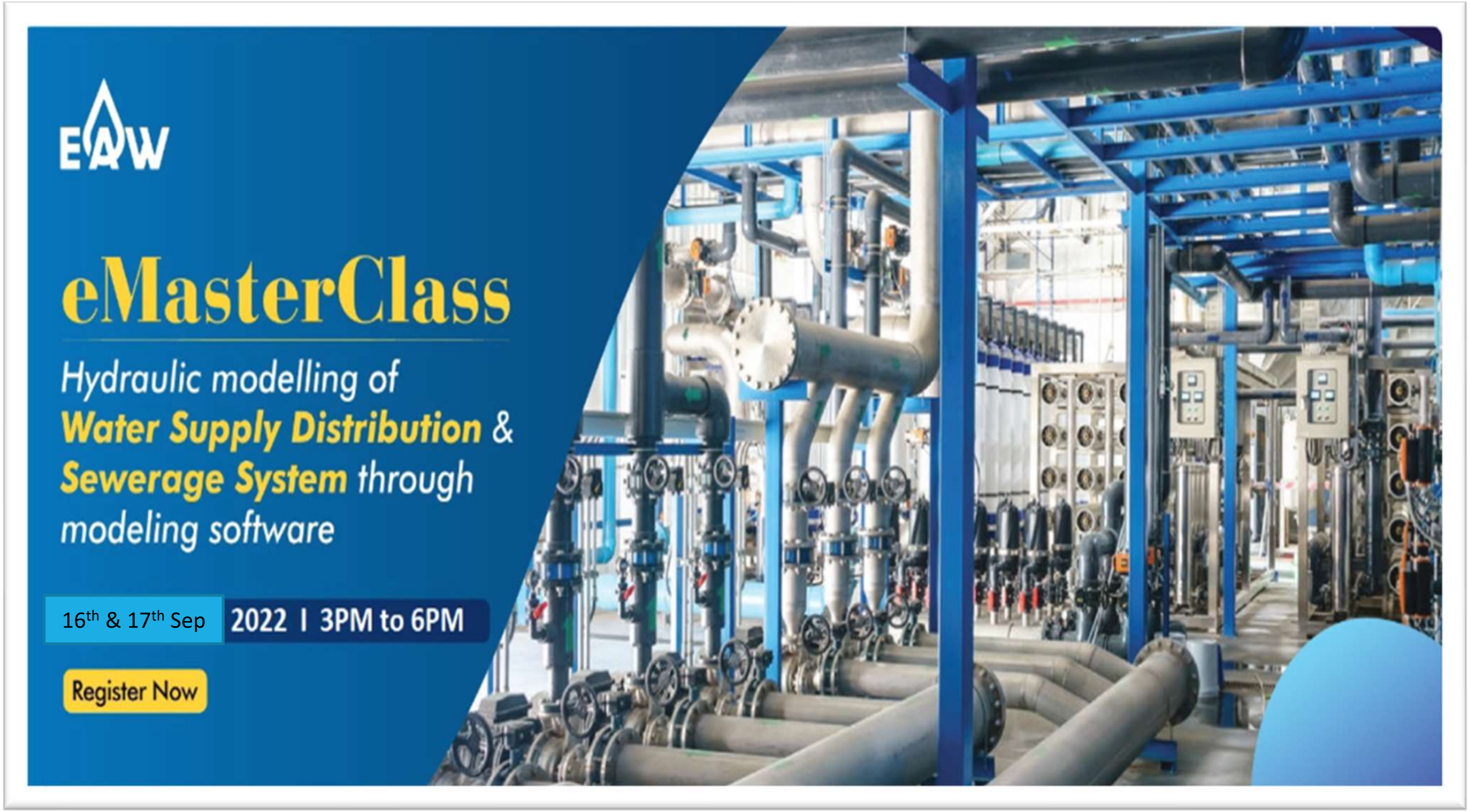
Hydraulic modelling of Water supply Distribution system through modelling software



Date of Training : 16.09.2022

Course Contents

- Overview on Water supply distribution components
- Design parameters
- Basics on Hydraulics of Water distribution system
- Creation of Hydraulic model of a water supply network
- Requirements of Hydraulic model
- Modelling software elements
- Happening inside a Hydraulic model
- Building a Hydraulic model & its process
- Creation of operational water zones & DMA in the Hydraulic model.
- Design criteria of operational water zones & importance on need for DMAs
- Optimization of pipe network through iterative steps in the model
- Use of various valves in the hydraulic modelling
- Extended period simulation vs Steady state method of modelling
- Benefits & Use of Simulated model results from a Hydraulic model

Water Distribution System

- The purpose of the distribution system is to convey wholesome water to the consumer at adequate residual pressure in sufficient quantity at convenient points for a combinations of the following demands:
  - Domestic
  - Commercial – Non Domestic
  - Industrial
  - Fire-fighting

- Consists of a network of pipes with appurtenances
- Transports water from treated water Source to consumer's tap
- Includes storage, service or balancing reservoirs

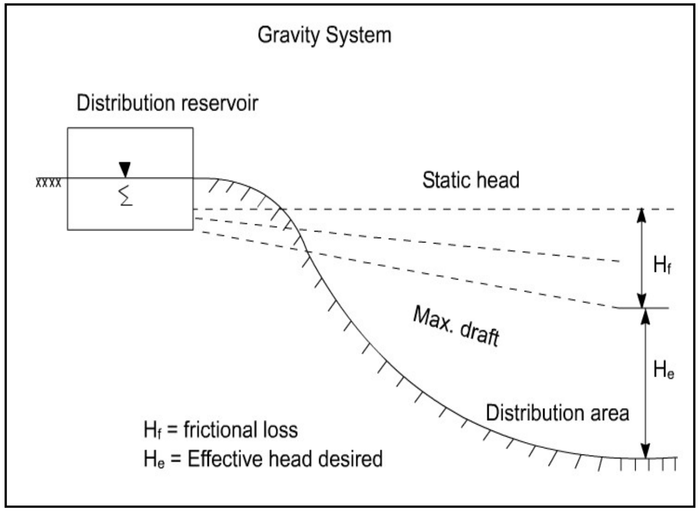
Water Distribution System

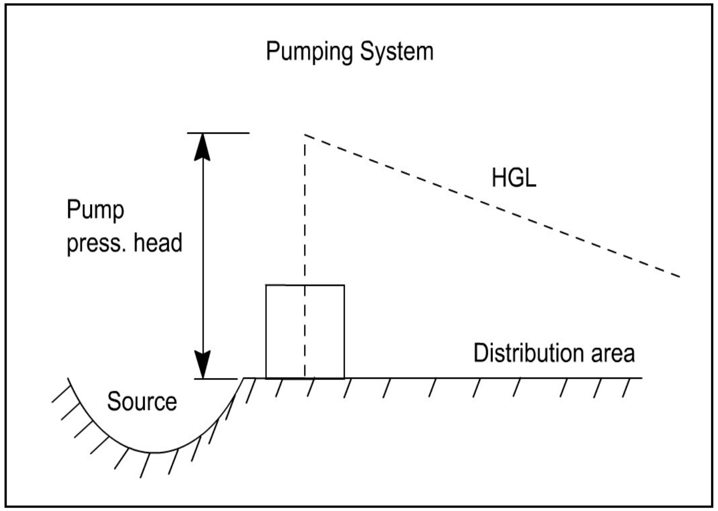
Distribution Methods

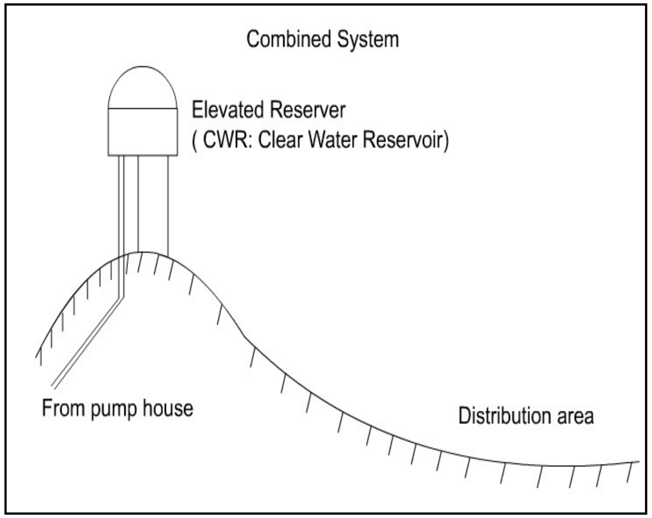
Three types:

1. Gravity System
2. Pumping system
3. Combined gravity and pumping system

Choice depends on topography of the area







Design Parameters – (1/2)

Basis of Design :

1. Manual on Water Supply and Treatment - 1999 – CPHEEO
2. Guidelines for Planning ,Design and Implementation of 24x7 Water supply systems. (Dec - 2021)

Design Period - 30 Years

- Base year – Year at which project is expected to be completed.
- Intermediate design year – 15^{th} Year from Base year.
- Ultimate design year -30^{th} Year from Base Year.

