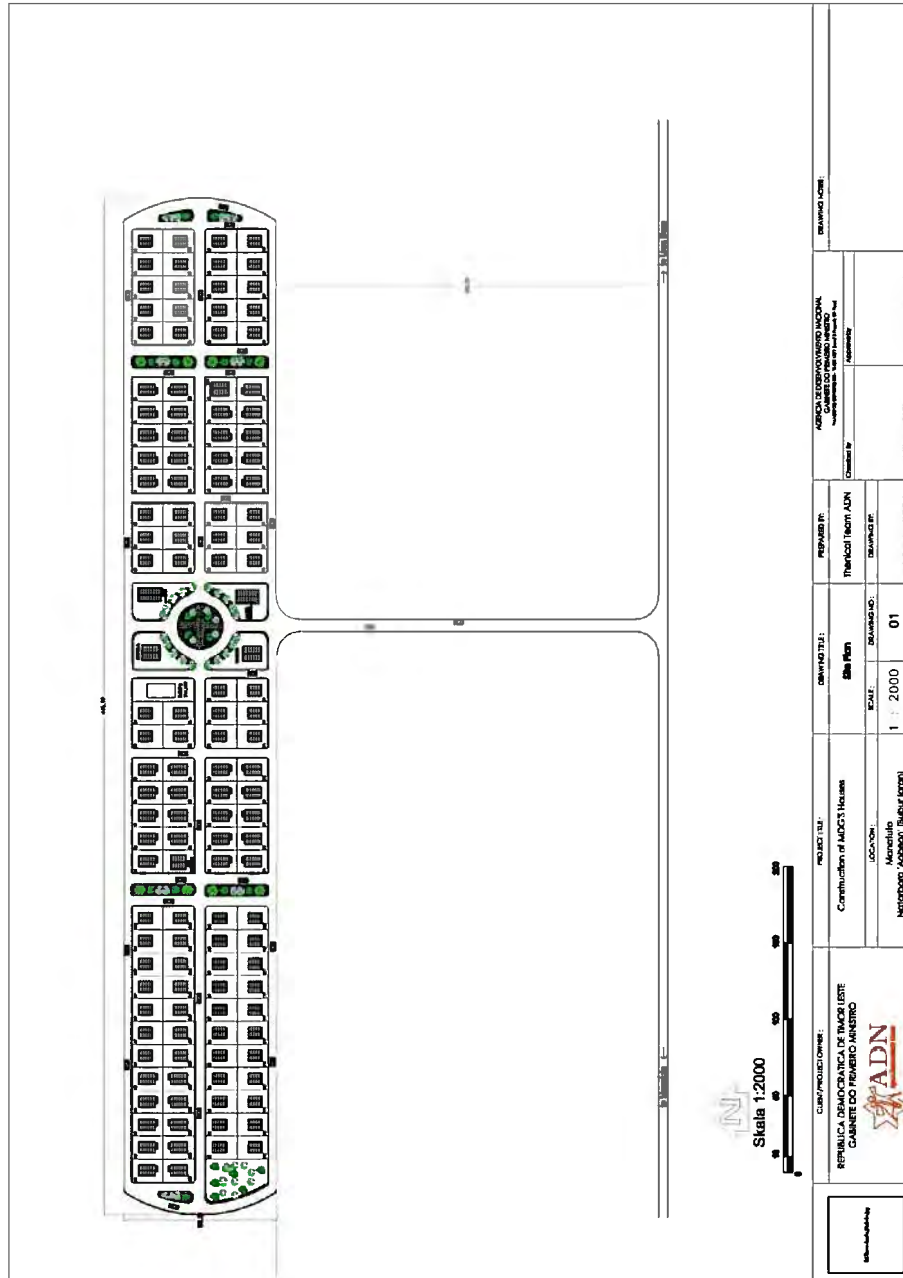


 CAHUPROJECCIONER: REPUBLICA DEMOCRATICA DE TIMOR-LESTE GABINETE DO PRIMEIRO MINISTRO 	PROJECT TITLE: Construction of MDG'S HOUSE	DRAWING NO.: 01	DRAWING DATE: 01	DRAWING BY: The local MDG's (Home)	ARCHITECT: P. Wernscheidt
	LOCATION: Westside/Vesoru	SCALE: 1 : 2000	PROJECT NO.: 01	PROJECT DATE: 01	PROJECT NO.: 01

