Research and Innovation Center of Excellence

Introduction to EPANET

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University of Cyprus
Imperial College London

Interreg
Ελλάδα-Κύπρος
Ευρωπαϊκό Ταμείο Περιφερειακής Ανάπτυξης
ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ
SmartWater2020
funded by:

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- A2_Why Epanet
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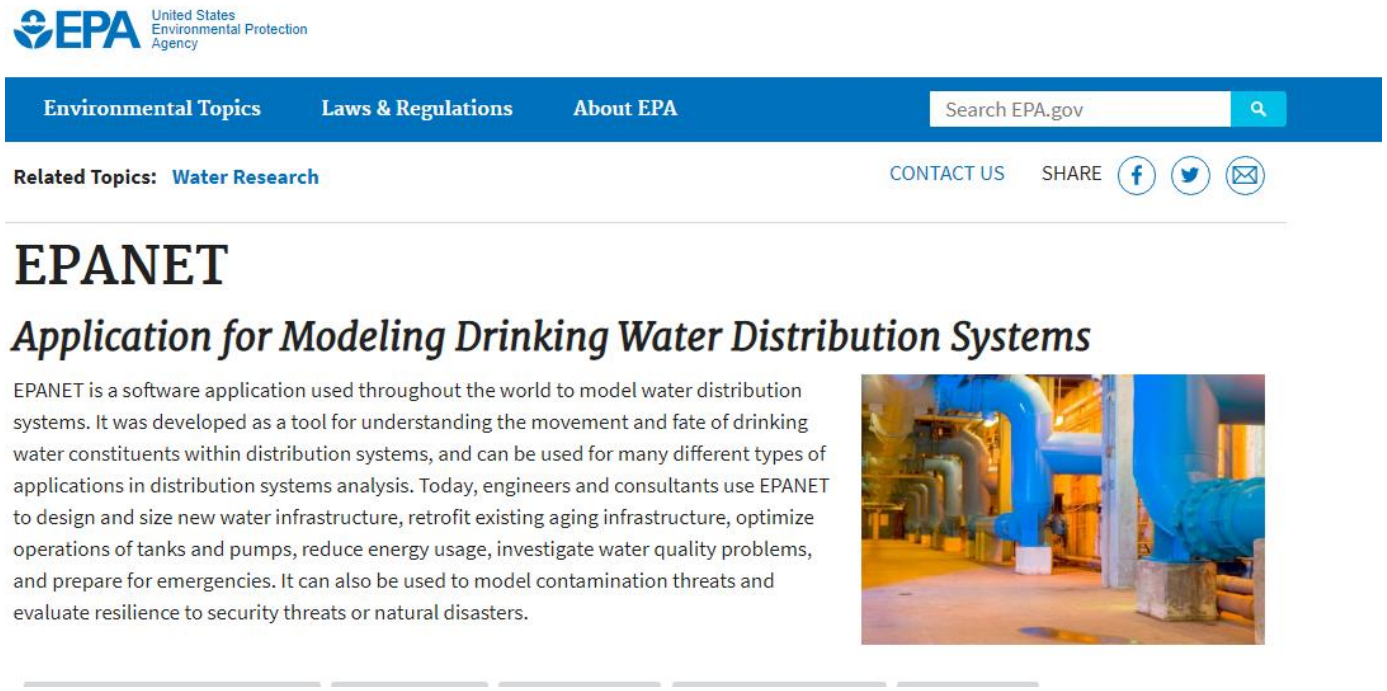
A1_ What is EPANET

EPANET

EPANET is developed by the United States Environmental Protection Agency's (EPA) Water Supply and Water Resources Division. It is a **public domain, water distribution system modeling software.**

https://www.epa.gov/water-research/epanet

- EPANET software
- EPANET manual



EPANET (cont.)

Hydraulics

- Perform ***extended-period simulation*** of the hydraulic and water quality behavior
- Pressure/Consumption at each node
- Flow/Velocity at each pipe
- Water height at storage tanks
- Energy/Electricity cost at pumps
- Variety of valves (PRVs, FCVs,…)
- Can use time / rule-based controls (PLC).
- Model leakages

EPANET (cont.)

Quality

- Chemical concentration/Water quality in all components (Nodes, pipes, tanks , …)
- Models movement of substance in network over time.
- Models growth/decay of substance (HOCL, TTHMs).
- Models water age.
- Models bulk/wall reactions.
- Models decay with different dynamics.
- Models substance injection.

EPANET Scenarios

- What happens if a valve is opened or closed.
- System's behavior under different flows and / or pressures.
- How does network pressure changes during the day and what is its magnitude.
- Sufficiency of water tanks in case of an emergency event (i.e. fire, interruption of the water supply into the tanks).
- Quality sensors placement.
- Most vulnerable locations within the network.
- …...

EPANET Formulas: Friction Losses – Head Loss

- **Hazen - Williams formula** *(for water and turbulent flow)*

$$h_L = \frac{K \times L \times Q^{1.852}}{C^{1.852} \times D^{4.871}}$$

[k: conversion factor for the unit system (k = 1.318 for US customary units, k = 0.849 for SI units)]

[C: roughness coefficient]

- **Darcy - Weisbach formula** *(all liquids and all flow regimes)*

$$h_L = f \frac{8 \times L \times Q^2}{g \times \pi^2 \times D^5}$$

[f: friction factor]

- **Chezy - Manning formula** *(mostly for open channel flow)*

$$h_L = \frac{4.66 \times n^2 \times L \times Q^2}{D^{5.33}}$$

[n = Manning's Roughness Coefficient]

EPANET Formulas: Friction Losses – Head Loss

Material	Hazen-williams C	Darcy-Weisbach ε	Manning's n
Cast Iron	130-140	0.85	0.012-0.015
Concrete or concrete lined	120-140	1.0-10	0.012-0.017
Galvanized Iron	120	0.5	0.015-0.017
Plastic	140-150	0.005	0.011-0.015
Steel	140-150	0.15	0.015-0.017
Vitrified Clay	110		0.013-0.015

A2_Why EPANET

EPANET

- EPANET is a useful tool to investigate what-if scenarios involving hydraulics and quality.
- EPANET is free to use, and is the state-of-art.
- It’s easy to use!
- There is an active community working on EPANET.
- Demand-driven; cannot capture pressure-driven demands.
- Can be used in any new software tool.

EPANET (cont.)

(a) EPANET ***Graphical User Interface (GUI)***

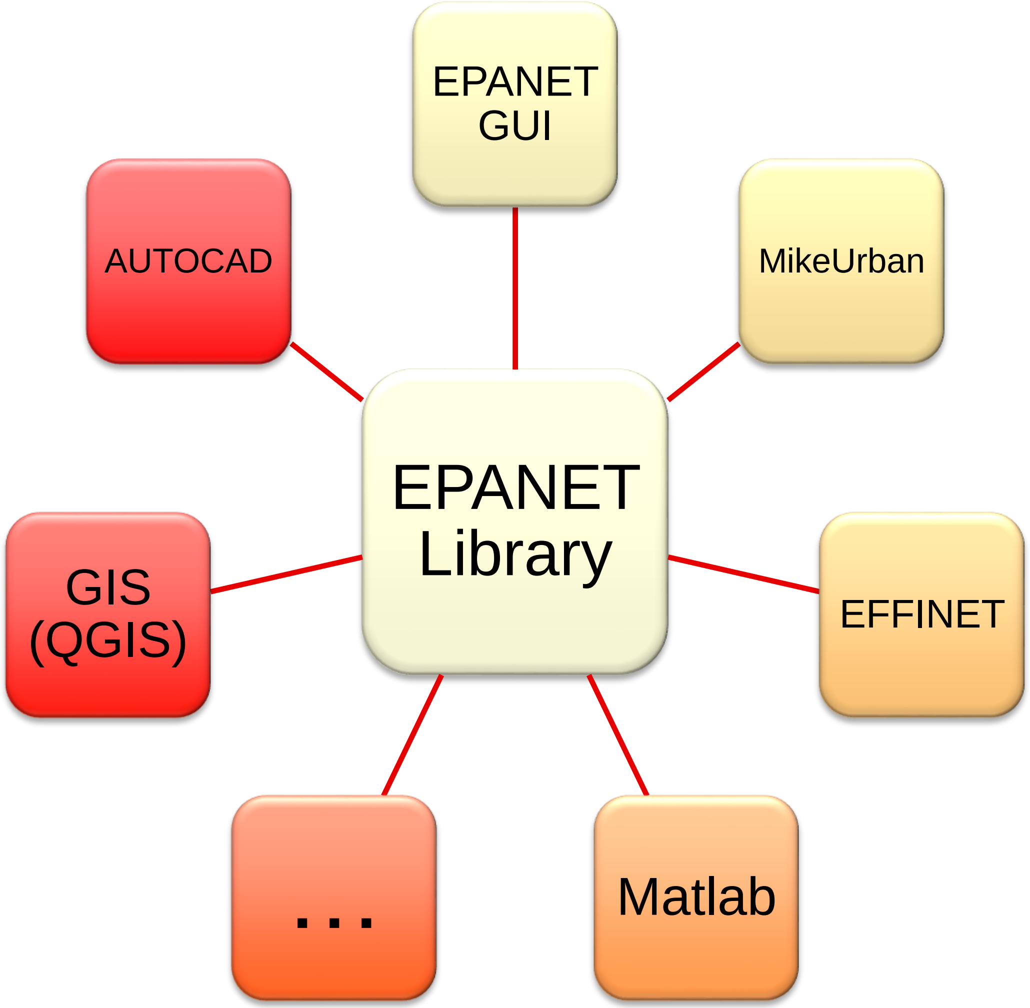
Standalone program that addresses the standard capabilities given by the EPANET Library.

(b) EPANET ***open-source toolkit***

EPANET Libraries can be integrated in any programming language and are compatible with any operating system.

[i.e H2OMap and H20Net (Innovyze), Mike Urban (DHI), WaterCAD and WaterGEMS (Bentley), WatDis (Transparent Blue)].

EPANET Library



A3_ EPANET COMPONENTS

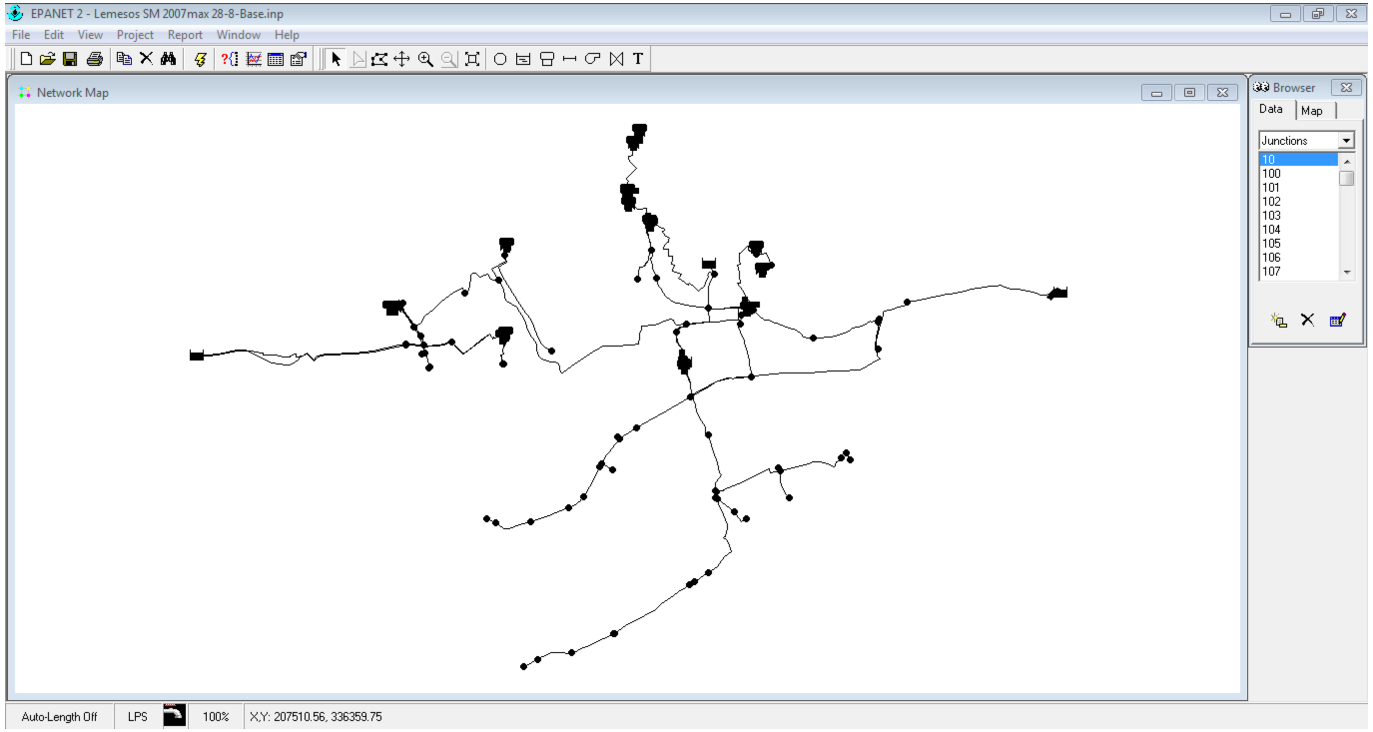
Components

Physical Components

- Nodes: Junctions, Reservoirs, Tanks.
- Links: Pipes, Pumps, Valves.

Non-Physical Components

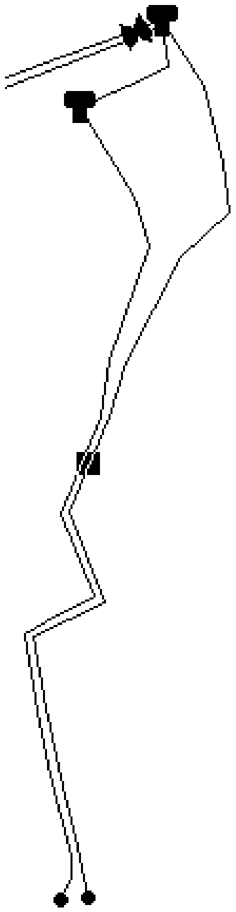
- Controls
- Curves
- Patterns



Pipe

- Length
- Diameter [Inner Diameter]
- Roughness [i.e. for PVC pipe is 140 (H-W), 0.005 (D-W)]
- Initial status [open/closed/cv]

- Loss coefficient [minor/local losses]
- Bulk coefficient [water quality]
- Wall coefficient [water quality]



Pipe 160

Property	Value
*Pipe ID	160
*Start Node	T-101
*End Node	128
Description	Outlet, Kato Polei
Tag	
*Length	528.473694
*Diameter	150.000000
*Roughness	1.000000
Loss Coeff.	0.000000
Initial Status	Open
Bulk Coeff.	
Wall Coeff.	
Flow	#N/A
Velocity	#N/A
Unit Headloss	#N/A
Friction Factor	#N/A
Reaction Rate	#N/A
Quality	#N/A
Status	#N/A

Junction

Pipe connections, consumers, points of substance injection, points of water entrance.

- Elevation
- Base Demand
- Demand Pattern
- Emitter Coefficient

  (sprinklers/leaks)

  Outflow depends on pressure $q = \boldsymbol{C} \times p^{\gamma}$
- Initial Quality
- Source Quality

Junction 64

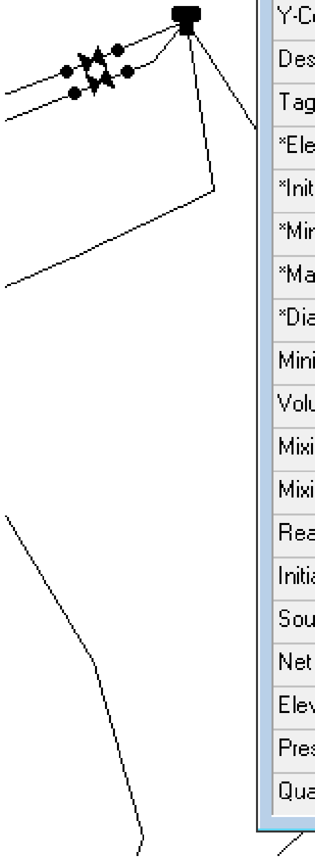
Property	Value
*Junction ID	64
X-Coordinate	200905.85
Y-Coordinate	336706.30
Description	W/M 124
Tag	
*Elevation	6.000000
Base Demand	3.722910
Demand Pattern	124
Demand Categories	1
Emitter Coeff.	
Initial Quality	
Source Quality	
Actual Demand	#N/A
Total Head	#N/A
Pressure	#N/A
Quality	#N/A

Tank

Water storage.

- Elevation
- Initial level
- Minimum level
- Maximum level
- Diameter

- Minimum volume
- …..



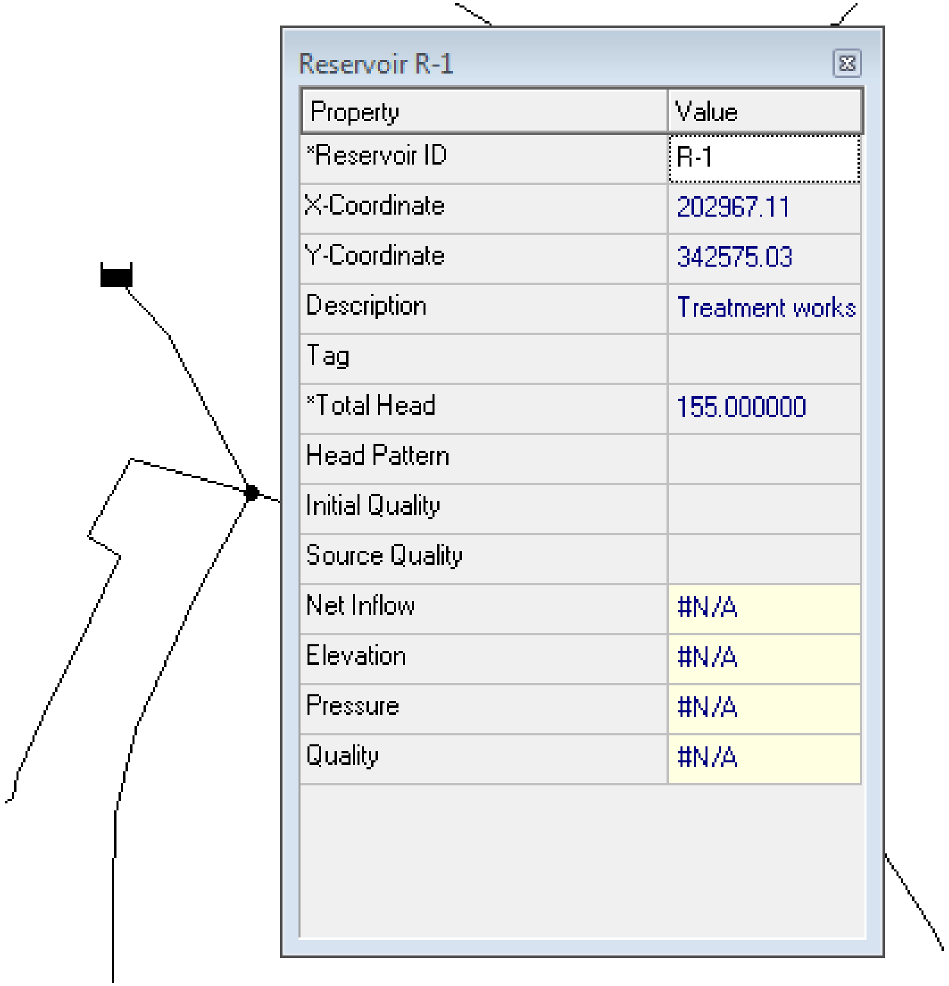
Tank T-101

Property	Value
*Tank ID	T-101
X-Coordinate	199907.86
Y-Coordinate	341527.92
Description	Kato Polemidia (A
Tag	
*Elevation	104.000000
*Initial Level	3.500000
*Minimum Level	0.000000
*Maximum Level	4.000000
*Diameter	12.620000
Minimum Volume	0.000000
Volume Curve	
Mixing Model	MIXED
Mixing Fraction	
Reaction Coeff.	
Initial Quality	
Source Quality	
Net Inflow	#N/A
Elevation	#N/A
Pressure	#N/A
Quality	#N/A

Reservoir

Infinite sources of water, treatment plants. Reservoirs are not affected by the flows/pressures.

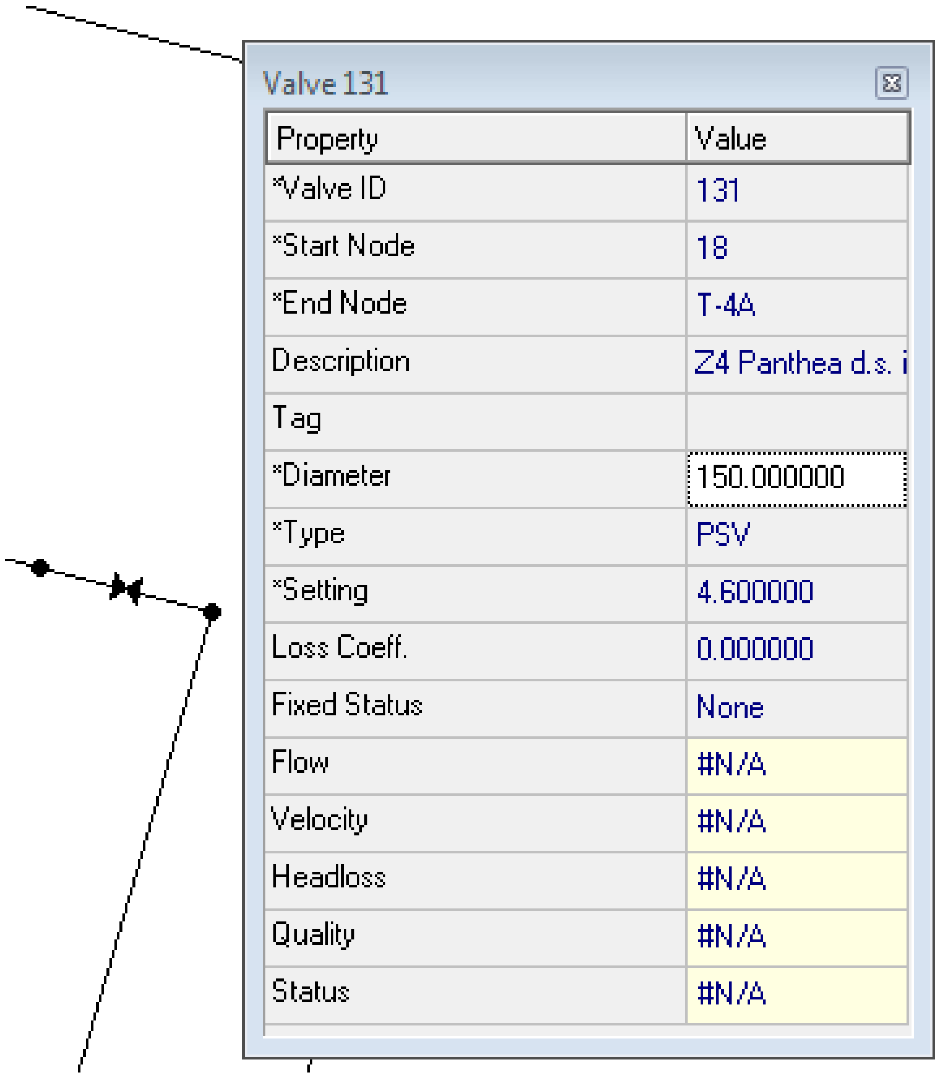
- Total Head (Elevation)
- Head Pattern
- Initial Quality
- Source Quality



Valve

- Diameter
- Type [PRV, PSV, PBV, FCV, TCV, GPV]
- Setting

- Loss Coefficient
- Fixed status [None, Open, Closed]



Valve 131

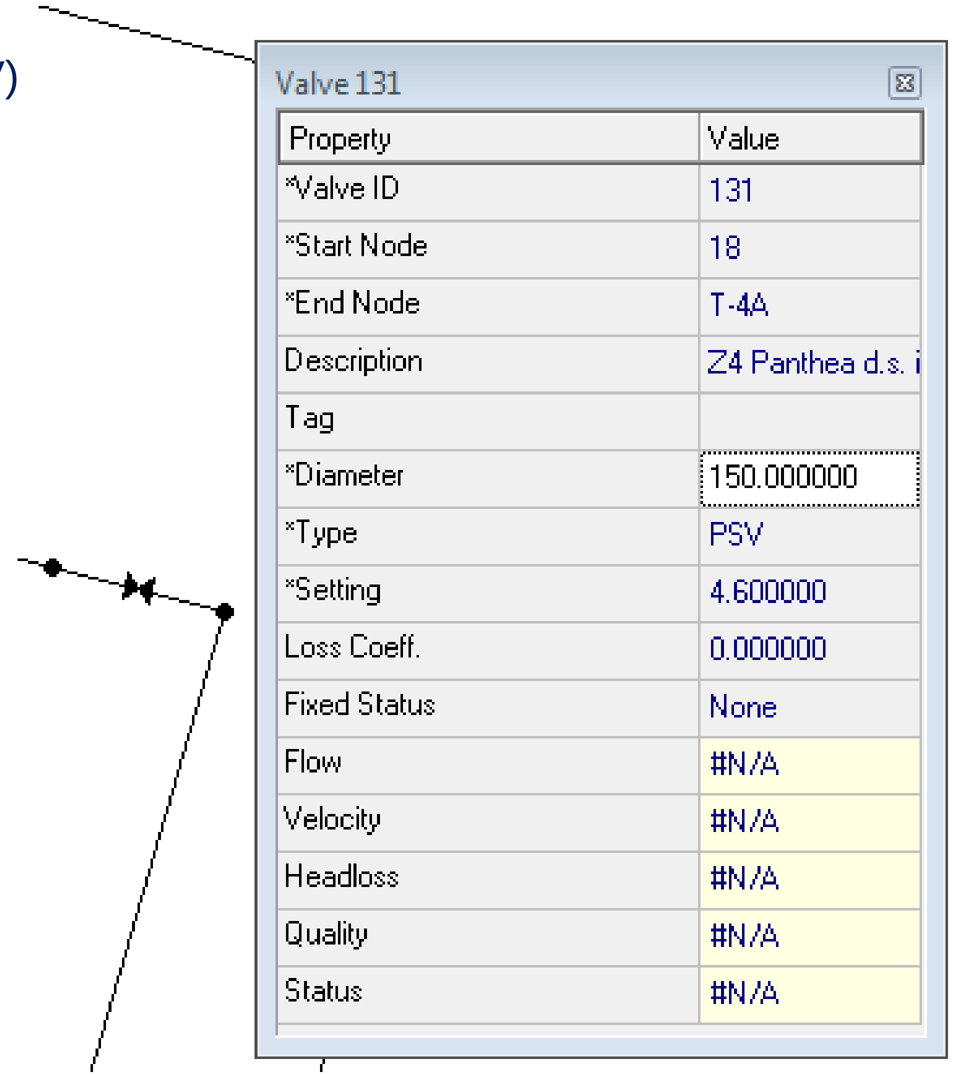
Property	Value
*Valve ID	131
*Start Node	18
*End Node	T-4A
Description	Z4 Panthea d.s. i
Tag	
*Diameter	150.000000
*Type	PSV
*Setting	4.600000
Loss Coeff.	0.000000
Fixed Status	None
Flow	#N/A
Velocity	#N/A
Headloss	#N/A
Quality	#N/A
Status	#N/A

Valve (cont.)