Per capita supply

- Supply at consumer end for cities/ towns with population less than 10 lakhs should be 135 lpcd and for larger cities having population of 10 lakh or more should be designed for 150 lpcd.
- Non-domestic demand, bulk supply etc. should be computed as per actual consumer survey.
- Floating population demand : 15 lpcd to 45 lpcd (Depends on local site conditions to be adopted)
- Fire demand $=100 \sqrt{P}$ (m^3/day)

Minimum Residual head at ferrule point : 7 m, 12 m & 17 m. *(As per latest guidelines on 24x7WS minimum **residual head shall be 12 m)***

Peak factor for design of water distribution system - 2.0 to 3.0

Design Parameters – (2/2)

S.No.	Components	Design Period
1	Civil Structures for pump house & WTP	30 years
2	Electrical motors and pumps	15 years with space to expand
3	Collection system & Pumping main	30 years.
4	Balancing tanks and service reservoirs (Overhead or ground level)	15 years with space to expand
5	Distribution system	30 years.

Storage requirement of Service Reservoirs – 1/3 of intermediate year water demand and it is recommended to do the mass balance calculations for arriving the storage requirements.

Minimum size of pipeline : 100 mm for class – I cities and 80 mm for hilly terrain.

Design Velocity for Gravity system

- Minimum velocity : 0.3 m/s
- Maximum velocity : 2.7 m/s

Pipe Materials

(1) Distribution system- Provide metallic and non-metallic pipes as per the site and service conditions.

(2) Raw and clean water Rising/ Feeder Mains-

These are the arteries of water supply projects and they must be laid with metallic pipes lined from inside & non-metallic pipes as per the site and service conditions.

Basics on Hydraulics of Water Distribution System (1/3)

Flow Q (m³/s) *through a cross-section A* (m²) *is determined as*

$$Q = AV,$$

where v (m/s) is the mean velocity of the cross-section for a uniform flow condition.

Water flows from a region of higher energy to a region of lower energy
- *Energy terms are typically expressed as head (m of Water)*

Darcy-Weisbach Equation

$$h_f = f \frac{L}{D} \frac{v^2}{2g}$$

h_f = headloss
f = Darcy-Weisbach friction factor
L = pipe length
V = average pipe velocity
g = gravitational constant

Hazen-Williams Equation

$$h_L = \frac{C_f L}{C^{1.852} D^{4.87}} Q^{1.852}$$

h_L = pipe friction head loss
L = pipe length
C = Hazen-Williams C factor
D = diameter
Q = flow rate
C_f = unit conversion factor

Basics on Hydraulics of Water Distribution System (2/3)

Continuity Principle

Conservation of mass: Mass in = Mass out

For steady incompressible flow:

- net flow into junction = use at junction.

$$\sum Q_i = U$$

Where:

Q_i = flow in ith pipe into junction

U = usage at junction

Energy Principle

$$H = Z + (P/\gamma) + (V^2/2g)$$

In hydraulics, energy converted to energy per unit weight (ft-lb/lb) of water, reported in length units (ft) called "head".

3 forms of energy:

- (1) Pressure - p / γ
- (2) Velocity - $V^2 / 2g$ (usually negligible)
- (3) Elevation - z

where:

p = pressure

γ = specific weight of fluid

V = velocity

g = gravitational acceleration

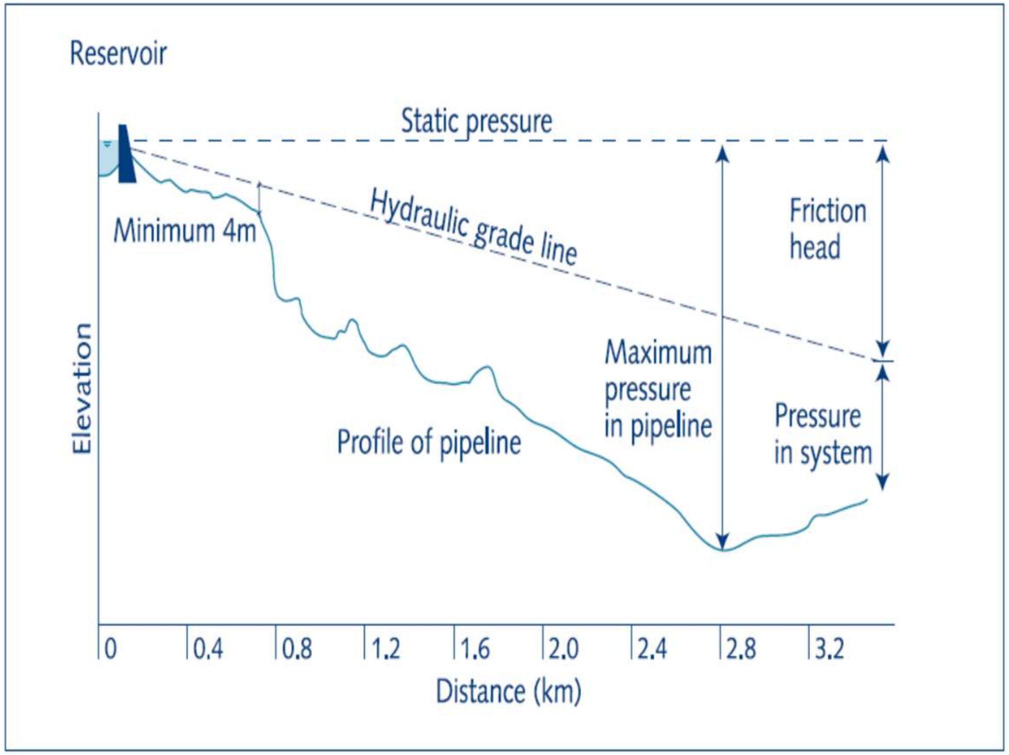
z = elevation

Basics on Hydraulics of Water Distribution System (3/3)

Hydraulic Grade Lines

HGL = Sum of the pressure and elevation head terms at-a-point

$$Pipe\ flow:\ HGL = \frac{P}{\gamma} + z$$



p = fluid pressure

g = specific weight of fluid

Z = elevation above an arbitrary datum plane

1. The slope of the hydraulic grade line is called the *hydraulic gradient*.
2. *The flow rate in pipes under pressure is related to the hydraulic gradient and not to the slope of the pipe. More energy is needed for a pipe to convey more water, which is expressed in the higher value of the hydraulic gradient.*

Timeline of Distribution System Modeling

1930's

Hardy Cross Network Flow Analysis

1960's

Computer Analysis of Networks

1970's

Widely available models for mainframes and minis

1980's

PC-based models

Steady-state water quality models

Dynamic water quality models

1990's

Integrated modeling - mapping - database – GIS - SCADA

Contaminant kinetics
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Optimization

2000's

Future

Multi-platform Models

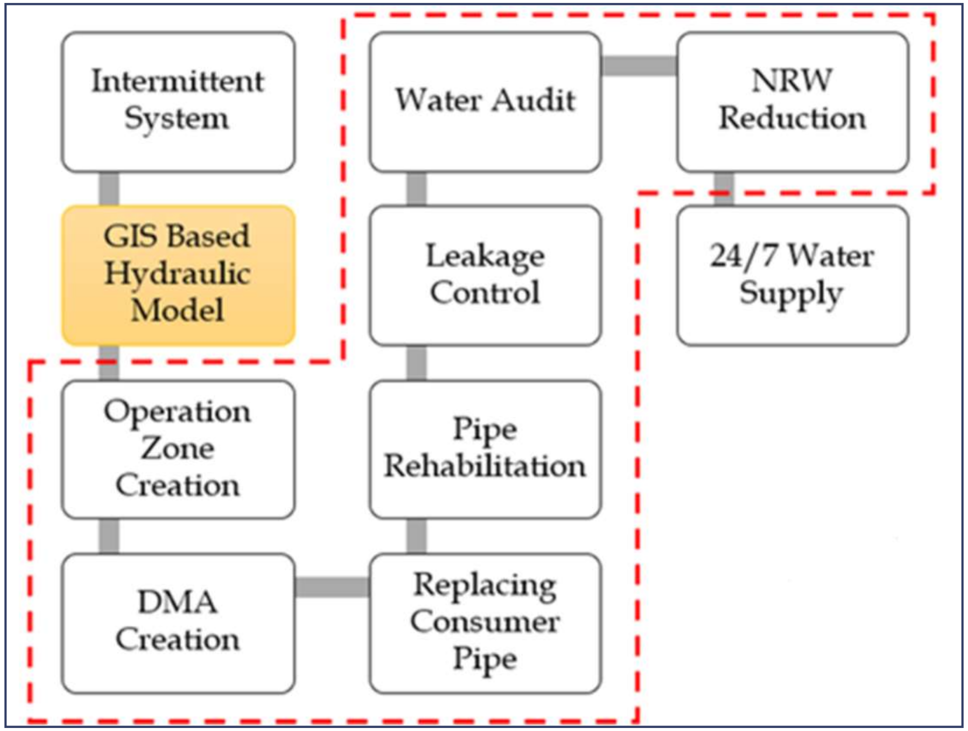
Critical Analysis Management

Integration of Transparent GIS

Detailed Water Quality Modeling

Creation of Hydraulic model of a water supply network

Major Activities in Creation of Hydraulic Model



- ✓ Population data collection and demand projection
- ✓ Field topogrpahical survey
- ✓ Existing water supply system study & pipe condition survey inlcuding water auditing.
- ✓ Adequacy of existing water supply distribution pipe network
- ✓ Mass balance for service reservoirs – Storage Capacity adequacy check
- ✓ Redesign and analysis of new distribution network
- ✓ Creation of Pressure & DMA Zones & Sub-zoning

Creation of Hydraulic model of a water supply network

Future Demand Projections :

The demand growth is considered based on the following criteria:

a) Growth of domestic population based on population density
b) Growth of non-domestic and industrial/institutional population in proportion to the customer survey
c) Bulk demand based on existing customers and expected future growth
d) Provision of 15 % System losses also to be added .

