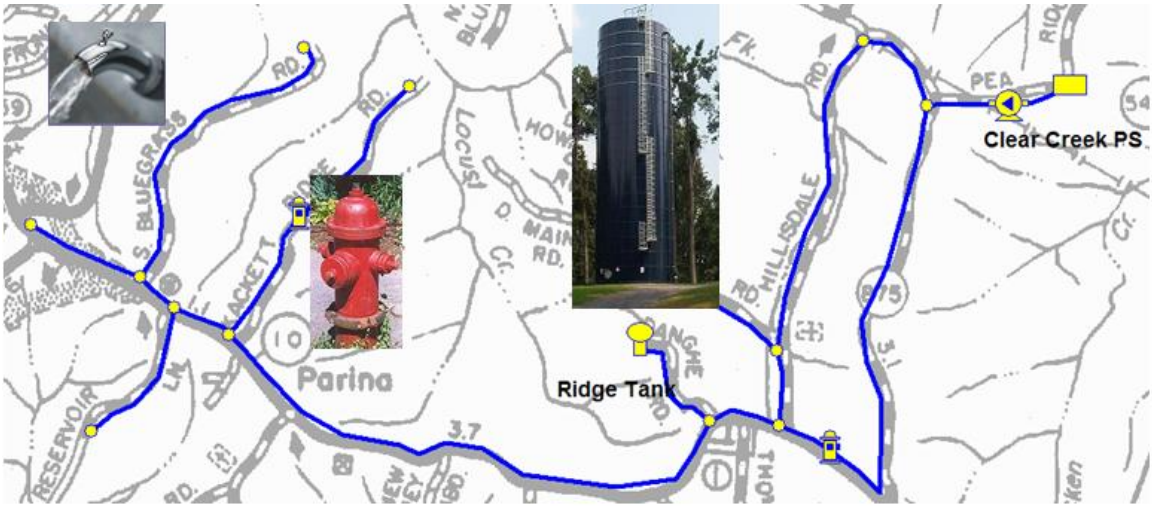
Pipe2010
Water Utility Modeling



A Comprehensive Guide to Hydraulic and Water Quality Modeling of Drinking Water Systems Using Pipe2010

October 2009

Contents

Part 1 - Steady State Hydraulic Modeling

1 Creating a Basic Model - Ultra Easy Pipe2010 GUI

2 Water Utility Distribution System Example- Steady State
- **2-1 – Description of System**
- **2-2 – Developing the Pipe2010 Model**
- **2-3 – Regular Simulations and Changes (*demoreg*)**
- **2-4 – Additional Node Types (*demoregex*)**
- **2-5 – Fire Hydrants (*demoreghyd*)**

3 Extended Period Simulation (EPS) Hydraulic Analysis
- **3-1 – EPS (*demoeps1*)**
- **3-2 – EPS (*demoeps2* – control switch))**
- **3-3 Using the Operational Control Screen (OCS)**

4 Water Quality Analysis
- **4-1 – Water Quality Example -- Chlorine Residual (*demoWQ*)**
- **4-2 -- Water Quality Simulation – Max. Water Age *(demomaxage)***
- **4-3 -- Water Quality Calibration – Chlorine Residual *(demoWQC)***

5 Optimized Calibration of Your Model
- **5-1 – Optimized Calibration Example *(democalibration)***

6 Transient (Surge) Modeling
- **6-1 Using the OCS for Transient (Surge) Modeling**

Appendix - A
Municipal Water Distribution Utility Data

1 Creating a Pipe2010 Model

Creating a Hydraulic Model

Using the UltraEasy Pipe2000 GUI
(for steady and transient modeling)

- Backgrounds
- Laying out Pipe Systems
- Providing data
- Hydraulic Calc.
- Labeling your Pipe System

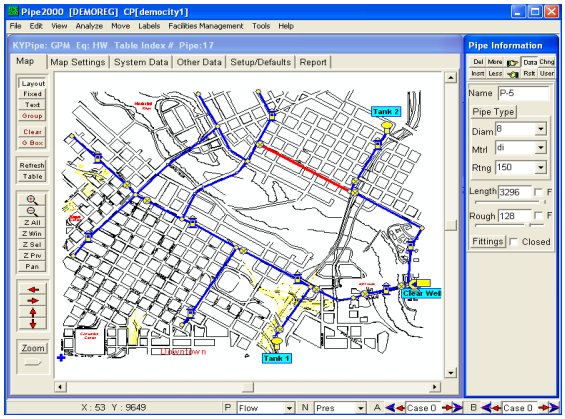


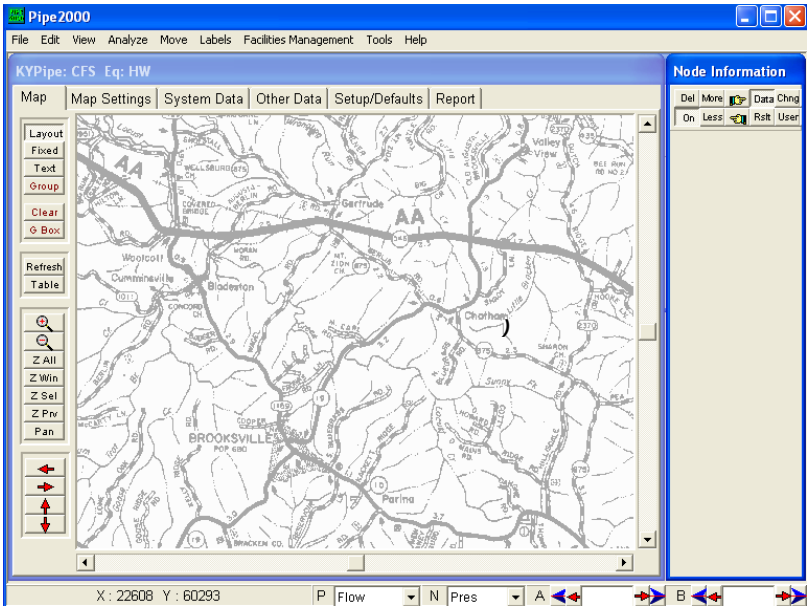
Figure 1-1

This section provides a very simple guide to allow you to develop a model of your water utility. The Pipe2010 **G**raphical **U**ser **I**nterface (**GUI**) was designed to provide the most simple model development possible as illustrated by this presentation. This presentation is also available as an AVI (audio/video) slide show.

The first step to model development is to import a background map to be used to layout pipes and scale their lengths. To import a map select **Map Settings/Backgrounds/Add Map** and you will access a browser which will allow you to select a vector (dxf, dwg, etc) or a raster (bmp, tif, etc) file which is stored in a computer subdirectory. Once this is done your screen will appear as shown in Figure 1-2. You are now ready to draw your piping system using the background map as your guide.

Figure 1-3 presents the 3 simple operations which will allow you to develop simple or complex pipe distribution systems. The model development is done in **Layout Mode** (top button on left side). In this mode a Left Click (LC) will select and highlight (red) the pipe of node that the cursor is pointing to. A Right Click (RC) will add a pipe section and a new node from the highlighted node to the point where the cursor is pointing. This new node will become the highlighted (selected) node. All nodes added in this manner are junctions or intermediate nodes. A highlighted node can be changed to any type of node by left clicking on the desired node type from the dropdown list which appears to the right of the map. The next few pages illustrate these simple steps to model development.

Pipe2000 Backgrounds



County Map (raster)

Figure 1-2

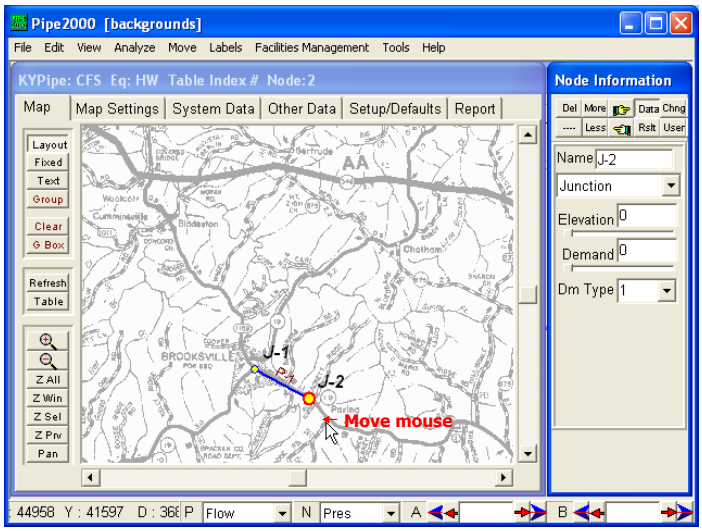
Laying Out Your Pipe System

As Easy as 1-2-3

- ***(1)*** Left Click (LC) to select existing node (or pipe)
- ***(2)*** Select first node – move mouse and Right Click (RC) to add Pipe and Node
- ***(3)*** Select Node and use Dropdown List to change Node Type

Figure 1-3

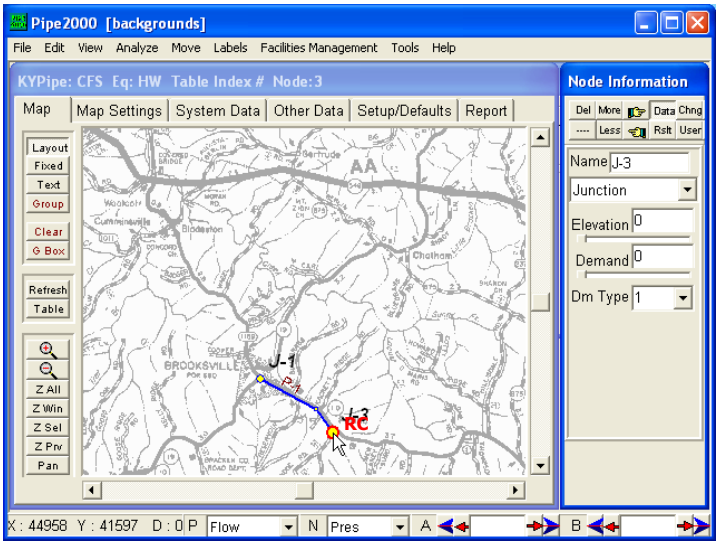
Laying Out Your Pipe System



1) Move mouse to next location

Figure 1-4

Laying Out Your Pipe System

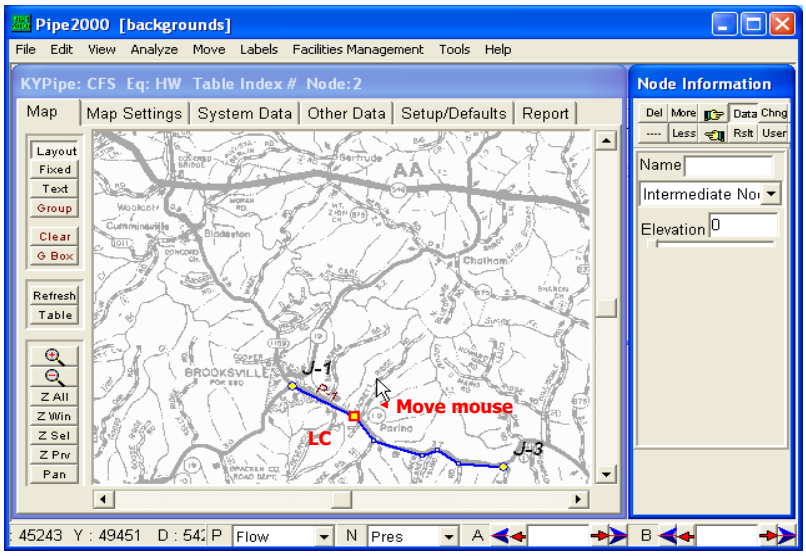


2) Right Click to add Pipe

Figure 1-5

Figure 1-4 and 5 illustrate the basic operation of adding a pipe section and node. Simply move the mouse to the location where the added pipe will terminate and RC. Note that if the mouse is pointed to an existing node and RC, the added pipe will connect the selected node to the existing node (only a pipe section is added – no new node is created)

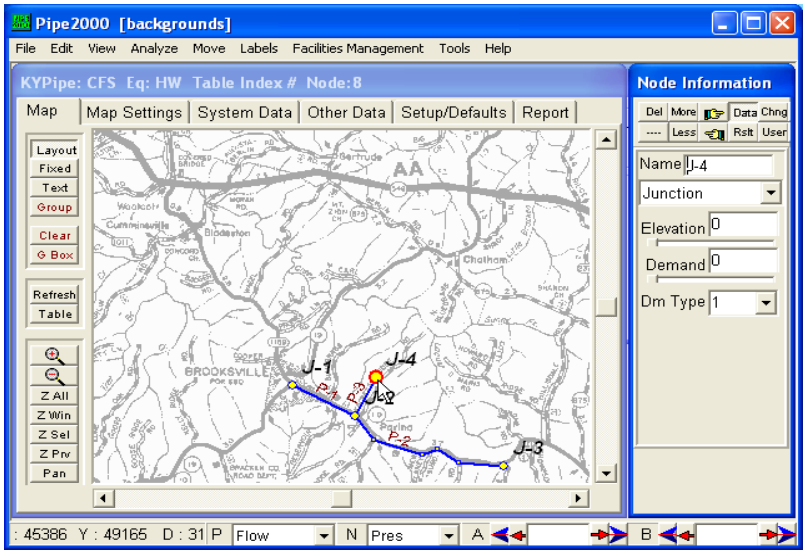
Laying Out Your Pipe System



3) Select new starting node (Left Click)

Figure 1-6

Laying Out Your Pipe System

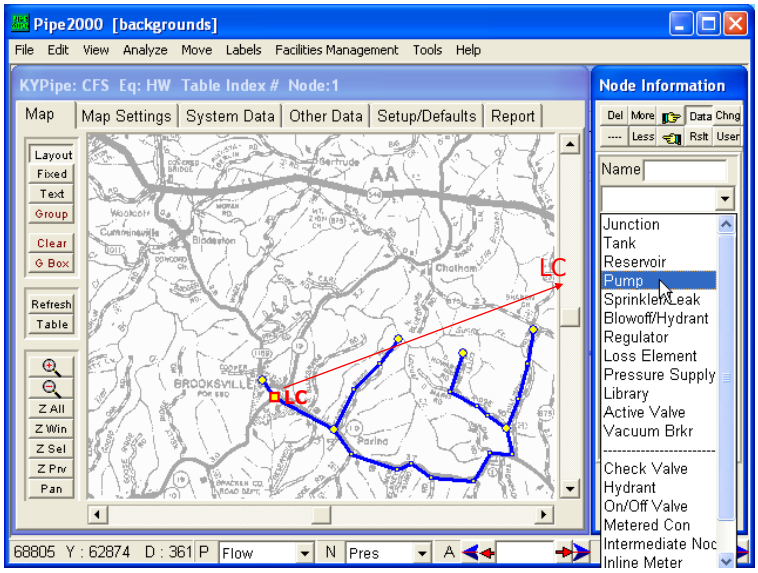


4) Move to next location and Right Click

Figure 1-7

Figure 1-6 and 7 illustrate how pipe sections are added to an existing part of the piping system. Simply select the new starting node (Figure 1-6) and move the mouse to the location where the new pipe section is to terminate and RC.

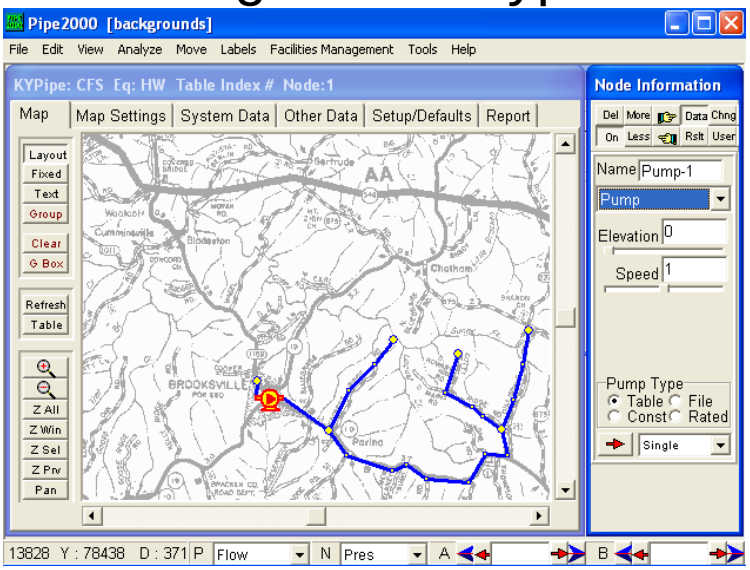
Change Node Types



1) Select node (LC) and select Type (Pump) from Dropdown List

Figure 1-8

Change Node Types

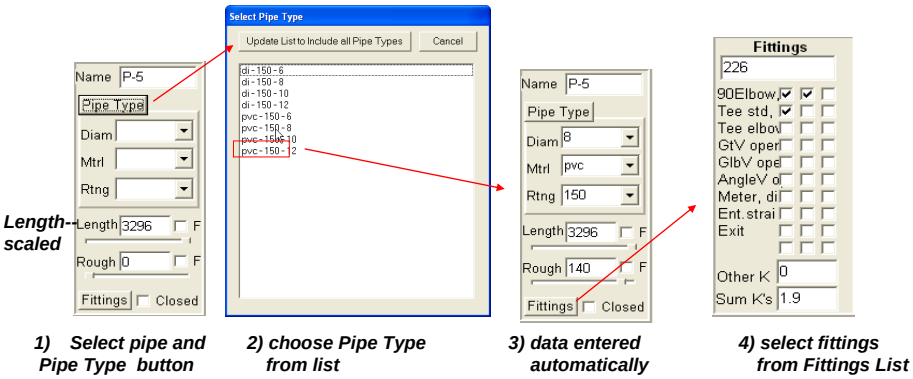


Node is changed to Pump

Figure 1-9

Figure 1-9 and 10 illustrate the very simple process of changing the node type from a junction or intermediate node to a different type (pump). Simply click on the node and select the desired type from the dropdown list as shown in Figure 1-9

Entering Pipe Data



One Click and Select Pipe Type can Provide Required Pipe Data

Figure 1-10

Enter Node Data

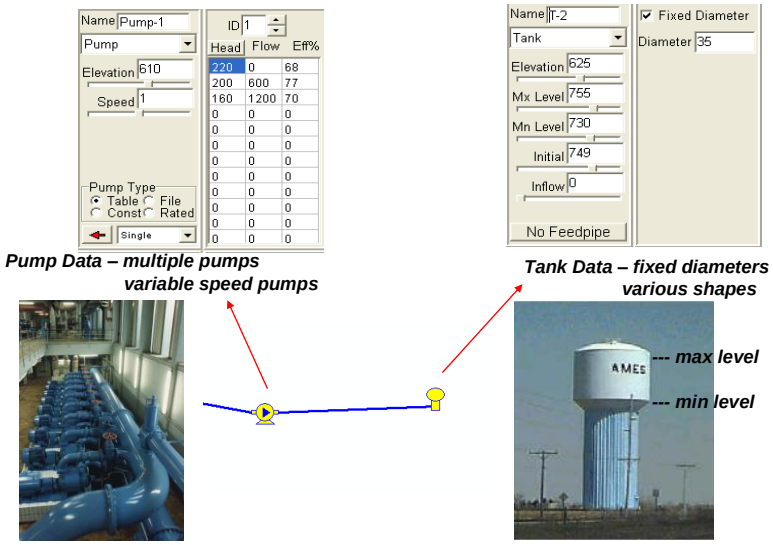


Figure 1-11

Once the pipe system layout is complete data must be entered for each pipe and node in the system. First select the pipe (or node) and click the **Data** button at the top of the Pipe (or Node) Information window (right side). Pipe data is best entered by using the Pipe Type dropdown and selecting the appropriate pipe size and material. Each node will have a data box which is customized for the type of node as shown in Figure 1-11.

Hydraulic Analysis and the Report

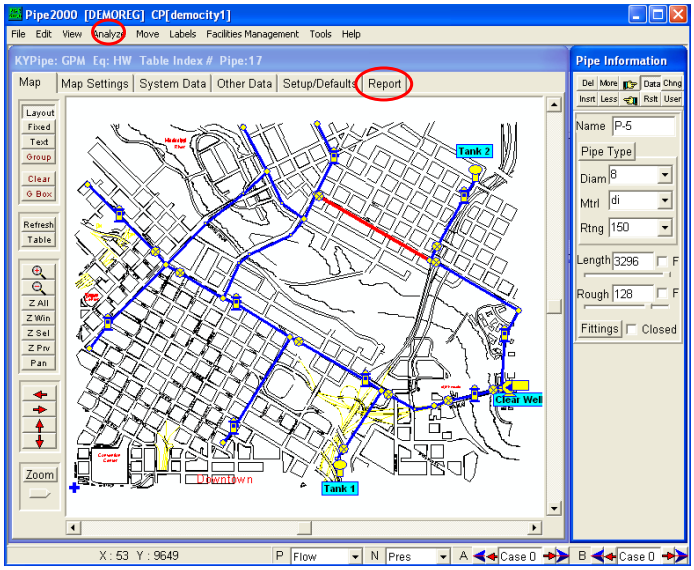
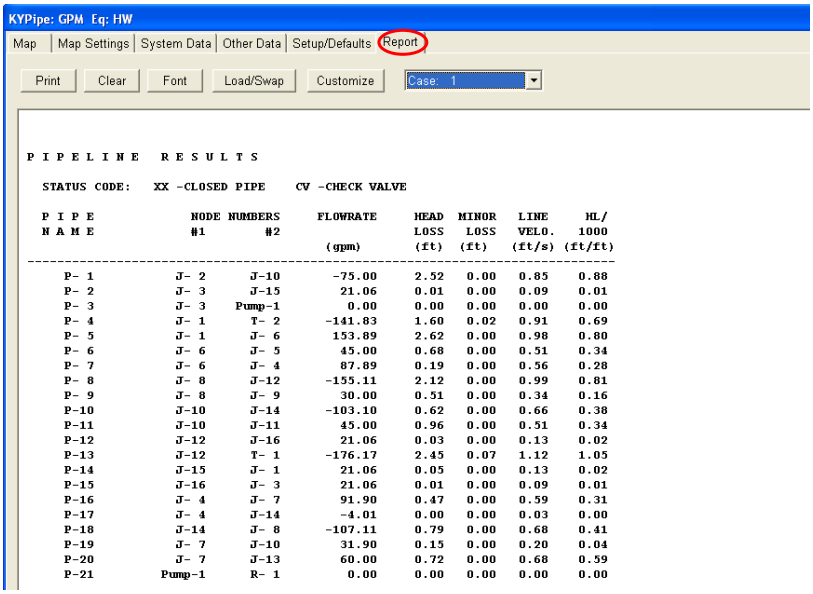


Figure 1-12

Hydraulic Analysis and the Report



P I P E L I N E R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

PIPE NAME	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL/ 1000 (ft/ft)
P- 1	J- 2	J-10	-75.00	2.52	0.00	0.85	0.88
P- 2	J- 3	J-15	21.06	0.01	0.00	0.09	0.01
P- 3	J- 3	Pump-1	0.00	0.00	0.00	0.00	0.00
P- 4	J- 1	T- 2	-141.83	1.60	0.02	0.91	0.69
P- 5	J- 1	J- 6	153.89	2.62	0.00	0.98	0.80
P- 6	J- 6	J- 5	45.00	0.68	0.00	0.51	0.34
P- 7	J- 6	J- 4	87.89	0.19	0.00	0.56	0.28
P- 8	J- 8	J-12	-155.11	2.12	0.00	0.99	0.81
P- 9	J- 8	J- 9	30.00	0.51	0.00	0.34	0.16
P-10	J-10	J-14	-103.10	0.62	0.00	0.66	0.38
P-11	J-10	J-11	45.00	0.96	0.00	0.51	0.34
P-12	J-12	J-16	21.06	0.03	0.00	0.13	0.02
P-13	J-12	T- 1	-176.17	2.45	0.07	1.12	1.05
P-14	J-15	J- 1	21.06	0.05	0.00	0.13	0.02
P-15	J-16	J- 3	21.06	0.01	0.00	0.09	0.01
P-16	J- 4	J- 7	91.90	0.47	0.00	0.59	0.31
P-17	J- 4	J-14	-4.01	0.00	0.00	0.03	0.00
P-18	J-14	J- 8	-107.11	0.79	0.00	0.68	0.41
P-19	J- 7	J-10	31.90	0.15	0.00	0.20	0.04
P-20	J- 7	J-13	60.00	0.72	0.00	0.68	0.59
P-21	Pump-1	R- 1	0.00	0.00	0.00	0.00	0.00

Figure 1-13

Once the data entry is complete the Hydraulic analysis can be carried out and comprehensive tabulated and graphical results can be accessed as shown in Figures 1-12 and 13. Click on the **Report** tab at the top (Figure 1-12) to see the report shown in Figure 1-13.

2 Water Utility Distribution System Example – Steady State

A simple pipe system representing the main pipes of a small water distribution system is shown in Figure 2-1. This system is used to demonstrate the use of Pipe2010 for regular and extended period simulations and Pipe2010 : Surge for surge analysis. A number of modeling features may be demonstrated using the data files provided in the *DEMO* subdirectory. In this manual the data along with additional details are provided so the user can set up these examples. A number of additional exercises are presented in this manual to illustrate Pipe2010 modeling elements and features.

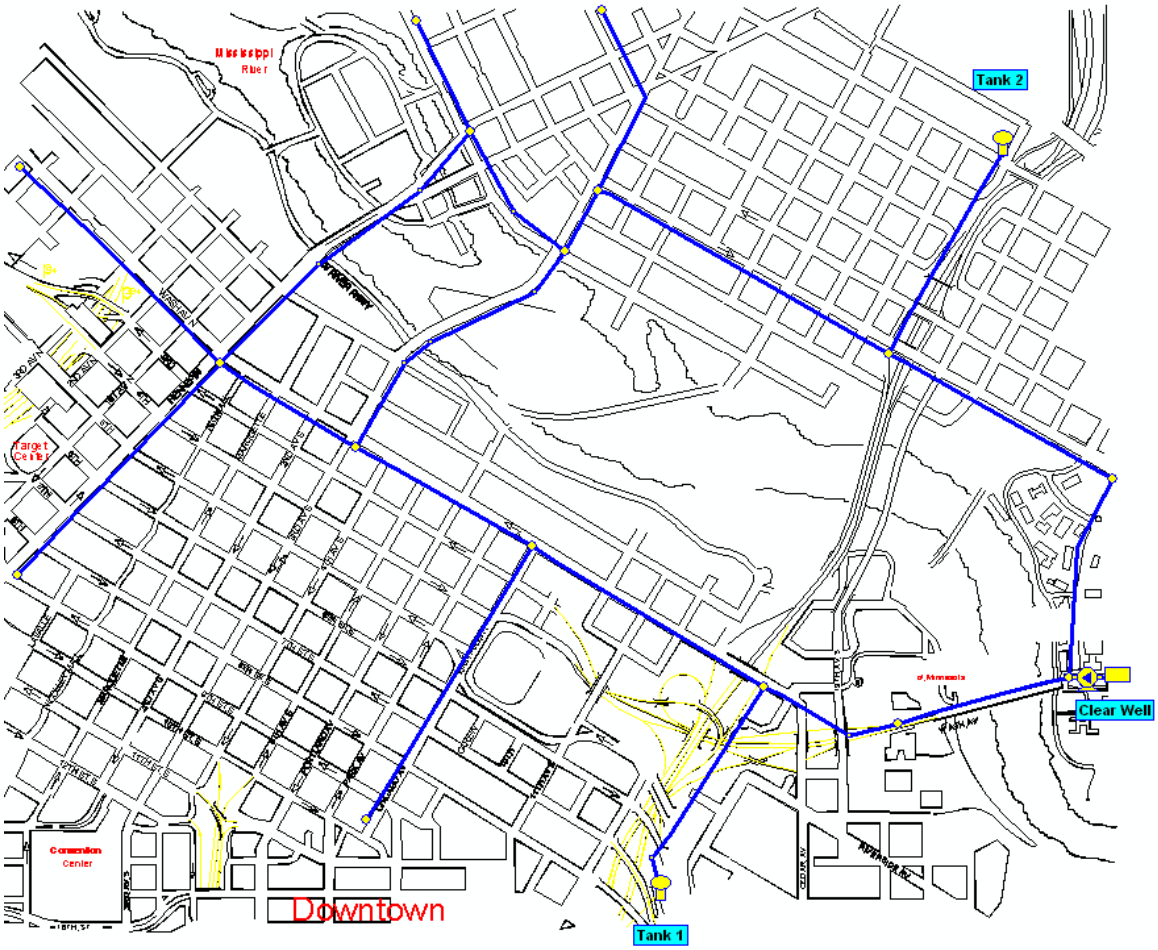


Figure 2-1 Pipe System –

2-1 –Description of System

The system is supplied by a pump which has the following head/flow/efficiency data:

Head	Flow	Eff%
220	0	68
200	600	77
160	1200	70

The system has 2 overhead 35 foot diameter storage tanks with the following characteristics:
Tank 1: Max. elevation = 755 ft., Min elevation = 735 ft. Initial level = 750 ft.
Tank 2: Max. elevation = 755 ft., Min elevation = 730 ft. Initial level = 749 ft.

