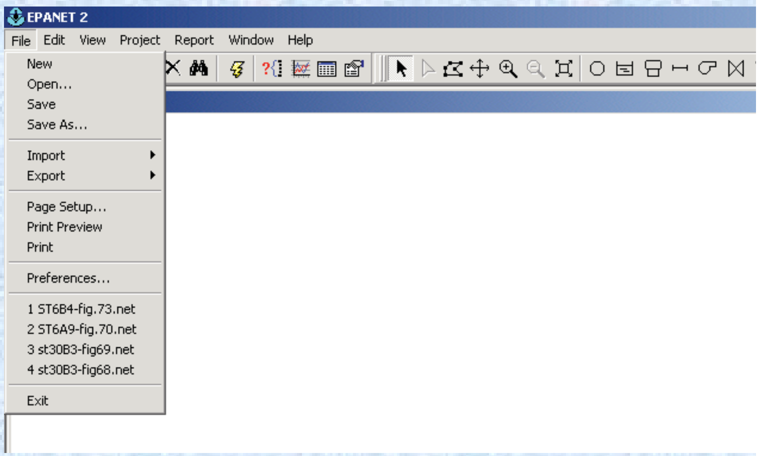
AAiT

Addis Ababa
Institute of Technology
School of Civil and
Environmental Engineering

Water Distribution Modelling
Lecture By Fiseha Behulu (PhD)

EPANET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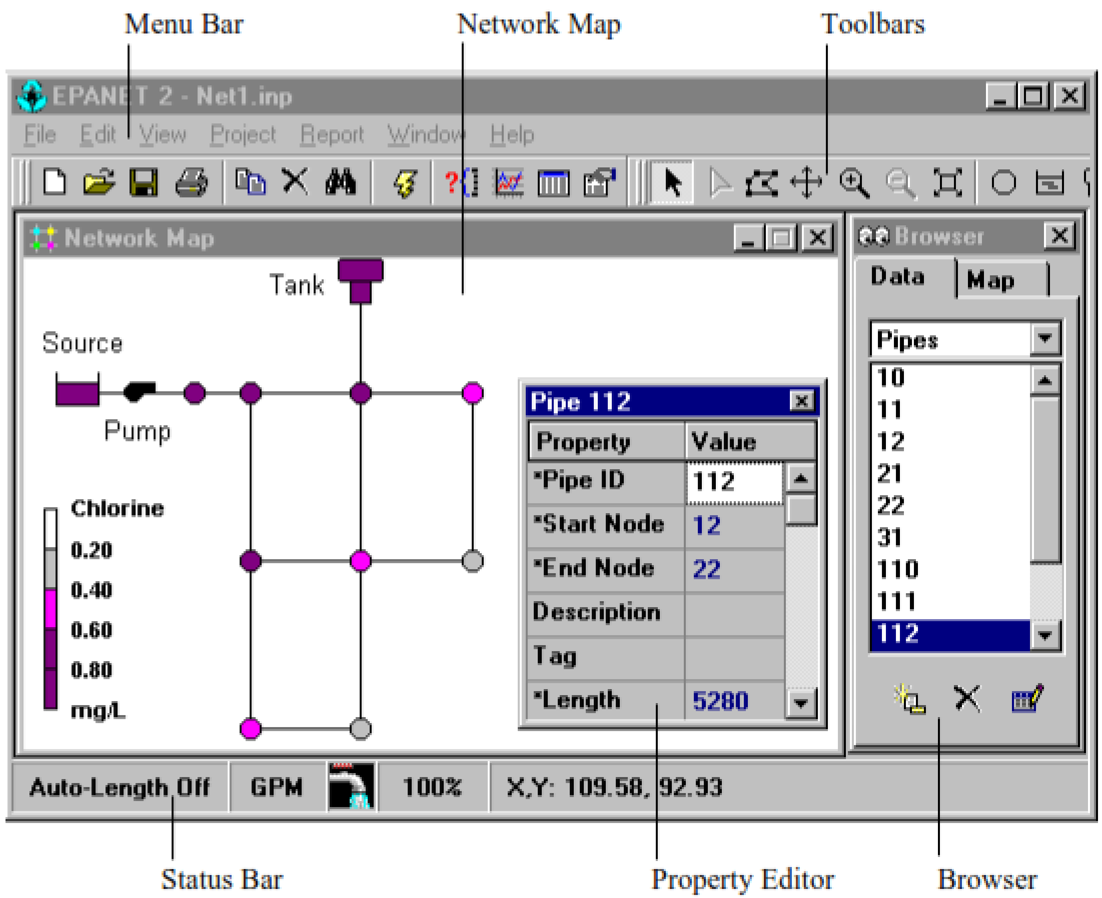
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Status Bar
Property Editor
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EPANET- Basics

- EPANET is a computer program that performs **extended period simulation** of **hydraulic** and **water quality** behavior **within pressurized pipe network**

- EPANET can help assess alternative management strategies for improving water quality throughout a system. These can include:
  - altering source utilization within multiple source systems,
  - altering pumping and tank filling/emptying schedules,
  - use of satellite treatment, such as re-chlorination at storage tanks,
  - targeted pipe cleaning and replacement.

EPANET- Basics…

- **Hydraulic Modeling Capabilities**
  - EPANET can help assess alternative management strategies for improving water quality throughout a system. These can include:
    - altering source utilization within multiple source systems,
    - altering pumping and tank filling/emptying schedules,
    - use of satellite treatment, such as re-chlorination at storage tanks,
    - targeted pipe cleaning and replacement.
    - models various types of valves including shutoff, check, pressure regulating, and flow control valves
    - allows storage tanks to have any shape (i.e., diameter can vary with height)
    - considers multiple demand categories at nodes, each with its own pattern of time variation
    - models pressure-dependent flow issuing from emitters (sprinkler heads)
    - can base system operation on both simple tank level or timer controls and on complex rule-based controls.

EPANET- Basics…

- **Water Quality Modeling Capabilities**

EPANET provides the following water quality modeling capabilities::

- altering source utilization within multiple source systems,
- altering pumping and tank filling/emptying schedules,
- use of satellite treatment, such as re-chlorination at storage tanks,
- targeted pipe cleaning and replacement.
- models various types of valves including shutoff, check, pressure regulating, and flow control valves
- allows storage tanks to have any shape (i.e., diameter can vary with height)
- considers multiple demand categories at nodes, each with its own pattern of time variation
- models pressure-dependent flow issuing from emitters (sprinkler heads)
- can base system operation on both simple tank level or timer controls and on complex rule-based controls.