Distribution /Service reservoirs (ESRs/ OHTs) :

a) To be preferably Located centrally
b) To be preferably Located on high grounds
c) Central location : reduces frictional losses
d) The elevation of the service reservoir should be such as to maintain the minimum residual pressure in the distribution system consistent with its cost effectiveness.
e) Boosting & Pumping:
For distant localities, boosters may be provided instead of increasing the size of mains or height of the reservoir unduly for maintaining the required pressure.

Base map Creation & Network marking:

a) Conduct field surveys
b) Fix the alignment of raising main
c) Prepare topographical map of the project area/town
d) Prepare cross-sections of streets etc
e) Mark tentative lay out of network
f) Show positions of reservoirs,
g) Mark the existing pipes, valves and other appurtenances

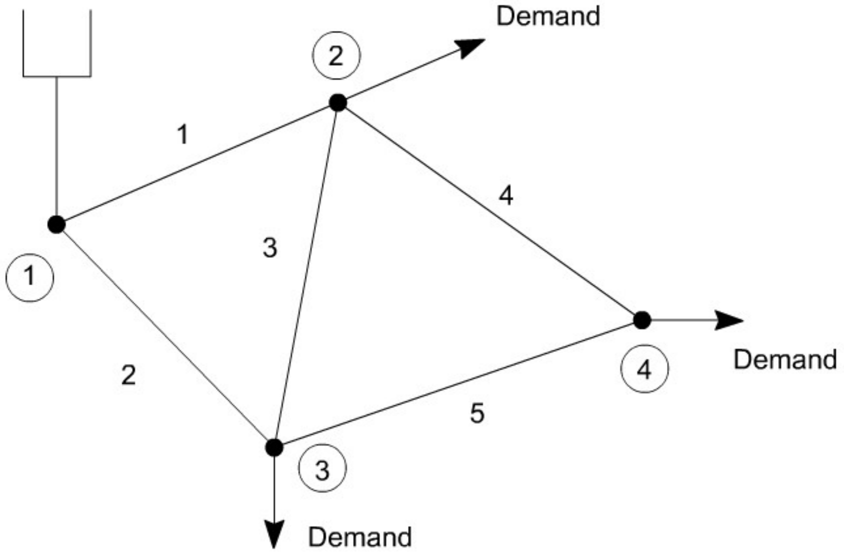
Network design

a) Estimate demands based on population density
b) Assume appropriate diameters
c) Analyze the system for pressures
d) Check for satisfaction of constraints
e) Assume another set of diameters
f) Repeat the process
g) Select the system: satisfies all the constraints and is most economical

Creation of Models.pptx

Happening inside a Hydraulic model

Water distribution network (WDN) Analysis



Analysis is based on...

•Flow into a node = flow out of node

•Piezometric head at any node is same irrespective of path we talk for computation

•Head loss, $H_u - H_d = RQ^2$

•Formulations can be extended if valves, pumps etc are present

•Can be computer coded & Analysis thus require a software like EPA-net, WaterGems Etc.

Referring to the fig

<u>Known</u>

1. demand De at each node
2. R for each pipe
3. Piezometric head, H_1

<u>Unknowns</u>

1. Flow rate in each pipe, Q
2. Piezometric heads, H_2, H_3 and H_4

•There are eight unknowns

•We require eight equations

•Flow balance eq. at node 2:

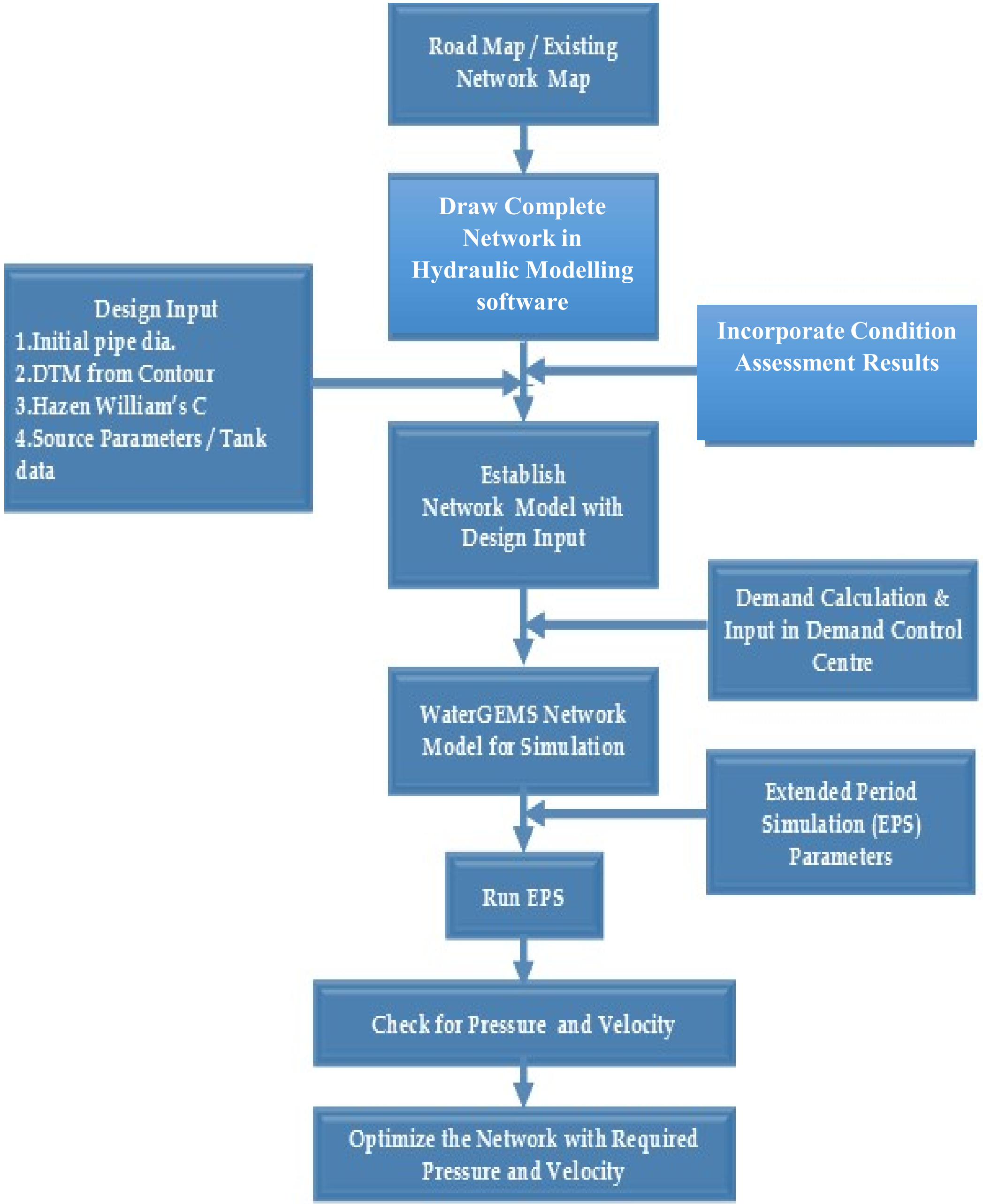
$$Q_1 - Q_3 - Q_4 - D_{e2} = 0$$

•Express flow in terms of piezometric head

$$\sqrt{\frac{H_1-H_2}{R_1}} - \sqrt{\frac{H_2-H_3}{R_3}} - \sqrt{\frac{H_2-H_4}{R_4}} - D_{e2}=0 \quad \sqrt{\frac{H_1-H_3}{R_2}} + \sqrt{\frac{H_2-H_3}{R_3}} - \sqrt{\frac{H_3-H_4}{R_5}} - D_{e3}=0$$

$$R=\frac{fL}{2g\left(\frac{\pi}{4}\right)^2 D^5} \quad \sqrt{\frac{H_2-H_4}{R_4}} + \sqrt{\frac{H_3-H_4}{R_5}} - D_{e4}=0$$

Building a Network Modelling & its Process



Design, Analysis and Network modelling

Strategic hydraulic model can be developed using any available Hydraulic modelling latest software

(USEPAnet, Bentley WaterGEMs, InfoWorks WS PRO / InfoWater Pro, Aqua ++ from tandler.com and many more)

like elevation, demand, peak factor for junctions and diameter, length, friction coefficient for the pipes.

