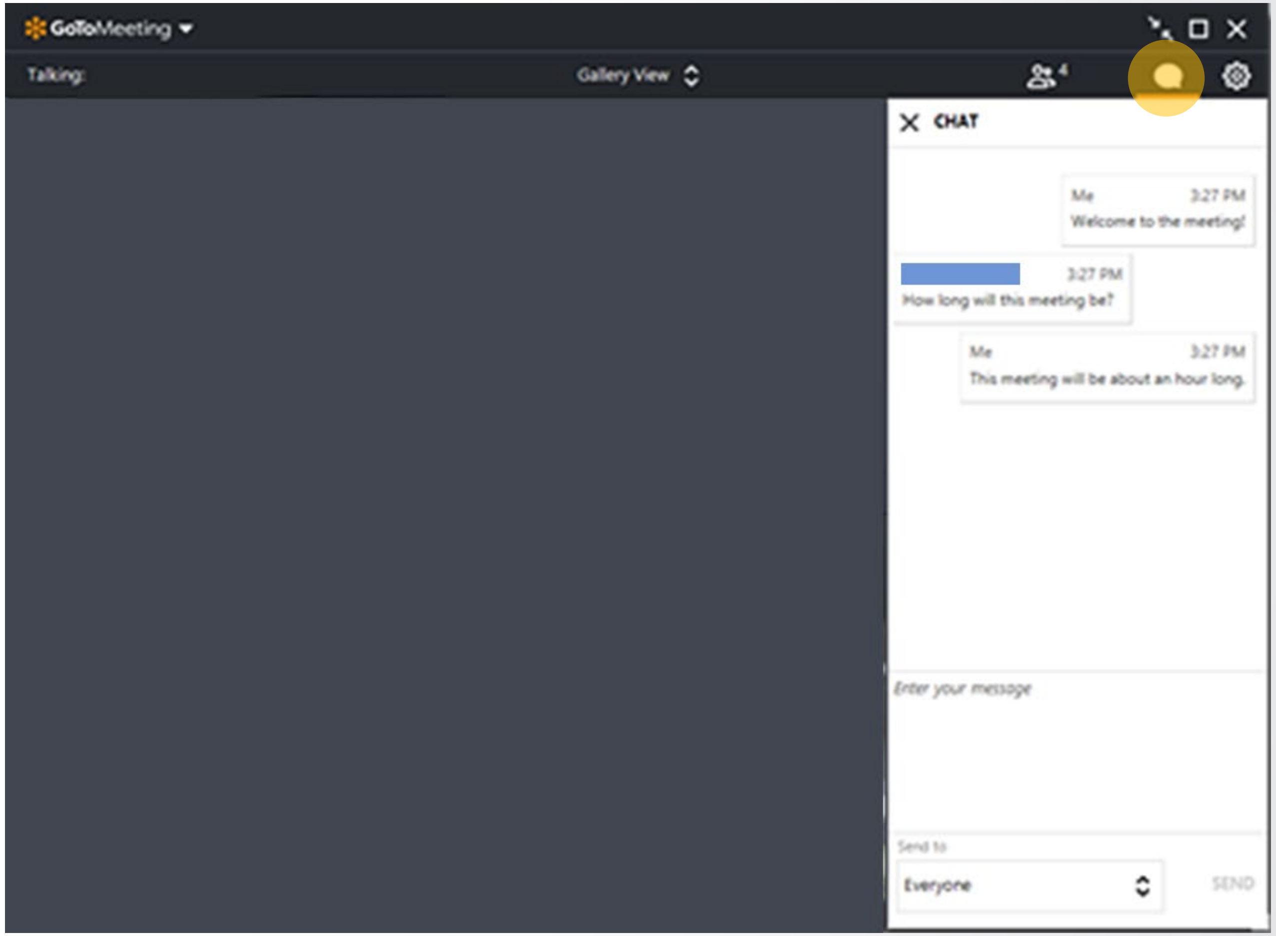
How to Submit Questions?

- Click the speech chat icon
- Type & submit your questions at anytime
- We’ll take time to answer them at the end of each section



18th Annual EPA Drinking Water Workshop

Introduction to EPANET and Example Applications

Center for Environmental Solutions and Emergency Response
US EPA Office of Research and Development

Disclaimer

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EPANET Presenters (I)

TERRA HAXTON has a B.S. in civil engineering from Rose-Hulman Institute of Technology and M.S. and Ph.D. in environmental engineering from Vanderbilt University. Since joining EPA in 2007, Terra's research has focused on modeling the fate and transport of contaminants in drinking water distribution systems. Past research areas have included using modeling tools to help detect contamination, identify the source of contamination, determine grab sample locations to outline contaminated areas, and evaluate flushing strategies for contamination incidents. Her current research area is developing and applying modeling and simulation tools to assess the resilience of drinking water systems to disasters (e.g., earthquakes, power outages, pipe breaks, loss of source water).

FENG SHANG received his bachelor's and master's degrees in environmental engineering from Tsinghua University in China. Feng completed his PhD at the University of Cincinnati in the Environmental Engineering program. After getting his PhD degree, Feng worked briefly as a postdoc for the EPA, during which time he wrote the initial code for the multiple species extension (MSX) to EPANET. Feng joined the engineering software company Innovyze in 2008 and worked there as a principal software engineer until 2019. Feng joined EPA's Water Infrastructure Division as an environmental engineer in April 2019. His focus at EPA is on researching hydraulic and water quality issues in water infrastructure systems.

EPANET Presenters (2)

ROBERT JANKE earned his bachelor's degree in Chemistry and a master's degree in Health Physics from the University of Cincinnati. Rob joined U.S. EPA in 2003. Prior to joining EPA, Rob spent 12 years with the Department of Energy overseeing a large-scale remediation while focused on developing real-time radiological survey instrumentation and procedures. Rob's research at EPA has focused on understanding and dealing with contaminant threats to drinking water distribution systems (TEVA-SPOT) and developing the tools for real-time modeling. Rob helped coordinate the establishment of the EPANET-RTX open-source project that helped lead to the community open-source software project for EPANET.

JONATHAN BURKHARDT earned his Ph.D., master's and bachelor's degrees in Chemical Engineering from the University of Cincinnati. Jon joined U.S. EPA in 2013 as an ORISE postdoctoral fellow, and more permanently in 2015. Jon's research at EPA has focused on modeling contaminant fate and transport in water distribution systems and more recently in premise plumbing systems. Jon has supported EPANET, EPANET-MSX, WNTR and PPMtools development to support research related to these systems. Jon also leads research efforts associated with understanding water treatment with granular activated carbon.

EPANET Presenters (3)

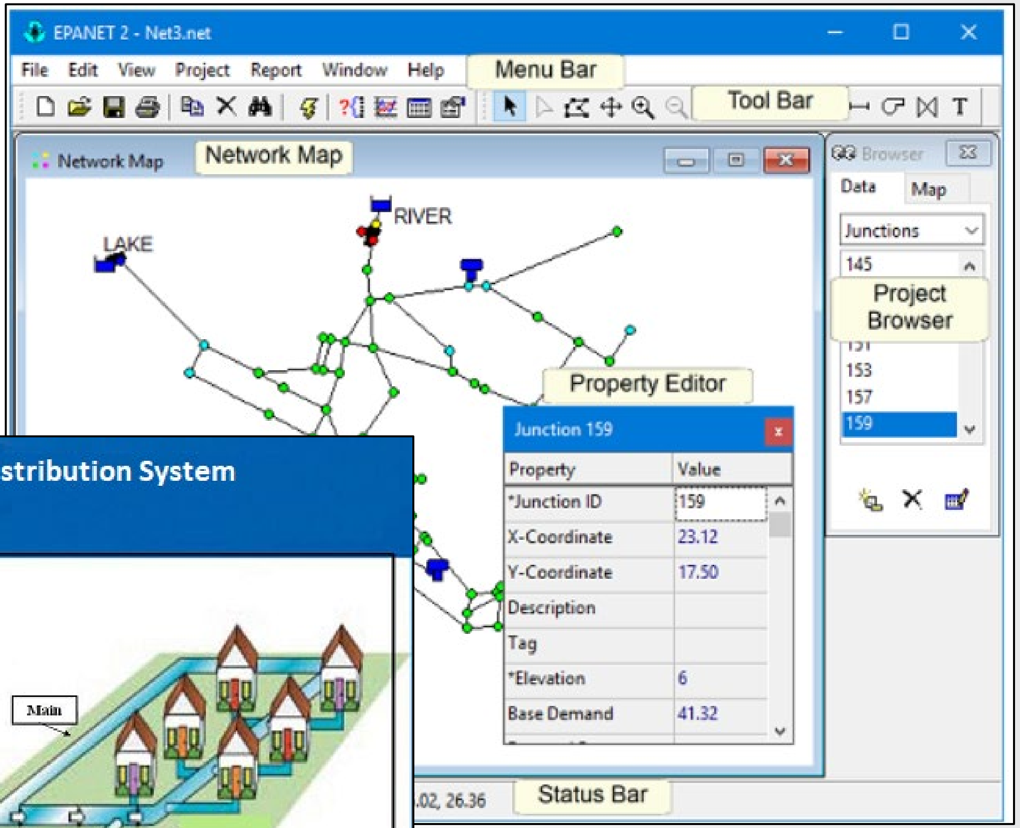
BEN BURKHART received his bachelor's degree in Mechanical Engineering from the University of Cincinnati. Ben joined the EPA in 2020 as an ORAU contractor. Prior to joining the EPA, Ben spent his last 3 co-ops at Wayne Water Systems designing and testing residential water pumps. Ben's research at the EPA has focused on water age and EPANET. Ben provides technical support for EPANET, including responding to users' questions and producing presentations and papers to help EPANET to be easier to learn and use.

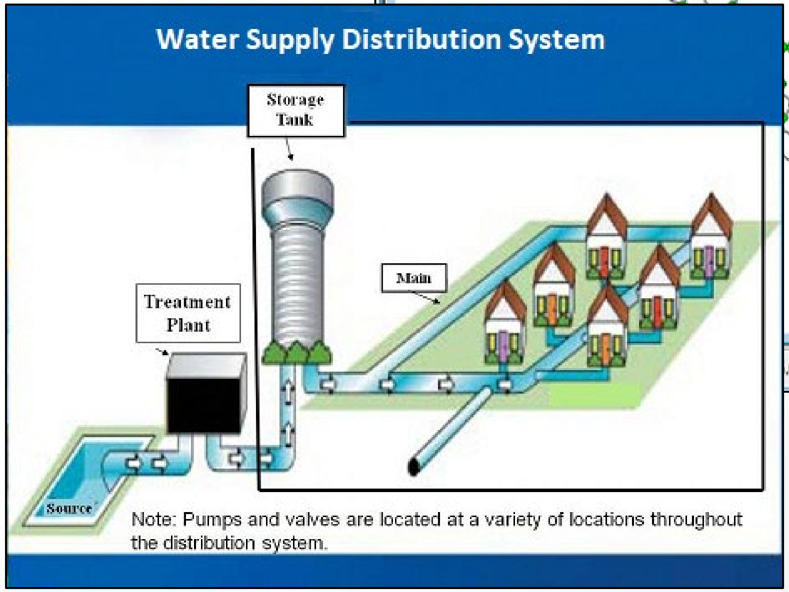
Summary

- This workshop on EPANET will be structured as two parts. Part 1 will provide an overview and introduction to EPANET. Part 2 will consist of presenting and discussing four example EPANET applications that participants can follow to get familiar with and use EPANET. The four applications will be in the form of exercises and will include (1) building an EPANET model, (2) performing a hydraulic simulation using demand dependent and pressure dependent demands, (3) performing a water age analysis, and (4) performing a water quality, chlorine analysis.

Outline for Workshop

- Overview & introduction to EPANET
- Details on hydraulics & water quality
- EPANET Applications
  - Model Building
  - Hydraulic Modeling
  - Water Age Modeling
  - Chlorine Modeling
- Application sections:
  - Lecture
  - Demonstration
  - DIY Exercise



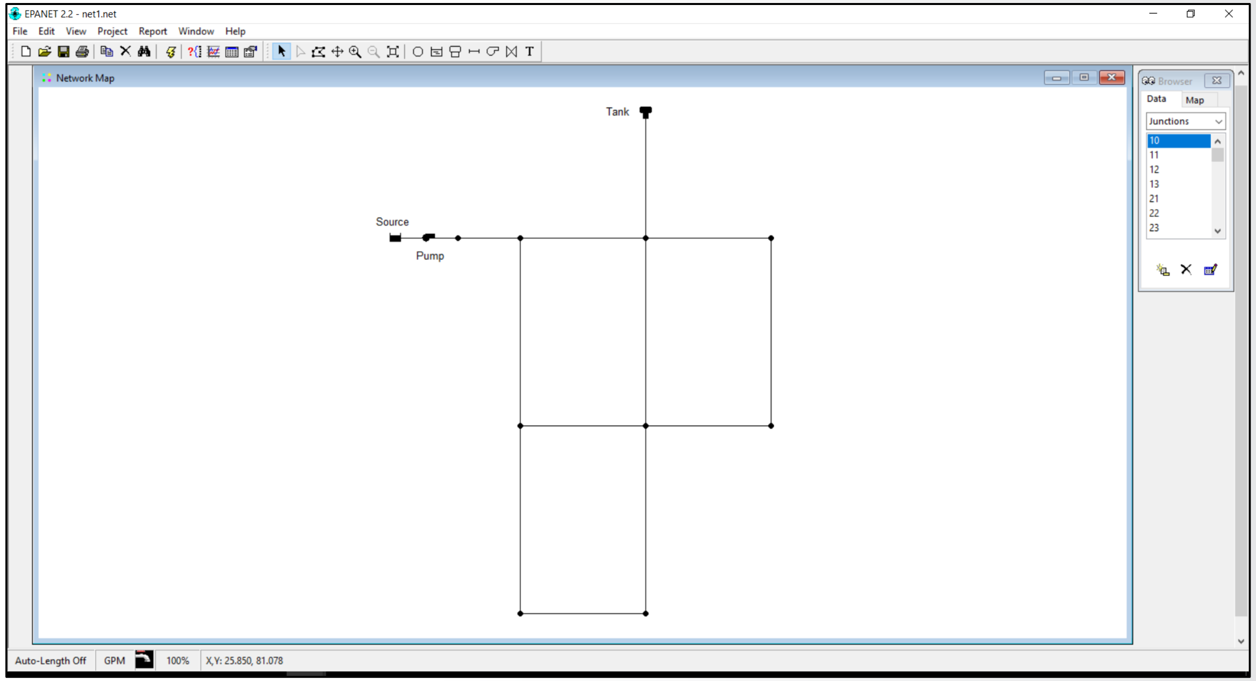


Overview & Introduction to EPANET

Terra Haxton & Feng Shang

What is EPANET?

- What is EPANET?
  - Not an acronym or initialism!
  - Computer program
    - Graphical user interface (GUI)
      - Microsoft Window Compatible
    - Command line & toolkit versions
- Used to model and analyze a water distribution system network
  - Input:
    - pipe network layout
  - Outputs:
    - hydraulics (e.g., pipe flows and pressures)
    - water quality (e.g., disinfectant concentrations and water age)



EPANET is open-source software that is free for anyone to use!

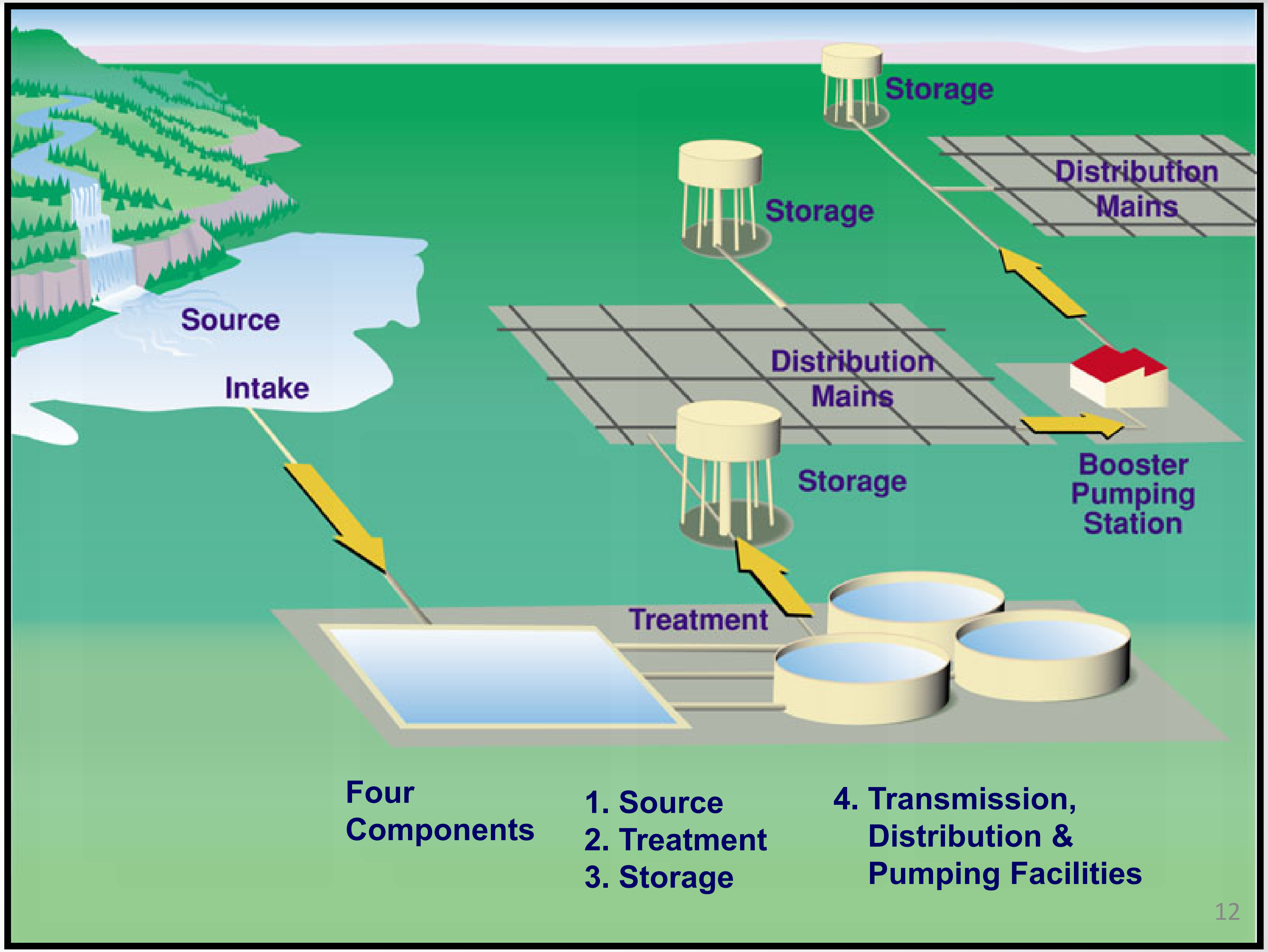
Knowledge Check I

What does EPANET stand for?

A. Environmental Protection Agency Network
B. It's not an acronym
C. Environmental Protection Agency National Emission Trends
D. Energy Partnership Agreement National Employee Training

Drinking Water System

- Major components:
  - Source water
  - Treatment
  - Storage
  - Transmissions, Distribution, and Pumping Facilities



Terms & Definitions (I)

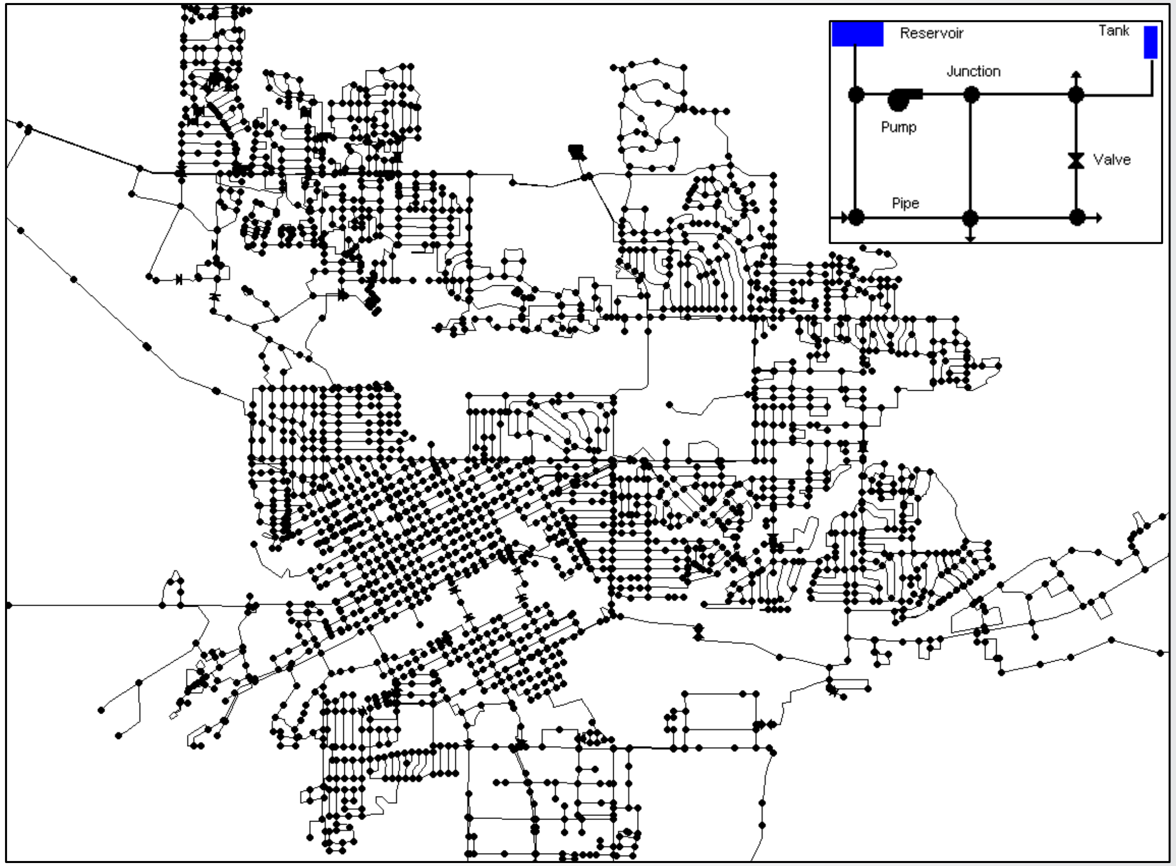
- Water distribution system (WDS)
  - Collection of pipes, tanks, pumps, valve control systems, and other components that work together to move water from a water source or treatment plan to individual users or customers' taps
- Network model (text file with .inp extension or binary file with .net)
  - Water distribution system representation!
  - Pipe network layout (infrastructure map) including tanks, pumps, valve control systems, and other components needed to describe a water distribution system
- Hydraulic model
  - Network model simulated in EPANET for hydraulics
- Water quality model
  - Network model simulated in EPANET for water quality

Terms & Definitions (2)

- Steady state simulation
  - Network analyzed as a snap-shot in time, time zero in EPANET
- Extended period simulation
  - Network analyzed over time
- Water distribution system modeling is a process to help understand:
  - How a water distribution system is designed and how designs can be improved
  - How a water distribution system is operating and how operations can be improved
- Water distribution system modeling is a mathematical process
  - Formulas are used to convert a physical (infrastructure) model into a form able to calculate hydraulics and chemical properties of water quality to represent or model the behavior of a water system

Why develop a model?

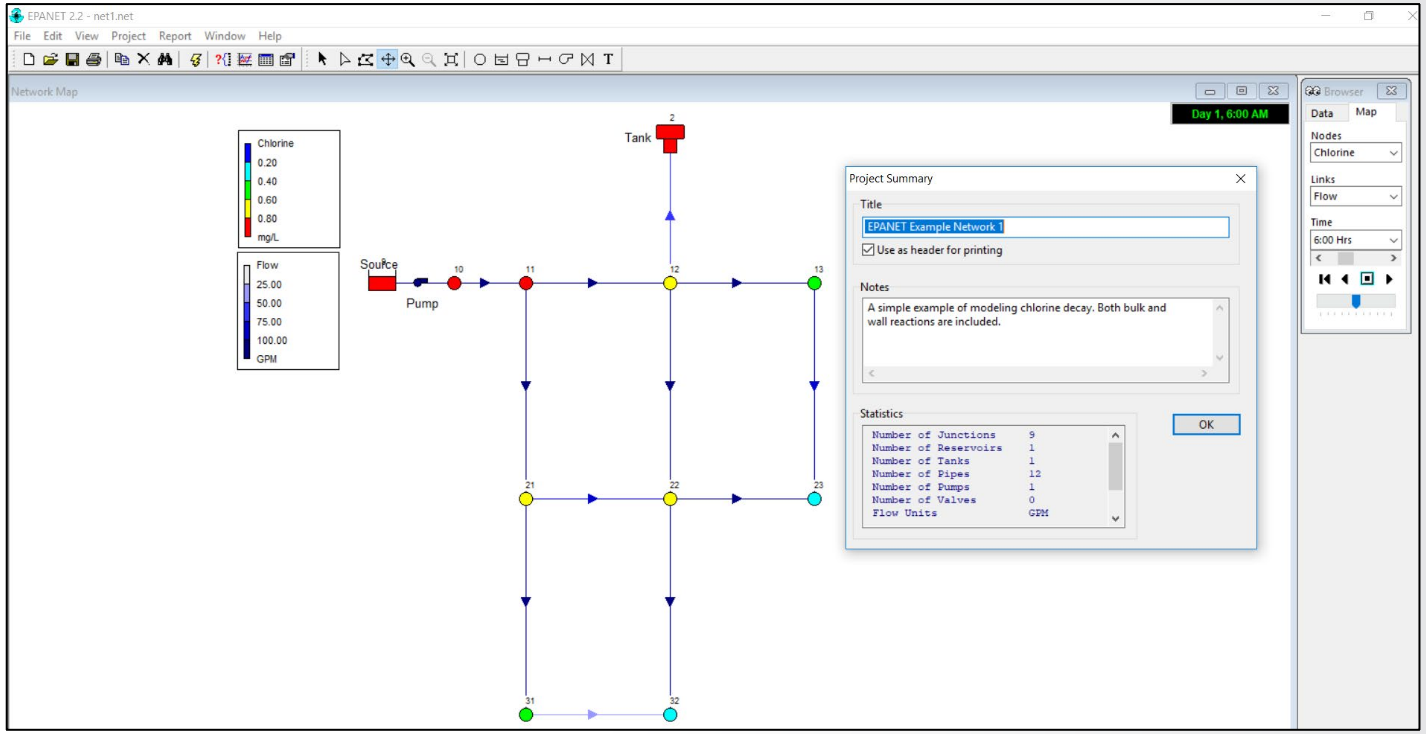
- Planning
  - Capital improvements
  - Water usage and conservation
  - Replacement and upgrade program
- Design
  - Facility sizing
  - Fire flow analysis
- Operations
  - Training
  - Hydraulic and water quality concerns
  - Emergencies



Network model

EPANET Modeling Types

- Hydraulic modeling
  - Evaluate operations
    - Current conditions
    - Test impact of changes to pumps, tanks, and valves
  - Design new water distribution systems or upgrade existing systems
- Quality modeling
  - Water age and disinfectant management
  - Contaminant transport, exposure, and risk analyses



Hydraulic & water quality (chlorine) modeling for Example Net 1

History of EPANET

- EPANET was developed by Lewis A. Rossman (retired March 2014) working for U.S. EPA in the early 1990's
- First non-beta release of EPANET was in 2000, version 2.00.00
- U.S. EPA's last release of version 2.00 was in 2008 with 2.00.12
- Maintenance and advancement of EPANET is now through community collaboration at https://github.com/OpenWaterAnalytics/EPANET

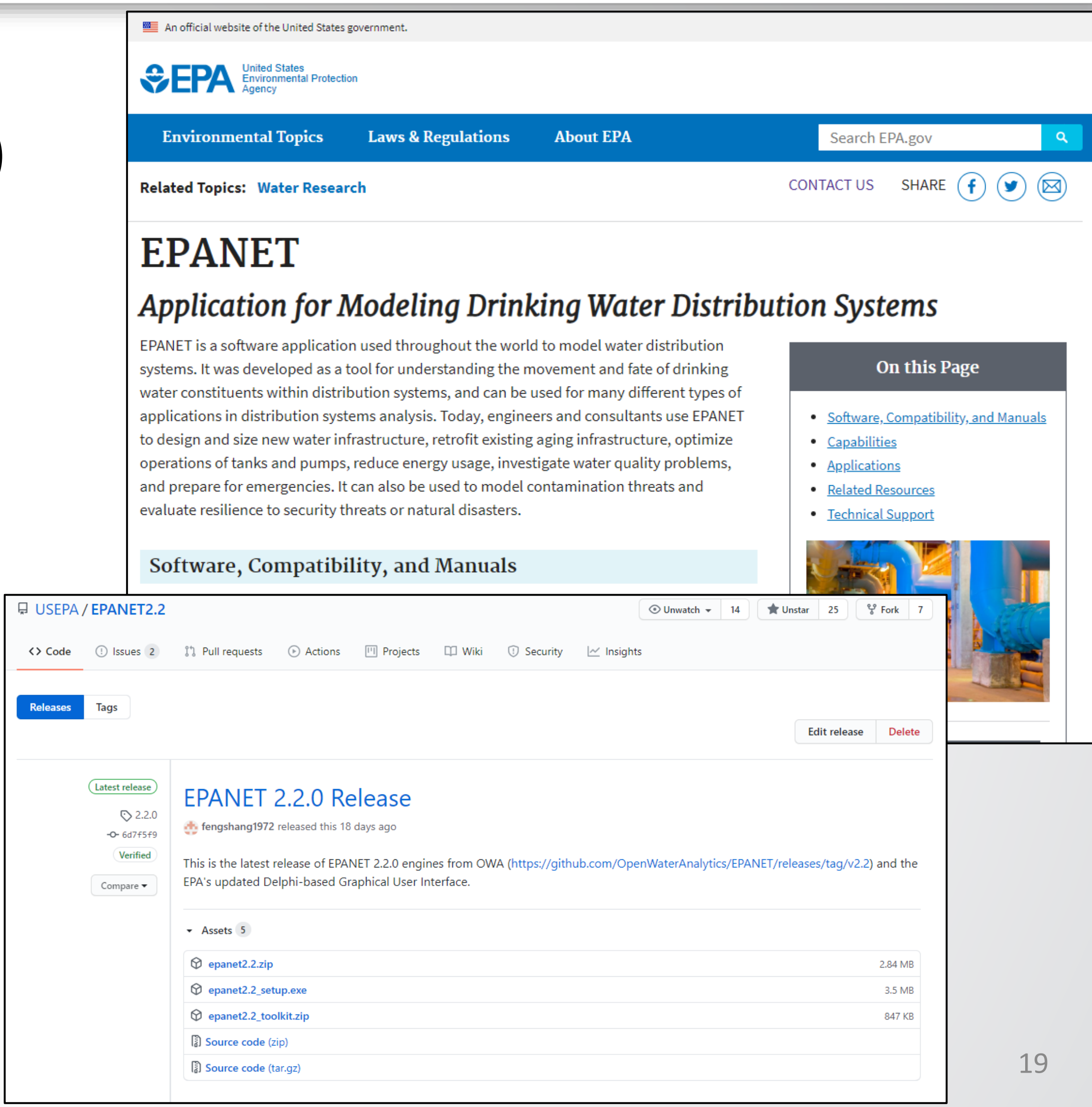
U.S. EPA's latest release is version 2.2.0