The pipes are 6, 8, and 10 inch ductile iron as shown below and the Hazen Williams Roughness coefficients are all 130. The pump suction and discharge lines (visible in Figure 2-3) are 12 inch ductile iron.

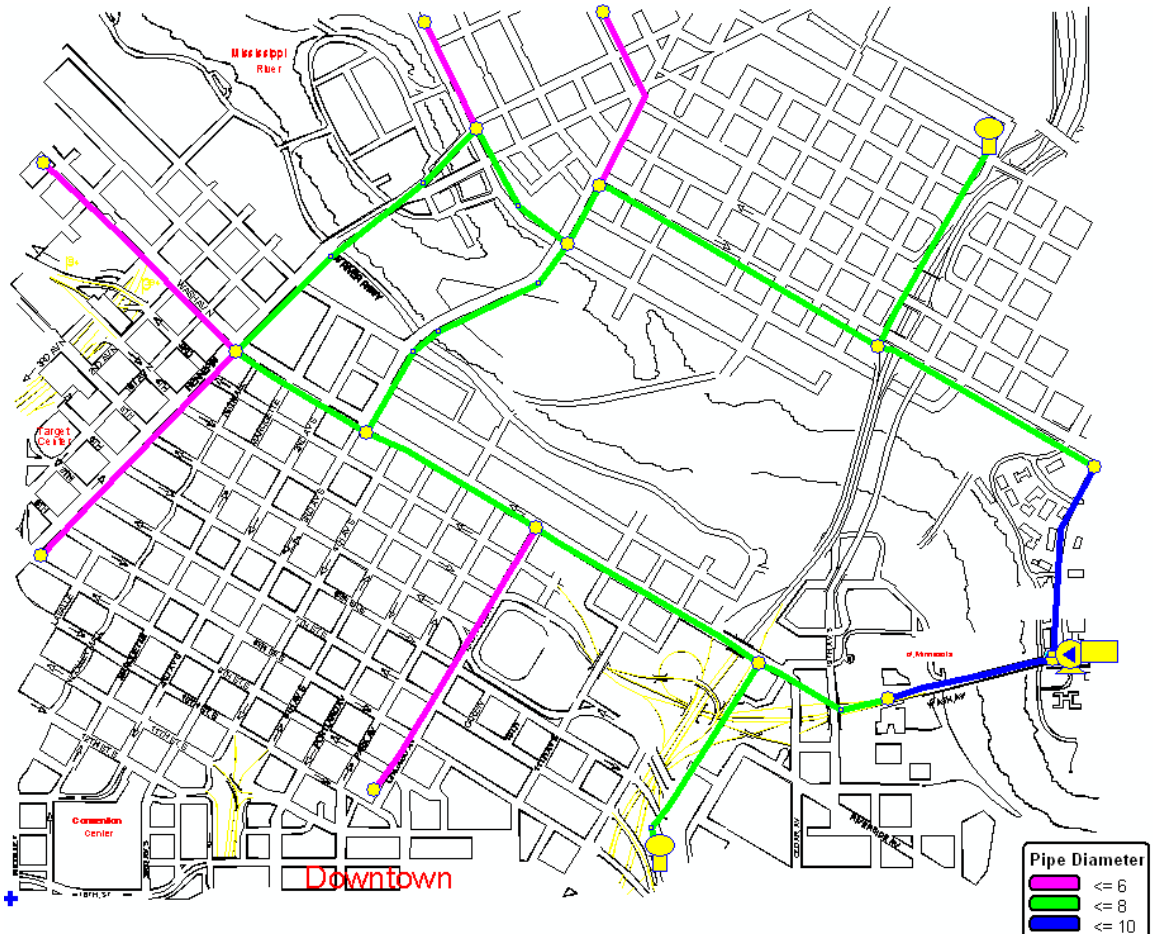
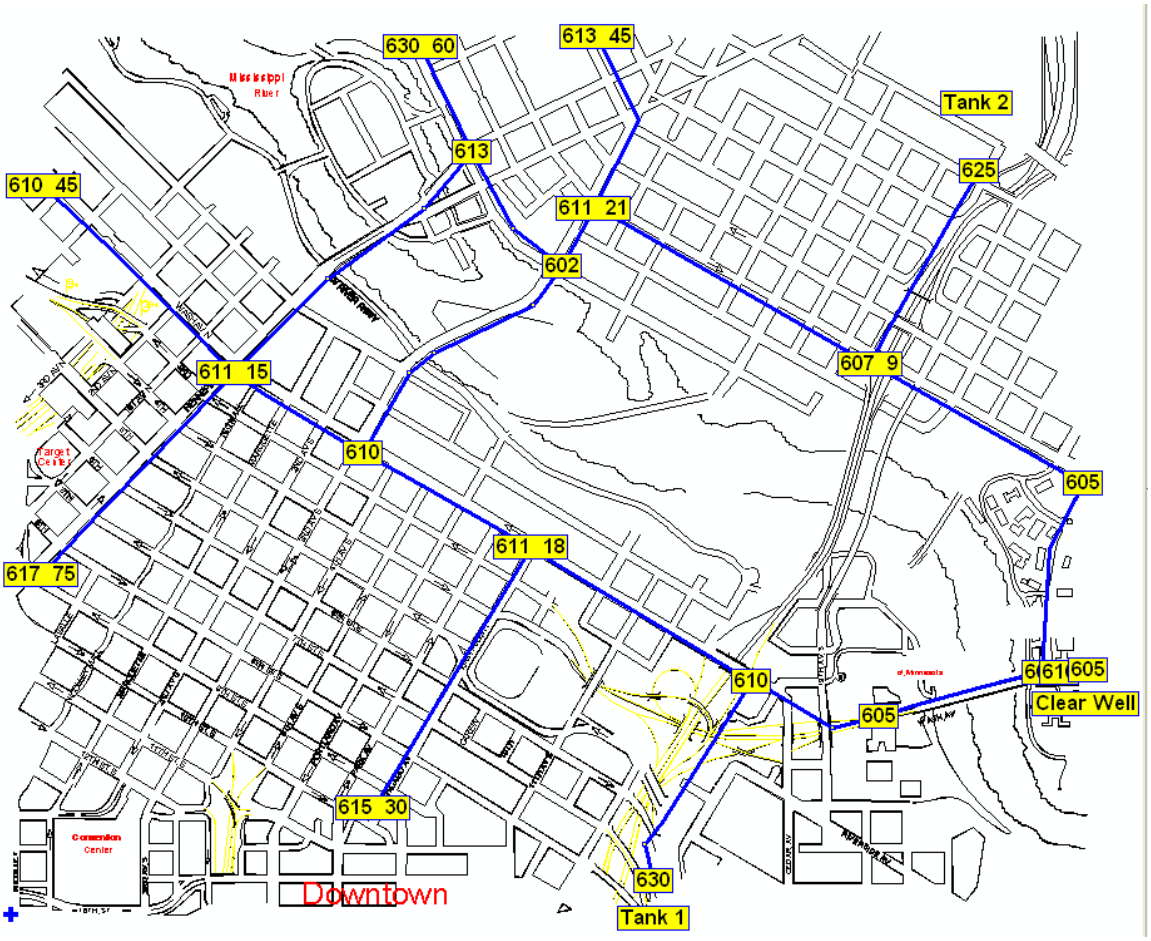


Figure 2-2 Pipe System Diameters

The node elevations (ft.) and demands (in gpm) are shown in the figures below. The demands are based on average consumer usage and are obtained from meter data. Alternately numbers of residential meter connections and individual meters can be added to the model and the demands assigned by Pipe2010. This feature will be illustrated in a later example.



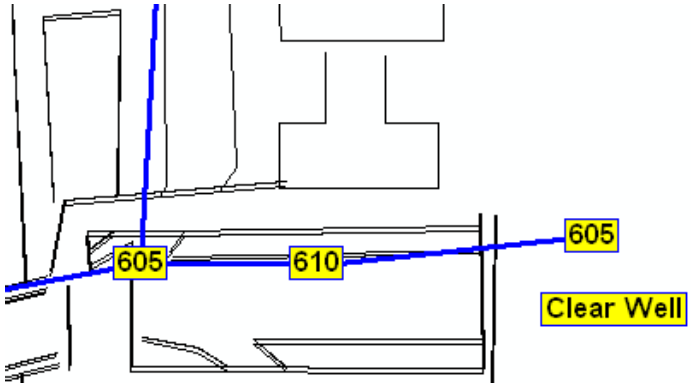


Figure 2-3 Pipe System Elevations and Demands -

2-2 – Developing the Pipe2010 Model

Step 1 – Background Map - Ideally you will have a scaled background map which can be imported into Pipe2010 and used to lay out the pipes and automatically scale the pipe lengths. If available this map should be imported to use as the background for the pipe system. For this example the background map shown in Figures 2-1 to 2-3 is a .dwg file which is a scaled vector drawing file. This map is called City.dwg and is available in the Demo subdirectory. The map may be imported as a background map as shown in Figure 2-4a and 2-4b. To add a map select **Map Settings/Backgrounds/Add Map** as shown in Figure 2-4a and use the Browser to locate the desired file as shown in Figure 2-4b

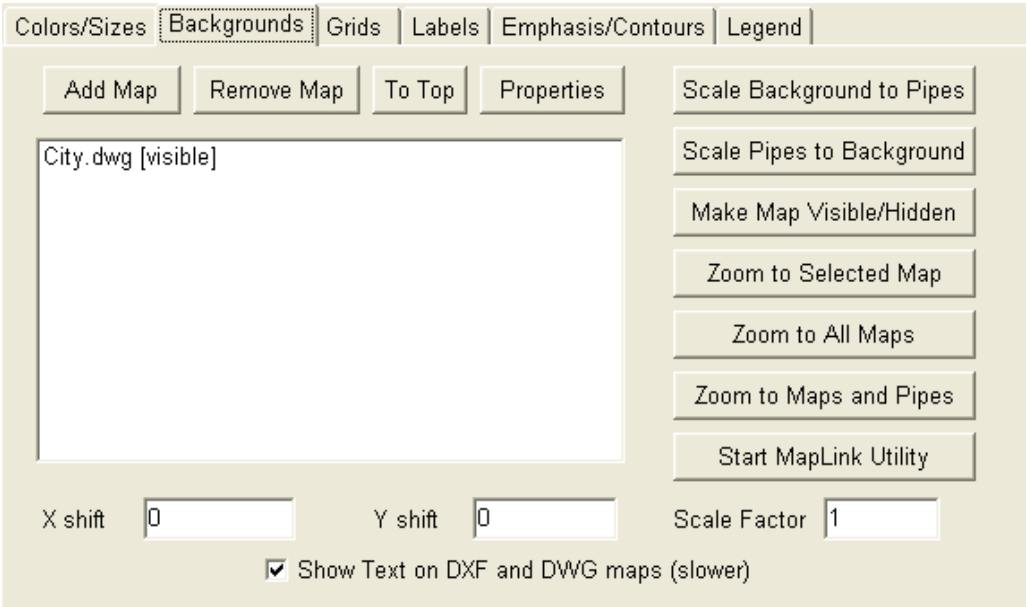


Figure 2-4a Adding the Background Map -

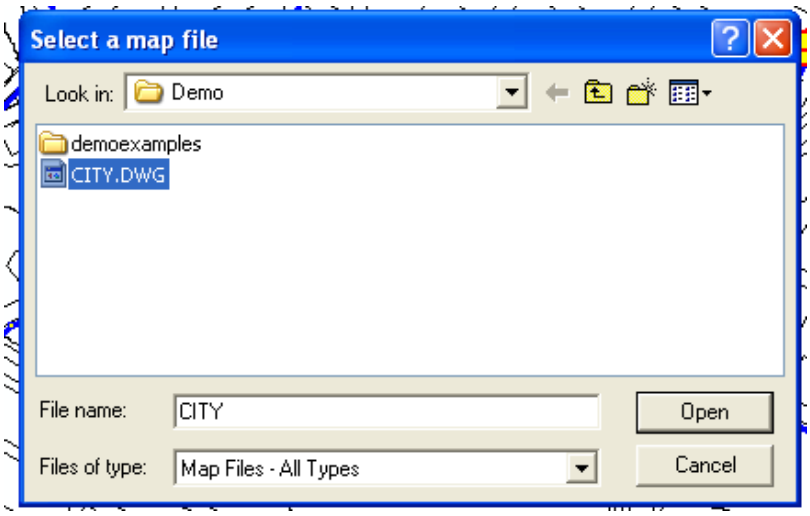


Figure 2-4b Adding the Background Map -

Step 2 – System Layout - Using the mouse and the background map as a guide the pipe system layout can be developed very quickly. Once the pipe layout is complete the 2 tanks, supply reservoir and pump nodes can be created by selecting their locations and using the Node Type dropdown list (Figure 1-8) to designate the node type. At this point your pipe system will appear as shown below in Figure 2-5a

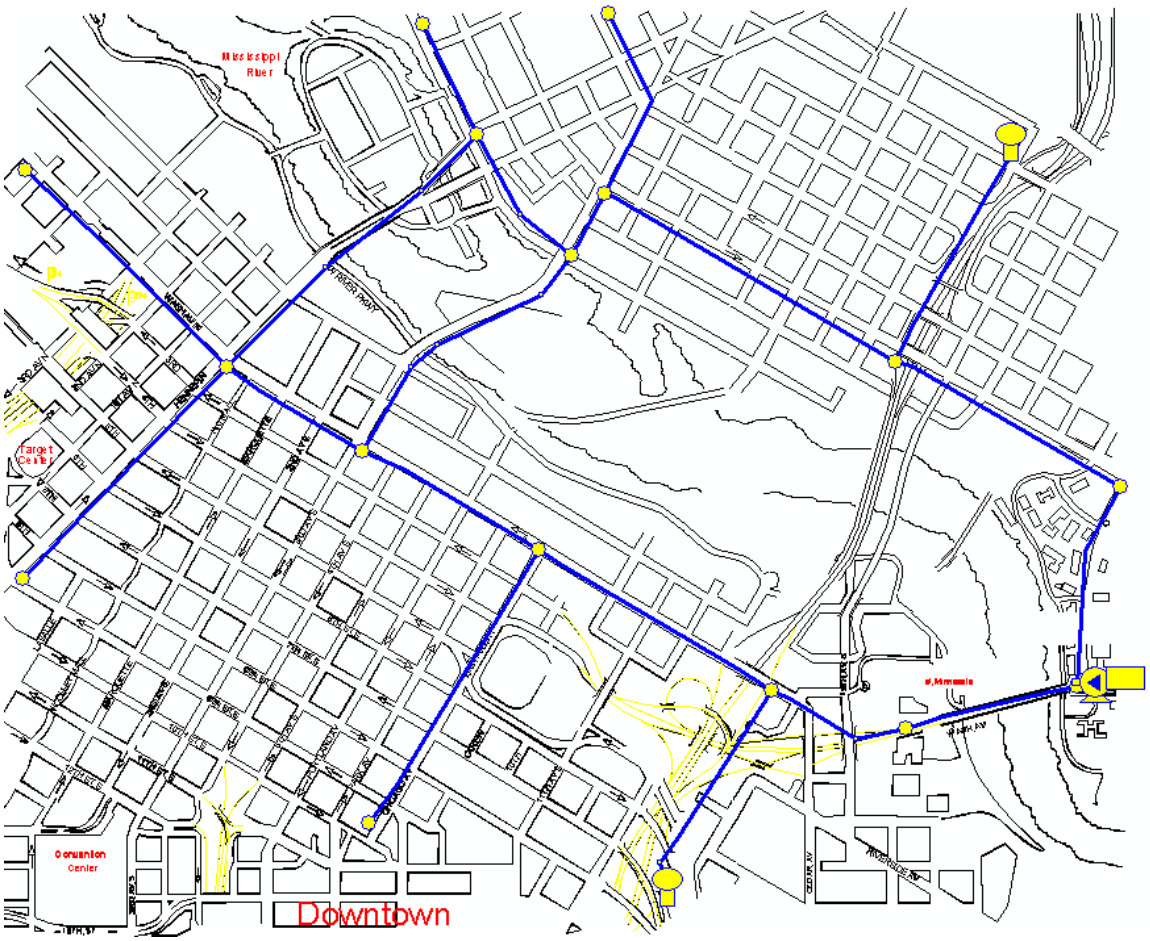


Figure 2-5a Pipe System Layout

As you lay out your piping system, Pipe2010 assigns node and pipe names. The node name assigned will depend on the order that the piping is laid out and will vary for different orders. The node names for this example which are referred to in this manual are shown in Figure 2-5b. A summary of the pipe and junction data is also presented in Appendix A along with schematics showing pipe and nodes names. For this system some elements have been added to illustrate surge analysis and surge protection devices (Part 2)

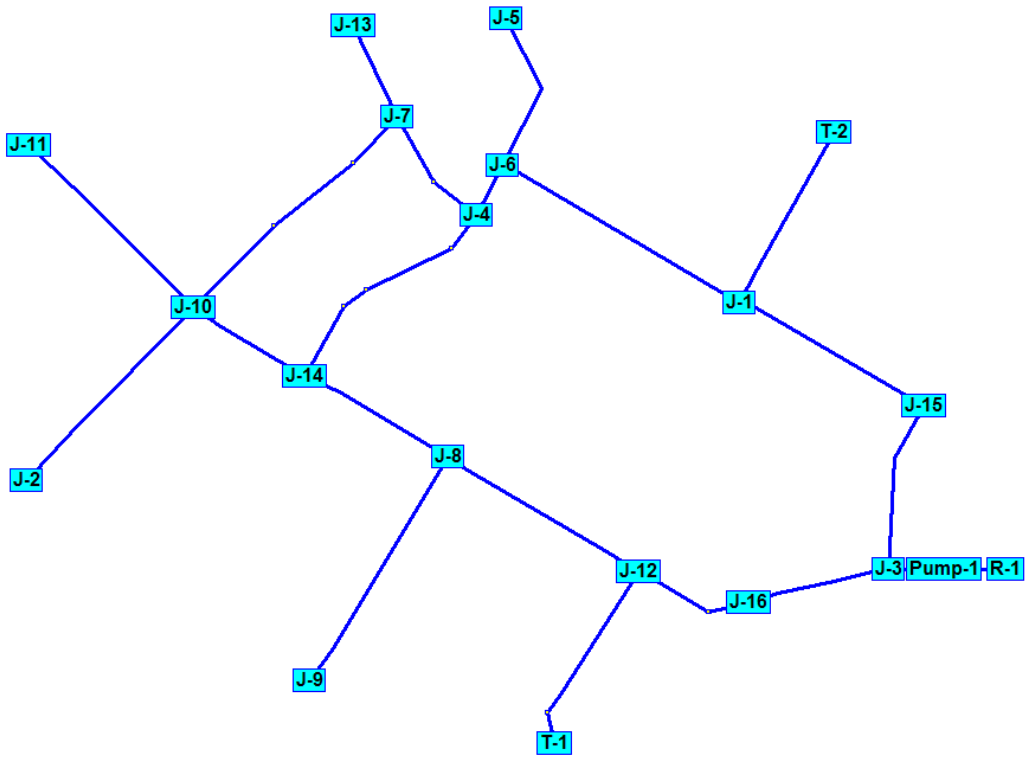


Figure 2-5b Pipe System Layout – Node Names (Part 1)

<u>Step 3 – Provide Pipe Data -</u> The recommended means to provide pipe data is to first develop the Pipe Type Table. This is accessed through **Setup/Defaults/Pipe Type** and the following table is appropriate for this example. The Reference Roughness will be the roughness assigned to this pipe unless the optional installation year is entered for the pipe along with the Estimated 10 Year Roughness. The Estimated 10 Year Roughness is utilized with the Pipe2010 aging feature and is optional.

	Material	Rating	Nominal Diameter	Actual Diameter	Unit Cost	Reference Roughness	Estimated 10yr Roughness
1	di	150	6			130	119
2	di	150	8			130	120
3	di	150	10			130	121
4	di	150	12			130	122

Figure 2-6 Pipe Type Table –

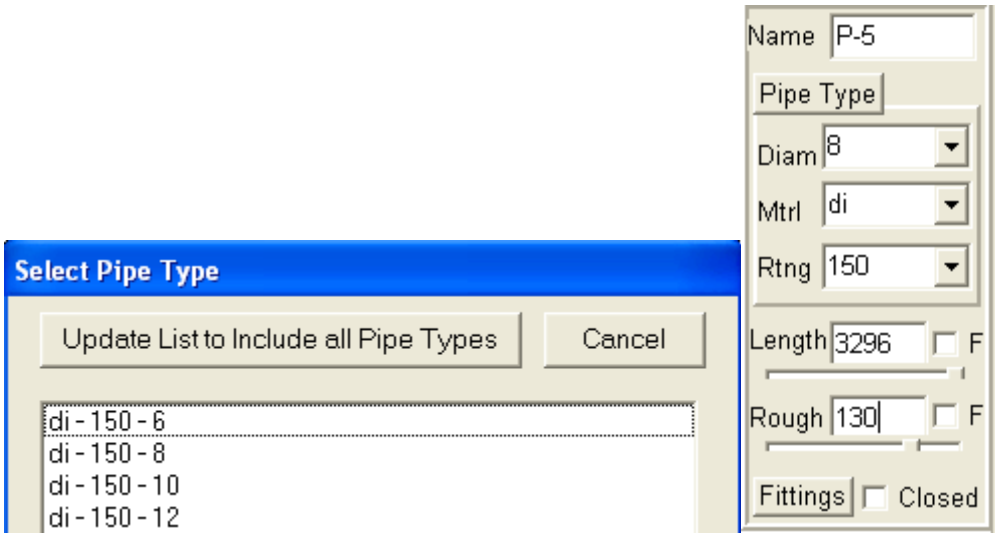
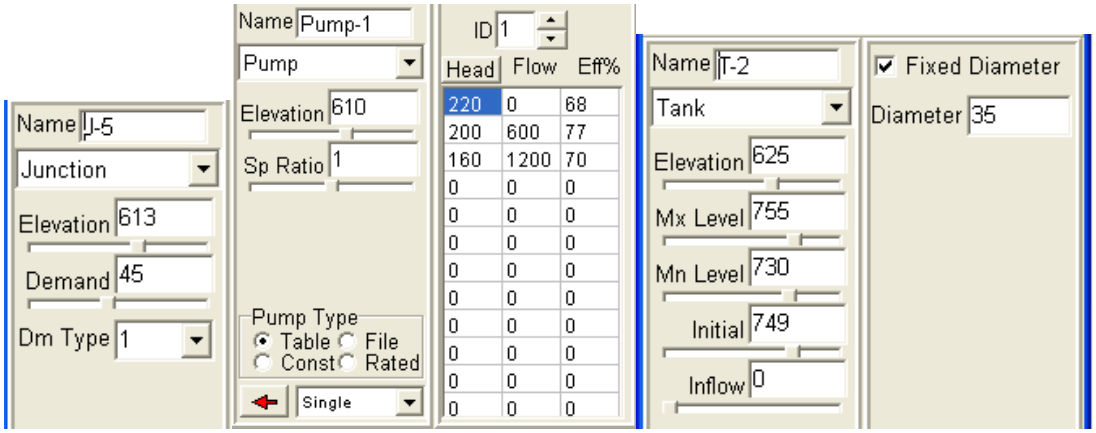


Figure 2-7 Pipe Type Table –

Figure 2-7 illustrates the Pipe Data entry. When the Pipe Type button is clicked the menu on the right appears. A click on the second entry (di-150-8) will result in all the data items except Length being entered. The length has been scaled using the background map so only the entry for Pipe Type is needed to provide the required pipe data. Additional data for Fittings or other Pipe2010 features may be entered but this is optional. The Pipe Type is entered for each pipe to complete the data requirements for pipes.

<u>Step 4 – Provide Node Data -</u> Data is then entered for each node in the system and the data requirements vary depending on the Node Type. Select the node and make sure the Data button in the Node Information is selected so the data entry screens shown below will be displayed. Node data entry is illustrated below for the top center junction, the pump and Tank 2.