Major Elements in a Hydraulic Model :

- **Junction**
- **Pipes**
- **Valves**
- **Storage Reservoir**
- **Hydraulic Pattern**

Elements in a Network Modelling

Junction:

Junction reference number

Ground elevation

Junction water demand

Pipes:

Pipe reference number

Length of the water distribution pipe line between junctions

Diameter of the pipe line

Material of the pipe line

Hazen Williams Coefficient ('C' Value)

Valves:

- Valve reference number
- Size of valve
- Type of valve (SV, AV, PRV etc.)

Storage Reservoir:

- Ground Elevation,
- Staging Height/ Hydraulic Grade Line
- Storage capacity
- Inlet/ out let size

Hydraulic Pattern:

- Flow pattern with peak factor
- Extended period simulation

Creation of Hydraulic model of a water supply network

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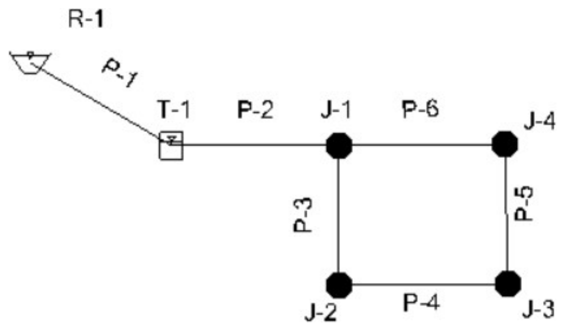
Creation of Models.pptx

System Configurations

Distribution systems may be classified as:

- Branching systems
- Grid systems
- A combination of the above two systems

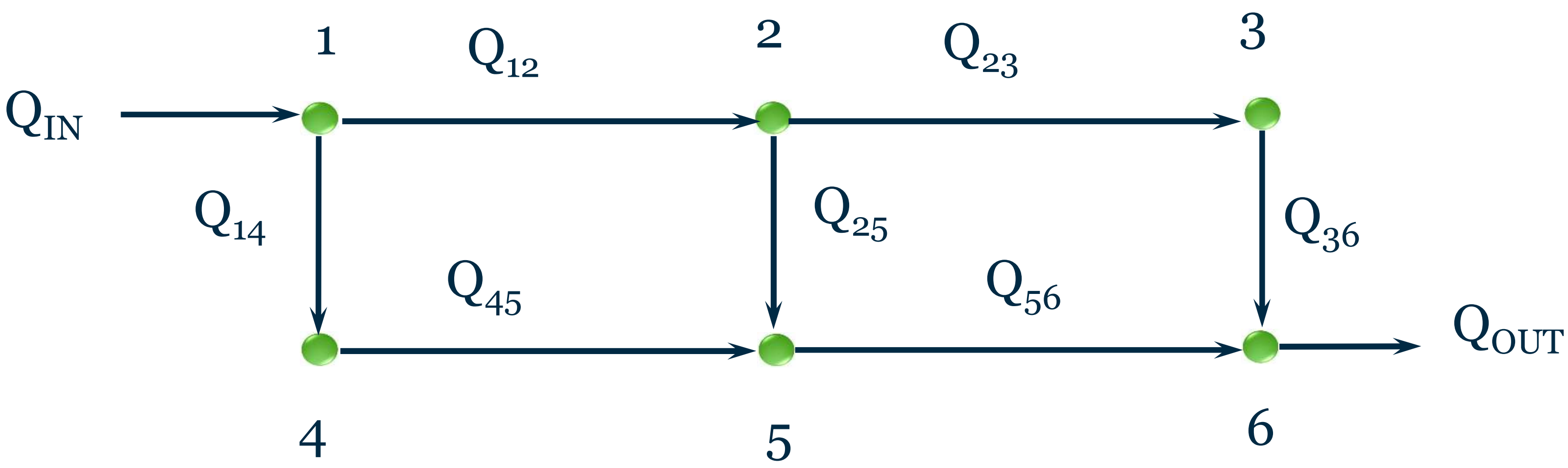


The configuration of the system is dictated by:

- Street patterns
- Topography
- Degree and type of development of the area
- Location of the treatment and storage works.

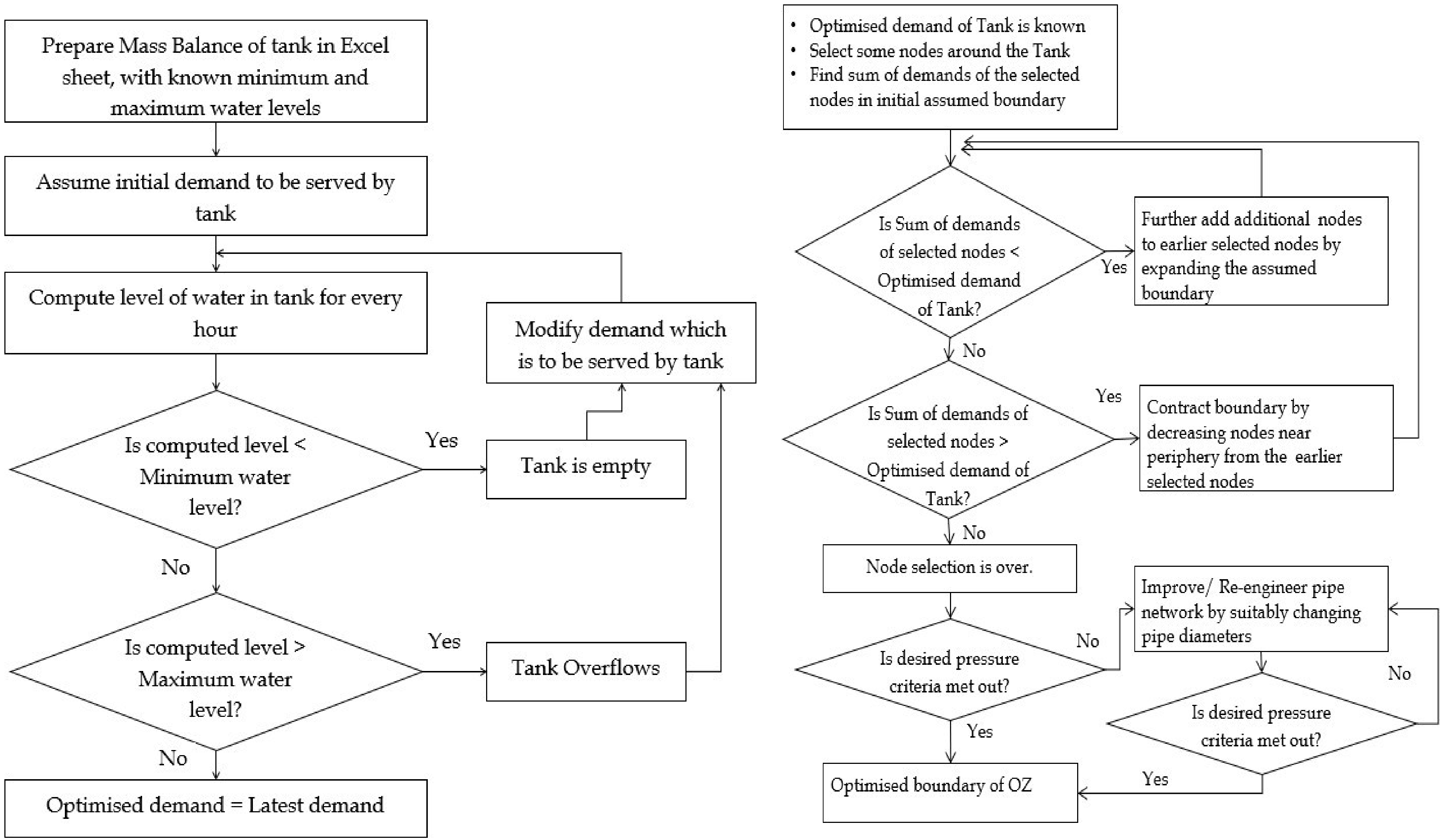
Building a Network Modelling & its Process