Improvements in EPANET 2.2

- Ability to use pressure-dependent demands in hydraulic analyses
- Option to allow full tanks to overflow
- Options that ensure a more accurate hydraulic analysis
- More robust handling of low and zero flow hydraulic conditions
- Faster solution times for single period hydraulic analyses
- Improved mass balance results for water quality analyses
- An enhanced API function library for customizing EPANET (see http://wateranalytics.org/EPANET/)

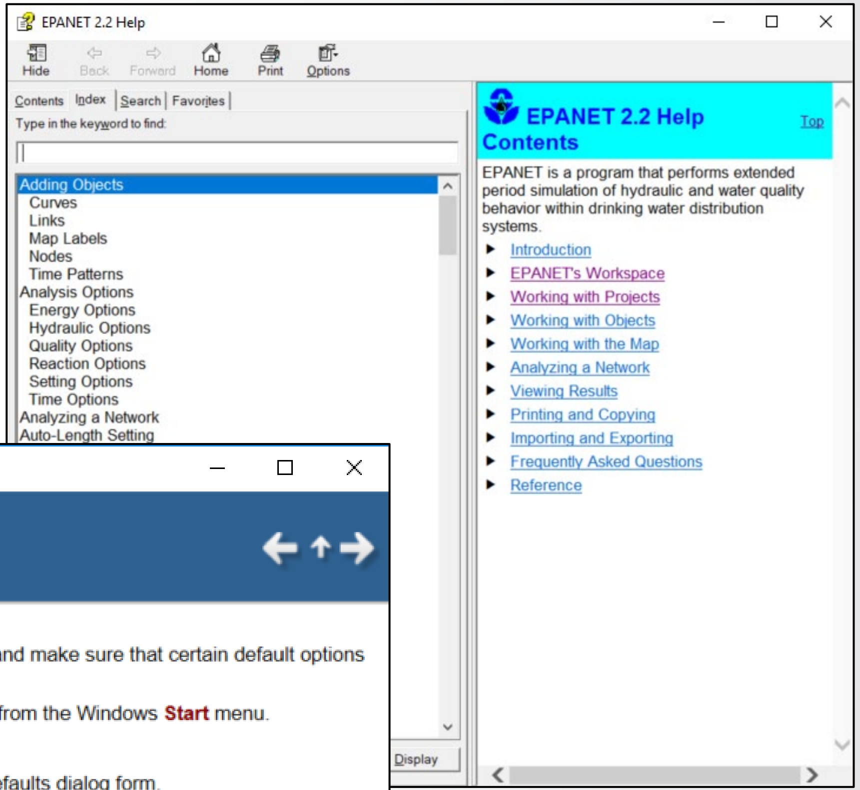
Downloading EPANET

- U.S. EPA's website (https://www.epa.gov/water-research/epanet)
  - Software (GUI)
    - Self-extracting installation program for EPANET 2.2
      - "epanet2.2_setup.exe" file
    - Non-installing software for EPANET 2.2
      - "epanet.zip" file
  - User's manual
    - PDF version
    - Read-the-Docs (https://epanet22.readthedocs.io/en/latest/)
  - Toolkit and extensions
- U.S. EPA's Github.com site (https://github.com/USEPA/EPANET2.2)
  - Mirror of the website
  - Easier to maintain & keep updated

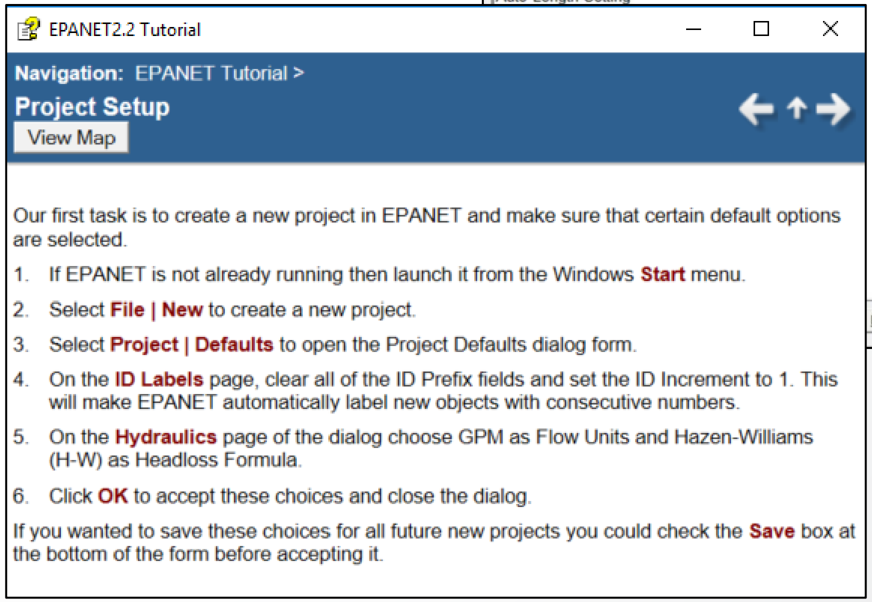


Installing & Running EPANET

- Self-extracting installation program for EPANET 2.2 (epanet2.2_setup.exe)
  - Requires administrative privileges for installation
  - Installs EPANET program, Help, Tutorial, and Release Notes in the Microsoft Windows Start Menu
  - Example networks may be hard to find:
    - Placed in a sub-folder named "EPANET Projects\Examples" in your Documents folder



EPANET's Integrated Help



EPANET's Tutorial

Running EPANET (non-installing)

- Non-installing software for EPANET 2.2 (epanet2.2.zip)
  - Notice everything is included – same as installed version
  - Can be saved anywhere on the computer
  - Runs EPANET (Epanet2w.exe)
  - DOS command line EPANET (runepanet.exe)
  - This option does not require administrative rights!

Name	Status	Date modified	Type	Size
Examples		8/11/2020 1:19 PM	File folder	
EPANET2.chm		1/24/2020 9:38 AM	Compiled HTML Help file	692 KB
epanet2.dll		1/24/2020 10:22 AM	Application extension	287 KB
Epanet2w.exe		2/26/2020 1:18 PM	Application	5,092 KB
notes.txt		1/24/2020 9:58 AM	Text Document	4 KB
runepanet.exe		1/24/2020 10:23 AM	Application	285 KB
Tutorial.chm		1/24/2020 9:32 AM	Compiled HTML Help file	99 KB

Knowledge Check 2

If you have questions about EPANET, where can you find answers?

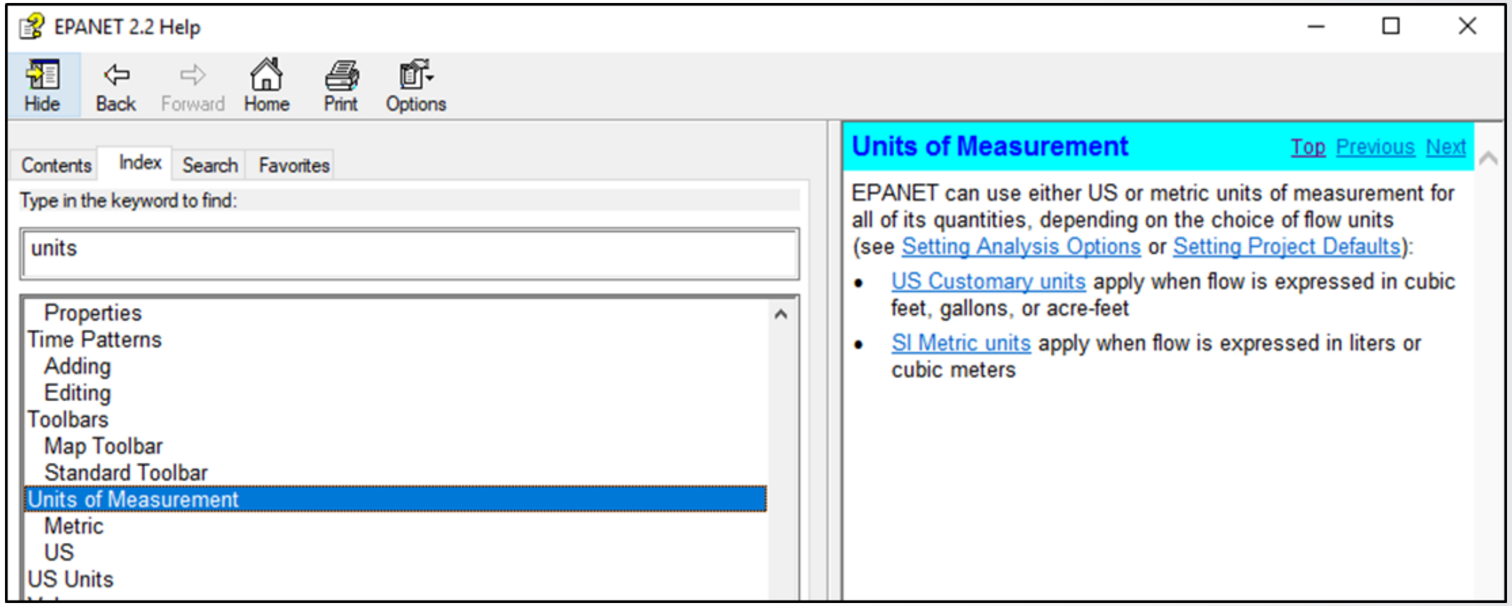
A. EPANET’s Integrated Help feature
B. Email the question to EPANET@EPA.GOV
C. The EPANET User Manual’s FAQ section
D. Ask the OWA community on GitHub
E. All the above

Brief Hydraulics Review

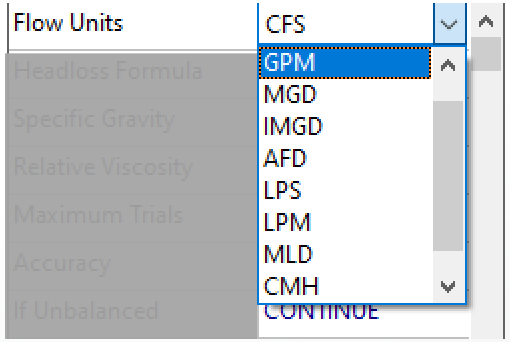
- EPANET’s basic assumptions about flow
  - Incompressible flow
  - Laminar, transition, and turbulent flows
  - Closed pipe (e.g., contaminant injections are modeled as mass/time)
  - Full pipe
- For background, supporting information, and review of basic principles~~:~~
  - Advanced Water Distribution Modeling and Management, Haestad Methods, T. Walski, D. V. Chase, D. A. Savic, W. M. Grayman, S. Beckwith, and E. Koelle
  - Water Distribution Systems Handbook, McGraw-Hill Handbooks, L. W. Mays editor

EPANET Units

- U.S. Customary
  - Gallons per minute (GPM)
  - Million gallons per day (MGD)
  - 1 MGD = 646 GPM
- SI Metric
  - Liters per second (L/s)
  - Cubic meters per second (m^3/s)
  - 1 m^3/s = 1000 L/s
- EPANET supports both unit systems



EPANET's Integrated Help – Open from Windows Start Menu



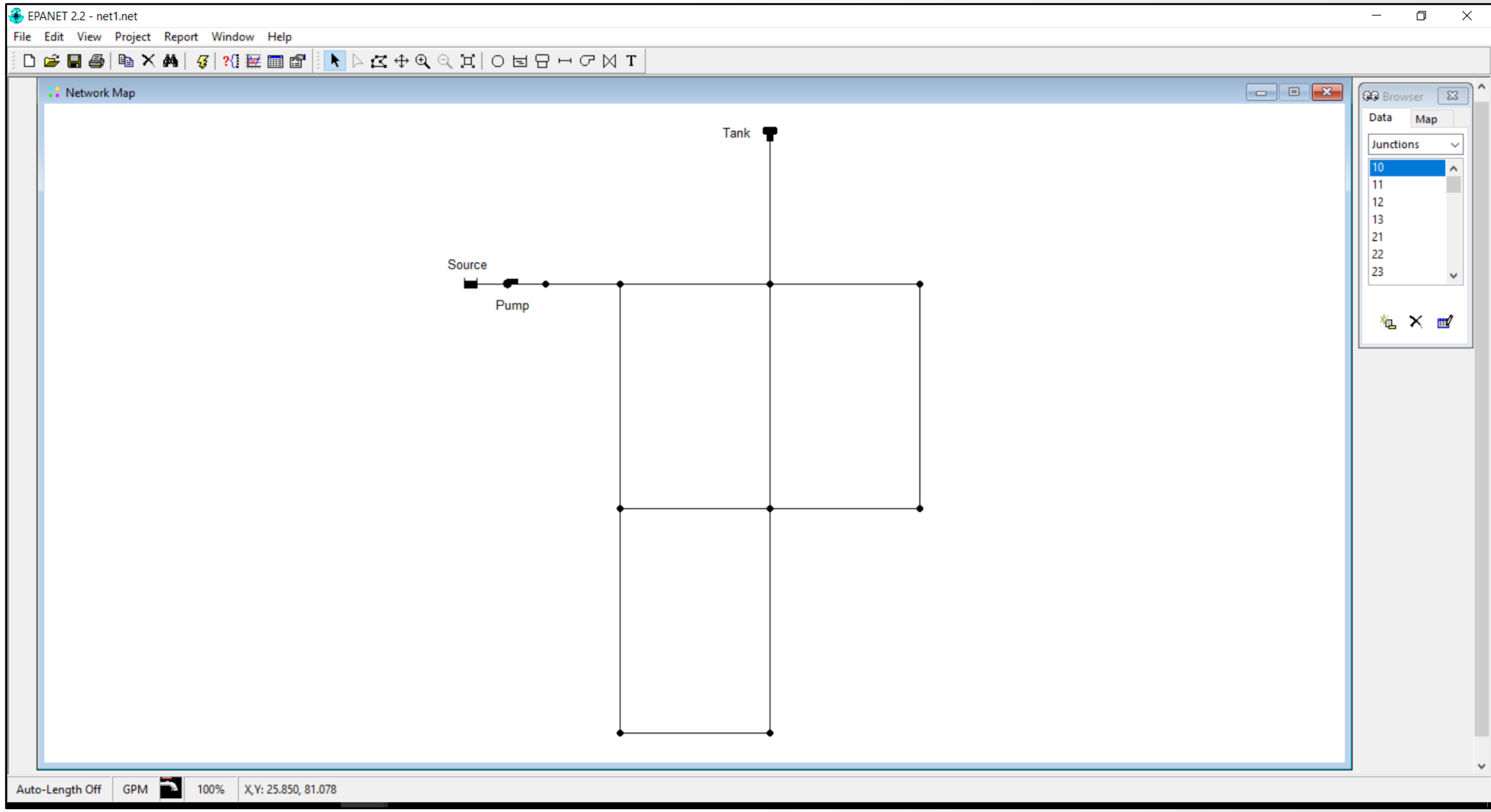
EPANET Units & Components

- Pressure
  - Pounds per square inch (psi) (U.S.)
  - Pascal (Pa) = N/m^2 (Metric)
  - 1 foot H_2O = 2.31 psi
- Normal range of allowable pressures in drinking water systems:
  - 20 psi (minimum)
  - 80-100 psi (maximum)

- Nodes
  - Junctions
  - Tanks
  - Reservoirs - Infinite external source or sink of water to the network
- Links
  - Pipes
  - Pumps
    - * Modeled with zero volume
  - Valves
    - * Modeled with zero volume
  - * Links require start and end nodes

How to get started?

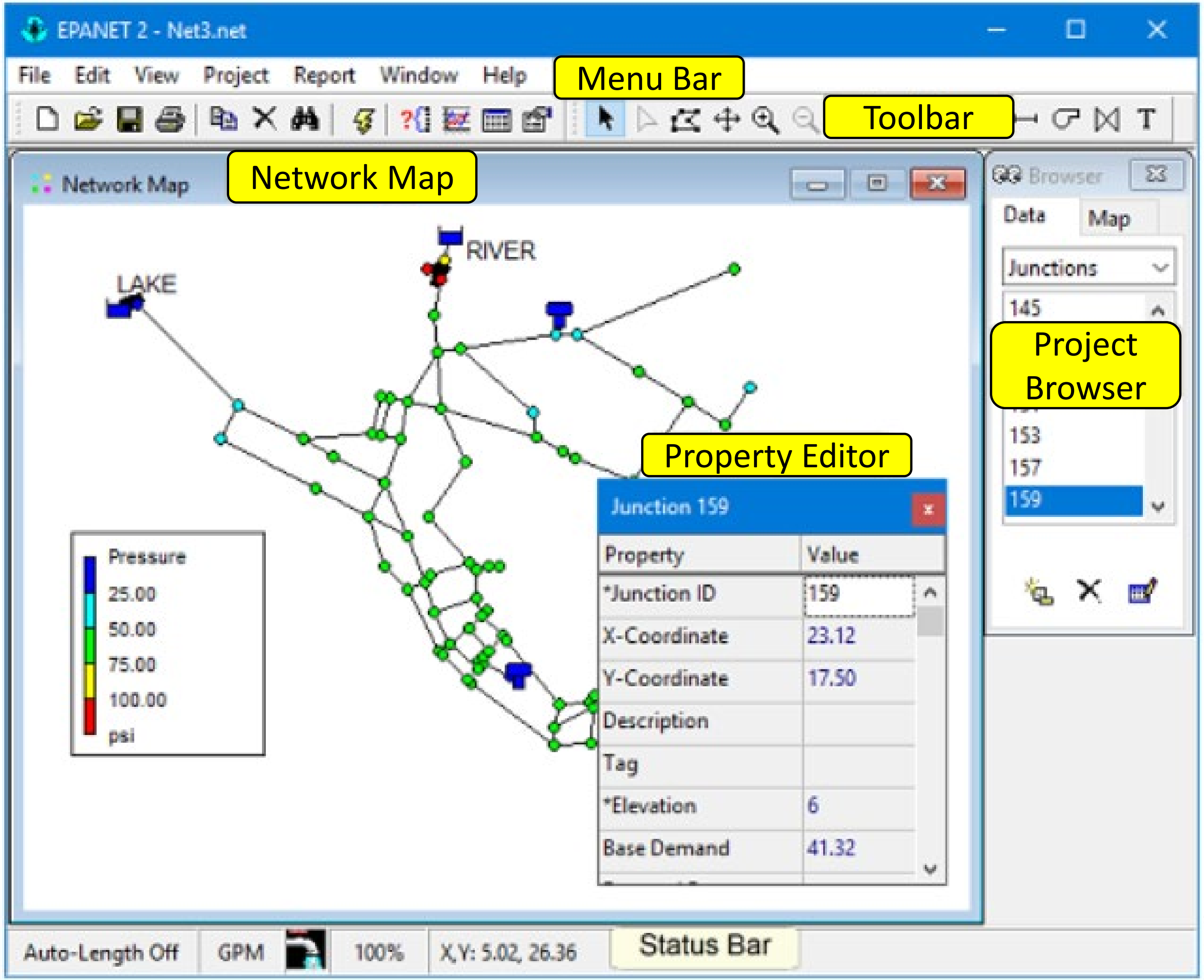
- Tutorial
  - Compiled HTML tutorial file and integrated help file
- User's manual
  - Opening an existing network
- Example networks
  - Experiment with example networks provided



Example Net 1 Opened in EPANET 2.2

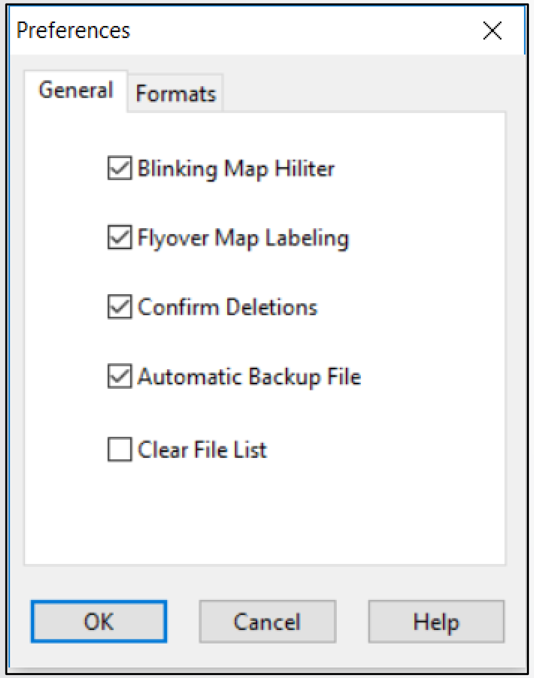
EPANET's Workspace

- EPANET's GUI
  - Menu Bar
  - Toolbar
  - Network Map
  - Project Browser
  - Property Editor
- User's manual chapter 4 "EPANET's Workspace"
- Questions?
  - Integrated Help (in the Menu Bar or by pressing F1 key)



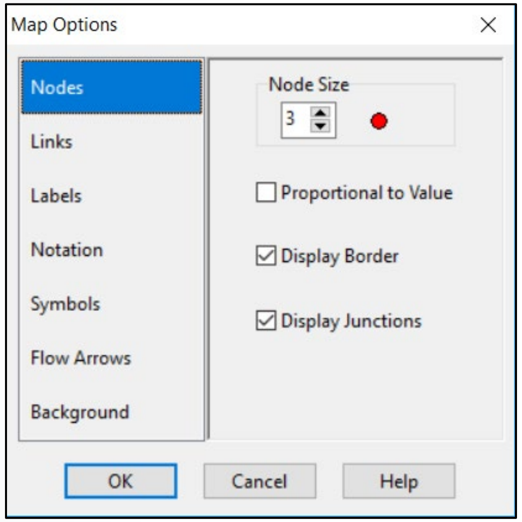
Menu Bar

File >> Preferences



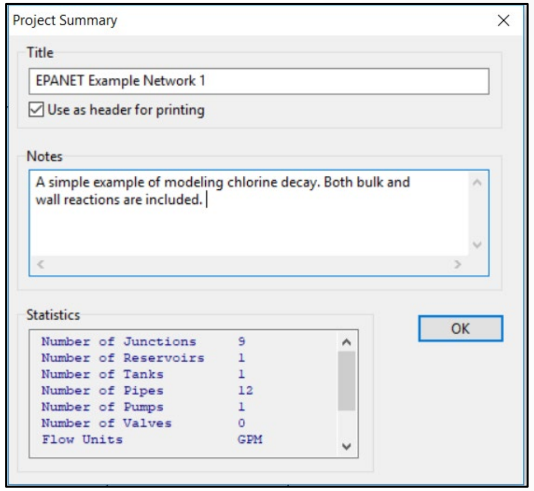
(set preferences e.g., decimal places)

View >> Options

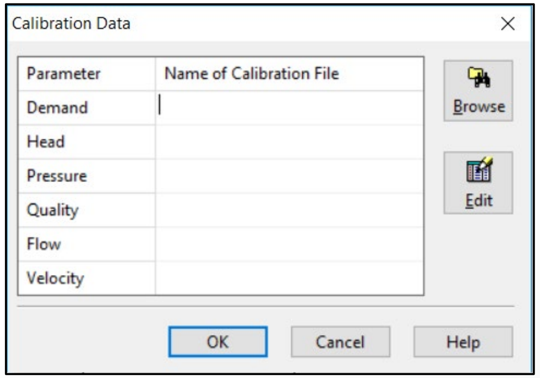


(set map viewing options)

Project >> Summary

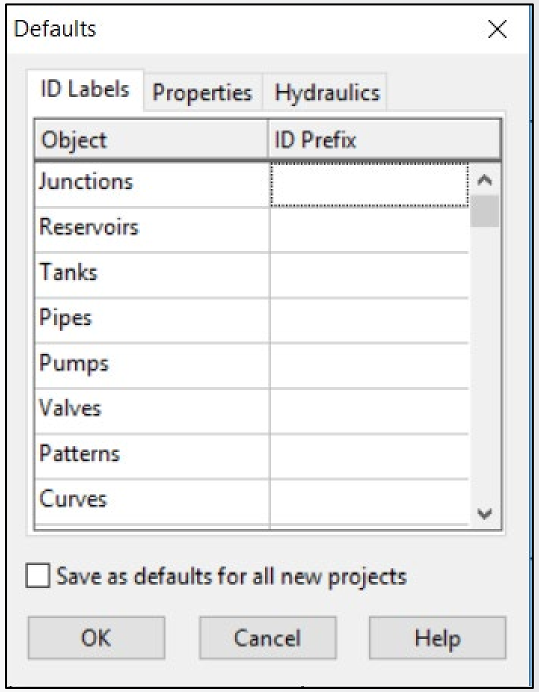


Project >> Calibration Data



(upload calibration data)

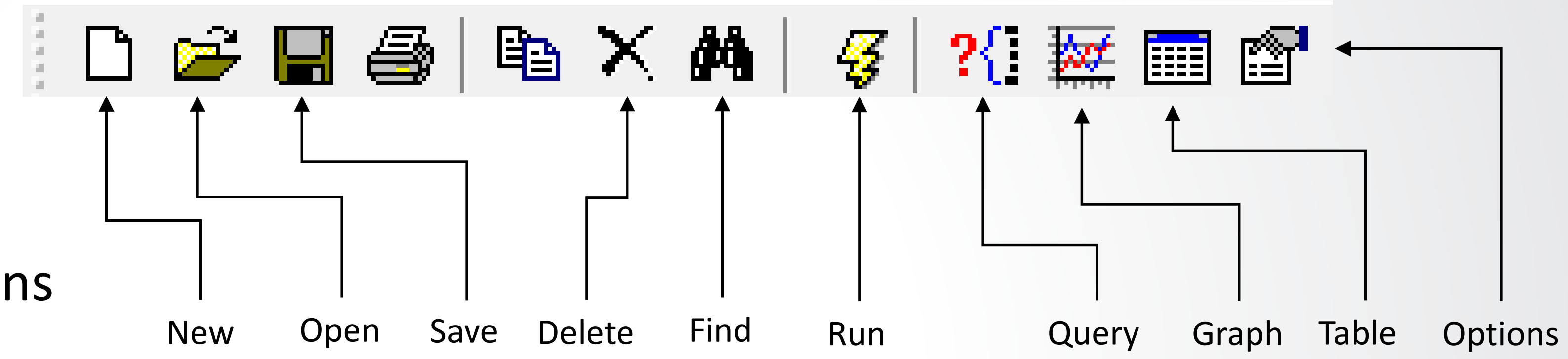
Project >> Defaults

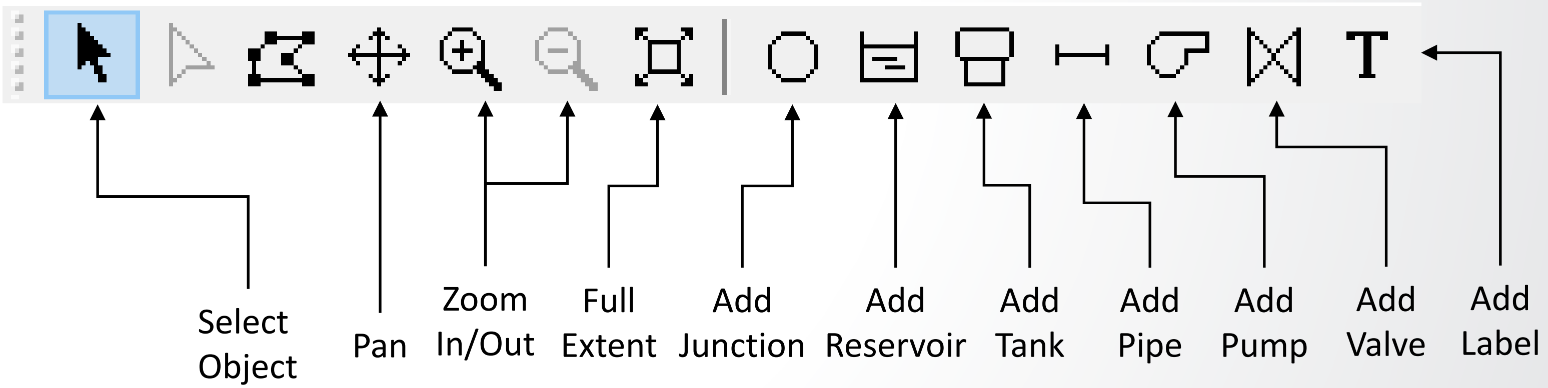


(set project defaults)