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

Setting:

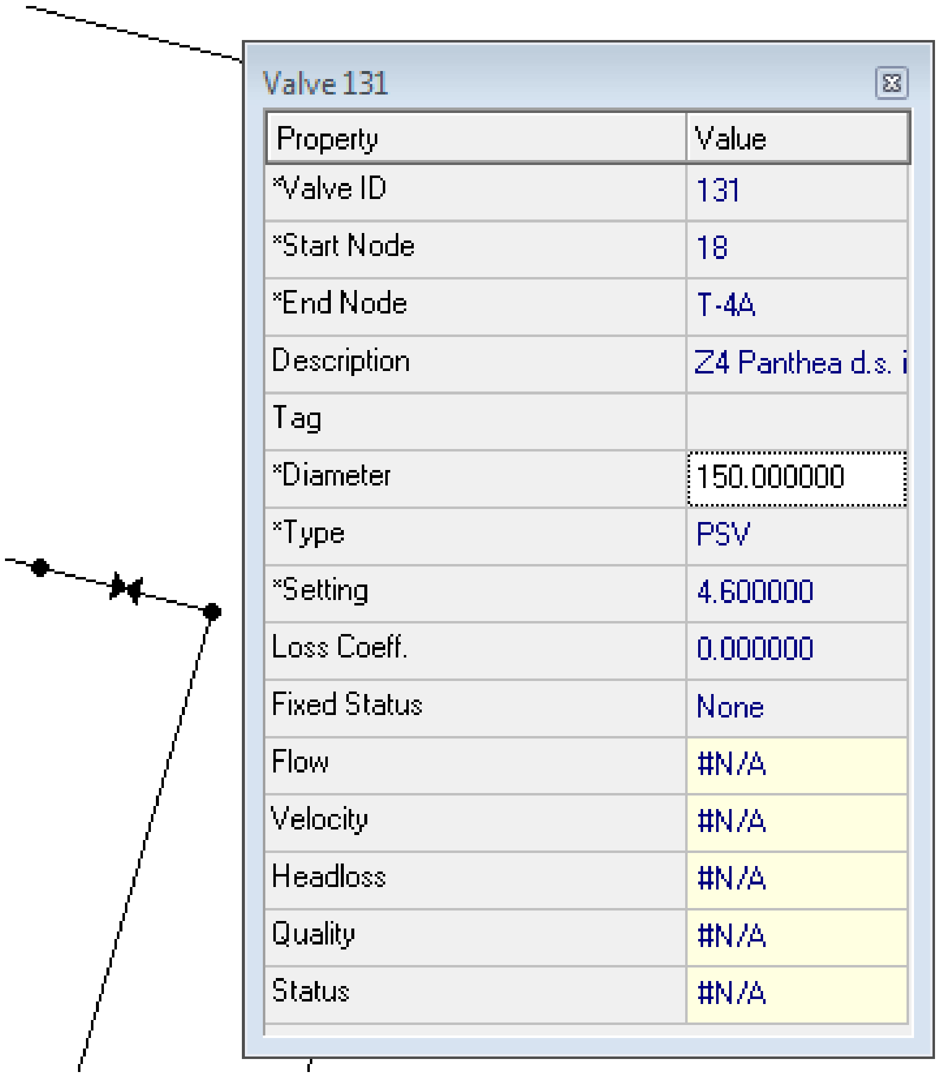
- *Pressure (PRVs, PSVs, PBVs)*
- *Flow (FCVs)*
- *Loss coefficient (TCVs)*
- *Head loss curve (GPVs)*


Valve 131

Property	Value
*Valve ID	131
*Start Node	18
*End Node	T-4A
Description	Z4 Panthea d.s. i
Tag	
*Diameter	150.000000
*Type	PSV
*Setting	4.600000
Loss Coeff.	0.000000
Fixed Status	None
Flow	#N/A
Velocity	#N/A
Headloss	#N/A
Quality	#N/A
Status	#N/A

Valve (cont.)

- PRV: Limits the pressure
- PSV: Maintains the pressure
- PBV: Simulate pressure drop (Not a physical device)
- FCV: Limits the flow
- TCV: Simulate a partially closed valve – head loss adjustment
- GPV: Simulate turbines or back-flow prevention valves – adjust flow - head loss curve


Valve 131

Property	Value
*Valve ID	131
*Start Node	18
*End Node	T-4A
Description	Z4 Panthea d.s. i
Tag	
*Diameter	150.000000
*Type	PSV
*Setting	4.600000
Loss Coeff.	0.000000
Fixed Status	None
Flow	#N/A
Velocity	#N/A
Headloss	#N/A
Quality	#N/A
Status	#N/A

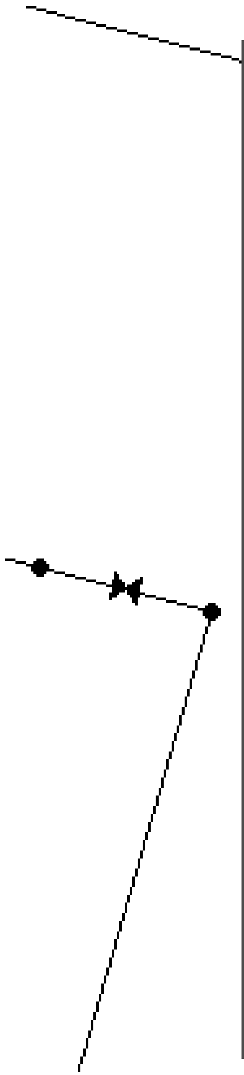
Valve (cont.)

- PRVs, PSVs or FCVs cannot be directly connected to a reservoir or tank (use a length of pipe to separate the two).

- PRVs cannot share the same downstream node or be linked in series.

- Two PSVs cannot share the same upstream node or be linked in series.

- A PSV cannot be connected to the downstream node of a PRV.



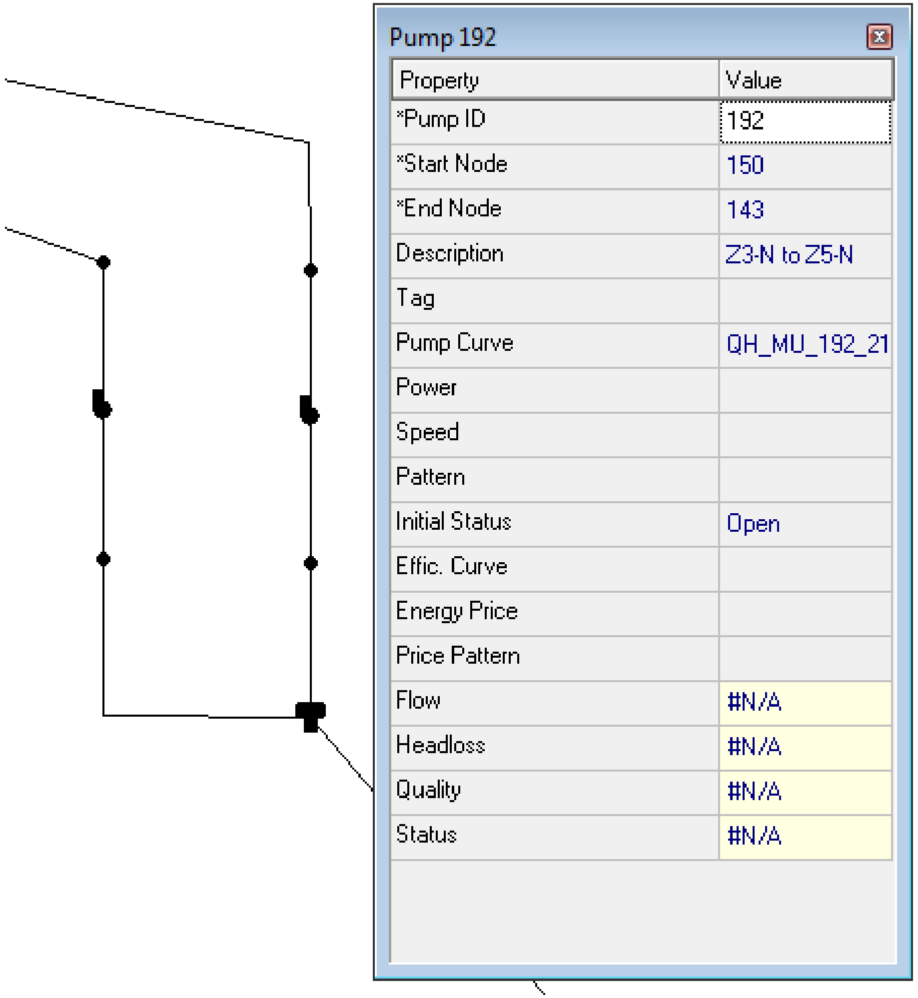
Valve 131

Property	Value
*Valve ID	131
*Start Node	18
*End Node	T-4A
Description	Z4 Panthea d.s. i
Tag	
*Diameter	150.000000
*Type	PSV
*Setting	4.600000
Loss Coeff.	0.000000
Fixed Status	None
Flow	#N/A
Velocity	#N/A
Headloss	#N/A
Quality	#N/A
Status	#N/A

Pump

Increase hydraulic head, can be turned on/off and can compute energy consumption and costs.

- Pump Curve (head vs flow)
- Power
- Speed
- Pattern
- Initial status
- ……



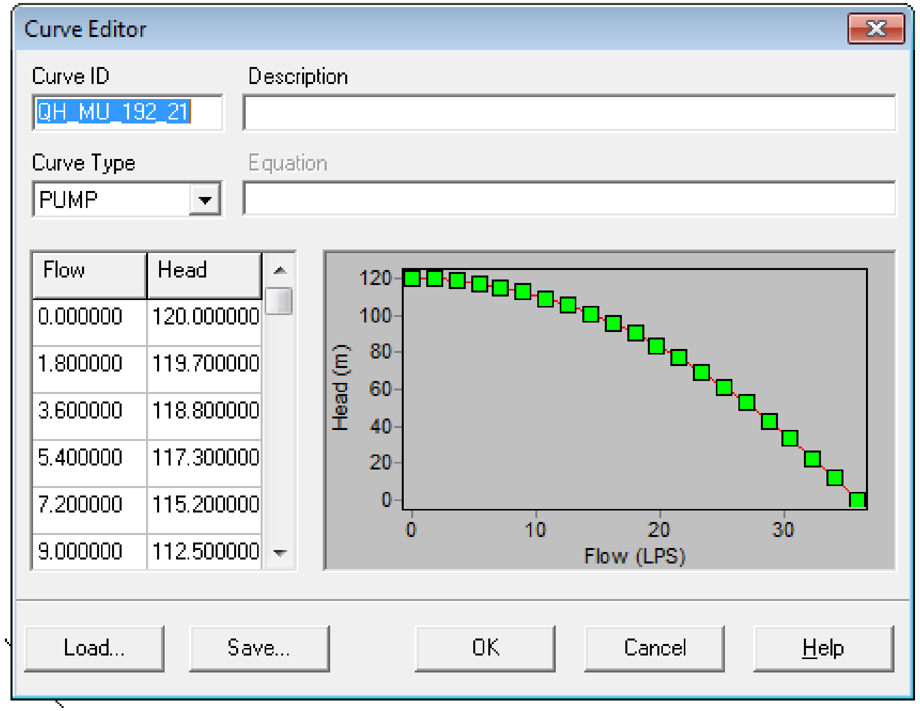
Curves

Type of Curves:

- Pump (pump)
- Efficiency (pump)
- Volume (tank)
- Head Loss (GPV)

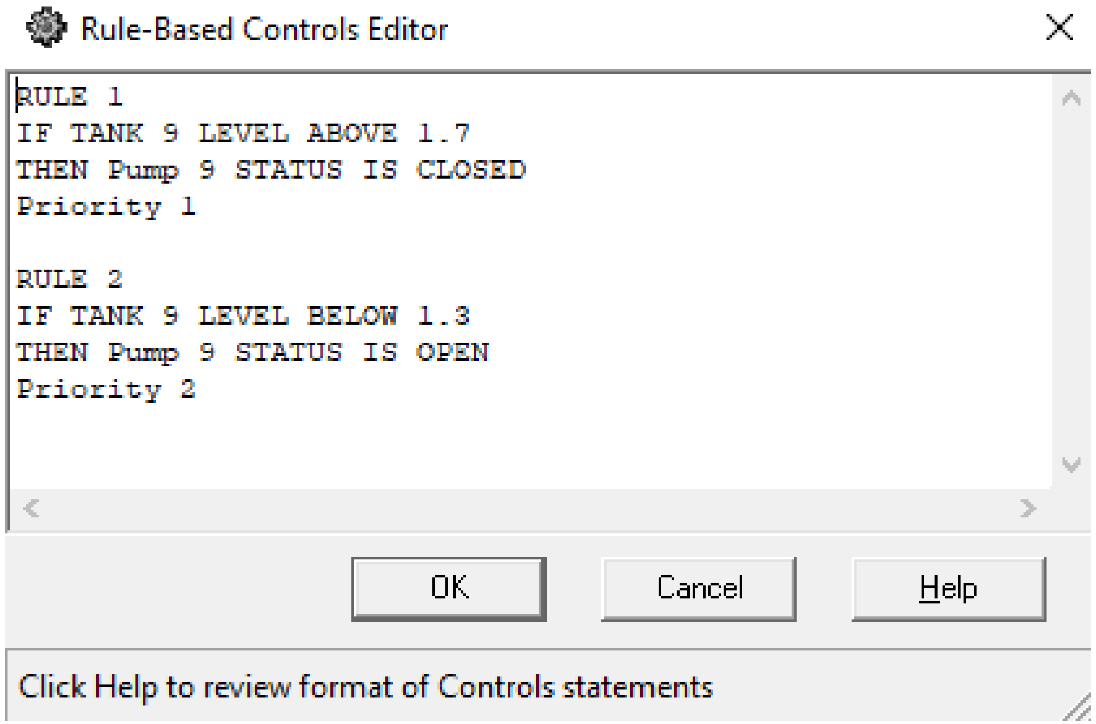
Pump Curve (Flow-Head):

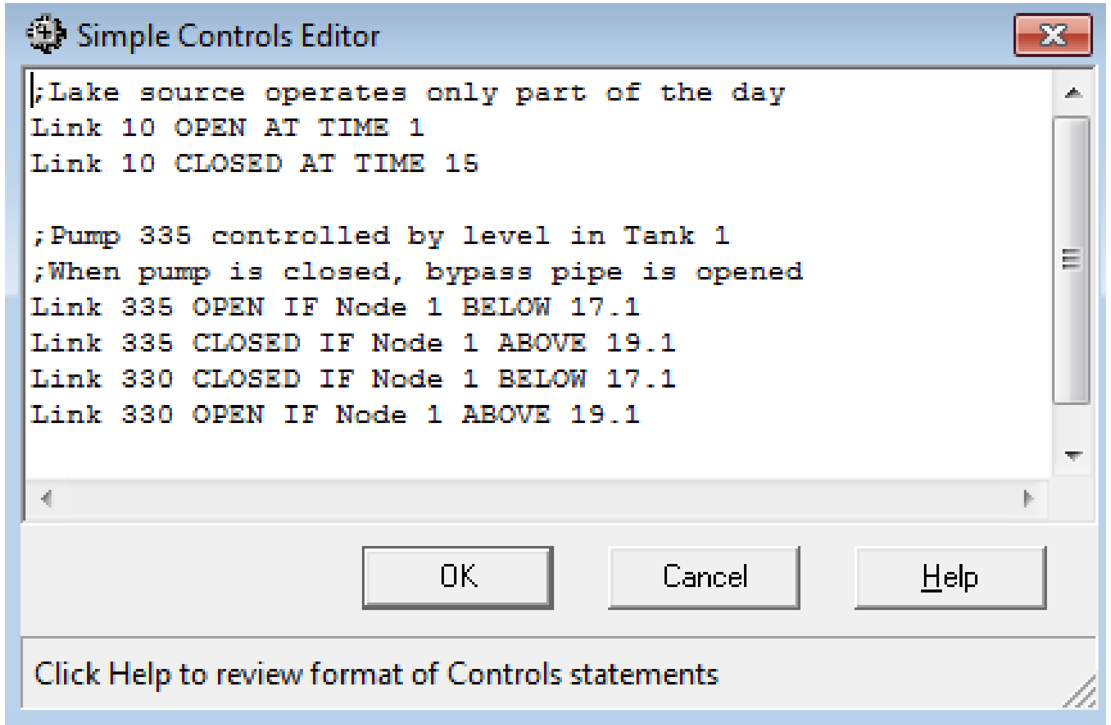
- The head that the pump can perform, at a given flow.



Controls

- Simple or Rule-Based

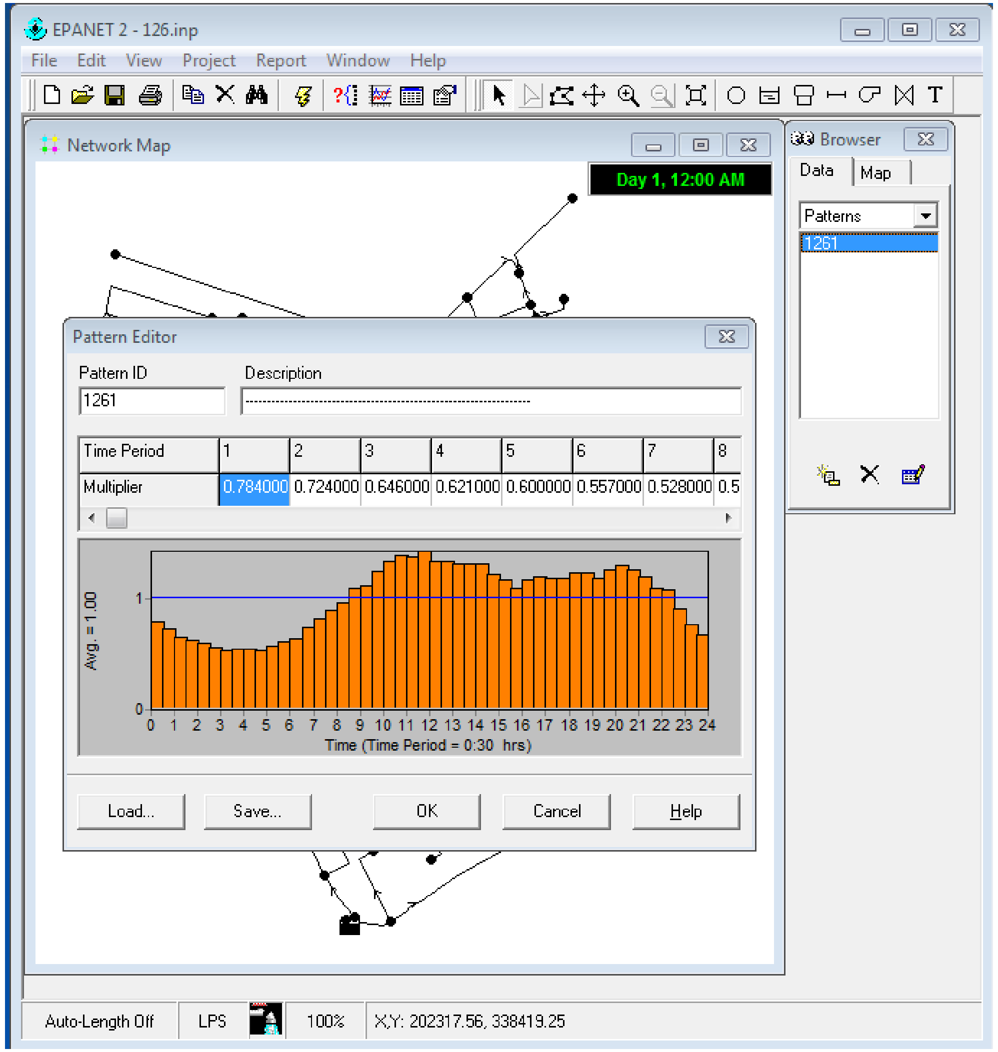




Pattern

Time Series Patterns

- Demand/Consumption Patterns (Nodes)
- Head/Pressure Patterns (Reservoir)
- Chemical concentration Patterns (Reservoir, Tank)

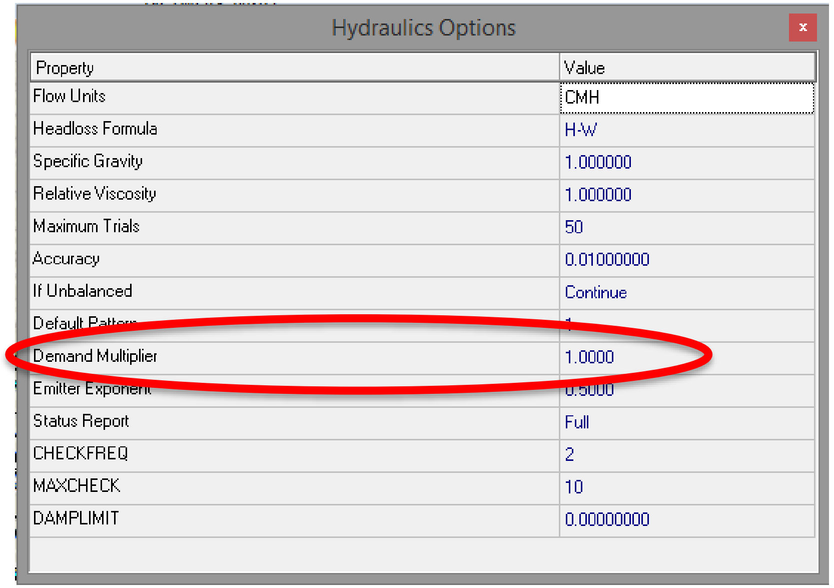


Demand Pattern – Design Scenario

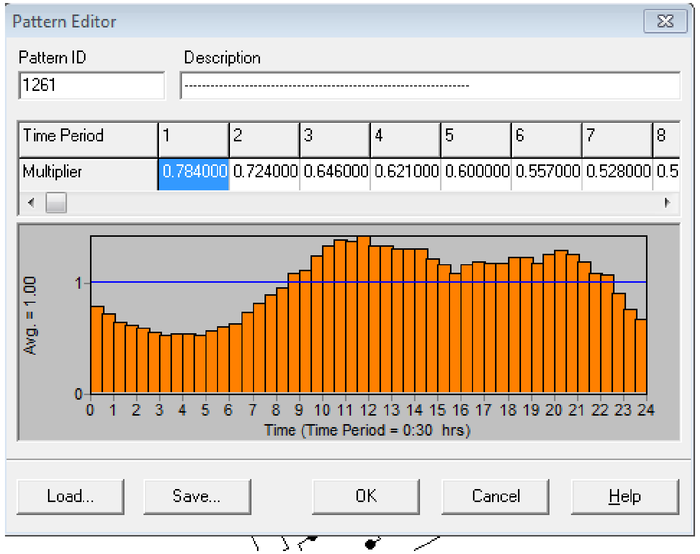
A pessimistic outlook!!