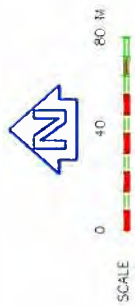
3. Aubeon-Buburlaran, Manatuto district



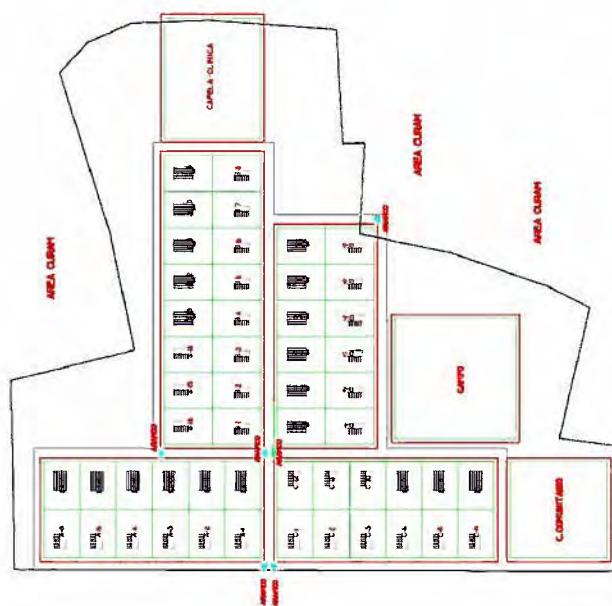
4. Uma Boco-Fehuk Krin, Manatuto district