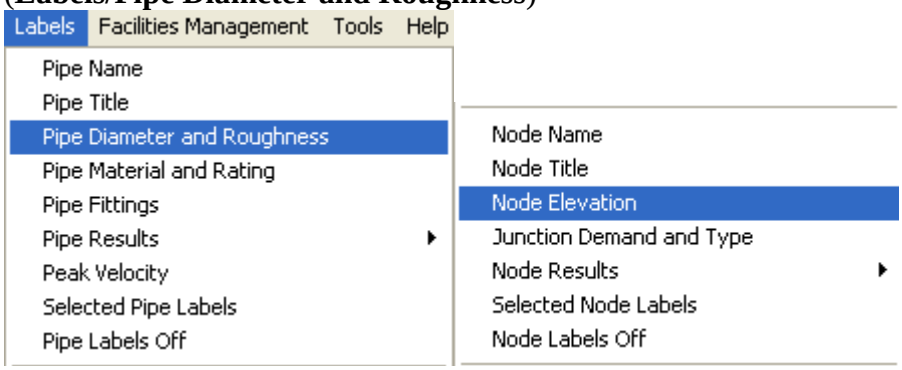
Junction **Pump (Table)** **Tank (constant diameter)**

Figure 2-8 Node Data – (Junction – Pump – Tank)

Steady State Hydraulic Analysis

2-3 – Regular Simulations and Changes (demoreg)

<u>Step 5 – Check the Data and Run the Analysis -</u> Once the data entry is complete various data checks should be performed and after the data is checked the Error Check should be run. A graphical data check is very useful and is performed by turning on labels such as Node Elevation and Pipe Diameter and Roughness as shown in Figure 2-9 (**Labels/Pipe Diameter and Roughness**)



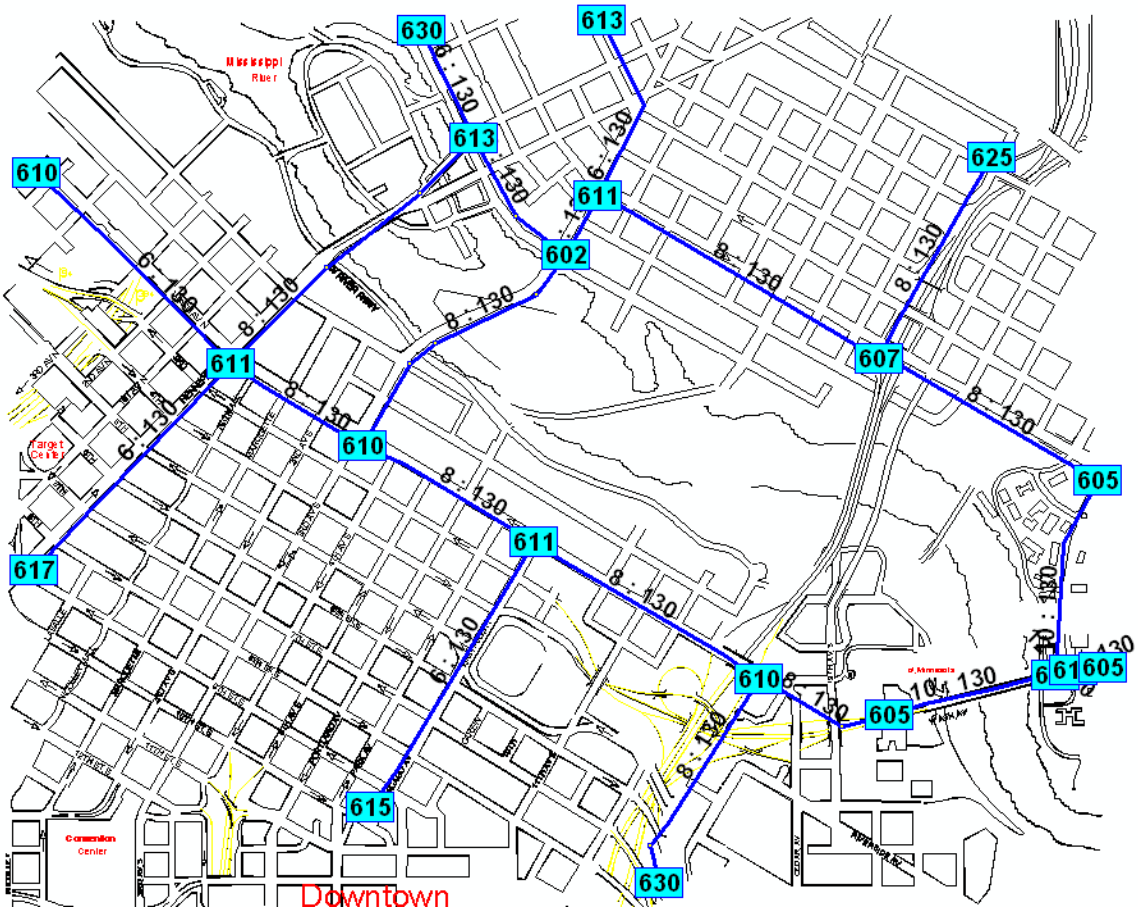


Figure 2-9 Graphically Checking Data –

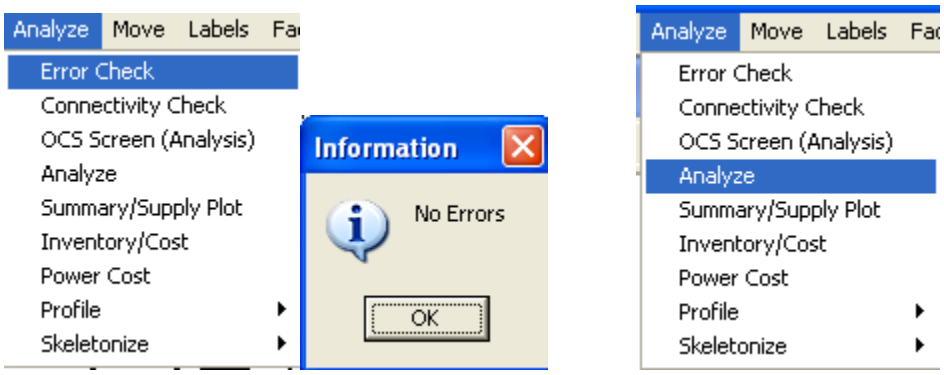


Figure 2-10 Error Check and Analysis Data –

Once the data is reviewed the Error Check and Analysis can be carried out as shown in Figure 2-10. The analysis will be for the Baseline Conditions described by the input data. The results for pressures (psi) at nodes are shown in Figure 2-11 and the flow (gpm) in Figure 2-12. Note after you select **Analysis** you will select **Use Current Year** and **KYPipe** on the Analysis Type screen which appears.

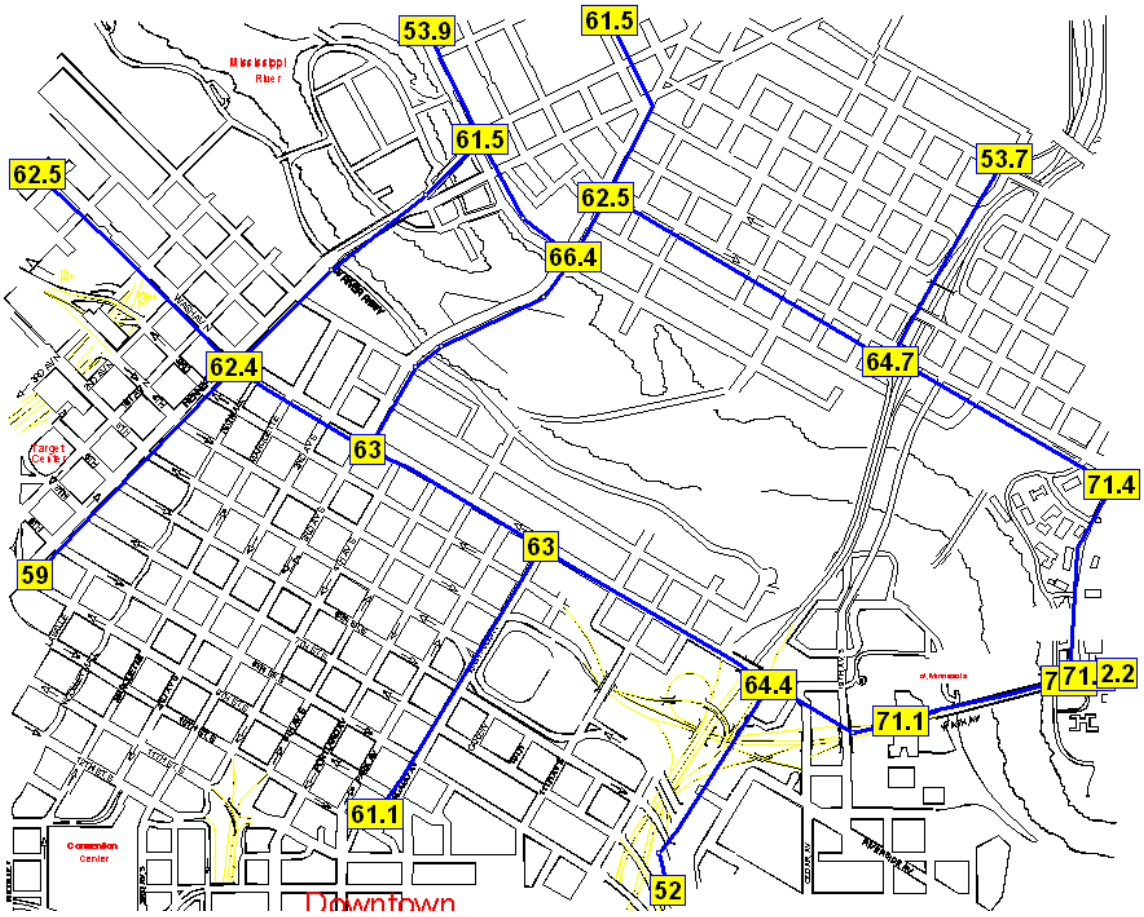


Figure 2-11 Node Pressures for Baseline Data –

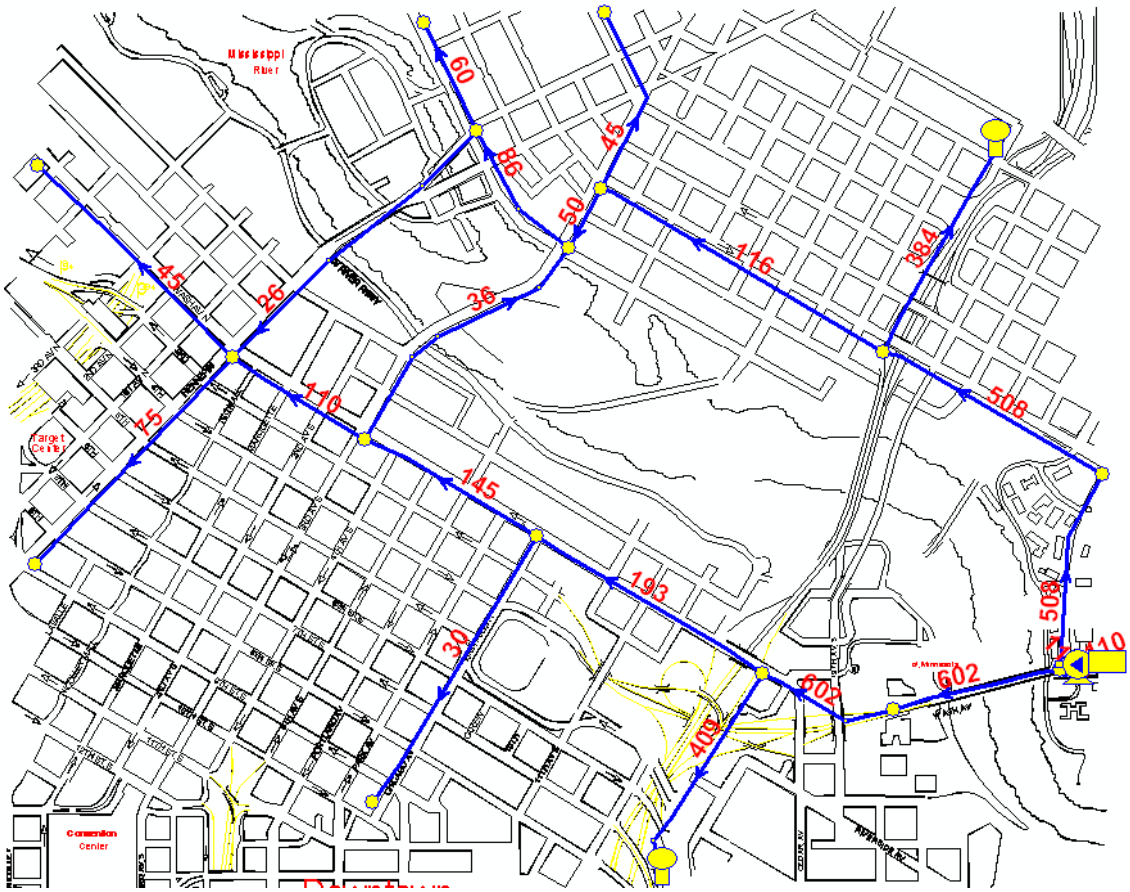


Figure 2-12 Pipe Flows (gpm) for Baseline Data –

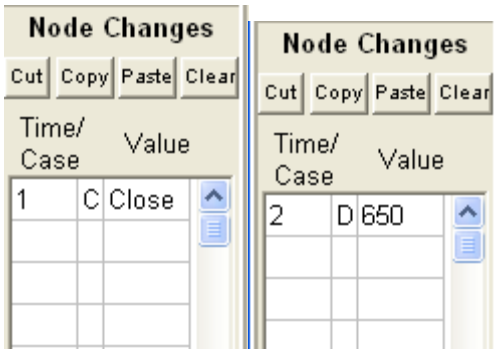
<u>Step 6 – Add Change Data and Run Additional Simulations Analysis -</u> It is desired to set up the 3 following simulations:

Case 0 - The pump is running with normal (Baseline) demands
Case 1 - The pump is off and the tanks supply the system
Case 2 - The pump is off and a fire demand of 650 gpm is placed Junction J-13 (north – pressure = 53.9 psi (Figure 2-11)).

The first simulation (Case 0) is always the Baseline Data and is the Analysis illustrated in Step 5. The additional cases can always be run by modifying the Baseline data and rerunning the analysis. However, Pipe2010 has the capability to run multiple simulations by specifying Changes to various Pipe and Node parameters. One advantage of this approach is that the results for the various runs are easily compared in Tables and Plots.

Change Data screens available for all nodes and pipes are used to set up additional simulations .The Change Data screens to set up these 2 additional simulations are shown in Figure 2-12. To set up an additional case just select the node(s) and/or pipe(s) and

enter the desired case number (remember the Baseline analysis is Case 0) , parameter type (select from list) and the new parameter value.



Case 1 Case 2

Figure 2-13 Change Data for Cases 1 and 2 –

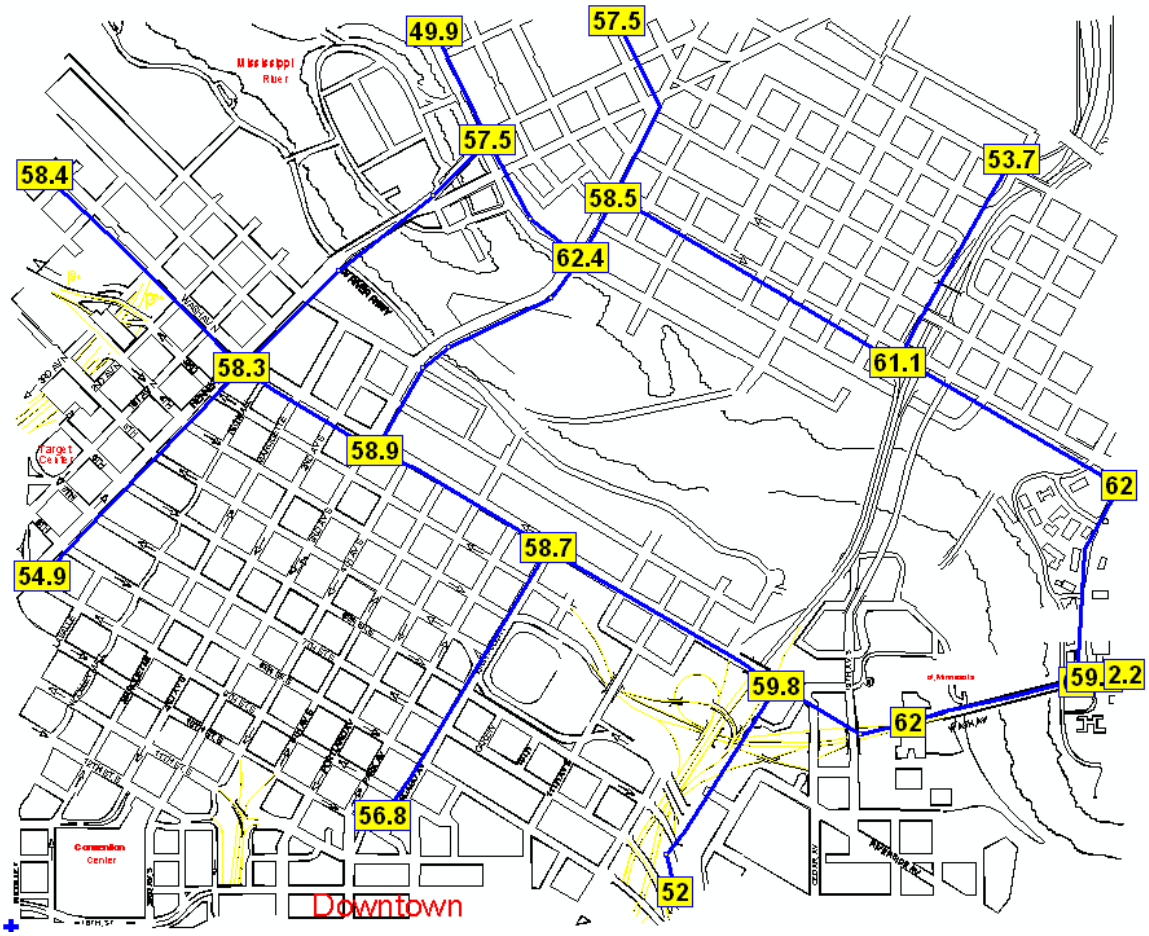


Figure 2-14 Node Pressures for Case 1 –

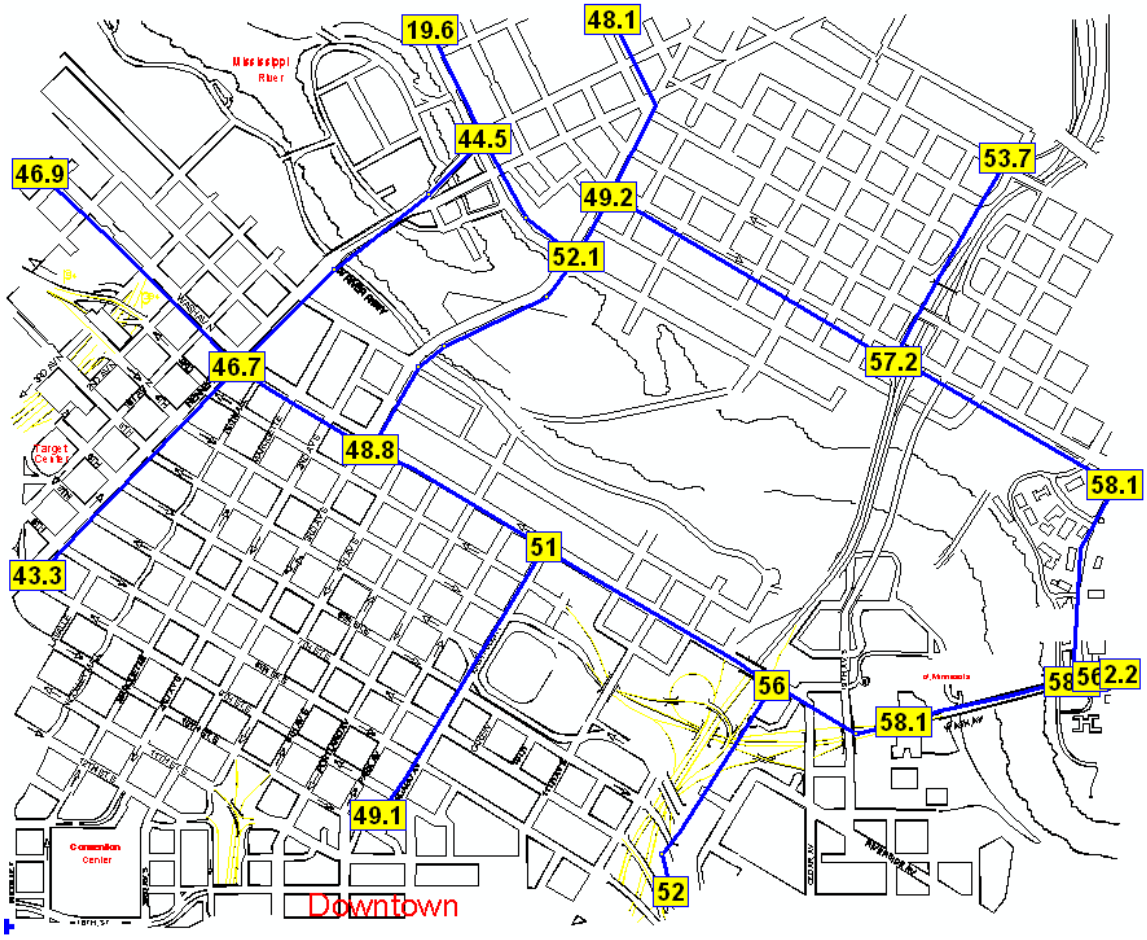


Figure 2-15a Node Pressures for Case 2

<u>Step 7 – Setup and display graphical results (pressure Contours)-</u> Pressure contours are an effective alternate way to present results. Figure 2-15b shows the setup screen (**Map Settings/Emphasis and Contours/Node Contours/Emphasis**) and the resulting pressure contour plot for Case 2. In addition you can set up displays using node emphasis (color codes) and pipe emphasis to show a variety of results such as flow velocity, node heads, etc.

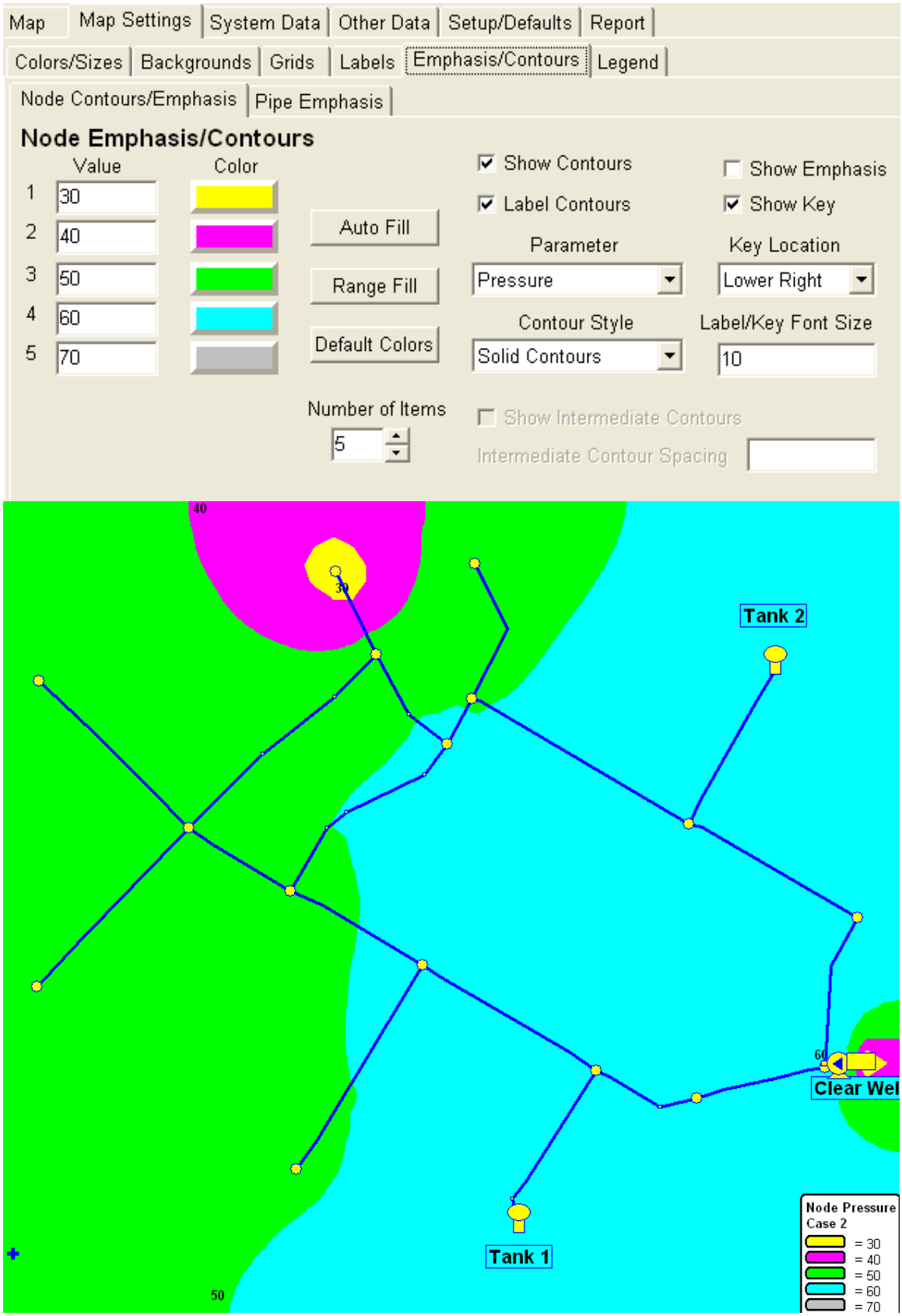


Figure 2-15b Node Pressures Contours for Case 2 – (Fire Demand)

2-4 – Additional Node Types (demoregex)

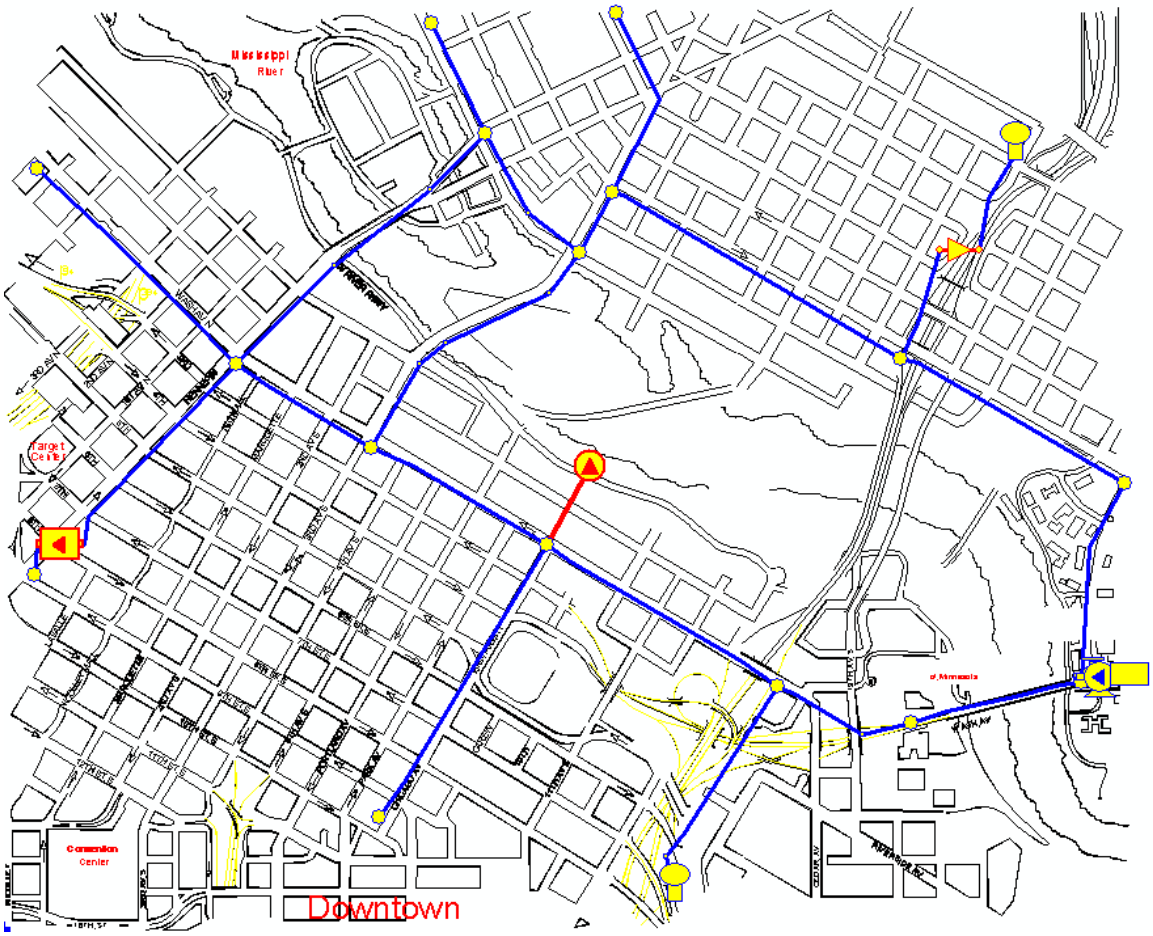


Figure 2-16 Additional Node Types –

A number of additional Node Types are illustrated in this example. These include:

a) Active Valve
b) Regulator
c) Loss Element
d) Pipe and Fountain (use Sprinkler -flow through orifice based on pressure)

For items a ,b and c insert an intermediate node at the indicated location and then simply select the node and use the Node Type dropdown list to select the specific element. To insert the intermediate node just select the pipe (LC) at the desired location and click on the **Insrt button** (Pipe Information) and select **Add Intermediate Node** from the dropdown.

The Active Valve is a pump control valve located just downstream from the pump. It is a 10 inch Butterfly valve with a Cv = 1000 when fully opened. Note that an Active Valve

can be characterized by the wide opened (100%) Valve Coefficient (Cv100%) or the resistance (R100%) and a user preference **System Data/Preferences** is available to switch from one description to the other (as shown in Figure 2-17). The data boxes for this Active Valve are shown in Figure 2-17.