The networks are designed for the worst case scenario:
The busiest time of the day during the busiest day of the week of the less favorable month with the biggest population served (30 years out). It is assumed that if it is capable of functioning at the moment of greatest demand, it will do so without problems the rest of the time. The way to represent this mathematically is by multiplying the coefficients:

$$f_{\mathrm{Global}} = f_{\mathrm{Daily}} \times f_{\mathrm{Weekly}} \times f_{\mathrm{Monthly}} \times f_{\mathrm{Consumption\ not\ measured}}$$


Hydraulics Options

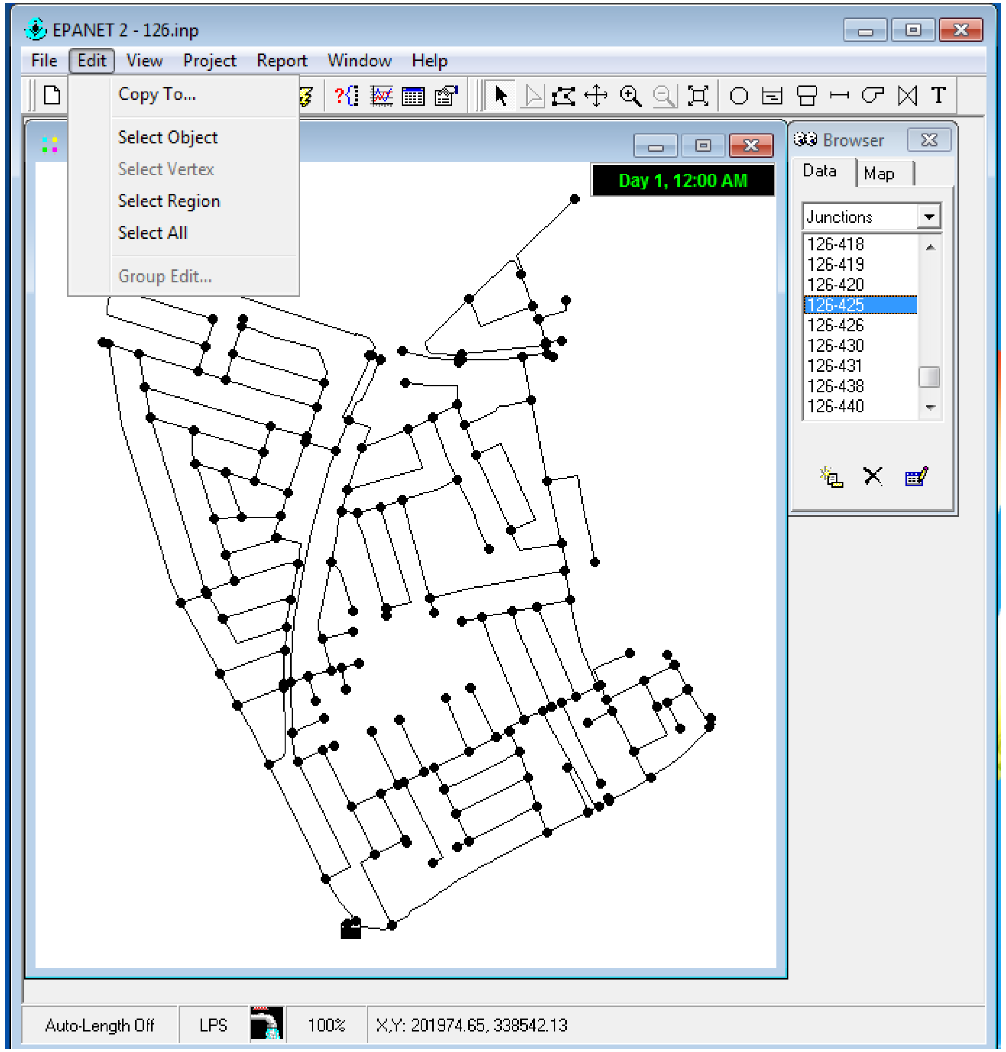
Property	Value
Flow Units	CMH
Headloss Formula	H-W
Specific Gravity	1.000000
Relative Viscosity	1.000000
Maximum Trials	50
Accuracy	0.01000000
If Unbalanced	Continue
Default Pattern	1
Demand Multiplier	1.0000
Emitter Exponent	0.5000
Status Report	Full
CHECKFREQ	2
MAXCHECK	10
DAMPLIMIT	0.00000000



A4_EPANET MENU

Edit Menu

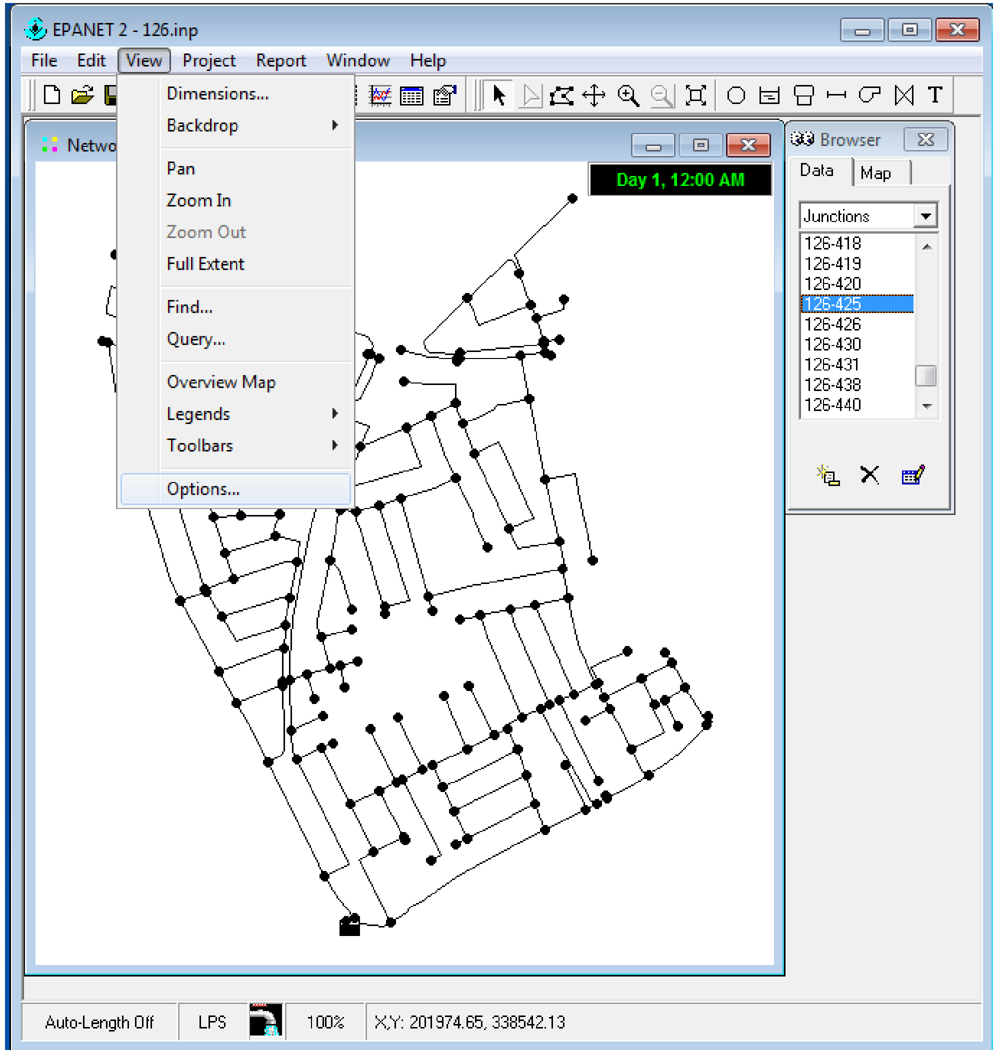
- Copy in memory
- Select network elements



View Menu

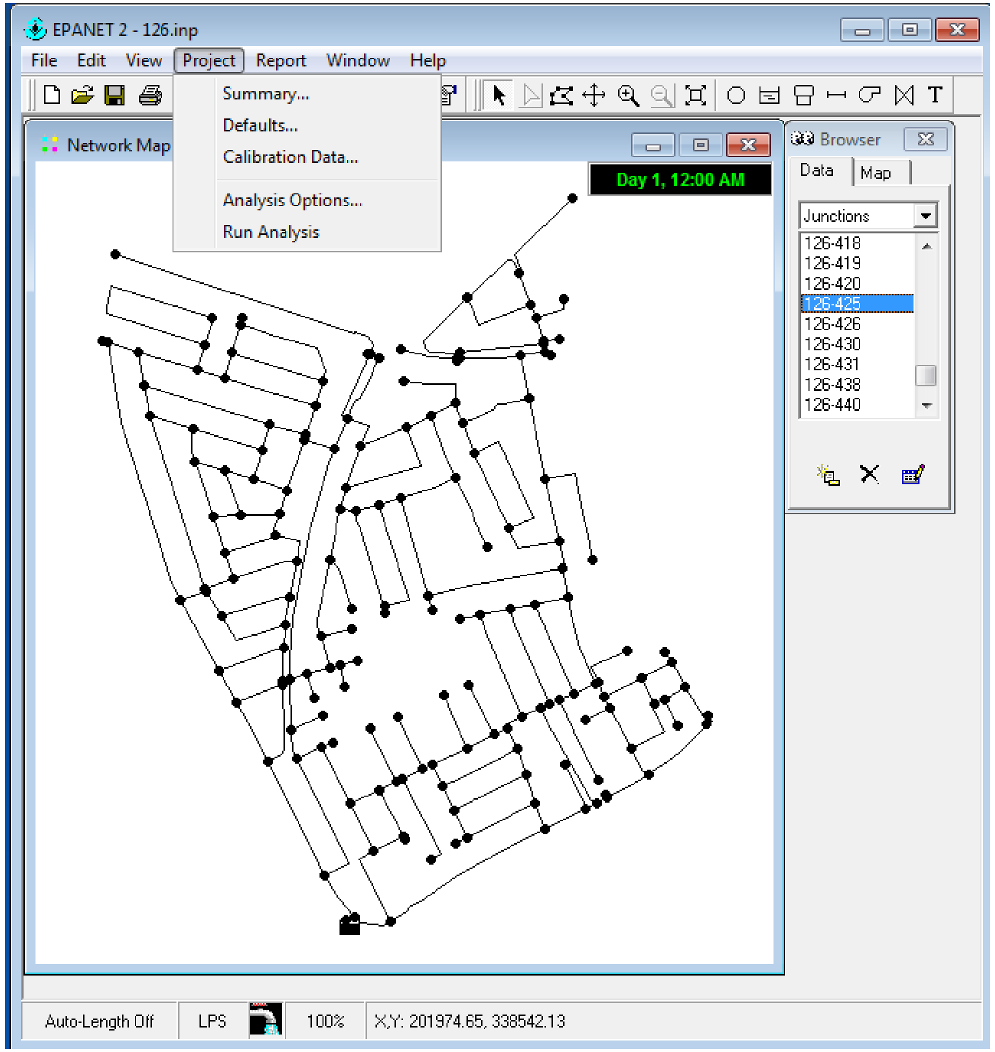
- Set map coordinates
- Add background image

  [e.g. map]
- Search network elements
- EPANET options



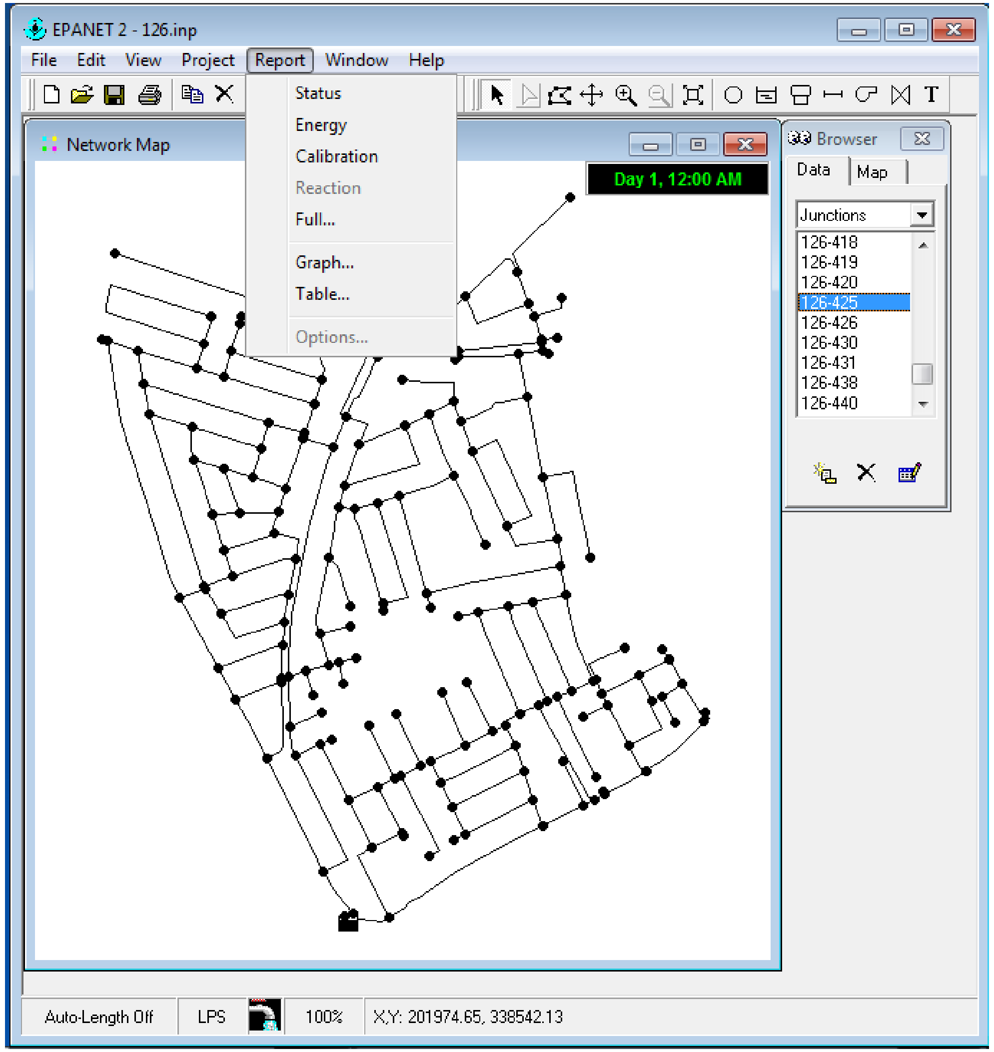
Project Menu

- Run simulation
- Specify default options
- Network summary
- Calibration tool



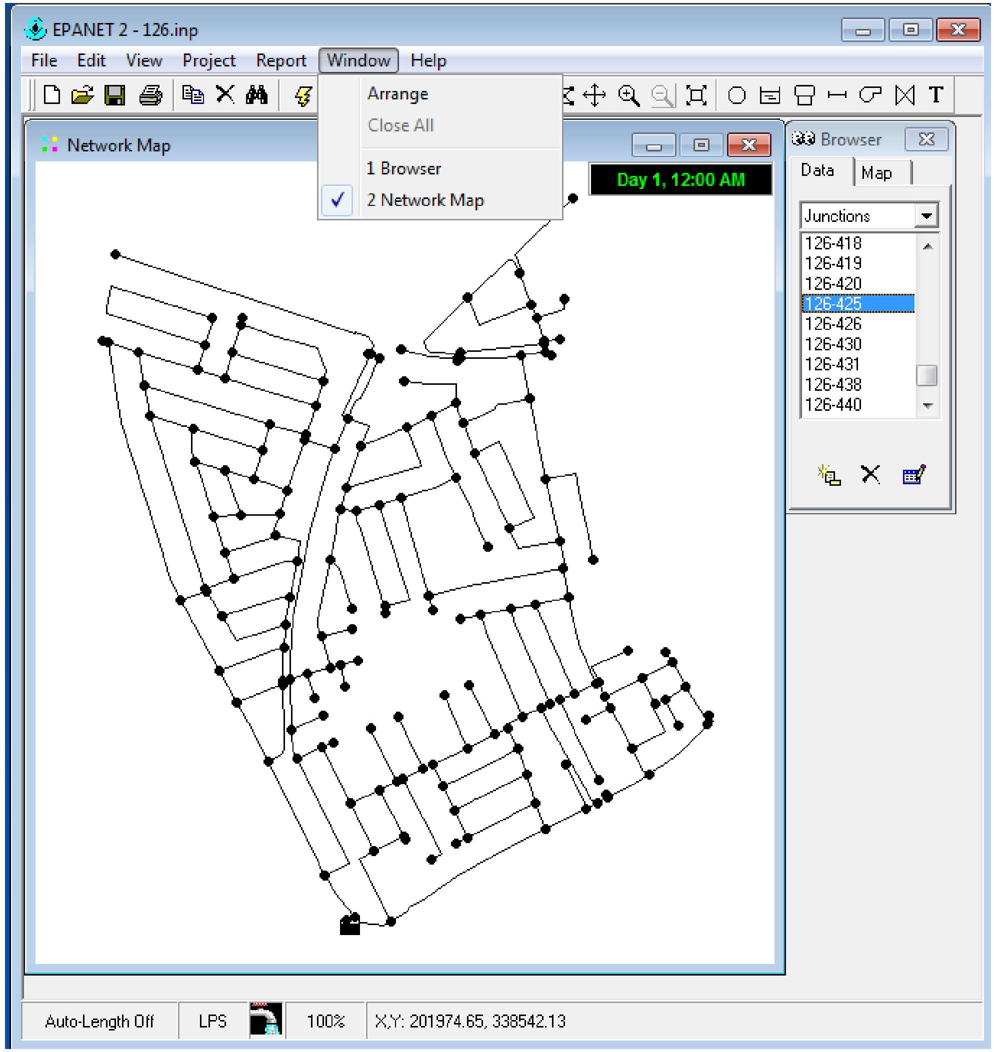
Report Menu

- Simulation results analysis
- Table of results
- Graphs
- Export results in files



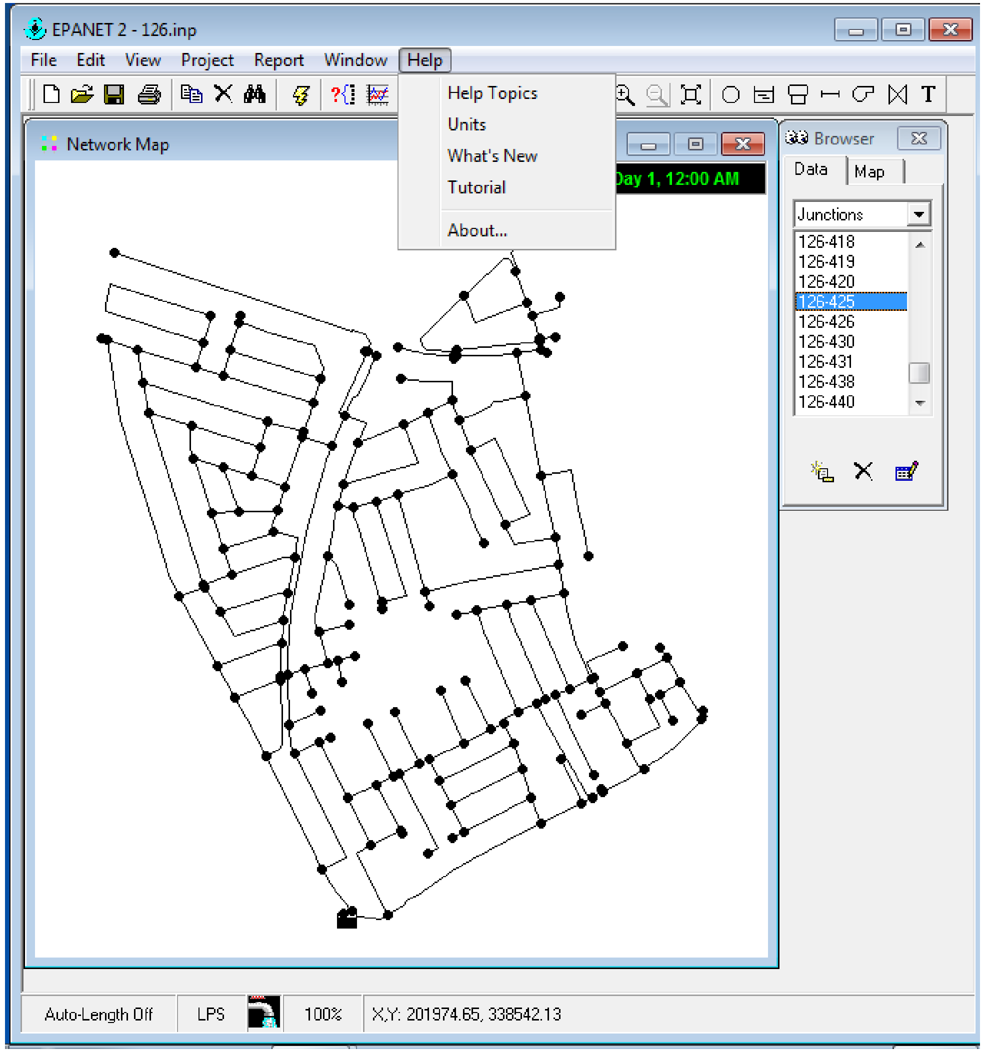
Window Menu

- Arrange Windows



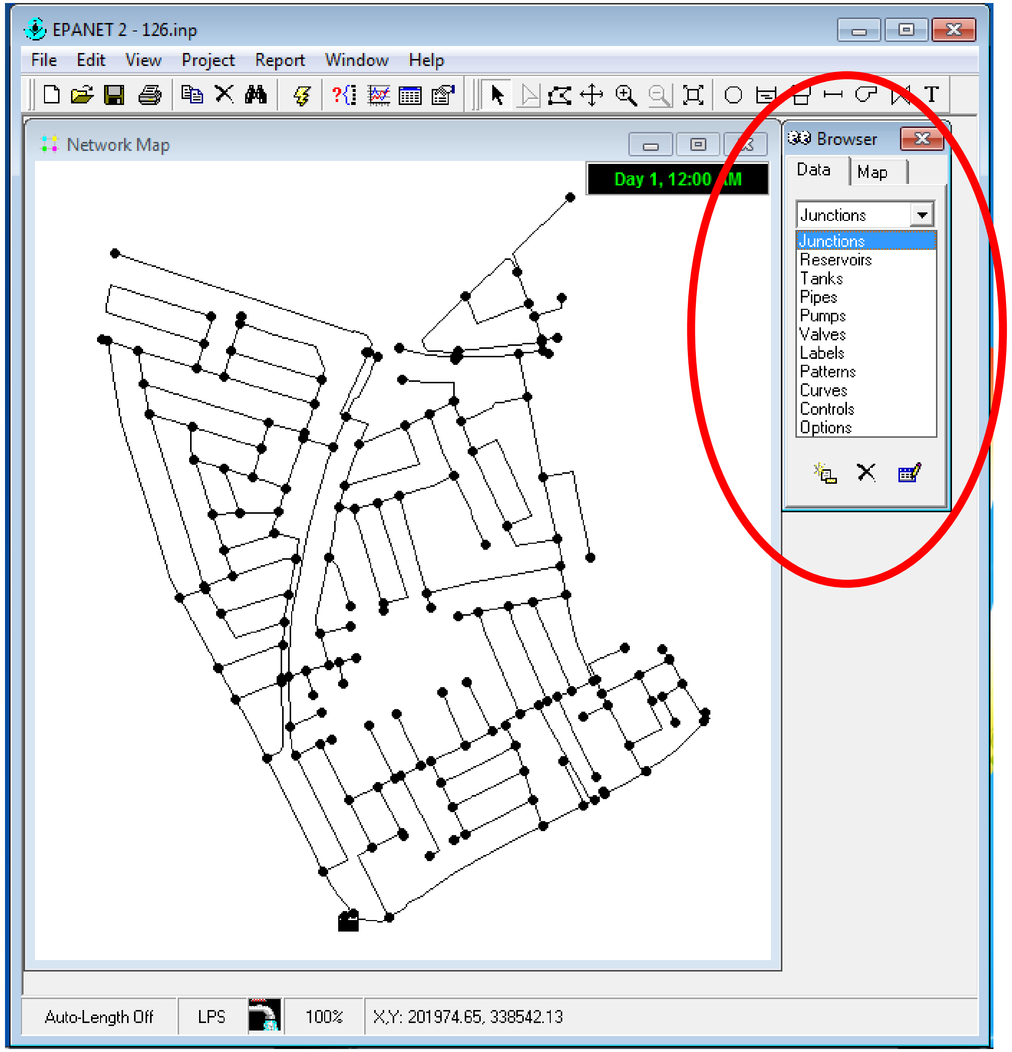
Help Menu

- Tutorials
- Help topics



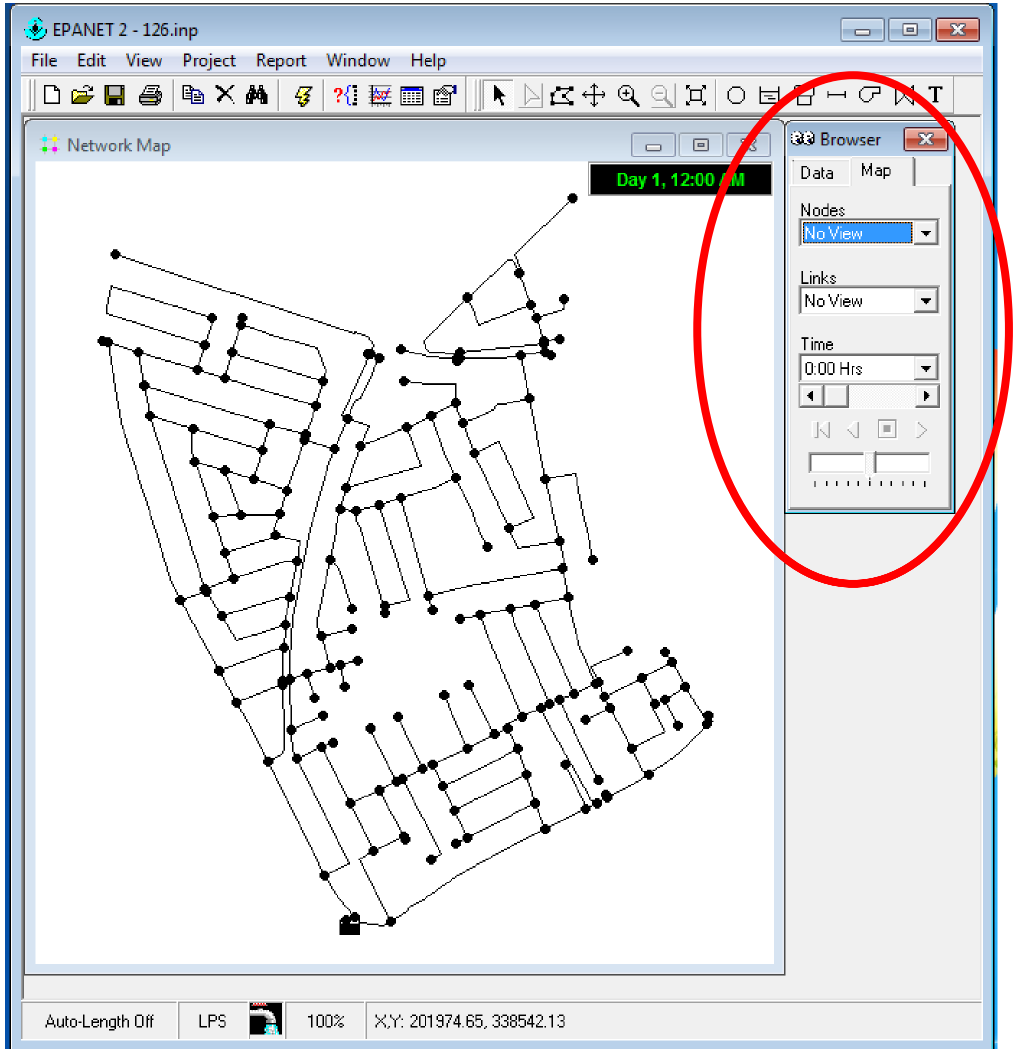
Data Browser

- Details of all the features
- Junctions
- Reservoirs
- Tanks
- Valves
- Patterns
- Curves
- Controls
- Options