Toolbar

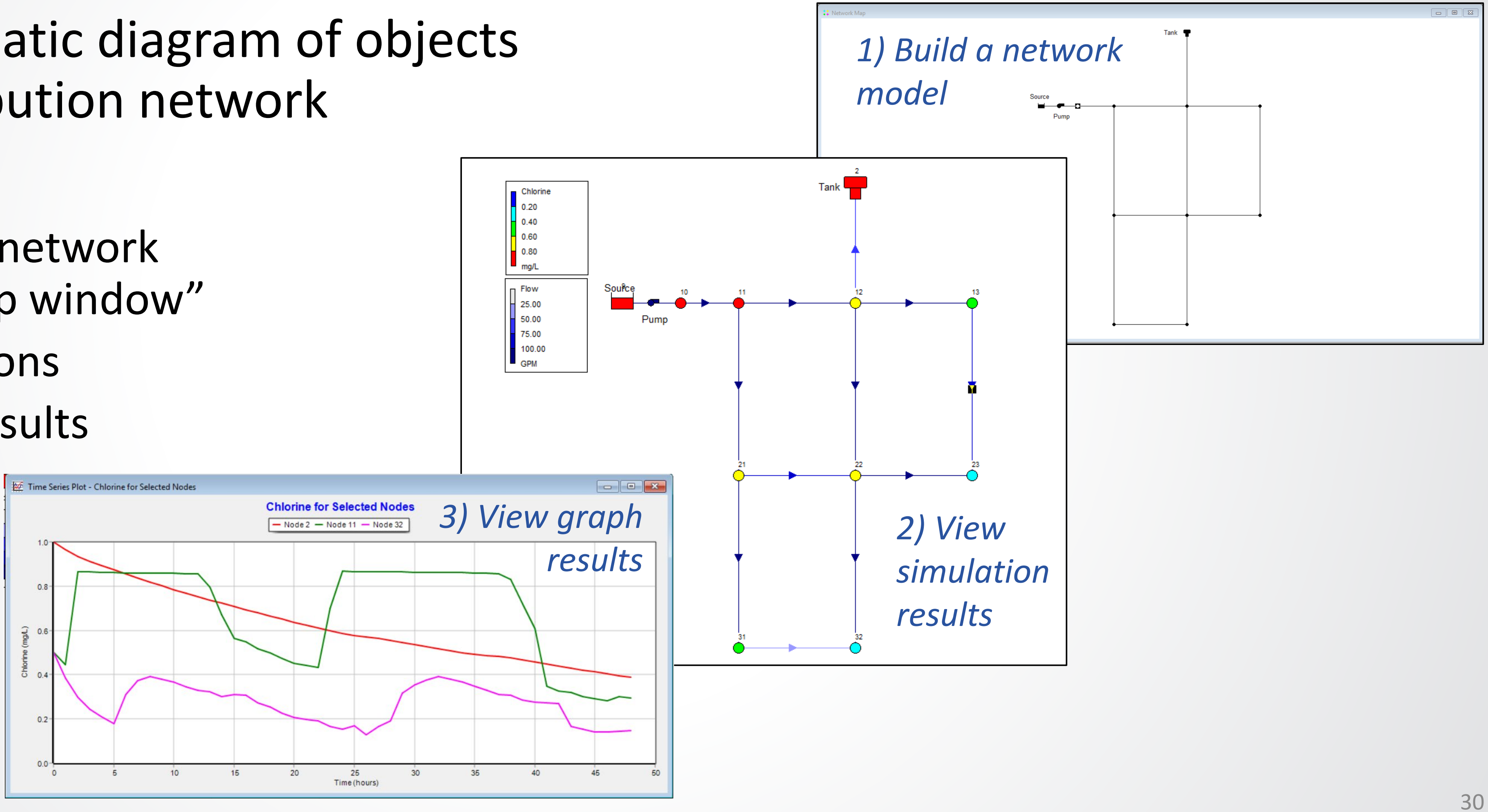
- Standard Toolbar
  - New, Open, Save, Print
  - Copy, Delete, Find
  - Run
  - Query, Graph, Table, Options
- Map Toolbar
  - Select
    - Object, Vertex, Region
  - Pan
  - Zoom In/Out
  - Full Extent
  - Add
    - Junction, Reservoir, Tank
    - Pipe, Pump, Valve
    - Label





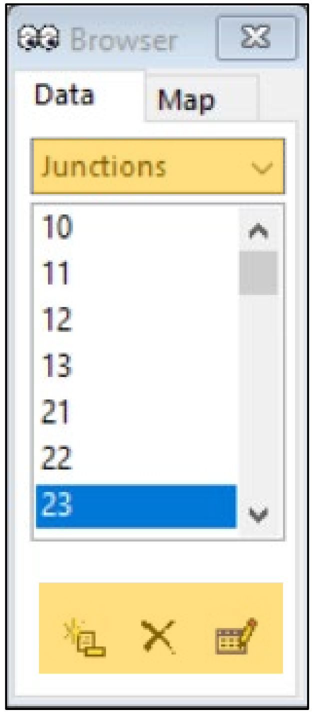
Network Map

- Displays schematic diagram of objects of water distribution network
- For example:
  - Build a water network model in “map window”
  - View simulations
  - View graph results

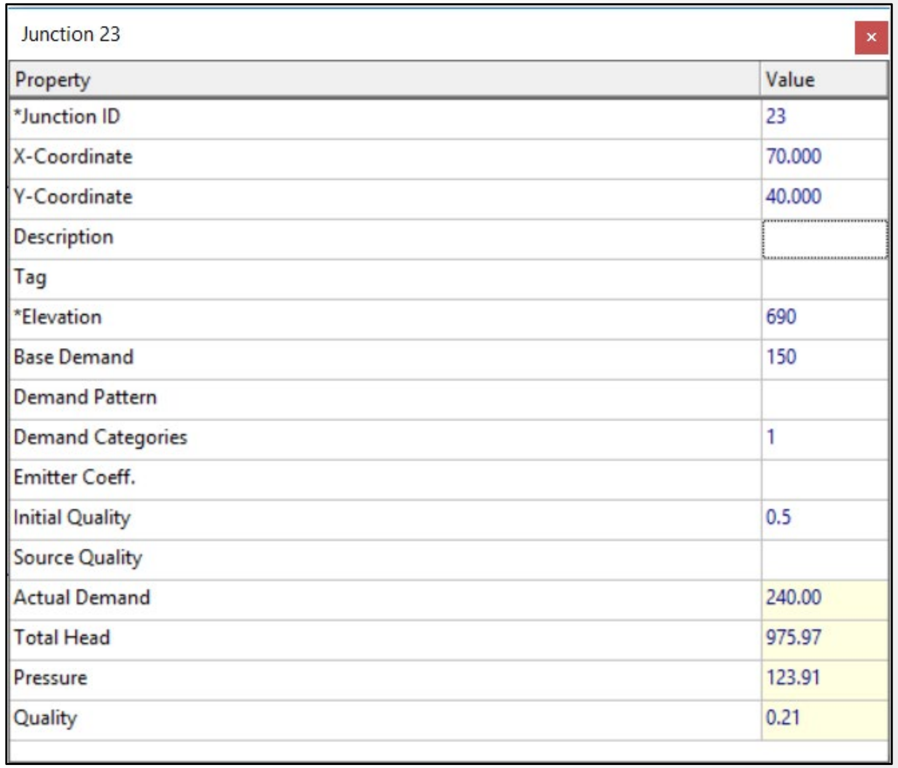


Project Browser

- Data Browser
  - Gives access to objects, by category
  - Buttons at bottom to add, delete, and edit objects
- Map Browser
  - Selects parameters and time period that are viewed in Network Map
  - Starts and stops the animation



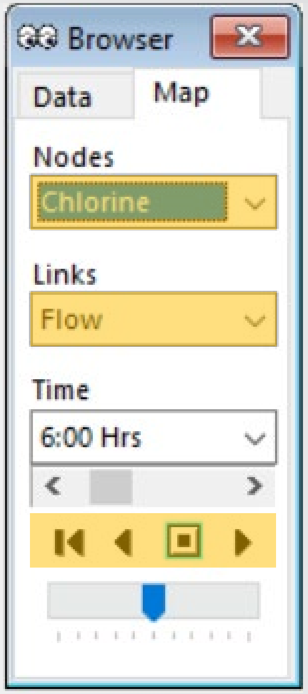
Data Browser



Junction 23

Property	Value
*Junction ID	23
X-Coordinate	70.000
Y-Coordinate	40.000
Description	
Tag	
*Elevation	690
Base Demand	150
Demand Pattern	
Demand Categories	1
Emitter Coeff.	
Initial Quality	0.5
Source Quality	
Actual Demand	240.00
Total Head	975.97
Pressure	123.91
Quality	0.21

Double-clicking object (Junction 23) in Data Browser brings up Property Editor above



Map Browser

Property Editor

Note: the Property Editor will look different depending on what type of component is selected

- (Junction vs Tank vs Reservoir vs Pipe vs Pump vs Valve)

Junction 10

Property	Value
*Junction ID	10
X-Coordinate	20.000
Y-Coordinate	70.000
Description	
Tag	
*Elevation	710
Base Demand	0
Demand Pattern	
Demand Categories	1
Emitter Coeff.	
Initial Quality	0.5
Source Quality	...
Actual Demand	#N/A
Total Head	#N/A
Pressure	#N/A
Quality	#N/A

Component Properties

- Double-Click Component >> Properties marked "*" are required
  - Yellow highlighted properties are required
  - Blue highlighted properties are not required, but are still commonly used

Junction 101

Property	Value
*Junction ID	101
X-Coordinate	13.810
Y-Coordinate	22.940
Description	
Tag	
*Elevation	42
Base Demand	189.95
Demand Pattern	
Demand Categories	1
Emitter Coeff.	

Reservoir Lake

Property	Value
*Reservoir ID	Lake
X-Coordinate	8.000
Y-Coordinate	27.530
Description	
Tag	
*Total Head	167.0
Head Pattern	
Initial Quality	
Source Quality	
Net Inflow	#N/A

Tank 3

Property	Value
*Tank ID	3
X-Coordinate	29.410
Y-Coordinate	27.270
Description	
Tag	
*Elevation	129.0
*Initial Level	29.0
*Minimum Level	4.0
*Maximum Level	35.5
*Diameter	164

Pipe 101

Property	Value
*Pipe ID	101
*Start Node	10
*End Node	101
Description	
Tag	
*Length	14200
*Diameter	18
*Roughness	110
Loss Coeff.	0
Initial Status	Open

Pump 10

Property	Value
*Pump ID	10
*Start Node	Lake
*End Node	10
Description	
Tag	
Pump Curve	1
Power	
Speed	
Pattern	
Initial Status	Closed

Valve 1

Property	Value
*Valve ID	1
*Start Node	Lake
*End Node	103
Description	
Tag	
*Diameter	12
*Type	PRV
*Setting	
Loss Coeff.	0
Fixed Status	None

Knowledge Check 3

Which part of the EPANET workspace would you use to view simulation results?

A. Menu Bar

B. Toolbar

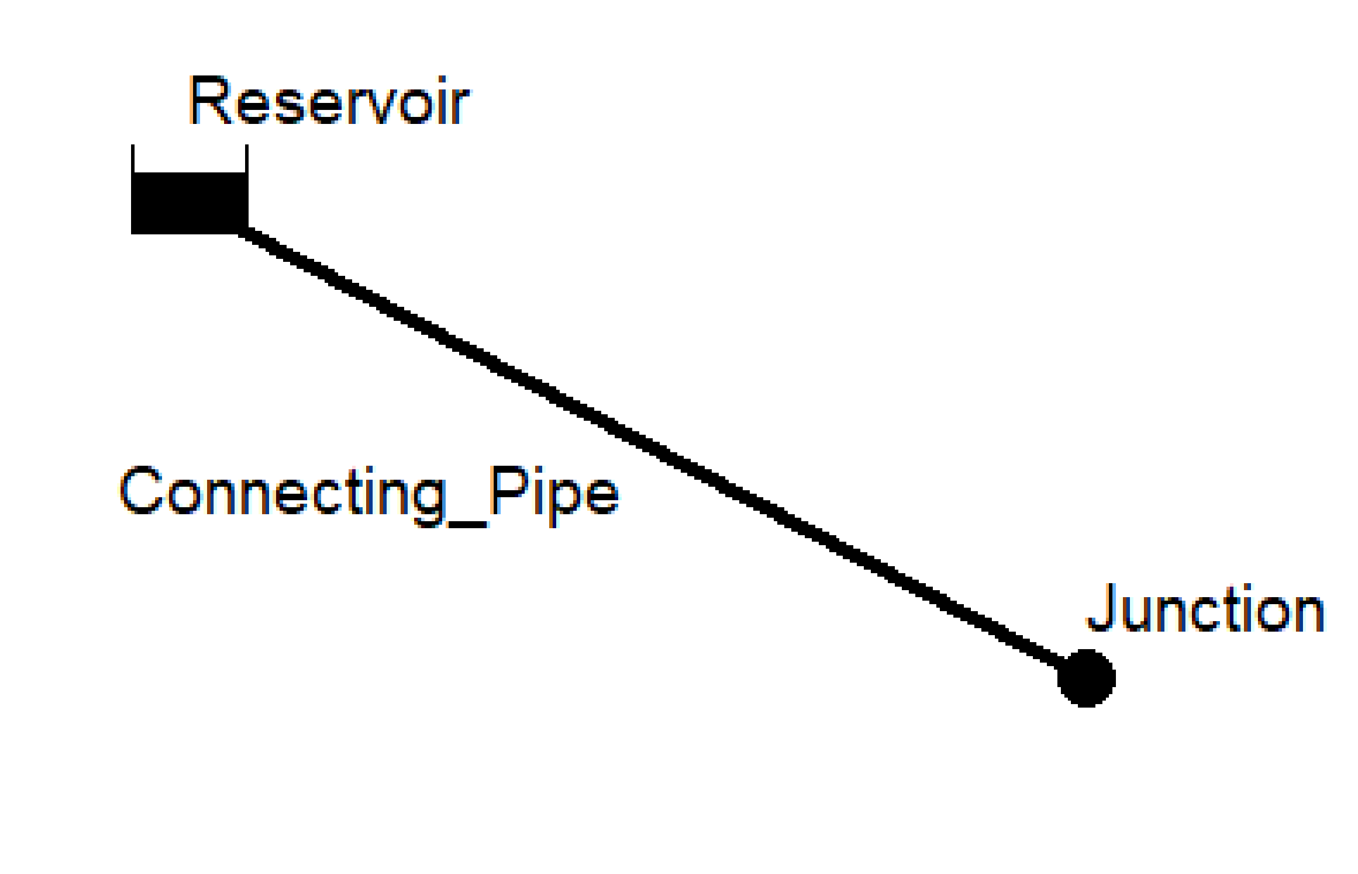
C. Network Map

D. Project Browser

E. Property Editor

EPANET Model

- EPANET model can be very simple
  - One reservoir to provide water
  - One pipe to transfer water
  - One junction to consume water



EPANET Hydraulics

- EPANET models hydraulic conditions over one period or multiple periods
- No transient/water hammer analysis in EPANET
- Demands needs to be assigned
- Pipes, pumps, and valves transfer water from sources to consumer nodes
- Steady state analysis
  - Fixed demand
  - Snapshot analysis
- Extended period simulation (EPS)
  - Changing demand over time (through Patterns)
  - Typically simulates a few days, e.g., seasonal peak days

Hydraulic Factors in WDS

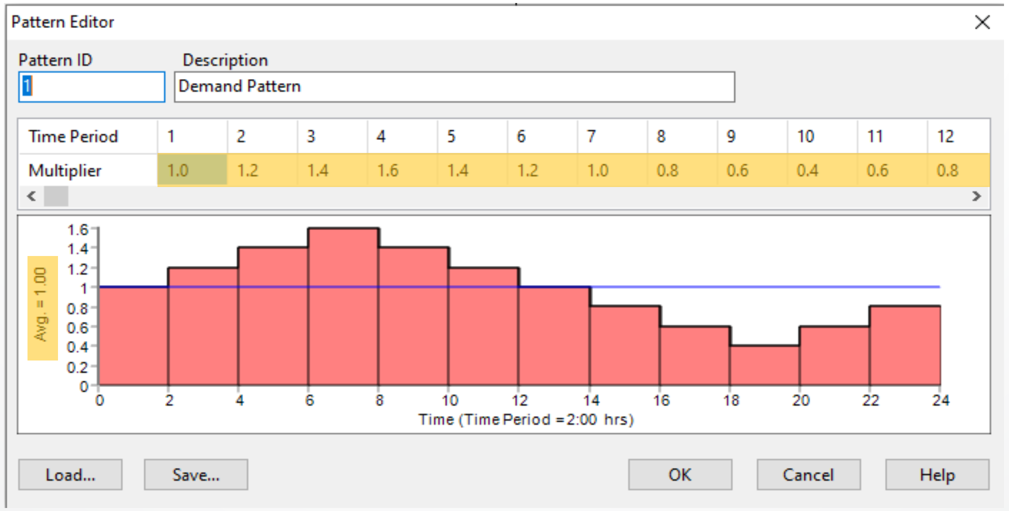
- Demands
- Dynamic Head
- Elevations
- Patterns & Controls
- Pipe Properties (diameter, length, roughness)
- Tanks, Pumps, & Valves

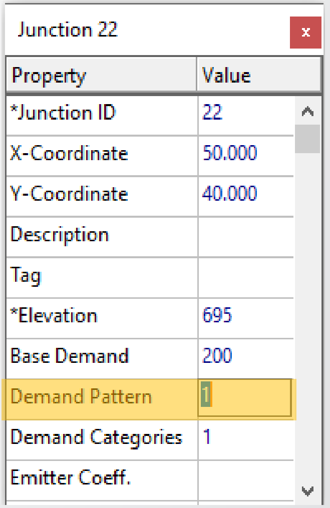
Extended Period Simulation

- Pattern Time Step usually set to 1 or 2 hours
  - Can be set very small (e.g., 1 minute)
- Each node has its own Base Demand
  - Base Demand is usually the average demand
- Pattern multipliers are applied to Junctions’ Base Demand
  - e.g., Base Demand = 1.0 GPM & Pattern Multiplier = 0.5 $\rightarrow$ Actual Demand = 0.5 GPM
- Patterns can be set to multiple nodes
  - Default Pattern is assigned to all junctions without a specified pattern

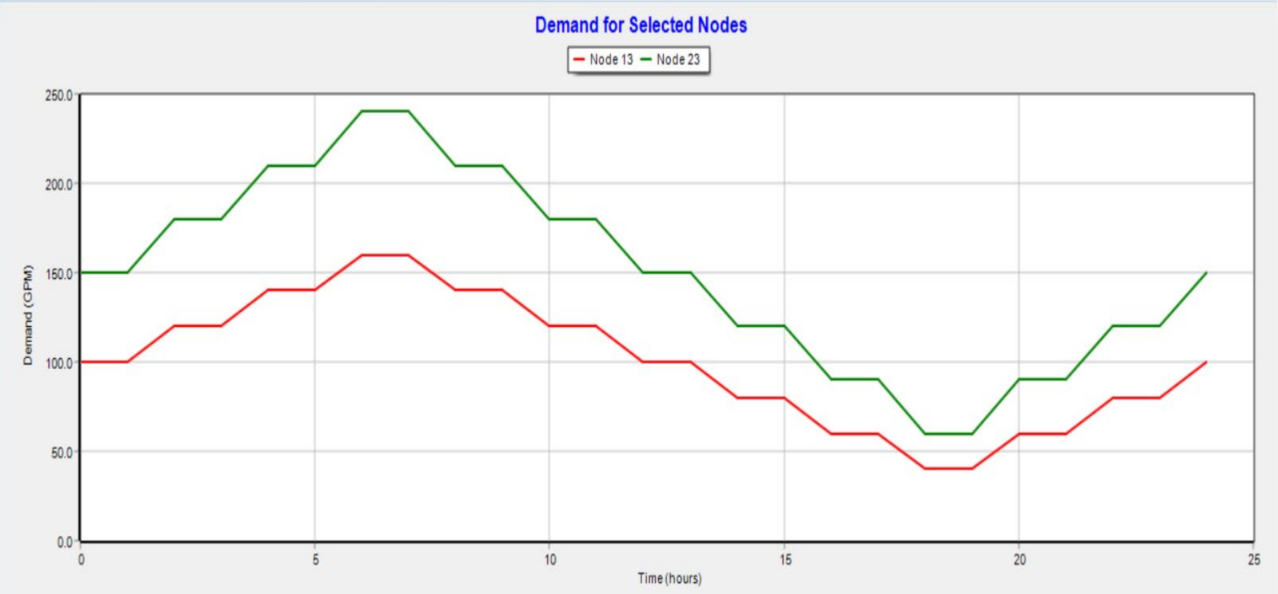
Patterns

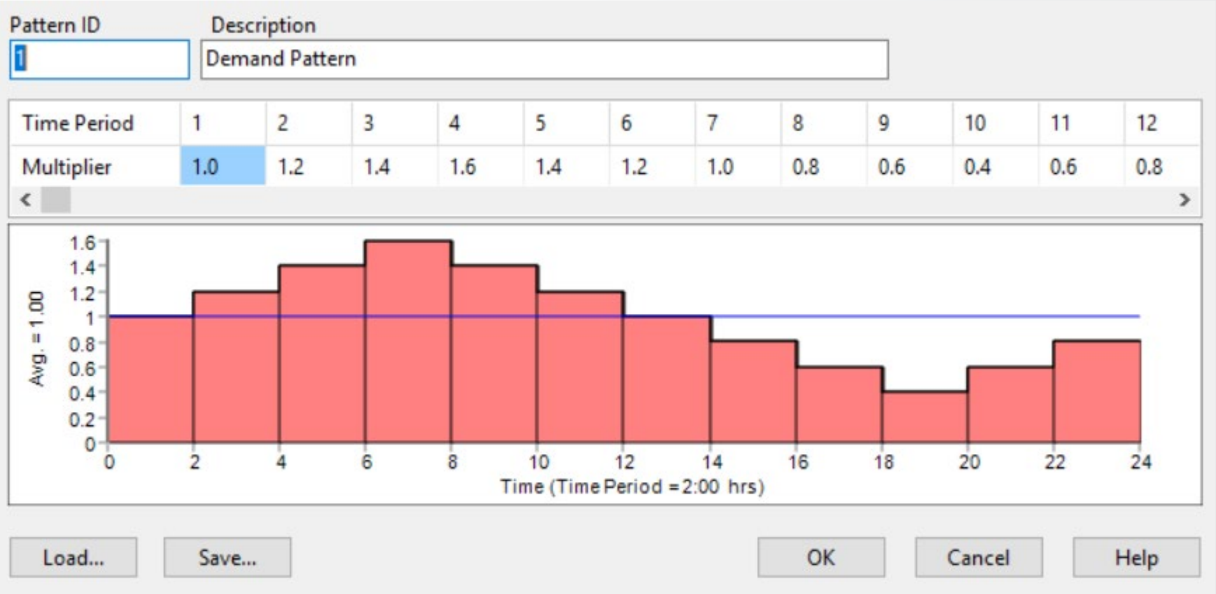
- Simulate changes over time
- Repeat for each time period (typically 1 day)
- Pattern ID is the name & how it is assigned in properties
- Multiplies the Base Demands of Junctions (or Heads for Reservoirs or Prices for Pumps) by specified amounts
  - Typically, the multipliers average 1.0 so the base value (demand, head, or price) is the average