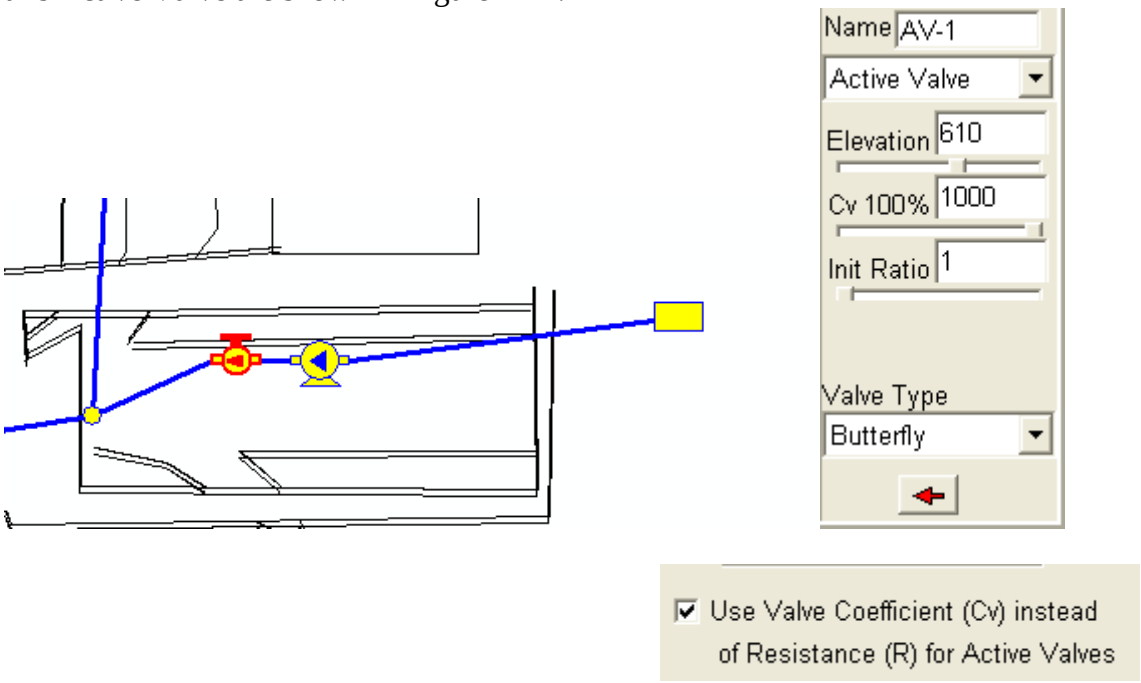
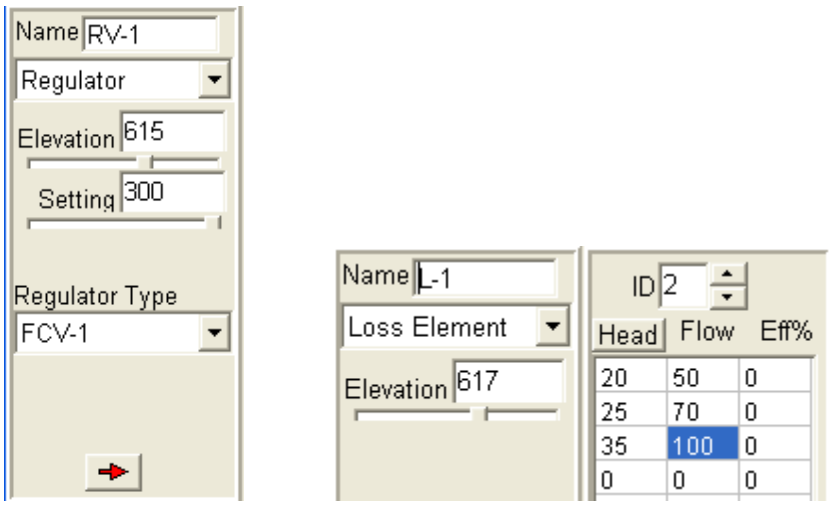


Figure 2-17 Active Valve Data

A Flow Control Valve is located in the pipe leading to Tank 2 to limit the flow to 300 gpm. The setup for this element is shown in Figure 2-18. In addition a Backflow Preventer located in the pipe leading to J-2 in the lower left side on the pipe system. This device has head loss/flow and uses a curve based on this data to determine the loss through the element (Loss Element). The data for this element is shown in Figure 2-18



Flow Control Regulator **Loss Element**

Figure 2-18 Regulator and Loss Element Data

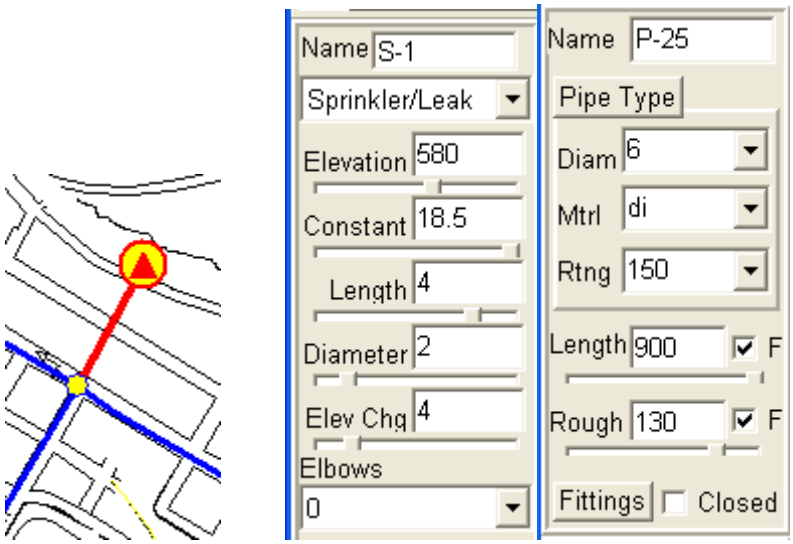


Figure 2-19 Additional Pipe and Sprinkler Data

For item d add a pipe to connect the distribution system to the sprinkler. Select the existing node where the new pipe will be added and move the mouse to the location of the fountain (sprinkler) and RC. Then select the new node and change it to a sprinkler. A 900 foot long 4 inch line leading to a 1 inch sprinkler (orifice) was added to model a fountain. At the fountain a 4 foot long 2 inch pipe rises 4 feet to the sprinkler orifice. The data for the additional pipe and sprinkler are shown in Figure 2-19. Note data for the pipe connecting a sprinkler is included with the sprinkler data. The Sprinkler Constant can be obtained using the Sprinkler/Blowoff Constant Tool as shown below.

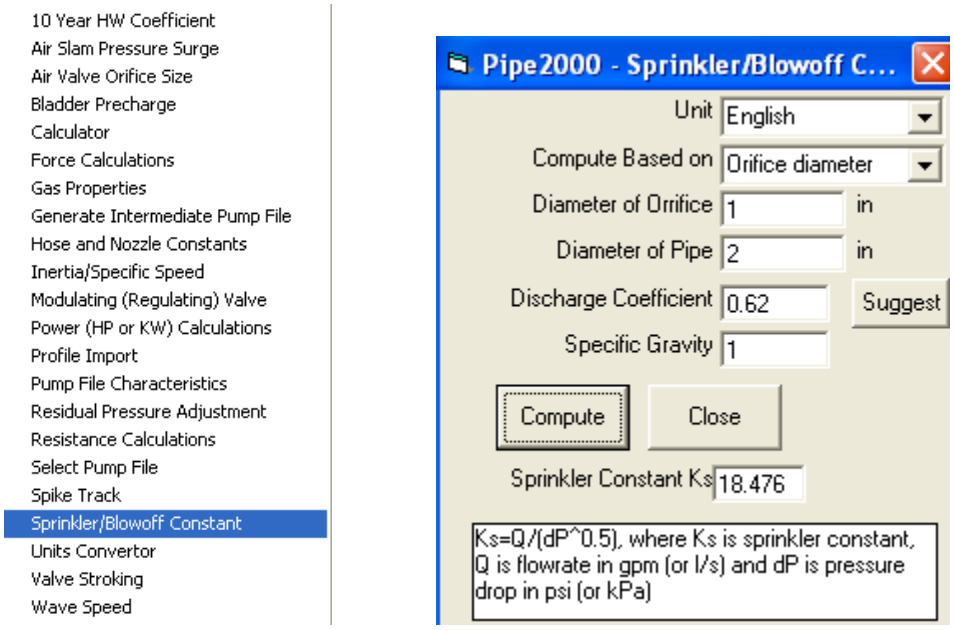


Figure 2-20 Sprinkler/Blowoff Constant Tool

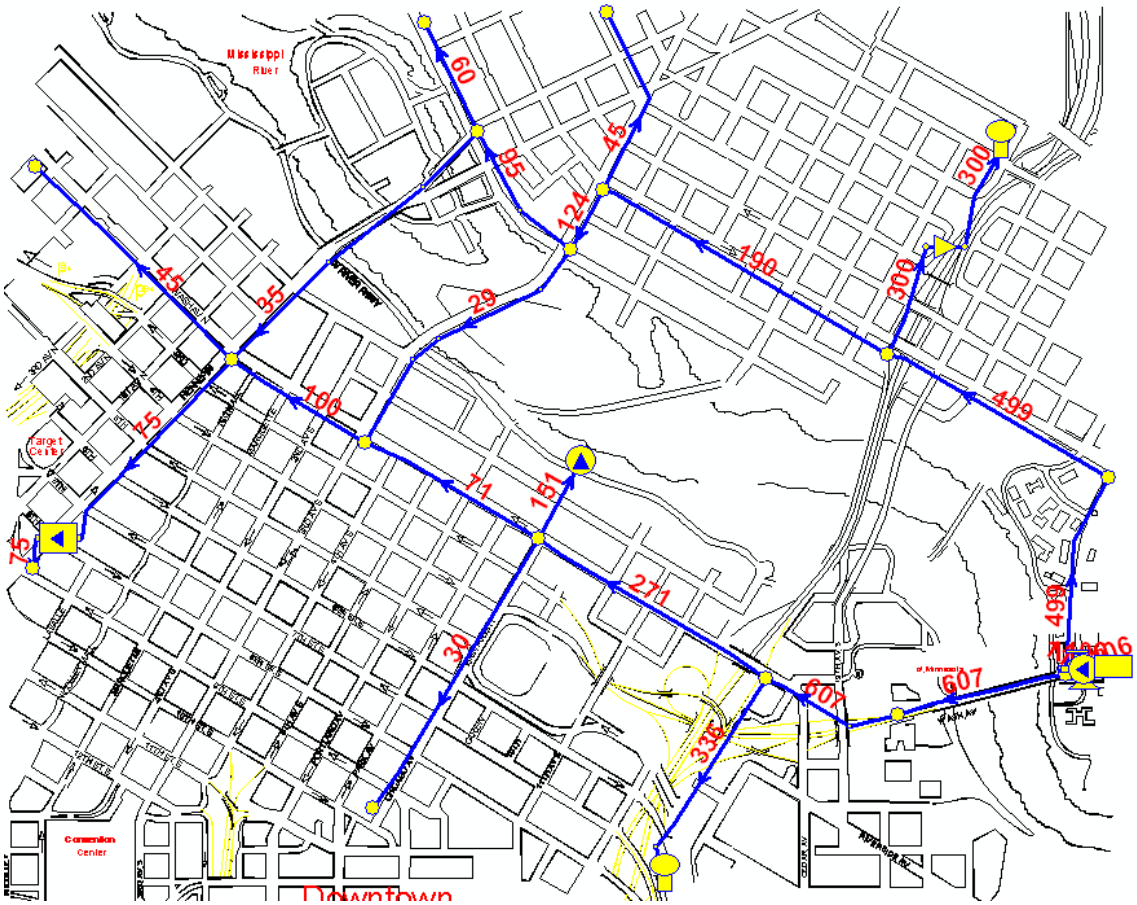
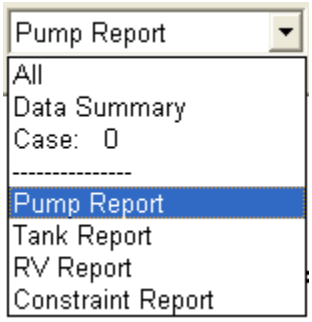


Figure 2-21a Flowrates (gpm)

Figure 2-21a and 2-21b show the pressures and flows obtained by the hydraulic analysis which includes the additional elements. The Tabulated Report contains additional sections summarizing results for various elements. The dropdown list illustrated below may be accessed when **Report** is selected from the main menu. Figure 2-22 shows the report generated for Pumps and Regulators.



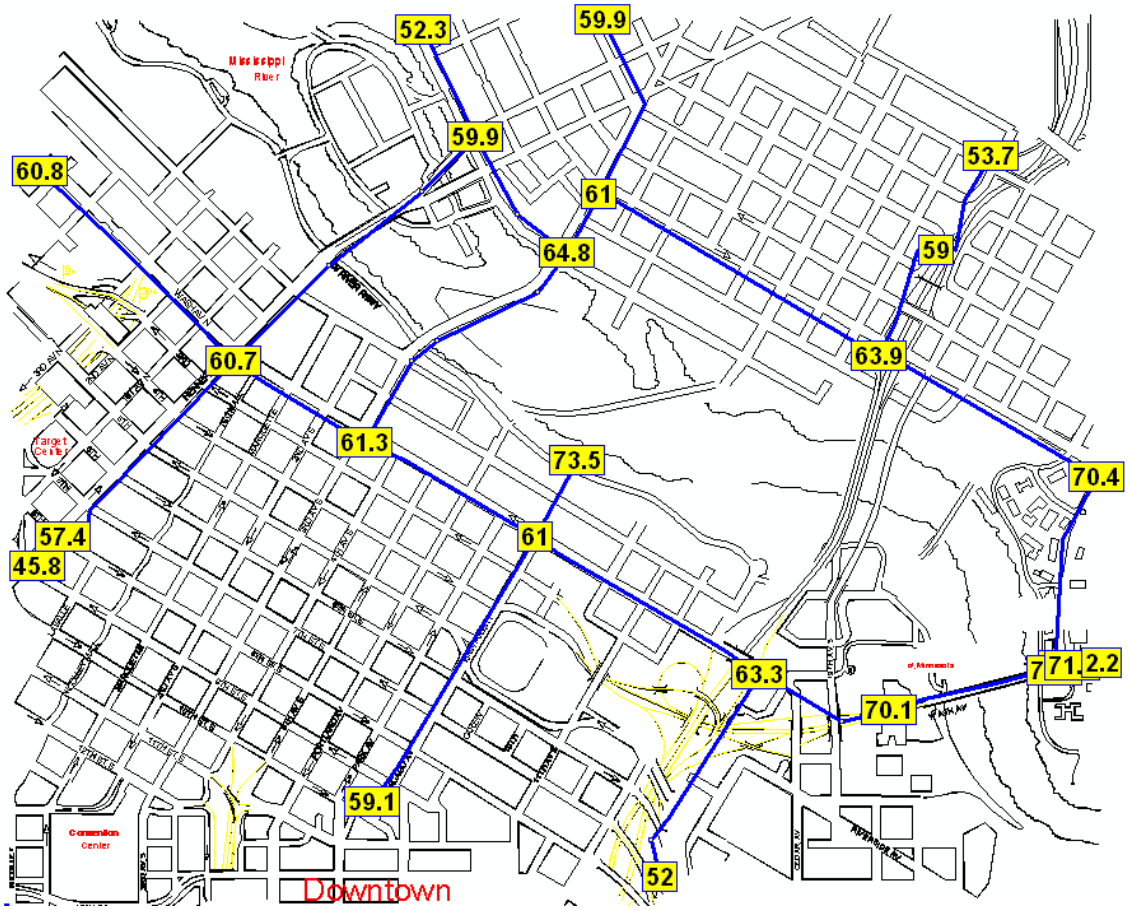


Figure 2-21b Pressures (psi)

P U M P/L O S S E L E M E N T R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
L-1	75.00	132.49	105.96	-26.5	----	-----	---	----	**	**	165.7
Pump-1	1105.50	-2.04	165.28	167.3	----	-----	---	----	**	**	31.0

R E G U L A T I N G V A L V E R E P O R T

VALVE	VALVE	VALVE (psi or gpm)	VALVE	UPSTREAM (psi)	DOWNSTREAM (psi)	THROUGH (gpm)
RV-1	FCV-1	300.00	ACTIVATED	59.38	59.01	300.00

Figure 2-22 Pump and Regulator Reports

2-5 – Fire Hydrants (demoreghyd)

Fire Flows - Pipe2010 has some very useful capabilities for fire flow and flushing calculations and plots. Locations and a reference name are shown below (Figure 2-23) for 9 fire hydrants and fire flow test data for the hydrants is shown in Figure 2-24. To add these hydrants to the model just select the pipe at the desired location in the pipe for the hydrant and click on the insert (**Insrt**) button and select Hydrant from the dropdown list.

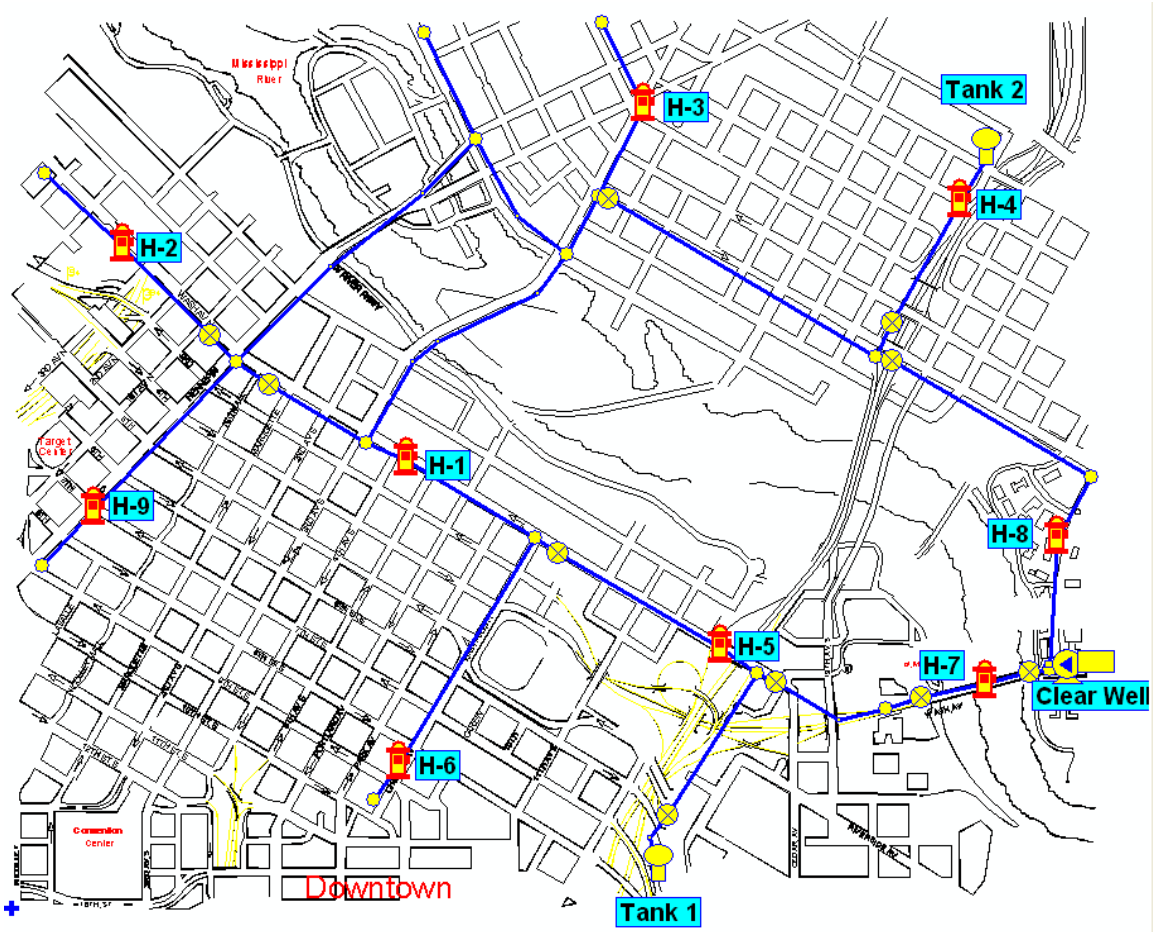


Figure 2-23 Fire Hydrant Locations

Name	Elv.	Static Pressure	Residual Pressure	Residual Flow
H-1	611	66	47	800
H-2	612	58	44	370
H-3	610	59	34	660
H-4	620	54	46	1400
H-5	610	65	39	1550
H-6	615	63	44	370
H-7	605	71	60	1700
H-8	605	70	58	1330
H-9	615	58	32	407

Figure 2-24 Fire Hydrant Test Data

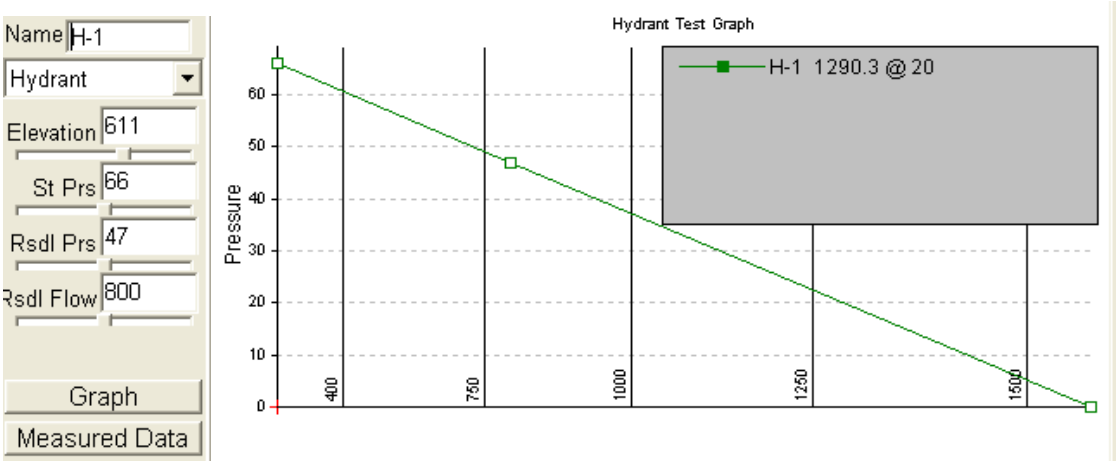


Figure 2-25 Fire Hydrant (Test) Data and Flow Plot

Once a hydrant is added the hydrant can be selected and the elevation and fire flow data shown in Figure 2-26 can be entered as shown above. The **Graph** button allows you to generate Fire Flow Test Data plots such as the one shown in Figure 2-25. This plot using a $Q^{1.85}$ factor for the X axis is used for predicting the available fire flow from the test data (this follows AWWA and NFPA guidelines). Hydrants also allow you to use your model to calculate available fire flows and flushing flows. The Pipe2010 setup screen for Fire Flow calculations is shown below in Figure 2-26. Pipe2010 provides a variety of fire flow and hydrant flushing calculations although the most common is the Available Fire Flow at a Specified pressure (usually 20 psi) which is illustrated below.

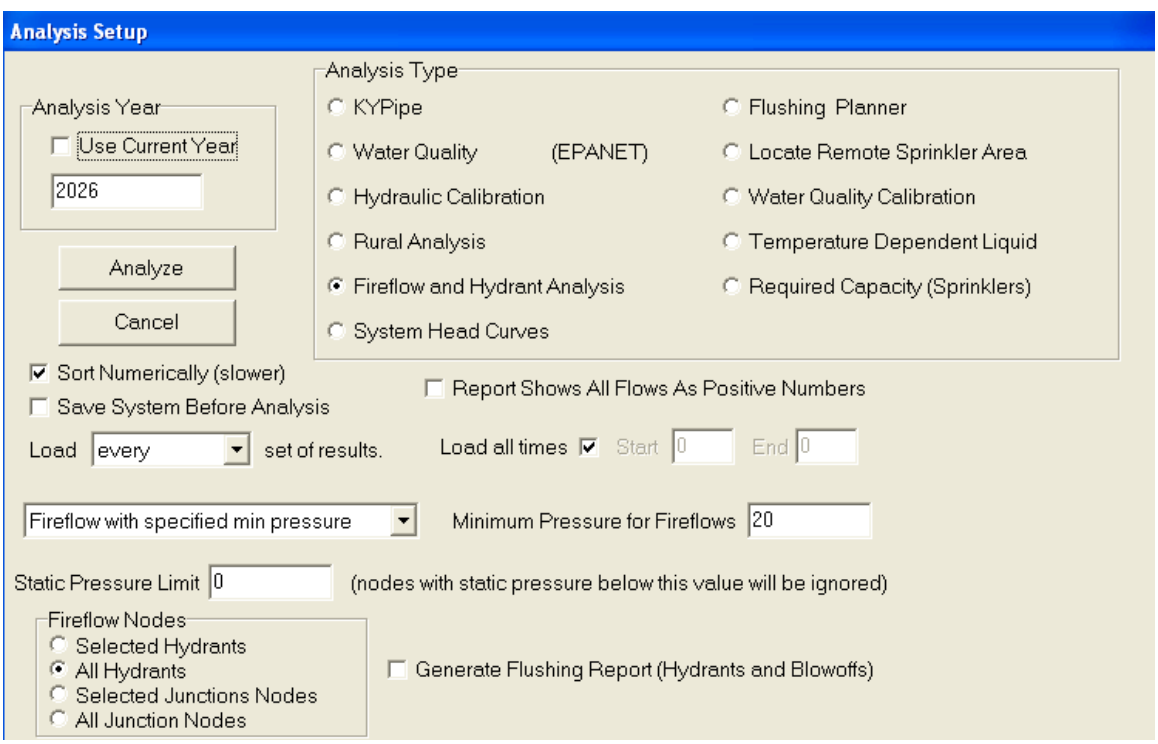


Figure 2-26 Fire Flow Calculations Set Up Screen

Fireflow/Hydrant Report:

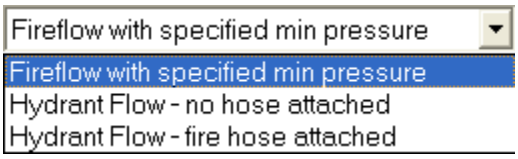
Specified Minimum Pressure(psi or kPa): 20.00
Minimum Static Pressure(psi or kPa) : 0.00

Flow-1: Flowrate to maintain the specified pressure at (hydrant) node
Node-2: Node that has a lower pressure than specified value at Flow-1
Flow-2: Flowrate to maintain the specified pressure at Node-2

Hydrant Node	Elevation	Demand gpm	Static Pressure	Flow-1 gpm	Flow-2 gpm	Node-2
H- 9	615.0	0.0	60.1	557.3	547.6	J- 2
H- 8	605.0	0.0	71.9	3570.6		
H- 4	620.0	0.0	56.6	4336.6		
H- 3	610.0	0.0	62.9	870.6	852.9	J- 5
H- 5	610.0	0.0	64.3	2764.3		
H- 6	615.0	0.0	61.1	562.4		
H- 2	612.0	0.0	61.7	654.9		
H- 7	605.0	0.0	72.2	3962.6		
H- 1	611.0	0.0	62.7	1718.1	1644.1	J-13

Figure 2-27 Fire Hydrant Analysis and Report

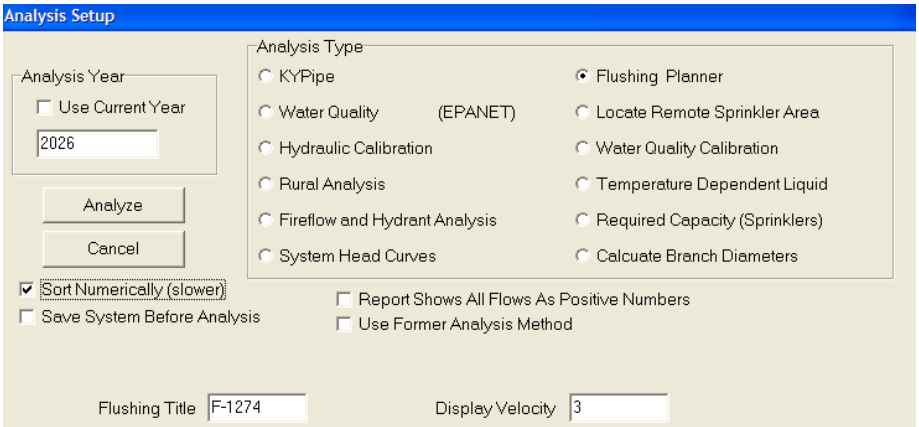
Flushing Flows - The Set Up screen shown in Figure 2-26 will analyze all the fire hydrants in your model to calculate the fire flow available at each hydrant (one at a time) such that the pressure in the system is above 20 psi at all locations. Normally the minimum pressure occurs at the fire hydrant but it may occur at a different location. If this happens the Fire Flow Report shown above will list 2 additional columns of calculations showing the reduced fire flow and the node location where the minimum pressure occurs. Additional options unique to Pipe2010 allow you to calculate flushing flows and flows with a fire hose and nozzle attached. The options are selected from the dropdown list shown below which appears on the Fire Flow and Hydrant Analysis setup screen.