- For each node there is a conservation of mass equation:
  - Node 2:
- For each link there is a conservation of energy equation:
  - Link 2 – 3:



$$Q_{12} = Q_{25} + Q_{23} \qquad h_2 - h_3 = a_{23} \times Q_{23}^{b}$$

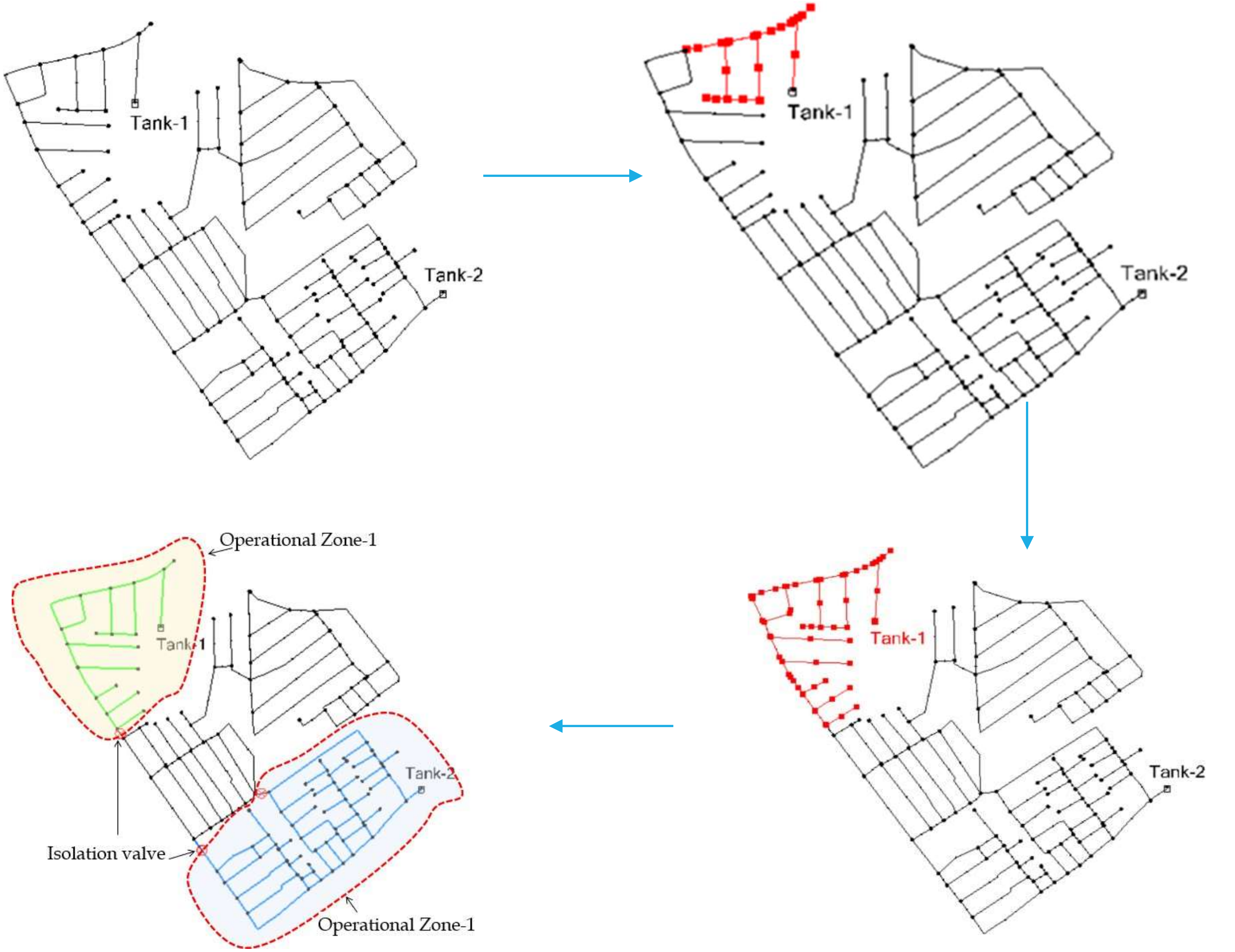
Design criteria of operational water zones & Importance on need for DMAs



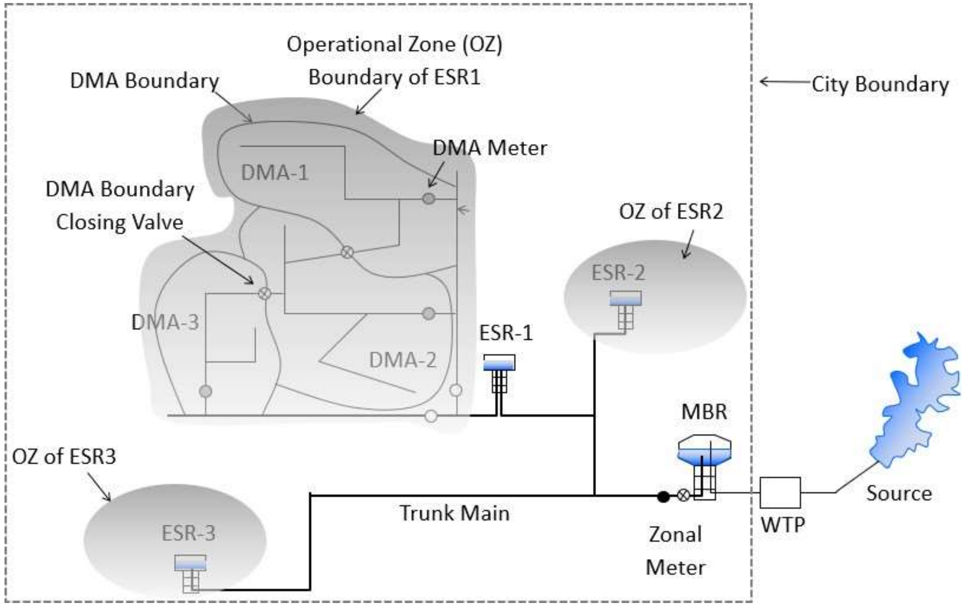
Design criterions for operational zones :

1) Compute optimum demand that a tank can serve and based on that, extent (boundary) of an operational zone should be determined so that when in full operation, the tank should not get empty, or will overflow.
2) The minimum nodal pressures are fulfilled.

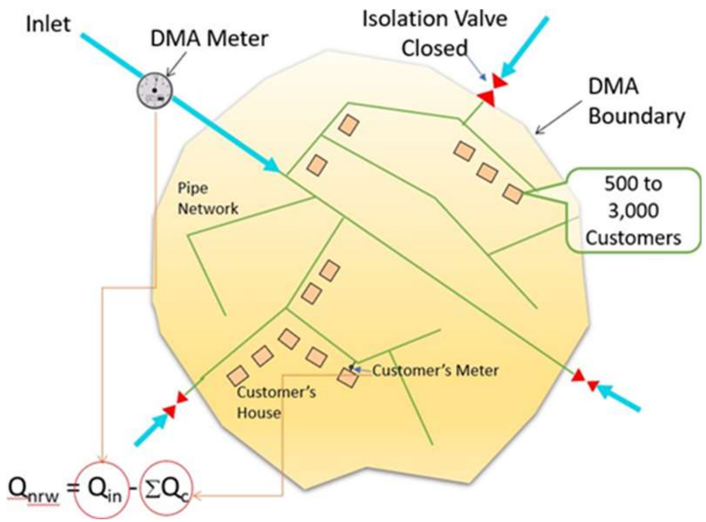
Design criteria of operational water zones