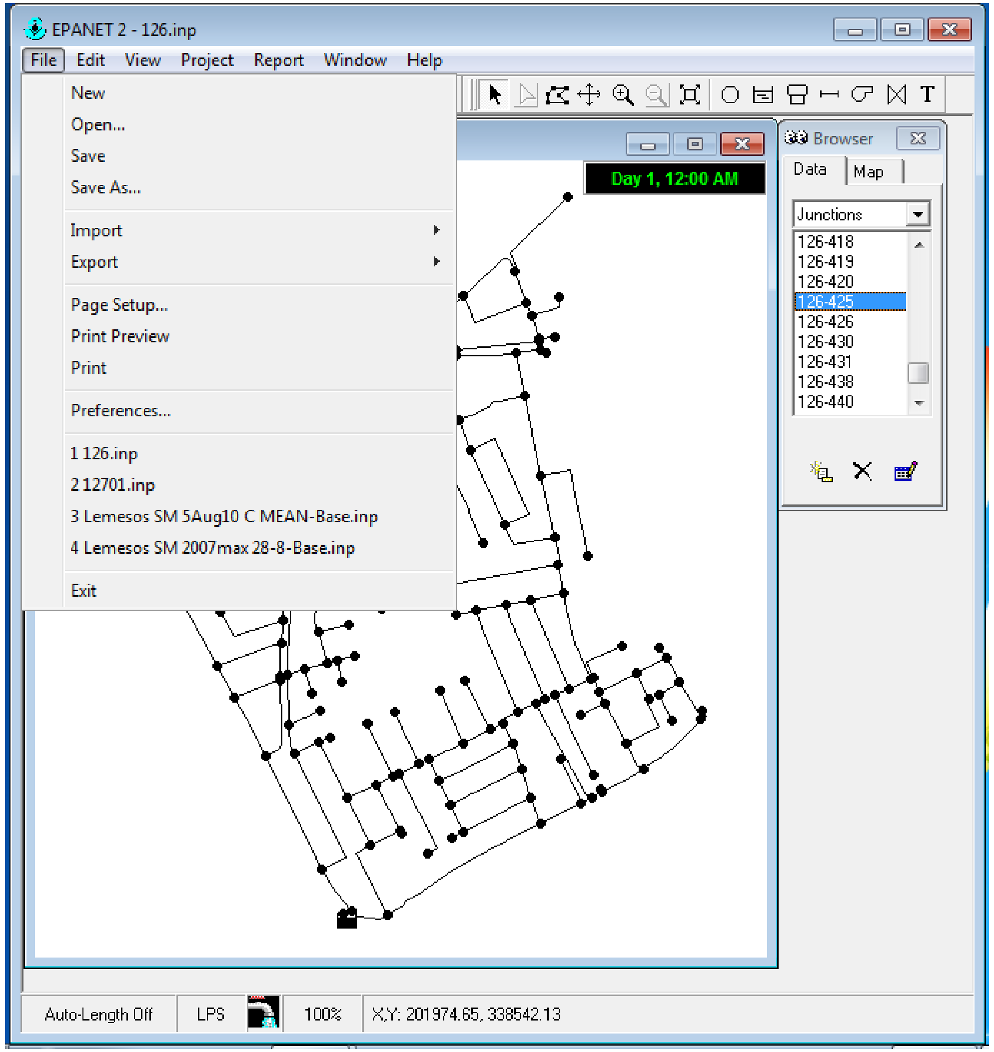
Map Browser

- What to view on the map [e.g. flows, velocities, elevations, pressures, heads]
- Play a time-lapse of the simulation



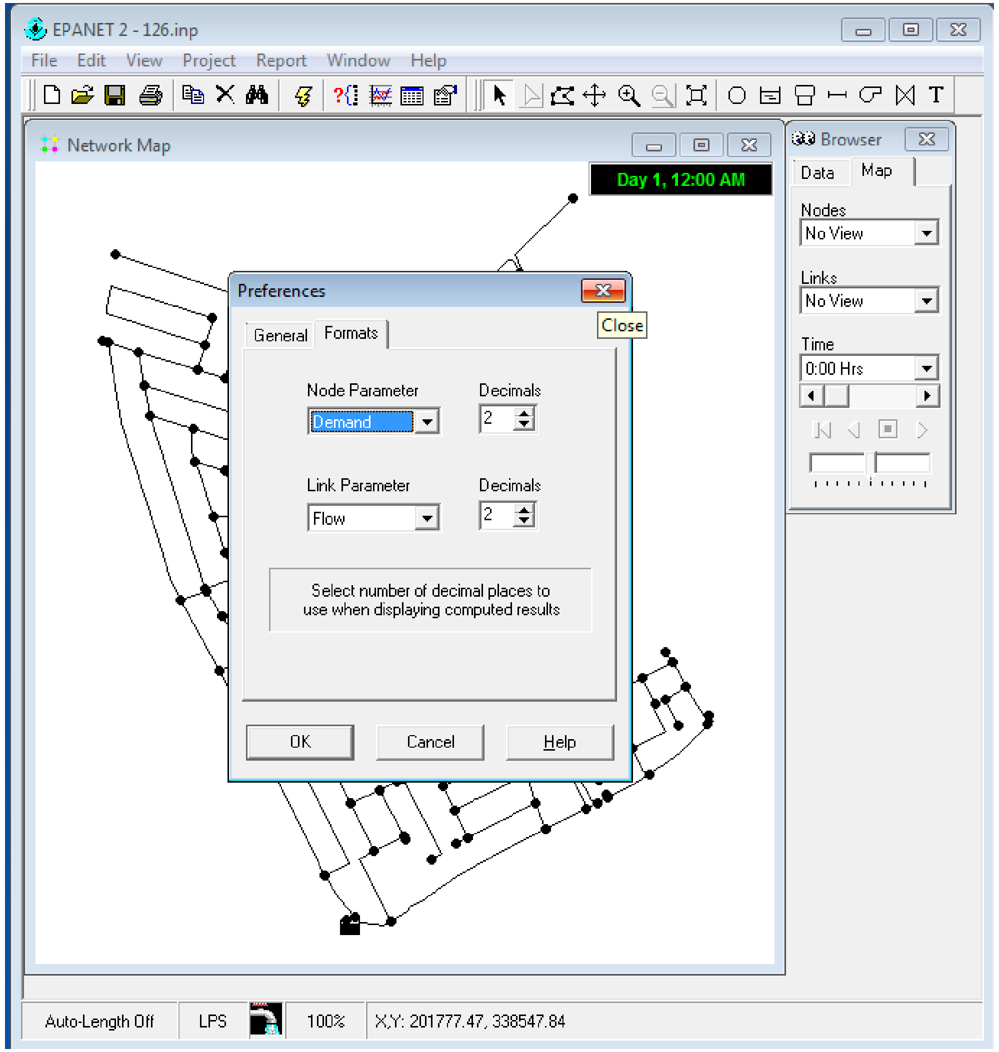
Preferences

- Specify system preferences



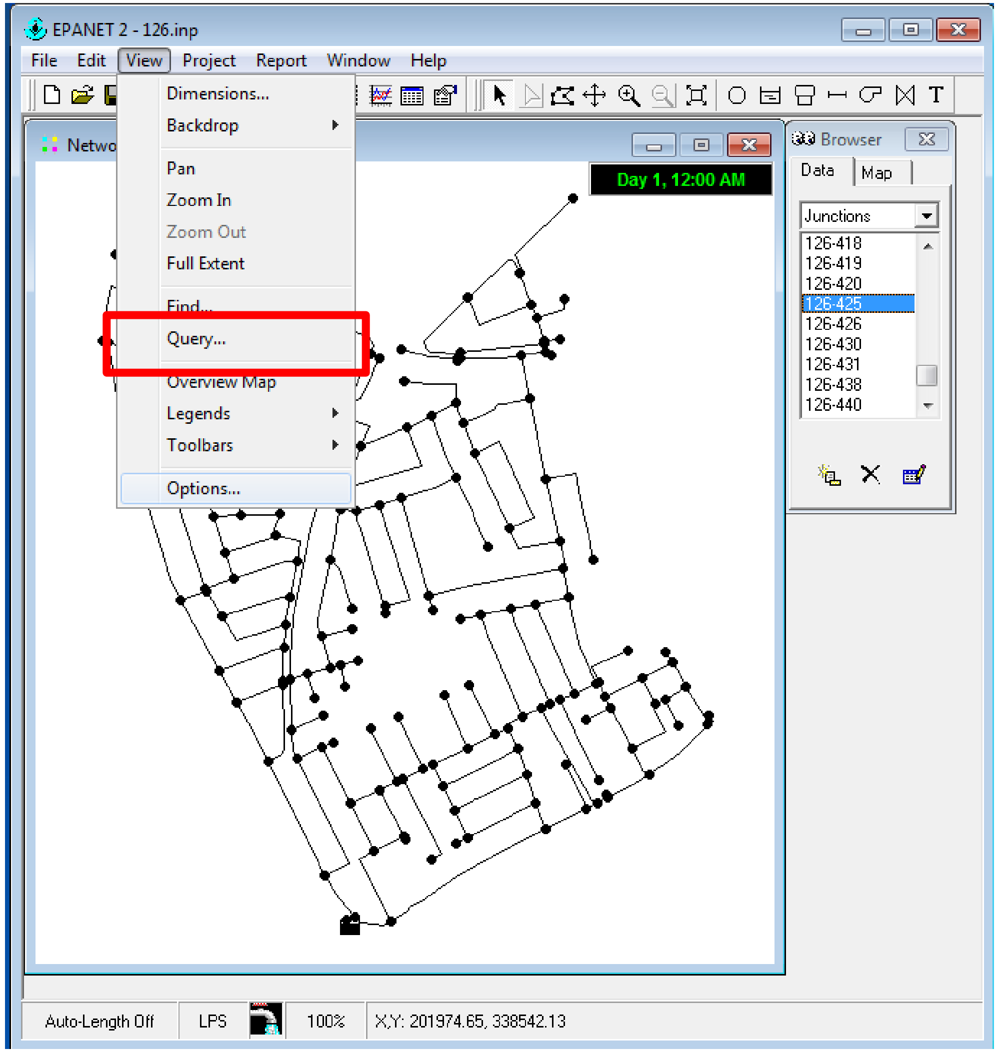
Preferences (cont.)

- General description
- Decimals



Query

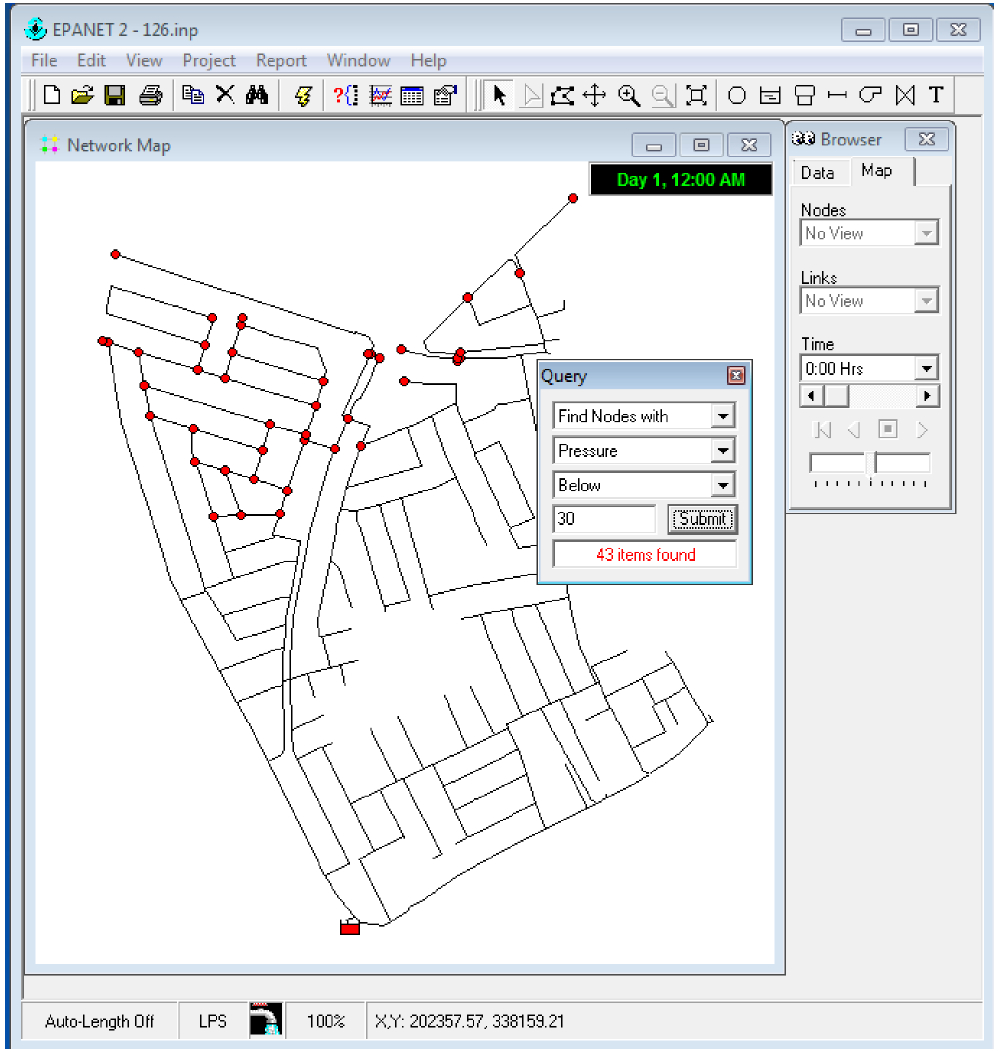
- Query network components



Query (cont.)

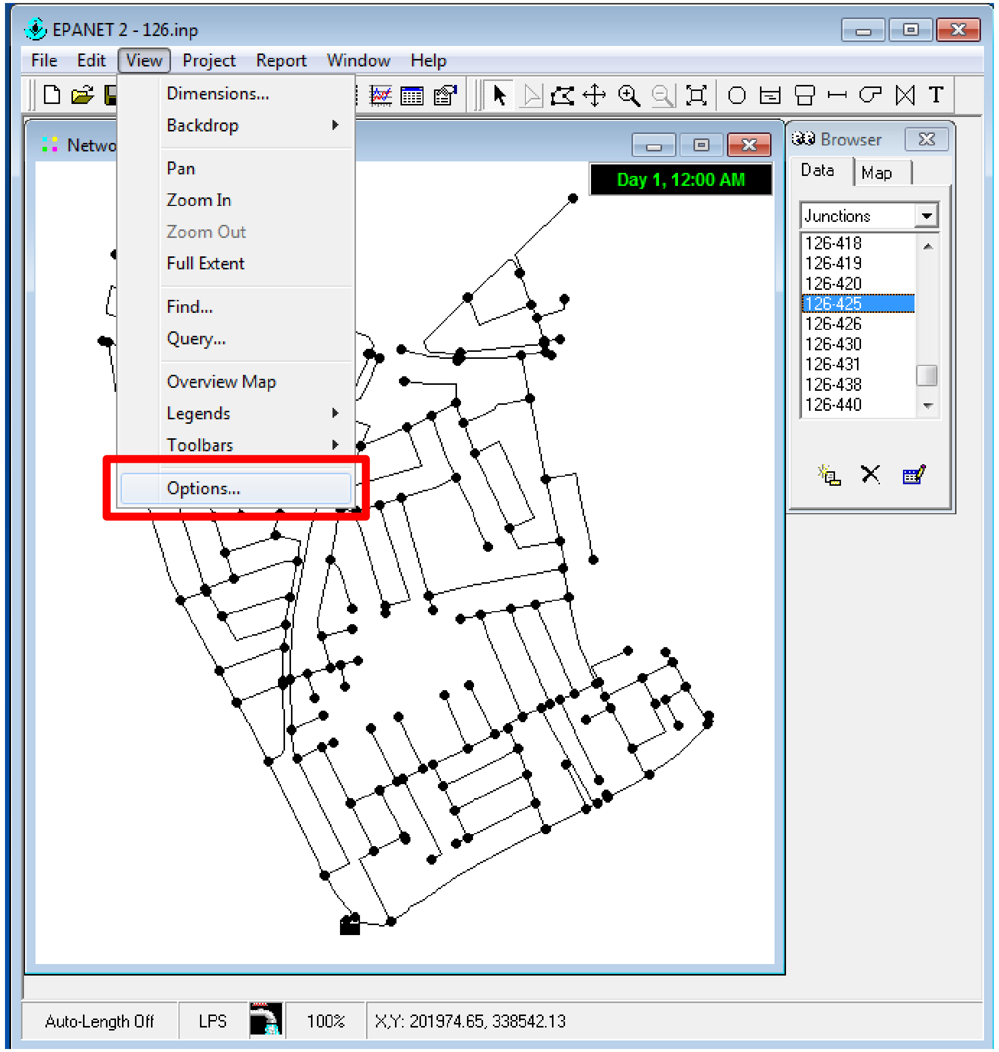
- Case Study:

  Find all nodes with pressure below 30 meters.



Options

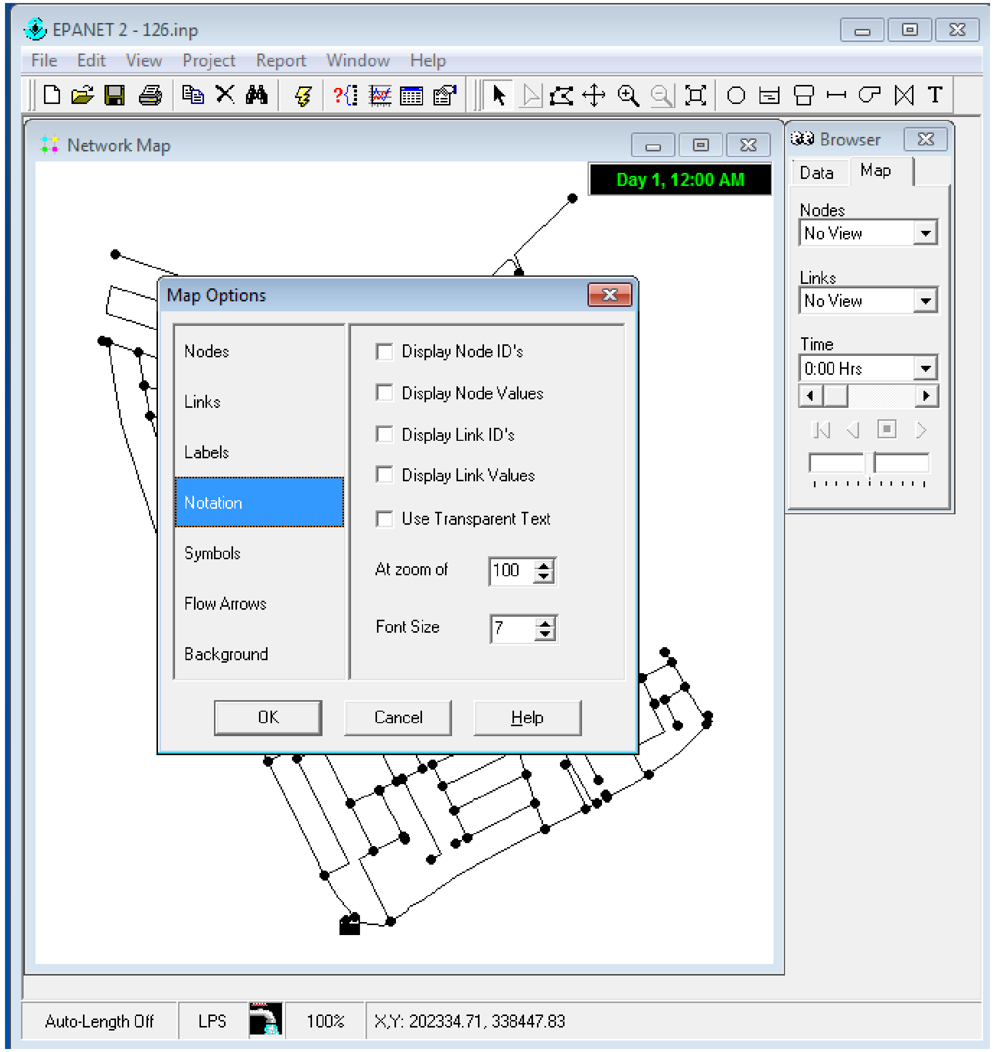
- Open Options menu



Options (cont.)

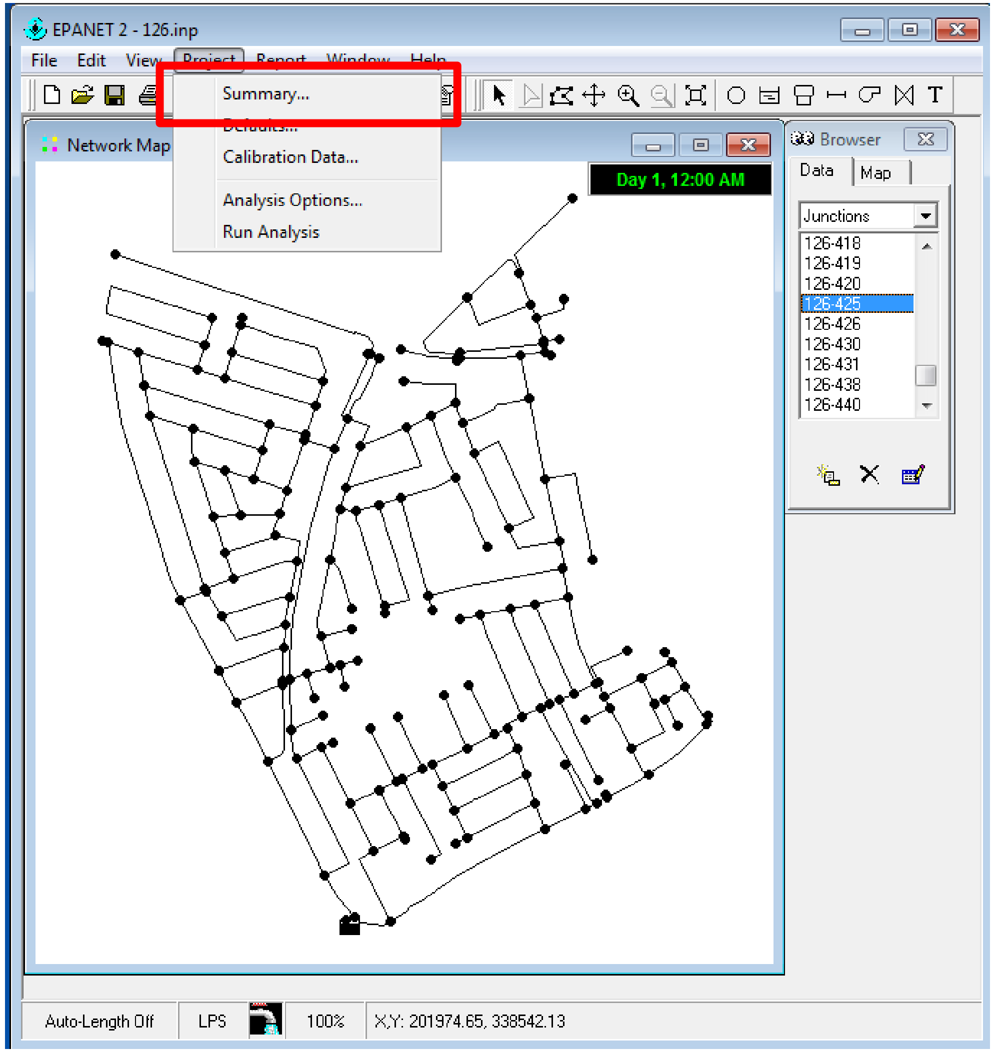
- Specify the style of the elements you view
- See node / link values

  [based on Map Browser]
- Flows arrows
- Size of node / links relative to size



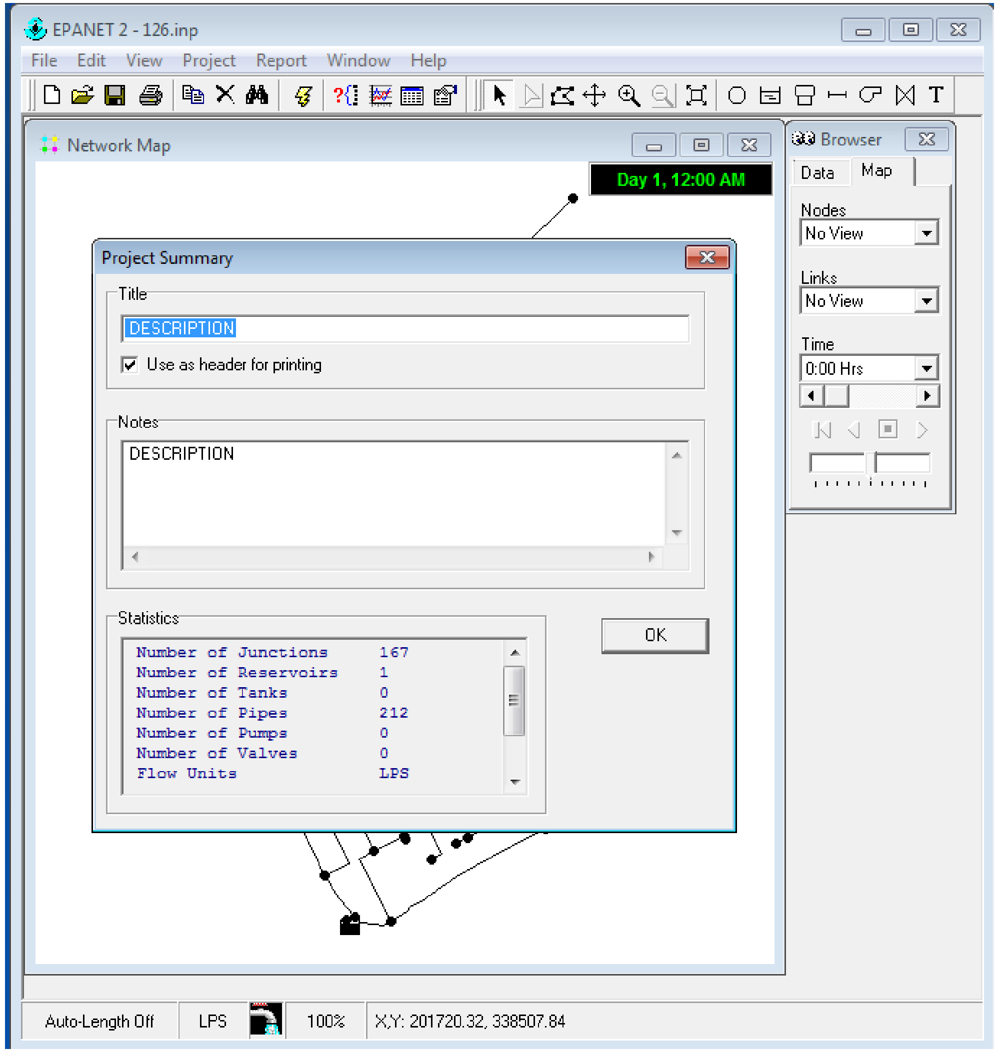
Summary

- Print network summary



Summary (cont.)