5. SP4, Viqueque district



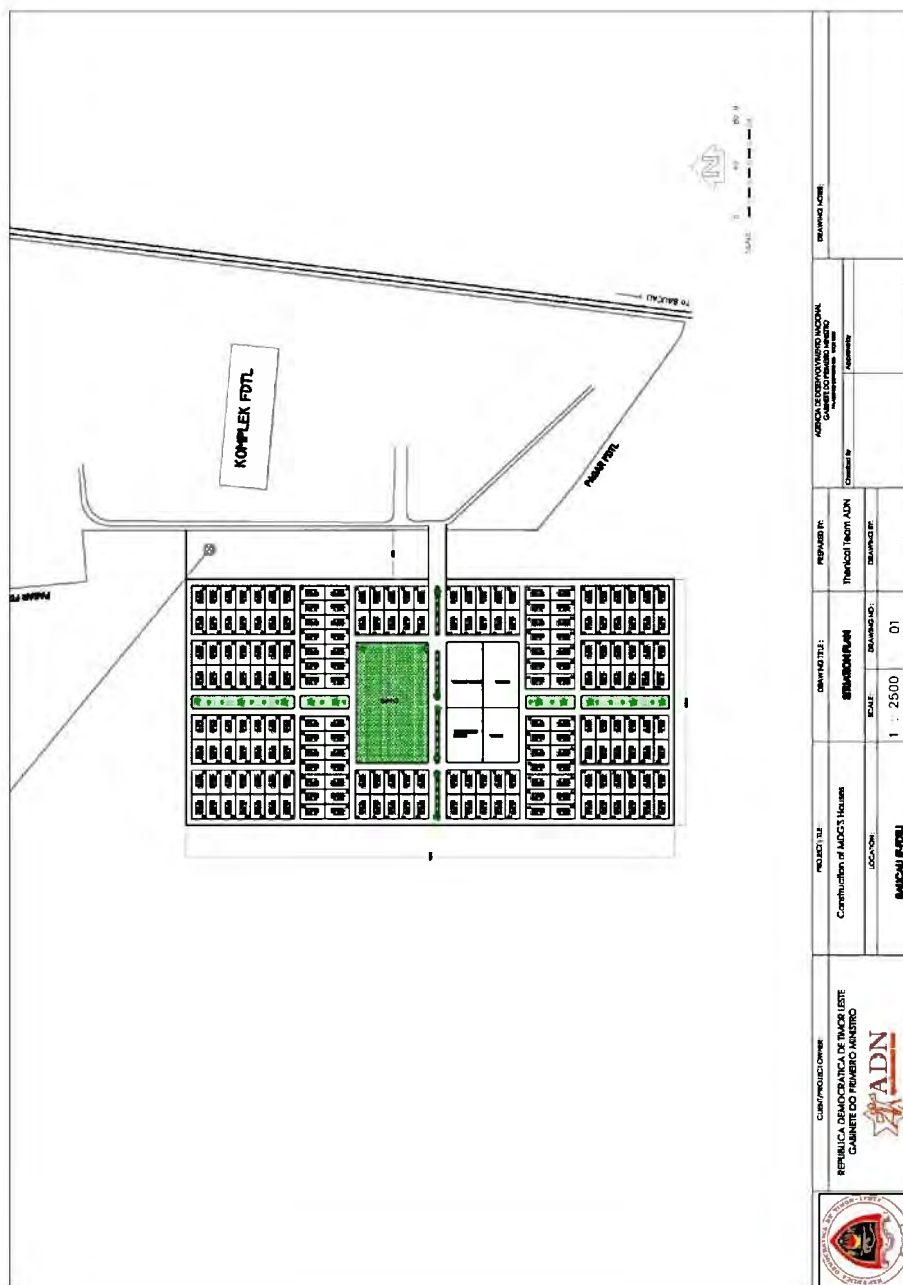
SITE PLAN VIQUE\_QUE\_02



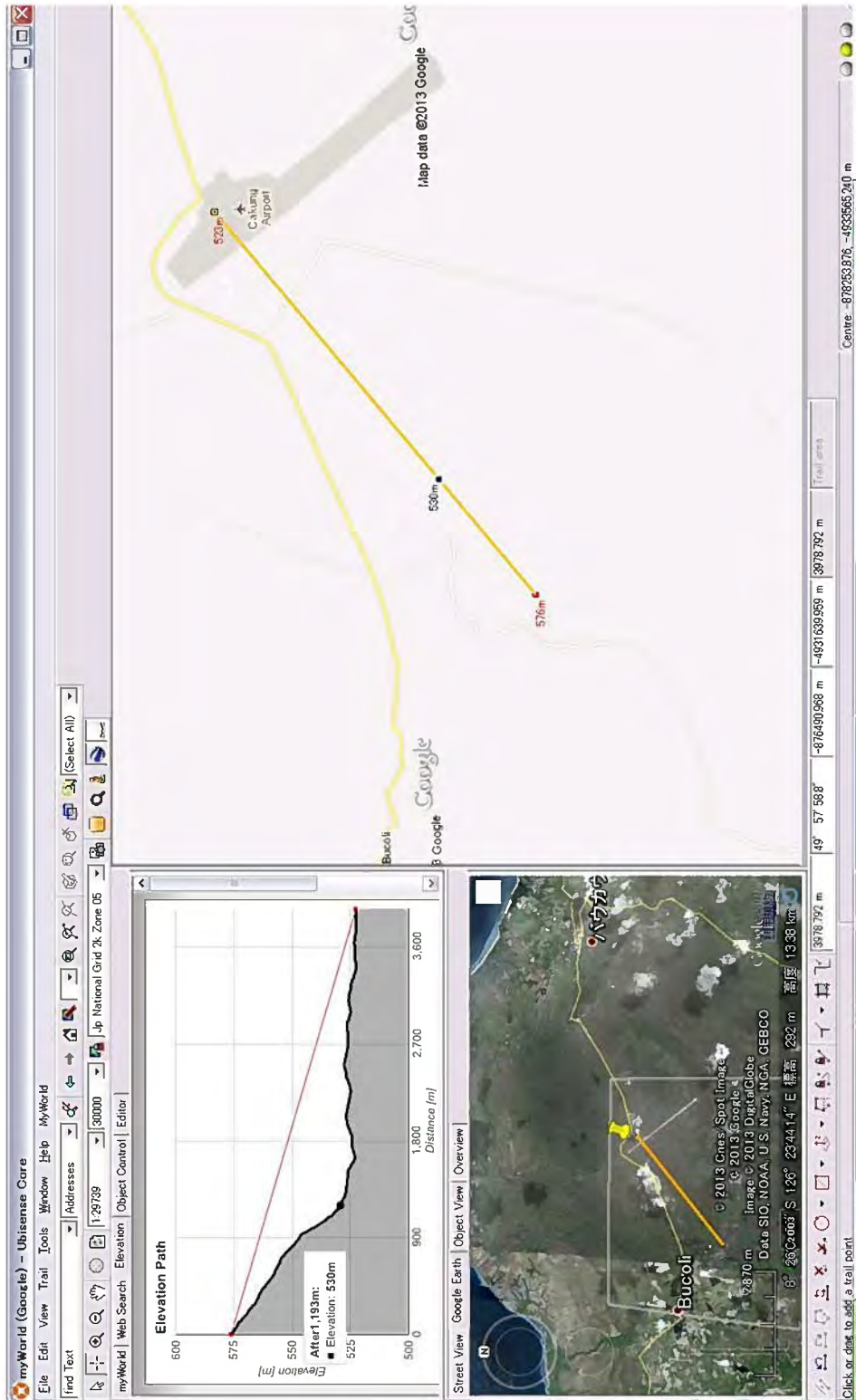


6. F-FDTL, Baucau district

1) Plan



## 2) Profile of Raw Water Main





## Site Inspection Report on Lahane, Dili District

By Higuchi Hideo, JICA-ADN

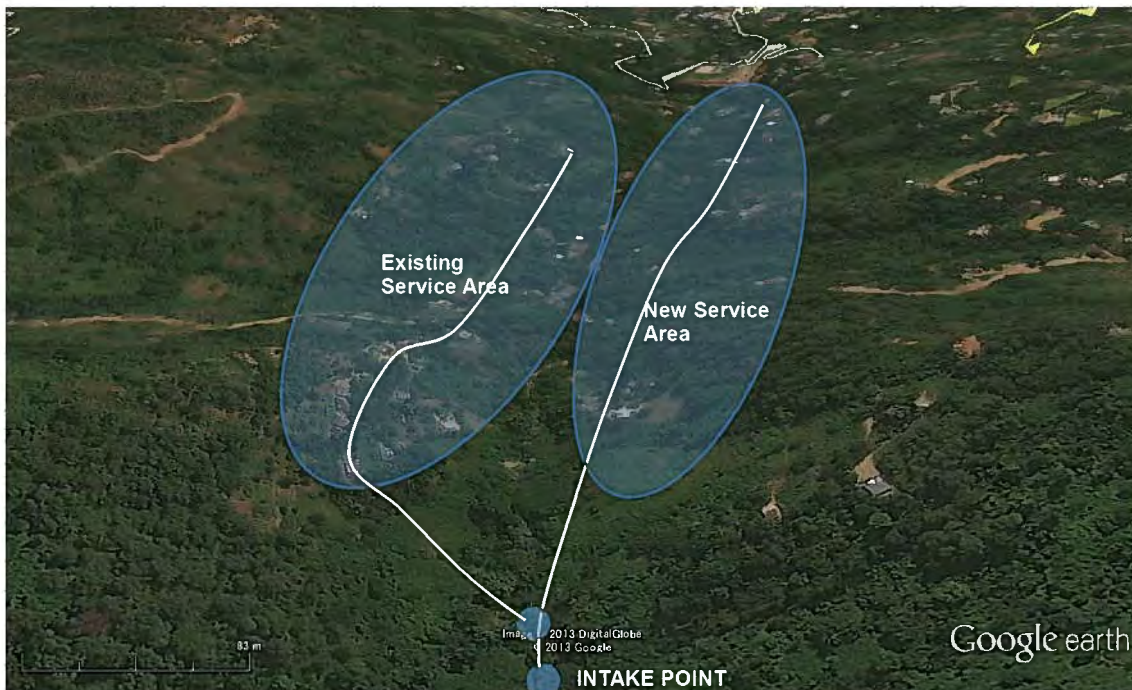
Inspection Date: 31 July, 2013, 9:00 – 14:00

Location: Suco Lahane Oriental, Dili District

Project name: Rehabilitation of Water Supply System in Suco Lahane Oriental

Inspector: Paul Abrantes, Lisandro Manuel

JICA-ADN: Higuchi Hideo



### 1. Inspection Root

The inspection was done from a distribution tank at downstream to the intake along the transmission pipeline.

### 2. List of facilities

- Intake facilities
- Distribution tanks (3 tanks)
- Transmission pipelines (4 lines)
- Distribution pipe
- Public taps (4 taps)

### 3. Results of inspection

#### a. General issues

The Inspector is responsible for determining that the work being done and the materials being used meet the requirements of the Drawings and Specifications. The authority of the Inspector is explained as followings:

- The Inspector has the authority to reject defective material or work that is being done improperly.
- The Inspector also has the authority and obligation to notify the Contractor when unusual conditions have been created or encountered during construction.
- The Inspector should realize that he/she is not authorized to revoke, alter, or relax any requirements of the Contract; or to issue a Stop Work Order to the Contractor.

In the Inspection of this time, the general issues of critical importance are as followings.

- Inspection is to ensure that the contractor's work is carried out in accordance with contract documents and specifications of the project. But the drawings are too poor, so it is unreasonable not only to construct in accordance with the design drawings, but also to inspect it based on the contract documents.
- The external appearances such as tank's dimension can be checked, but invisible parts such as reinforced bars in concrete and concrete strength cannot be inspected by site inspection.
- The contract document must be changed according to the actual situation and conditions before the inspection. But, there is no person in charge of supervising and the work variation.
- It is very difficult to ensure good quality of infrastructure without daily supervising because contractors often select cheaper materials and easier ways.