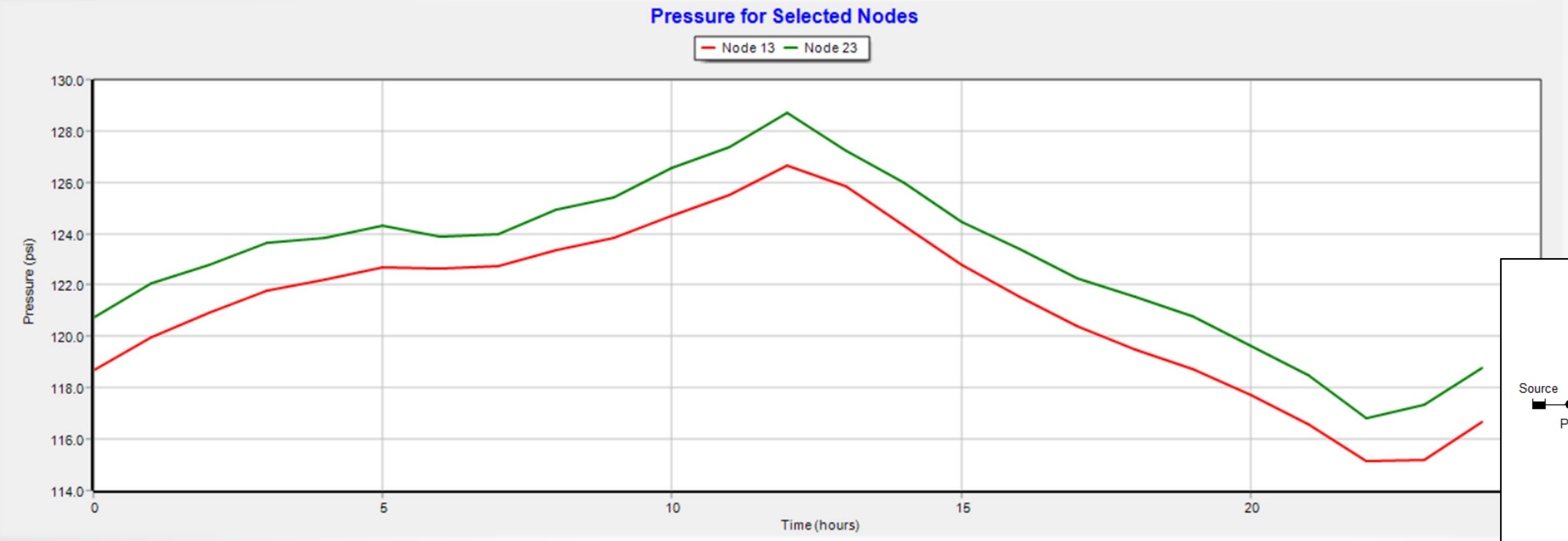


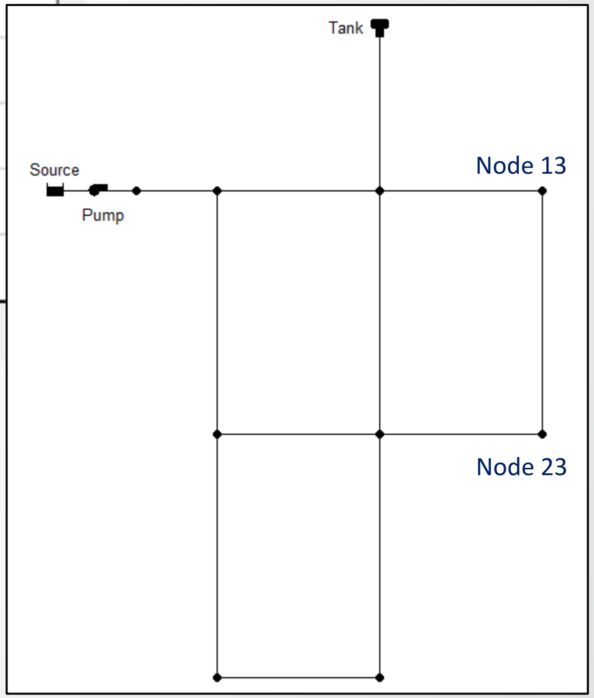
Demand Patterns



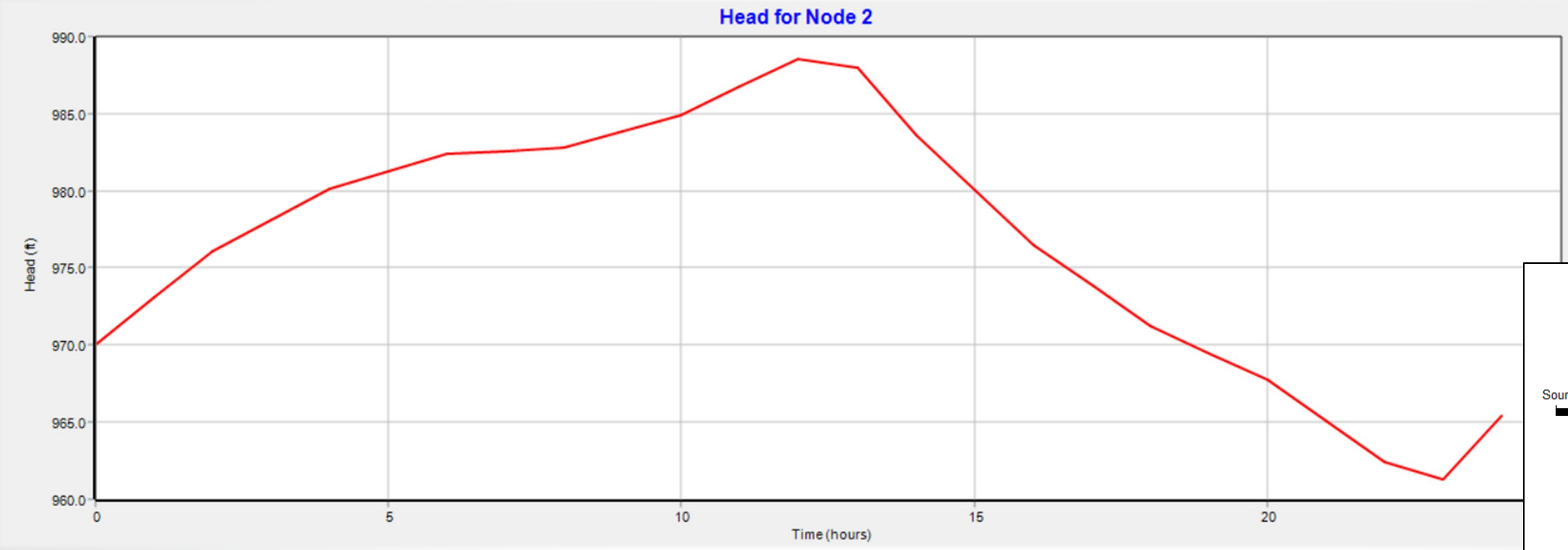


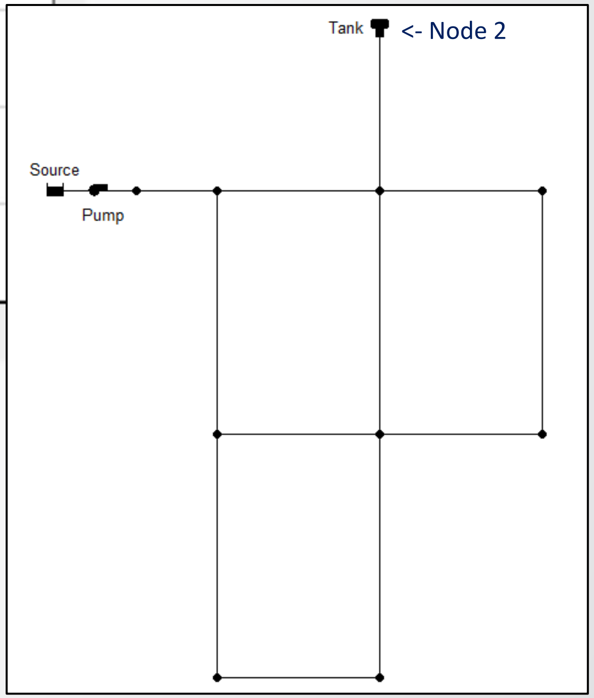
EPS Results – Node Pressure



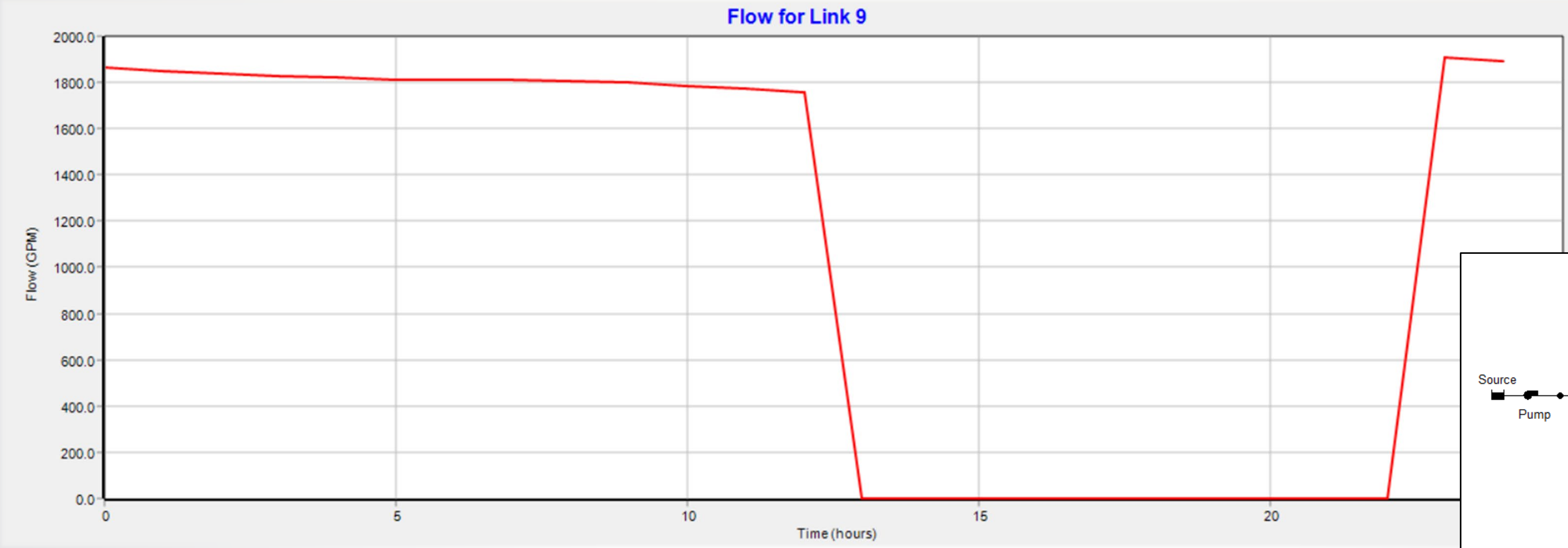


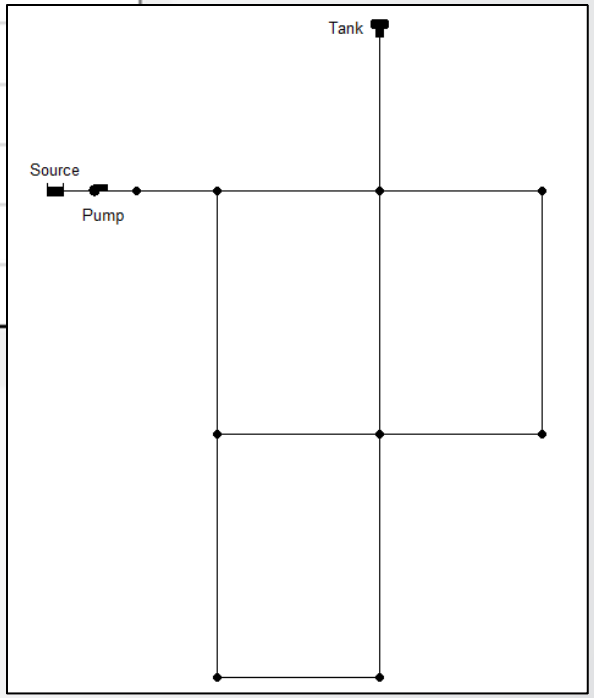
EPS Results – Tank Operation





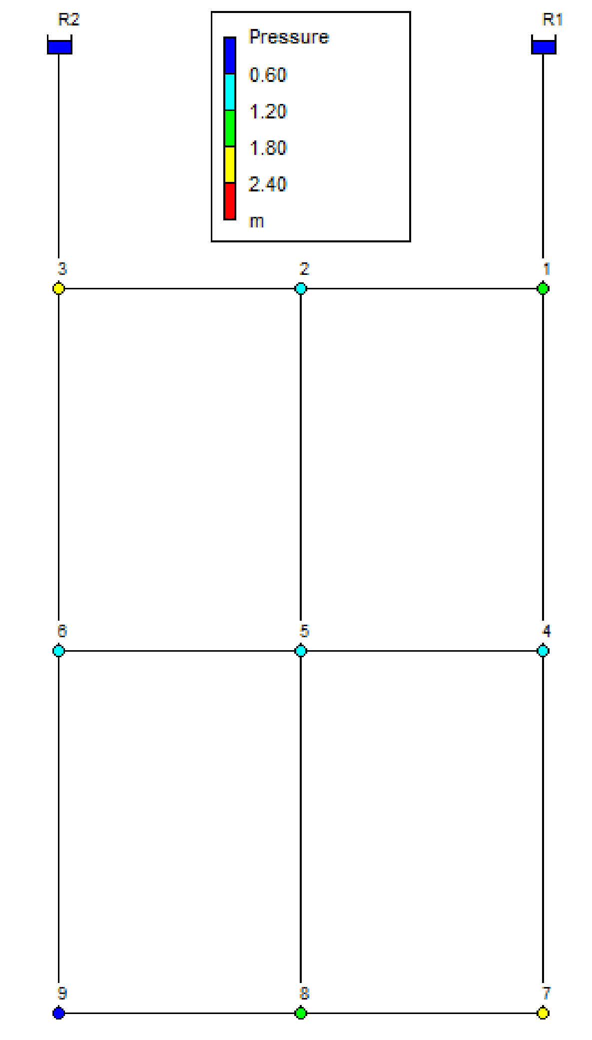
EPS Results – Pump Operation





EPANET Pressures

- Negative pressure
  - Why negative pressure warnings?
  - What should we do?
- Pressure dependent analysis (PDA)
  - User assigned demand is delivered if the pressure is high enough (Pressure > Required Pressure)
  - Actual demand is lower than user assigned demand is delivered if the pressure is not high enough (Pressure < Required Pressure)
  - Zero flow if the pressure is too low (Pressure < Minimum Pressure)



Pressure Dependent Analysis

- Data Browser Window >> Options >> Hydraulics >> Demand Model
- Minimum Pressure: Demand = 0 if Pressure < Minimum Pressure
- Required Pressure: full Demand if Pressure ≥ Required Pressure
  - Set to at least 0.1 psi or m above Minimum Pressure
- Pressure Exponent: used to calculate partial demand
  - Its suggested value is 0.5

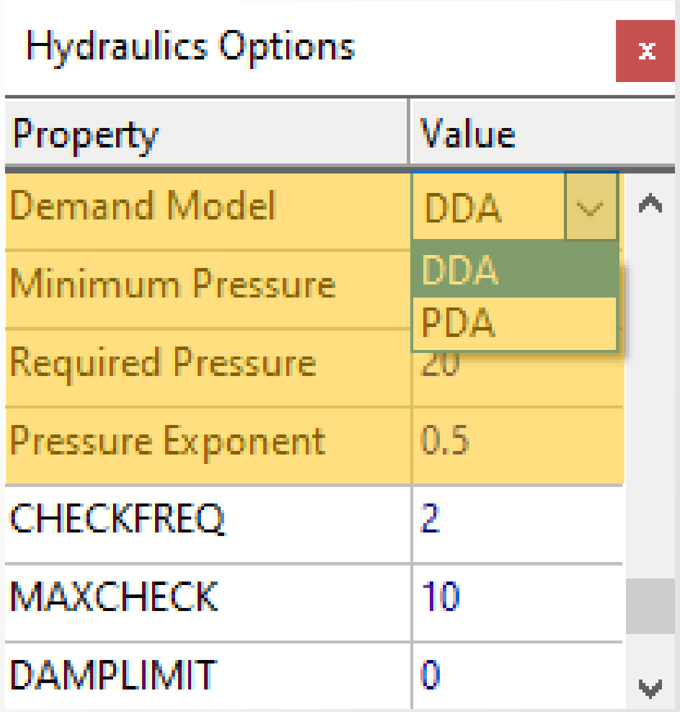
$$y = ax^k$$

y = Demand Delivered

x = Calculated Pressure / Required Pressure

a = Requested Demand

k = Pressure Exponent



Pressure-Dependent Analysis (PDA)

Without PDA

Network Table - Nodes

Node ID	Demand LPS	Pressure m
Junc 1	25.00	0.40
Junc 2	25.00	-0.44
Junc 3	25.00	1.25
Junc 4	25.00	-0.58
Junc 5	25.00	-0.70
Junc 6	25.00	-0.71
Junc 7	25.00	0.32
Junc 8	25.00	-0.19
Junc 9	75.00	-2.73
Resvr R1	-124.23	0.00
Resvr R2	-150.77	0.00

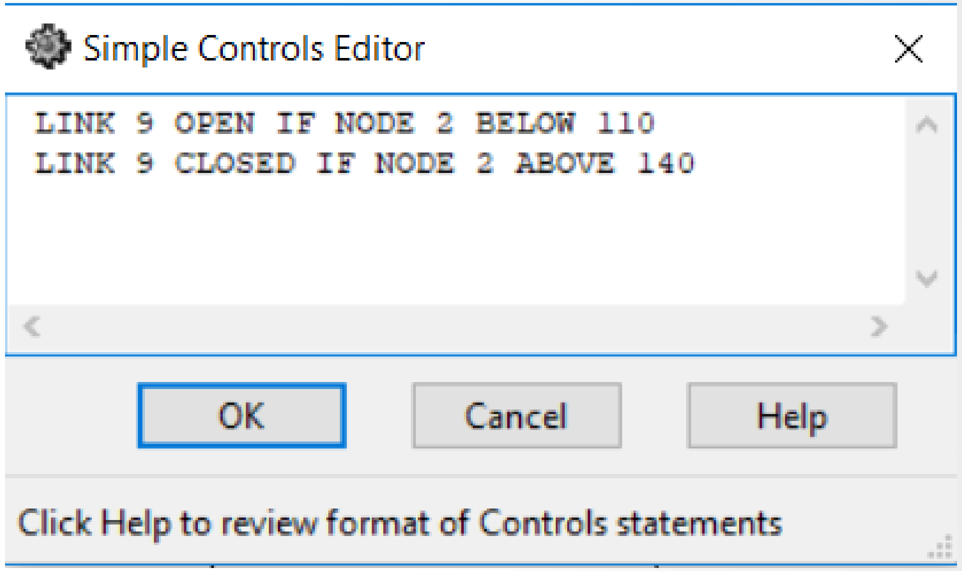
With PDA

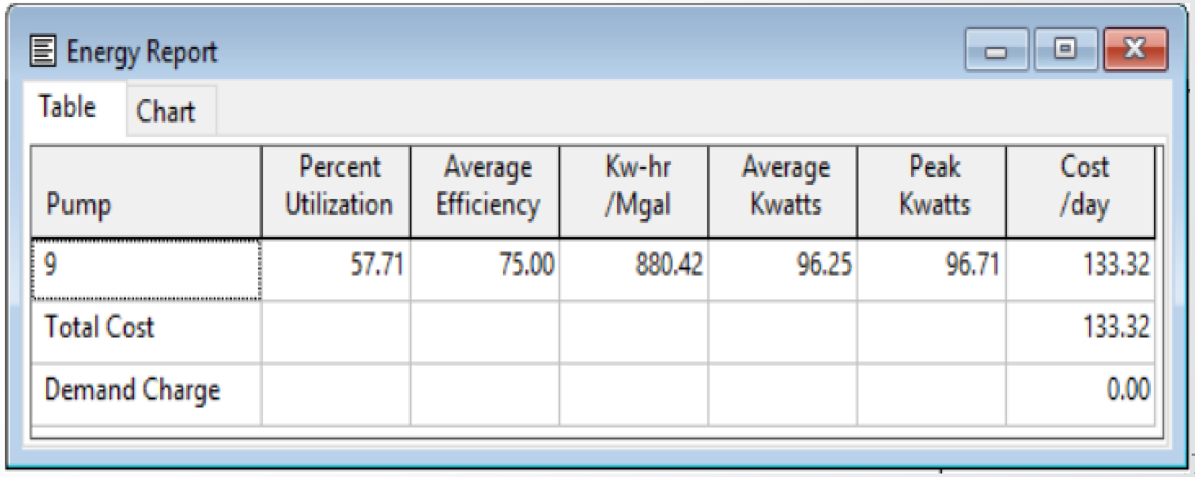
Network Table - Nodes

Node ID	Demand LPS	Pressure m
Junc 1	25.00	1.40
Junc 2	25.00	0.69
Junc 3	25.00	2.28
Junc 4	25.00	0.79
Junc 5	25.00	0.73
Junc 6	25.00	0.74
Junc 7	25.00	1.92
Junc 8	25.00	1.60
Junc 9	61.63	0.07
Resvr R1	-117.04	0.00
Resvr R2	-144.59	0.00

Other Hydraulic Functionalities

- Controls
  - Simple
  - Rule-Based
- Pumps
  - Pump Curves
  - Pump Efficiency analysis
  - Pump Energy analysis
- Valves
  - Pressure Relief Valve (PRV)
  - Pressure Sustaining Valve (PSV)
  - Pressure Breaker Valve (PBV)
  - Flow Control Valve (FCV)
  - Throttle Control Valve (TCV)
  - General Purpose Valve (GPV)





Pump	Percent Utilization	Average Efficiency	Kw-hr /Mgal	Average Kwatts	Peak Kwatts	Cost /day
9	57.71	75.00	880.42	96.25	96.71	133.32
Total Cost						133.32
Demand Charge						0.00

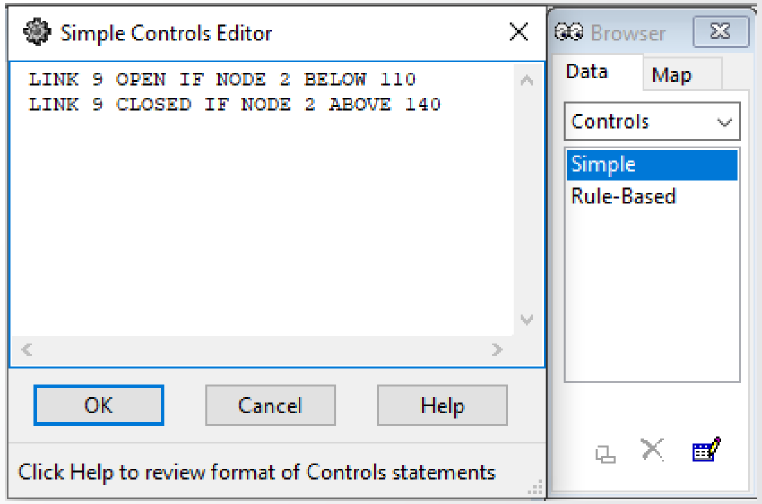
Knowledge Check 4

Which of these can EPANET NOT do?

A. Steady State Analysis
B. Transient State Simulation
C. Extended Period Simulation
D. Trick Question; EPANET can do all of these

Controls (I)

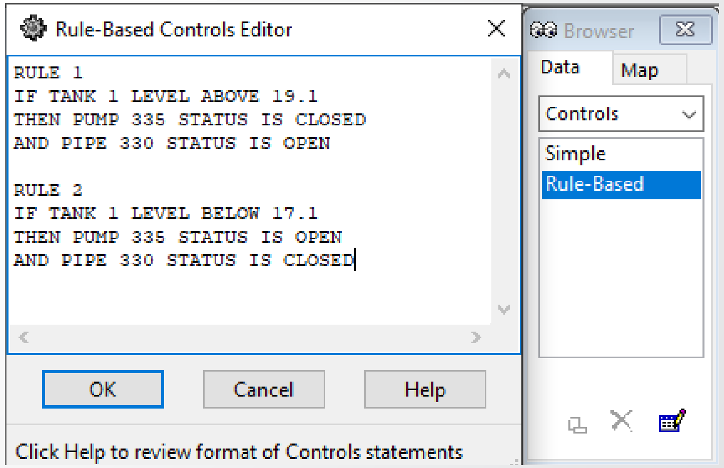
- Statements that determine how the network is operated over time.
- Controls can be either Simple Controls or Rule-Based Controls
- Simple Controls change the status of links based on:
  - Water level in a tank
    - Format: **LINK** *linkID status* **IF NODE** *tankID* **ABOVE/BELOW** *value*
  - Pressure at a junction
    - Format: **LINK** *linkID status* **IF NODE** *junctionID* **ABOVE/BELOW** *value*
  - Time into the simulation
    - Format: **LINK** *linkID status* **AT TIME** *time*
  - Time of day
    - Format: **LINK** *linkID status* **AT CLOCKTIME** *clocktime* **AM/PM**



Controls (2)

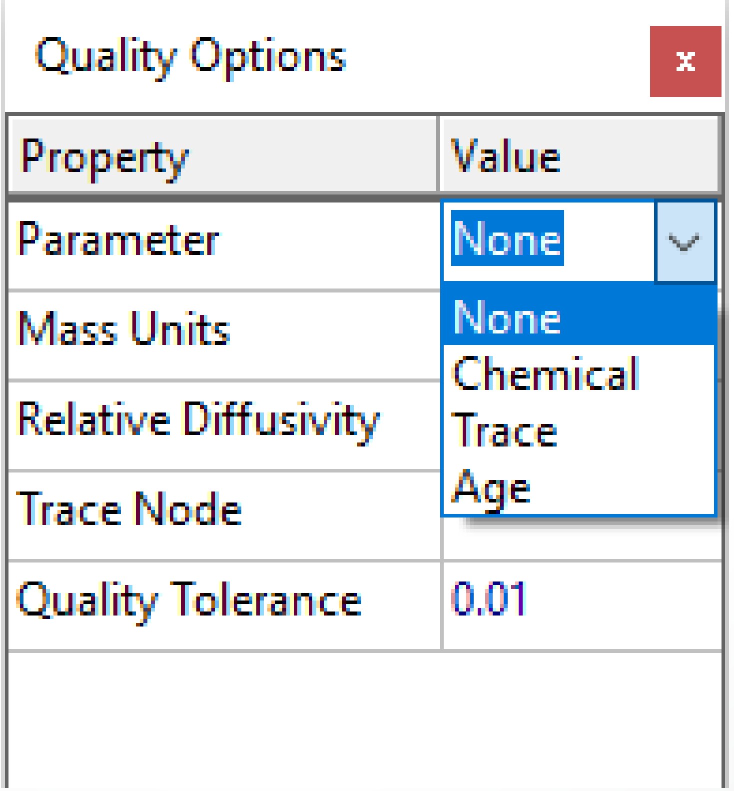
- Controls can be either Simple Controls or Rule-Based Controls:
- Rule-Based Controls change the status of links and settings based on:
  - Combinations of conditions that might exist in the network over an extended period simulation
    - Uses combinations of “IF” & “IF, THEN” statements, and “AND” and “OR” clauses/operators
    - Statements are in the form of:
      - **RULE** *ruleID*
      - **IF** condition_1
      - **AND** condition_2
      - **OR** condition_3
      - Etc…
      - **THEN** action_1
      - **AND** action_2
      - Etc…
      - **ELSE** action_3
      - **AND** action_4
      - Etc…
      - **PRIORITY** *priority*

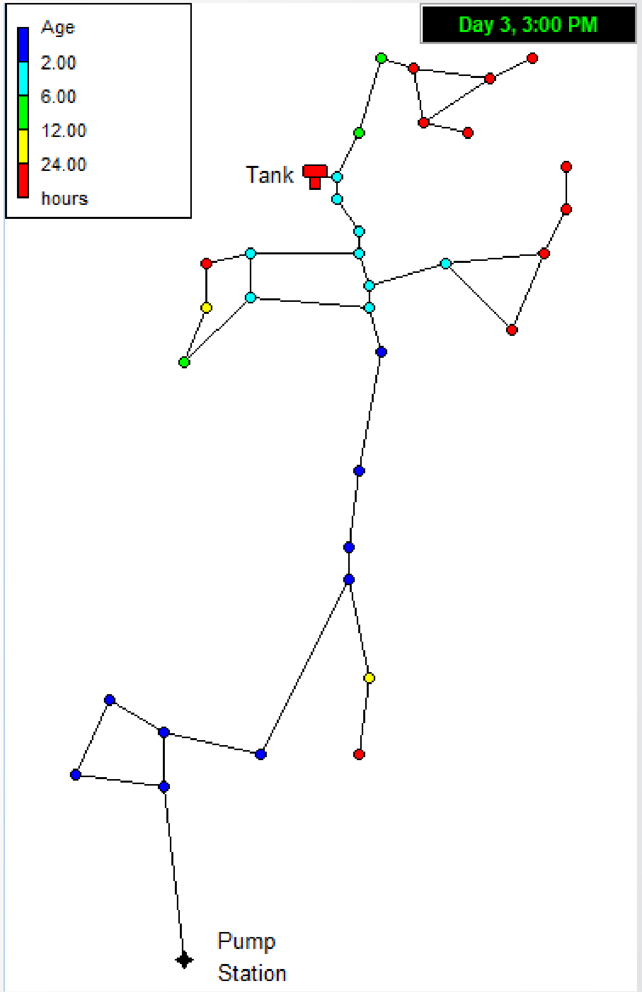
`ruleID`	=	an ID label assigned to the rule
`conditon_n`	=	a condition clause
`action_n`	=	an action clause
`priority`	=	a priority value (e.g., a number from 1 to 5)



EPANET Water Quality

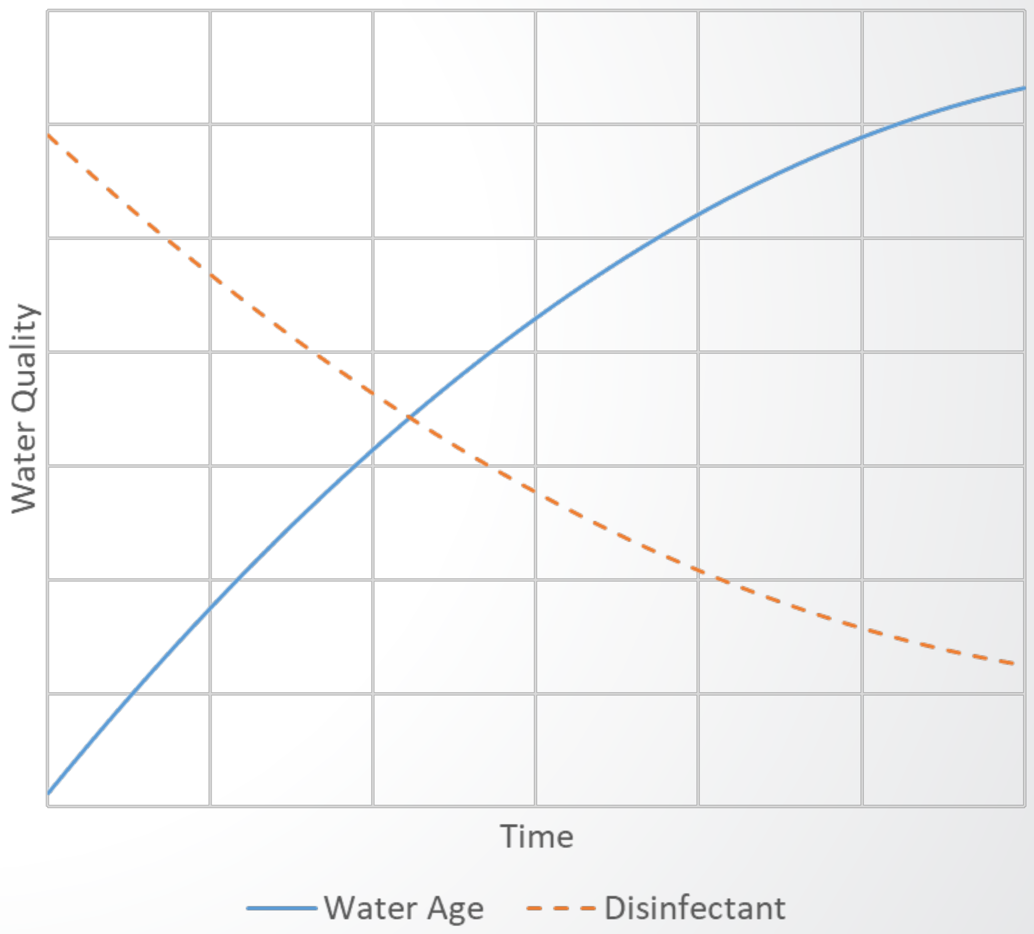
- Quality Options Parameters
  - Age
    - Ex: water age
  - Trace
    - Ex: source tracing
  - Chemical
    - Ex: chlorine decay





Water Age – Definition

- **Water age:** a non-explicit measurement of water quality and consists of a quantity of time that a parcel of water exists before being consumed. Water age is measured from the time water leaves the treatment plant or well until it is used/consumed by the water user.

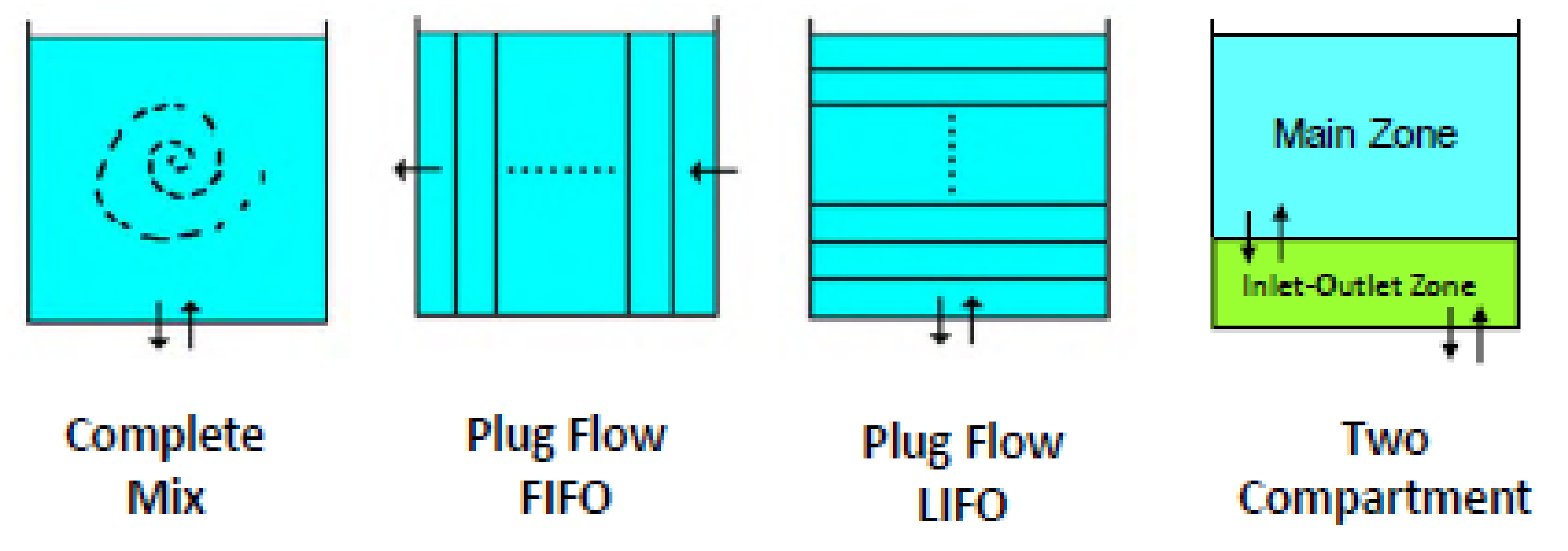


Water Age – Simple Explanation

- Water age represents the time water has been in the WDS after leaving the source and until it is used at junctions
- Water age is frequently used as a surrogate for water quality
  - new water → good
  - old water → bad
- Age is influenced by residence times in tanks and travel times through pipes
- Age is typically highest in dead ends, downstream of a series of tanks and at nodes at the far end of the distribution network

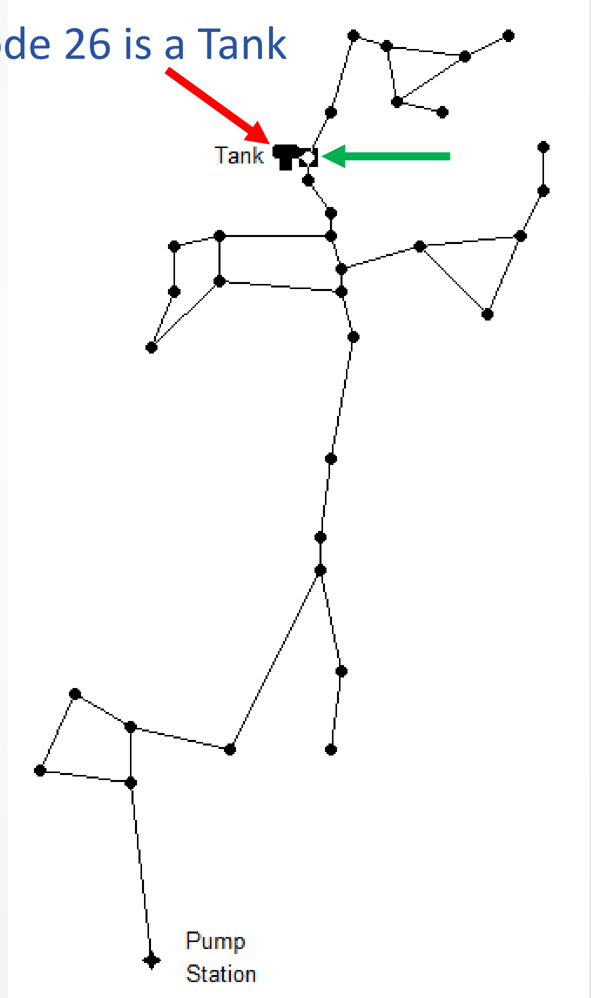
Tank Mixing Methods

- Tanks have 4 choices to simulate theoretical tank mixing
- Theoretical tanks models are unlikely to represent any tank perfectly
  - But may be close!