EPANET- Basics…

- **By employing these features, EPANET can study such water quality phenomena as:**
  - blending water from different sources
  - age of water throughout a system
  - loss of chlorine residuals
  - growth of disinfection by-products
  - tracking contaminant propagation events..

Steps in Using EPANET

Steps	Description	Sections in Manual
Step-1:	Draw a network representation of your distribution system	Section 6.1/ 11.4
Step-2:	Edit the properties of the objects that make up the system	Section 6.4
Step-3:	Describe how the system is operated	Section 6.5
Step-4:	Select a set of analysis options	Section 8.1
Step-5:	Run a hydraulic/water quality analysis	Section 8.2
Step-6:	View the results of the analysis.	Chapter 9

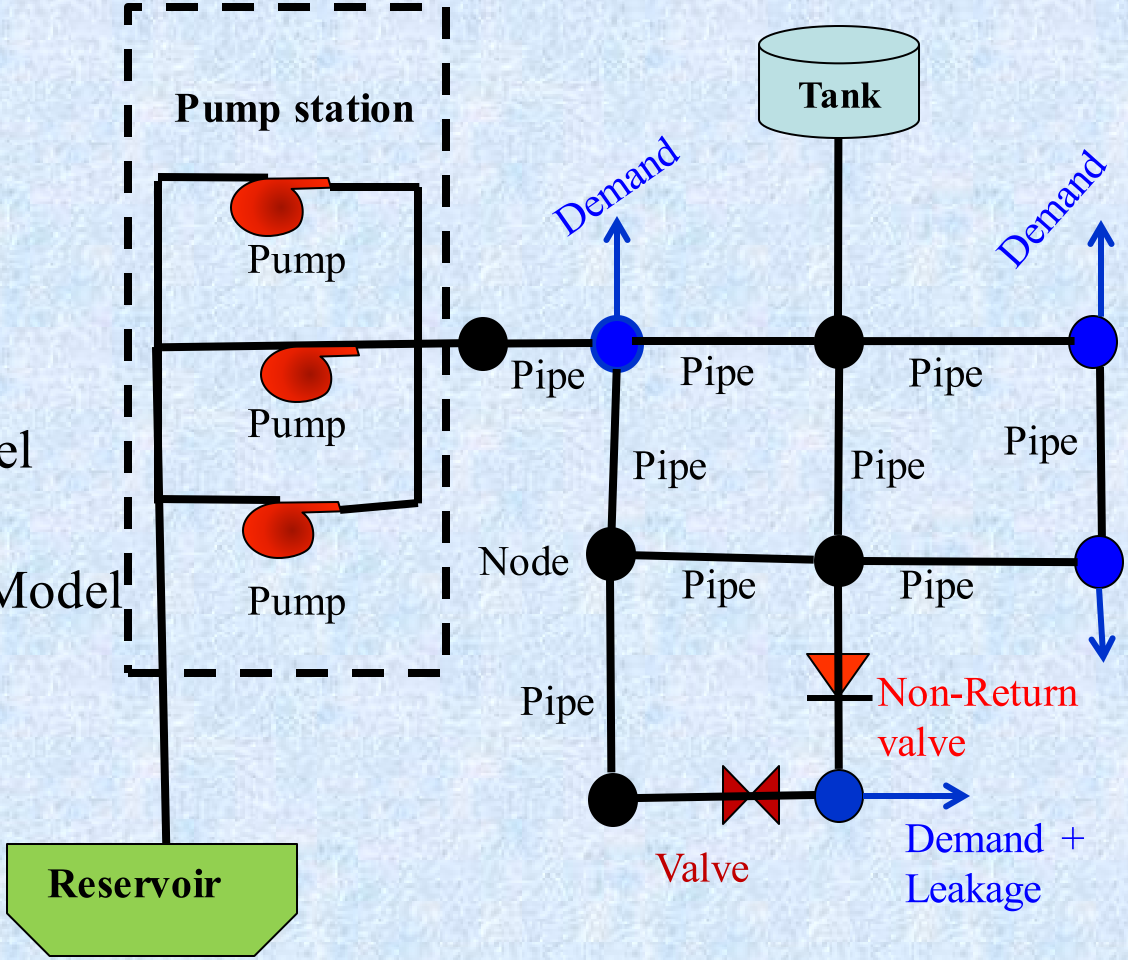
EPANET- Basics…

- **The Network Model**
  - Physical Components
  - Non-Physical Components
  - Hydraulic Simulation Model
  - Water Quality Simulation Model

PHYSICAL COMPONENTS
in
EPANET

The Network Model

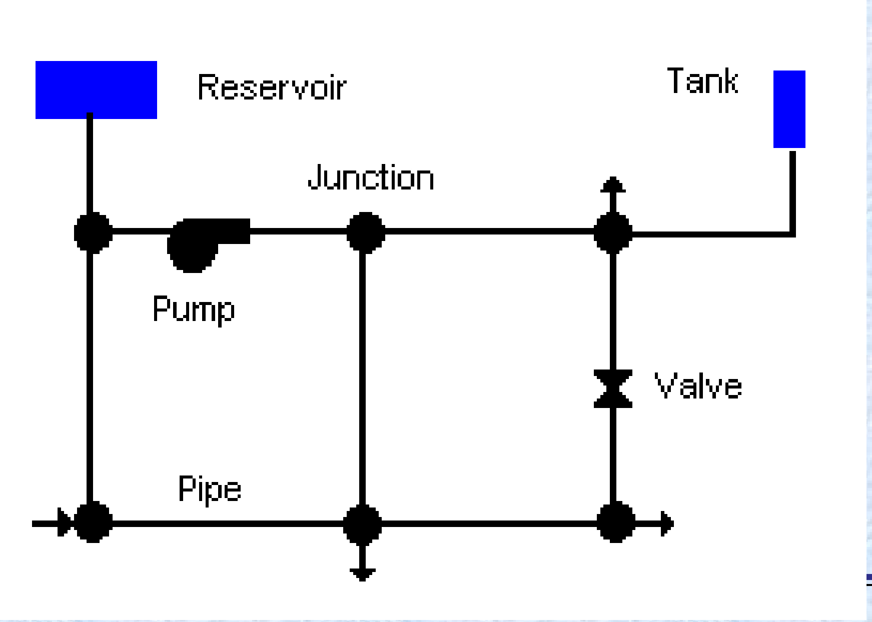
- Physical Components
- Non-Physical Components
- Hydraulic Simulation Model
- Water Quality Simulation Model

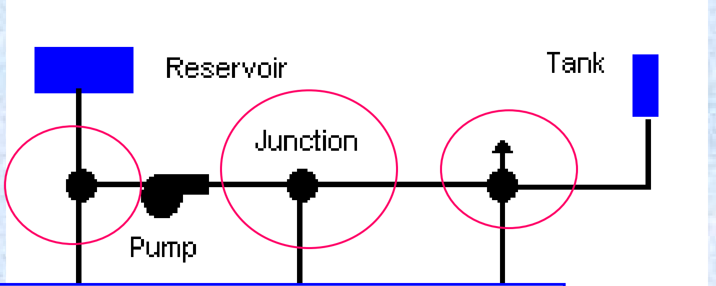


EPANET- Physical Components

Physical Components

- EPANET models a water distribution system as a collection of links connected to nodes
- The links represent pipes, pumps, and control valves. The nodes represent junctions, tanks, and reservoirs.