#### b. Intake facilities



photo-1



photo-2



photo-3

photo-1 to 3: unsatisfactory infiltration basin

- The raw water is surface water of a stream, it looks like clean.
- An infiltration basin is made next to the stream. The idea is very good.
- The structure is not optimal. The bed depth is 40 cm, it is too shallow.
- The bed is designed as three layers of gravel and sand, but the constructed bed structure is different from the design.
- The bottom of basin is not necessary to get better quality water.

c. Distribution tanks

- The dimension of tanks are almost correct.
- Concrete thickness of a tank roof is not sufficient.
- Manhole structure of a tank roof is not correct.
- Inlet amount of a tank is not sufficient.
- There are some additional outlet pipes from tanks (not on design drawings).
- There are no valves on inlet and outlet pipes.
- There are no air ventilation on design drawings. Ones are there at some tank, but there is no ventilation at one tank.
- The tanks are painted, so the workmanship of concrete cannot be confirmed.
- Reinforcing bar and concrete thickness of wall cannot be confirmed.



photo-4: painted tank



photo-5: bad manhole structure





photo-6: low water level



photo-7: small Q of inlet



photo-8: another inlet



photo-9: with air ventilator



photo-10: additional outlet pipe

#### d. Transmission pipeline

- The pipeline lengths and diameters are inspected correctly.
- The pipeline lengths are far different from the design. Lack of survey at designing.
- GI pipe are bended by force without using bend-joints.
- Pipes are laying on ground. In design they are laid underground.
- There are no drawing of profile of pipe laying.
- Pipes are laid up-and-down without air valves.



photo-11: complex jointing



photo-12: bending without bend-joint

#### e. Public tap

- Pipe connected to a faucet is not installed in the concrete stand.



photo-13: pipe passed through concrete stand

#### 4. Summary

- a. It is the biggest problem that water cannot be served to residents after the completion of water supply system in spite that there is sufficient amount of water source. It is not the hydraulics of the pipeline or the diameter of pipes. The main causes are (1) up-down profile of the pipeline, (2) no air release valve at summit of pipeline, and (3) insufficient air release from the pipeline when water was filled into the pipeline first.
- b. There are many differences between the design drawings and the actual site conditions. In these cases the contract including the drawings must be changed to meet the actual site conditions during the construction works. The different works from the contract are equal to no-contract works. Finally it may become a trouble at the payment.
- c. Construction inspection consists of the site inspection and the document inspection generally. At the document inspection the records of used materials and photos under constructing are necessary as the evidences to prove that the works were done correctly.
- d. The construction works were proceeded without any supervising. Therefore many incorrect points were found at the inspection, but it was too late. In the worst case some constructed facilities must be destroyed or replaced. Daily supervising is very important to prevent incorrect construction. Supervising system in small projects such as PDD should be established.

## CHECKSHEET: Design of Water Supply System of Gleno Residence (MDGsuco)

### 1. Project concept

Is the project proposed in accordance with Government Strategy (rural and urban water supply development strategy)?

MDGsuco: New Residence Development

### 2. Coordination

Was all coordination made between the relevant agencies?

### 3. Project area

a. Are data/information available, including:

a-1. number of present population and households,

a-2. major income sources,

a-3. development history of the villages/towns,

a-4. rainfalls?

b. Are the area frequently affected by natural disaster like

floods or  landslides?

c. Present population =   0   HHs x        Persons/HH

HH: Household

### 4. Project target

a. Target year: \_\_\_\_\_

b. Number of households to be served:   170  

c. Number of population to be served:   170 x 5 = 850  

### 5. Existing condition

a. Are data are available on:

a-1. What are the present water sources for people's daily lives?

a-2. What are their major problems

(quantity, quality, distance)?

a-3. What are health condition of the people? (morbidity rate of water borne diseases)

### 6. Planned water source

a. Is water source sufficient in quantity and quality?

a-1. Quantity: 2.0 L/sec

a-2. Quality :  turbid,  not turbid

The category of water source is stream, not spring. Turbidity may be under 5 ntu (WHO Guideline), but pollution by microbial contaminants is worried. Slow sand filtration or intake of infiltrated water/ground water as raw water is recommended.

b. Is its yield stable throughout the year?  yes,  no

c. Is gravity flow system applied for water transmission?