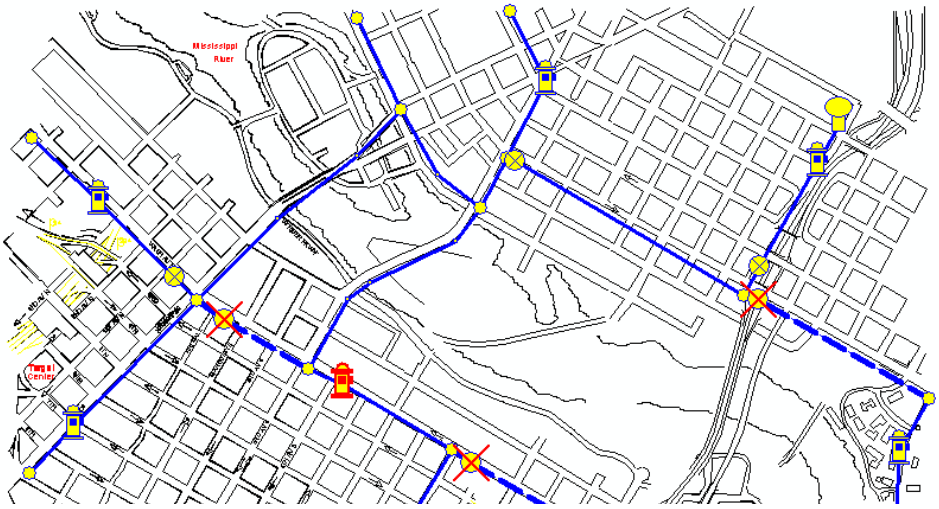


In addition you can use the Pipe2010 Flushing Planner to evaluate flushing capabilities. To use this module the following steps illustrated in Figure 2-28 are required.

1) Close appropriate On/Off valves (LC and clock on On/Off button) (2nd display)
2) In Group mode select one or more hydrants to be opened (2nd display)

3) Select Analysis/Flushing Planner and set desired velocity (top display)
4) The Pipe2010 analysis automatically produces display highlighting flushed pipes (bottom display)





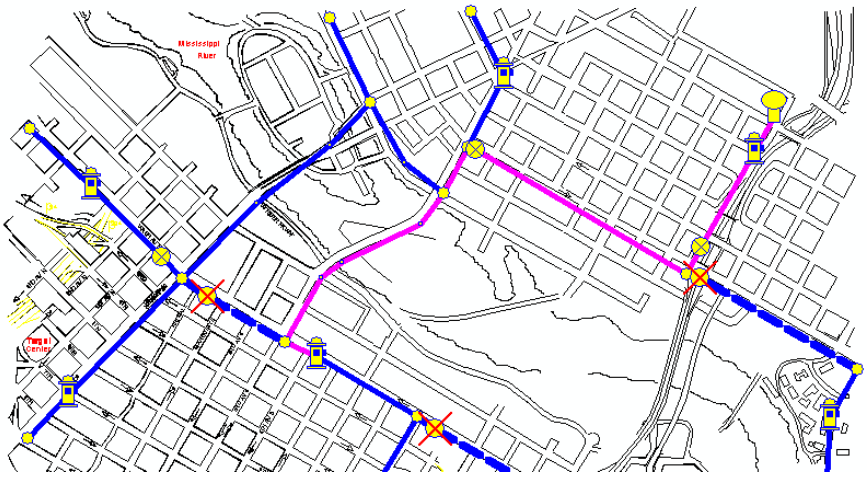


Figure 2-28 Flushing Setup and Graphical Presentation

3 Extended Period Simulation (EPS) Hydraulic Analysis

3-1 –Setting up an EPS (demoeps1)

It is a simple matter to set up an Extended Period Simulation (EPS) using the Baseline Data for the system. Care should be taken to initially clear any Change Pattern Data before setting up the EPS (select **Setups and Defaults/Change Patterns** and click on the **Clear** button). To run an EPS go to the EPS Setup Screen (**System Data/EPS**) and enter data as shown in Figure 3-1. For a utility water distribution system such as this example a 24 hour period using a 1 hour computational period is a common selection although a shorter time period may be needed if there are numerous events during the period (tanks filling or emptying and pumps coming on and off).

Figure 3-1 EPS Setup Screen

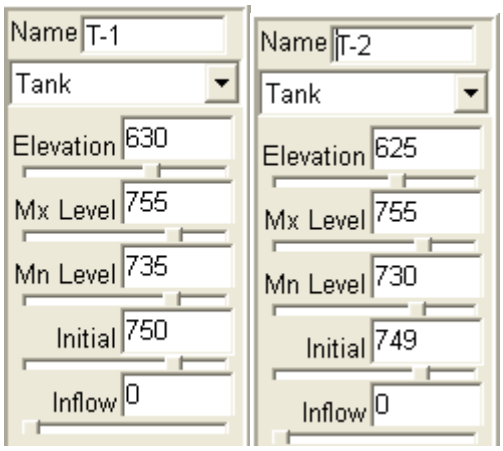


Figure 3-2 Tank EPS Data

For an EPS the maximum (Mx) and Minimum (Mn) tank levels are significant items. This data shown in Figure 3-2 will cause the tanks to shutdown if either of these limits is

reached. For municipal water systems the demands will vary hour by hour because of the variation in the Diurnal Curve as shown in Figure 3-3. This curve shows the demand factors which multiply the average demand to get hourly demand levels. This curve was developed by AWWA based on field measurements provides a rational basis for varying the demands over a 24 hour period (Demand Pattern). Pipe2010 has the capability to setup, save and load any Demand Pattern and provides one based on the AWWA curve (AWWA.dmt). This Demand Pattern file is loaded as shown in Figure 3-3 and used for this example.

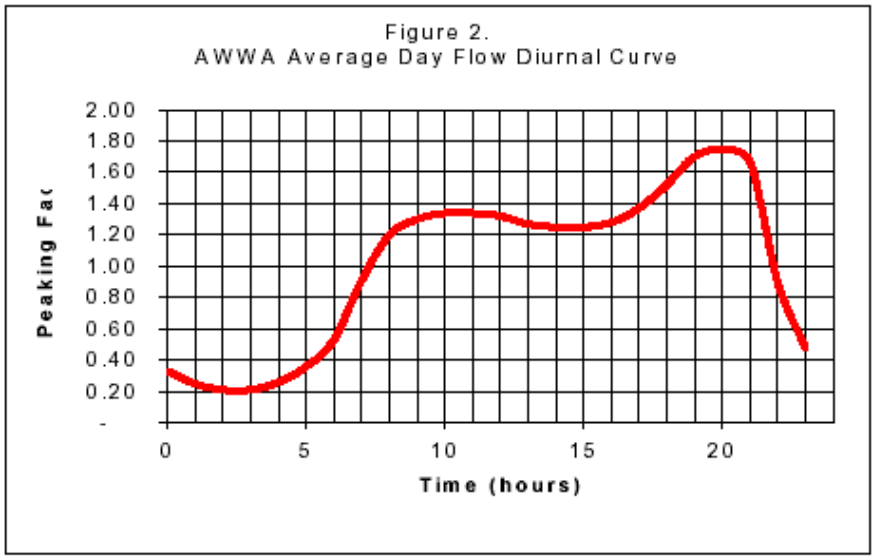


Figure 2
AWWA Average Day Flow Diurnal Curve
(Source: AWWA Manual M32)

Figure 3-3 Diurnal Curve Data from AWWA

Pipe Type | Fittings | Sliders/Precision | Change Patterns | Demand Patterns | Table Setup

Load | Save | Clear | Total Time 23 | Time Inc 1

Pattern Name AWWA.dmt | Global Demand Factor 1

Time/Change	0	1	2	3	4	5	6	7
Power Cost								
Residential								
Type 1	0.33	0.25	0.21	0.21	0.26	0.36	0.53	0.91
Type 2								
Type 3								

Figure 3-4 Demand Pattern EPS Data

For this example the pump is always on. For an EPS the pump status can be controlled either by inputting Change Data which can be used to turn the pump on or off at designated times or a Control Switch which can be used to control the pump on/off status based on pressures of tank levels. Therefore, this EPS example illustrated the tank action based only on demand variations.

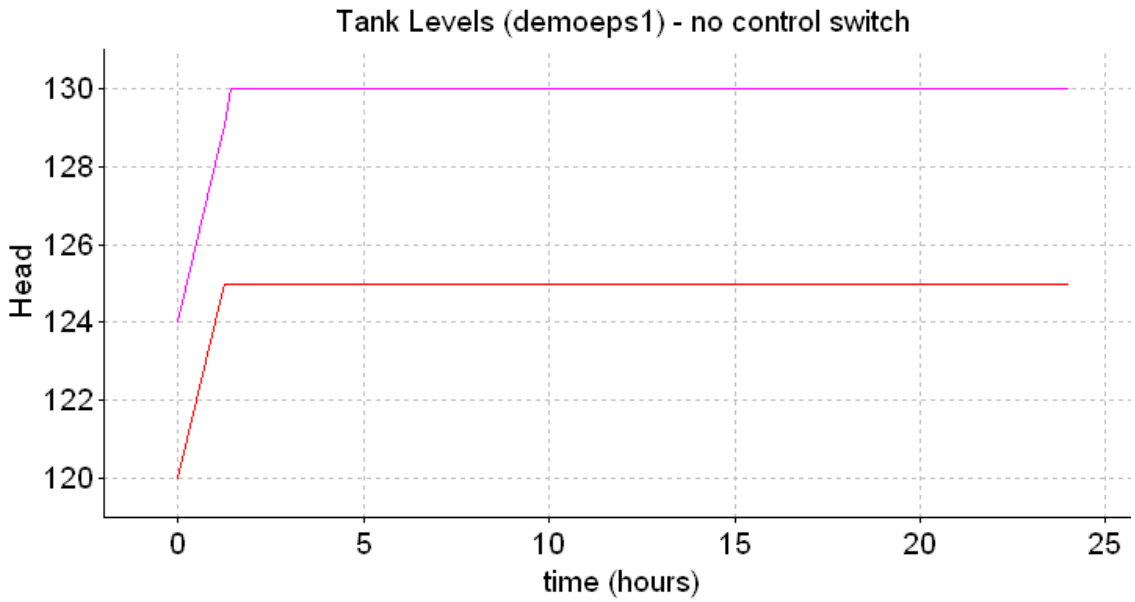


Figure 3-5 Tank Levels

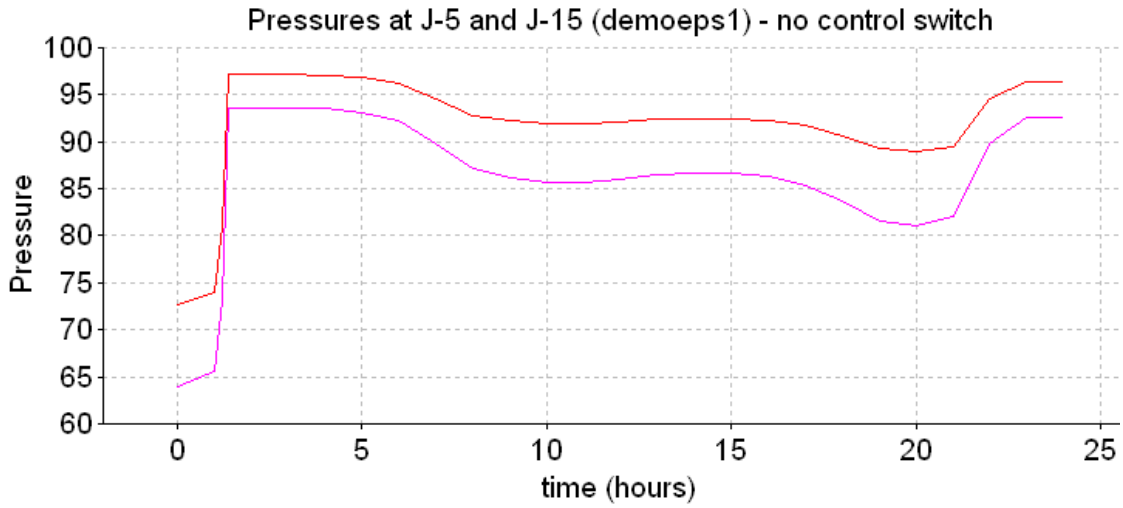


Figure 3-6 Pressures at Selected Nodes

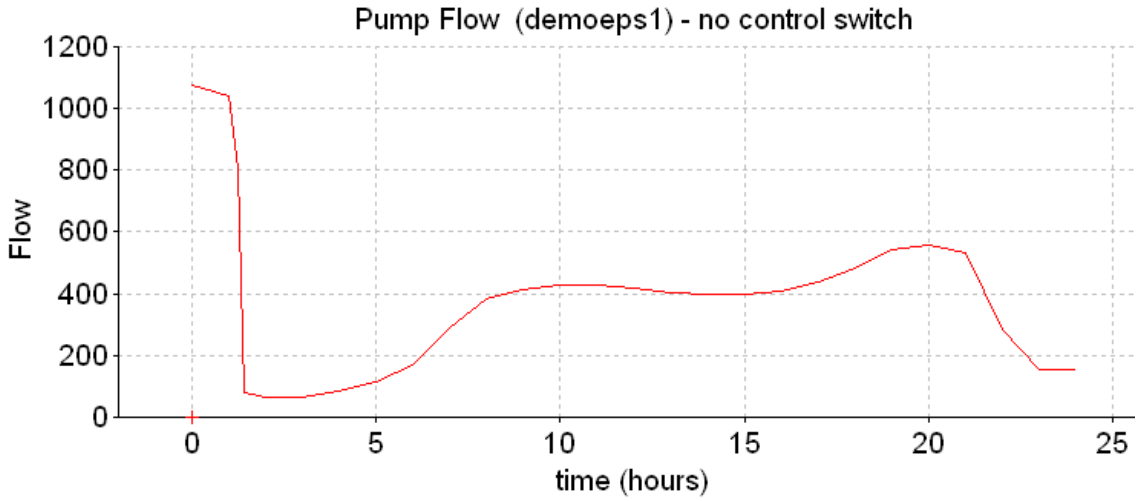


Figure 3-7 Pump Flow

Figures 3-5 through 3-7 show results for this simulation. Figure 3-5 shows that the tanks are completely filled within the first 2 hours and stay full for the rest of the simulation. This causes the pump to run at a low flow and high head and produces a substantial pressure increase when the tanks fill as shown in Figure 3-6. Figure 3-8 shows the report on the pumping cost from the tabulated report. To obtain this report you must enter a cost/kilowatt hour as shown in Figure 3-1.

```
****************************************************

TOTAL POWER COST($) FOR THIS SIMULATION =     36.30

****************************************************
```

Figure 3-8 Power Costs - Pump On

3-2 – EPS (demoeps2 – control switch))

The results for the previous example illustrate a situation which would normally be unacceptable for a water utility distribution system. The tanks cannot remain full because of water quality concerns. This example (demoeps2) illustrates controlling the pump using the level of the water in Tank 1 (T-1). For this illustration we add a pump control switch which will turn the pump (Pump-1) off when the water level exceeds 753 feet (hydraulic grade) or 123 feet based on ground elevation. This is 2 feet below the maximum level (125 feet). The pump will then come on when the level drops below 107 feet (HGL = 737 feet). The setup for this Control Switch (**Other Data/Control Switches**) is shown in Figure 3-9.

Control Switches | Constraints | Calibration | Quality | Quality Calibration | Meters | Library Elements | Active Valves

Switch Units HGL (ft or m)

controlled element	is	on/ off	when	sensing node	is	below/ between	low level	and	on/ off	when	above	high level
Pump-1	is	on	when	T-1	is	below	737	and	off	when	above	753

Figure 3-9 Control Switch Data

The results for this EPS are shown in Figures 3-10 thru 3-12. As can be seen the pump switches off at around 2 hours and turns back on at around 14 hours. This results in less pressure fluctuations and a significantly reduced power cost (Figure 3-13)

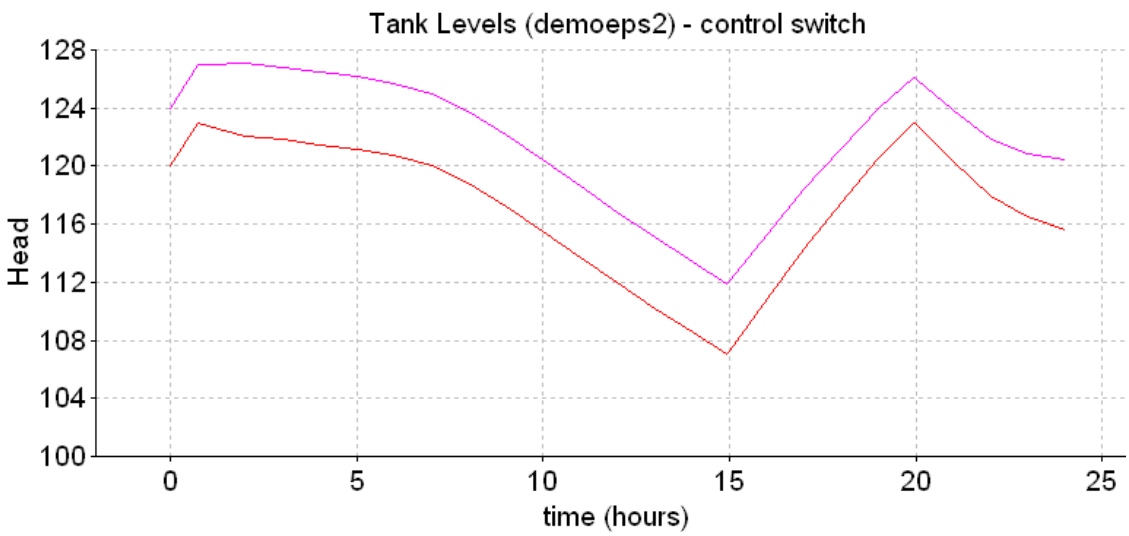


Figure 3-10 Tank Levels in Overhead Tanks

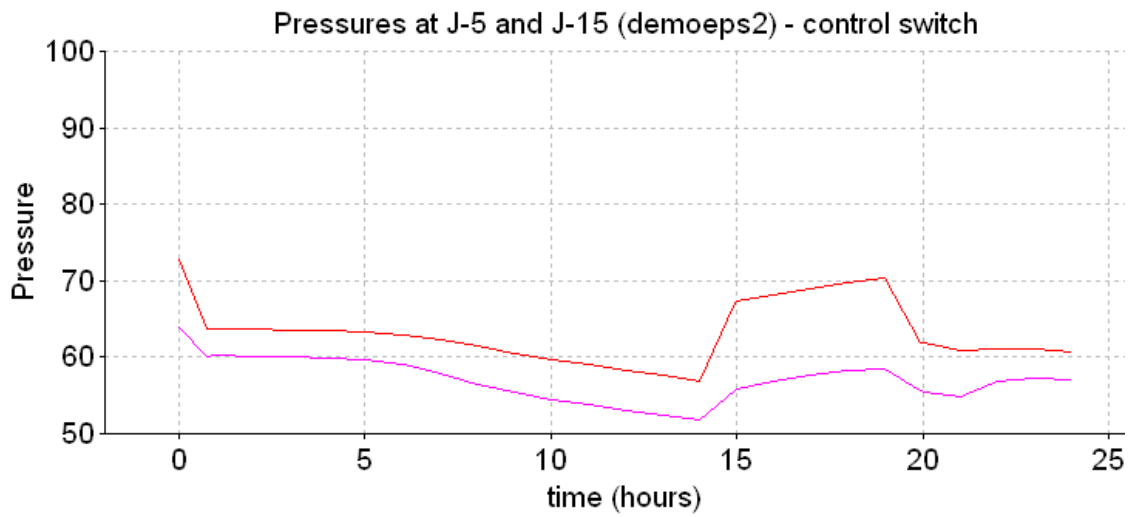


Figure 3-11 Pressures at Selected Nodes

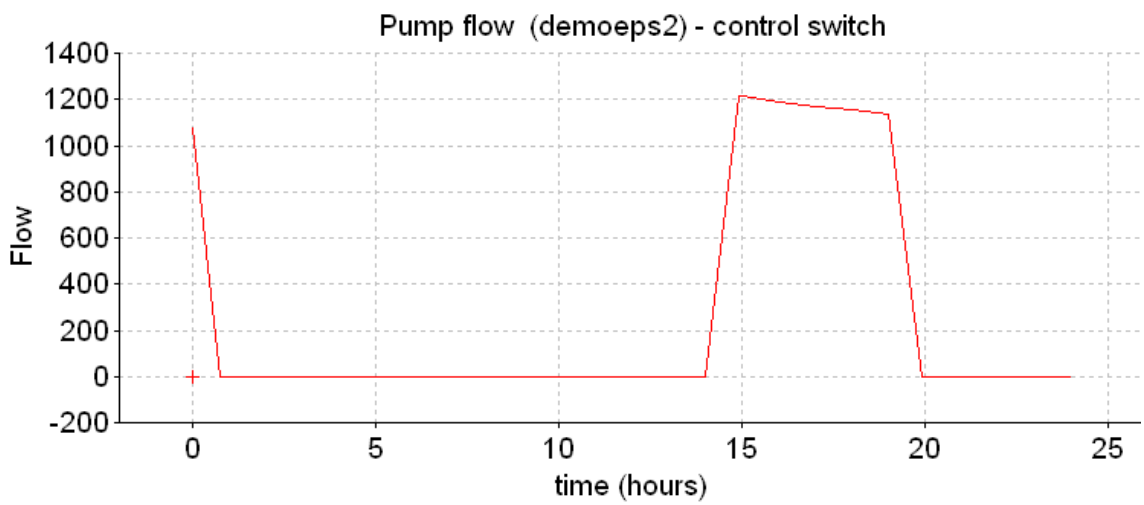


Figure 3-12 Pump Flow

```
*****************************************************

TOTAL POWER COST($) FOR THIS SIMULATION =      23.42

*****************************************************
```

Figure 3-13 Power Costs – Control Switch

3-3 – Using the Operational Control Screen (OCS)

Pipe2010/Surge2000 provides a very useful and intuitive screen which can be used to review the operational settings, modify these settings and launch a hydraulic analysis. This screen is shown in Figure 3-14. This screen displays the following conditions:

1) Water levels in all reservoirs and tanks
2) Pump speed and status and multiple pump operation
3) Valve settings and status
4) Regulator settings and status

Each of these settings can be modified on the OCS screen. In addition the type of analysis can be designated. This selection includes an analysis at a selected time of day where a demand factor based on a 24 hour Demand Pattern curve will be employed. A diurnal demand Factor Curve such as the AWWA pattern shown in Figure 3-3 can be employed. This curve can be input by selecting **Edit Demand Factors** and entering values as shown in Figure 3-15. Alternately a demand curve file (.dmd) can be loaded and a file AWWA.dmd is available for this purpose.

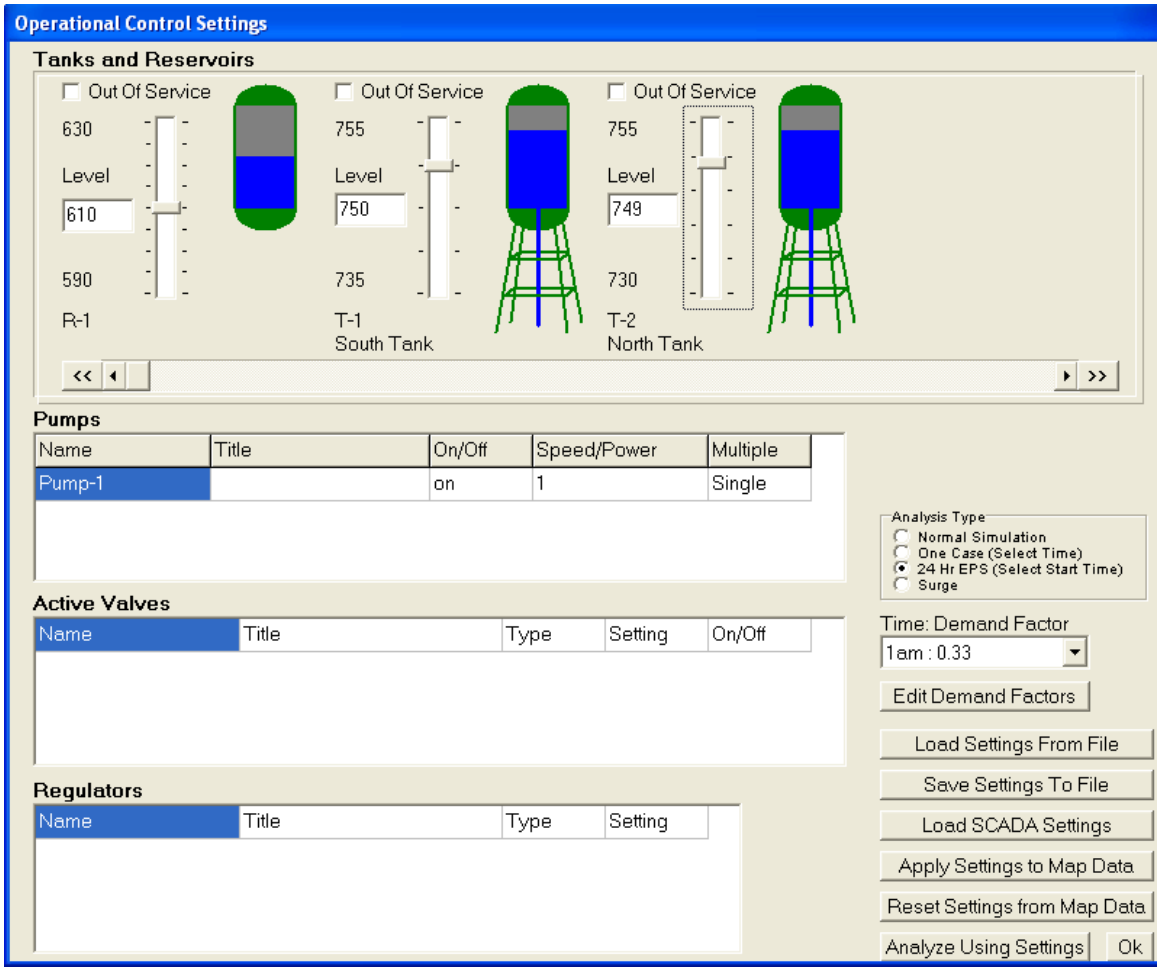


Figure 3-14 Operational Control Screen (OCS)

Once the 24 hour demand factors are input the user can quickly modify conditions and launch a single case simulation or a 24 hour EPS.

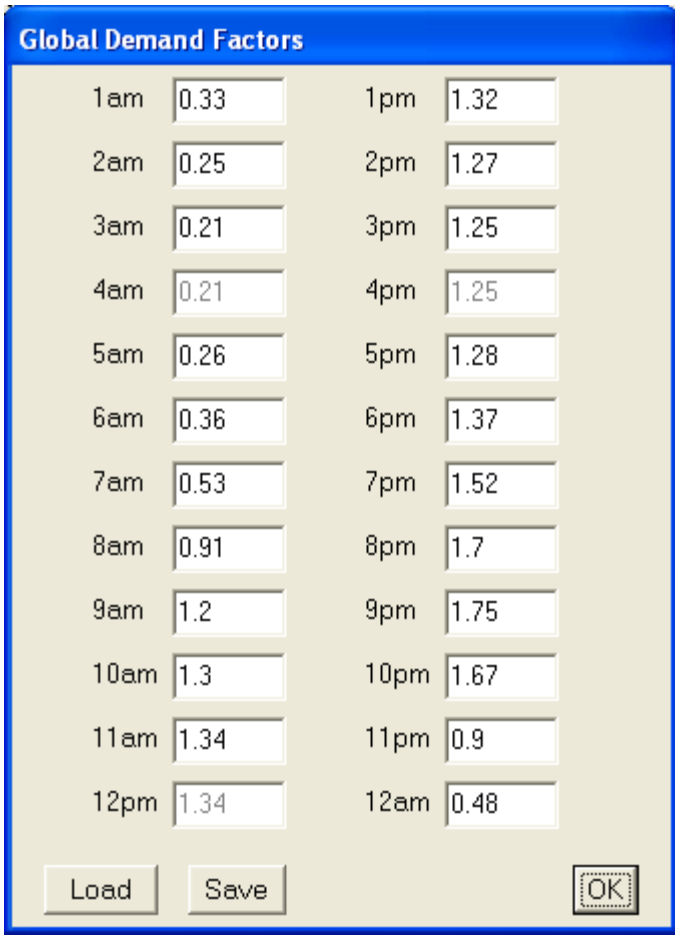


Figure 3-15 AWWA Demand Factors

Figure 3-16 sets up a 24 hour EPS with the North Tank out-of service. Figure 3-17 shows the tank level in the South Tank for this situation. As expected the tank fill/drain cycle time is decreased due to the loss of the North Tank

Figure 3-18 sets up a 24 hour simulation starting at the peak demand time of day (9 PM). The North Tank is out-of –service and the pump is off. This may well be a worst case scenario. Figure 3-19 shows pressures at 2 locations over the next 24 hours.