Creation of DMA in the Hydraulic model



Source: "Water Loss Reduction", Bentley Publication



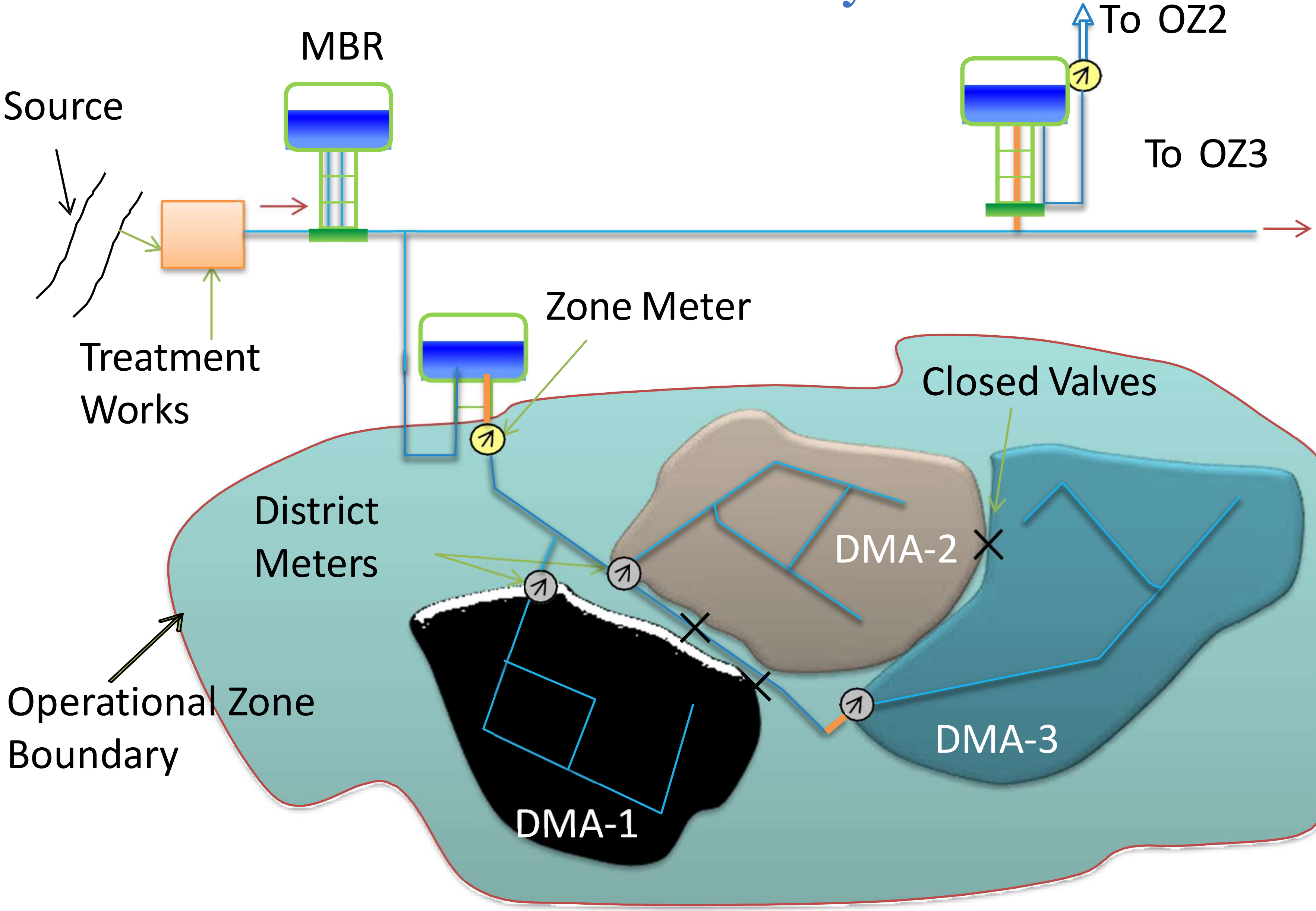
- ❑ DMA size is expressed in the number of properties. As per BIS IS 17482:2020, the size of a typical DMA in urban areas varies between 500 and 3,000 properties/metered connections.

- ❑ The size of an individual DMA may vary, depending on several local factors and system characteristics, such as:
  - ❑ the required economic level of leakage
  - ❑ geographic area and the /demographic factors (like, urban or rural, residential, commercial, industrial areas)
  - ❑ previous leakage control technique (like, ex-waste meter districts)
  - ❑ individual water Agency/ Board preference (like, discrimination of service pipe bursts, ease of location survey)
  - ❑ Hydraulic conditions.

- ❑ DMAs in dense urban areas, like, inner portion of cities, may be larger than 3,000 properties/metered connections, because of the high housing density

DMA NRW = Total DMA Inflow- Total DMA Consumption

Creation of DMA in the Hydraulic model



Design of DMA & its categories

Several factors shall be considered when designing a DMA, such as:

a) the required economic level of leakage:
b) size (geographical area and the number of properties):
c) variation in ground level:
d) drinking water quality considerations.

Topography:

DMA boundary is so fixed that it remains within normally available natural topographical features such as rivers, lakes, railway track, roads etc.

Hydraulically Discrete:

•DMAs should be isolated from other adjoining DMAs for precision in measurements.

•Each DMA Shall have a single inlet for water and a district meter should be placed to monitor the inflow into it.

Cost of setting up DMAs:

•DMAs should be formed in such a manner that, there will be minimum cost.

Slopes and elevation:

- DMA should be set up on uniform terrain. If a DMA has lot of uneven terrain conditions, supplying water would be difficult.
- Ideally it is recommended to maintain pressure difference of 4 -5m

DMA & its categories

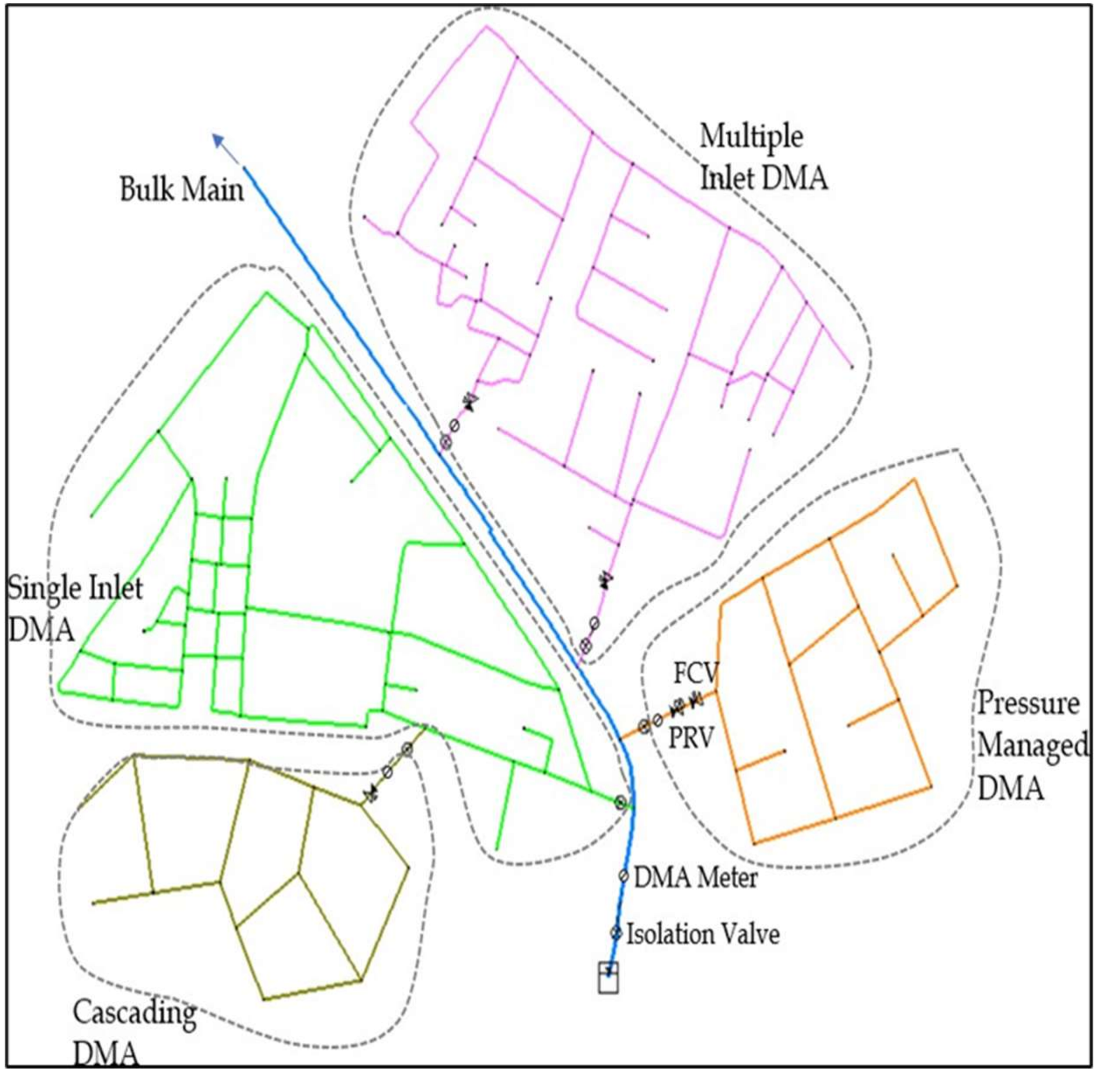
DMAs are categorised into four different types- single inlet DMAs, multiple inlet DMA, cascading DMA and Pressure managed DMA

(a) **Cascading DMA:**

(b) **Single inlet DMA**

(c) **Multiple inlet DMA**

(d) **Pressure managed DMA:**



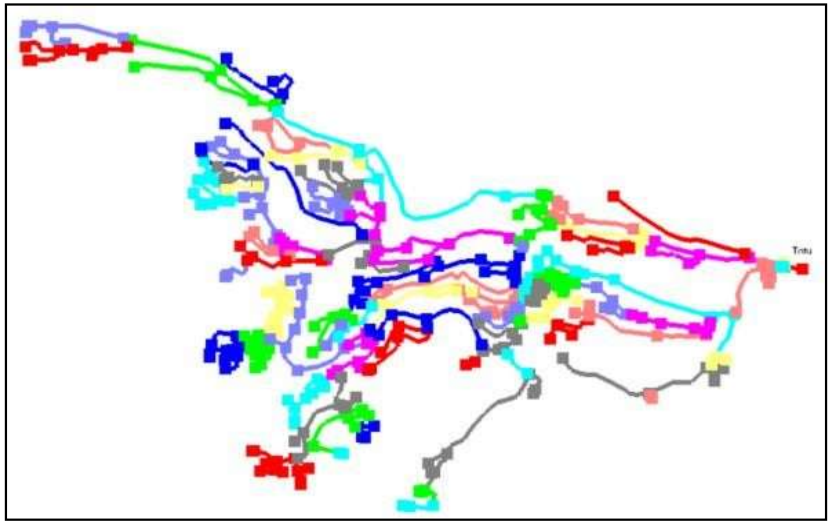
Importance on need for DMAs & Subzoning

DMAs :