yes,  no

d. Catchment area of the source: \_\_\_\_\_ m length x \_\_\_\_\_ m width

## 7. Future water demand

a. How to supply water to the people

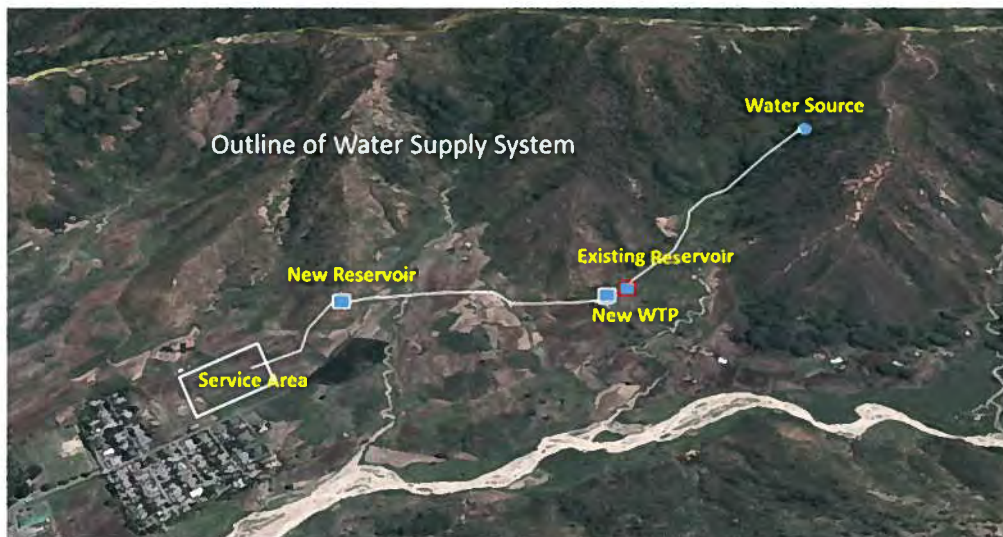
house connection  public taps

b. Design value of unit water consumption per capita per day: 100 L/c/d

c. Is calculation for future water demand by the service population made or not?

yes,  no

## 8. Pipeline design



a. Is pipe diameter estimated using pipe-flow formula with variables of distance, height and flow rate?

yes,  no

b. Are drawings of hydraulic profile based on field survey attached?

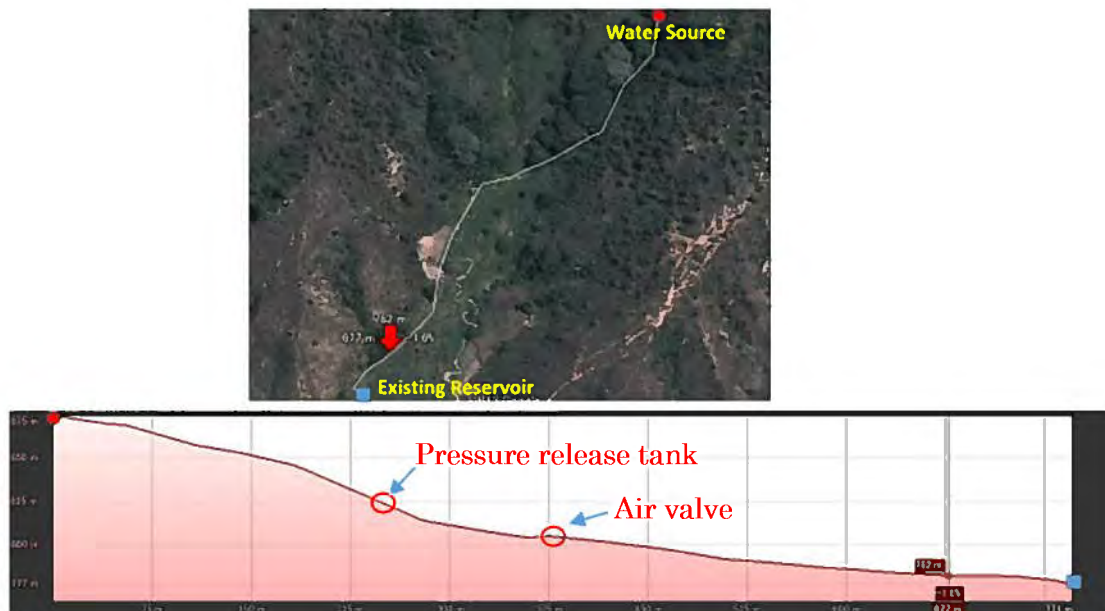
yes,  no

c. Are pipe accessories such as gate valves, air valves, wash-outs properly designed?