These screens and examples illustrate the power and ease of use of the OCS screen. This approach gives the user a simple graphical overview of the operational settings and the means to change them and launch an analysis.

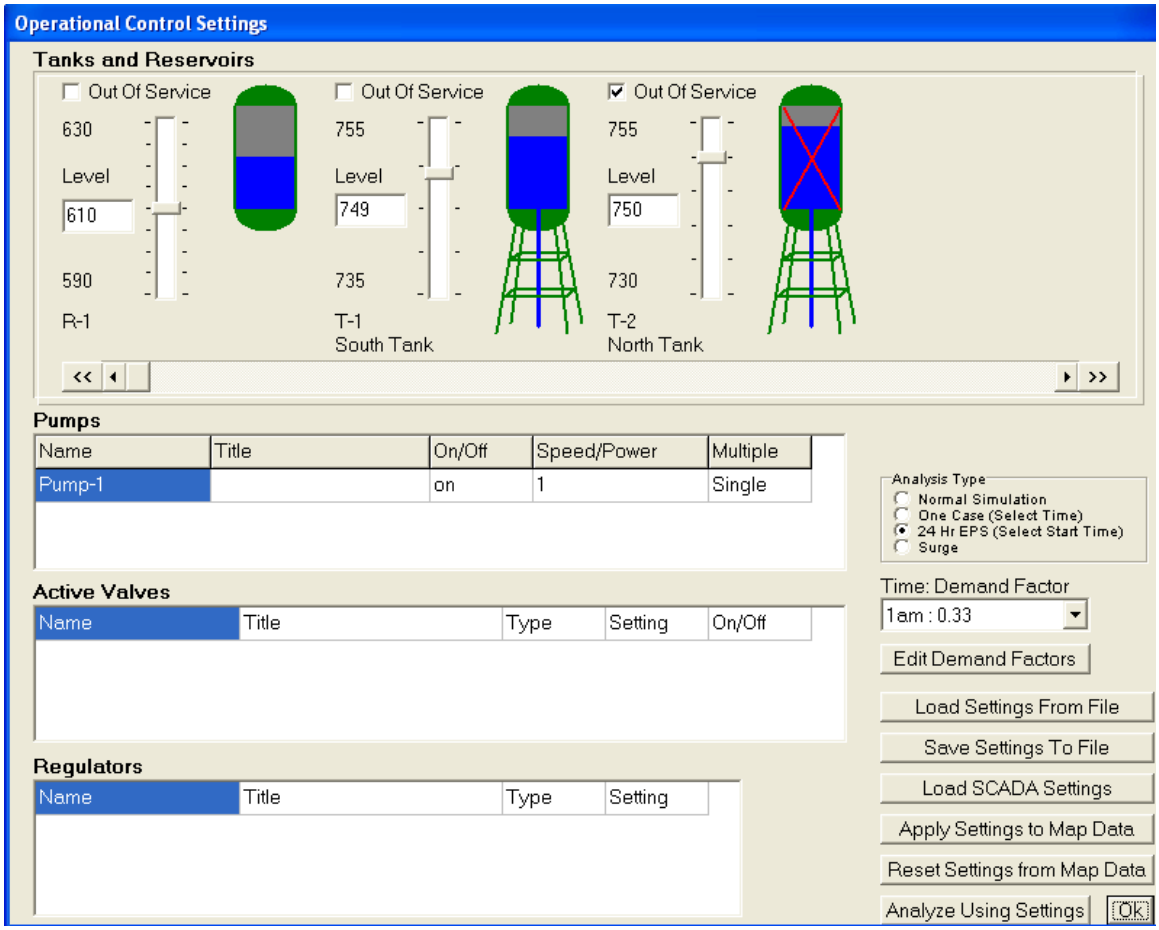


Figure 3-16 Operational Control Screen (OCS) North Tank out-of-service

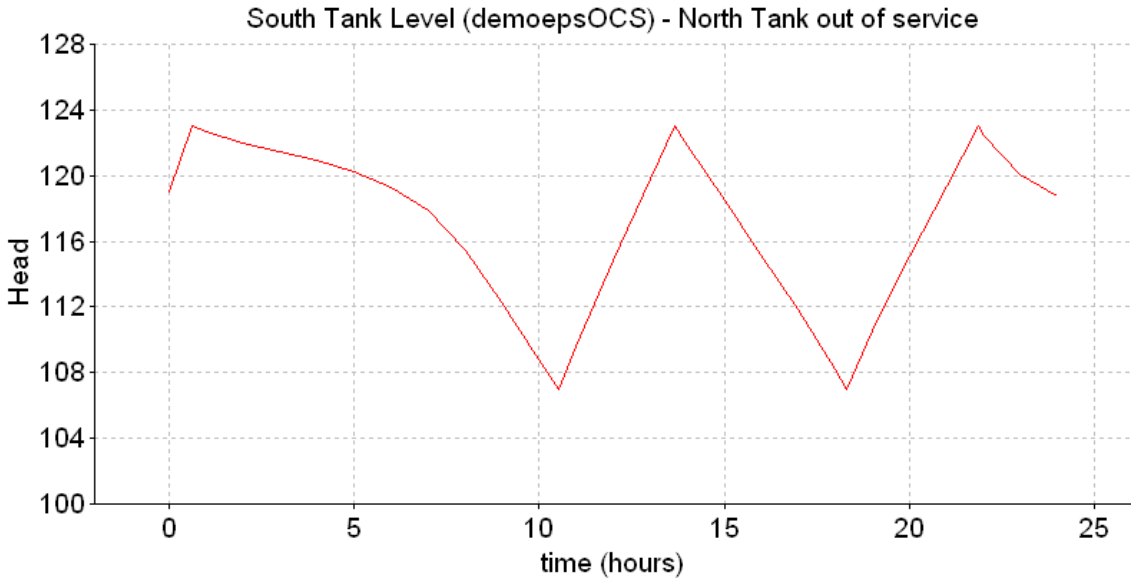


Figure 3-17 Level in South Tank - North Tank out-of-service

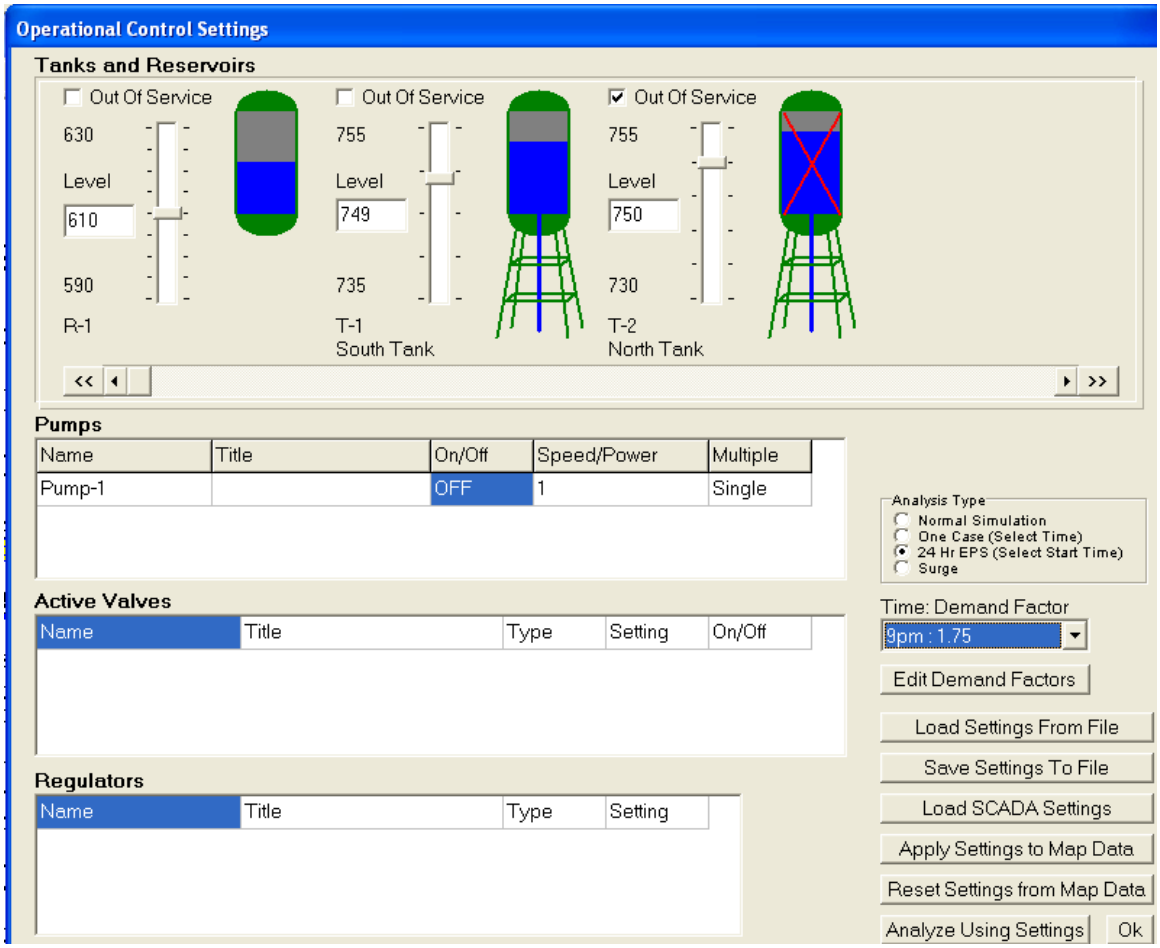


Figure 3-18 Operational Control Screen (OCS) North Tank out-of-service

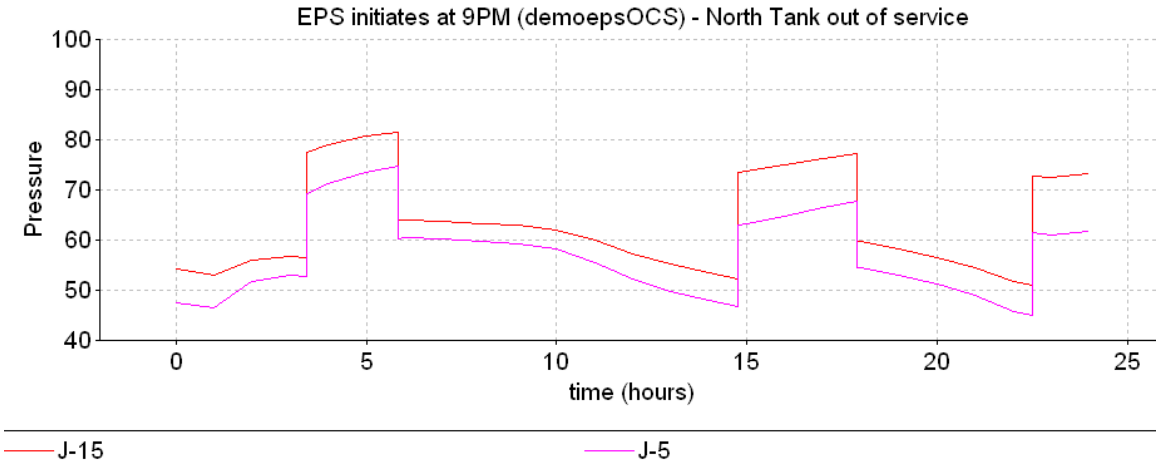


Figure 3-19 Pressures at 2 locations - North Tank out-of-service (9PM – pump off)

4 Water Quality Analysis

4-1 Water Quality Simulation – Chlorine Residual *(demoWQ))*

A water quality analysis is generally run using an EPS file. This is to determine the variance in the water quality parameters over a time period (generally 24 hours). Once you have an appropriate EPS setup only one screen of additional data is required to set up the corresponding water quality analysis. To see this data, click on File and Open and select the file demoWQ. Click on Other Data and Quality to see the data screen shown below.

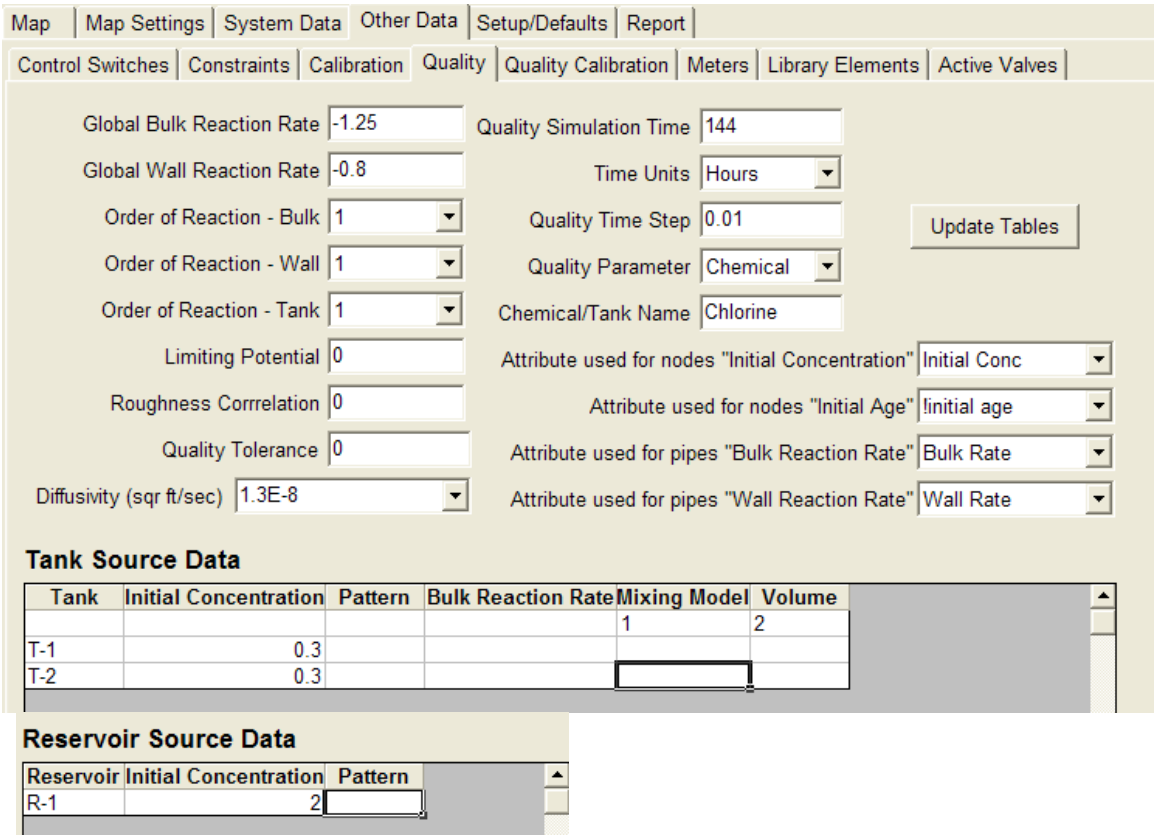


Figure 4-1 Water Quality Data – Chlorine Residuals

The Bulk and Wall Reaction Rates are set for all pipes using the global value shown rather than averaging values for each pipe. A Simulation Time of 144 hours is chosen to provide ample time for the solution to reach a repeatable condition. For this example a Chemical analysis is chosen to determine the chlorine residuals. We could choose to calculate the age of the water (select Age) or trace the origin of the water (select Trace). One additional useful data input is the Initial Concentration of chlorine at each node. This can be assigned an initial value of zero. However, a reasonable estimate of this value will provide the solution more quickly and accurately. Since the chlorine is

supplied at 2 ppm, a value of 1 ppm is used for the initial concentration and this data is assigned by using the Gbox (Group Mode) to select the entire system and the Edit Node Set to assign a value of 1.0 to the Initial Concentration. When this is done the User Data for each node should display this data as shown below:

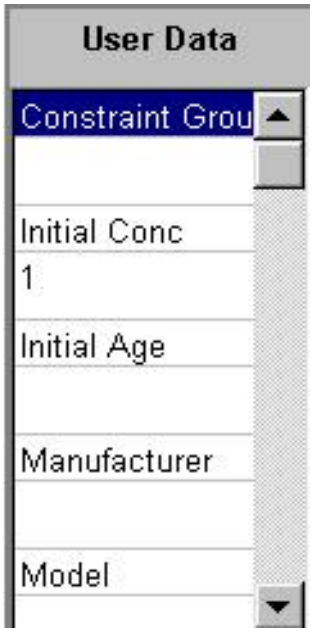


Figure 4-2 User Data with Initial Concentration

The Water Quality Analysis is then run by selecting Analyze / Analyze System and Water Quality.

Once the analysis is completed the results are reviewed. Figure 4-3 shows the results for the minimum and maximum chlorine levels. This is obtained by selecting Chlorine in the N Box (Results Selector) and Node Results/Node Results Min and Max under Labels.

A plot of the variations in the chlorine residuals at various nodes can be shown as illustrated in Figure 4-4.

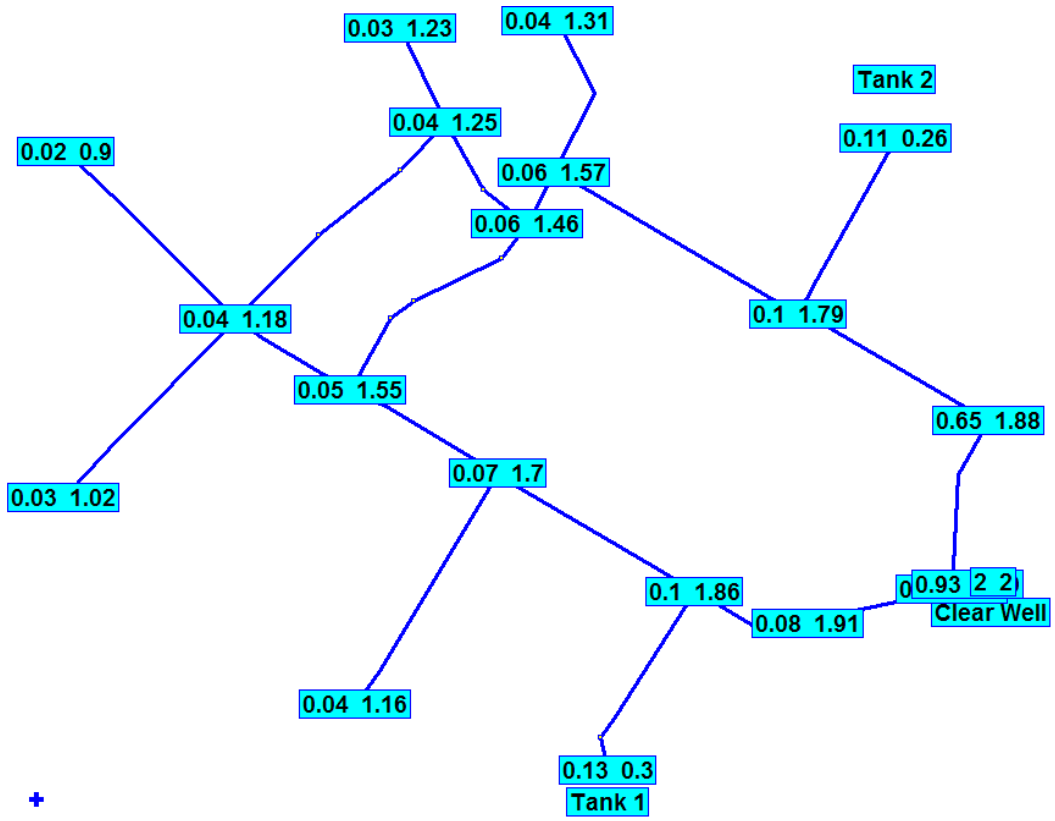


Figure 4-3 Min/Max Chlorine Residuals

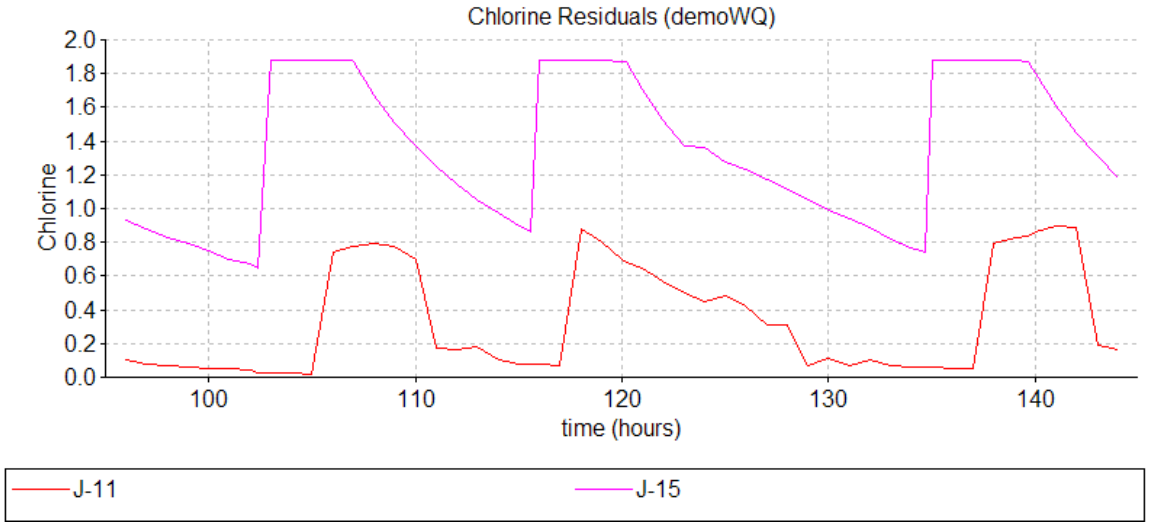


Figure 4-4 Chlorine Residuals at Selected Nodes

4-2 Water Quality Simulation – Maximum Water Age *(demomaxage)*

A second Water Quality analysis is set up to calculate the water age variation for this utility model. Figure 4-5 shows the setup for this example. Note that a 288 hour simulation was performed to allow repeatable results to be reached. Typical results are shown in Figure 4-6 which shows the maximum water age at each node and Figure 4-7 which shows the variation in age at selected nodes (highlighted in Figure 4-6

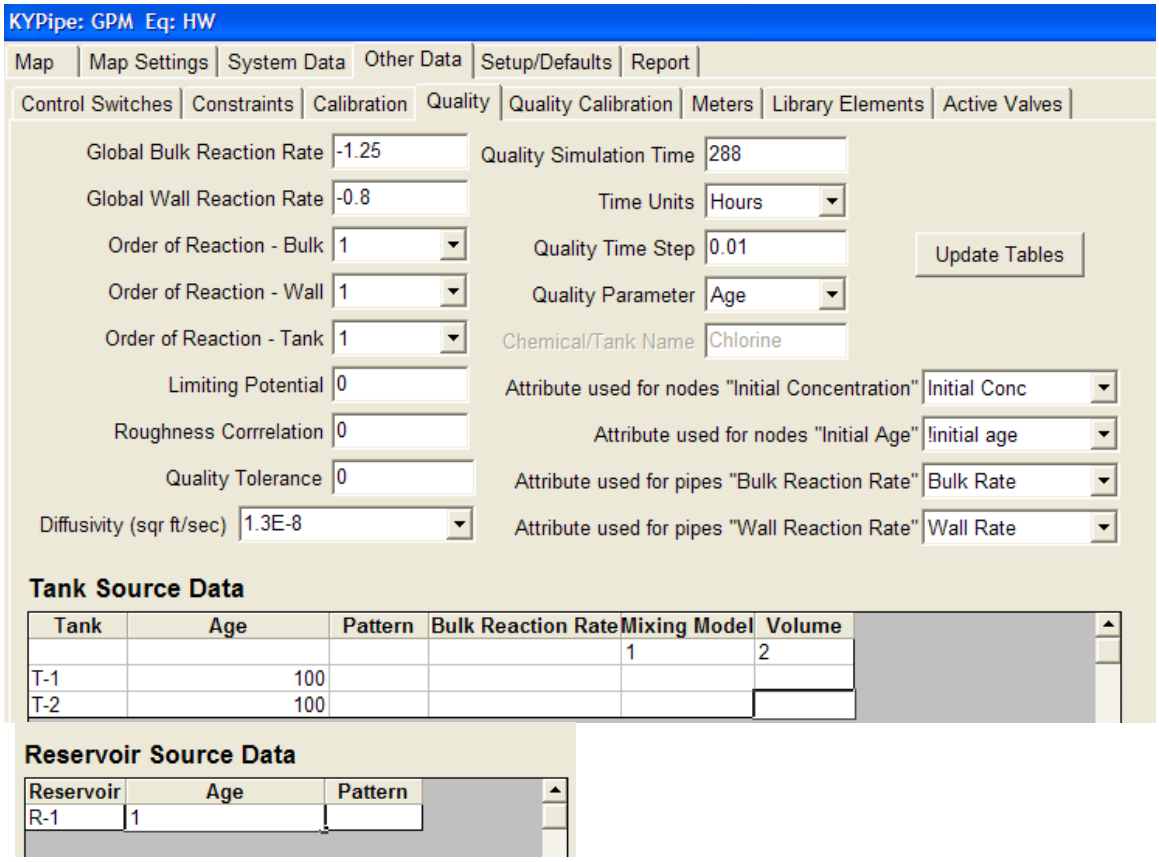


Figure 4-5 Water Quality Data – Water Age

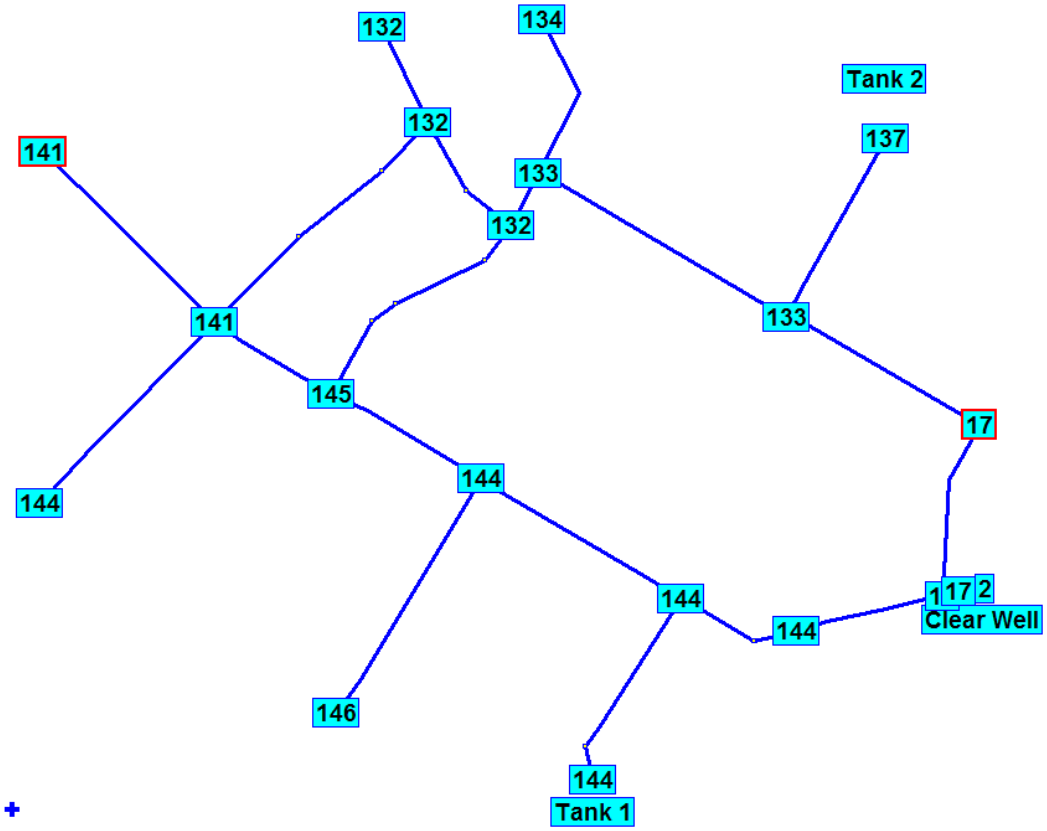


Figure 4-6 Maximum Water Age

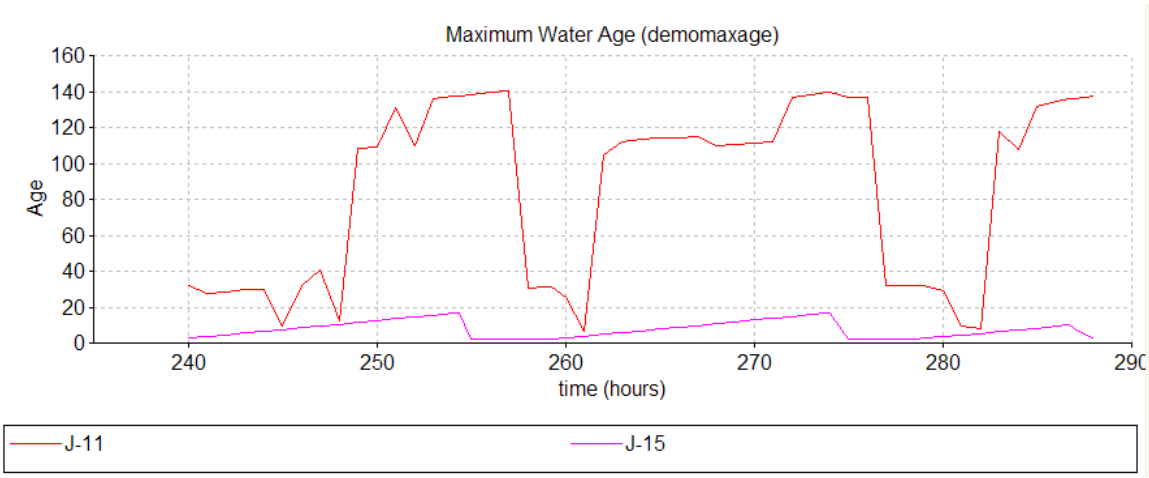


Figure 4-7 Variation in Age at Selected Nodes

4-3 Water Quality Calibration – Chlorine Residual *(demoWQC)*

This example illustrates calibration of water quality models based on field measured residual chlorine concentrations. For illustration purposes, data was synthetically generated using chlorine concentration calculation model setup in the previous example (***demoWQ.p2k***). Pipes in the system are divided into three groups - all 6 inch pipes as one group (designated as "Calibration Group" 2), all 8 inch pipes as one group (designated as "Calibration Group" 1) and the rest as the other group (designated as "Calibration Group" 0). Bulk reaction rates of -1.25/day were assigned for all groups of pipes. Wall reaction rates of -0.8ft/day, -1.25 ft/day, and -2.0 ft/day were assigned for groups 0, 1, and 2 respectively. The Pipe2010 model used for generating the water quality calibration data is (***demoWQG.p2k***). Water Quality analysis was conducted on this model and residual chlorine concentration at 4 representative nodes were noted at different time periods as shown in the following Table