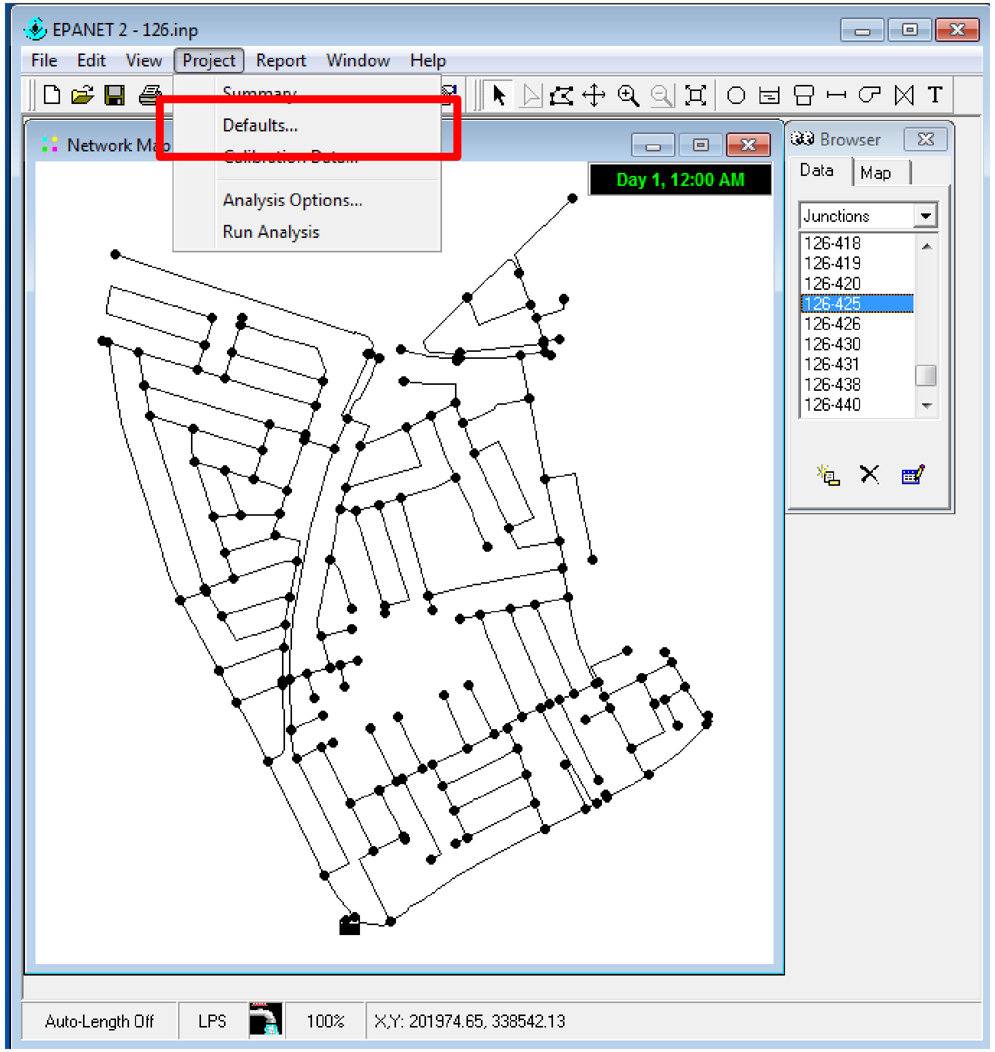
- Print network summary



A5_EPANET NETWORK ANALYSIS

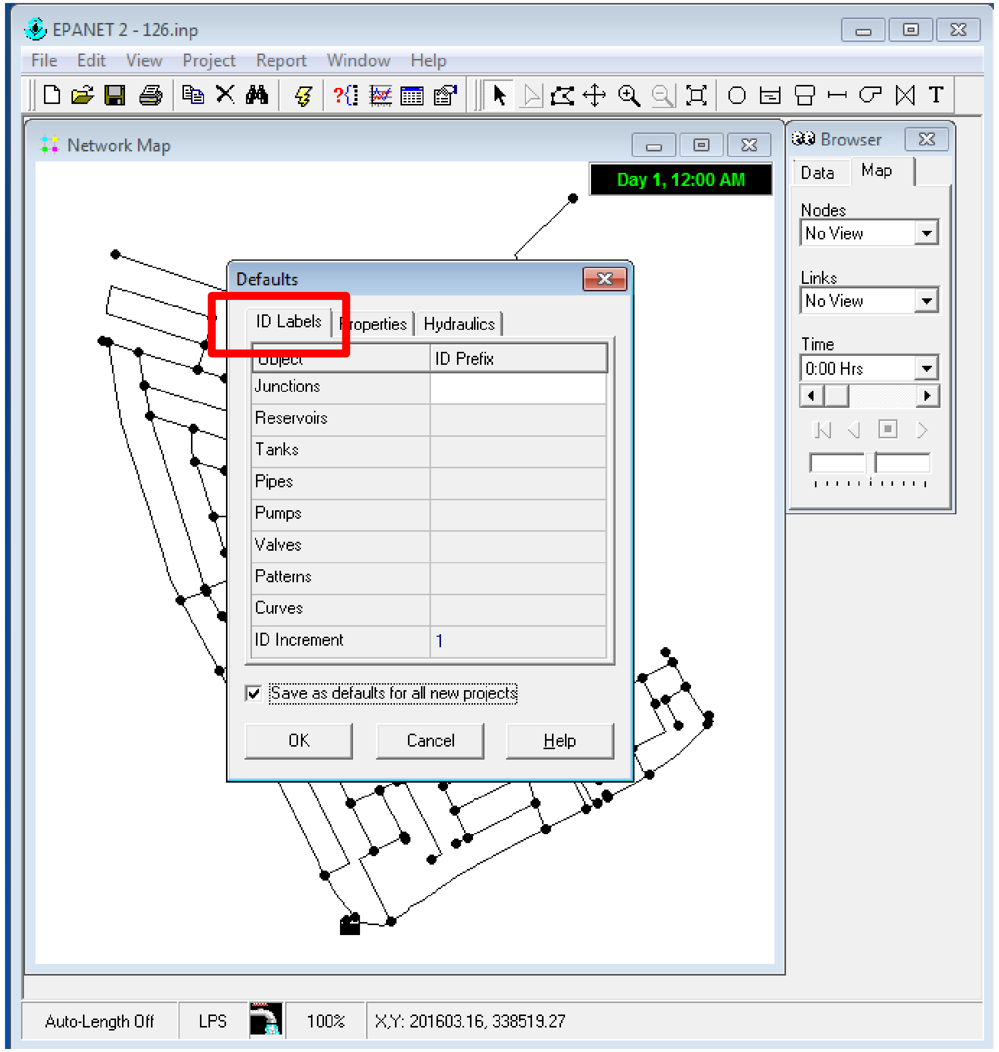
Defaults

- Set the defaults



Defaults (cont.)

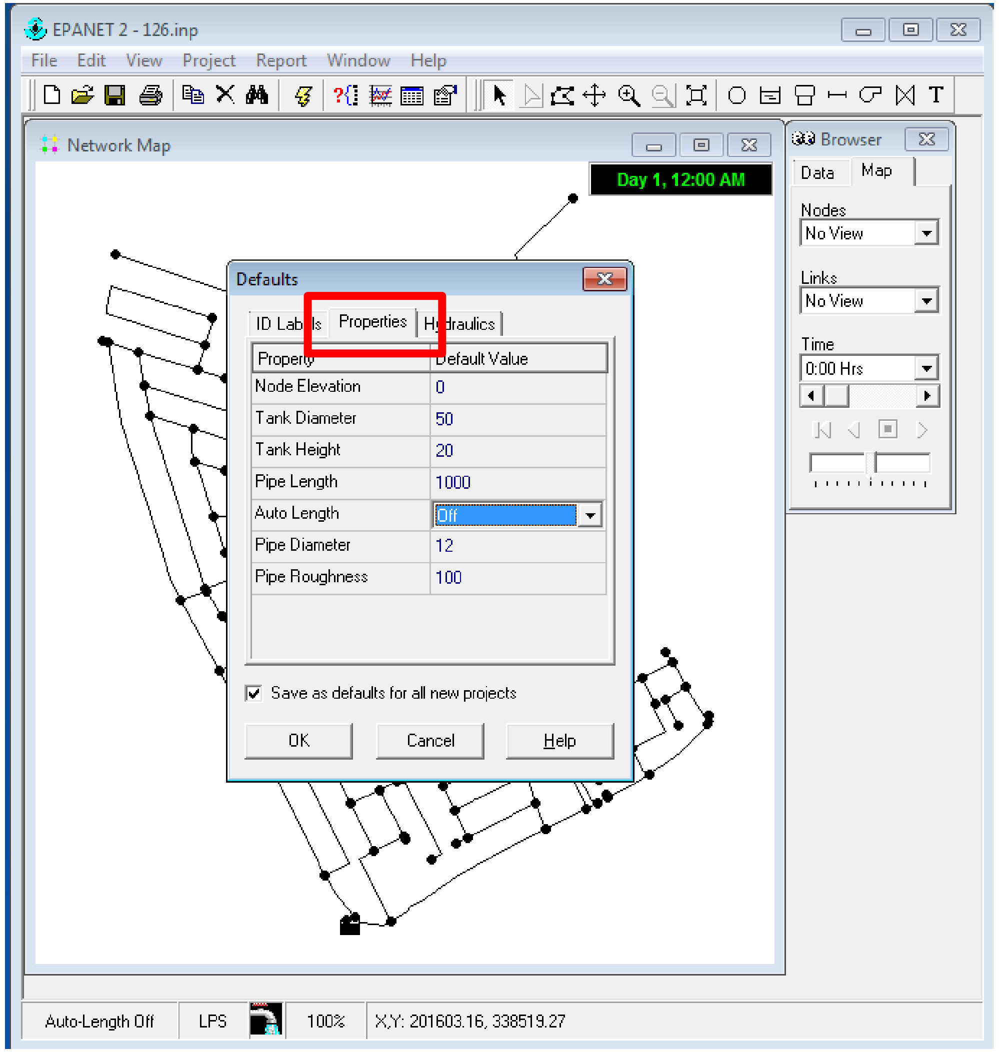
- Set the defaults



Defaults (cont.)

- Set default values
- Auto length

[ON]



Defaults (cont.)

- Litres per second (LPS)

  Flow: liters/second

  Pressure: column meters of water

  Diameter: millimeters

  Length: meters

  Elevation: meters

  Dimensions: meters

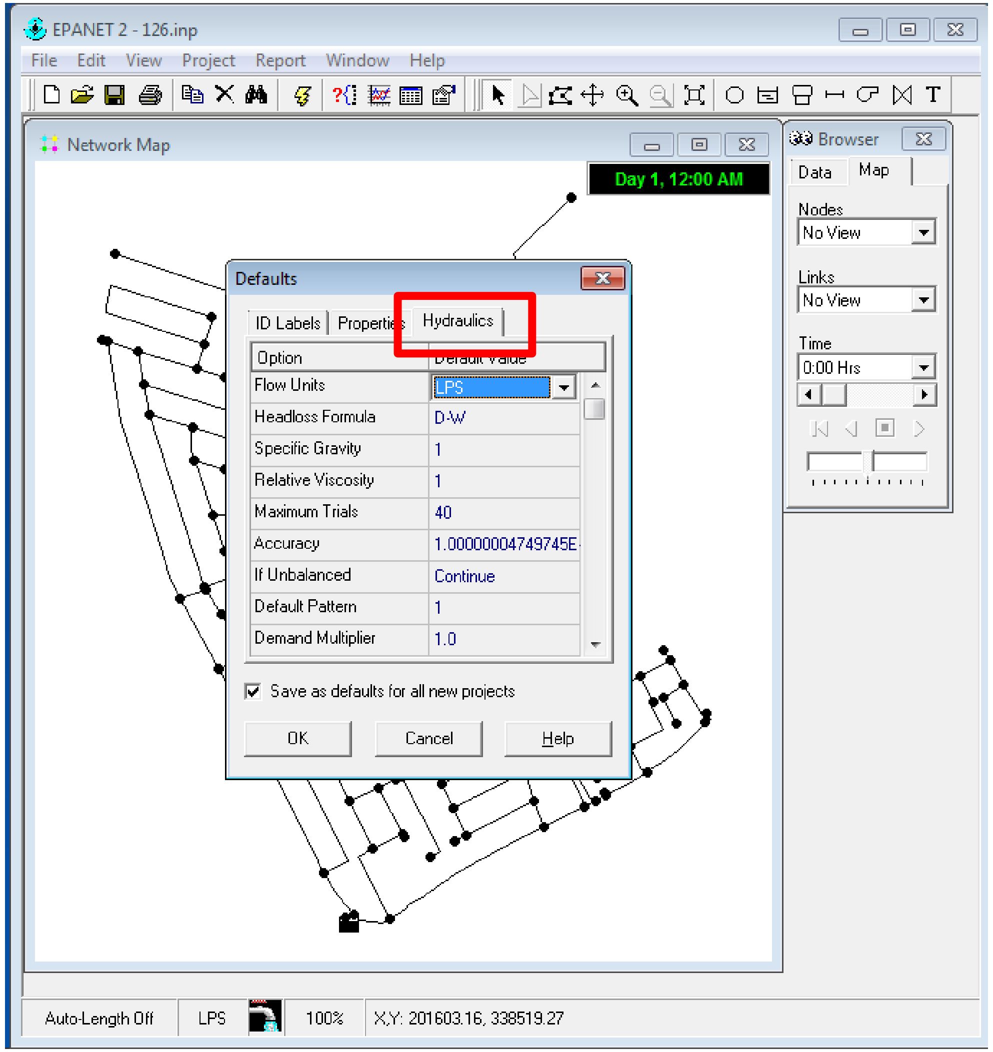
- Headloss Formula

  D-W

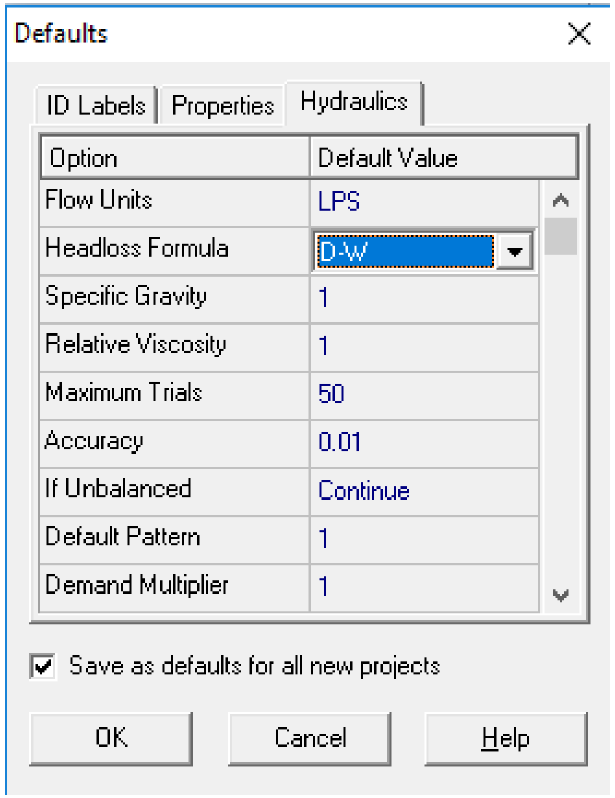
  H-W

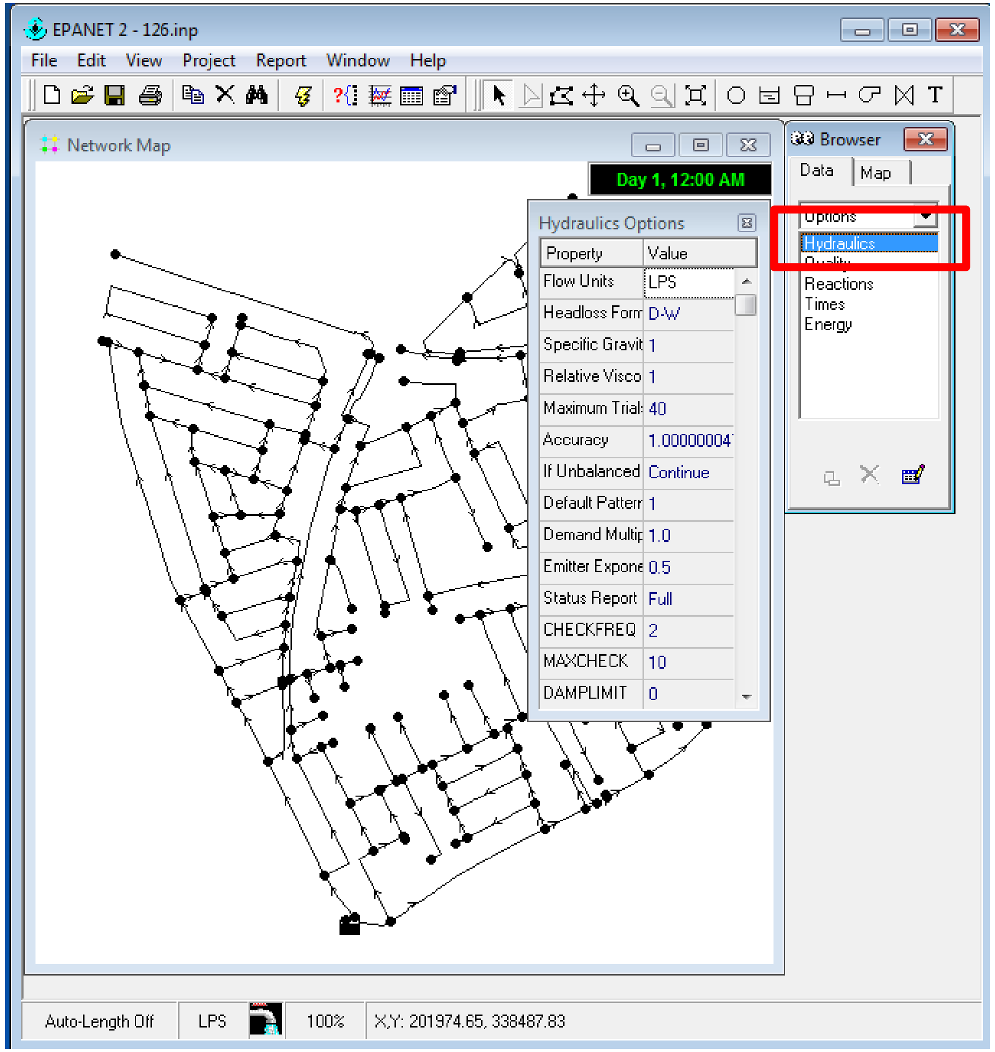
  C-M

- Increase maximum trials or increase accuracy if problem in convergence



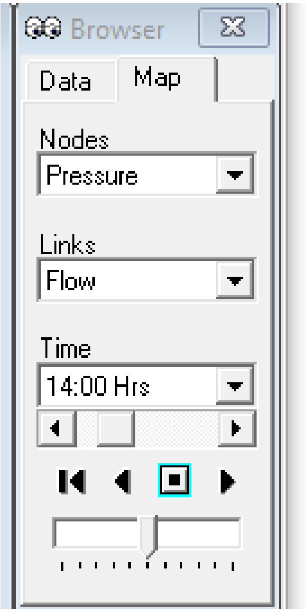
Hydraulics

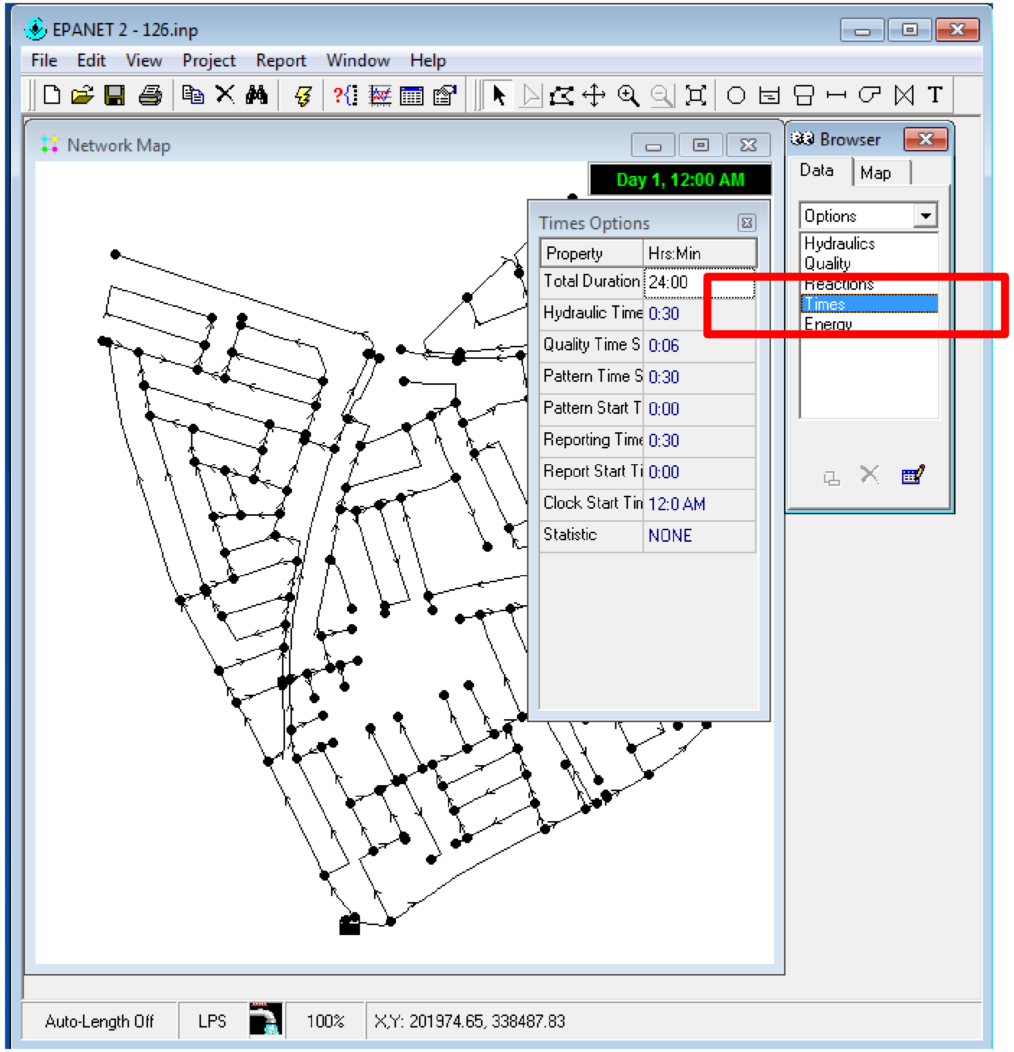

Defaults
ID Labels
Properties
Hydraulics
Option
Default Value
Flow Units
LPS
Headloss Formula
D-W
Specific Gravity
1
Relative Viscosity
1
Maximum Trials
50
Accuracy
0.01
If Unbalanced
Continue
Default Pattern
1
Demand Multiplier
1
Save as defaults for all new projects
OK
Cancel
Help


EPANET 2 - 126.inp
File Edit View Project Report Window Help
Network Map
Day 1, 12:00 AM
Hydraulics Options
Property
Value
Flow Units
LPS
Headloss Form
D-W
Specific Gravit
1
Relative Visco
1
Maximum Trial:
40
Accuracy
1.00000004
If Unbalanced
Continue
Default Patterr
1
Demand Multip
1.0
Emitter Expone
0.5
Status Report
Full
CHECKFREQ
2
MAXCHECK
10
DAMPLIMIT
0
Browser
Data
Map
Options
Hydraulics
Reactions
Times
Energy
Auto-Length Off
LPS
100%
X,Y: 201974.65, 338487.83

Times

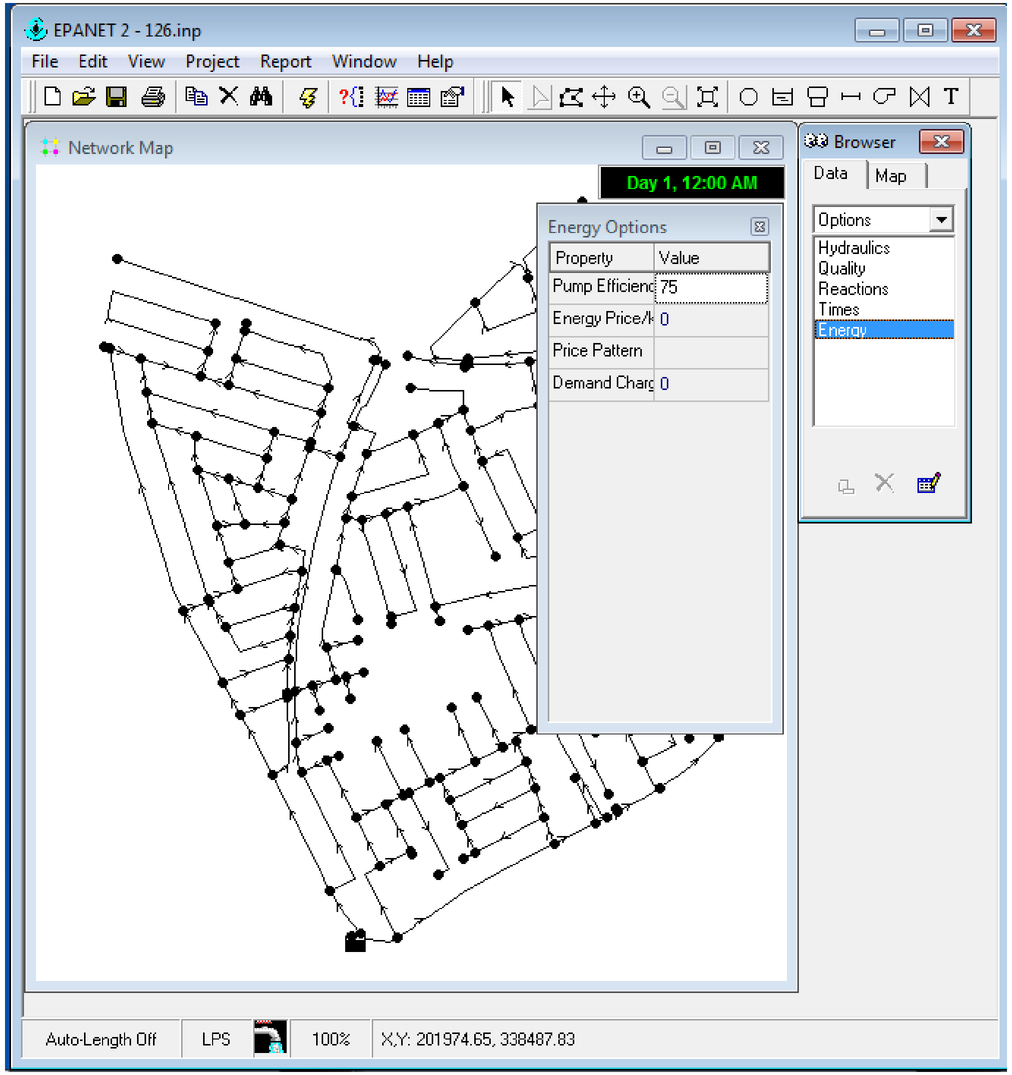
- Times Attributes
- Simulation time
- Hydraulic step
- Quality step
- Pattern step