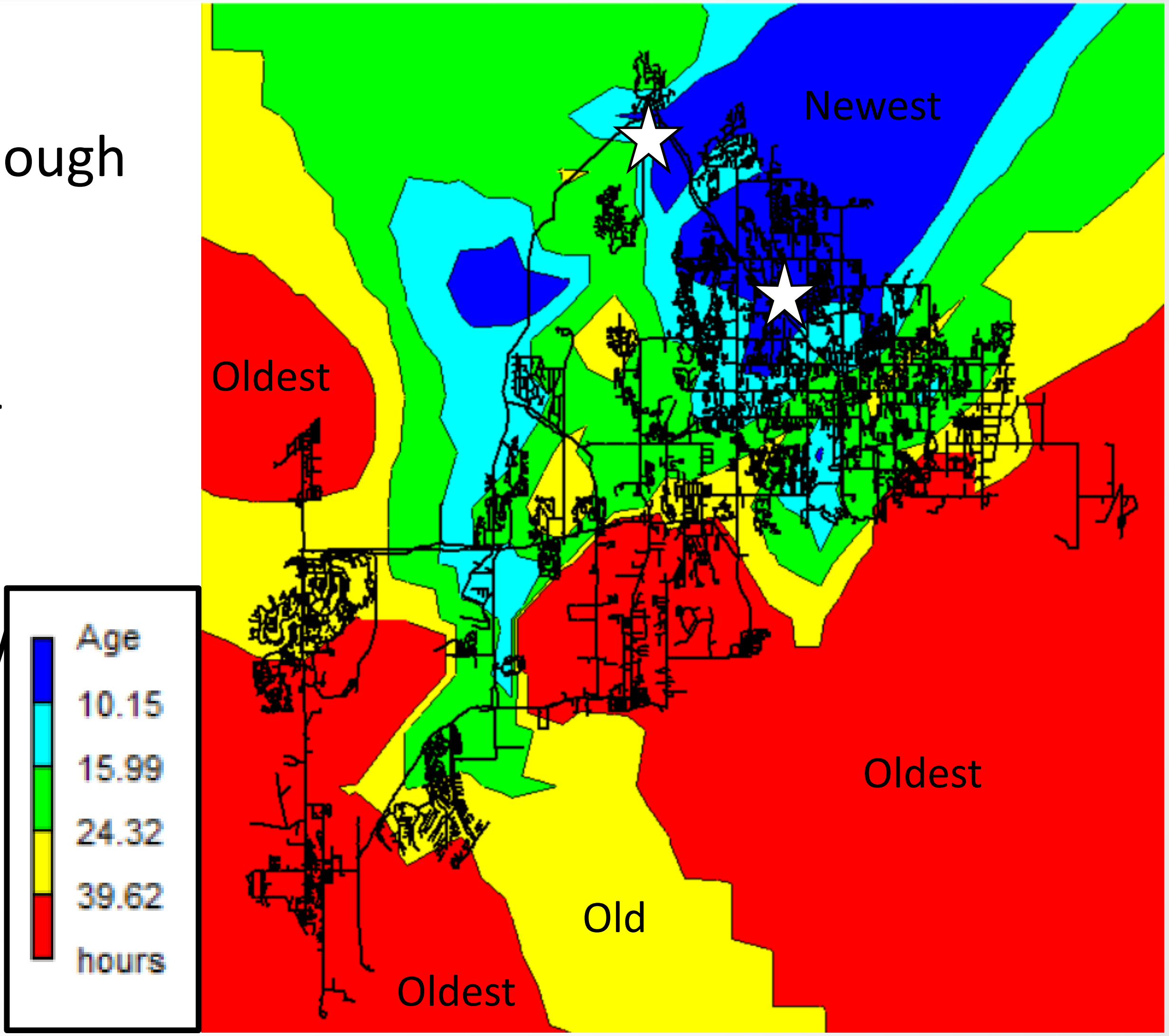
Water Age – Plot

Note: Node 26 is a Tank



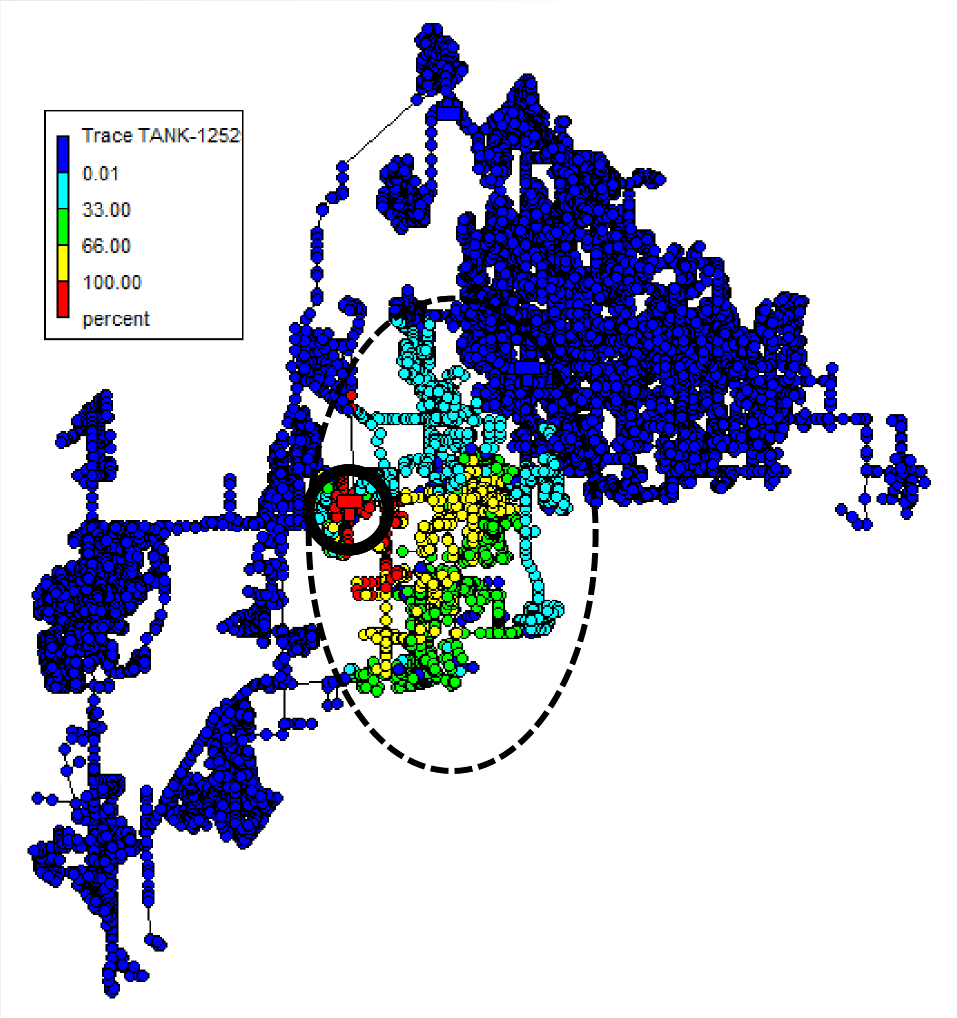
Water Age – Distance

- Graph >> Contour Plot >> Age
  - * Example networks don't have enough nodes to make a Contour Plot
- Water takes time to flow
  - Especially at dead-ends and low-demand nodes
- Typically, nodes farther from treatment plants have higher w
age

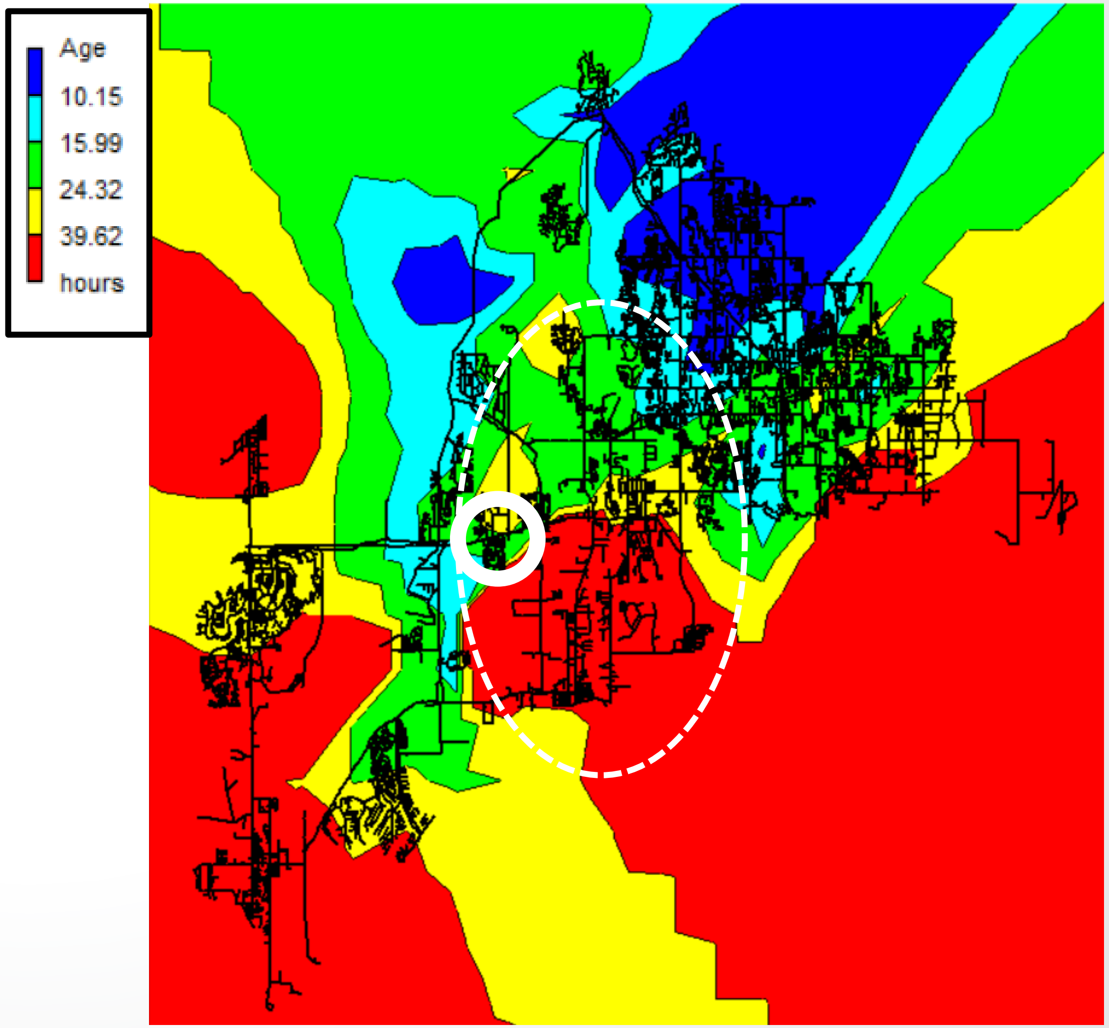


Water Age – Tank Influence

600h EPS Max Tracer Test

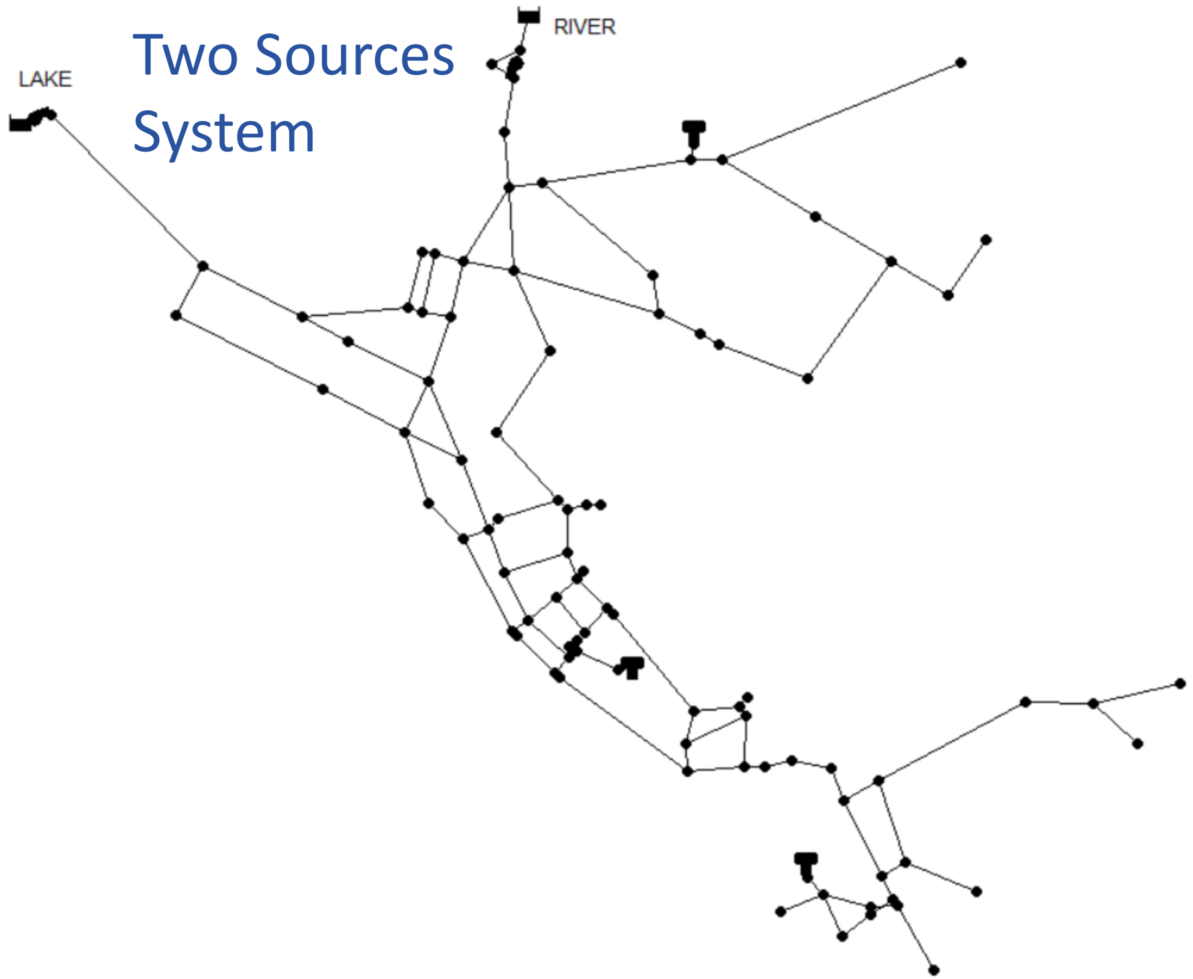


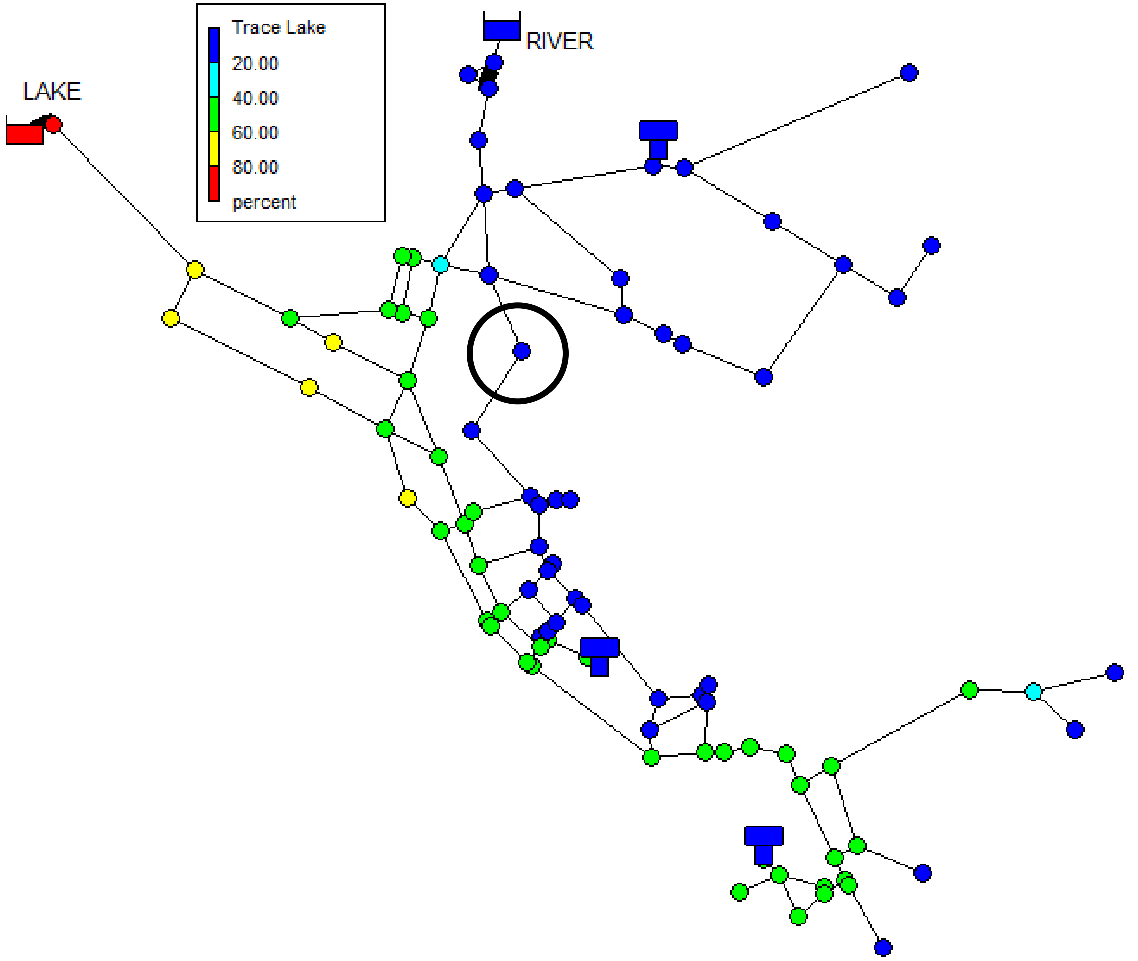
600h EPS Average Water Age



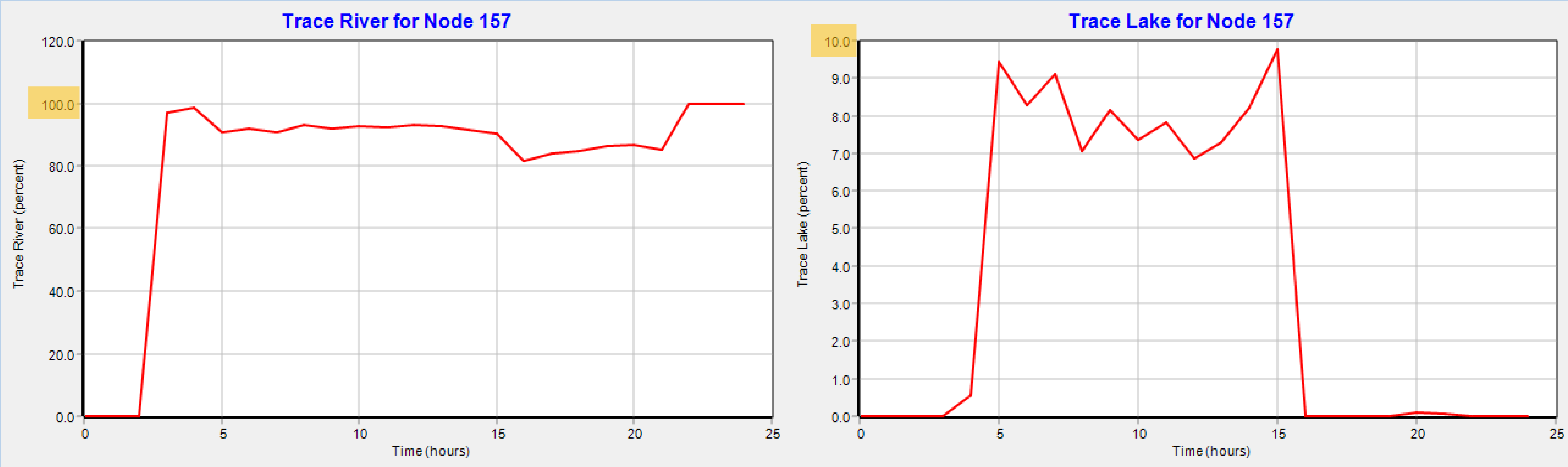
EPANET Application – Water Quality

- Trace Analysis: where the water comes from?





Trace Analysis



Knowledge Check 5

Which of the following best explains what a EPANET's tracer test is, using a Trace Node?

A. A periodic measurement to track changes in fluoride levels in the physical WDS

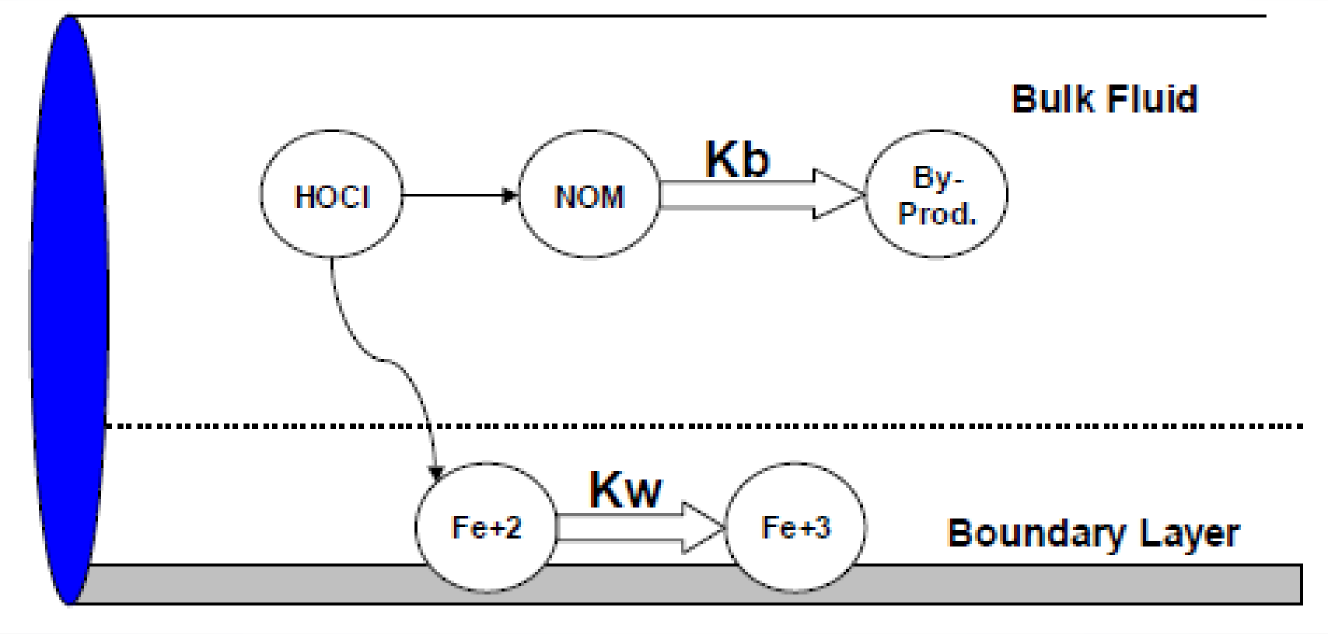
B. A hydraulic simulation that calculates where the water from one point in the model ends up

C. A water quality simulation of an unreactive chemical in each of the water sources

D. A superimposed layer on the Network Map that lets you copy part of the model by following the pipes with your cursor

Chlorine Modeling

- Chlorine is the most common water quality constituent modeled
- Modeling predicts the chlorine residual throughout the distribution system
- Chlorine & chlorine residual varies significantly during the day & over time



Chlorine – First Order Decay

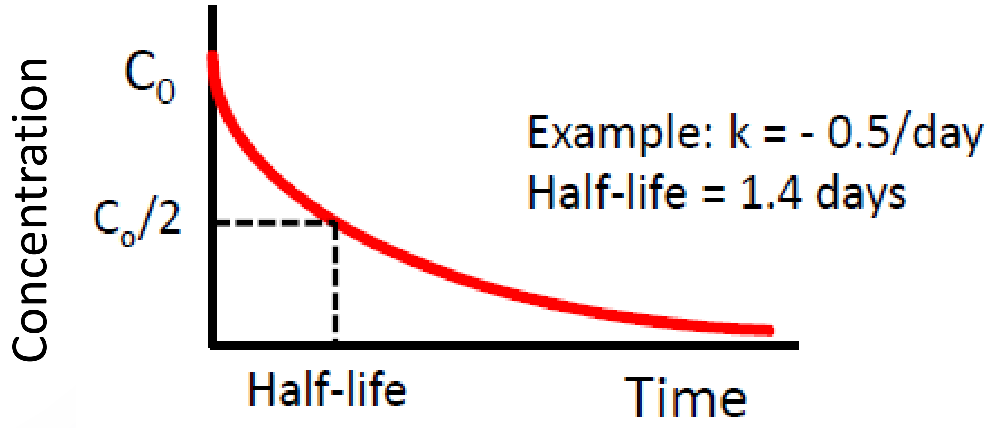
- Chlorine residual usually follows 1st order decay
- Chlorine decays proportionally to its concentration

$$\frac{dC}{dt} = kC$$

- Exponential decay:

$$C_t = C_0 e^{-kt}$$

  - C_0 = Initial Concentration
  - t = Time
  - k = Decay Coefficient
    - usually expressed per day (e.g., -0.5/day)