Node	Time (Hours)	Cl2 Concentration (mg/l)
J-15	120	1.87
J-15	125	1.25
J-15	135	0.7
J-15	140	1.87
J-6	120	1.48
J-6	122	0.4
J-6	135	0.1
J-6	140	1.35
J-11	122	0.68
J-11	125	0.44
J-11	130	0.05
J-11	140	0.55
J-8	130	0.1
J-8	135	0.1
J-8	140	1.58
J-8	143	0.2

Figure 4-8. Water Quality Calibration Data

This data was used as then used to predict the bulk and wall reaction rates for the two groups of pipes in the model. A new Pipe2010 model called ***demoWQC.p2k*** was created using the existing ***demoWQ***.p2k model from the previous example. The water quality calibration data screens may be accessed using "Other Data" and then "Quality Calibration" tabs. Fill in the observed data table as shown in Figure 4-9.

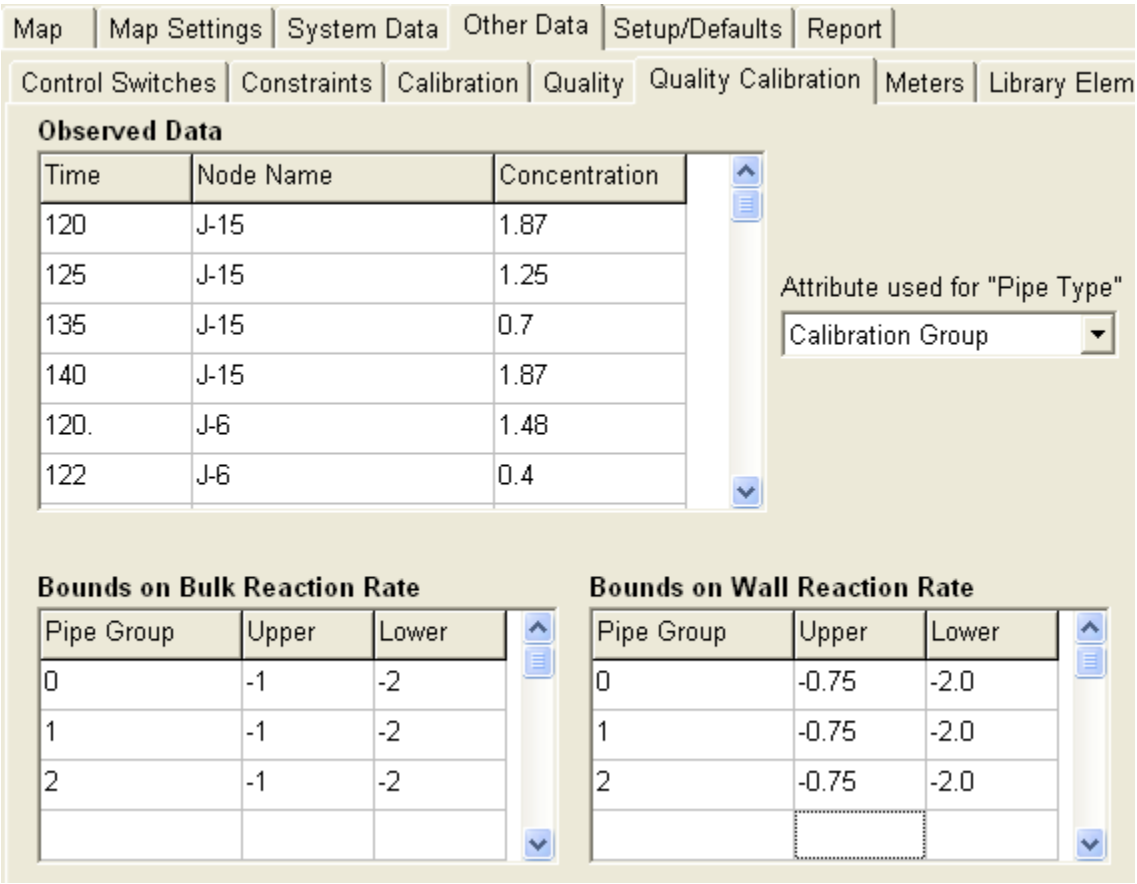


Figure 4-9 Data Screens for Water Quality Calibration

Provide upper and lower bounds for the bulk and wall reactions as shown in Figure 4-9. Select "Water quality Calibration" option under analysis screen and click on "Analyze" button as shown below in Figure 4-10.

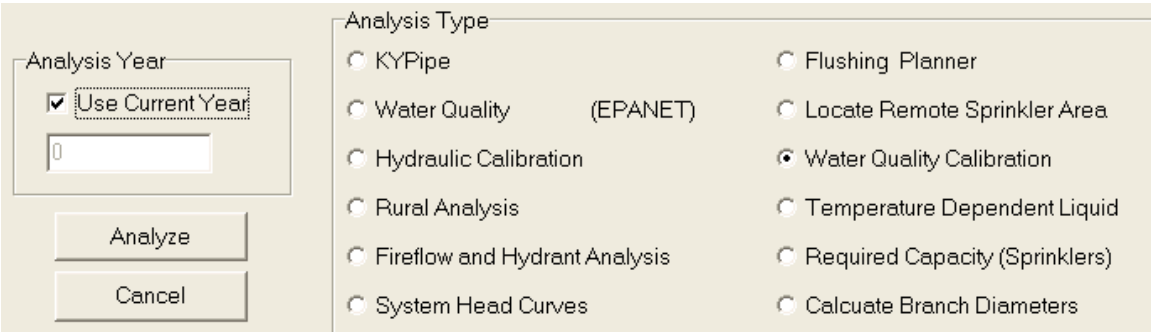


Figure 4-10 Selection Screen for Water Quality Calibration Analysis

The program will search for an optimal solution within the specified bounds based on a genetic algorithm. The calibration results may then be accessed by clicking on the "reports" tab. Figure 4-11 shows the water quality calibration results.

```
Calibration Results
  -------------------

Measured Vs Modeled Chemical Concentration :

Node#    Time(hr) Measured Conc.(mg/l)    Modeled Conc.(mg/l)
-------------------------------------------------------------
J-15        120               1.87              1.88
J-15        125               1.25              1.22
J-15        135               0.7               0.715
J-15        140               1.87              1.88
J-6         120               1.48              1.47
J-6         122               0.4               0.258
J-6         135               0.1               0.0116
J-6         140               1.35              1.37
J-11        122               0.68              0.724
J-11        125               0.44              0.462
J-11        130               0.05              0.0414
J-11        140               0.55              0.577
J-8         130               0.1               0.0178
J-8         135               0.1               0.00492
J-8         140               1.58              1.59
J-8         143               0.2               0.0842

Optimal values for the Decision variables :

For Group# 0
      Bulk reaction rate  =  -1.25     [ -1     < > -2     ]
      Wall reaction rate  =  -0.845    [ -0.75  < > -2     ]

For Group# 1
      Bulk reaction rate  =  -1.03     [ -1     < > -2     ]
      Wall reaction rate  =  -1.21     [ -0.75  < > -2     ]

For Group# 2
      Bulk reaction rate  =  -1.36     [ -1     < > -2     ]
      Wall reaction rate  =  -1.75     [ -0.75  < > -2     ]
```

Figure 4-11 Results from Water Quality Calibration

The optimal bulk reaction rates are -1.25/day, -1.03/day, and -1.36/day for groups 0, 1, and 2 respectively while the data used for calibration was generated using a bulk decay rate of -1.25/day for three pipes. A sensitivity analysis shows that the group 1 bulk reaction rates have little influence on the predicted chlorine residuals resulting in a significant deviation in optimal and actual bulk reaction rates for group 1 pipes.

The optimal wall reaction rates are -0.845ft/day, -1.21ft/day, and -1.75 ft/day for groups 0, 1, and 2 respectively. The group 0 and group 1 optimal wall reaction rates compare very well with the actual values used for generating the calibration data (-0.85ft/day and -1.25ft/day for groups 0 and 1 respectively). Group 2 optimal wall reaction rates (-1.75ft.day) are not quite close to the actual values (-2.0ft/day). This could be due to non-availability of more data on the tail end nodes of the system where group 2 wall reaction rates have influence most.

5 Optimized Calibration *(democalibration)*

Figure 5-1 shows a network schematic with the test results of four fire flow tests displayed. This fire flow test data provides the basis for performing a calibration of the distribution system. The calibration will determine the optimum value for pipe roughnesses for various groups of pipes.

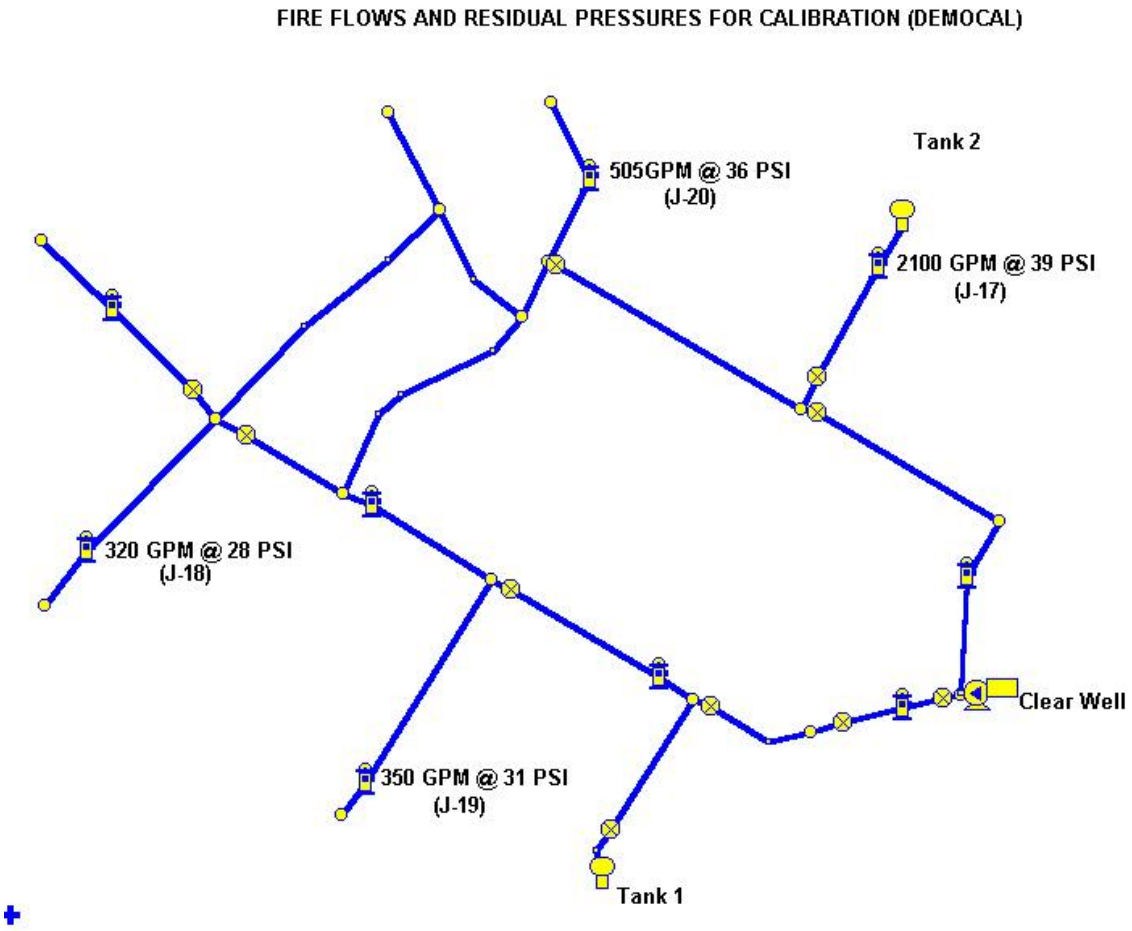


Figure 5-1 Fire Flow Test Results

The test data include the residual flow and pressure for each of the tests. For the calibration these four hydrants were converted to junctions as required to set up the calibration data. For this demonstration, it is assumed that the boundary conditions for each fire flow test were the same and that the baseline demands and the tank levels are those used for the DemoReg file and shown in Figure 5-2. Thus, it is not necessary to enter change data for the four separate fire flow tests. The only additional data required is the Calibration Data shown in Figure 5-3.

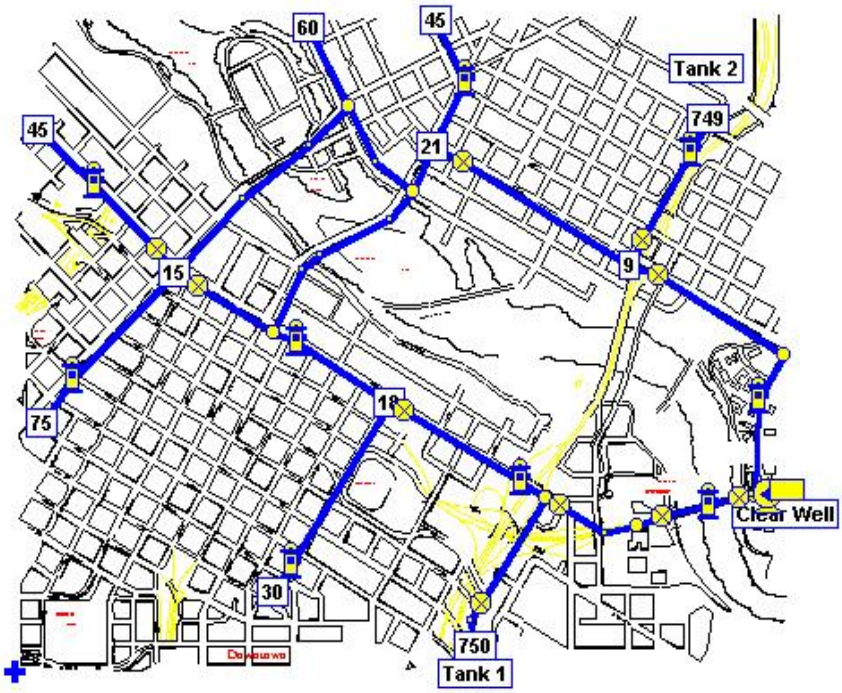


Figure 5-2 Tank Levels and Baseline Demands for Calibration

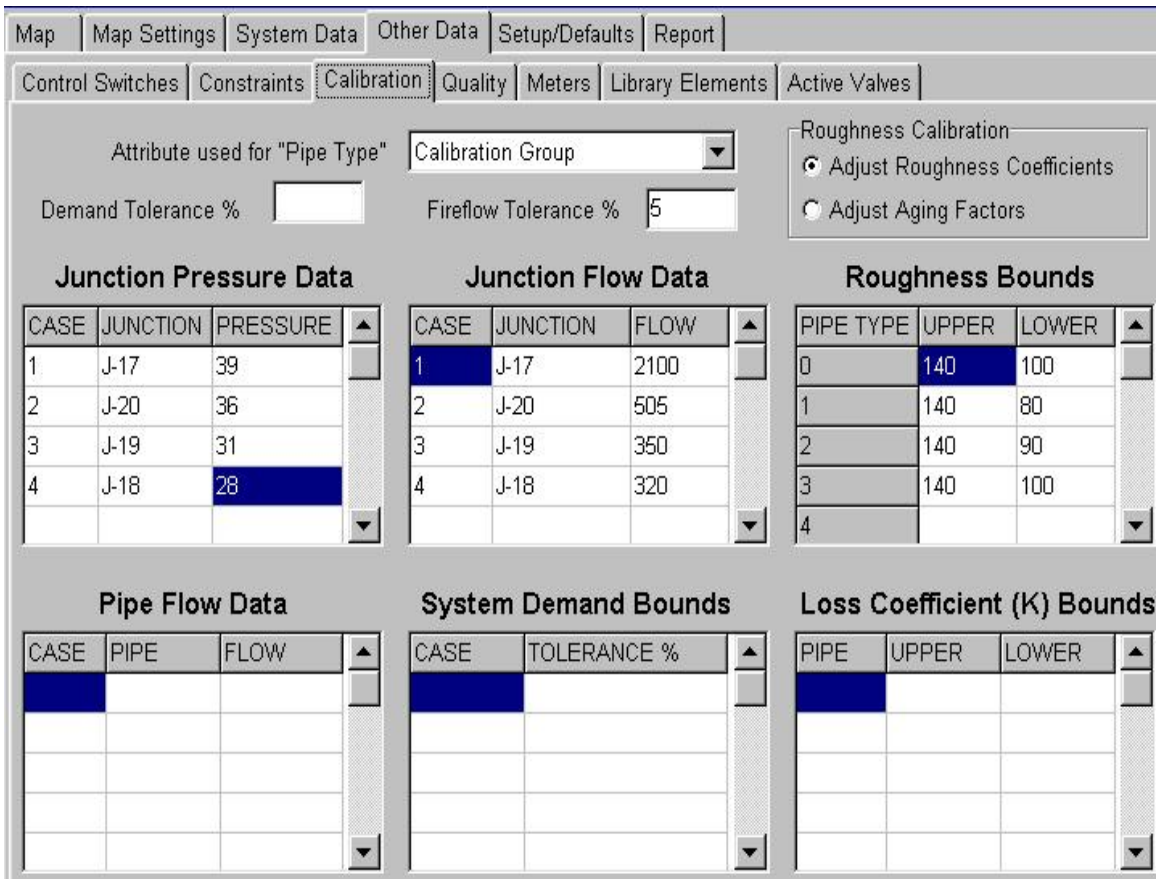


Figure 5-3 Fire Flow and Calibration Data

The roughness bounds were defined for four Calibration Groups selected using various diameters as follows:

Group	**Diameter**
0	12
1	6
2	8
3	10

Two calibration analyses were run.

For the first calibration a 5% tolerance was introduced for the fire flows. This means that the fireflows can be +/- 5% of the measured residual flow and accounts for a small error in this measurement. The calibration run produced a calibration where the optimal pressure differed from the measured pressure by only 1.4% where the difference is greater than 1.6% for the uncalibrated model. The results for the first case are shown in Figure 5-4.

For the second case, a zero percent fire flow tolerance was used and, as expected, a larger difference of 4.8% was obtained. These results are shown in Figure 5-5

```
SUMMARY OF RESULTS :
---------------------


 Percent Deviation between MEASURED and TARGET Values =   1.576


 OPTIMAL values for the Decision variables:

 Hazen William coefficients: for group number    0 =  100.  [140.0< >100.0]
 Hazen William coefficients: for group number    1 =  111.  [140.0< > 80.0]
 Hazen William coefficients: for group number    2 =   92.  [140.0< > 90.0]
 Hazen William coefficients: for group number    3 =  109.  [140.0< >100.0]

 No demand adjustments are made.
 Demand Tolerance is meant for re-distributing
 demands among nodes of diff demand types, keeping
 the total demand constant. There must be at least
 TWO types of demands to use this feature.

 Junction (Fire) Flow(s) for Change  1 are INCREASED by  4.68%
 Junction (Fire) Flow(s) for Change  2 are DECREASED by  3.39%
 Junction (Fire) Flow(s) for Change  3 are INCREASED by  5.00%
 Junction (Fire) Flow(s) for Change  4 are INCREASED by  5.00%


 Measured and Target pressures (psi or kPa):

    TEST        NODE      MEASURED        OPTIMAL
    CASE       NUMBER     PRESSURE       PRESSURE
  ------------------------------------------------
      1         J-17        39.0           39.4
      2         J-20        36.0           36.5
      3         J-19        31.0           32.0
      4         J-18        28.0           28.5


 Date & Time:  Mon Aug 29 15:50:14 2005


  ------- NETWORK CALIBRATION COMPLETED --------
```

Figure 5-4 First Case Results (5% fire flow tolerance)

```
SUMMARY OF RESULTS :
---------------------


 Percent Deviation between MEASURED and TARGET Values =   4.782


 OPTIMAL values for the Decision variables:

 Hazen William coefficients: for group number    0 =  100.  [140.0< >100.0]
 Hazen William coefficients: for group number    1 =  103.  [140.0< > 80.0]
 Hazen William coefficients: for group number    2 =   90.  [140.0< > 90.0]
 Hazen William coefficients: for group number    3 =  100.  [140.0< >100.0]



 Measured and Target pressures (psi or kPa):

    TEST        NODE      MEASURED        OPTIMAL
    CASE       NUMBER     PRESSURE       PRESSURE
  ---------------------------------------------------
      1         J-17        39.0           40.7
      2         J-20        36.0           32.6
      3         J-19        31.0           31.1
      4         J-18        28.0           30.3
```

Figure 5-5 Second Case Results (0% fire flow tolerance)

6 Transient (Surge) Modeling

Importance of Surge Analysis for Water Utilities - Transient (surge) analysis of the performance of water distribution systems is often more important than the analysis of the steady state operating conditions that engineers normally use as the basis for system design. Transient pressures are most important when the rate of flow is changed rapidly, usually resulting from rapid valve closures or pump stoppages. Such disturbances, whether caused by design or accident, may create traveling pressure waves of large magnitudes. These transient pressures are superimposed on the steady state conditions present in the line at the time the transient occurs. The severity of transient pressures must be determined so that the water mains and joint connections can be properly designed to withstand these additional loads.

Transient regimes in water distribution systems are inevitable and will normally be most severe at pump stations and control valves, high elevation areas, locations with low static pressures, and remote locations that are distanced from overhead storage. All systems will be started up, switched off, undergo unexpected flow changes, etc., and will likely experience the effects of human errors, equipment breakdowns, earthquakes, or other unforeseen disturbances. Although transient conditions can result in many situations, the water utility manager and engineers must be most concerned with those that might endanger the safety of a plant and its personnel and that have the potential to cause equipment or device damage. These conditions can result in operational difficulties or pose a risk to the public health.

Transient events often have significant water quality implications. These events can generate high intensities of fluid shear and may cause re-suspension of settled particles as well as biofilm detachment. So-called red water events have often been associated with transient disturbances. Moreover, a low-pressure transient event, say arising from a power failure or pipe break, has the potential to cause the intrusion of contaminated groundwater into a pipe at a leaky joint or break. Depending on the size of the leaks, the volume of intrusion can range from a few gallons to hundreds of gallons Negative pressures induce back-siphonage of non-potable water from domestic, industrial, and institutional piping into the distribution system. Dissolved air (gas) can also be released steel and iron sections with subsequent rust formation and pipe damage. Even some common transient protection strategies, such as relief valves or air chambers, if not properly designed and maintained, may permit pathogens or other contaminants to find a “back door” route into the potable water distribution system.

Water Utility managers and engineers must carefully consider all potential dangers for their pipe designs and estimate and eliminate the weak spots. To do this they need to be able to routinely do surge analysis using their water utility hydraulic model. This capability is closely integrated in the Pipe2010 modeling package. This capability allows water utility managers and engineers to embark upon a detailed transient analysis to make informed decisions on how to best protect their systems and ensure safe, reliable operations .

6-1 Using the OCS for Transient (Surge) Modeling

The OCS screen provides Water Utility users an extremely simple method to set up a surge analysis involving pump shutdowns or start up or valve operations. When the analysis is proceeding the progress will be displayed on the computer screen by showing the pressure at a designated node. Before accessing the OCS screen select one node (in Layout mode) as shown in Figure 6-1.

Figure 6-2 shows the OCS screen for setting up the Surge Analysis. Simply select **Surge** under Analysis Type. Provide a simulation time and a Default Wave Speed as shown. Note that wave speed does depend on the pipe type and it may be necessary to enter different wave speeds for different types of pipes.