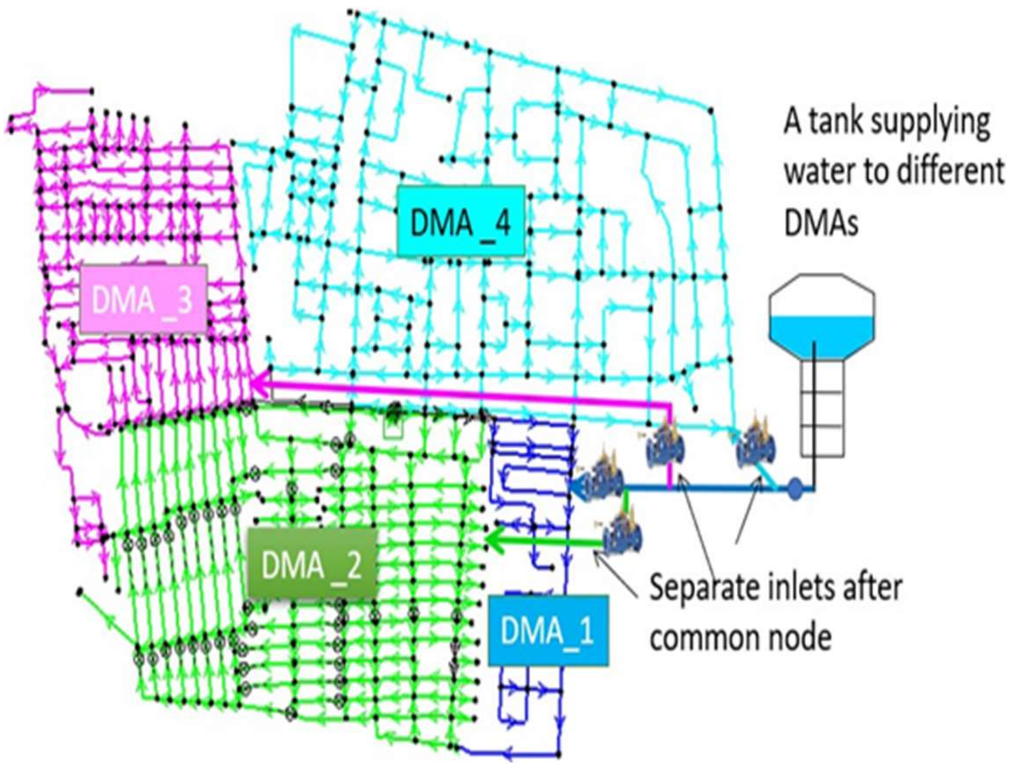
- ✓ DMA management is the use of flow to determine the level of leakage within a defined area of the water network.
- ✓ Enable the current levels of leakage to be determined and to consequently prioritise the leakage location activities.
- ✓ To ensures equalization of supply of water throughout the area Zoning in the distribution system is essential.

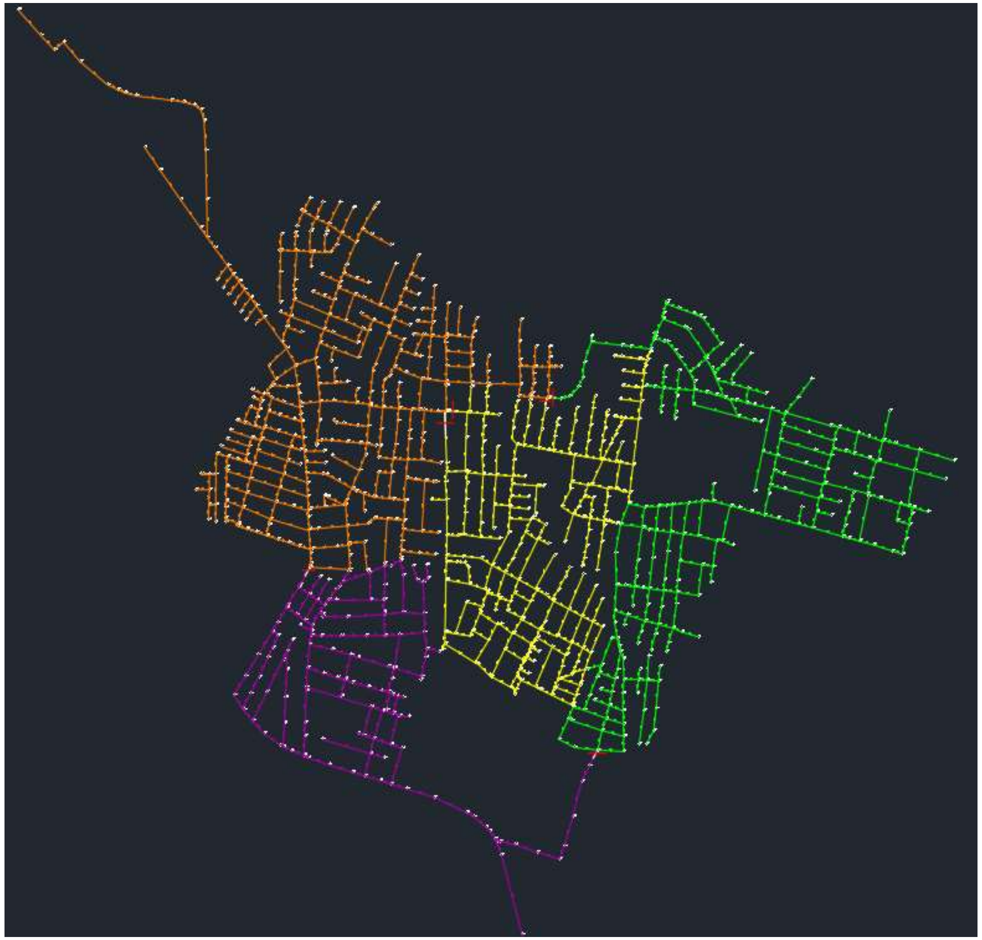
Sub zoning formation and its Importance :

- ❑ Adequate number of isolation valves should be provided.
- ❑ A segment not exceeding 50 to 250 connections gets isolated for the purpose of repairs and at the same time, rest of the connections remain unaffected.
- ❑ Optimization of number of isolation valves is possible and recommended to operate the scheme on continuous supply basis