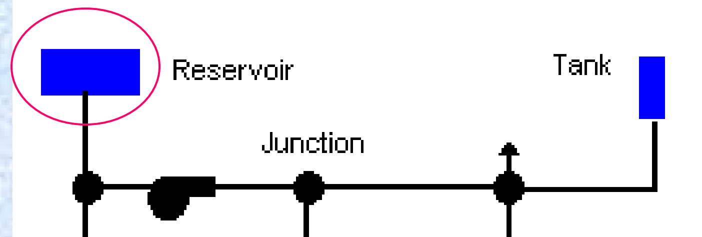




❑ Junctions

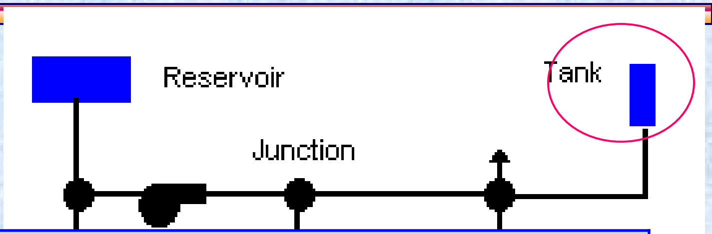
Description	Junctions are points in the network where links join together and where water enters or leaves the network.
Input Data:	• elevation above some reference (usually mean sea level) • water demand (rate of withdrawal from the network) • initial water quality.
Output results	• hydraulic head (internal energy per unit weight of fluid) • Pressure • water quality.

EPANET- Physical Components…



❑ Reservoirs

Description	Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, and tie-ins to other systems. Reservoirs can also serve as water quality source points..
Input Data:	• hydraulic head (equal to the water surface elevation if the reservoir is not under pressure) and • initial quality for water quality analysis.
Output results	• No computed output properties Because a reservoir is a boundary point to a network, its head and water quality cannot be affected by what happens within the network



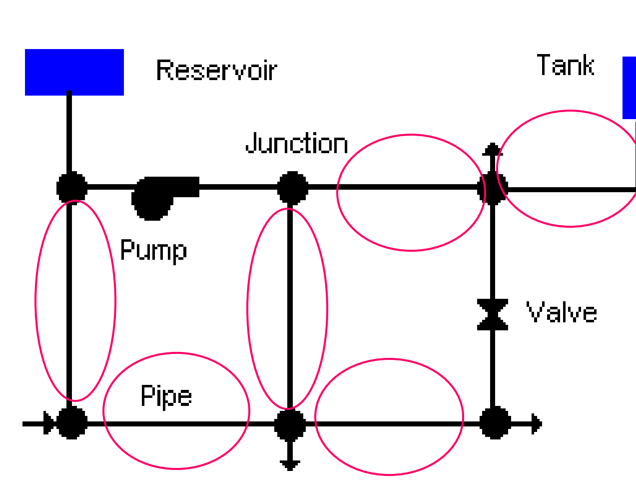
❑ Tanks

Description	• Tanks are nodes with storage capacity, where the volume of stored water can vary with time during a simulation. • 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.
Input Data:	• bottom elevation (where water level is zero) • diameter (or shape if non-cylindrical) • initial, minimum and maximum water levels • initial water quality.
Output results	• hydraulic head (water surface elevation) • water quality

EPANET- Physical Components…

❑ Pipes

Description	• Pipes are links that convey water from one point in the network to another. • EPANET assumes that all pipes are full at all times.
Input Data:	• start and end nodes • diameter • length • roughness coefficient (for determining head loss) • status (open, closed, or contains a check valve)
Output results	• flow rate • velocity • headloss • Darcy-Weisbach friction factor • average reaction rate (over the pipe length) • average water quality (over the pipe length).



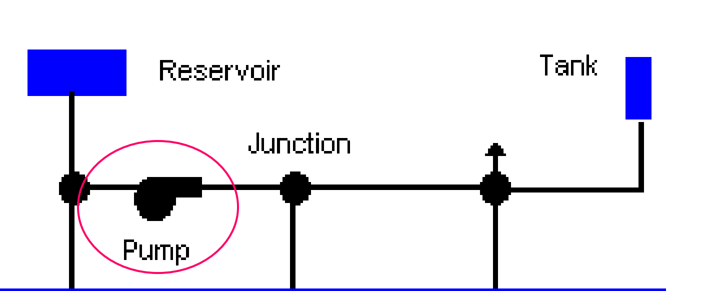
- **Pipes**
  - The hydraulic **head lost** by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas:

Equation	Q (m^3/s); D (m)	Q (cfs); D (ft)	Q (gpm); D (in.)
Darcy-Weisbach	$S_f = \frac{0.083 f Q^2}{D^5}$	$S_f = \frac{0.025 f Q^2}{D^5}$	$S_f = \frac{0.031 f Q^2}{D^5}$
Hazen-Williams	$S_f = \frac{10.7}{D^{4.87}}\left(\frac{Q}{C}\right)^{1.852}$	$S_f = \frac{4.73}{D^{4.87}}\left(\frac{Q}{C}\right)^{1.852}$	$S_f = \frac{10.5}{D^{4.87}}\left(\frac{Q}{C}\right)^{1.852}$
Manning	$S_f = \frac{10.3(nQ)^2}{D^{5.33}}$	$S_f = \frac{4.66(nQ)^2}{D^{5.33}}$	$S_f = \frac{13.2(nQ)^2}{D^{5.33}}$

Compiled from ASCE (1975) and ASCE/WEF (1982)