- Half-life: Time to decay to 50% of initial concentration

Chlorine – Bulk Decay

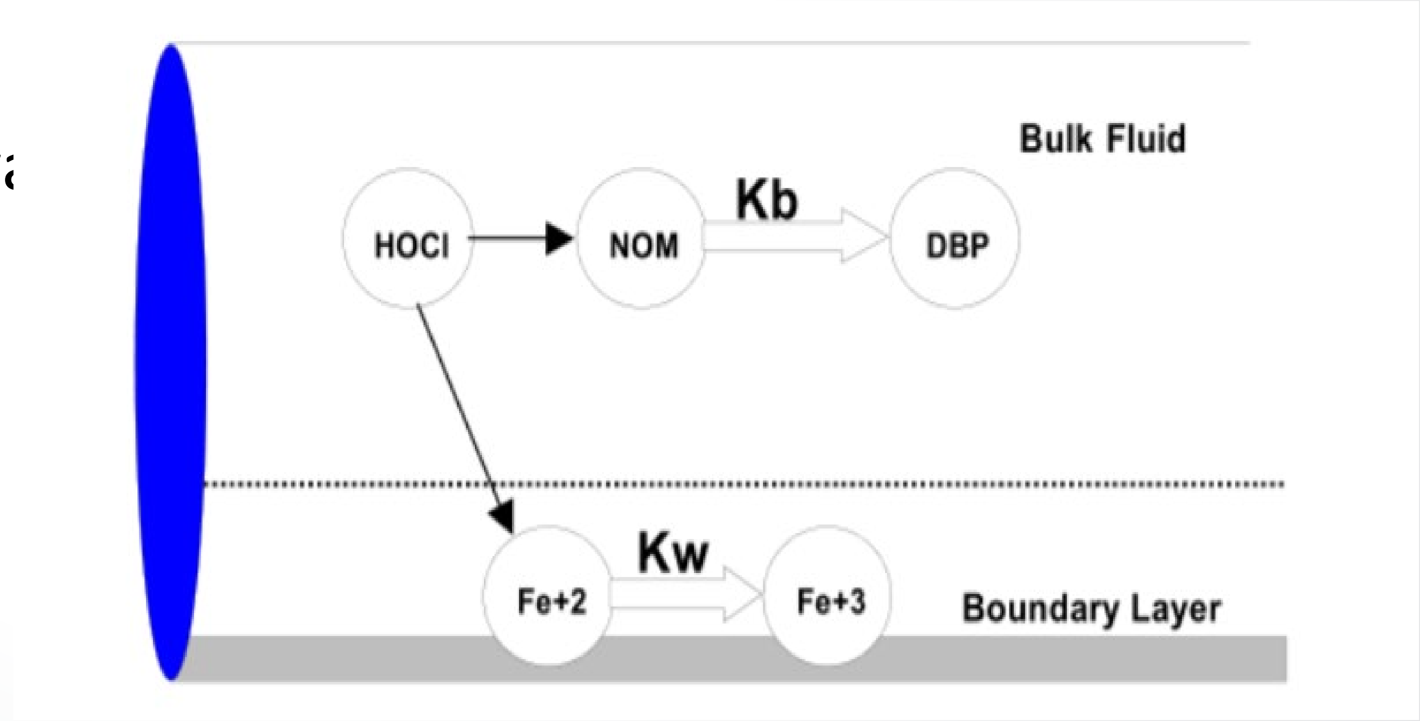
- Bulk decay is the decay in flowing water
- Usually represented as first order decay: $C_t = C_0 e^{-kt}$
- Decay rate
  - depends on water quality characteristics
  - is independent of pipe material
- Negative k (e.g., $C_0 e^{-kt}$) indicates decay
- Decay Coefficients (k) range between -0.05 & -15 per day
  - Equivalent to half life of 14 to 0.05 days (1.2 hours)
- Typically, between -0.2 & -1.0 per day
  - Equivalent to half life of 3.5 to 0.7 days (16.8 hours)

Chlorine – Wall Decay

- Wall decay is the interaction of water with pipe walls
  - Due to corrosion, biofilm, etc. at the wall
  - Determined by pipe material (Copper, PVC, Concrete, Steel, etc.)
- Rate of loss of chlorine at wall depends upon
  - wall decay coefficient
  - rate at which mass is transferred to the wall
- The Wall Decay Coefficient is determined through field studies or chosen from literature values
- Negligible in tanks & reservoirs
  - Very small ratio of wall to volume

Chemical Analysis

- Chlorine decay
- Relatively complicated analysis compared to water age and trace analysis
- Water chemistry
  - Reaction/decay in bulk
  - Reaction/decay on pipe wa

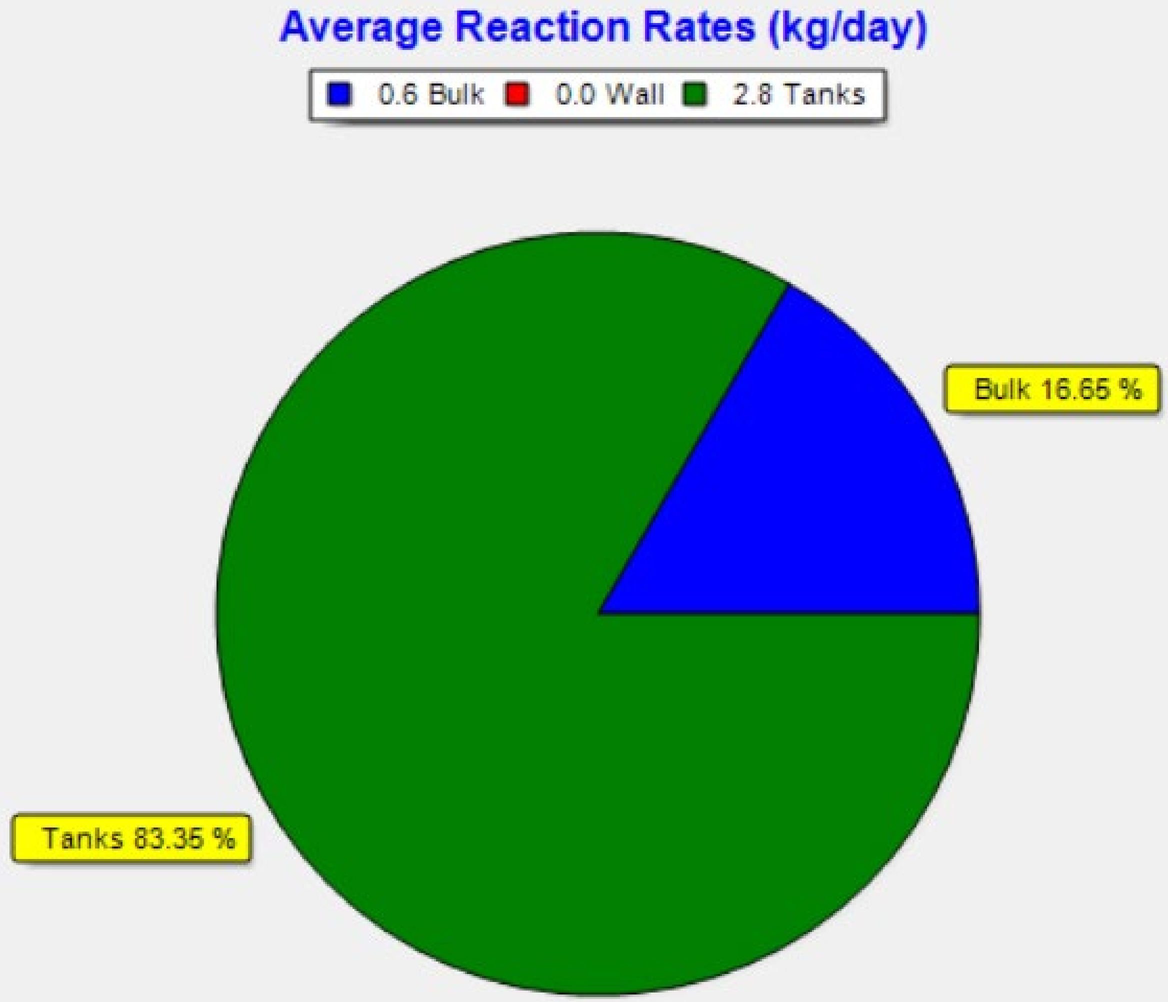


Chemical Analysis Results (I)

- Report >> Reactions

Reactions Options

Property	Value
Bulk Reaction Order	1
Wall Reaction Order	First
Global Bulk Coeff.	-.5
Global Wall Coeff.	0
Limiting Concentration	0.0
Wall Coeff. Correlation	0.0

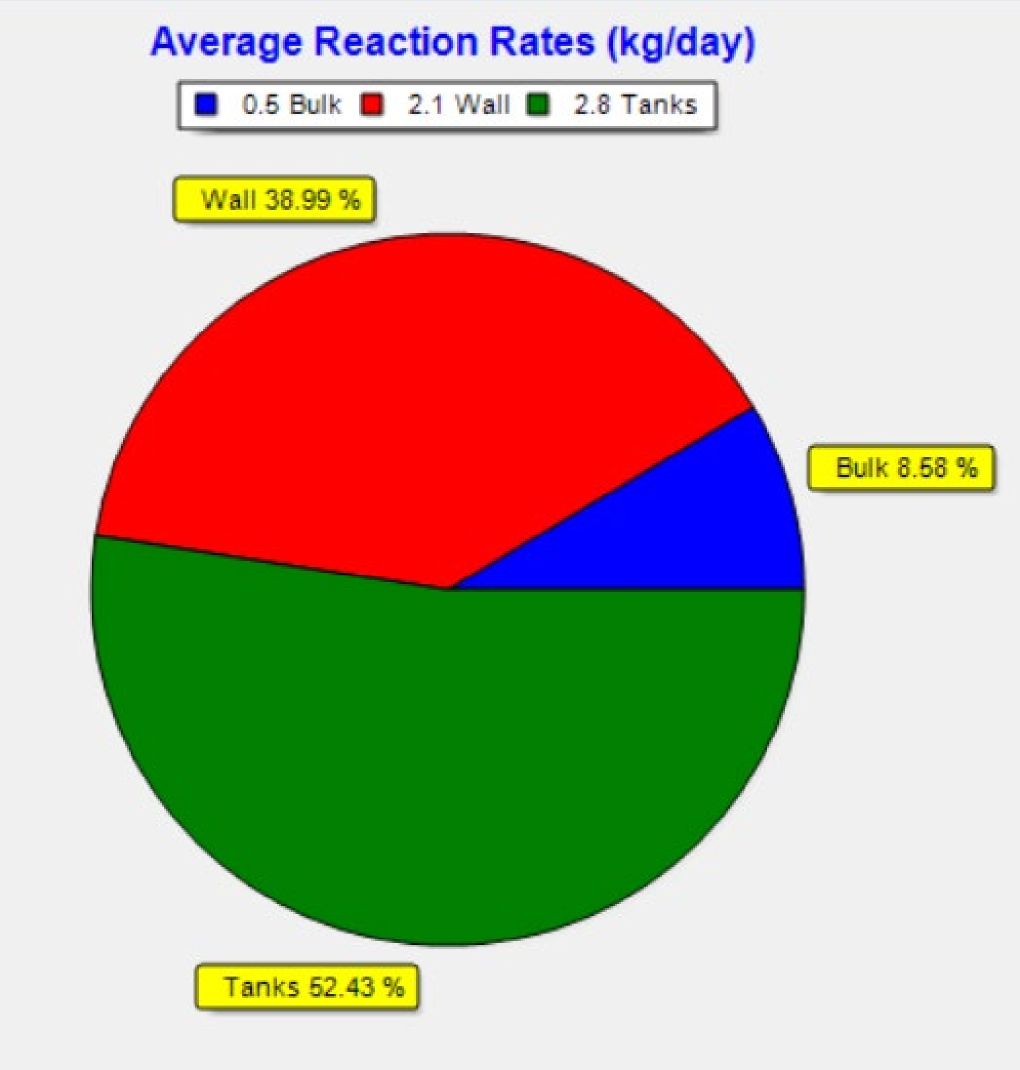


Chemical Analysis Results (2)

Reactions Options

Property	Value
Bulk Reaction Order	1
Wall Reaction Order	First
Global Bulk Coeff.	-.5
Global Wall Coeff.	-1
Limiting Concentration	0.0
Wall Coeff. Correlation	0.0

- Report >> Reactions



Knowledge Check 6

Where in the WDS is chlorine usually used up the most?

A. Treatment plants
B. Tanks
C. Bulk
D. Wall

Lunch Break

Download & launch EPANET

Enjoy your lunch

Join us for the walkthrough sessions at <Time> EST

Download and Run EPANET

EPANET 2.2 can be downloaded from:
github.com/USEPA/EPANET2.2/releases/download/2.2.0/epanet2.2_setup.exe

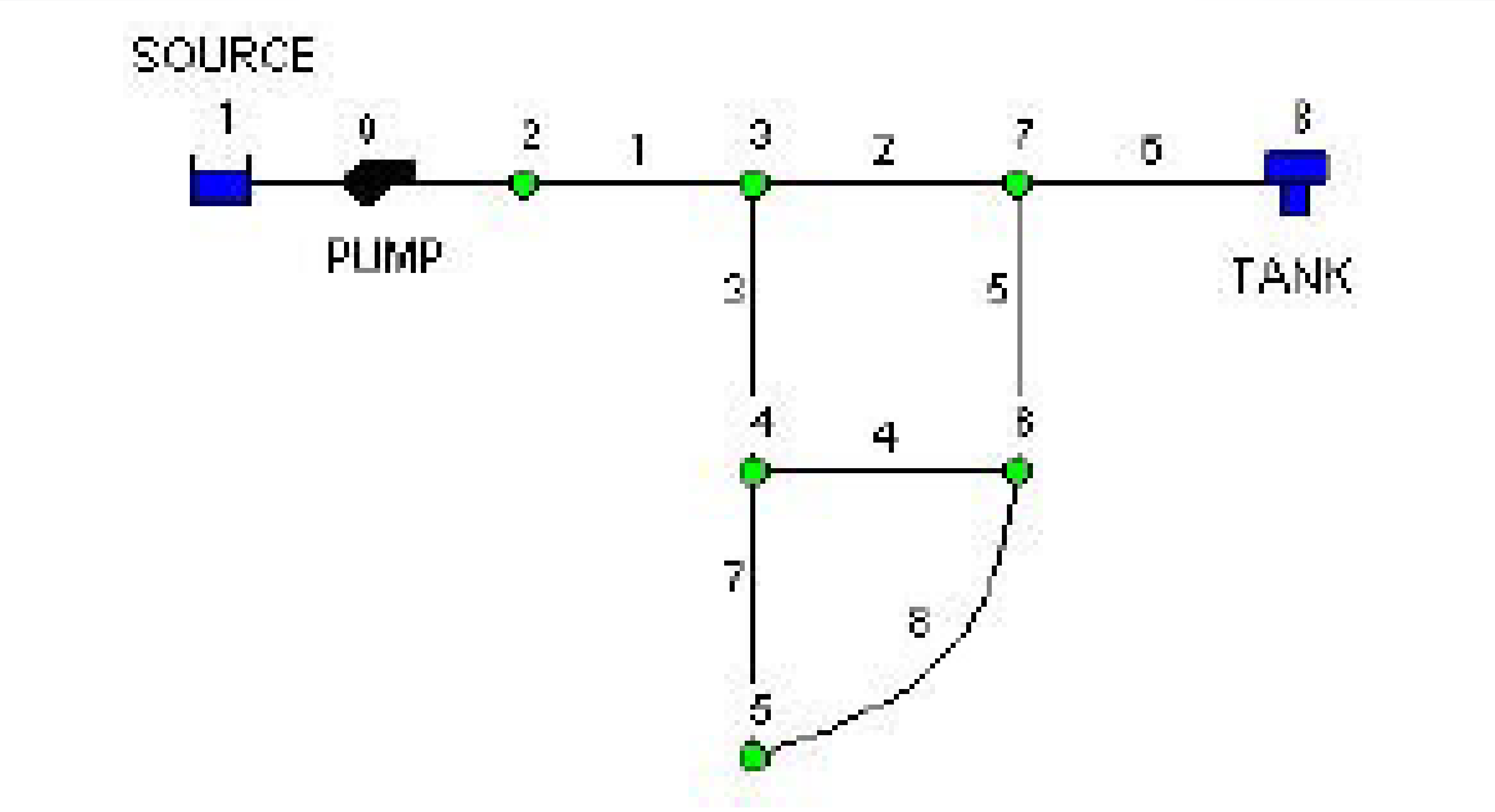
- Download and open non-installing version of EPANET
  - Non-installing software for EPANET 2.2 (epanet2.2.zip)
  - Notice everything is included – same as installed version
  - Runs EPANET (Epanet2w.exe)
  - DOS command line EPANET (runepanet.exe)
  - This option does not require administrative rights!

Model Building Application

Ben Burkhart

Tutorial Example Network

- The Tutorial Example Network we're building will eventually look like:

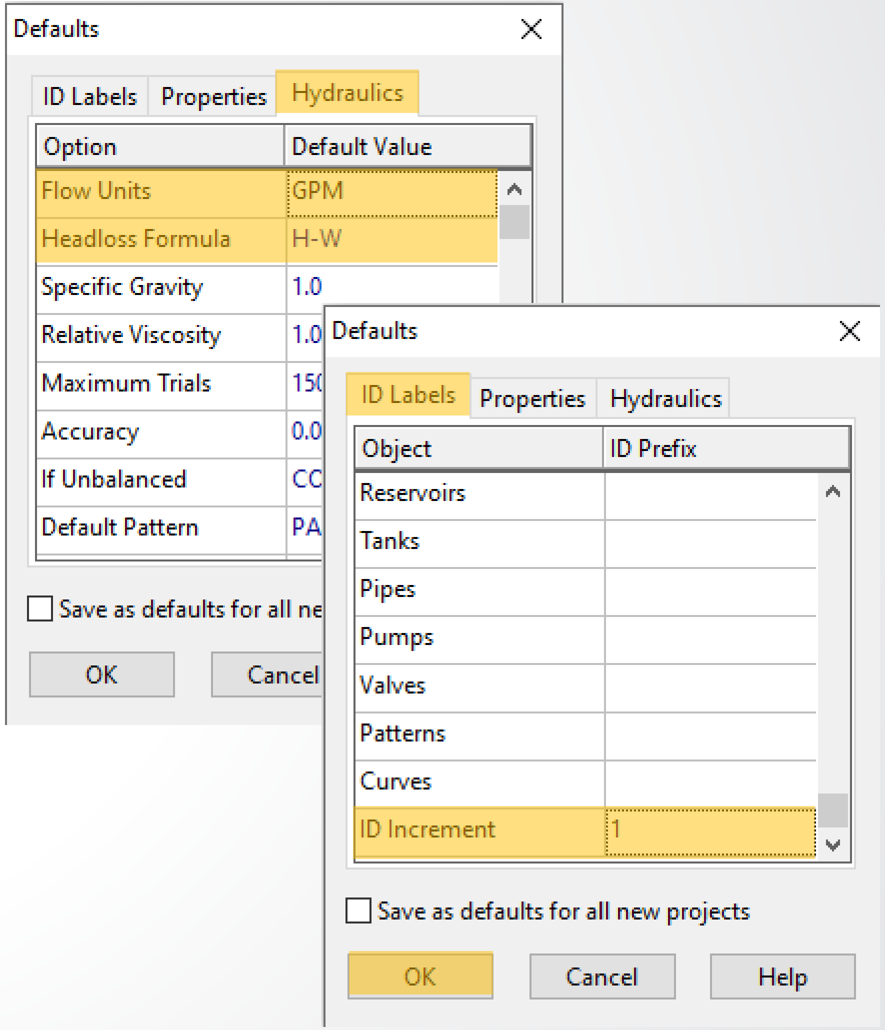


Project Setup - Defaults

- Launch EPANET, or if it is already running select File >> New
- Select the Hydraulics tab
  - Set the choice of Flow Units to GPM
  - Set the headloss formula to H-W
- Select Project >> Defaults >> ID Labels
  - Clear all the ID Prefix fields
  - Set the ID Increment to 1

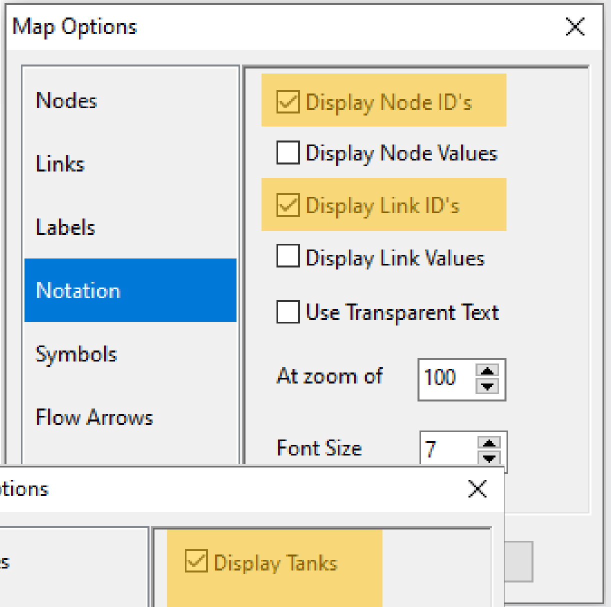
* EPANET can save these Default values and settings between projects

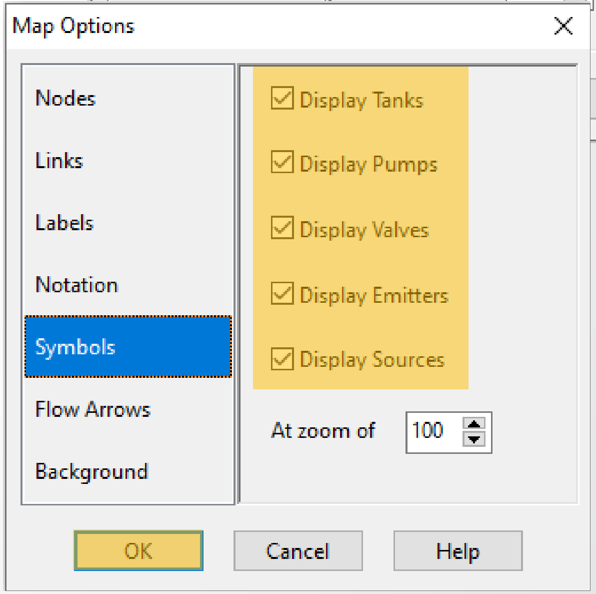
  * It's good practice to set Defaults early on

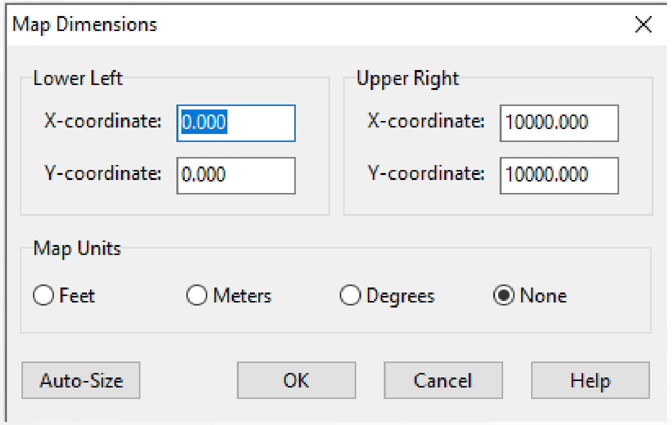


Project Setup – Map Options

- View >> Options to bring up the Map Options
  - Notation >> check Display Node IDs & Display Link IDs
  - Symbols >> check all boxes
  - Click “OK” to accept and close
- View >> Dimensions to bring up the Map Dimensions
  - Note the default dimensions assigned for a new project.
  - These settings will suffice for this example, so click “OK”



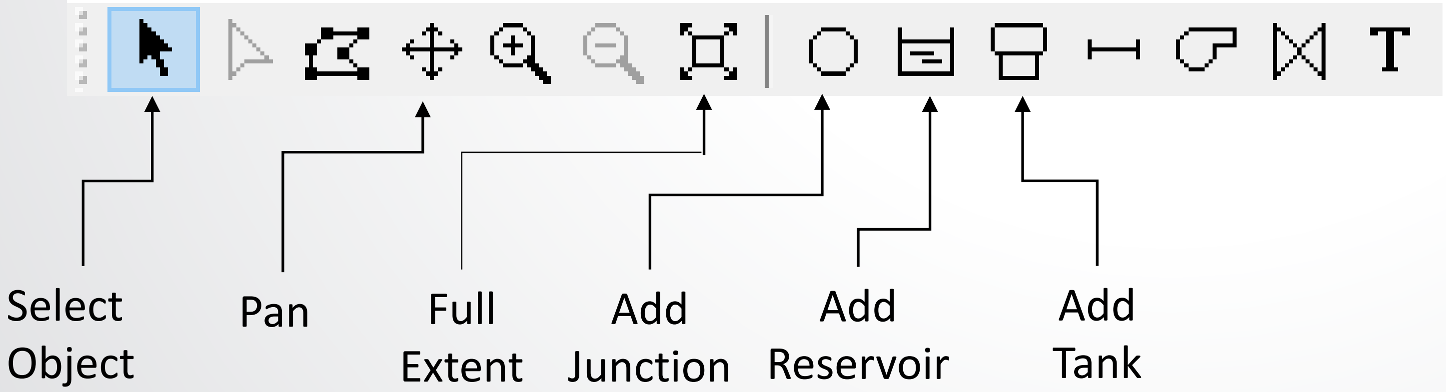


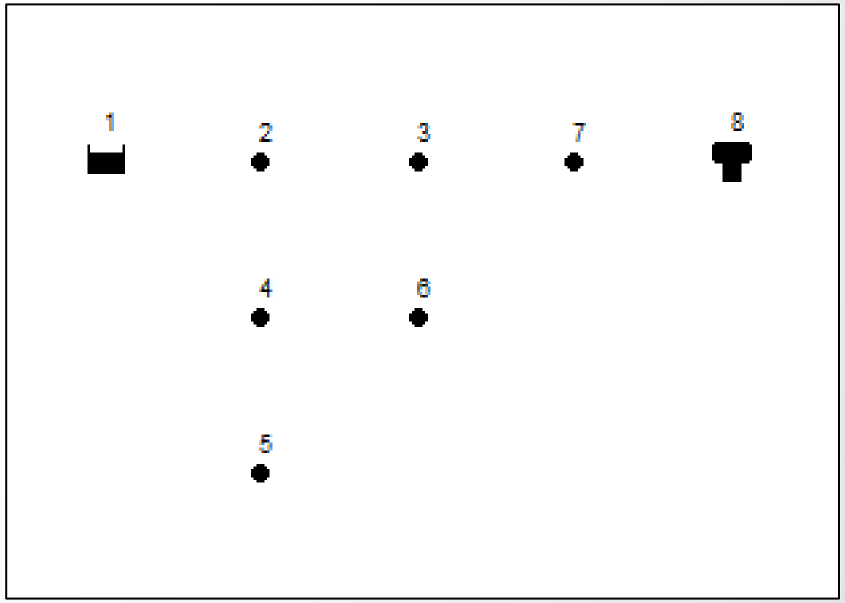


Placing the Nodes

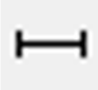
- Click the Reservoir button then click the mouse on the map at the location of the reservoir.
- Click the Junction button and then click on the map at the locations of nodes 2 through 7.
- Add the tank by clicking the Tank button and clicking the map where the tank is located.