yes,  no

**Point 1: Raw water transmission main (from the water source to the existing water reservoir)**

- ◇ Pipe diameter (by PIPECAL)
- ◇ Air valve
- ◇ Wash-out valve
- ◇ Pressure release
- ◇ New pipe laying or existing pipe repair
- ◇ Water quantity control valve (Inlet valve of reservoir)



GL of Water Source: 875 m (uncertain)

GL of Existing Reservoir: 777 m

It is better to set a pressure release tank at place of GL 825 m, and water quantity control valves are necessary at inlet pipes of both new tank and existing reservoir.

**Point 2: Transmission main (from the WTP to the new reservoir)**

- ◇ Pipe diameter (by PIPECAL)
- ◇ Air valve
- ◇ Wash-out valve
- ◇ Water quantity control valve (Inlet valve of reservoir)

**Point 3: Distribution main (from the new reservoir to houses)**

- ◇ Pipe diameter (by EPANET) and Peak Factor (=2.0)
- ◇ District valve



- ✧ Air valve
- ✧ Wash-out valve
- ✧ Fire hydrant

### 9. Service reservoir design

a. Is the capacity of reservoir sufficient? \_\_\_\_\_ m<sup>3</sup>

$$Cr = (1/4) (ADD)$$

where:

Cr = Reservoir capacity in liters

ADD = Average day demand in liters per day

$$Cr = 1/4 \times 850 \times 100 = 22000 \text{ L (L 4m x W 3m x H 2m)}$$

b. Is the reservoir equipped with

- inlet valves,  outlet valves,  drain pipes,  overflow pipes,
- air ventilator.

c. Is concrete structure with reinforcement bars normally designed:

- yes,  no

### 10. Public taps

a. Number of faucets equipped at a public stand: \_\_\_\_\_ faucets

b. Number of households to be served by a public stand: \_\_\_\_\_ households

c. Are concrete apron properly designed:

- yes,  no

d. Are drain pipes equipped at the concrete apron:

- yes,  no

### 11. Operation & maintenance after construction

a. Is water user committee planned to organize in the village/town:

- yes,  no

b. Is an operation plan (cleaning, valve control, etc.) prepared:

- yes,  no

c. Will fixed amount of fees for O&M be collected from the households:

US\$ \_\_\_\_\_ /month/household

### 12. People's awareness

a. Do people have an awareness to pay for O&M fees:

- yes,  no

b. Do people have a willingness to be serviced:

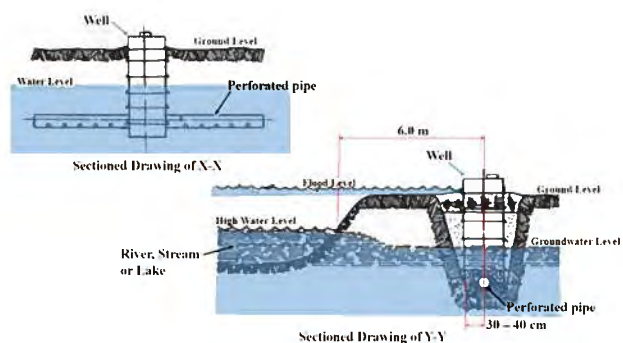
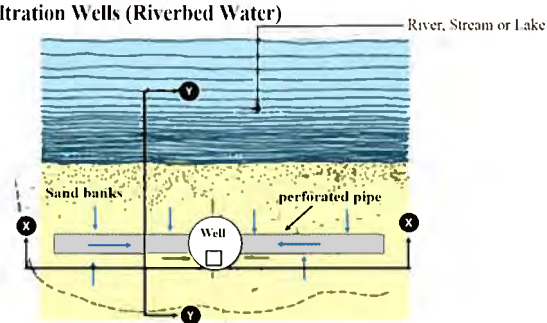
\_\_\_\_\_ households out of \_\_\_\_\_ households

### Alternative Plan

It is better to find another water source when WTP would not be constructed.

Infiltration intake is an alternative.