EPANET- Physical Components…

- **Pumps**

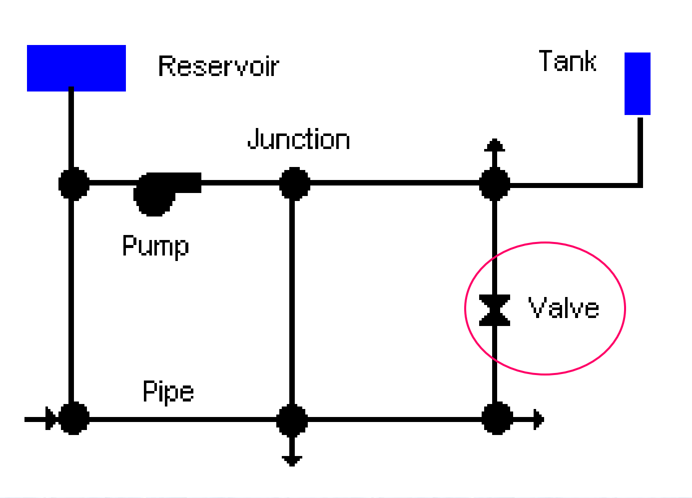


Description	• Pumps are links that impart energy to a fluid thereby raising its hydraulic head. • Flow through a pump is **unidirectional** and EPANET will not allow a pump to operate outside the range of its pump curve.
Input Data:	• The principal input parameters for a pump are its start and end nodes and its pump curve (the combination of heads and flows that the pump can produce)
Output results	• The principal output parameters are flow and head gain.

EPANET- Physical Components…

❑ Valves

Description	• Valves are links that limit the pressure or flow at a specific point in the network.
Input Data:	• start and end nodes • diameter • setting • status
Output results	• flow rate and • headloss.



- Pressure Reducing Valve (PRV)
- Pressure Sustaining Valve (PSV)
- Pressure Breaker Valve (PBV)
- Flow Control Valve (FCV)
- Throttle Control Valve (TCV)
- General Purpose Valve (GPV)

NON-PHYSICAL COMPONENTS
in
EPANET

EPANET: Non-Physical Components

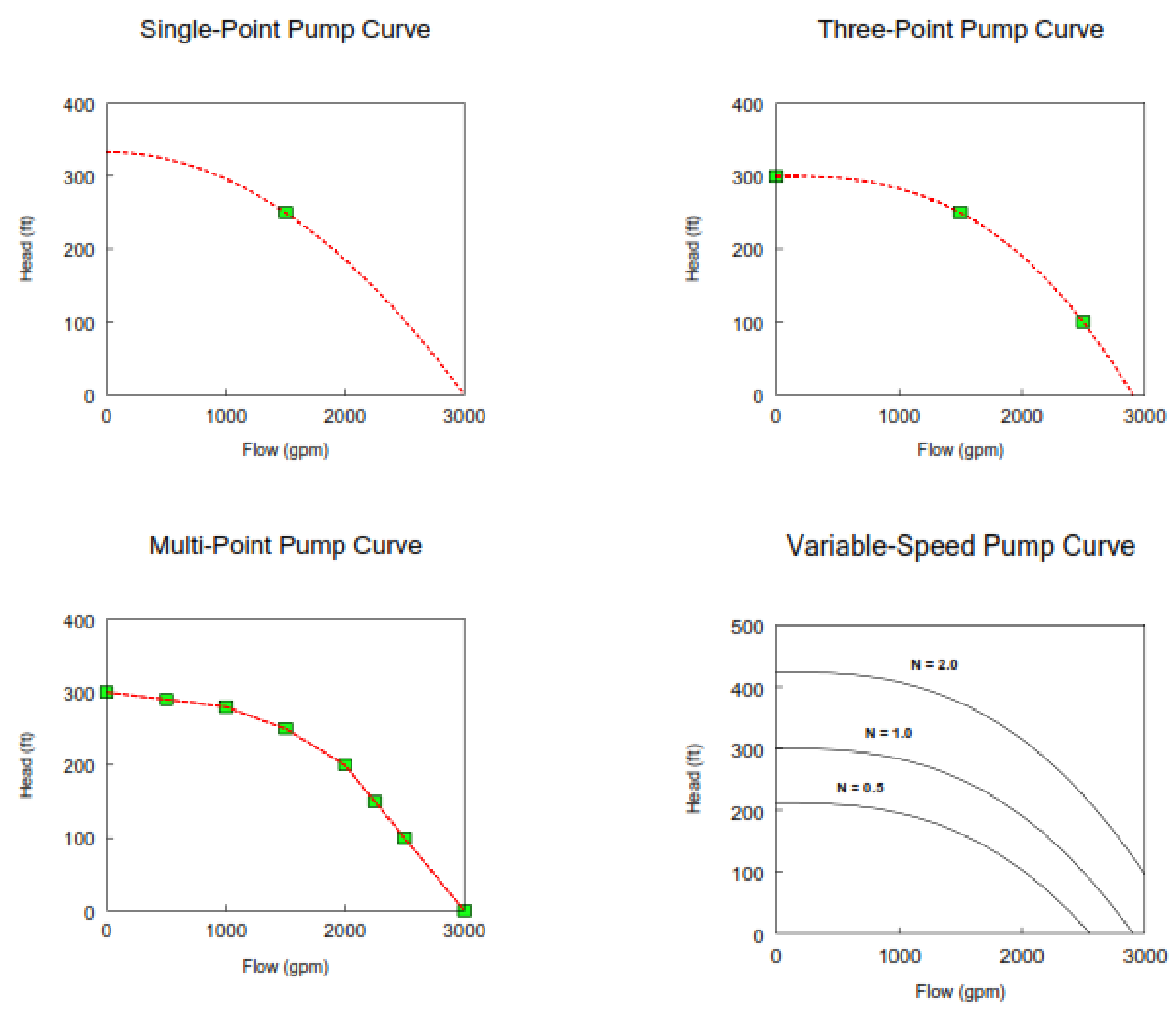
Non-Physical Components

- In addition to physical components, EPANET employs three types of informational objects that describe the behavior and operational aspects of a distribution system
  - **curves,**
  - **patterns,** and
  - **controls** -.