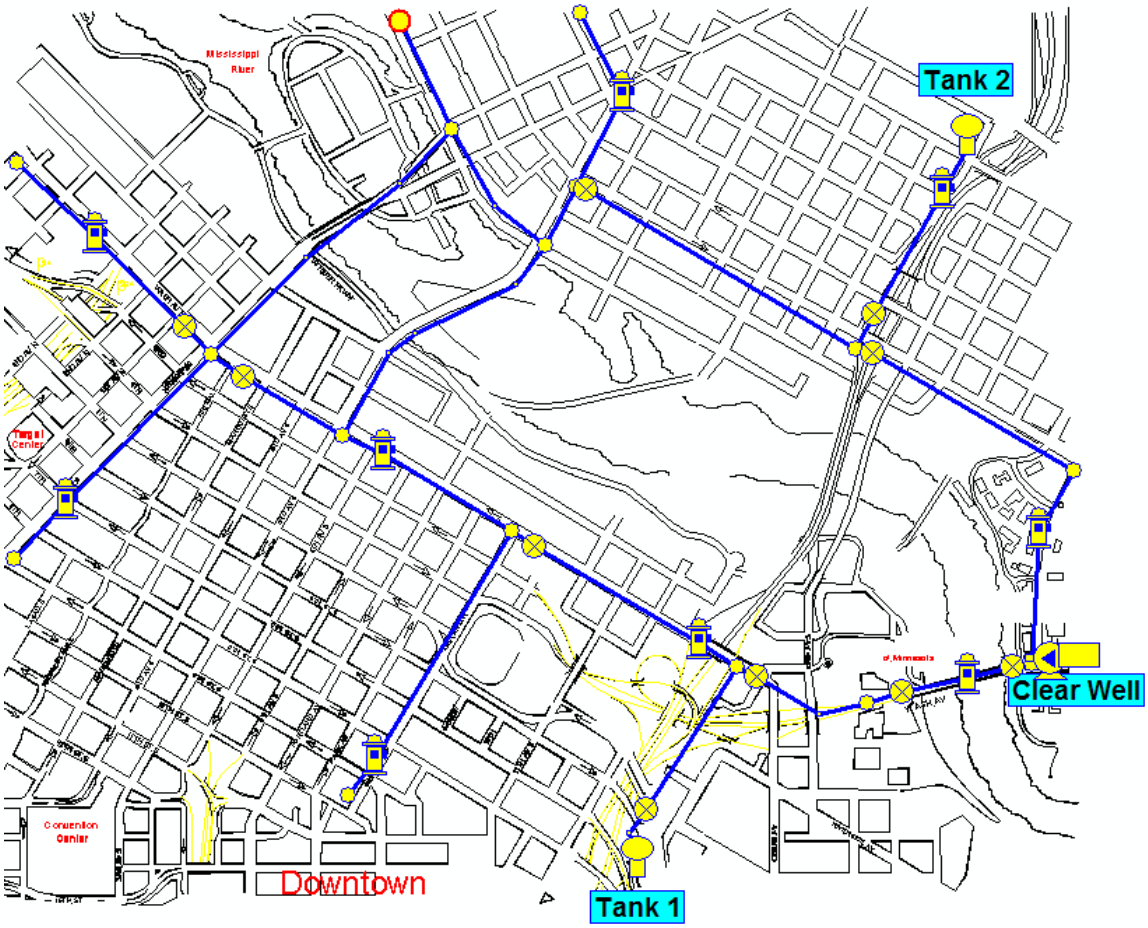


Figure 6-1 Example System with Node Selected for Screen Display

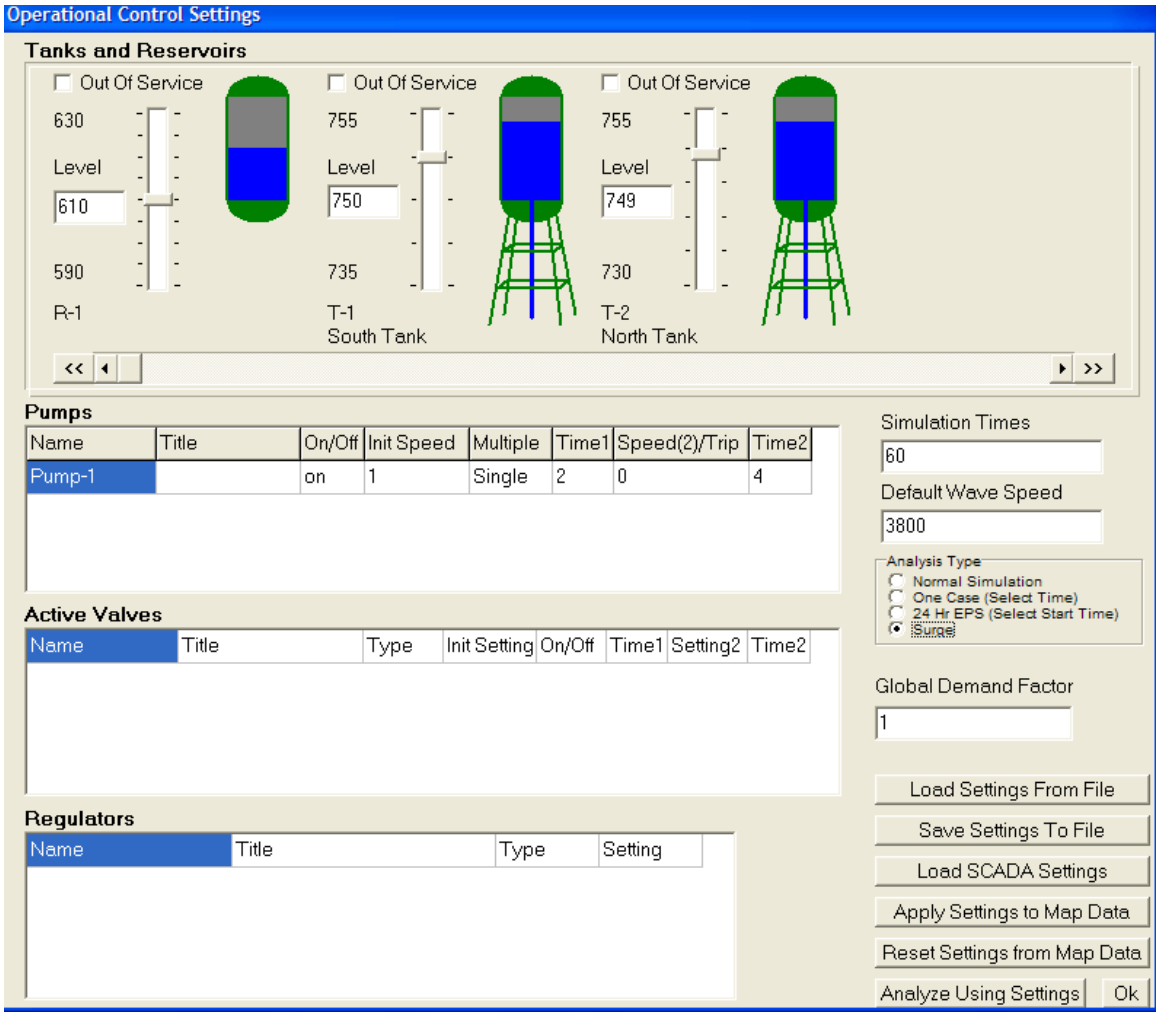


Figure 6-2 OCS Screen for Surge Analysis #1 (2 sec. rundown)

The first analysis setup (#1) is shown in Figure 6-2. Here the pump is shutdown in 2 seconds to simulate a fast rundown as a result of power loss to the pump. The pump runs at normal speed for the first 2 seconds and then ramps down to 0 speed over the next 2 seconds. This setup illustrates the recommended method of holding the initial steady state condition for a short time to verify that the system initially runs under steady conditions.

Figure 6-3 shows the OCS setup for a second surge analysis (#2) for a 10 second rundown. Figure 6-4 compares the pressure at node J-13 for these two cases. As expected the 10 second rundown will produce a significantly smaller pressure surge. Figure 6-5 shows the setup for a 10 second rundown with the North Tank out-of-service (#3). Figure 6-6 compares the results for surge analyses #2 & #3. This example illustrates the fact that overhead storage tanks act as surge tanks. Without the overhead tank in service the pressure surge is significantly worse. It should be point out that for both cases #1 and #3 pressures dropped to -14 psi which means that cavitation occurs. This is a highly undesirable condition for water utilities.

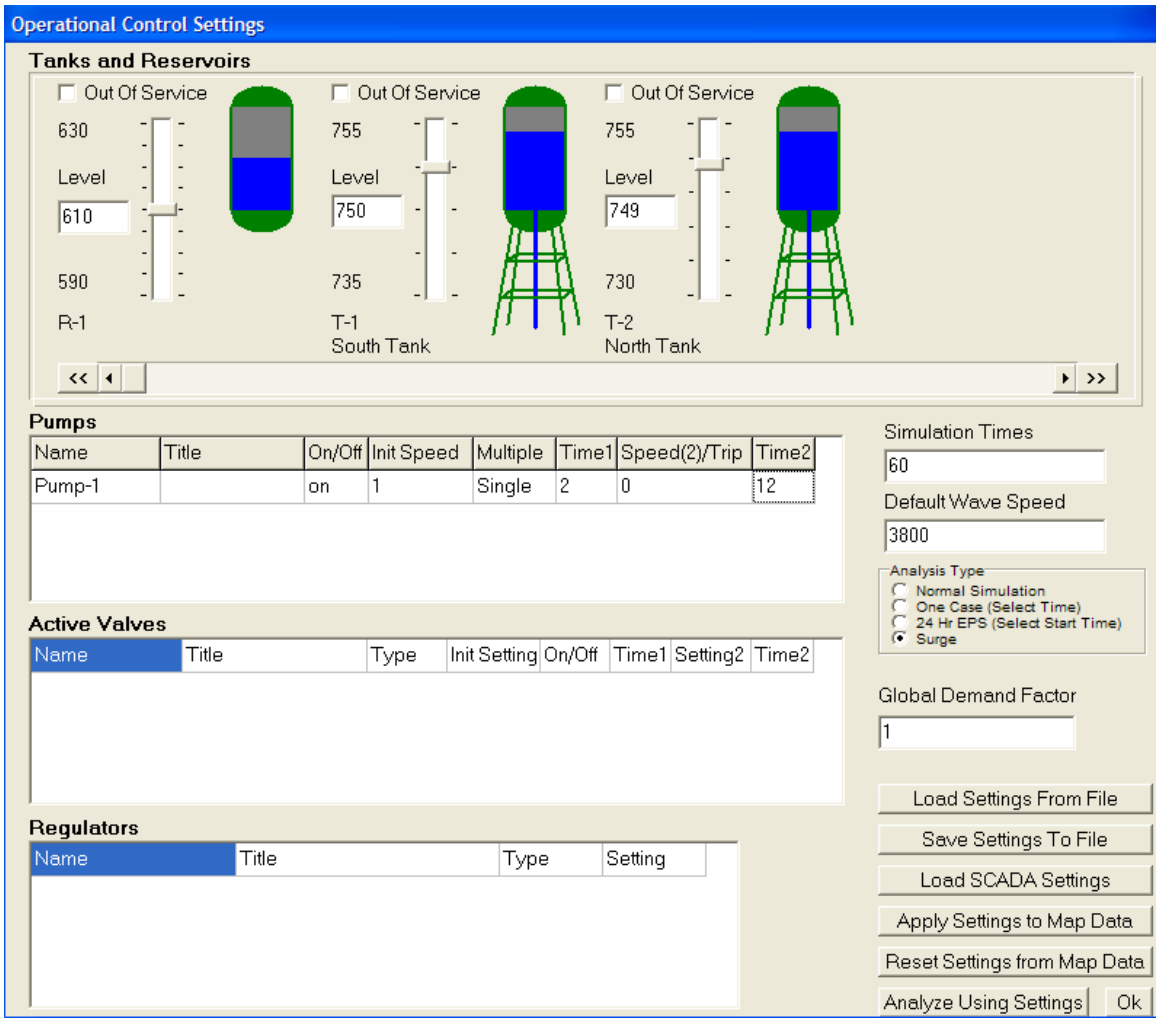


Figure 6-3 OCS Screen for Surge Analysis #2 (10 second rundown)

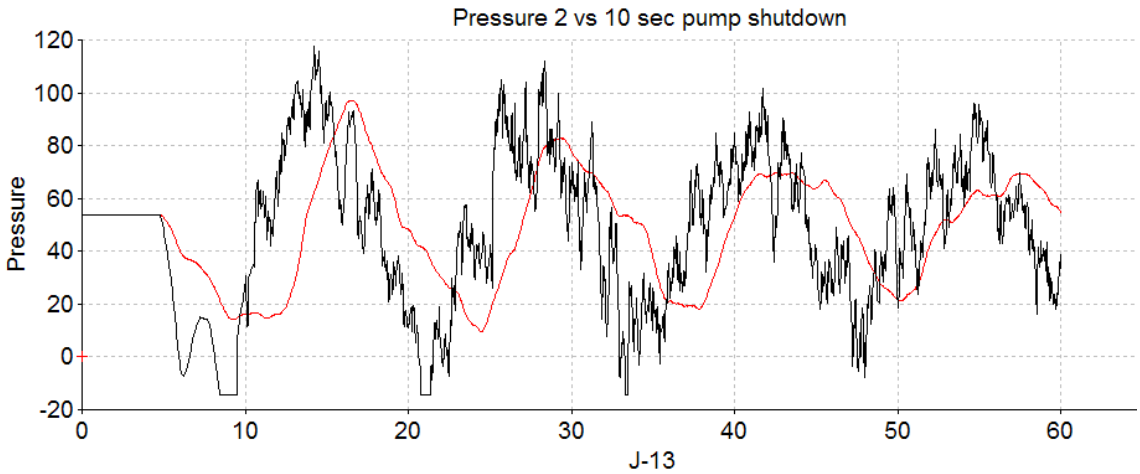


Figure 6-4 Results for Surge Analyses #1 & #2

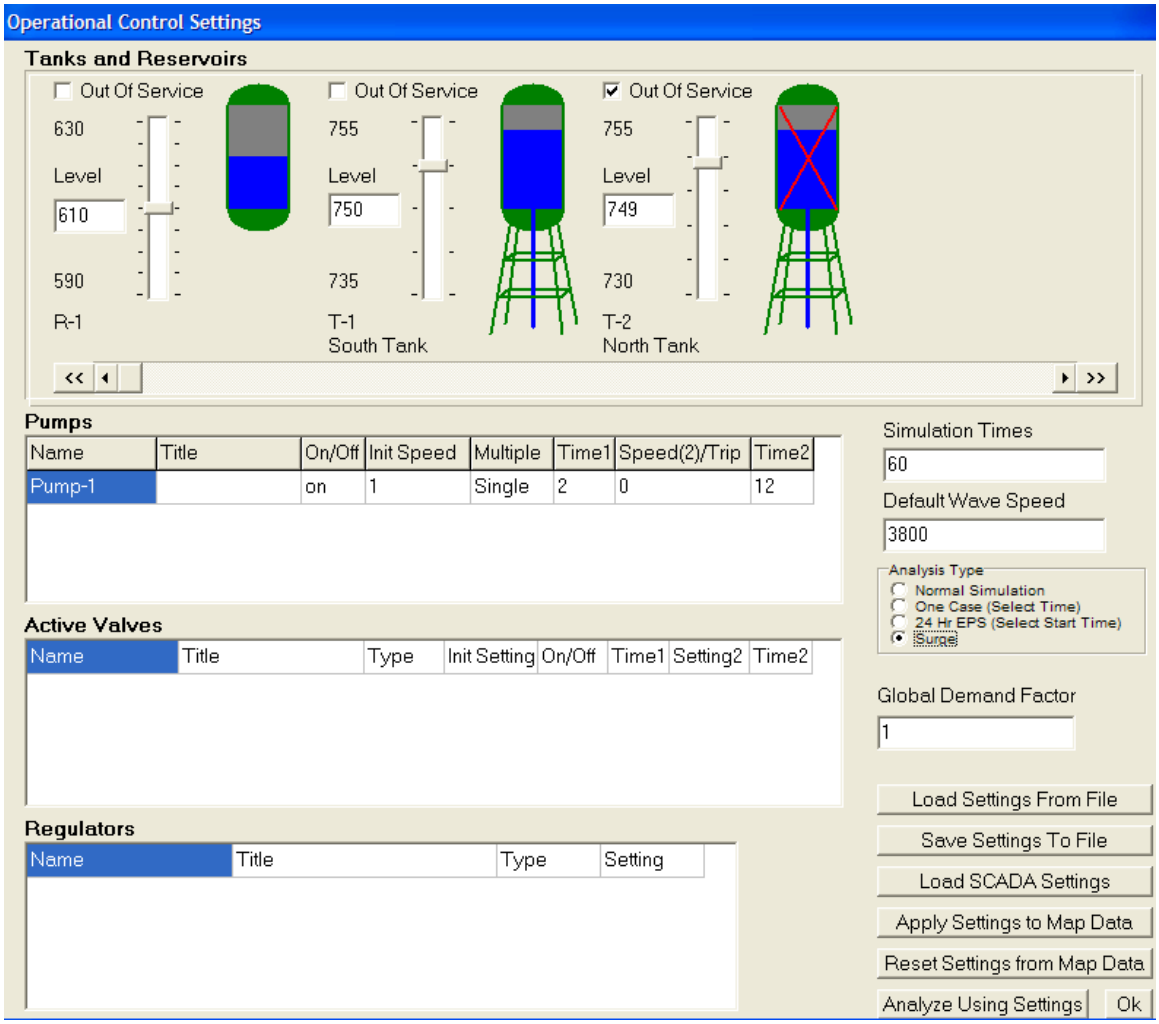


Figure 6-5 OCS Screen for Surge Analysis #3 (10 sec. rundown – North Tank Off)

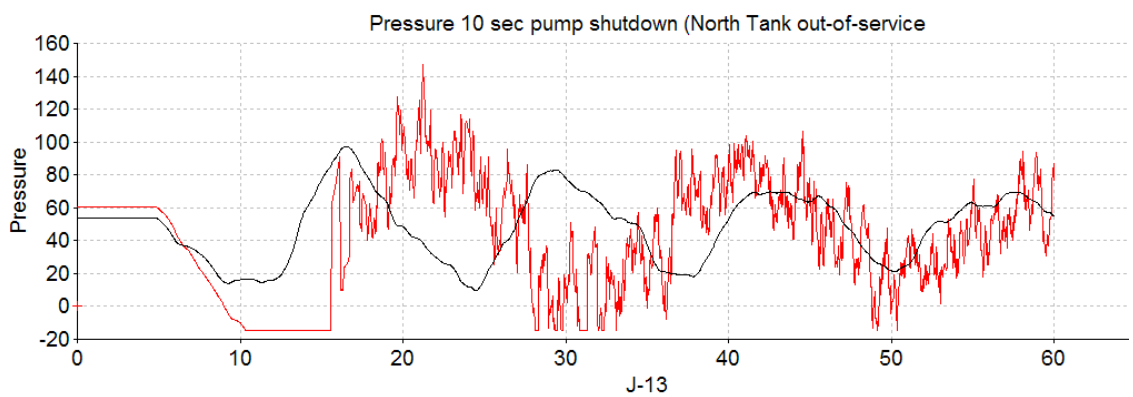


Figure 6-6 Results for Surge Analyses #2 & #3

Appendix - A – Municipal Water Distribution Utility Data

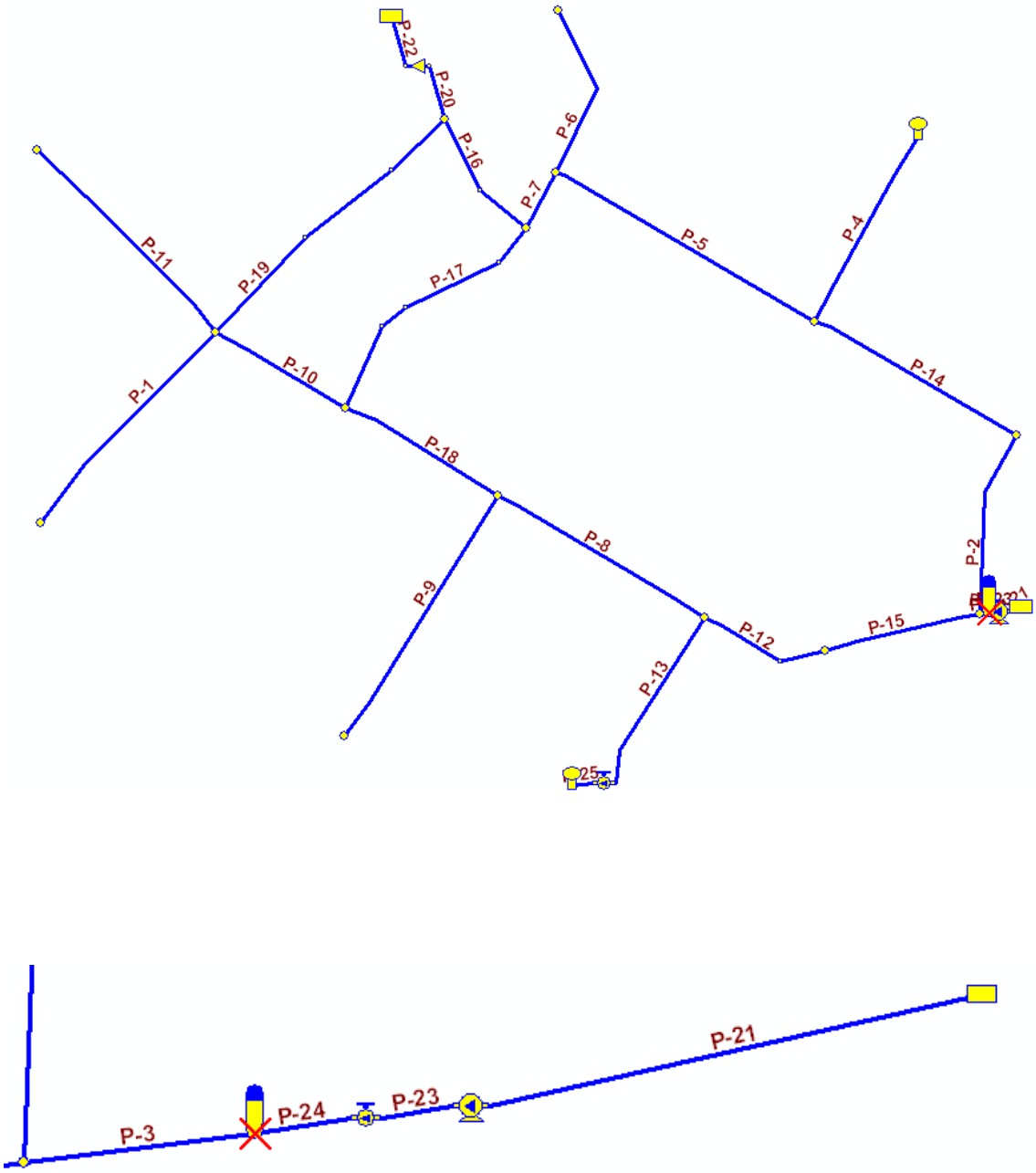


Figure I-1 Pipe Names

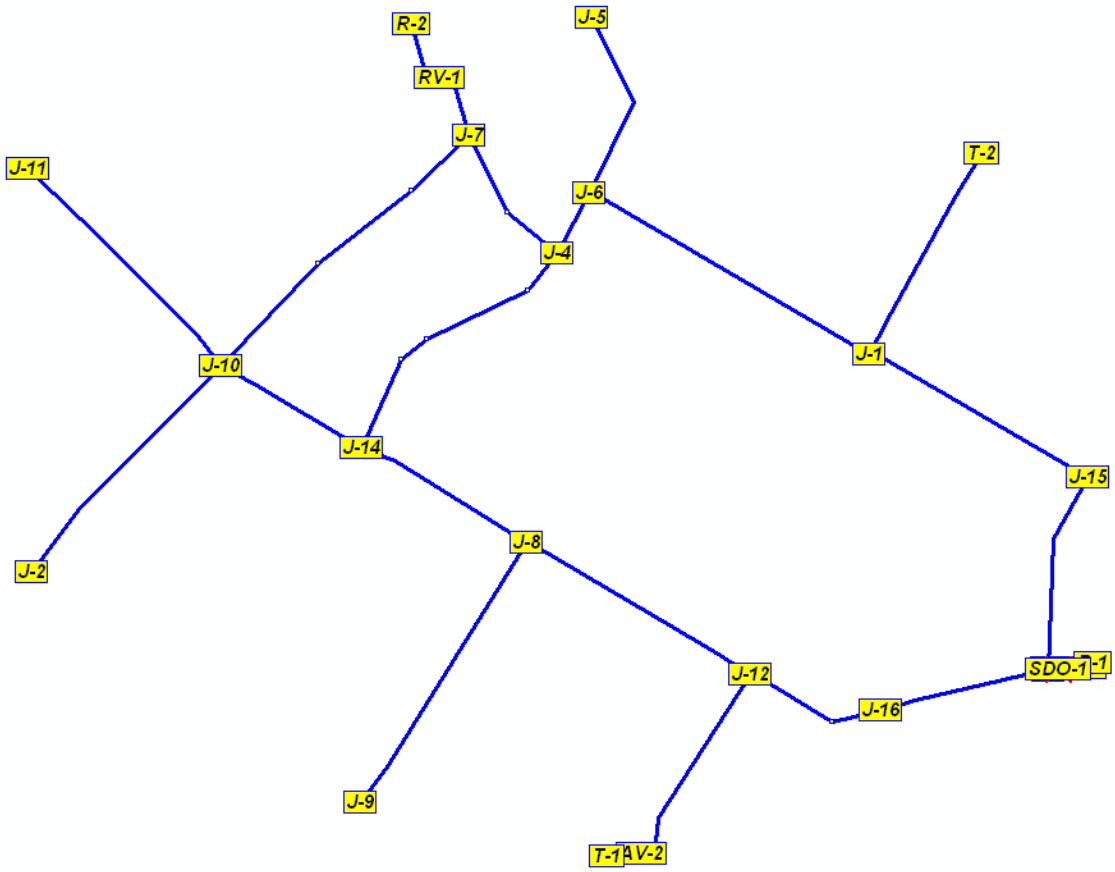


Figure I-2 Node Names

Pipe and Node Data

PIPE NAME	NODE NAMES #1	#2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
- P- 1	J- 2	J-10	2844.00	6.00	130.0000	0.00
P- 2	J- 3	J-15	2059.00	10.00	120.0000	0.00
P- 3	J- 3	SDO-1	100.00	12.00	120.0000	6.40
P- 4	J- 1	T- 2	2337.00	8.00	140.0000	1.90
P- 5	J- 1	J- 6	3296.00	8.00	140.0000	0.00
P- 6	J- 6	J- 5	1983.00	6.00	130.0000	0.00
P- 7	J- 6	J- 4	686.00	8.00	140.0000	0.00
P- 8	J- 8	J-12	2633.00	8.00	140.0000	0.00
P- 9	J- 8	J- 9	3138.00	6.00	130.0000	0.00
P-10	J-10	J-14	1649.00	8.00	140.0000	0.00
P-11	J-10	J-11	2801.00	6.00	130.0000	0.00
P-12	J-12	J-16	1464.00	8.00	140.0000	0.00
P-13	J-12	I-AV-2	2131.00	8.00	140.0000	3.40
P-14	J-15	J- 1	2550.00	8.00	140.0000	0.00
P-15	J-16	J- 3	1753.00	10.00	120.0000	0.00
P-16	J- 4	J- 7	1532.00	8.00	140.0000	0.00
P-17	J- 4	J-14	2938.00	8.00	140.0000	0.00
P-18	J-14	J- 8	1942.00	8.00	140.0000	0.00
P-19	J- 7	J-10	3447.00	8.00	140.0000	0.00
P-20	J- 7	I-RV-1	657.00	6.00	130.0000	0.00
P-21	I-Pump-1	R- 1	250.00	12.00	120.0000	7.50
P-22	O-RV-1	R- 2	613.00	6.00	130.0000	0.00
P-23	I-AV-1	O-Pump-1	50.00	12.00	120.0000	0.00
P-24	SDO-1	O-AV-1	50.00	12.00	120.0000	0.00
P-25	O-AV-2	T- 1	355.00	8.00	140.0000	0.00

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)
I-AV-1		0.00	610.00	
I-AV-2		0.00	630.00	
J- 1		9.00	607.00	
J- 2		75.00	617.00	
J- 3		0.00	605.00	
J- 4		0.00	602.00	
J- 5		45.00	613.00	
J- 6		21.00	611.00	
J- 7		0.00	613.00	
J- 8		18.00	611.00	
J- 9		30.00	615.00	
J-10		15.00	611.00	
J-11		45.00	610.00	
J-12		0.00	610.00	
J-14		0.00	610.00	
J-15		0.00	605.00	
J-16		0.00	605.00	
I-Pump-1		0.00	610.00	
R- 1		----	605.00	610.00
R- 2		----	630.00	630.00
I-RV-1		----	630.00	722.31
SDO-1		0.00	610.00	
T- 1	South Tank	----	630.00	750.00
T- 2	North Tank	----	625.00	749.00
O-AV-1		0.00	610.00	
O-AV-2		0.00	630.00	
O-Pump-1		0.00	610.00	
O-RV-1		0.00	630.00	