#### Infiltration Wells (Riverbed Water)



## Site Inspection Report on Water Supply Facilities in Viqueque District

By Higuchi Hideo, JICA-ADN

Inspection Date: 12 - 13 August

Location: Viqueque District

Project name: (a DNSA's project)

Inspector: Demistocles G. X. F. Cabral (PDID Section Chief),  
two ADN engineers

JICA-ADN: Higuchi Hideo

*This is an inspection report on only water supply facilities.*

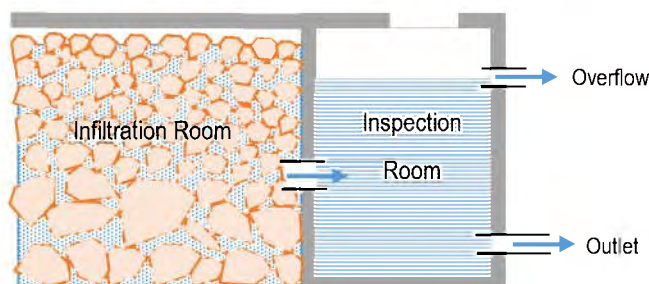
### 1. Inspection facilities

- Intake facilities

### 2. Results of inspection

#### Intake facilities of water supply system

- The water source is spring water, it looks like clean and sufficient judging from the overflow water.
- The structure of intake facilities in the design consists of two rooms which are an infiltration room and an inspection room.



- The partition wall between the infiltration room and the inspection room was not constructed. Therefore, the whole space was filled with sand and gravel. As a result, it is impossible to monitor the quantity and the quality of the raw water.
- The transmission pipe from the water source is crossing a fast-flowing stream and the protection on the pipe from rolling stones is not sufficient. The pipe is easy to be damaged.



photo-1: Overall view of the Intake facilities and Transmission pipe



photo-2: the Intake facilities



photo-3: the Intake facilities filled with sand and gravel



photo-3: the Transmission pipe crossing a fast-flowing stream

### 3. General Issue

The construction works might be proceeded without any supervising. Therefore several critical points were found at the inspection, and the repairs or the recovery of faults after construction completion are usually very difficult. In the worst case some constructed facilities must be destroyed or replaced. This is waste of time, energy and money.

To prevent these incorrect constructions or to control the quality of constructions, supervising during construction is very important.

The fig.-1 shows the general structural chart of project implementation. In governmental projects, the parts of outline letters on a colored background are the actual governmental works in general.

In a case of PDID, the parts of Verification and Inspection are the roles of ADN. The ADN's inspection is the last gate to ensure good quality of infrastructures, but it does

not have the function to control the quality of infrastructures. Supervising system (the place of duty and job description) in small projects such as PDID should be made clear.

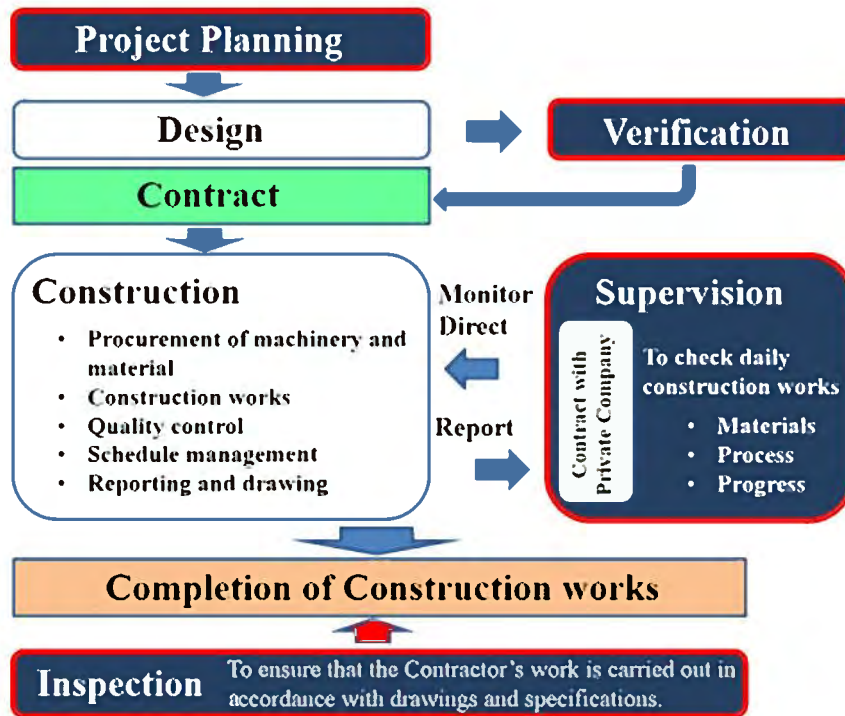


fig.-1: General structural chart of project implementation