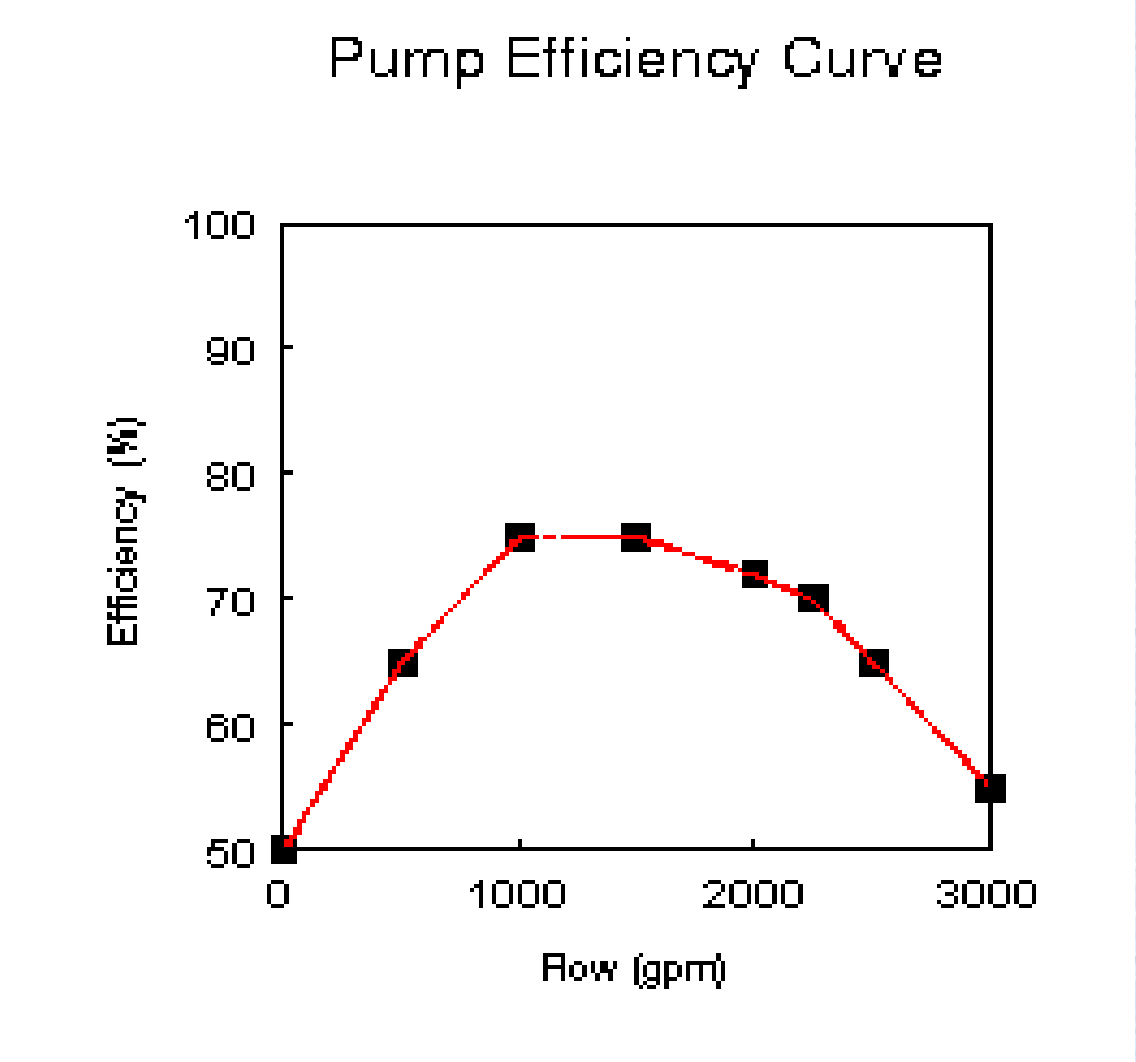
EPANET: Non-Physical Components…

- **Curves:**
  - Curves are objects that contain data pairs representing a relationship between two quantities. Two or more objects can share the same curve. An EPANET model can utilize the following types of curves:
    - **Pump curve**
    - **Efficiency curve**
    - **Volume curve**
    - **Head Loss curve**

- **Pump Curves:**

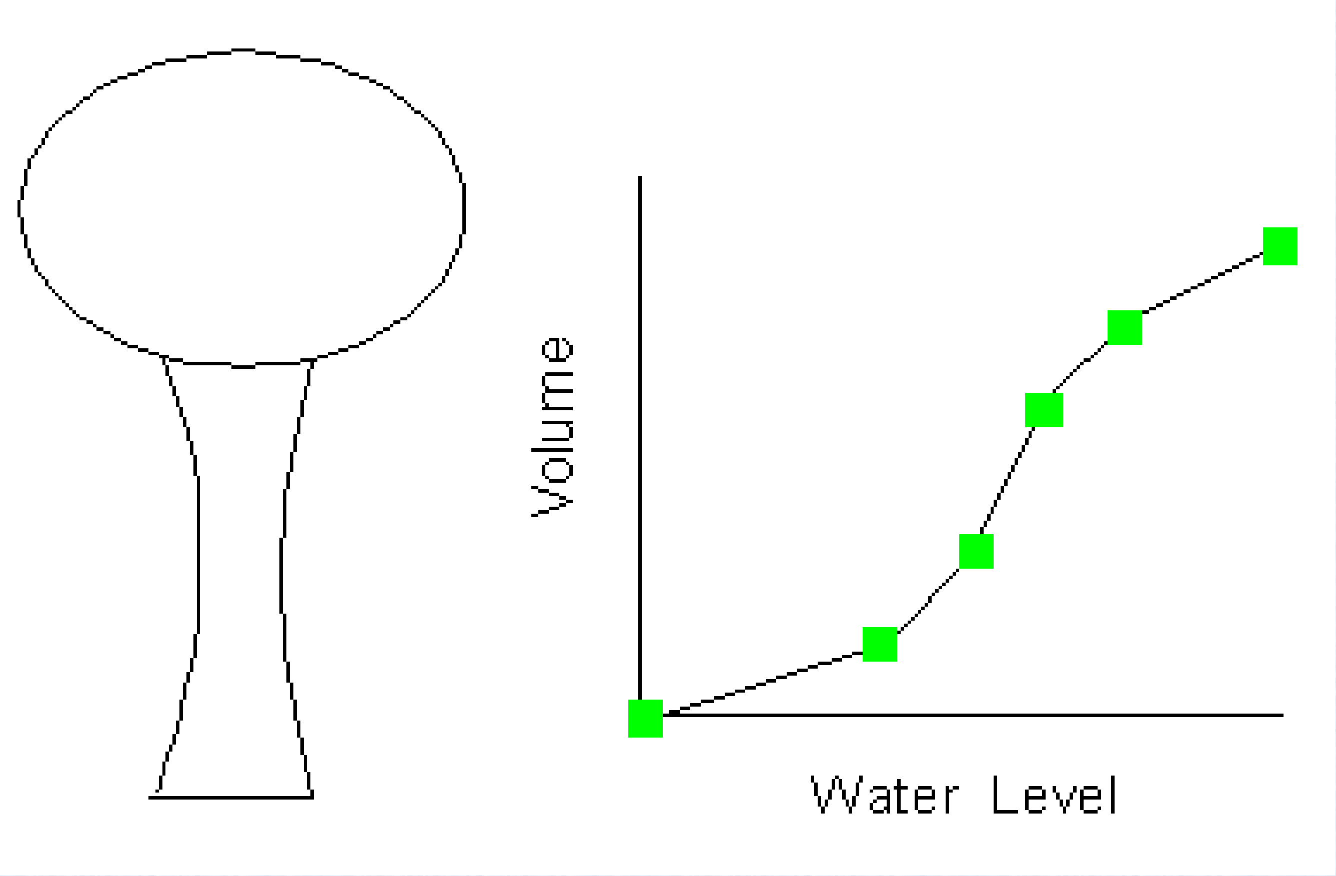

Single-Point Pump Curve
Three-Point Pump Curve
Multi-Point Pump Curve
Variable-Speed Pump Curve
Head (ft)
Flow (gpm)
N = 2.0
N = 1.0
N = 0.5
0
100
200
300
400
500
1000
2000
3000