Sample of Hydraulic model with DMA





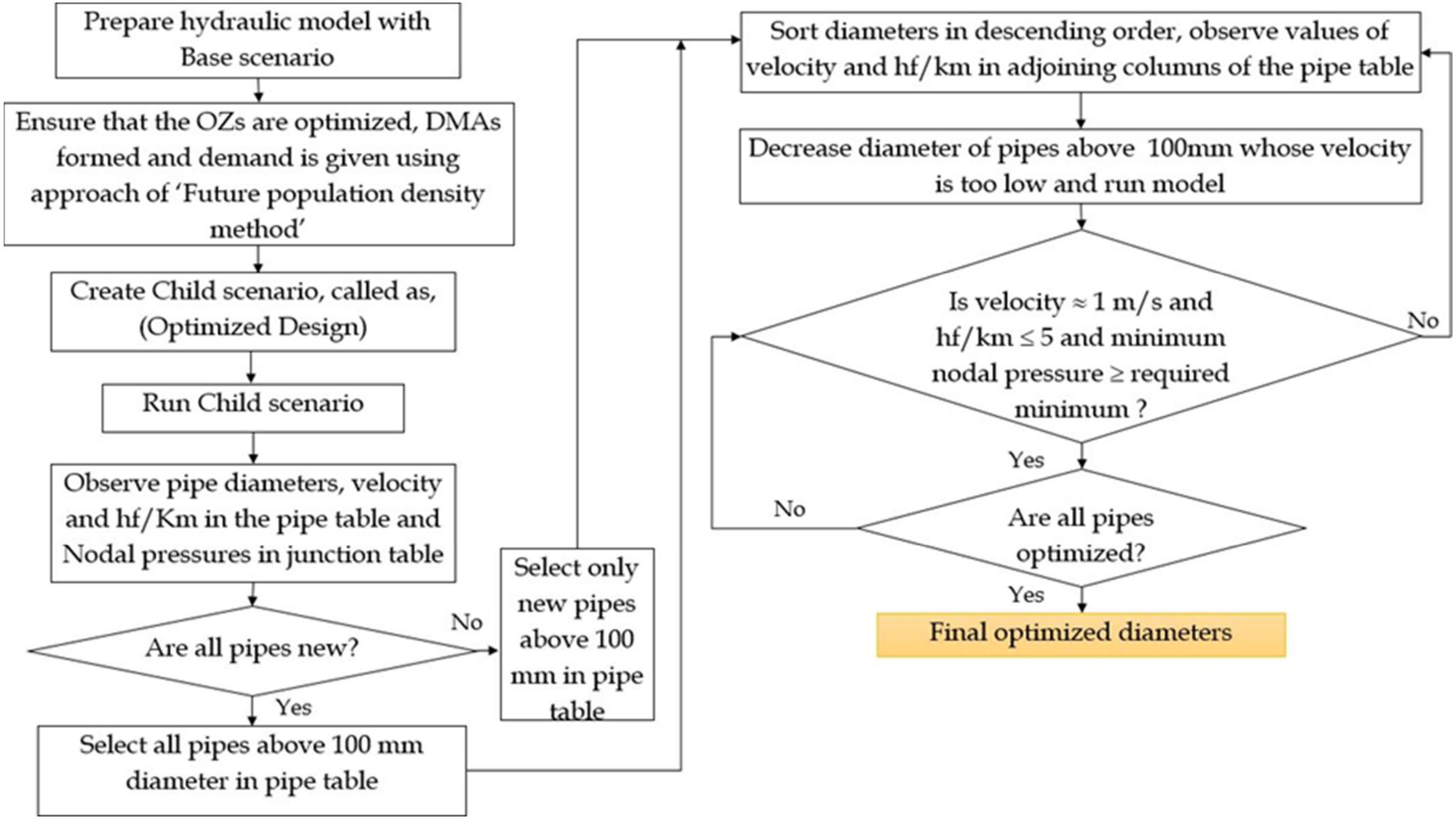
Optimization of Diameters of Pipes

- Optimization - “The action of making the best or most effective use of a situation or resource.”
- In the design of distribution system, the optimized or the best diameter of pipe needs to be selected with respect to criterion ***that the nodal pressure shall not be less than the design norm***, and ***that the velocity shall not exceed say, 2.1 m/s.***

DESIGN PRINCIPLES FOR OPTIMIZING DIAMETERS

1) Achieving higher velocity reduces the diameters which reduces capital cost.
2) Optimally reduced diameters mean less volume of water in the network within operational zone and DMA, it takes less time to build up pressures after starting water supply on every cycle of suppling water.
3) Optimally reduced diameters mean, easy, less time taking and less cost for repairs/ replacement of pipes.
4) Provide appropriate staging height of ESR to achieve above.
5) Lowest supply level of water of ESR should be equal to highest ground level in operational zone + minimum residual head + head loss for getting desired velocity.
6) Velocity should not be less than 0.3 m/s in all diameters above 80/100mm.
7) The minimum diameter in the distribution system of city/ town should be 100 mm for class I & II cities and for others it should be minimum 80mm.

Optimization of Diameters of Pipes



a) Observe the values of velocities in the pipe table. If velocity is less than 1 m/s and hf (m/km) is also less than 5 m/Km, and minimum nodal pressure is also more than or equal to residual nodal head as per norm, the steps are repeated. (Sometimes diameter needs to be increased).

b) The process is repeated for all the new pipes whose diameters are more than 100mm, till we get all optimized diameters.

Extended period simulation vs Steady state method of modelling

METHOD OF ANALYSIS

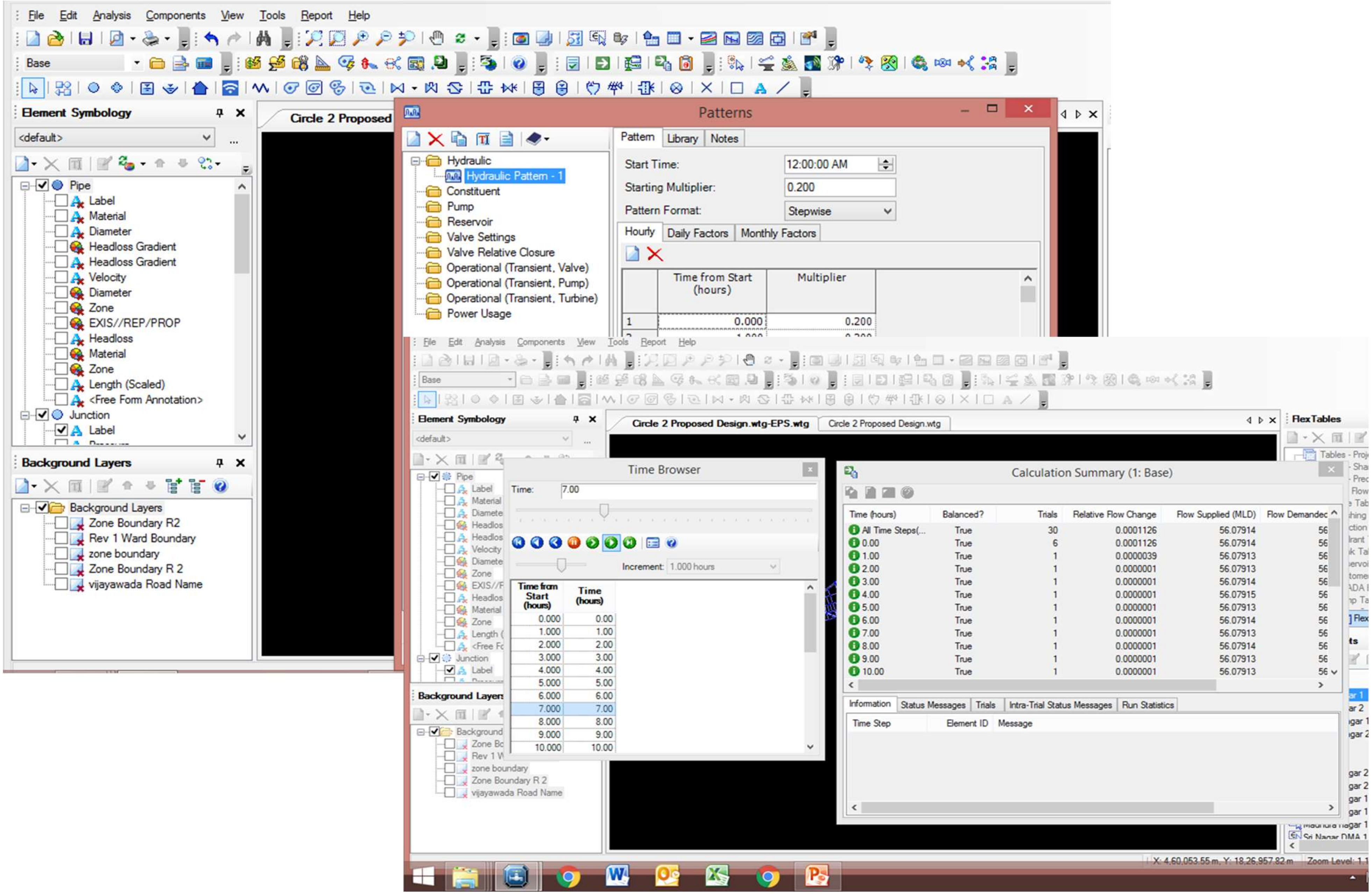
Steady state method:

- ✓ Represents behaviour of the system for a specific case or at a given point of time.
- ✓ Used to assess the adequacy of the pipe size for the ultimate stage, i.e., for the demand of 30 years.

Extended period simulation (EPS):

- ✓ More rational and realistic to the real world when the behaviour of the network is observed/ checked with respect to the varying time of levels.
- ✓ How tank levels fluctuate, when pumps are running, whether valves are open or closed, and how demands change throughout the day.
- ✓ The behaviour of system is different at different points of times. Say, at peak hours, the demand is maximum in comparison with demands in non-peak hours.
- ✓ This type of behaviour is modelled by the EPS function which is a continuous function.

Extended period simulation(EPS)



Use of various valves in the Hydraulic modelling

Isolation valves / Sluice Valves (SV)	For enabling effective break down maintenance of leaky pipes in distribution system, adequate number of isolation valves should be provided to isolate the network.
Scour Valves (SCV)	i. Scour valves are located at low points or between valved sections of the pipeline. ii. Main function is to allow periodic flushing of the lines to remove sediment and to allow the line to be drained for maintenance and repair work.
Flow & Pressure Control valves **(i)PRVs** **(ii)FCVs**	i. PRVs are needed in hilly cities/ areas. PRVs are also needed when some of the DMAs are situated on lower elevations. ii. FCVs with Solenoid at entry of DMA are proposed.

Benefits & Use of Simulated model results from a Hydraulic model

- Equitable distribution of drinking water
- Reduction of Non Revenue Water (NRW)
- Creation of District Metering Areas (DMAs)
- Help in leakage identification
- Help in efficient pressure management
- Rezoning of the distribution system scientifically
- To rehabilitate and replacement of pipes in network
- To identify defects in pipe network.
- Help in achieving 24x7 Water supply.

References for self learning and training of Hydraulic modelling and design of water supply

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12. https://mohua.gov.in/pdf/624eb498862a7Guidelines-for-Planning-Design-and-Implementation-of-24x7-Water-Supply-Systems.pdf

Q & A ?

Thank You !

For further clarifications
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