Energy

- Energy Attributes
- Efficiency
- Cost
- Price pattern



Quality - Reactions

- Numerical method to simulate how substances propagate and react (decay/grow) in the network
    - Chlorine
    - Water age
    - Trihalomethanes (THMs)

- Reactions occur within the bulk water and at the pipe walls

Quality Options

Property	Value
Parameter	Chlorine
Mass Units	mg/L
Relative Diffusivity	1.0
Trace Node	
Quality Tolerance	0.01

Options

Hydraulics
Quality
Reactions
Times
Energy

Reactions Options

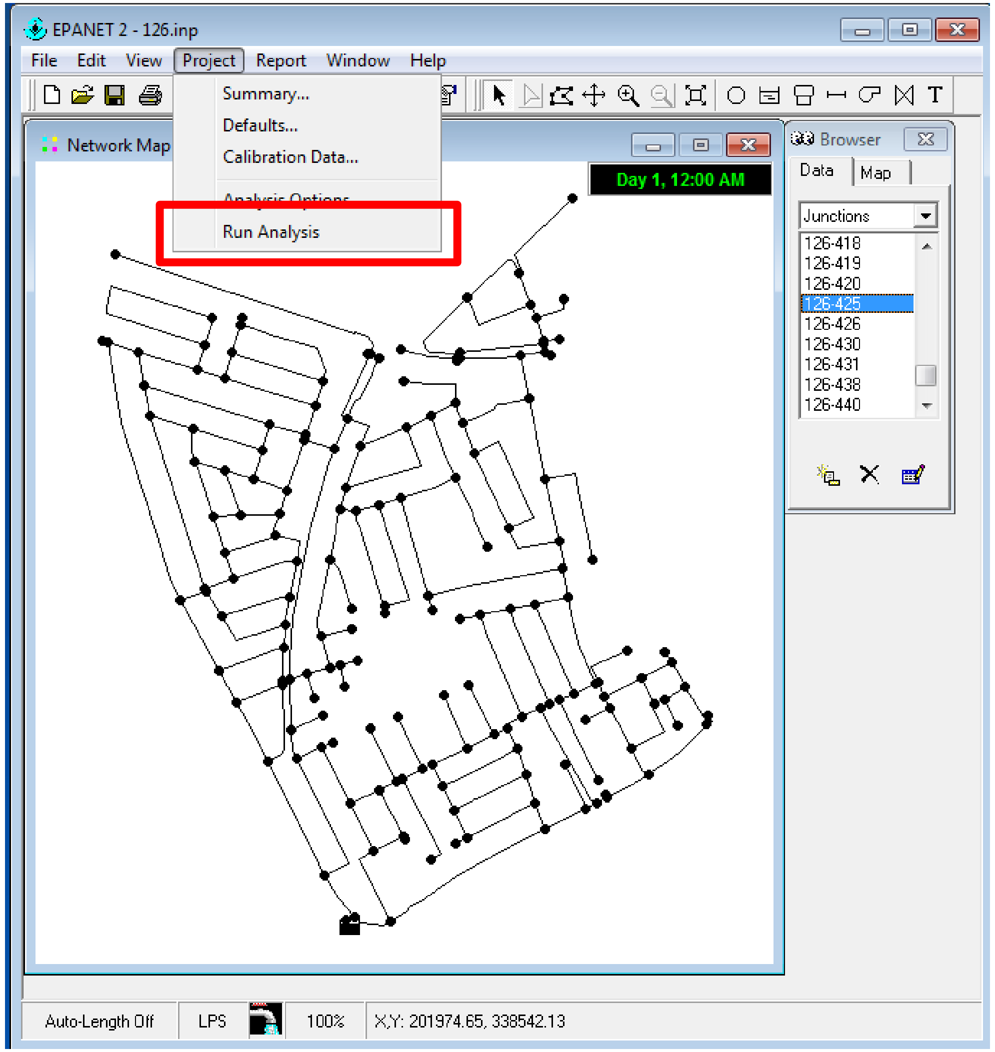
Property	Value
Bulk Reaction Order	1
Wall Reaction Order	First
Global Bulk Coeff.	-.5
Global Wall Coeff.	-1
Limiting Concentration	0.0
Wall Coeff. Correlation	0.0

Options

Hydraulics
Quality
Reactions
Times
Energy

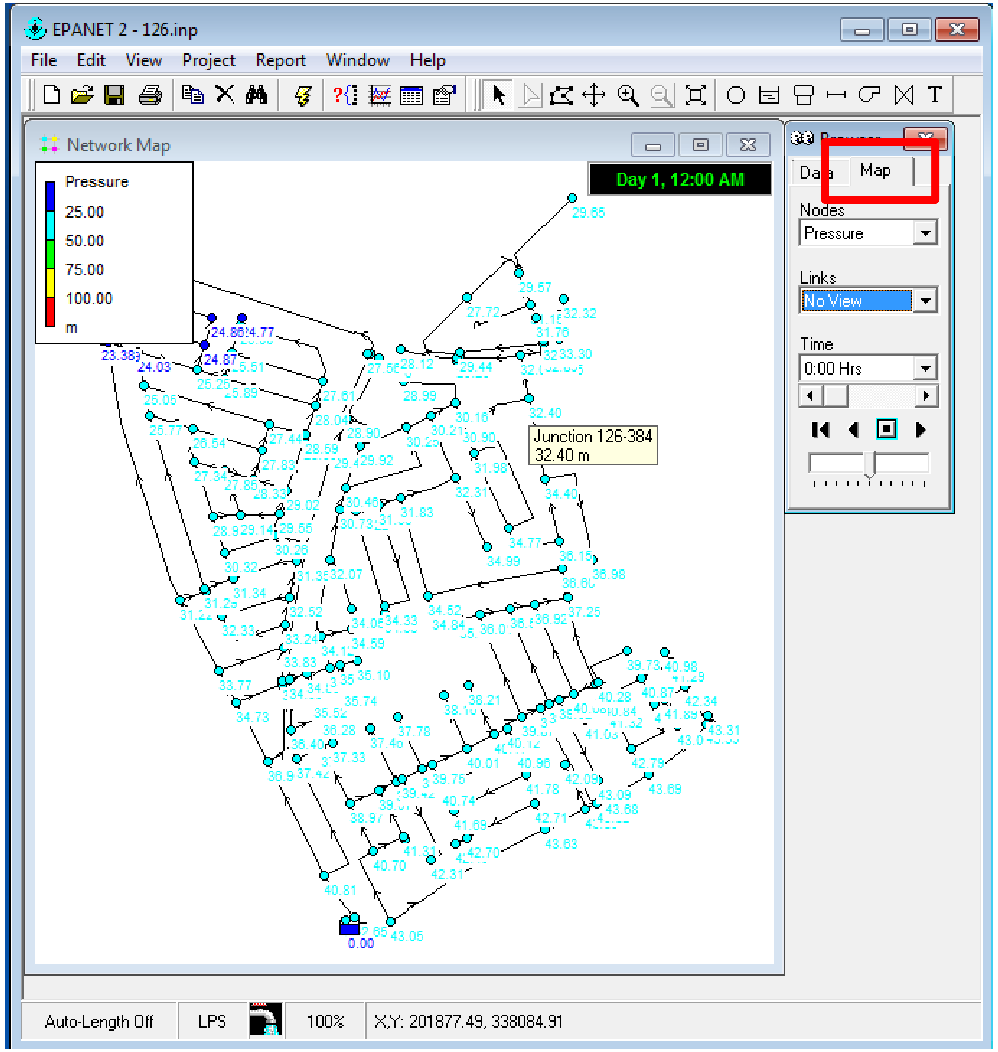
Run Analysis

- Run simulation



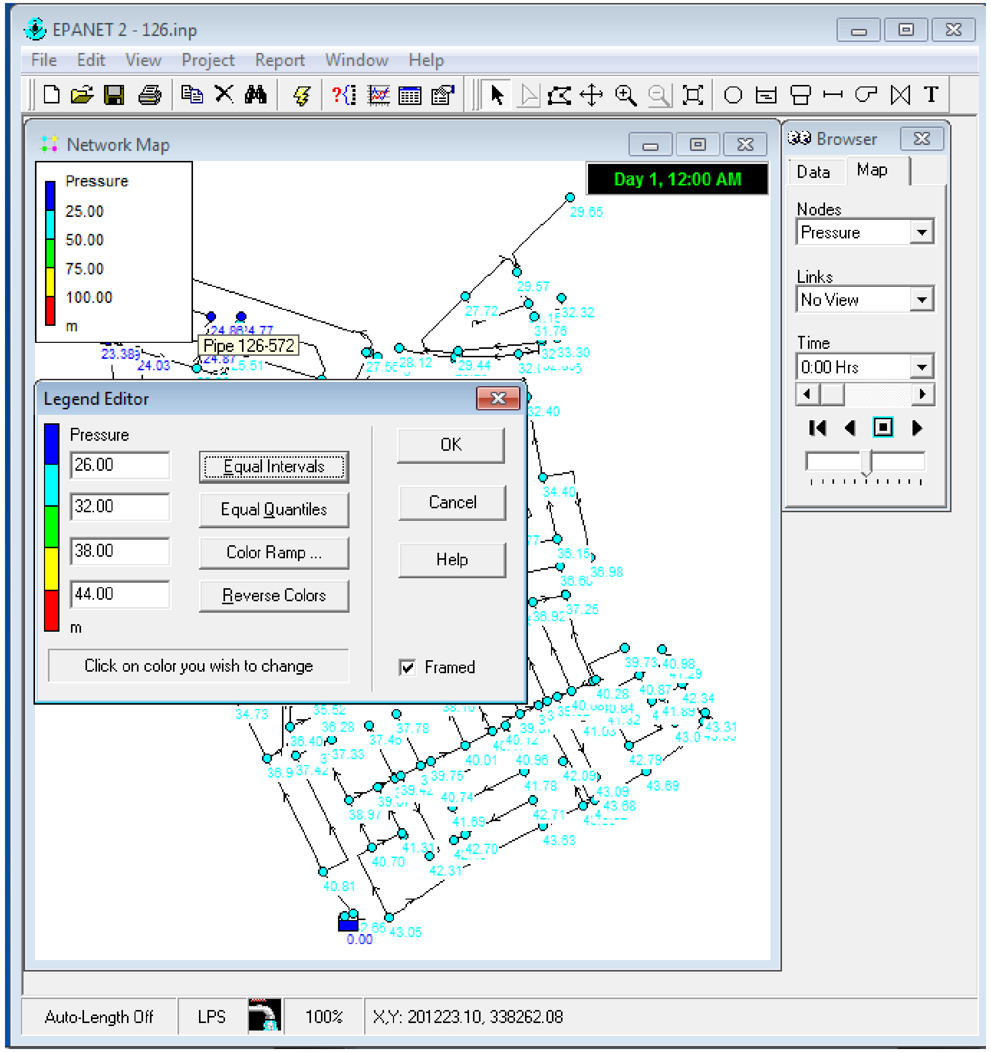
Run Analysis (cont.)

- Legend with automatic colors
- View results by hovering at a node / link



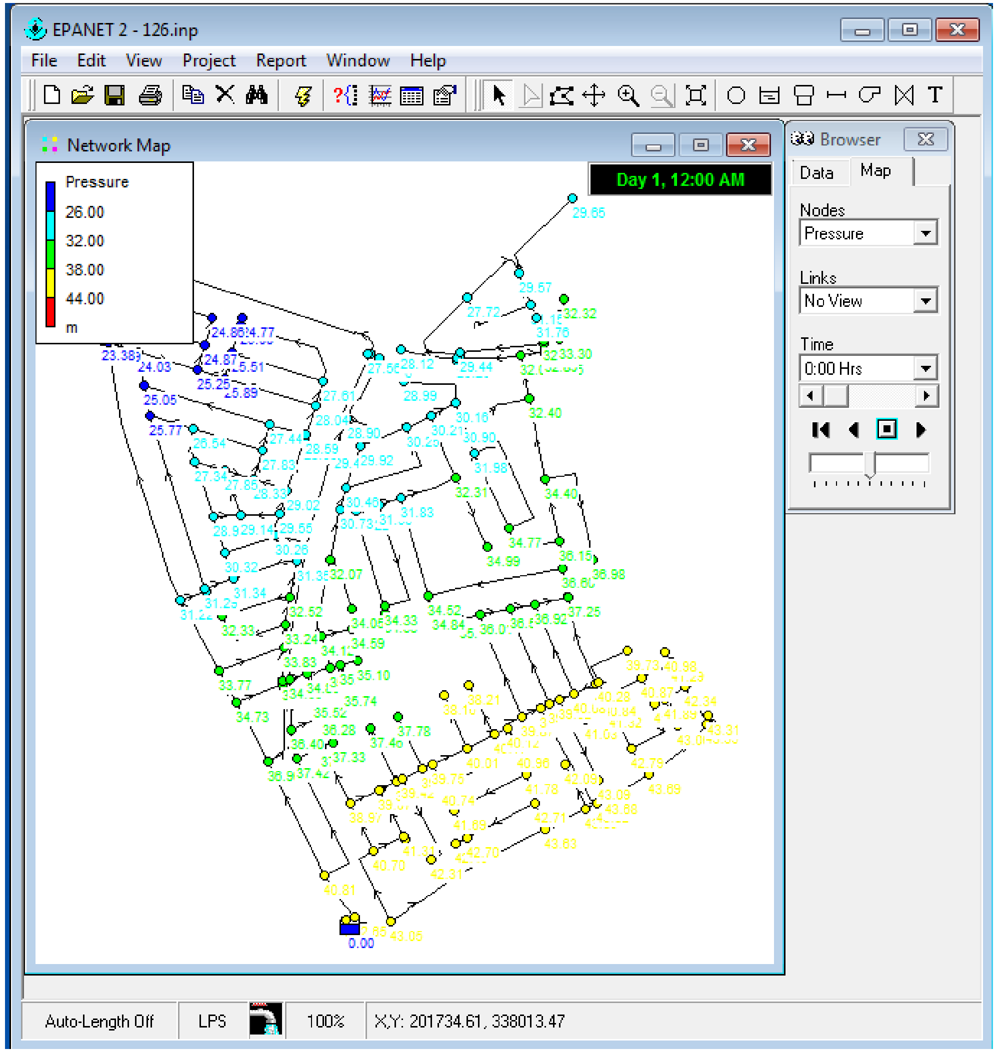
Run Analysis (cont.)

- Change legend colors



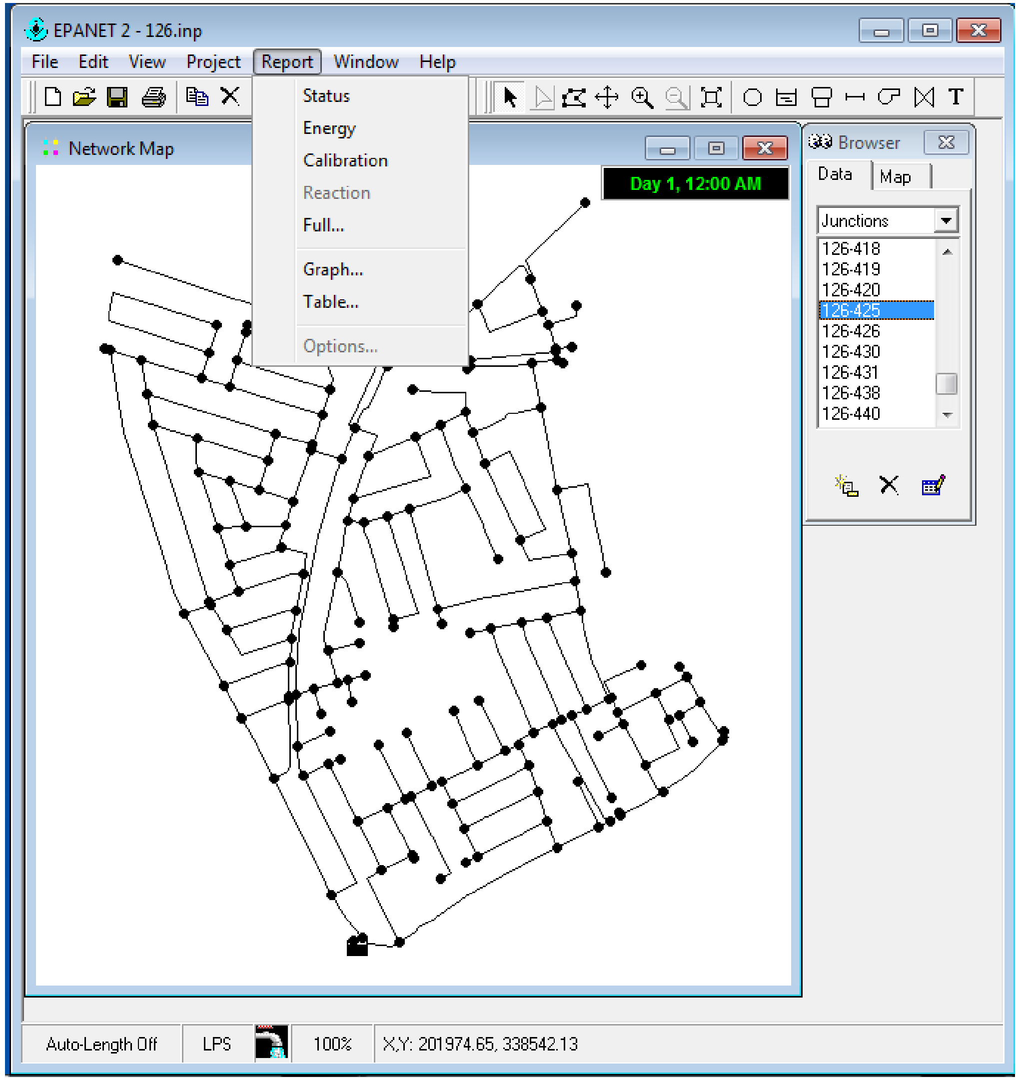
Run Analysis (cont.)

- Updated legend colors



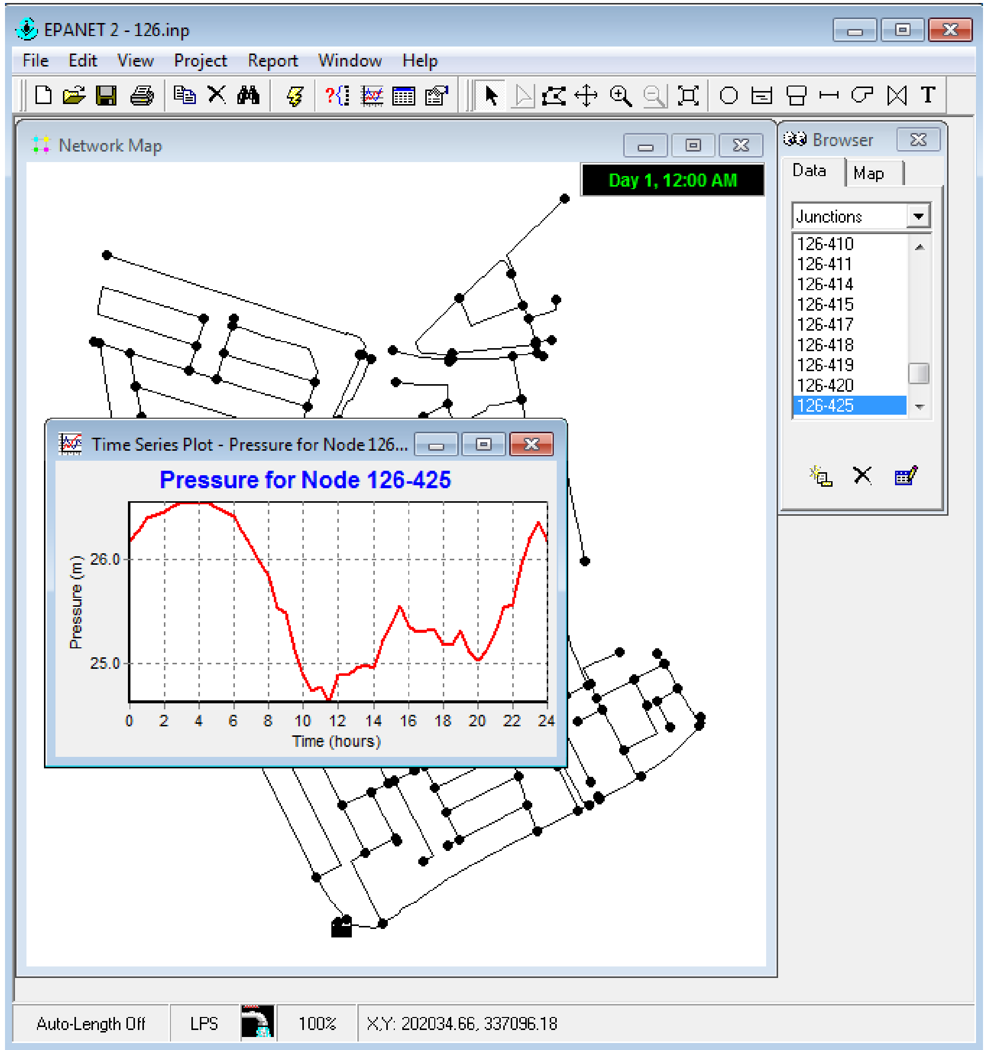
Results

- Simulation results
- Table of results
- Graphs
- Export results in files



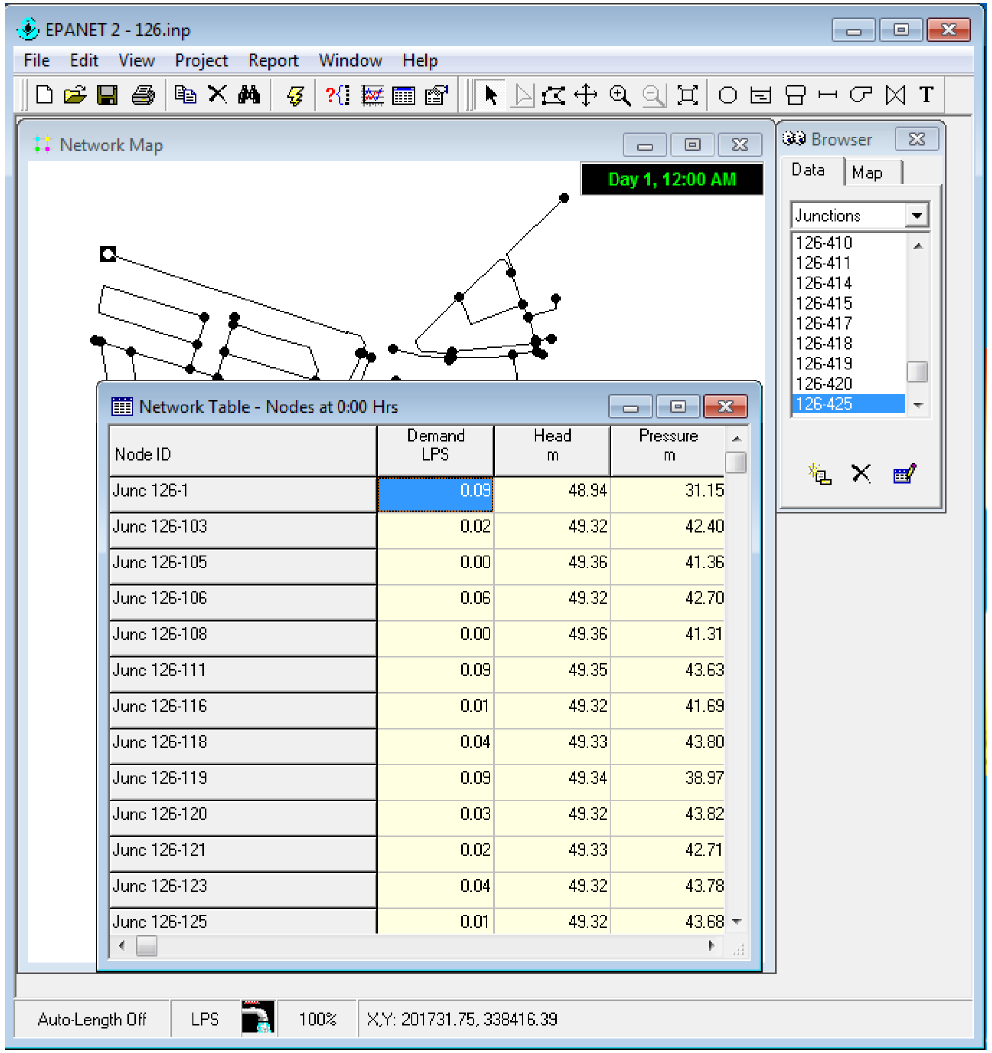
Results

- View simulated time-series results



Results

- View results in table form



Type of Errors/Warnings

Run Status

Run was unsuccessful. See Status Report for reasons.

OK

```
Hydraulic Status:
----------------------------------------------------
  0:00:00: Pump 107 changed by Tank T-1 control
  0:00:00: Balancing the network:
  0:00:00: System ill-conditioned at node 1
  0:00:00: Reservoir R-2 is closed
  0:00:00: Reservoir R-3 is closed
  0:00:00: Tank T-1 is closed at 5.00 m
  0:00:00: Pump 107 open
```

Run Status

Warning messages were generated. See Status Report for details.