- **Efficiency Curve:**



EPANET: Non-Physical Components…

- **Volume Curve:**



EPANET: Non-Physical Components…

- **Head Loss Curve:**
  - A **head loss** Curve is used to described the head loss (Y in meters) through a General Purpose Valve (GPV) as a function of flow rate (X in flow units). It provides the capability to model devices and situations with unique head loss-flow relationships, such as reduced flow - backflow prevention valves, turbines, and well draw-down behavior

EPANET: Non-Physical Components…

Time Patterns:

- A Time Pattern is a collection of multipliers that can be applied to a quantity to allow it to vary over time. Nodal demands, reservoir heads, pump schedules, and water quality source inputs can all have time patterns associated with them.

Example: At a given node with an average demand of 10 m^3/day; assume that the time pattern interval has been set to 4 hours and a pattern with the following multipliers has been specified for demand at this node

Period	1	2	3	4	5	6
Multiplier	0.5	0.8	1.0	1.2	0.9	0.7

Hours	0-4	4-8	8-12	12-16	16-20	20-24
Multiplier	5	8	10	12	9	7

EPANET: Non-Physical Components…

Controls:

- Controls are statements that determine how the network is operated over time. They specify the status of selected links as a function of time, tank water levels, and pressures at select points within the network. There are two categories of controls that can be used:

  - Simple controls
  - Rule-Based Controls

EPANET: Non-Physical Components…

- **Simple Controls:**
  - Simple controls change the status or setting of a link based on:
    - the water level in a tank,
    - the pressure at a junction,
    - the time into the simulation,
    - the time of day

They are statements expressed in one of the following three formats:

```
LINK x status IF NODE y ABOVE/BELOW z
LINK x status AT TIME t
LINK x status AT CLOCKTIME c AM/PM
```

where:

x	=	a link ID label,
status	=	OPEN or CLOSED, a pump speed setting, or a control valve setting,
y	=	a node ID label,
z	=	a pressure for a junction or a water level for a tank,
t	=	a time since the start of the simulation in decimal hours or in hours:minutes notation,
c	=	a 24-hour clock time.

- **Simple Controls- Examples:**

Control Statement	*Meaning*
`LINK 12 CLOSED IF NODE 23 ABOVE 20`	(Close Link 12 when the level in Tank 23 exceeds 20 ft.)
`LINK 12 OPEN IF NODE 130 BELOW 30`	(Open Link 12 if the pressure at Node 130 drops below 30 psi)
`LINK 12 1.5 AT TIME 16`	(Set the relative speed of pump 12 to 1.5 at 16 hours into the simulation)
`LINK 12 CLOSED AT CLOCKTIME 10 AM` `LINK 12 OPEN AT CLOCKTIME 8 PM`	(Link 12 is repeatedly closed at 10 AM and opened at 8 PM throughout the simulation)

EPANET: Non-Physical Components…

- **Simple Controls- Examples:**

Control Statement	*Meaning*
`LINK 12 CLOSED IF NODE 23 ABOVE 20`	(Close Link 12 when the level in Tank 23 exceeds 20 ft.)
`LINK 12 OPEN IF NODE 130 BELOW 30`	(Open Link 12 if the pressure at Node 130 drops below 30 psi)
`LINK 12 1.5 AT TIME 16`	(Set the relative speed of pump 12 to 1.5 at 16 hours into the simulation)
`LINK 12 CLOSED AT CLOCKTIME 10 AM` `LINK 12 OPEN AT CLOCKTIME 8 PM`	(Link 12 is repeatedly closed at 10 AM and opened at 8 PM throughout the simulation)

Rule-Based Controls

- Rule-Based Controls allow link status and settings to be based on a combination of conditions that might exist in the network after an initial hydraulic state of the system is computed.

Rule-Based Controls- Examples:

This set of rules shuts down a pump and opens a by-pass pipe when the level in a tank exceeds a certain value and does the opposite when the level is below another value

```
RULE 1
IF   TANK   1 LEVEL ABOVE 19.1
THEN PUMP 335 STATUS IS CLOSED
AND  PIPE 330 STATUS IS OPEN

RULE 2
IF   TANK   1 LEVEL BELOW 17.1
THEN PUMP 335 STATUS IS OPEN
AND  PIPE 330 STATUS IS CLOSED
```

❑ Rule-Based Controls

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❑ Rule-Based Controls- Examples:

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AND  PIPE 330 STATUS IS OPEN