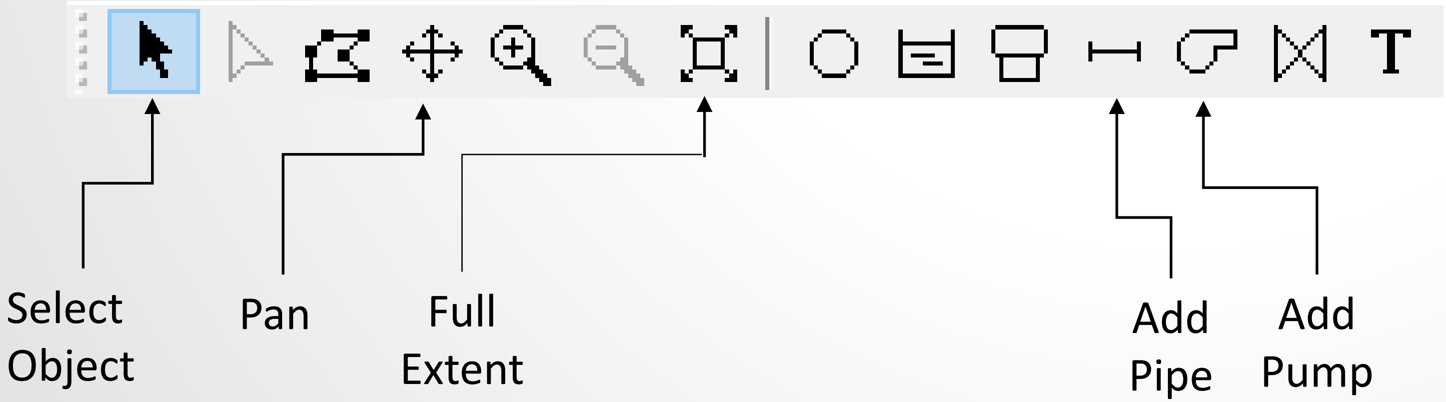
*If this toolbar is not visible, then select View >> Toolbars >> Map

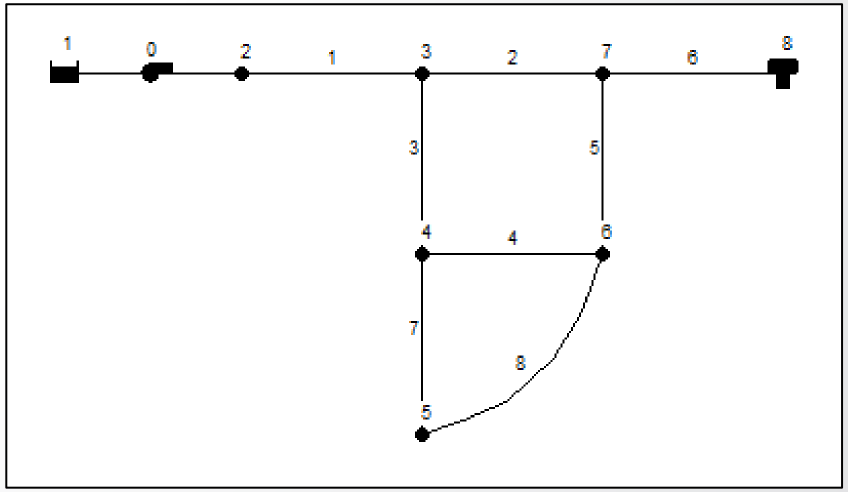




Connecting the Links

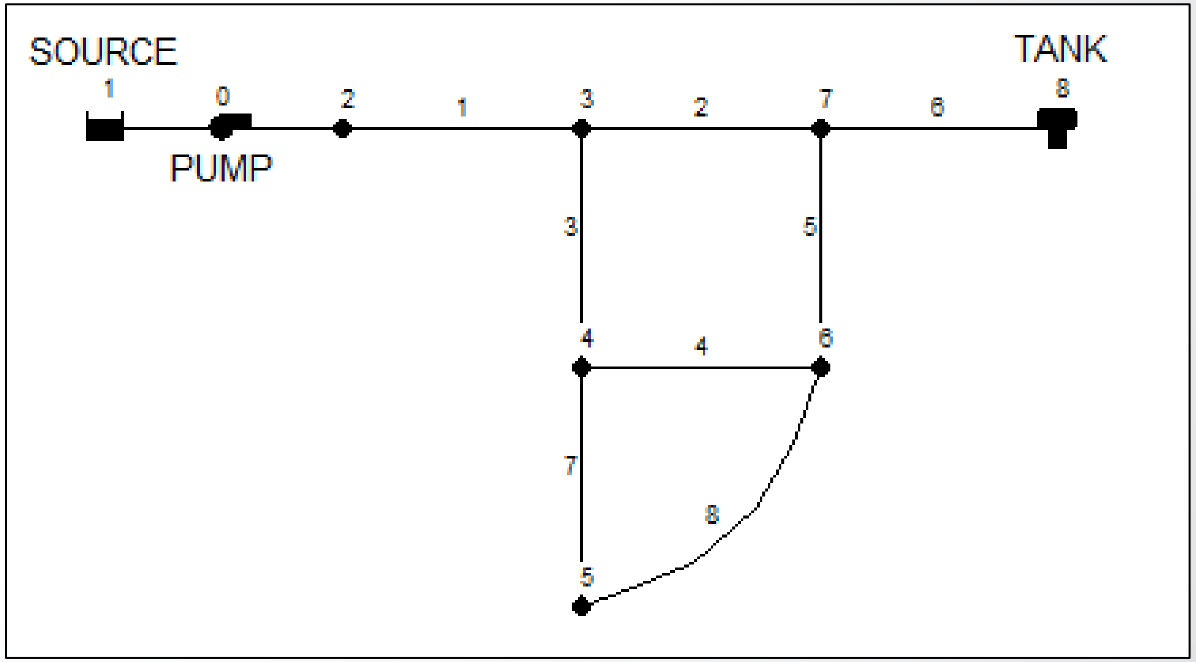
- Next, we will add the pipes using the Pipe button  on the Toolbar
- Pipe 8 is curved; to draw it:
  - click on Node 5.
  - Click at points before Node 6 to change direction & maintain the desired shape
  - Complete the process by clicking on Node 6
- Click the Pump button , click on node 1 and then on node 2





Add the Labels

- Select the Text button **T** on the Map Toolbar
- Click in the Network Map & an edit box will appear
  - Click near the reservoir (Node 1) & type the word “SOURCE”, then hit the Enter key.
  - Click next to the pump and enter its label
  - Do the same for the tank

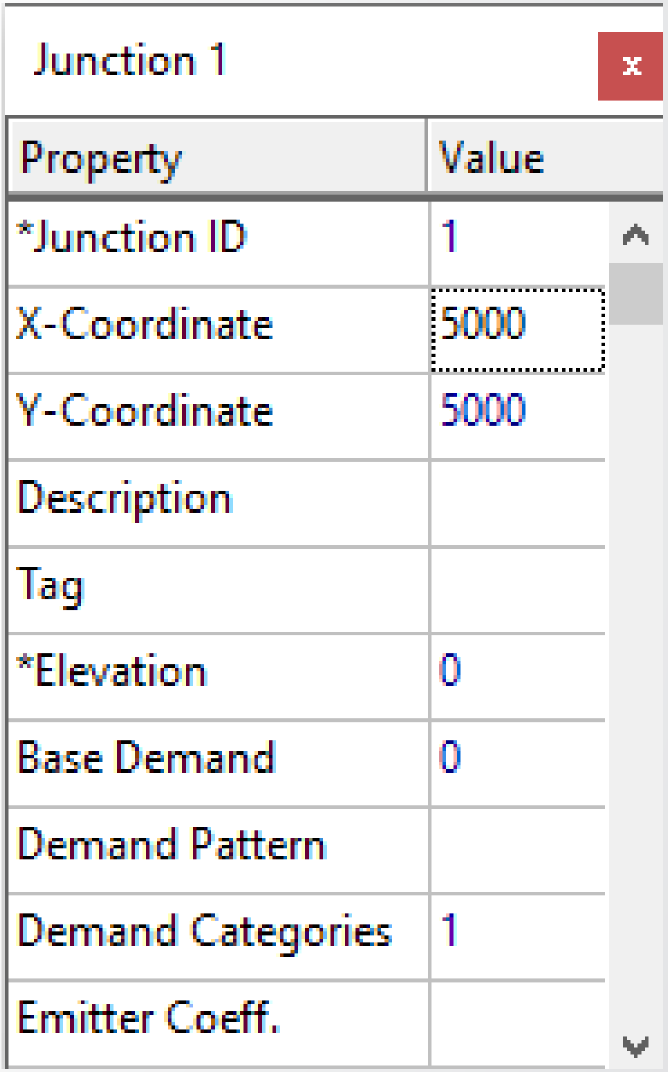


Setting Object Properties

Use the Property Editor to change the value of an object's properties

Open the Property Editor by either:

- Double-click the object on the map
- Right-click on the object and select Properties
- Select the object from the Data page of the Browser window and then click the Edit button

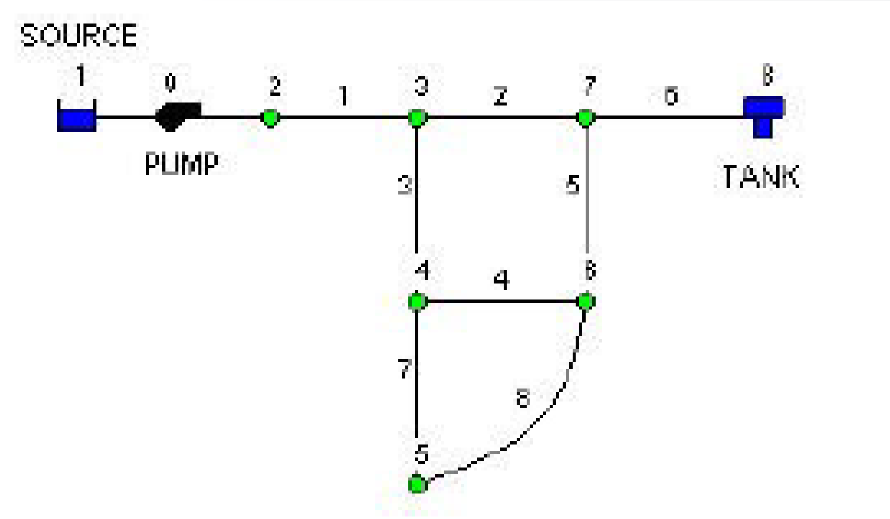


Set Properties

- Use the tables to set the properties of the nodes and pipes

Node	Elevation (ft)	Demand (GPM)
1	700 (Total Head)	N/A
2	700	0
3	710	150
4	700	150
5	650	200
6	700	150
7	700	0
8	830	N/A

Pipe	Length (ft)	Diameter (inches)	C-Factor
1	3000	14	100
2	5000	12	100
3	5000	8	100
4	5000	8	100
5	5000	8	100
6	7000	10	100
7	5000	6	100
8	7000	6	100



- Make a Curve with one point; Head = 150 ft & Flow = 600 GPM
  - For the pump (Link 9), set Pump Curve to “1”
- Set the tank (Node 8) properties as:
  - Diameter to 60 feet, Initial Water Level to 3.5 feet, & Maximum Level to 20 feet

Saving and Opening Projects

- Having completed the initial design of our network it is a good idea to save our work to a file at this point.

1. File >> Save As
2. Select a folder to save this project & name the file **Tutorial.net**
   - An extension of .net will be added to the file name if one is not supplied
   - .net files are in a special binary format
3. Click "OK" to save the project

- File >> Export >> Network & save it as .inp if you wanted to save the network data to file as readable text

Modeling Knowledge Check

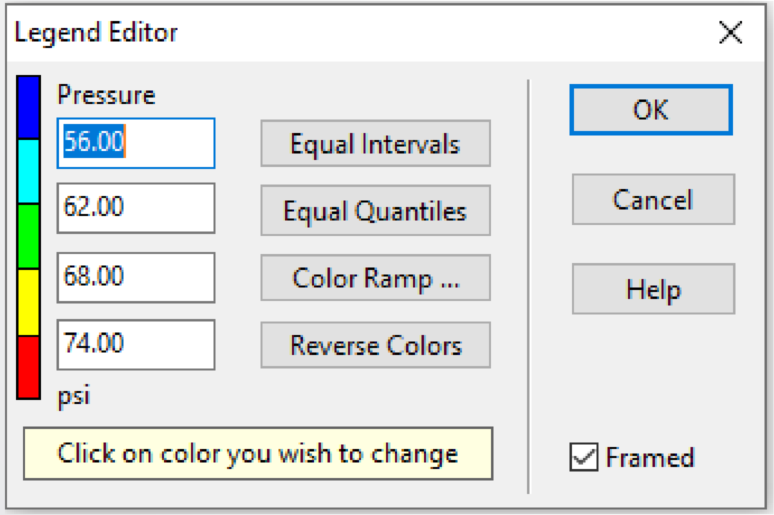
T/F: Junctions must be placed at the exact coordinates / distances from each other to simulate the pipe lengths

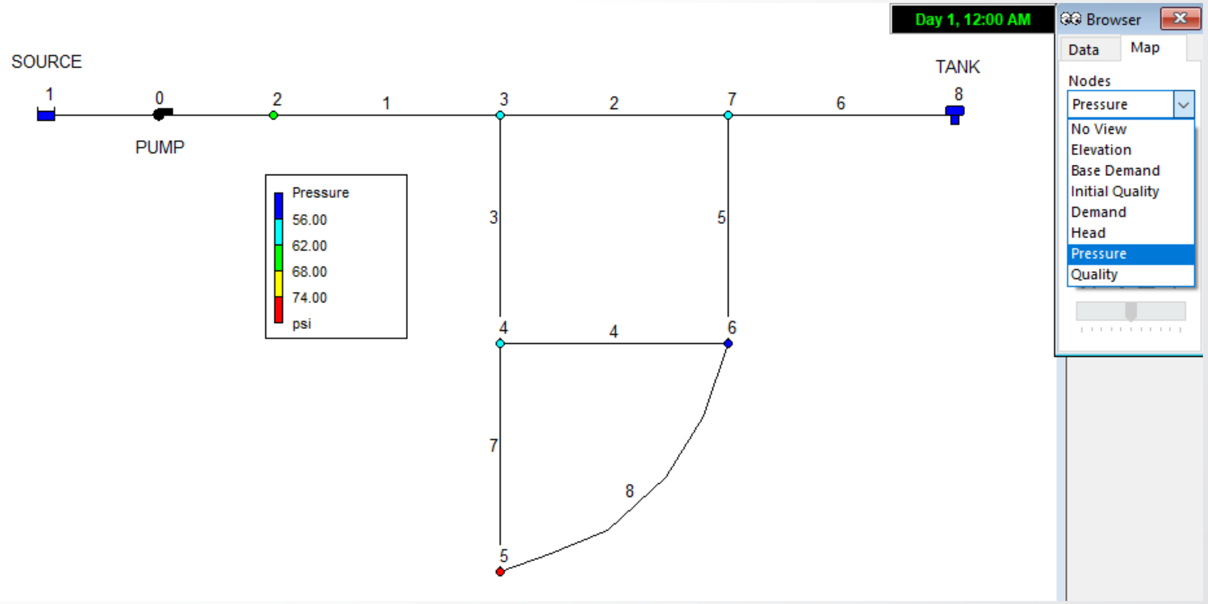
- True
- False

Running a Single Period Analysis

To run the analysis, select Project >> Run Analysis or click the Run button

- Map Browser >> Node >> Pressure and node pressures are color-coded
  - To view the legend for the color-coding, select View >> Legends >> Node (or right-click on the map >> Node Legend)
  - Right-click the legend to open the Legend Editor
    - Change the legend intervals and colors





Results

- Open Property Editor (double-click any node/link)
  - Note the computed results are displayed at the end of the property list
- Create a tabular list of results
  - Report >> Table (or click the Table button)

Junction 6

Property	Value
Initial Quality	
Source Quality	
Actual Demand	150.00
Total Head	828.75
Pressure	55.79
Quality	5.00

Network Table - Nodes

Node ID	Demand GPM	Head ft	Pressure psi	Quality hours
Junc 2	0.00	843.89	62.35	5.00
Junc 3	150.00	841.37	56.92	5.00
Junc 4	150.00	829.81	56.25	5.00
Junc 5	200.00	828.75	77.45	5.00
Junc 6	150.00	828.75	55.79	5.00
Junc 7	0.00	839.97	60.65	5.00
Resvr 1	-635.62	700.00	0.00	0.00
Tank 8	-14.39	840.00	4.33	0.00

Hydraulic Modeling Application

Feng Shang

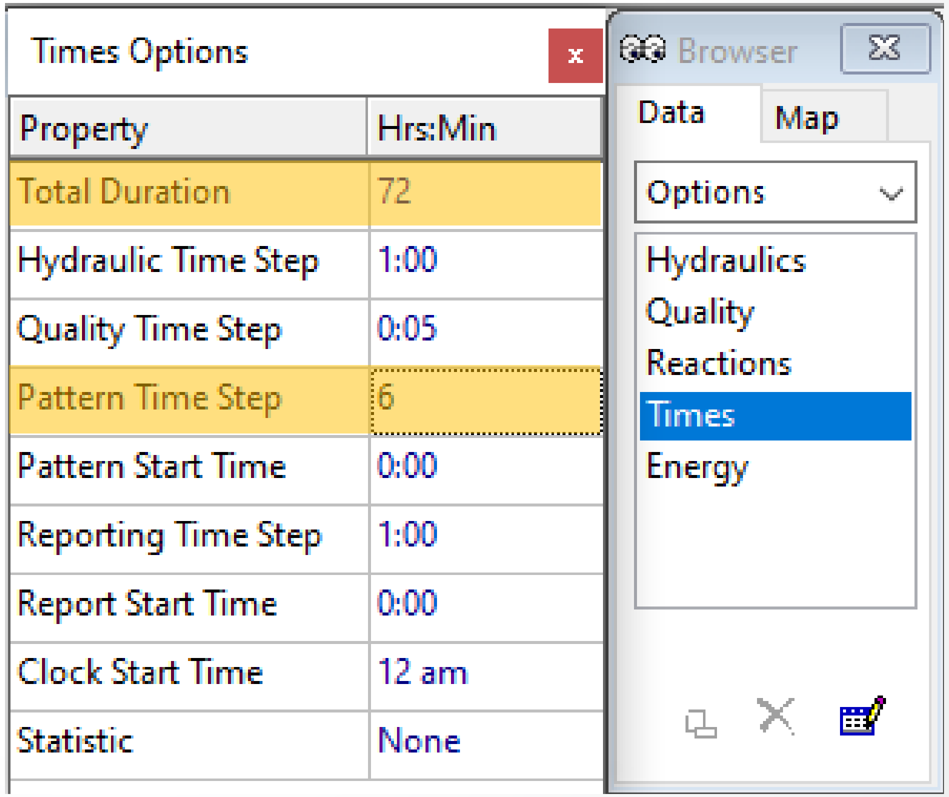
Running a Hydraulic Model

- Start with a model with the appropriate components & layout
- Set all relevant/required component properties
    - Base Demand, Elevation, Head, Mixing Method, etc.
- Set the Total Duration of the simulation (set to 0 for SPS)
- Make and assign any Patterns (EPS only)
- Optional: Set and sort the Controls
- Optional: Set initial conditions (tank Initial Levels)
- Run the model and look at results

Hydraulics Modeling Demonstration

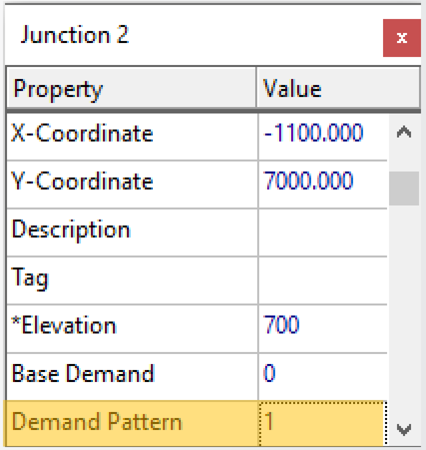
Hydraulics – Time Options

- Browser Window >> Data Tab >> Options >> Time
  - Total Duration = 72
  - Pattern Time Step = 6



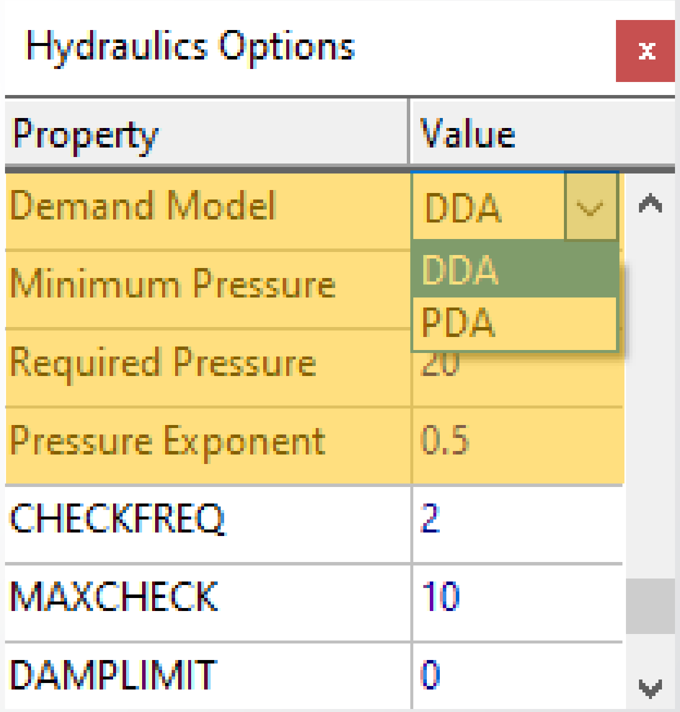
Hydraulics – Patterns

- Browser Window >> Patterns >> New
- Create the Pattern below & assign it to each Junctions using the Property Editor



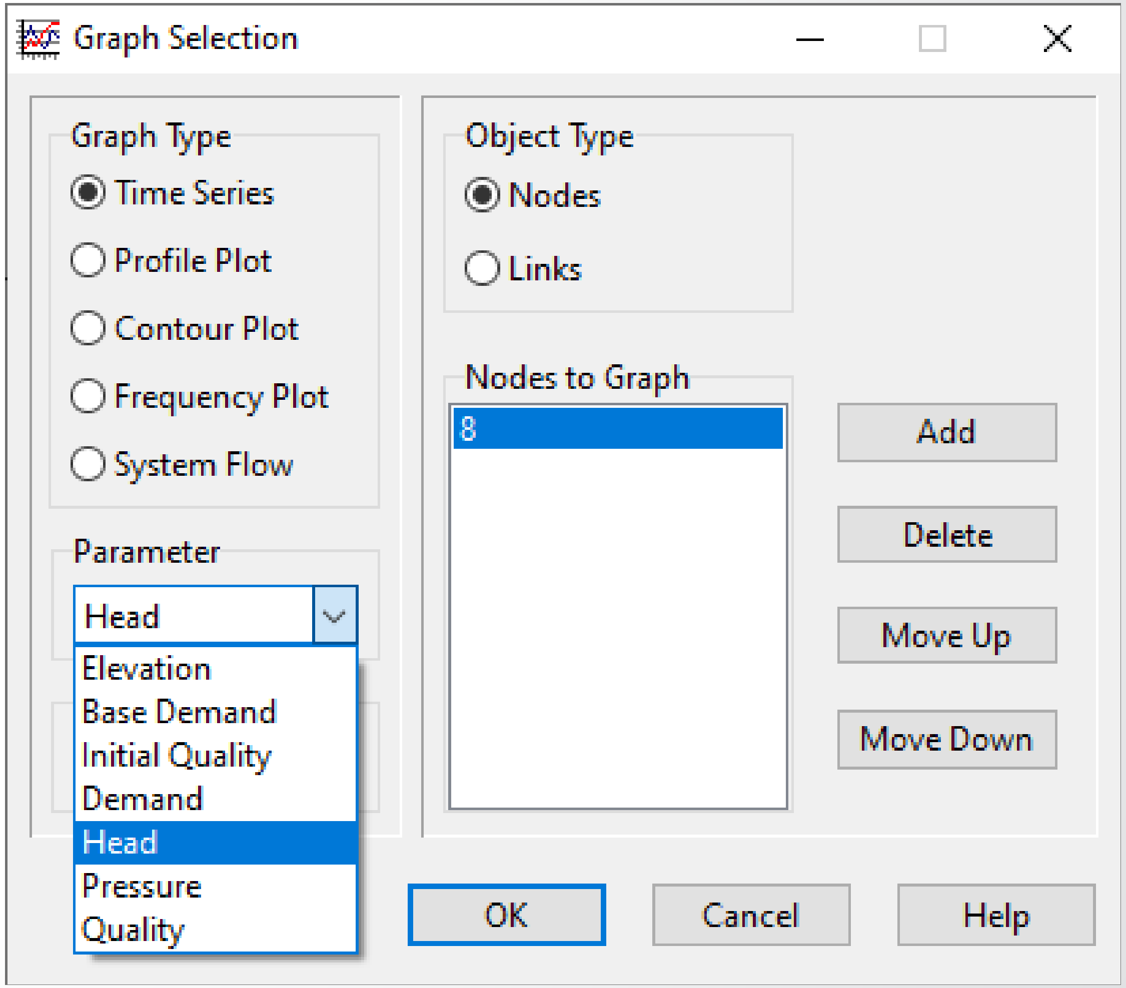
Hydraulic Options - PDA

- Data Browser Window >> Options >> Hydraulics >> Demand Model
- Minimum Pressure: Demand = 0 if Pressure < Minimum Pressure
- Required Pressure: full Demand if Pressure ≥ Required Pressure
  - Set to at least 0.1 psi or m above Minimum Pressure
- Pressure Exponent: used to calculate partial demand
  - Its suggested value is 0.5



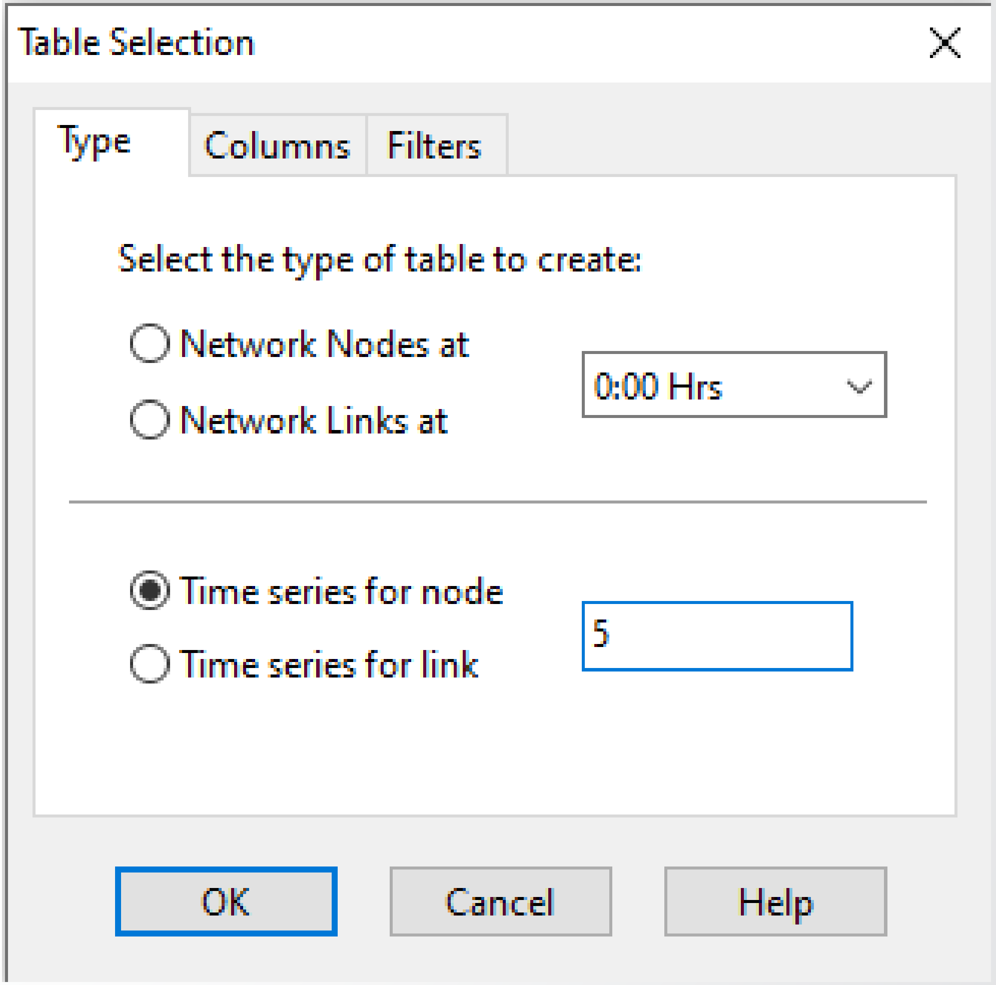
Hydraulics – Time Series (Head)

- Report >> Graph (or just Graph button)
  - Graph Type: Time Series
  - Parameter: Head
  - Nodes to Graph: 8 (the Tank)
    - Move the Graph Selection Window until you can see the Tank in the Network Map
    - Click the Tank so it is blinking
    - Click Add



Hydraulics - Table

- Report >> Table (or just Table button)
  - Select the type of table to create: Time series for node
  - Type “5” in the box for Node/Junction 5



Hydraulics Knowledge Check

EPANET can use a ________-driven or _______-driven approach to solve hydraulic simulations. (Fill in the blank.)