OK

Status Report

```
Page 1                                          Wed Dec 05 12:32:08 2018

******************************************************************
*                          E P A N E T                           *
*                  Hydraulic and Water Quality                   *
*                  Analysis for Pipe Networks                    *
*                        Version 2.00.12                         *
******************************************************************

Analysis begun Wed Dec 05 12:32:08 2018


Hydraulic Status:
-----------------------------------------------------------------------
   0:00:00: Pump 107 changed by Tank T-1 control
   0:00:00: Balancing the network:
            Trial  1: relative flow change = 1.000000
            Trial  2: relative flow change = 0.186391
            PSV 79 switched from active to closed
            Trial  3: relative flow change = 0.479213
            Trial  4: relative flow change = 0.008888
            Trial  5: relative flow change = 0.000003
   0:00:00: Balanced after 5 trials
   0:00:00: Reservoir R-2 is emptying
   0:00:00: Reservoir R-3 is emptying
   0:00:00: Tank T-1 is emptying at 5.00 m
   0:00:00: Pump 107 open
   0:00:00: PSV 79 closed

WARNING: Negative pressures at 0:00:00 hrs.
WARNING: Pump 107 open but exceeds maximum flow at 0:00:00 hrs.
```

A6_Water Network Design

Exercise A6.1_Drawing Elements

Steps:

1. Set Defaults
   - ID Labels: Set ID increment to 1
   - Properties: Choose default values for some properties
   - Hydraulics: Choose Flow Units and Headloss formula

2. Display options
   - View – Options

3. Draw the network
   - First import nodes (reservoir, junctions, tank)
   - Draw links (pipes, valves, pumps)

4. Set object properties

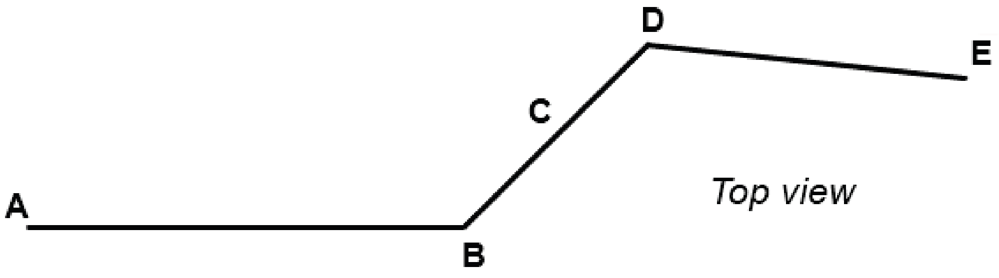
5. Add patterns, controls and curves

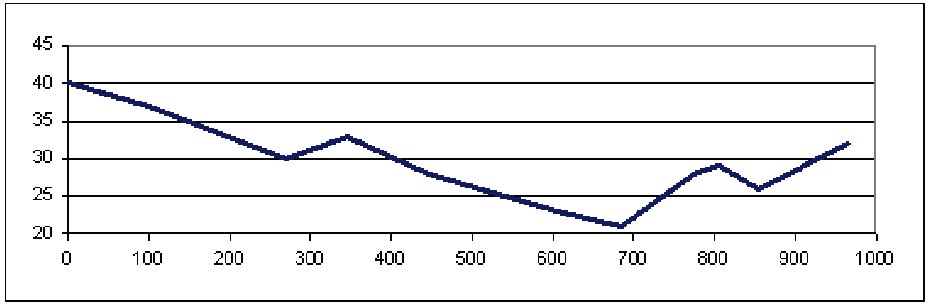
6. Set time options

7. Run analysis

Exercise A6.1_Drawing Elements (cont.)

A. Design the following gravity system in galvanized iron knowing that at point E consumption is 5 l/s and that A is a comparatively infinite source of water. Diameter of the pipeline is 125 mm and pipe roughness is 120 (H-W) *[Set these values as default]*.





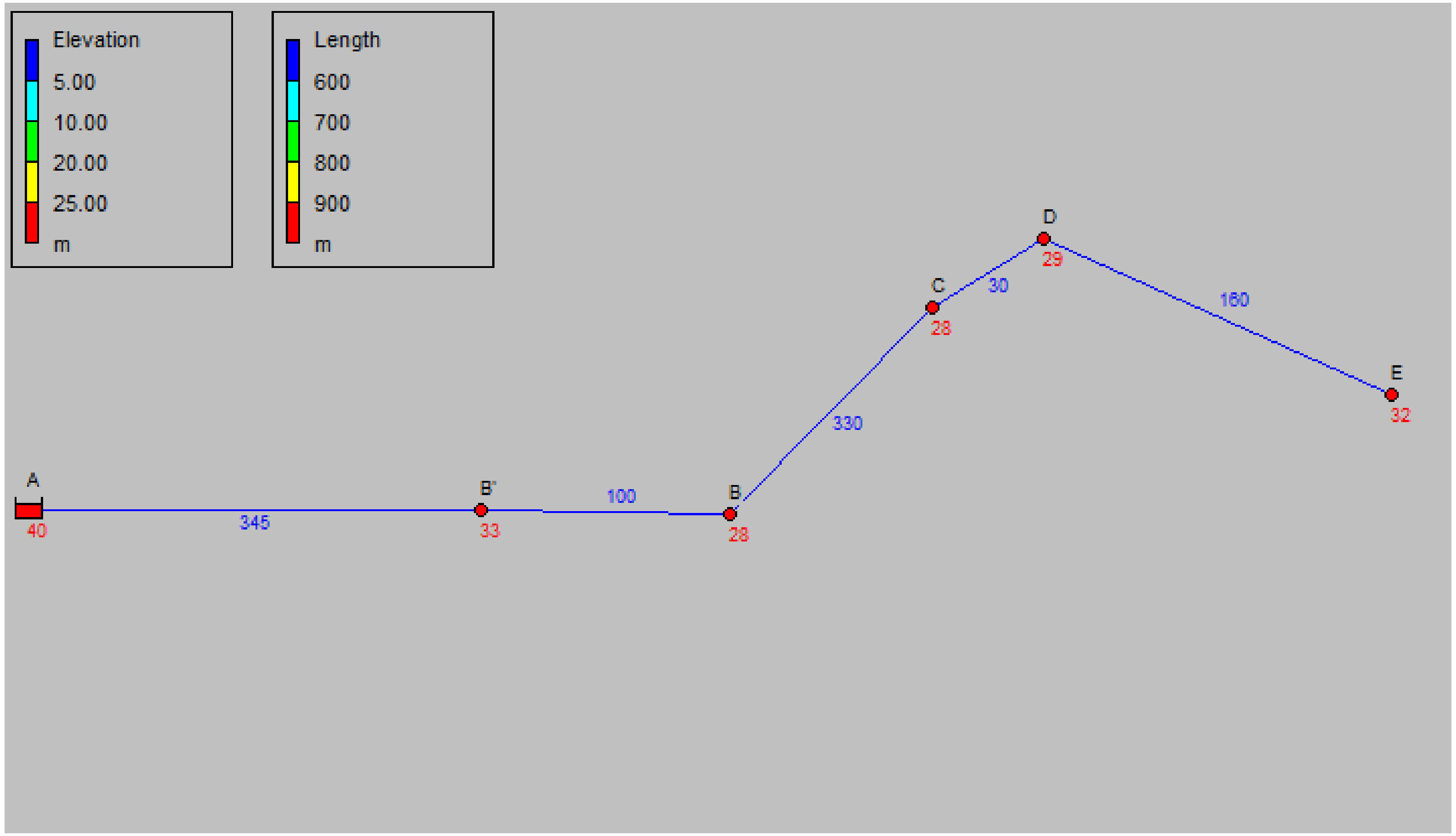
Elevation	40	37	32	30	33	28	23	21	28	29	26	32
Length	0	100	120	50	75	100	160	80	90	30	50	110
Chainage	0	100	220	270	345	445	605	685	775	805	855	965
	A					B			C	D		E

Exercise A6.1_Drawing Elements (cont.)

Hints: 1. First import the nodes and afterwards the pipes.

2. Always place a node in the intermediate highest points (i.e. Node B' at 345m from A).

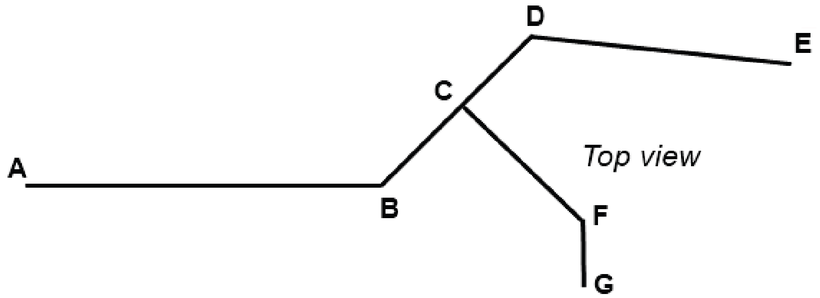
By placing an extra node in high points you will be able to verify that the pressure is sufficient.

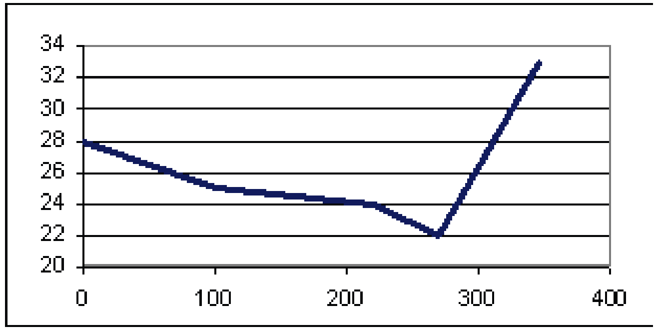


Exercise A6.1_Drawing Elements (cont.)

B. A branch line must be added to the design, to supply a second town, point G, with 7 l/s. Modify the design according to the new data.

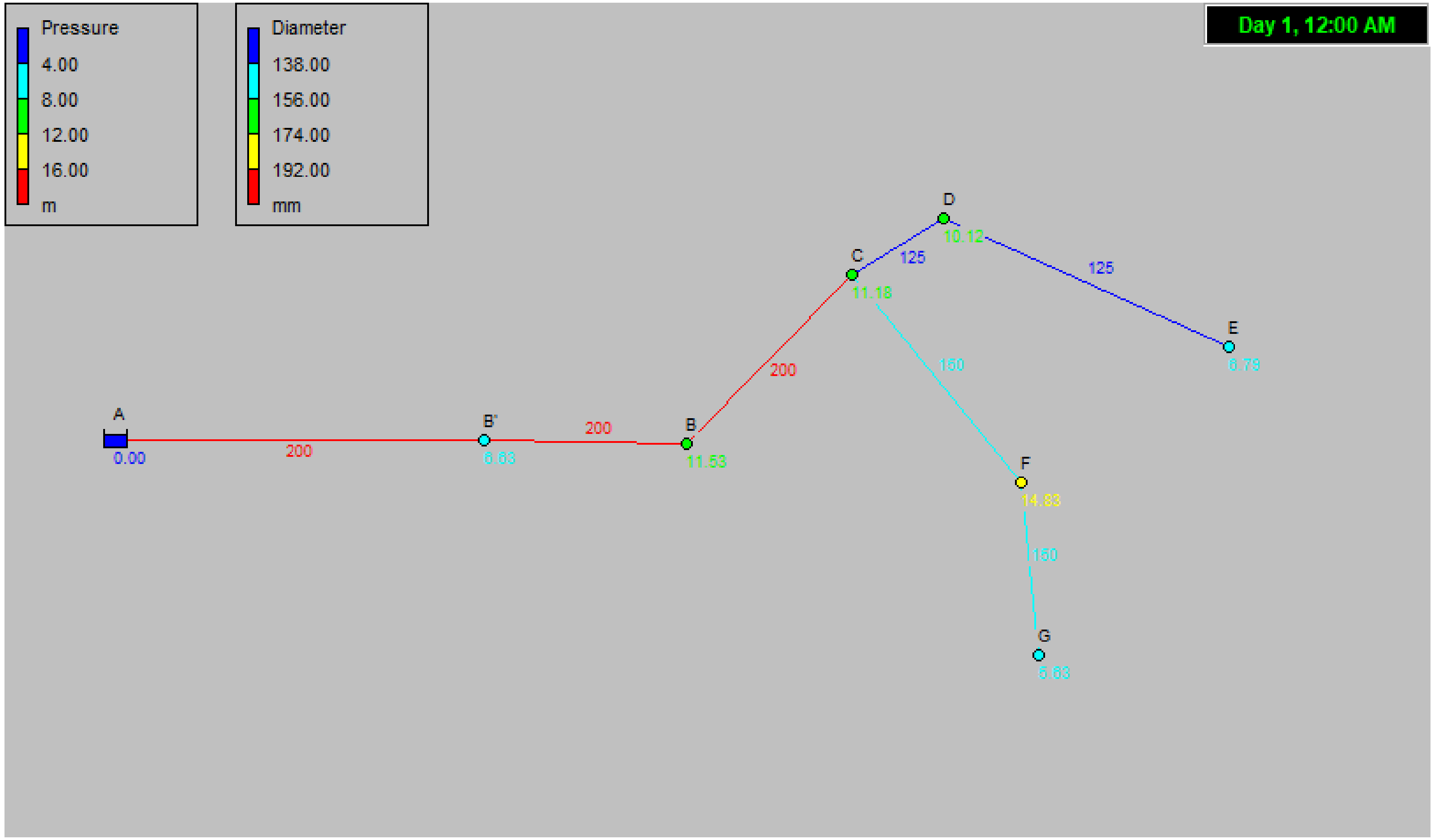
Redesign some pipes in order to have pressure above 5 m in nodes E, G and B’ and above / close to 10 m to the rest of the nodes. For the new members, Diameter is 150 mm and pipe roughness is 120 (H-W).





Elevation	28	25	24	22	33
Length	0	100	120	50	75
Chainage	0	100	220	270	345
	C		F		G

Exercise A6.1_Drawing Elements (cont.)

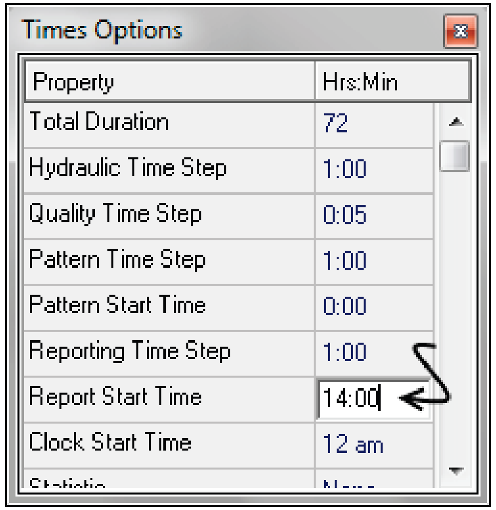


Exercise A6.1_Drawing Elements (cont.)

C. Load the demand pattern and run a 72 hr. simulation.

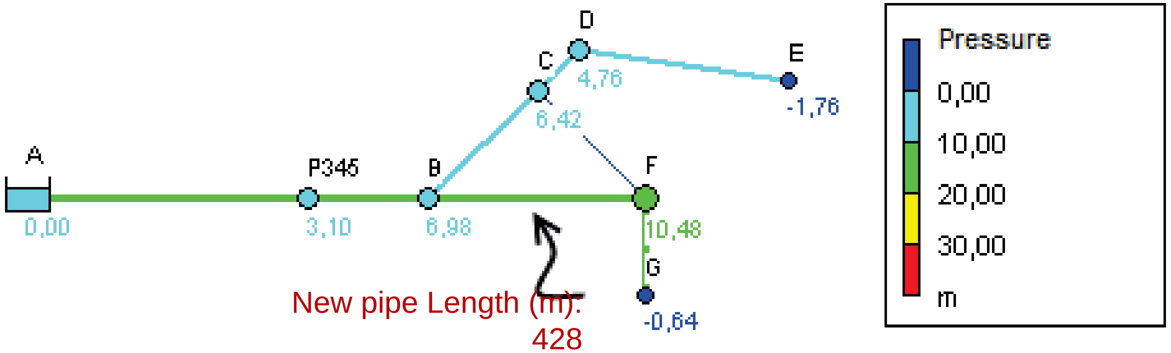
Is there any change? Is there any negative pressure (if yes, at which time step?)

Optimize network (change diameters and / or add new pipes).

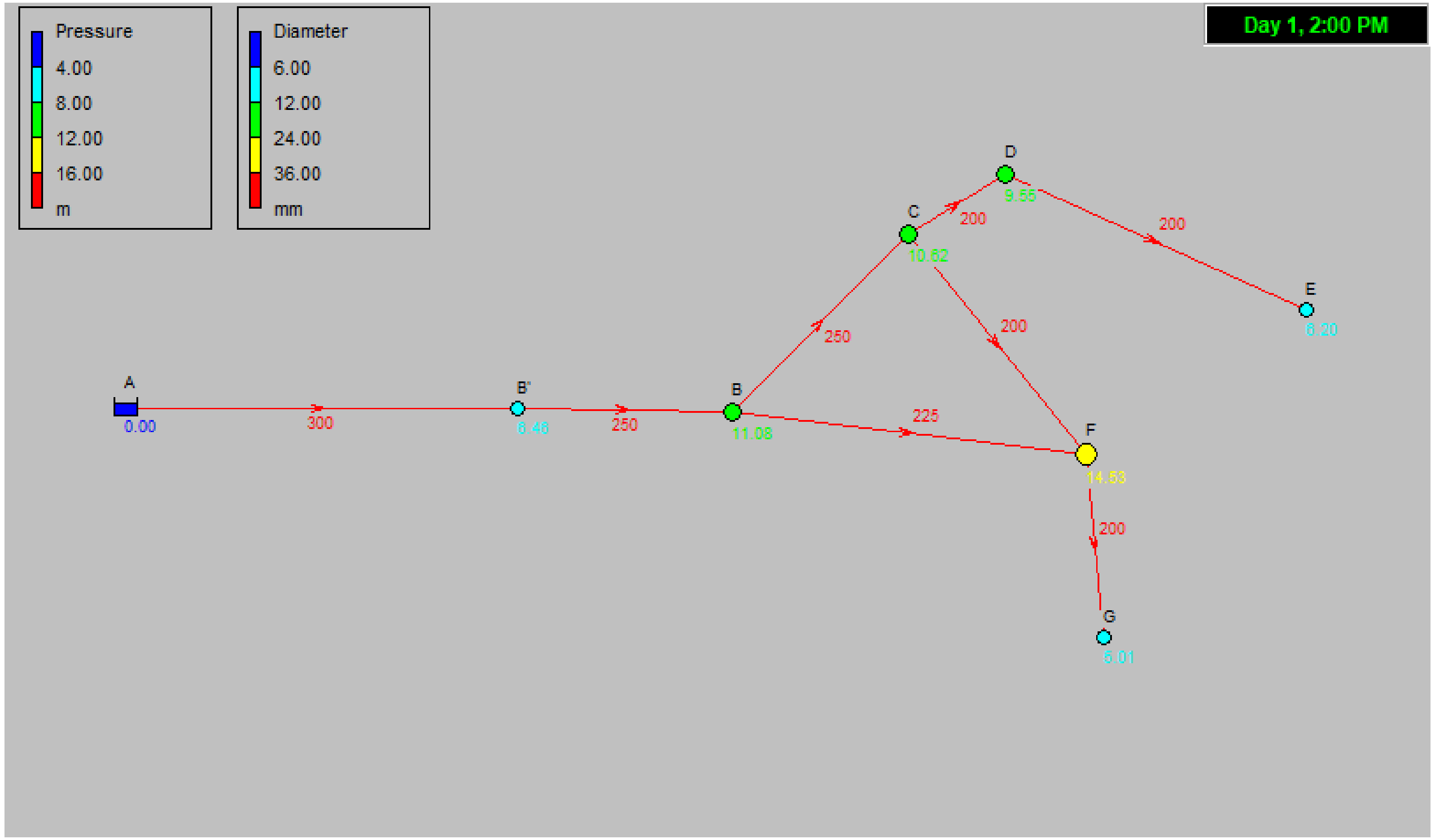


Times Options

Property	Hrs:Min
Total Duration	72
Hydraulic Time Step	1:00
Quality Time Step	0:05
Pattern Time Step	1:00
Pattern Start Time	0:00
Reporting Time Step	1:00
Report Start Time	14:00
Clock Start Time	12 am



Exercise A6.1_Drawing Elements (cont.)



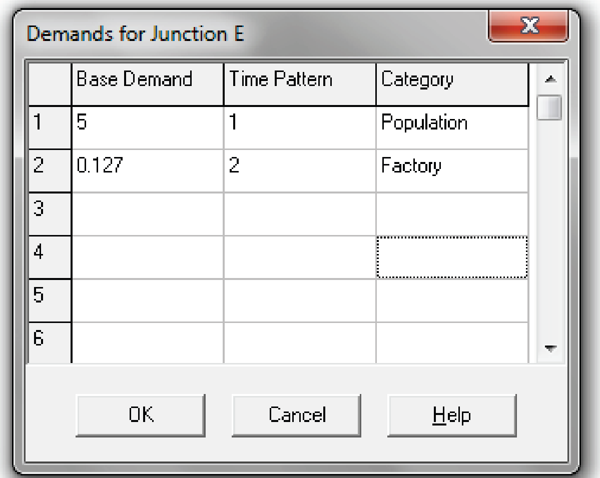
Exercise A6.1_Drawing Elements (cont.)

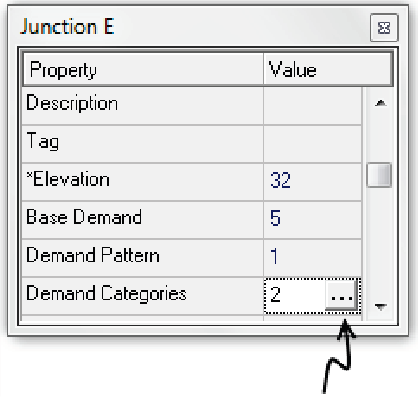
D. New factory at point E with a base demand of 0,127 l/s

(Add the new factory demand pattern).

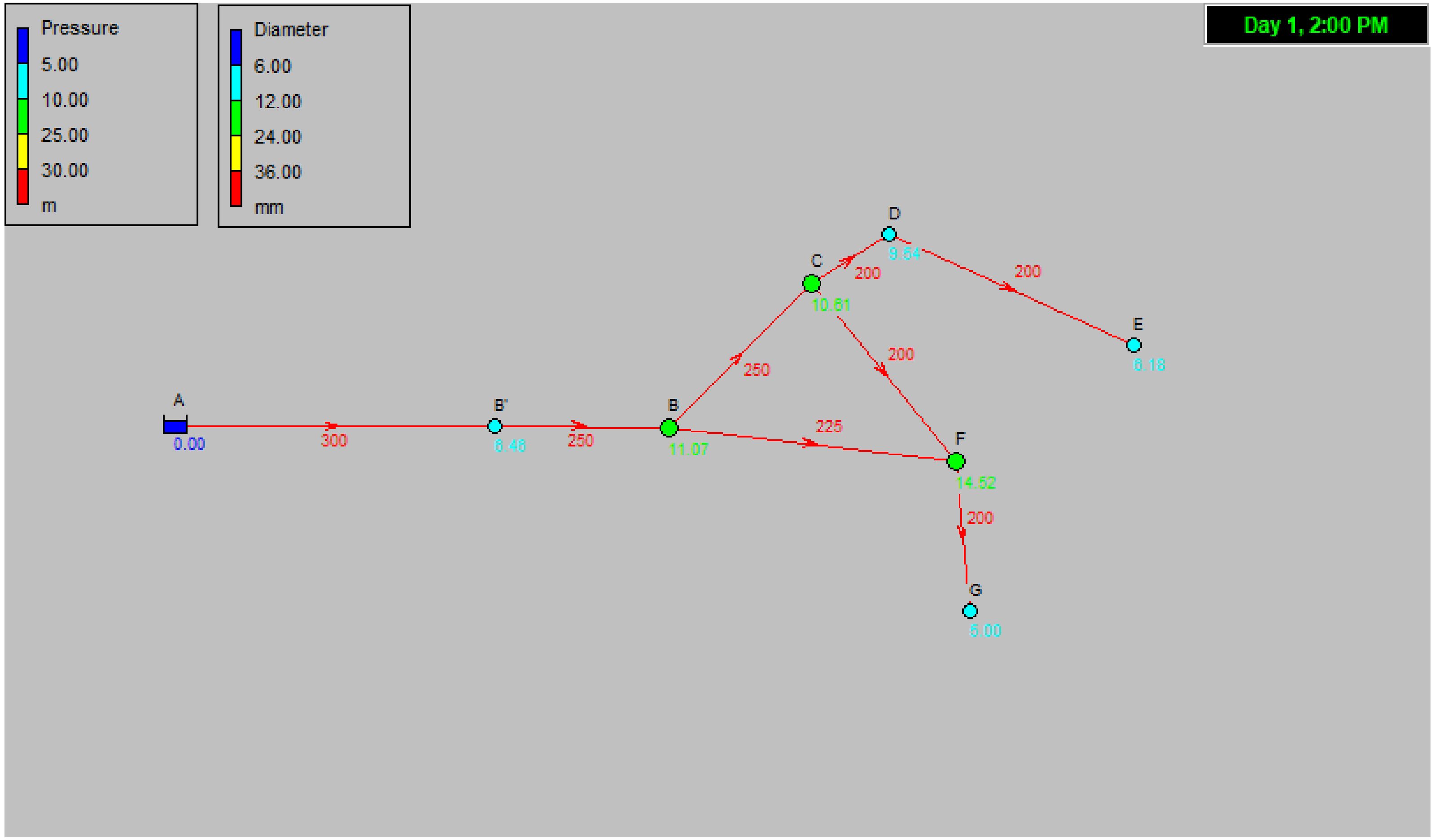
Is this factory affecting the system?

Is it necessary to enlarge the current system?





Exercise A6.1_Drawing Elements (cont.)