RULE 2
IF   TANK   1 LEVEL BELOW 17.1
THEN PUMP 335 STATUS IS OPEN
AND  PIPE 330 STATUS IS CLOSED
```

HYDRAULIC SIMULATION MODEL

in

EPANET

EPANET: Hydraulic Simulation Model

- EPANET's hydraulic simulation model computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time.

- From one time step to the next reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution.

- The solution is based on "**hydraulically balancing**" of network.
  - *The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the head loss relationship across each link in the network.*
  - *It requires an iterative technique to solve the nonlinear equations involved.*

EPANET employs the "Gradient Algorithm"

- The hydraulic time step used for extended period simulation (EPS) can be set by the user. A typical value is 1 hour. Shorter time steps than normal will occur automatically whenever one of the following events occurs:

  - the next output reporting time period occurs
  - the next time pattern period occurs
  - a tank becomes empty or full
  - a simple control or rule-based control is activated.

Water Quality Simulation Model

In

EPANET

EPANET: Water Quality Simulation Model

- EPANET's water quality simulator uses a Lagrangian time-based approach to track the fate of discrete parcels of water as they move along pipes and mix together at junctions between fixed-length time steps.

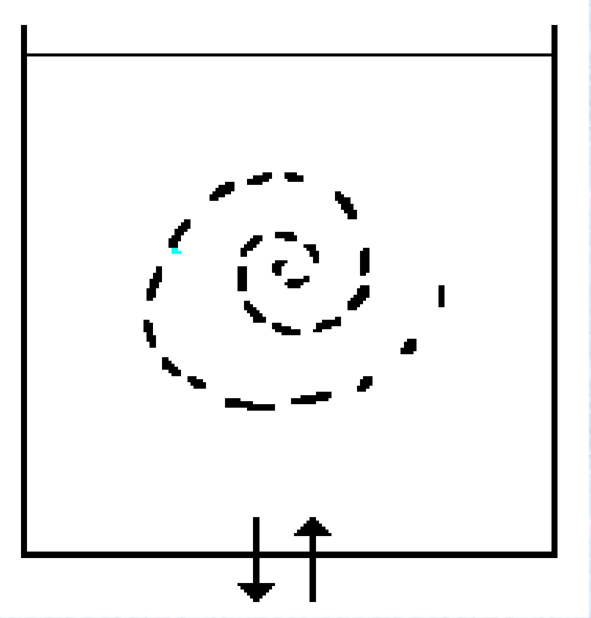
- The water quality time steps are typically much **shorter than** the hydraulic time step (e.g., minutes rather than hours) to accommodate the short times of travel that can occur within pipes

- Details of the basic transport concept can be found on **page 41** of the EPANET Manual

EPANET: Water Quality Simulation Model…

- Mixing in Storage Tanks:
  - EPANET can use **four different types of models** to characterize mixing within storage tanks.
    - Complete Mixing
    - Two-Compartment Mixing
    - FIFO Plug Flow
    - LIFO Plug Flow

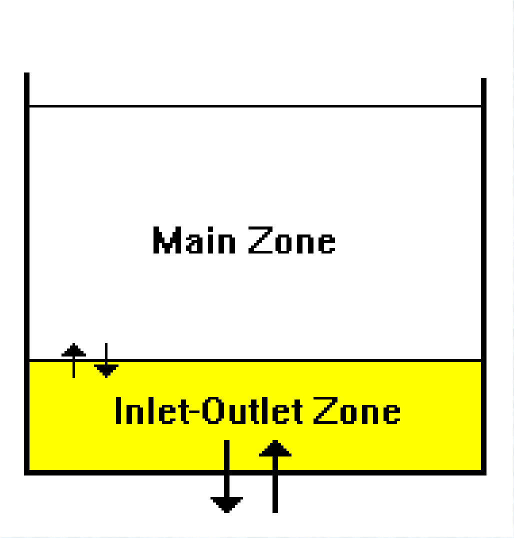
Complete Mixing Model:



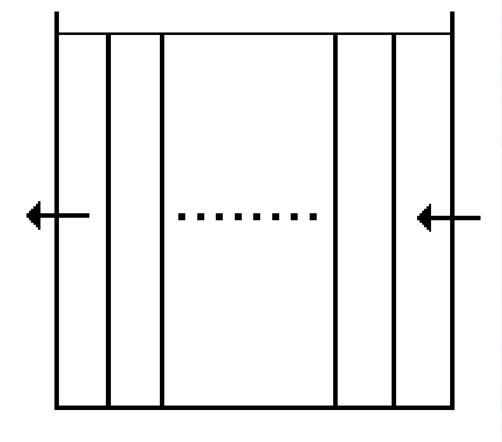
- It is the simplest form of mixing behavior to assume;
- It assumes that all water that enters a tank is instantaneously and completely mixed with the water already in the tank.
- requires no extra parameters to describe it, and seems to apply quite well to a large number of facilities that operate in fill-and-draw fashion.

EPANET: Water Quality Simulation Model…

❑ Complete Mixing Model:



- It divides the available storage volume in a tank into two compartments, both of which are assumed completely mixed;
- The inlet/outlet pipes of the tank are assumed to be located in the first compartment. If this compartment is full, then it sends its overflow to the second compartment where it completely mixes with the water already stored there.
- When water leaves the tank, it exits from the first compartment, which if full, receives an equivalent amount of water from the second compartment to make up the difference.

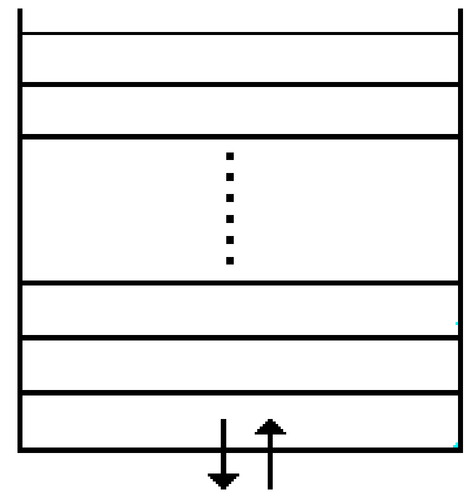


The FIFO Plug Flow model:

- **FIFO= First In First Out**
- It assumes that there is no mixing of water at all during its residence time in a tank;
- Water parcels move through the tank in a segregated fashion where the first parcel to enter is also the first to leave. Physically speaking, this model is most appropriate for baffled tanks that operate with simultaneous inflow and outflow.

The LIFO Plug Flow model:

- **LIFO= Last In First Out**



- It assumes that there is no mixing between parcels of water that enter a tank. However in contrast to FIFO Plug Flow, the **water parcels stack up one on top of another**, where water enters and leaves the tank on the bottom;

- This type of model might apply to a tall, narrow standpipe with an inlet/outlet pipe at the bottom and a low momentum inflow

Water Quality Reactions:

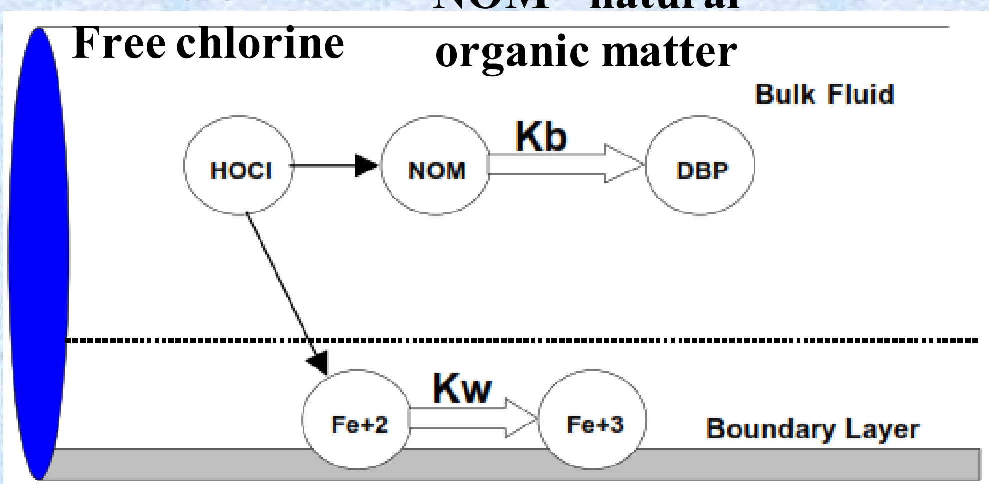
- EPANET can track the growth or decay of a substance by reaction as it travels through a distribution system. In order to do this it needs to know the rate at which the substance reacts and how this rate might depend on substance concentration.

- Reactions can occur both within the bulk flow and with material along the pipe wall

HOCl= Free chlorine

NOM= natural organic matter

Example



EPANET: Water Quality Simulation Model…

Bulk Reactions:

- EPANET allows a modeler to treat these two reaction zones separately.
- In bulk reaction of n[th] order kinetics, instantaneous rate of reaction (R mass/volume/time) is given by:
- $\boldsymbol{R = K_b C^n}$

  Where:

  K_b = a bulk reaction rate coefficient

  C= reactant concentration (mass/ volume)

  n = a reaction order
- For reactions where a limiting concentration exists on the ultimate growth or loss of the substance the expression becomes:

$$\boldsymbol{R = K_b(C_L - C)C^{(n-1)}} \qquad \text{for } n>0,\ K_b>0$$

$$\boldsymbol{R = K_b(C - C_L)C^{(n-1)}} \qquad \text{for } n>0,\ K_b<0$$

EPANET: Water Quality Simulation Model…

- **Bulk Reactions:**

Model	*Parameters*	*Examples*
First-Order Decay	$C_L = 0, K_b < 0, n = 1$	Chlorine
First-Order Saturation Growth	$C_L > 0, K_b > 0, n = 1$	Trihalomethanes
Zero-Order Kinetics	$C_L = 0, K_b <> 0, n = 0$	Water Age
No Reaction	$C_L = 0, K_b = 0$	Fluoride Tracer

EPANET: Water Quality Simulation Model…

❑ Wall Reactions:

- The rate of water quality reactions occurring at or near the pipe wall can be considered to be dependent on the concentration in the bulk flow by using an expression of the form

$$R = \left(\frac{A}{V}\right) K_w C^n$$

Where:

K_w = a wall reaction rate coefficient

A/V= the surface area per unit volume within a pipe (equal to 4 divided by the pipe diameter)

- **EPANET** limits the choice of wall reaction order to either 0 or 1

Wall Reactions:

- K_w can be a function of coefficients used to describe its roughness.

Headloss Formula	*Wall Reaction Formula*
Hazen-Williams	$K_w = F / C$
Darcy-Weisbach	$K_w = -F / log(e/d)$
Chezy-Manning	$K_w = F\ n$

Where:

C = Hazen-Williams C-factor

e = Darcy-Weisbach roughness

d = pipe diameter

n= Manning roughness coefficient

F= wall reaction-pipe roughness coefficient. F must be developed from site-specific field measurements and will have a different meaning depending on which head loss equation is used.

EPANET: Water Quality Simulation Model…

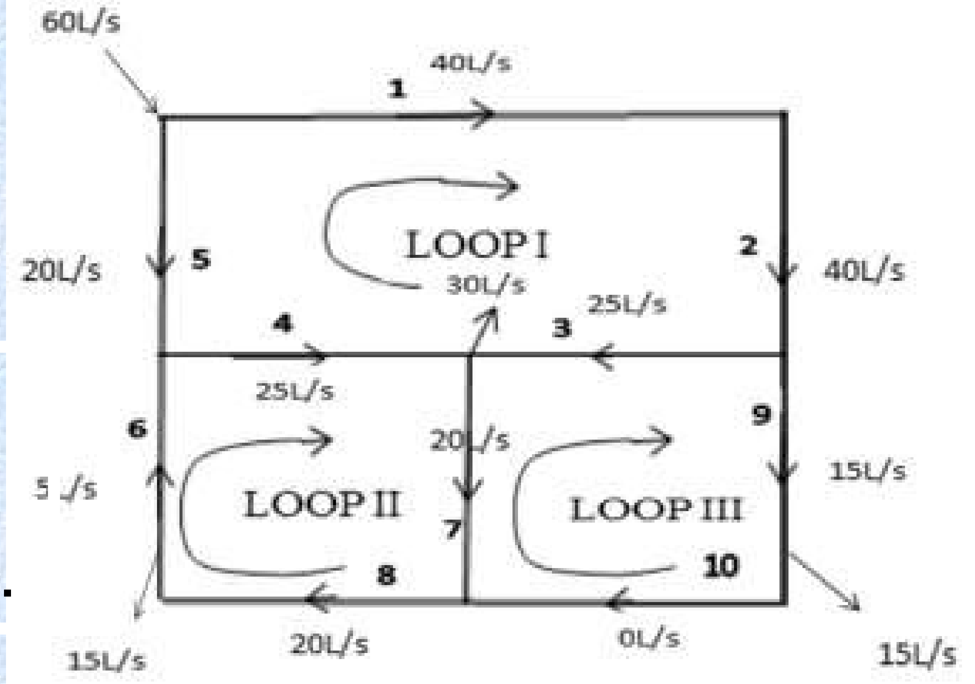
- **Water Age and Source Tracing:**
  - In addition to chemical transport, EPANET can also model the changes in the **age** of water throughout a distribution system.
  - Water age is the time spent by a parcel of water in the network. New water entering the network from reservoirs or source nodes enters with age of zero.
  - EPANET can also perform source tracing. Source tracing tracks over time what percent of water reaching any node in the network had its origin at a particular node
  - Source tracing is a useful tool for analyzing distribution systems drawing water from two or more different raw water supplies. It can show to what degree water from a given source blends with that from other sources, and how the spatial pattern of this blending changes over time

Demonstration

- The following demonstration is adopted from a research article entitled **" Analysis of Head-loss Equations under EPANET and Hardy Cross Method"** by Nwajuaku et.al. (2017)

- Solve the problem using
  - EPANET-2.0 Software
  - Microsoft Excel Spreadsheet

Follow the class demonstration using the software or read the article for step-by-step procedures.



Separate video lecture for all software demonstration will be prepared and forwarded to students registered for this course at AAiT.

The video will include the use of EPANET, WaterCAD and other essential tools in water supply system design.

Any one interested to get the demonstration material can e-mail to

fiseha.behulu@aait.edu.et

fishbehulu@gmail.com