A. Demand & Head

B. Pressure & Demand

C. Power & Pressure

D. Head & Power

Hydraulics Modeling Exercise

Hydraulic Exercise (I)

- The first exercise will be to simulate the hydraulics for the system under average day conditions. Use the input file: **Tutorial.net**
- The model is currently set up for a single period analysis (Total Duration = 0 hours) and the initial conditions are set to 0 for all nodes
  - Change the Total Duration to “168” hours (1 week)
  - Change the Pattern Time Step to “6”
- Make a new Pattern with multipliers of “0.8”, “1.1”, “1.0”, and “1.1”
  - Assign the Pattern to every Junction
- Run the model and plot the Head in the tank
  - What do you see? Has it reached a dynamic equilibrium?
- Save the input file as **Tutorial Hyd1.net**

Hydraulic Exercise (2)

- Use the **Tutorial Hyd1.net** as your starting input file
- Change the Total Duration to “504” (3 weeks) hours. Then re-run the model and graph the tank’s Head again. How long did it take for the tank(s) to reach cyclic equilibrium?
- From the plots for the tank, what is the approximate minimum water level at the cyclic equilibrium? Use this value as initial conditions (Value – Elevation = Initial Level) for the tank and rerun the model
    - Observe how much more quickly, the models reach equilibrium.
- Save the input file under a different name such as **Tutorial Hyd2.net**

Hydraulic Exercise (3)

- Use the **Tutorial Hyd1.net** as your starting input file
- Change the Elevation of Junction 5 from 650 to 820 feet
- Run the model, you'll get Negative Pressure Warnings (that's ok)
- Go to Table >> Time series for node >> 5 >> OK. See how it has full demand, but negative pressures sometimes (e.g., 6:00-23:00)?
- Change the Demand Model to "PDA" and the Required Pressure to "20" and rerun the model. Make that table again. See how junction 5 has Demands less than its Base Demands, but higher & positive Pressures?
- Save the input file under a different name such as **Tutorial HydPDA.net**

Water Age Modeling Application

Ben Burkhart

Uses of Water Age Models

- Design
  - Checking impacts of a new tank
  - Checking impacts from skeletonization
- Operation
  - Determine general water quality
  - Insights despite disinfectant types

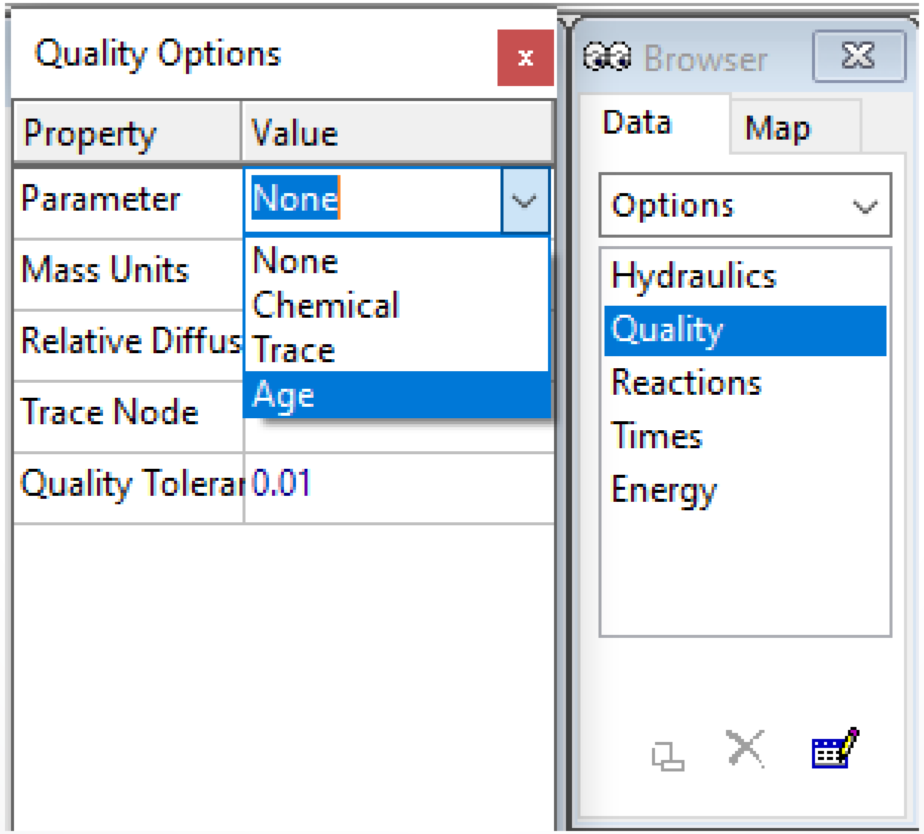
Running a Water Age Model

- Start with a (calibrated) hydraulic model
- Set the Total Duration & Quality Time Step of the simulation
- Set the Quality Parameter to "Age" for water age
- Choose the best mixing model (Mixed, FIFO, LIFO, or 2Comp) for each tank
- Optional: Set initial conditions (tank Initial Levels & nodal Initial Quality)
- Run the model and analyze the results

Water Age Modeling Demonstration

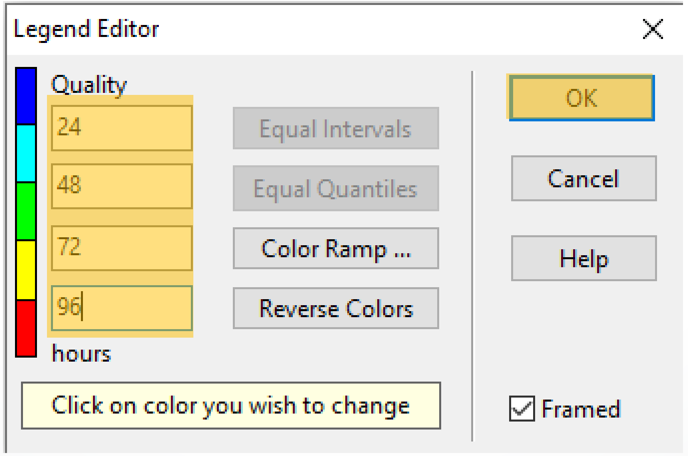
Water Age – Quality Parameter

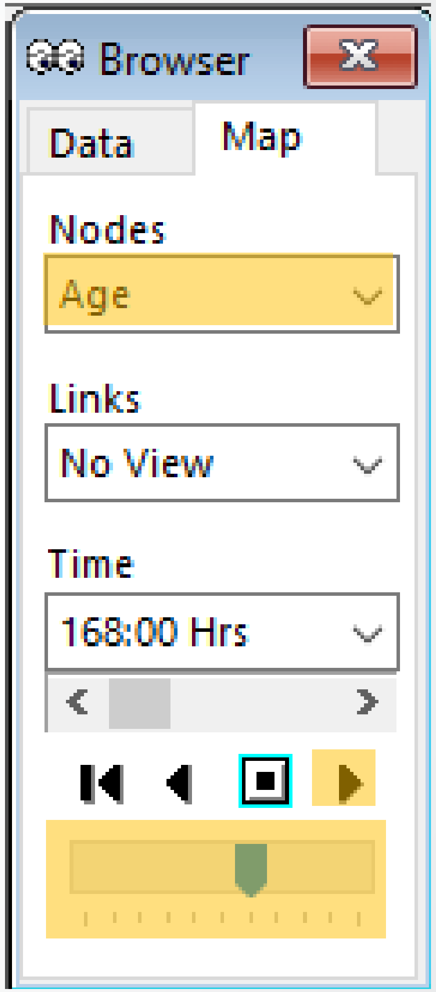
- Browser Window >> Data Tab >> Options >> Quality >> Parameter to "Age"



Water Age – Map Animation

- Map Browser
  - Nodes: Age
  - Click Play
  - (Adjust the bottom bar to change animation speed)





Water Age – Time Options

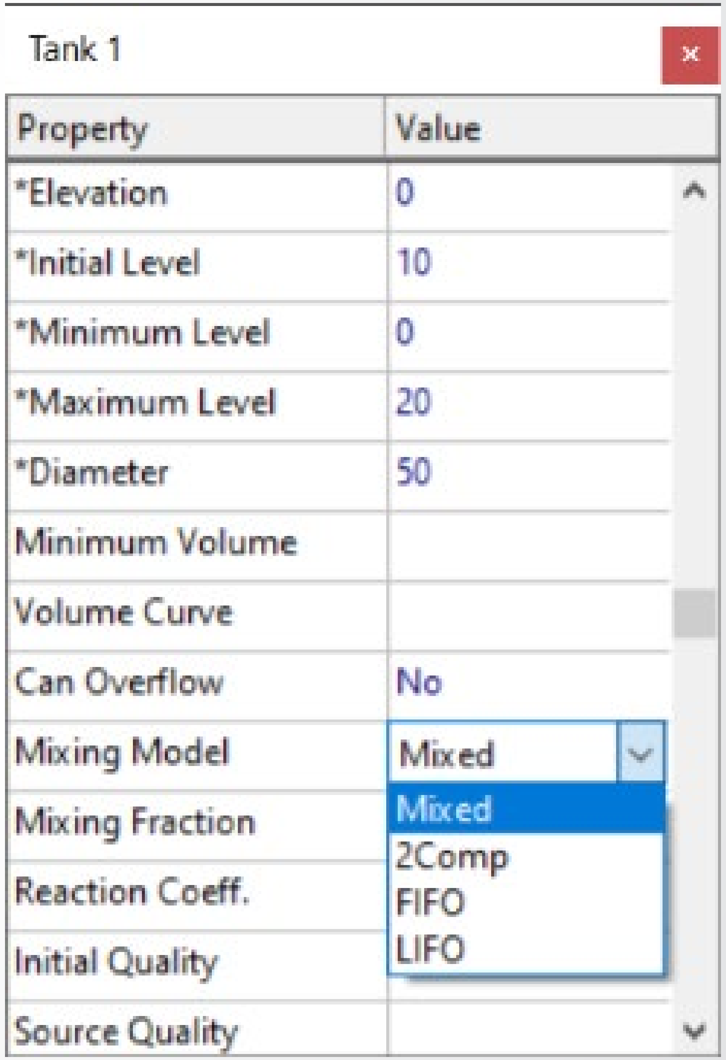
- Browser Window >> Data Tab >> Options >> Time
  - Total Duration = 240
  - Report Time Start = 168
    - Setting the Report Start Time removes results from earlier times (usually prior to reaching/approaching steady state) and 'cleans up' the results, making them easier to analyze

Times Options

Property	Hrs:Min
Total Duration	240
Hydraulic Time Step	1:00
Quality Time Step	0:05
Pattern Time Step	2:00
Pattern Start Time	0:00
Reporting Time Step	1:00
Report Start Time	168
Clock Start Time	12 am
Statistic	None

Water Age – Tank Mixing Models

- Open the tank properties table (double click the Tank)
- Set the most appropriate Mixing Model from the drop-down list (Mixed, FIFO, LIFO, or 2Comp)
  - Only the 2-compartment method requires a value for the "Mixing Fraction"



Water Age Knowledge Check

Which of these does NOT affect water age?

A. Distance from the treatment plant
B. Levels of disinfectants
C. Use of tanks
D. Use of loops or branches for pipe layouts

Water Age Modeling Exercise

Water Age Exercise (1)

- From EPANET's example folder, use the input file: **Net1.net**
- Open the *Quality Options* and set the *Parameter* to "Age"
- Open the *Times Options* and set the *Total Duration* to "240" (10 days) & the *Report Start Time* to "168" (7 days)
- Run the model
- In the Map Browser, set *Nodes* to "Age"
- Right-click the Node Legend that appeared in the Network Map area
  - Use the Legend Editor to set the increments by days ("24", "48", "72", & "96"), click OK
- Run the animation (Feel free to increase the *Animation Speed*)
- What times of day does it seem the Junctions have the highest water age (red)? Why?
- Save the input file as **Net1 Age1.net**

Water Age Exercise (2)

- Use the **Net1 Age1.net** as your starting input file
- Using the Property Editor, change the tank's *Mixing Model* to "FIFO"
- Re-run the model & play the animation
  - Did this improve (lower) or worsen (raise) the water age in the system? Why?
- Using the Property Editor, change the tank's *Mixing Model* to "LIFO"
- Re-run the model & play the animation
  - Did this improve (lower) or worsen (raise) the water age in the system? Why?
- Save the input file under a different name such as **Net1 Age2.net**

Chlorine Modeling Application

Feng Shang

Uses of Chlorine Models

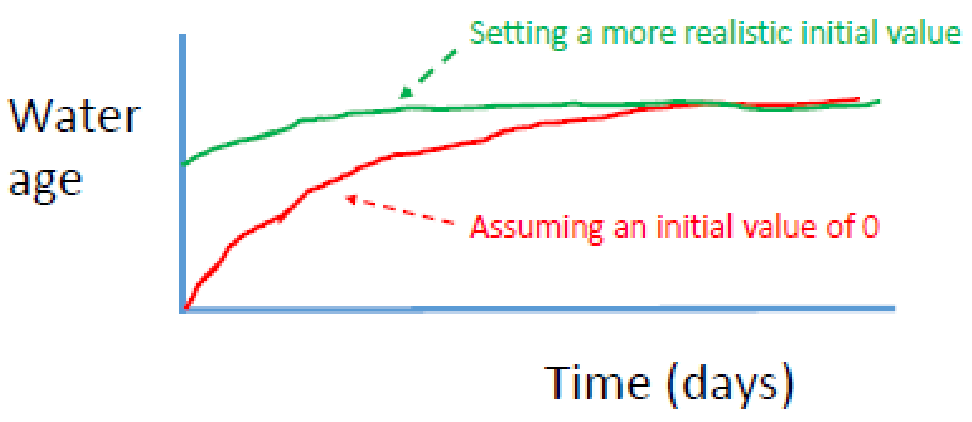
- Design
  - Checking impacts of a new tank
  - Find where booster stations are needed
- Operation
  - Adjusting disinfectant feeds (Source Concentrations)
  - Selecting disinfectant type (Free Chlorine vs Chloramine)
- Hindcasting
  - Recreating complaints
  - Litigation cases

Chlorine Factors in WDS

- Source water quality
- Operation of system
- Transport in distribution system
- Transformations
- Storage

Setting Initial Conditions

- Junctions & Tanks can optionally have Initial Quality set
  - Initial Quality is the Chemical concentration (or water Age / Trace fraction) at t=0
- Reduces time to reach dynamic equilibrium
  - Allows for shorter Total Durations & shorter simulation run times
- Important for tanks because it may take days (or months) to reach a steady state



Example: setting an initial water age value in a tank

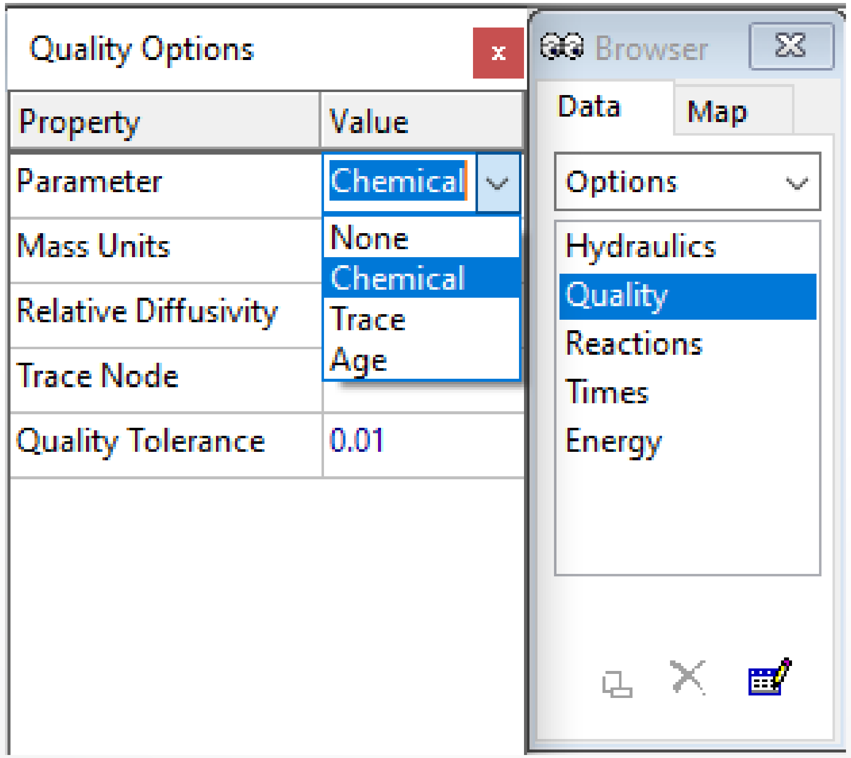
Running a Chlorine Model

- Start with a (calibrated) hydraulic model
- Set the Total Duration & Quality Time Step of the simulation
- Set the Quality Parameter to “Chemical” for chlorine
- Define Reaction parameters for chlorine
- Choose the best mixing model (Mixed, FIFO, LIFO, or 2Comp) for each tank
- Set source concentrations (Initial Quality or Source Quality at Reservoirs)
- Optional: Set initial conditions (tank Initial Levels & nodal Initial Quality)
- Run the model and look at results

Chlorine Modeling Demonstration

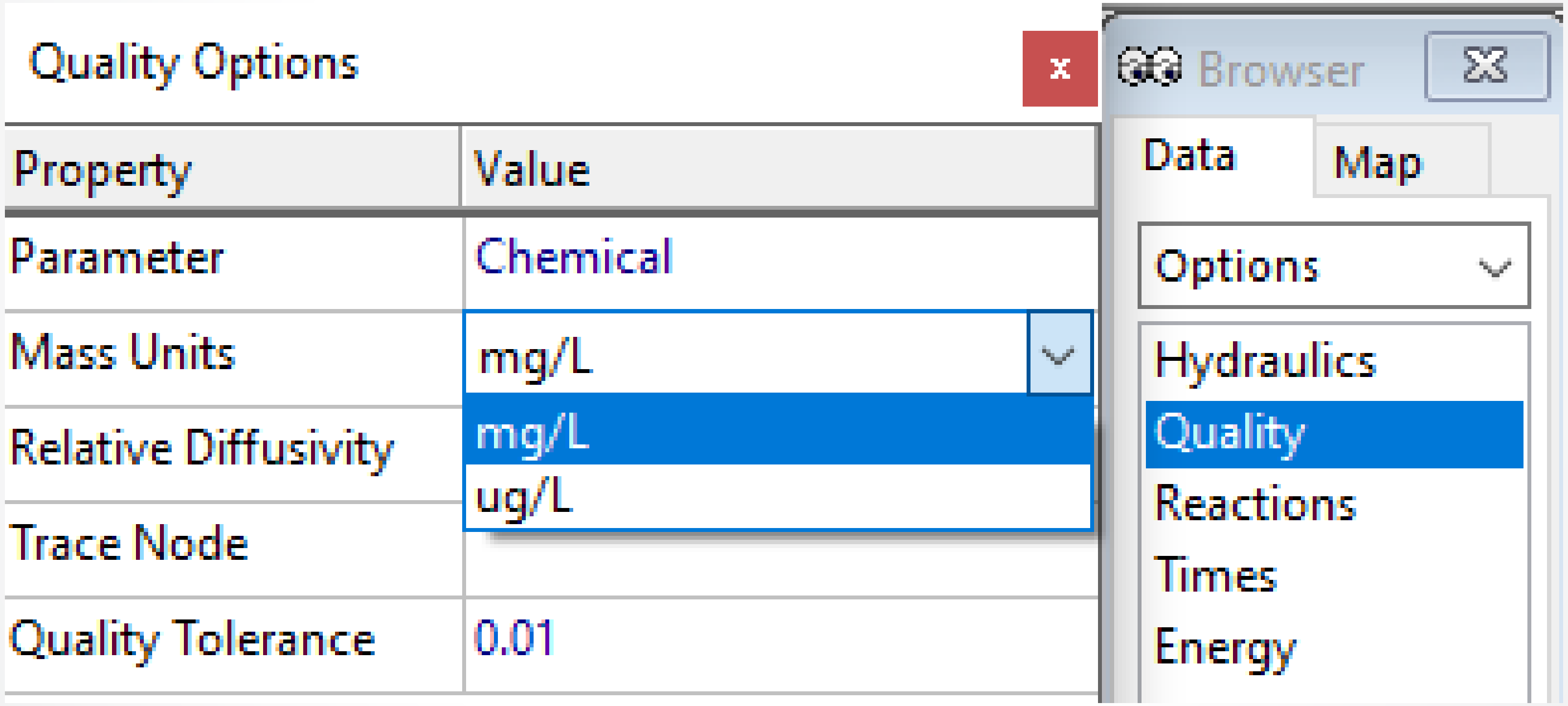
Chlorine – Quality Parameter

- Browser Window >> Data Tab >> Options >> Quality >> Parameter to "Chemical"
  - You can also type a custom entry in Parameter (e.g., "Chlorine") & it will be the same as Chemical but more identifiable



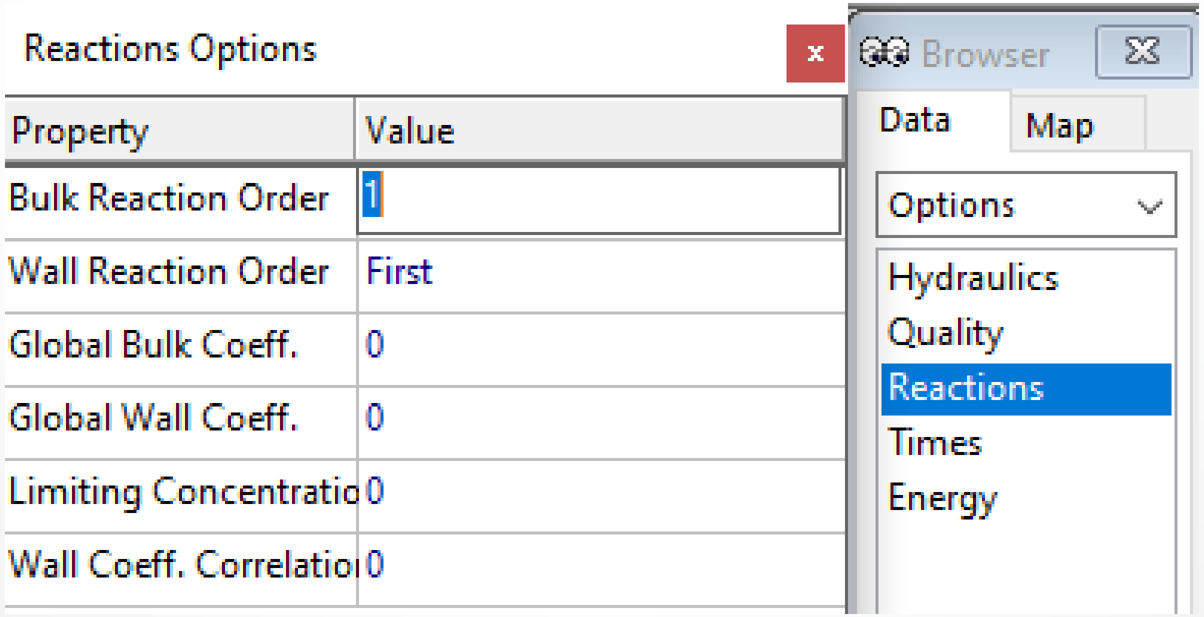
Chlorine – Mass Units

- Browser Window >> Data Tab >> Options >> Quality >> Mass Units to mg/L or µg/L



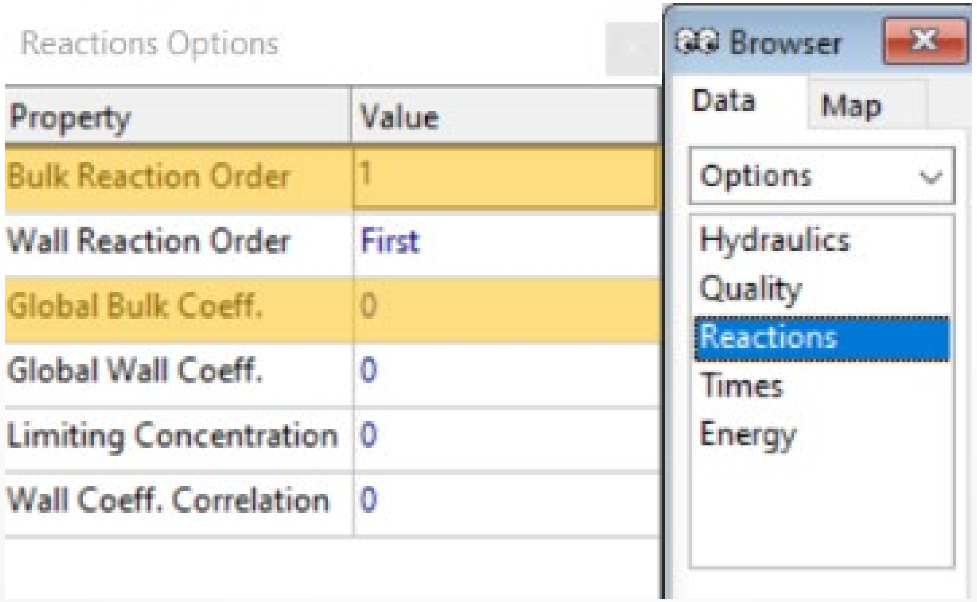
Chlorine – Reaction Order & Coefficients

- Browser Window >> Data Tab >> Options >> Reaction
  - Set Global Bulk and Wall coefficients (usually the default values) to 0 for conservative chemicals
  - Values must be entered for several properties for non-conservative chemicals



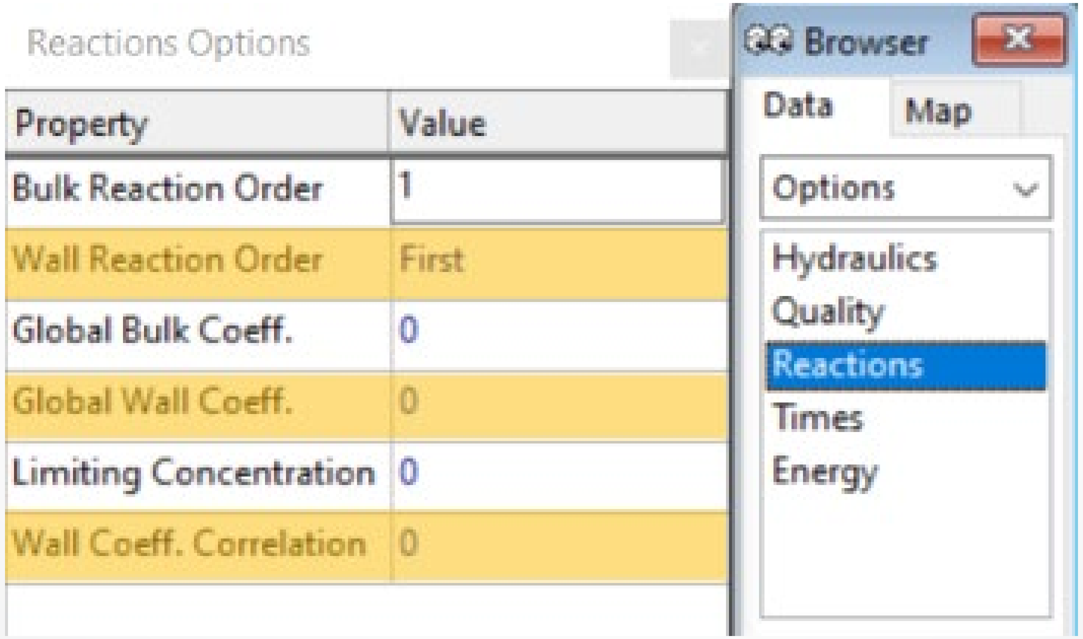
Chlorine – Bulk Reactions

- Bulk Reaction Order & Global Bulk Coeff. must be set to define bulk reactions
  - Set 0, 1, or 2 for the Bulk Reaction Order ("1" for Chlorine)
  - Enter a value for Global Bulk Coeff. depending on the chemical and system
    - Use a negative value for decay



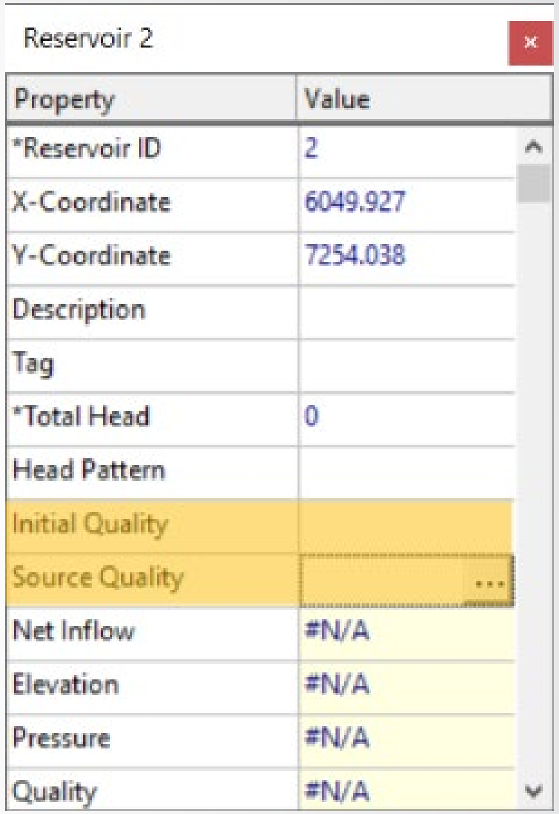
Chlorine – Wall Reactions

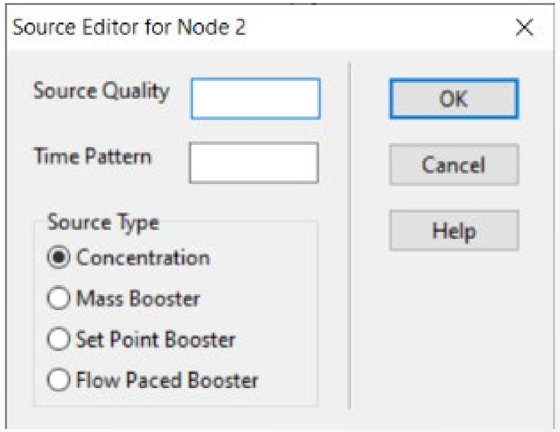
- Wall Reaction Order, Global Wall Coeff. & Wall Coeff. Correlation must be set to define bulk reactions
  - Set 0, 1, or 2 for the Bulk Reaction Order (“1” for Chlorine)
  - Enter a value for Global Wall Coeff. depending on the chemical, pipes, and system
    - Use a negative value for decay



Chlorine – Source Concentrations

- The Initial Quality and Source Quality represents the Chemical concentration at each Reservoir (treatment plant)
- Set only the Initial Quality if the Reservoir has a constant concentration
- Set the Source Quality if the Reservoir changes over time
  - The Source Editor connects Source Quality & a Time Pattern





Chlorine Knowledge Check

Typically, within what range is the Global Bulk Coefficient for modeling chlorine decay?

A. Between -5.00 & -15

B. Between -0.2 & -1.0

C. Between 3.5 & 0.7 days

D. Between 0.2 & 1.0

Chlorine Modeling Exercise

Chlorine Exercise (I)

- Initially we are only going to simulate bulk reactions (no wall demand)
- Use the input file **Tutorial Hyd1.net**
- In the *Options* menu, open *Quality Options* and choose "Chemical"
- In the *Options* menu, open *Reactions Options* and for the *Bulk Reaction Order* choose "-1"
  - If you choose a value of 1, chlorine concentrations will grow instead of decay as it should
- Still in the *Reactions Options* window, set the *Global Bulk Coeff.* to "-0.5"
- Set the Reservoir's *Initial Quality to* "1" to define the chlorine concentration in the source
- Run the model & plot the time series for 3 nodes and look at the concentrations
- Save this input file under a different name such as **Tutorial BulkOnly.net**

Chlorine Exercise (2)

- Now we are going to look at how the chlorine wall demand affects chlorine concentrations. Use the same input file: **Tutorial BulkOnly.net**
- In the *Options* menu, select the *Reactions* item and for the *Wall Reaction Order* choose "First" and for the *Global Wall Coeff.* choose "-1"
- Re-run the model
- Plot the same nodes as the previous run and compare the results
- Save this input file under a different name such as **Tutorial Bulk-Wall.net**

Need Help?

- U.S. EPA website (General Information)
  - (https://www.epa.gov/water-research/epanet)
  - Questions - Email us at epanet@epa.gov

- USEPA Github.com repository (General Information & User Interface)
  - https://github.com/USEPA/EPANET2.2

- EPANET community at OpenWaterAnalytics (Hydraulic & Water Quality Engines)
  - https://github.com/OpenWaterAnalytics/EPANET/wiki
  - Community forum http://community.wateranalytics.org/

- If you want to contribute to EPANET https://github.com/OpenWaterAnalytics/EPANET/issues

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Concluding Knowledge Check

Y/N: Do you feel like you learned something about EPANET from this presentations?

- Yes
- No

Reasons to Build WDS Models

- Want to understand the WDS & have a record of the structure
- Water movement is complex & non-intuitive
- Typically much cheaper & faster than testing the physical system
- Can be linked to sensors in the physical system to validate and verify the model
- Used to assess alternative designs and operational plans on water delivery

EPANET Application

- Can examine both hydraulic and water quality issues for water distribution system analysis
- Improving hydraulic reliability may hurt water quality (large tanks with low turnover rate)
- It is not hard to build a simplified (skeletonized) system model
- Significant effort is needed to develop (& calibrate) a good model

Reasons to Model Water Age

- Want to better understand water quality across the distribution network.
- Water movement is complex & non-intuitive
- Water age varies spatially and temporally
- Sampling provides a limited picture of water quality throughout the system
- Used to assess the effects of alternative designs and operational plans on water quality

Reasons to Model Chlorine

- Want to know water quality at the tap (required by Safe Drinking Water Act)
  - Simulations don't fulfill the Safe Drinking Water Act, but they can be used to estimate and find ways to improve
- Water movement is complex & non-intuitive
- Water quality varies spatially and temporally
- Sampling provides a limited picture of water quality throughout the system
- Used to assess the effects of alternative design and operational plans on water quality delivered to customer