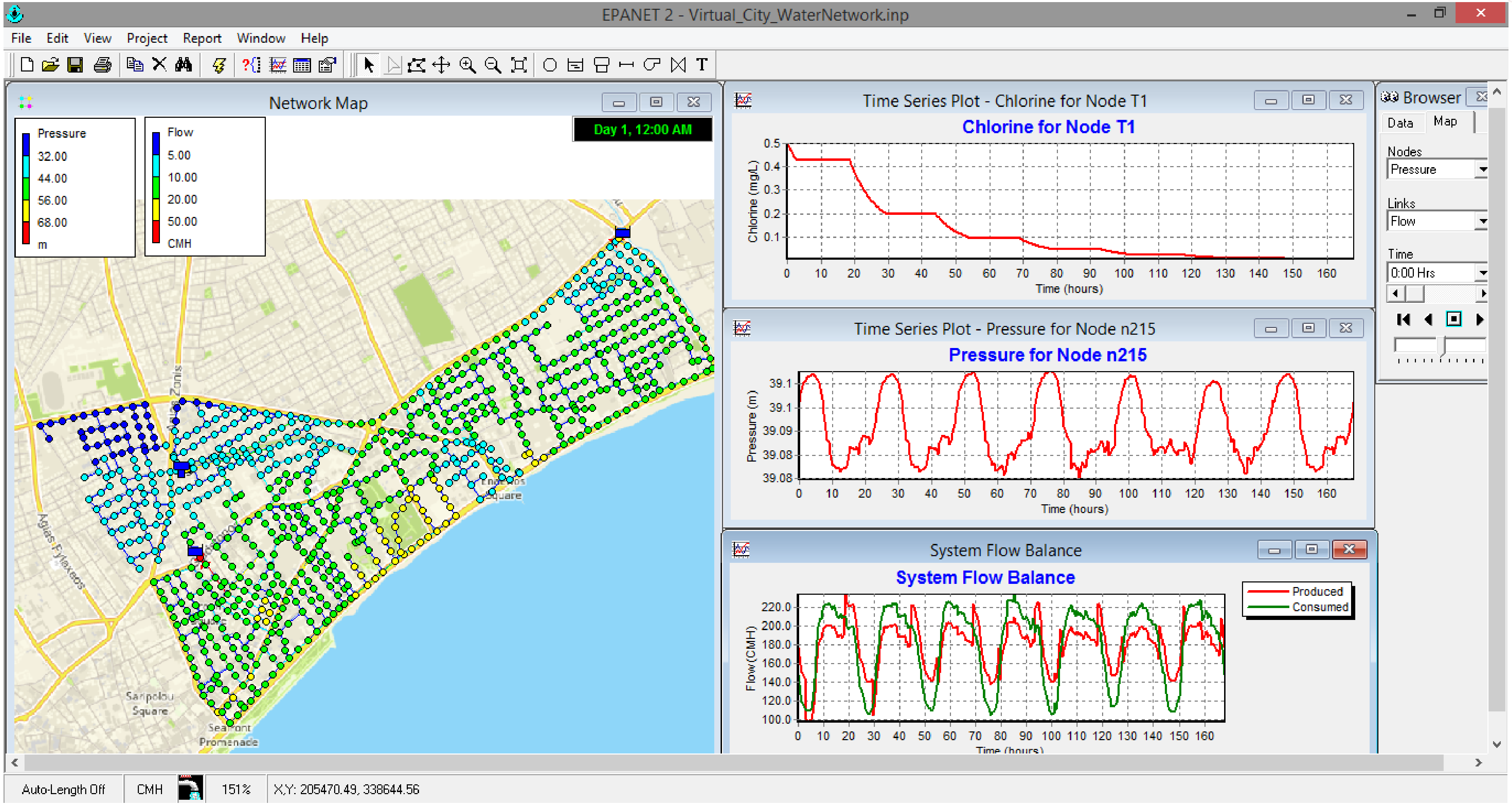


A7_EPANET EXTENDED SIMULATIONS

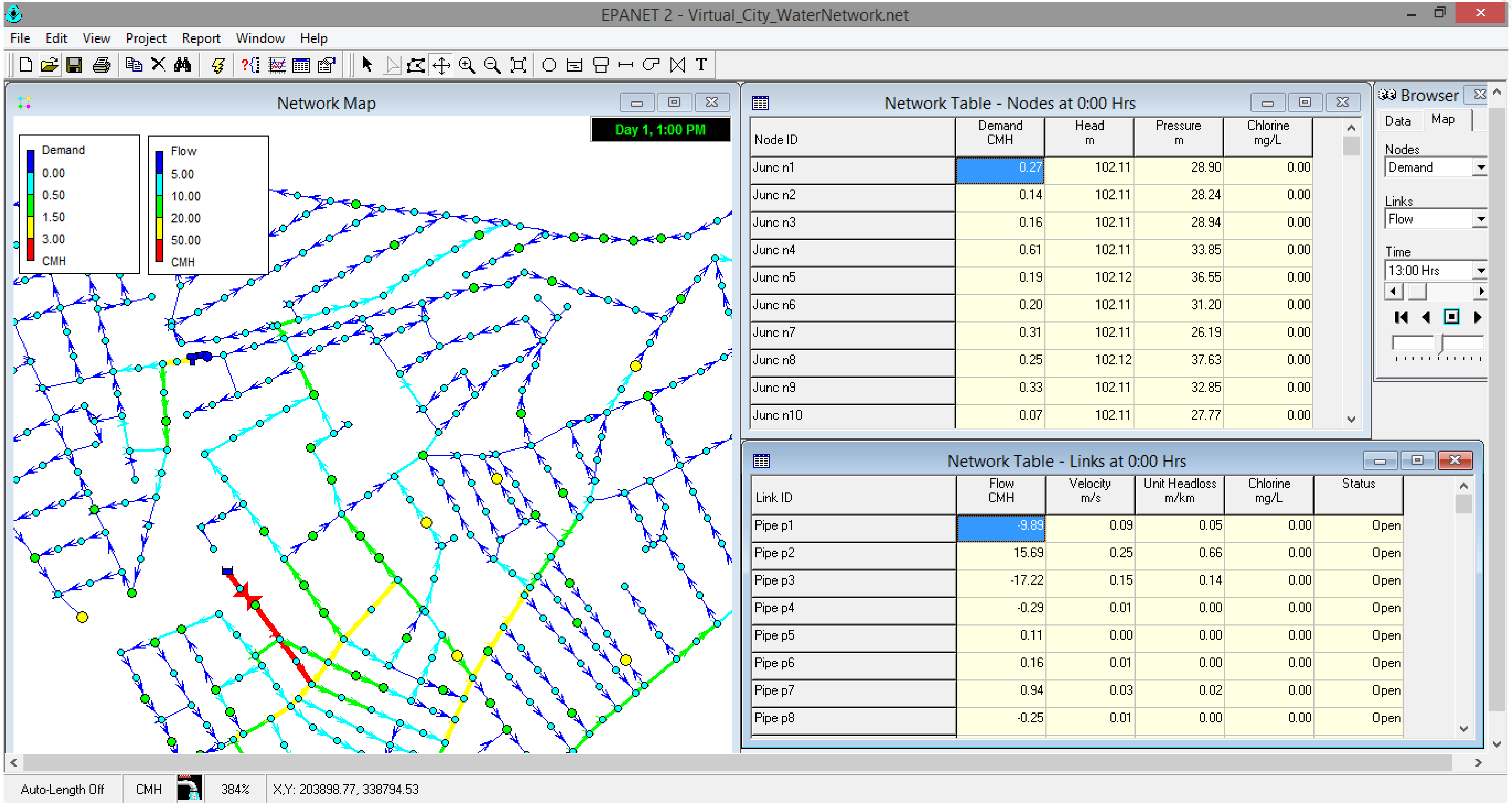
EPANET SCENARIOS

- Network analysis
  - Coordinates, Elevations, Demand Categories, Patterns
  - Tank, valve, pump, reservoir properties
  - Sub-DMAs: tank area, PRV area
  - Load map
- PRV - Active/Inactive - Pressure change
- Tank Capacity (closed pump)
- Pump control – Energy cost relationship
  - System flow graph
  - Energy cost table
- Chlorination scenario
  - Bulk coefficient: - 0.2378
  - Select reservoir/tank – Set Initial Quality (Concentration)
- Contamination scenario
  - Select node – Set Source Quality/Setpoint Booster

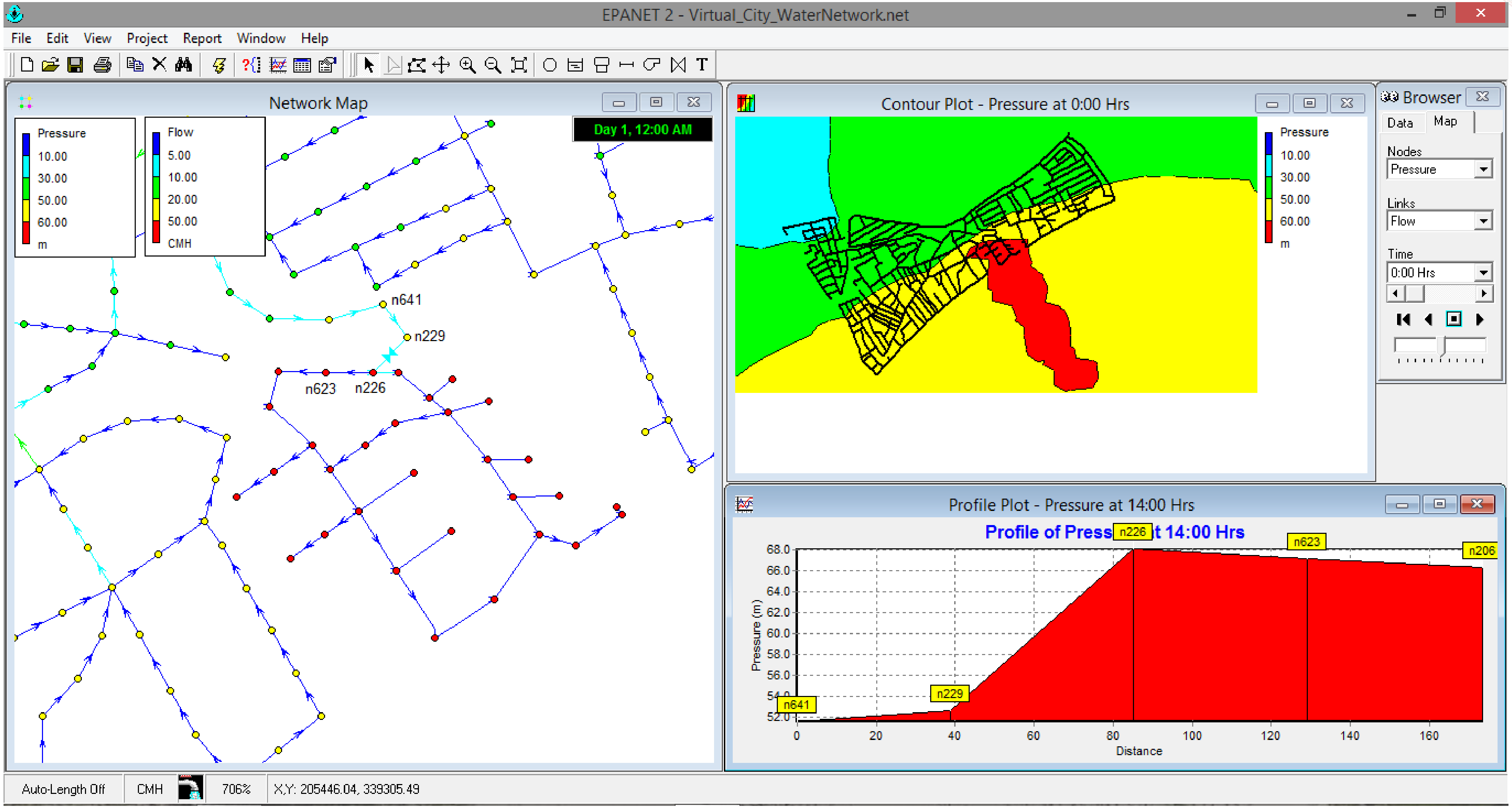
EPANET Graphs



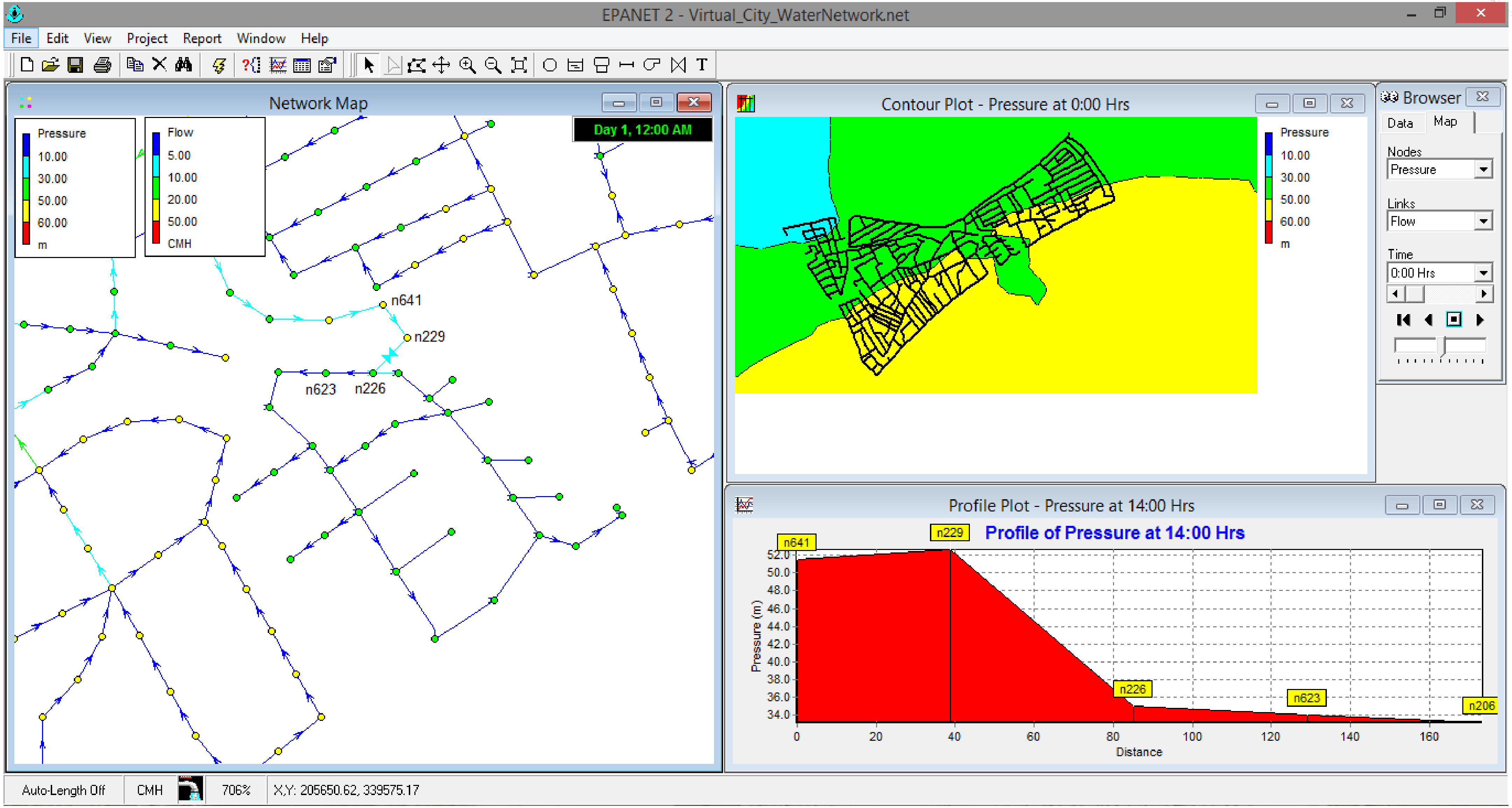
EPANET Tables



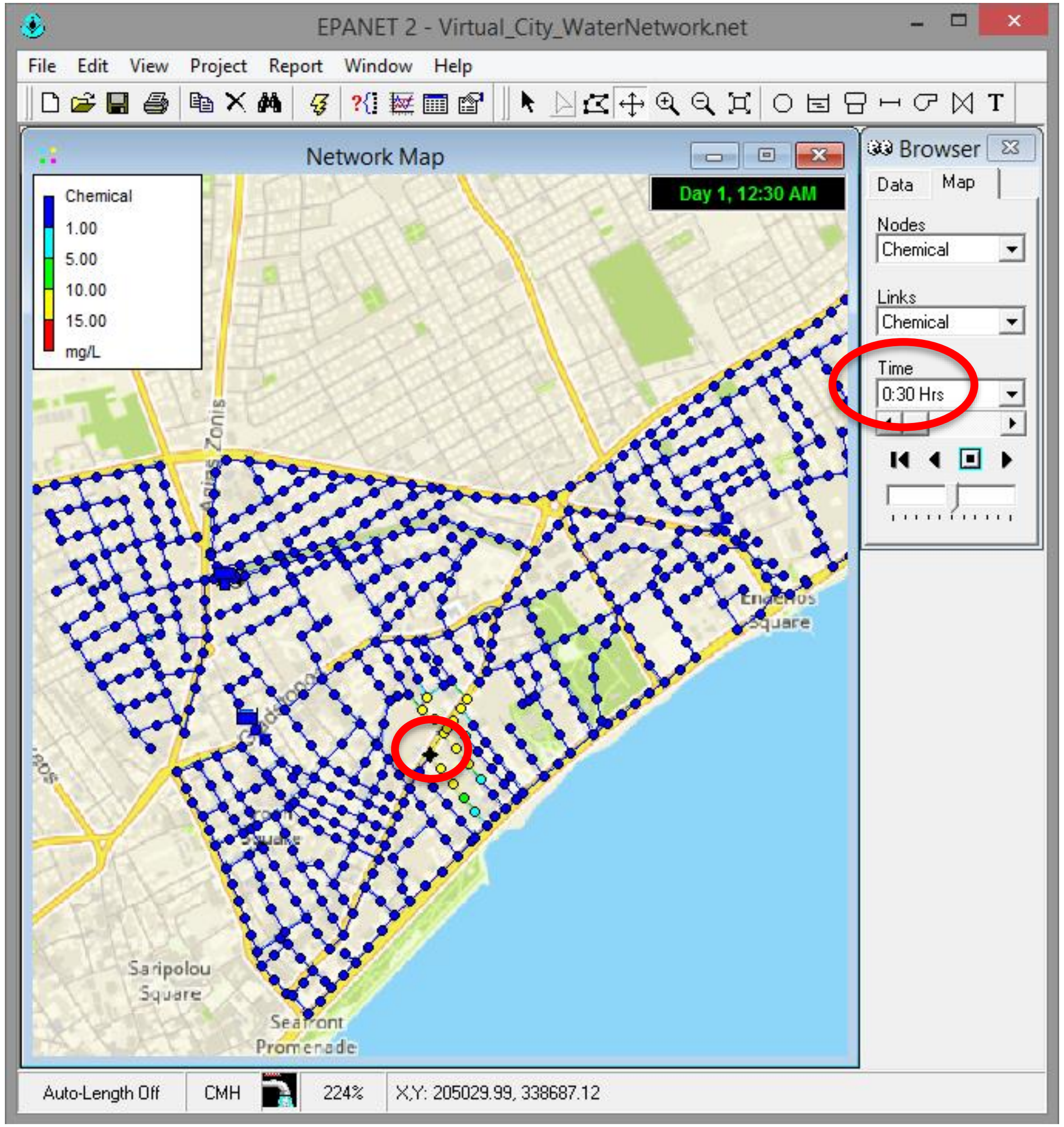
PRV Inactive – Pressure Profile

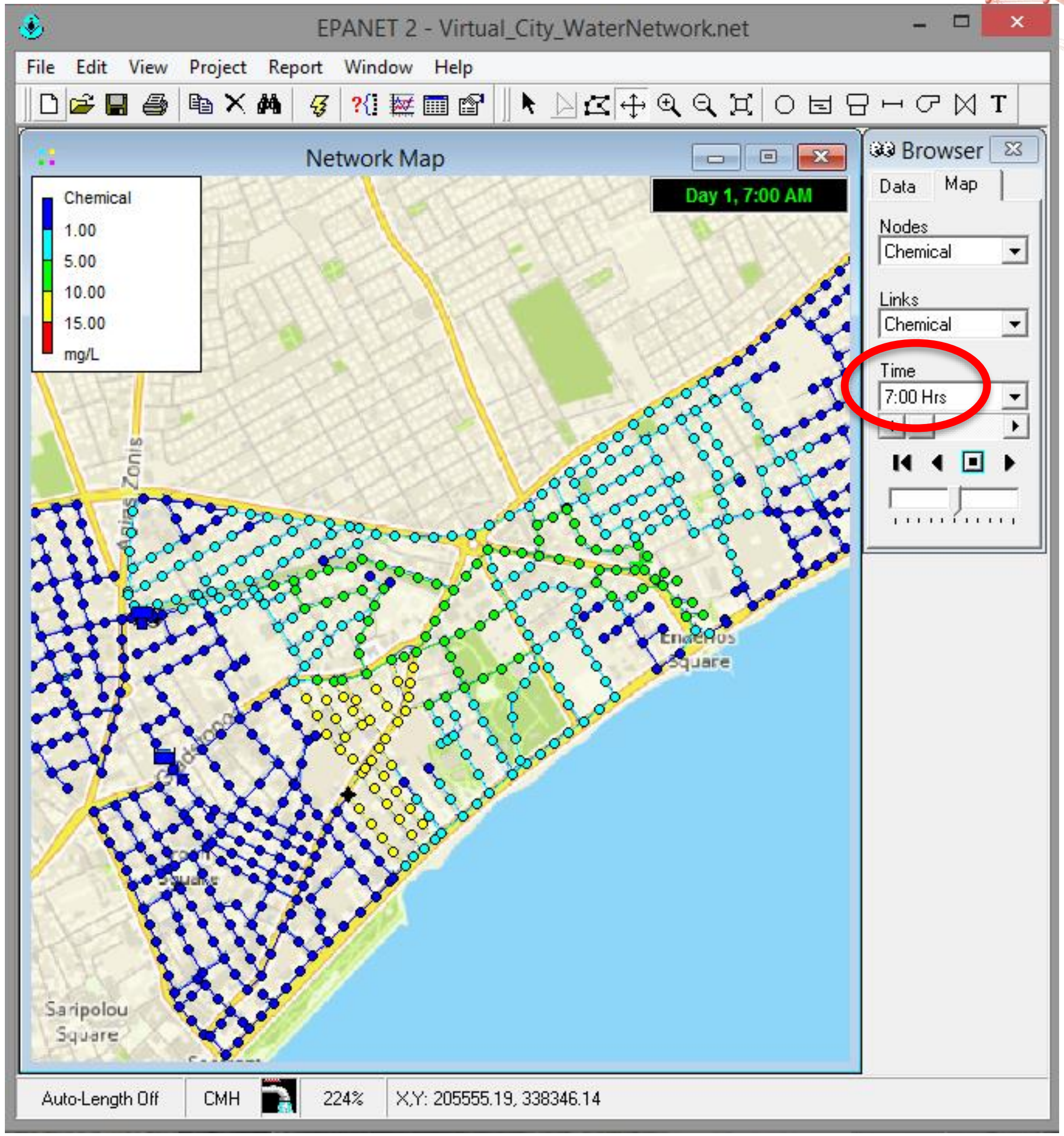


PRV Active – Pressure Profile

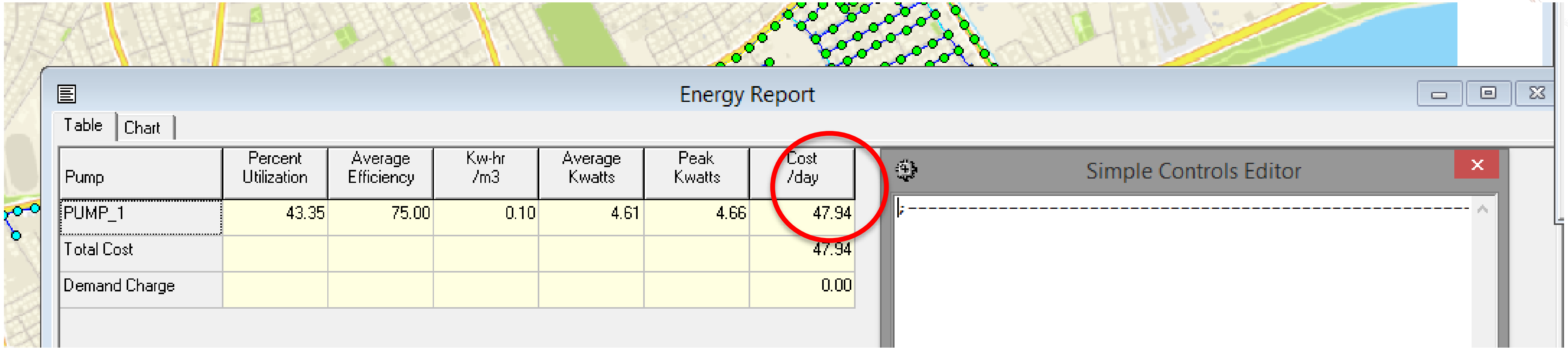


Chemical Spread

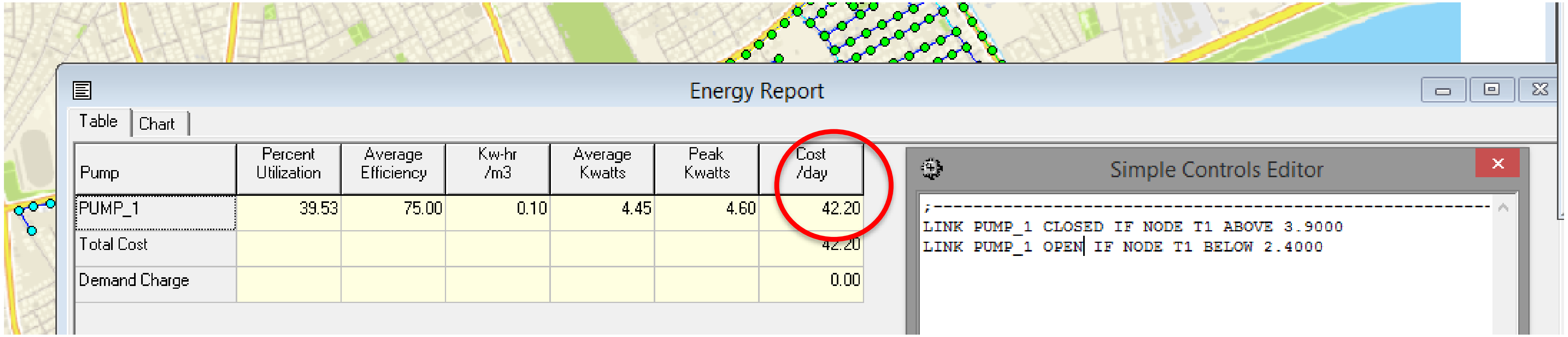




Pump Controls – Energy Cost



Pump	Percent Utilization	Average Efficiency	Kw-hr /m3	Average Kwatts	Peak Kwatts	Cost /day
PUMP_1	43.35	75.00	0.10	4.61	4.66	47.94
Total Cost						47.94
Demand Charge						0.00



Pump	Percent Utilization	Average Efficiency	Kw-hr /m3	Average Kwatts	Peak Kwatts	Cost /day
PUMP_1	39.53	75.00	0.10	4.45	4.60	42.20
Total Cost						42.20
Demand Charge						0.00

Acknowledgments

Research Projects

- **KIOS CoE**: Teaming for Excellence Project
- Interreg V-A Greece-Cyprus, **SmartWater2020**
- CyRPF Enterprises, **WaterAnalytics**
- ERC Advanced Grant, **Fault-Adaptive**
- ERC Proof-of-Concept, **SmartTap**
- 7th Framework Program**, EFFINET**

Partners

- Water Board of Limassol
- Cyprus Water Development Department
- PHOEBE Research and Innovations Ltd

Introduction to EPANET

Pavlos Pavlou (M.Sc)
Research Engineer
KIOS Research and Innovation Center of Excellence
University of Cyprus

Monday 27/4/2020
10:00 – 12:00 a.m.

Thank you

funded by: