Pipe Line Loss Calculator

The Basics

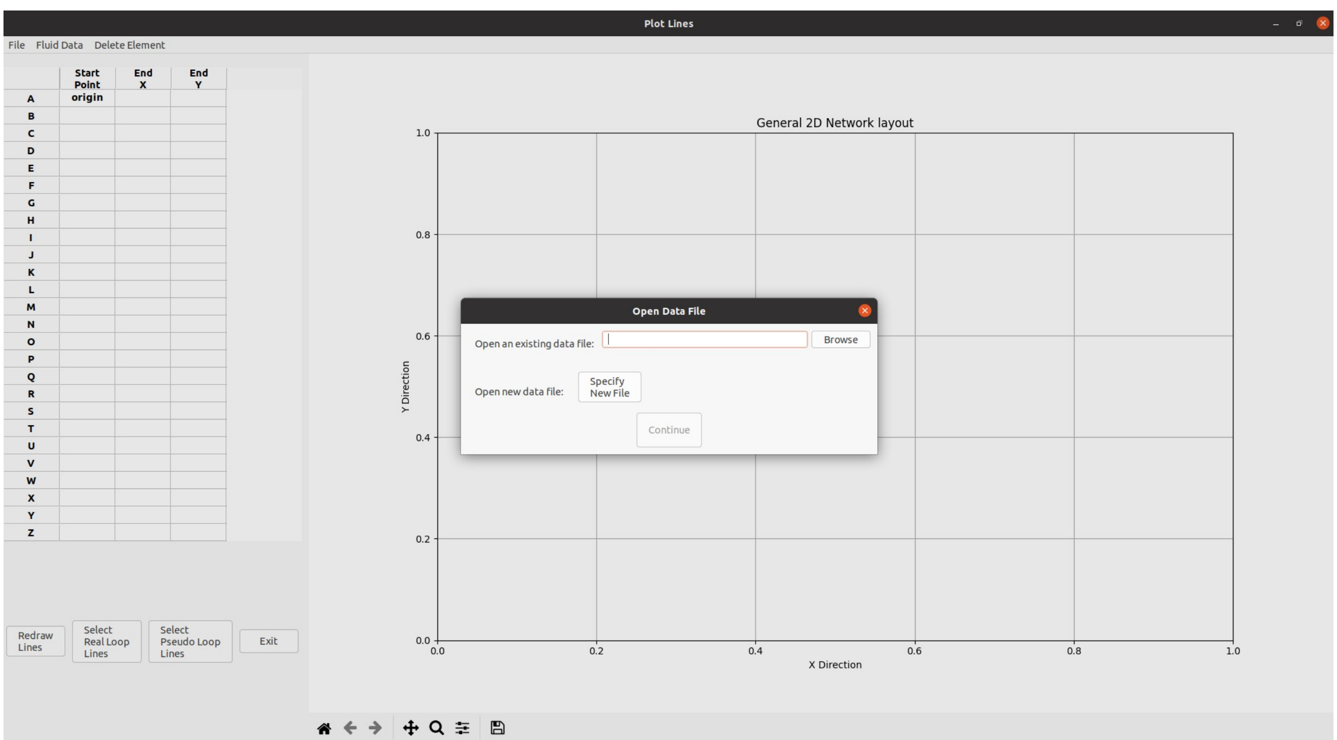
This program is based on the technical paper ‘Steady Flow Analysis of Pipe Networks; An Instructional Manual’ by Roland W. Jeppson, the book Hydraulic Pipeline Sytems by Bruce E. Larock, Roland W. Jeppson, Gary Z. Watters. Additional information has been drawn from the Crane technical paper 410 for fitting resistance coefficients. The program is intended for non-compressible fluids including slurry flows, even though use in the case of slurries should be with some caution.

The piping systems which can be analysied include simple straight runs of pipe, pipe runs with take off points (consumption points), closed pipe loop(s) with consumption points. The pipe system can be fed by pump(s), tank(s) or just by specifying an input flow. When specifying input flows care needs to be used in that the flows entering the loop(s) need to equal the flows exiting the loop(s).

The Program Interface

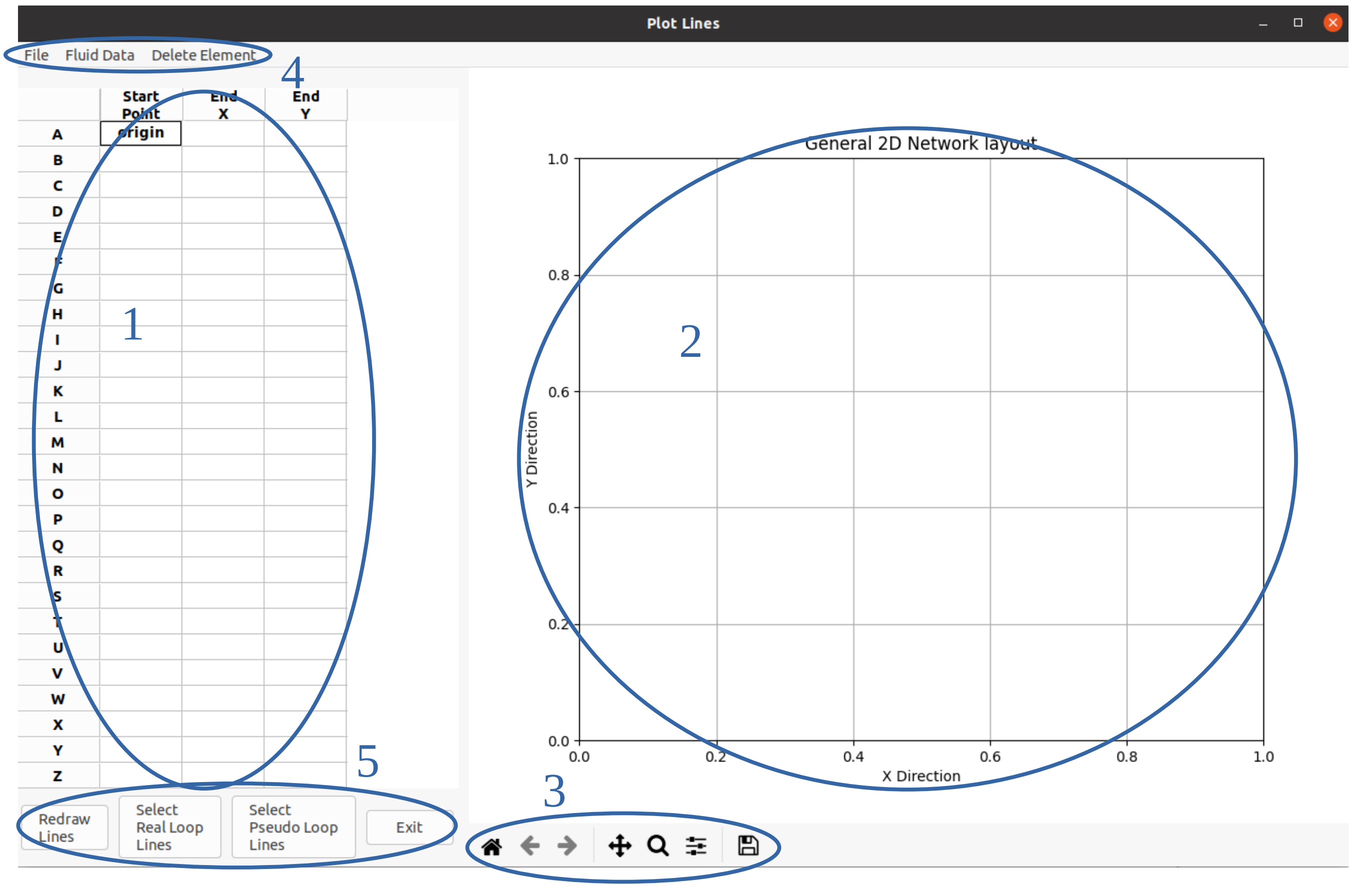
Data is entered using a simple graphic interface, NOTE; this interface is more of a line schematic of the pipe system, it is not intended to be a scaled or even a geometrically accurate layout of the pipe system. It is just a series of lines and nodes representing how the pipe is connected.

The Opening Screen:



This what you see at start up, likely you don't have a data file to open so click the 'Specify New File' button. The next popup should be your standard save file screen, complete it as you would normally and save the file. The file path and name will now appear in the above 'Open Data File' form click the 'Continue' button. If you have a data file already use the 'Browse' button to locate the file then click 'Continue'. For now I will assume you have created a new file, for two reasons; 1) I am lazy and do not want to do this for two different options and 2) if you already have a data file your beyond this point anyway. You are now at the information entry screen, more on that later.So here we are later.

The Information Entry Screen



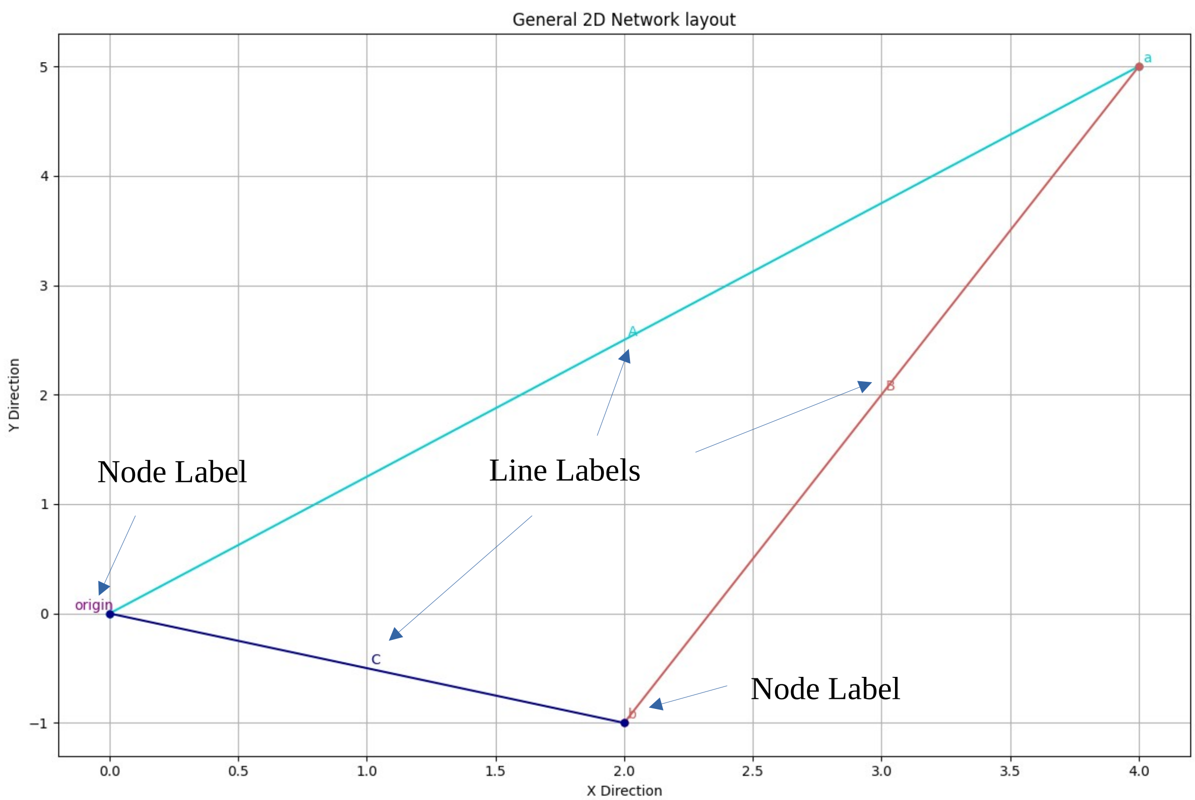
The areas of the screen are:
1 – data entry for the pipe end points
2 – the interactive graphics area
3 – buttons to manipulate the graphics area
4 – menu buttons
5 – command buttons

On the first line after a new point is entered in the grid (area 1) a line will be draw in the graphics (area 2). The line will be labelled with an upper case letter the end point will be labelled with a lower case letter. The line label will be the same as the row label in the grid, the node label will just be the first unused available letter. Again the end points do not and should not represent any scaling of the actual pipe layout, in-fact for ease of reading line and node labels it is recommended that line lengths be keep to 3 – 5 units long, both X and Y coordinates are needed. From this point on the first point entered in the grid as a start point must be a node letter (or the word 'origin') which shows in the graphics area.

The X – Y coordinates can be entered either as coordinates or by entering a node letter the line is connection with.An example of data entered is:

	Start Point	End X	End Y
A	**origin**	4	5
B	**a**	2	-1
C	**origin**	b	
D			
E			

Which produces the graphics as:



Now that you have a line and node drawn, clicking on the line letter will popup the line input form and it’s may pages. Clicking on the node letter will bring up the node entry form. And yes more on these forms will follow later.

Its not later enough, so we will continue to look at the entry form. Area 3 manipulates the graphics area.

The `Home`, `Forward` and `Back` buttons

These are akin to a web browser's home, forward and back controls. `Forward` and `Back` are used to navigate back and forth between previously defined views. They have no meaning unless you have already navigated somewhere else using the pan and zoom buttons. This is analogous to trying to click `Back` on your web browser before visiting a new page or `Forward` before you have gone back to a page -- nothing happens. `Home` always takes you to the first, default view of your data. Again, all of these buttons should feel very familiar to any user of a web browser.

The `Pan/Zoom` button

This button has two modes: pan and zoom. Click the toolbar button to activate panning and zooming, then put your mouse somewhere over an axes. Press the left mouse button and hold it to pan the figure, dragging it to a new position. When you release it, the data under the point where you pressed will be moved to the point where you released. If you press 'x' or 'y' while panning the motion will be constrained to the x or y axis, respectively. Press the right mouse button to zoom, dragging it to a new position. The x axis will be zoomed in proportionately to the rightward movement and zoomed out proportionately to the leftward movement. The same is true for the y axis and up/down motions. The point under your mouse when you begin the zoom remains stationary, allowing you to zoom in or out around that point as much as you wish. You can use the modifier keys 'x', 'y' or 'CONTROL' to constrain the zoom to the x axis, the y axis, or aspect ratio preserve, respectively.

With polar plots, the pan and zoom functionality behaves differently. The radius axis labels can be dragged using the left mouse button. The radius scale can be zoomed in and out using the right mouse button.

The `Zoom-to-rectangle` button

Click this toolbar button to activate this mode. Put your mouse somewhere over an axes and press a mouse button. Define a rectangular region by dragging the mouse while holding the button to a new location. When using the left mouse button, the axes view limits will be zoomed to the defined region. When using the right mouse button, the axes view limits will be zoomed out, placing the original axes in the defined region.

The `Subplot-configuration` button

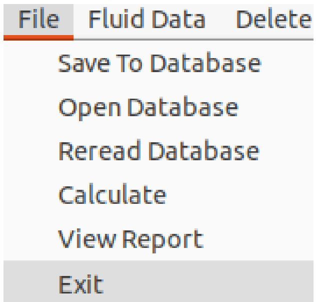
Use this tool to configure the appearance of the subplot: you can stretch or compress the left, right, top, or bottom side of the subplot, or the space between the rows or space between the columns.

The `Save` button

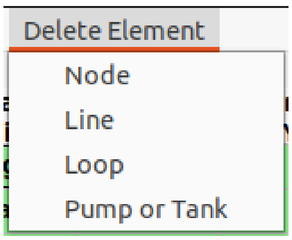
Click this button to launch a file save dialog. You can save the graphics files with the following extensions: `png`, `ps`, `eps`, `svg` and `pdf`.

NOTE: after selecting any one of these buttons they need to be clicked again to deselect them.

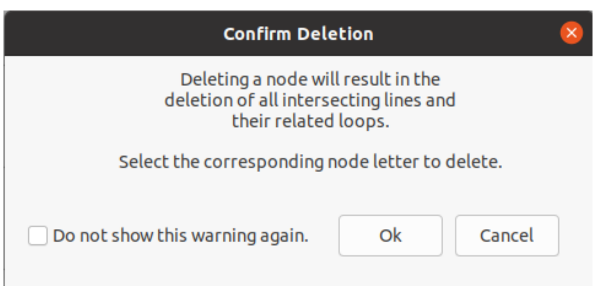
The Menu buttons, have nothing to do with food.



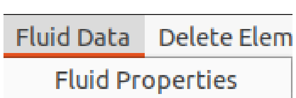
The File menu drop down gives you the option to:
- Save the currently input data to the database
- Open and existing database or create a new database
- Reread the database data, if it was changed and needs to update the screen
- To run the final calculations was all the required information is input
- To view the final calculated results in a PDF report which is generated automatically after the calculations are completed.



In order to remove certain elements from the graphics area you will need to use the Delete Element drop down menu.
To remove a node you would click the Node menu item this will introduce a pop up warning form, shown below (no waiting for this one). Once you acknowledge the warning you can proceed to delete a node. But be forewarned (oh scary stuff), deleting a node removes all the associated lines and anything associated with those lines. If its a matter that you just don't like the location of a node its easier to modify the coordinates in the grid area.
The same procedure can be followed for deleting Lines, Loops and Pumps or Tanks along with the same ominous warning.

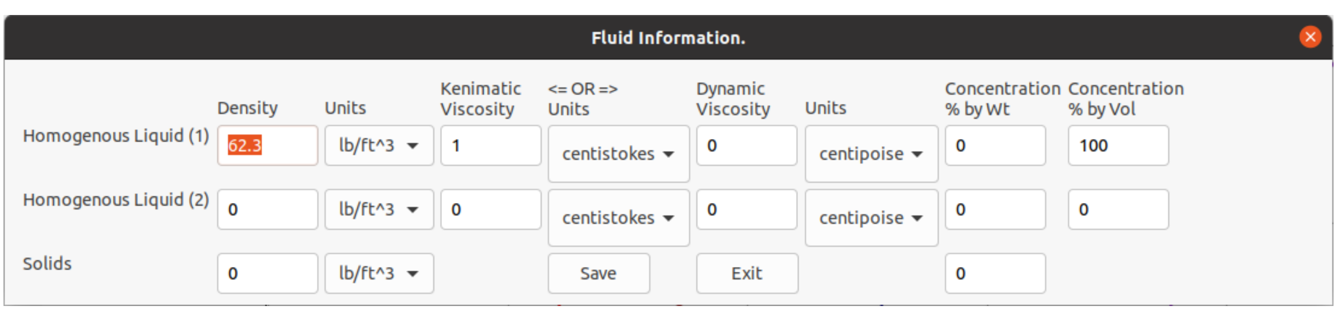


You can stop this warning from appear by checking the 'Do not show this warning again', box, neat eh!

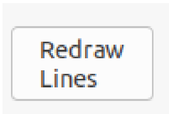


Selecting the Fluid Properties drop down from the Fluid Data menu pops up the fluid entry form. This is an annoying 2 step process but sometime life is like that. But its not as annoying as the pop up which will appear if you click the Calculate button before Saving this screen.

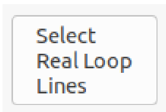
It comes preloaded with water, but you can make up your own homogeneous mix or slurry properties, just like a mad scientist.



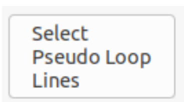
The last area to look at is area 5, the Command Buttons.



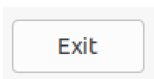
This button redraws the graphics and changes the line and node colors in the process.



Selecting this command will put you into the mode to draw the ‘real’ or closed loops, used in the energy equations.



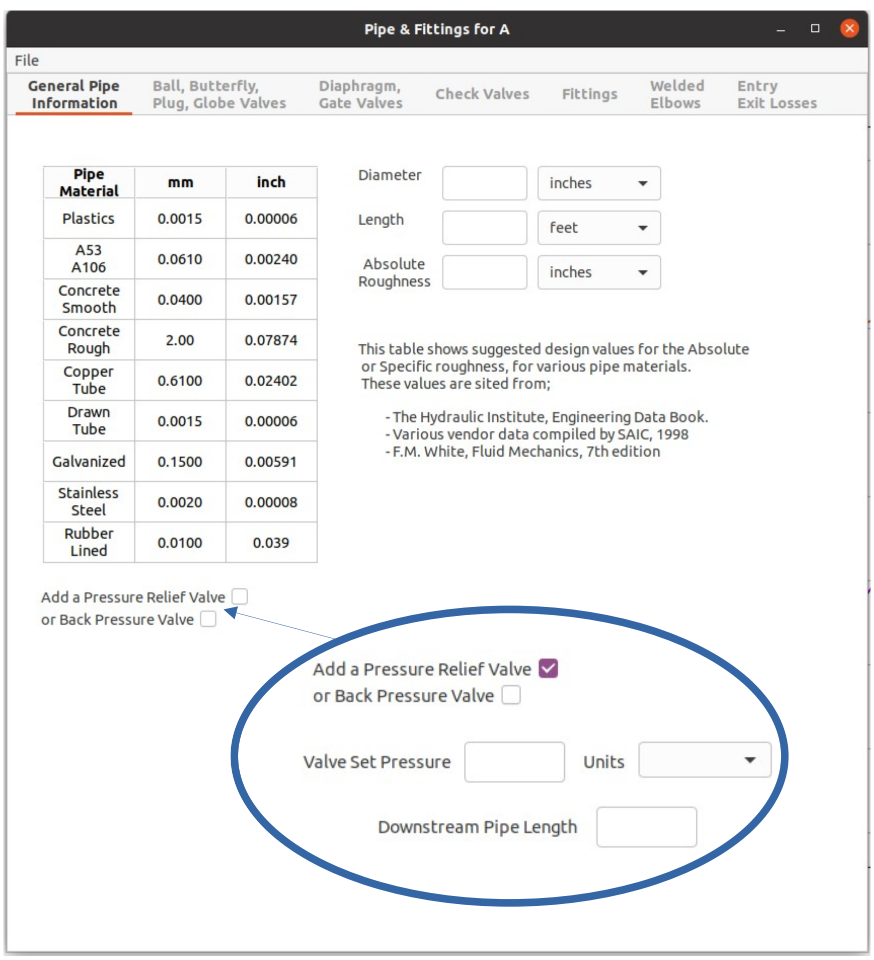
The pseudo loop button will allow you to select the lines forming a pseudo loop between tanks, pumps or control valves. All of this will, (you have it), be explained later.



The last button is the exit or close the application button. There are actually 3 ways to close the application, don’t ask why there just are. The other two are the little icon in the top right corner of you screen, and the Exit option in the File drop down menu, which I forgot to mention previously.

Define the Pipelines

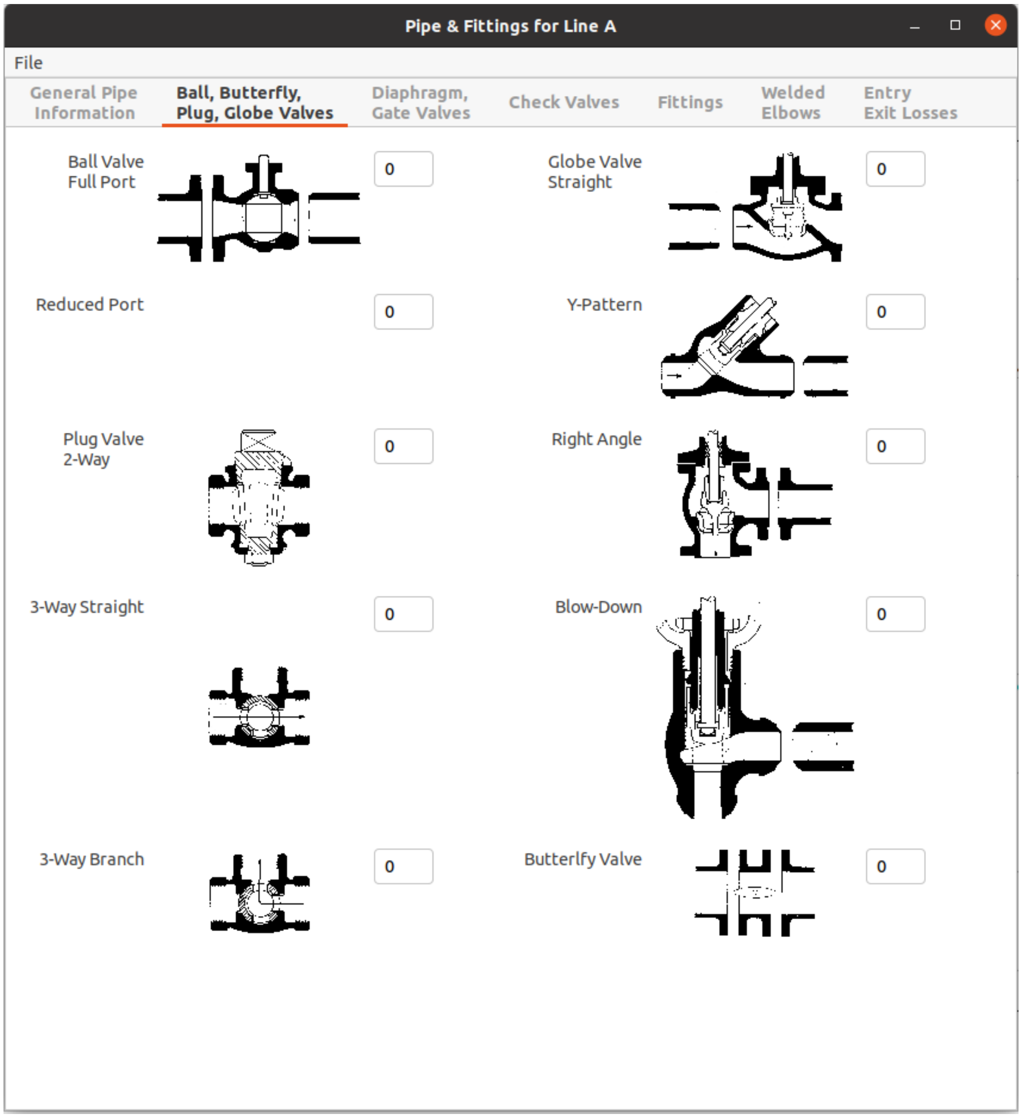
Well now it’s latter enough and I can mention the line and node entry forms, final some of the good stuff. The line entry form pops up when you select a line label in the graphics, the line selected shows up in the form title. It allows you to enter information specific to the pipe line selected. The opening screen gets general data pipe diameter, inside, pipe length and surface roughness of the pipe material. You can also select if there is a pressure relief valve or a back pressure valve in the line by clicking the appropriate check box.



Click on line label ‘A’ and enter diameter 4”, length 1000’ and roughness .0102”. then File --> Data Complete.

If you are entering a consumption line, either one which supplies flow to the circuit or removes fluid flow you would leave the form blank.

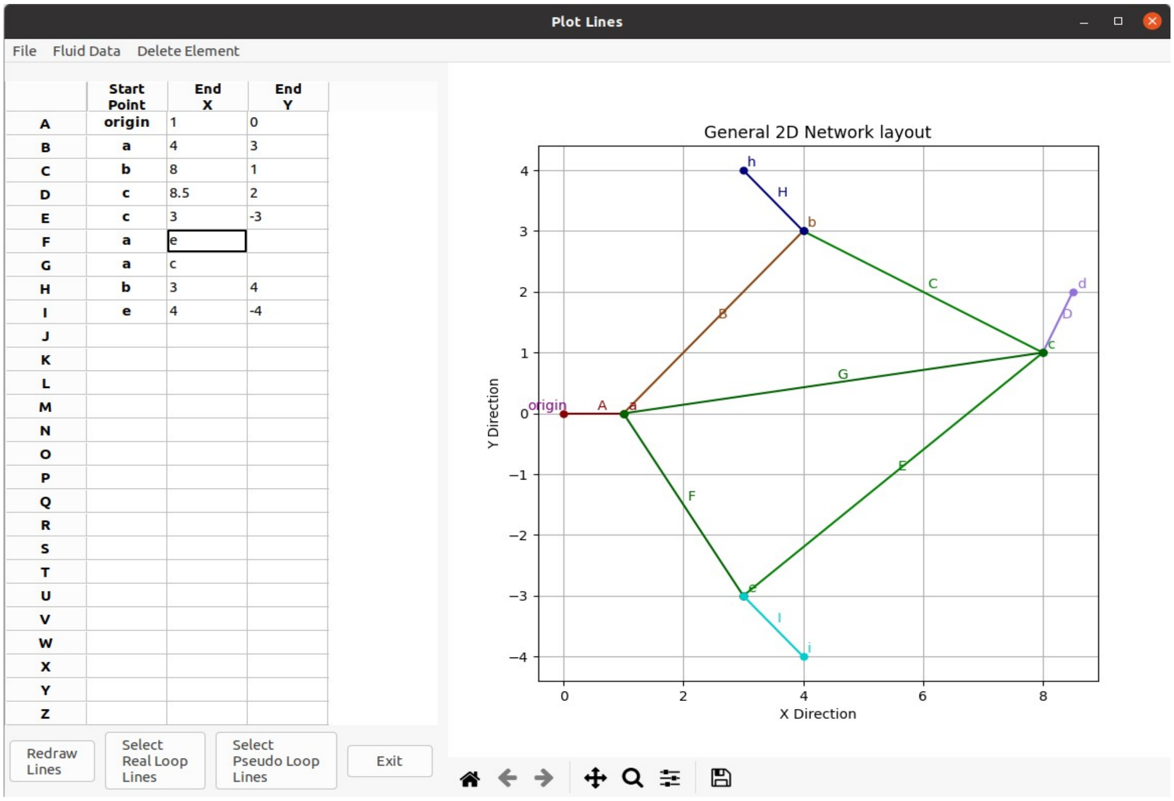
This is the required additional information needed if you click either the Add Pressure Relief or Back Pressure valve boxes. For a Back Pressure valve you would be entering the Upstream pipe length.



I am sure you noticed that this form actually has 7 different pages; but because I am lazy, as previously stated, we will look at only one other page.

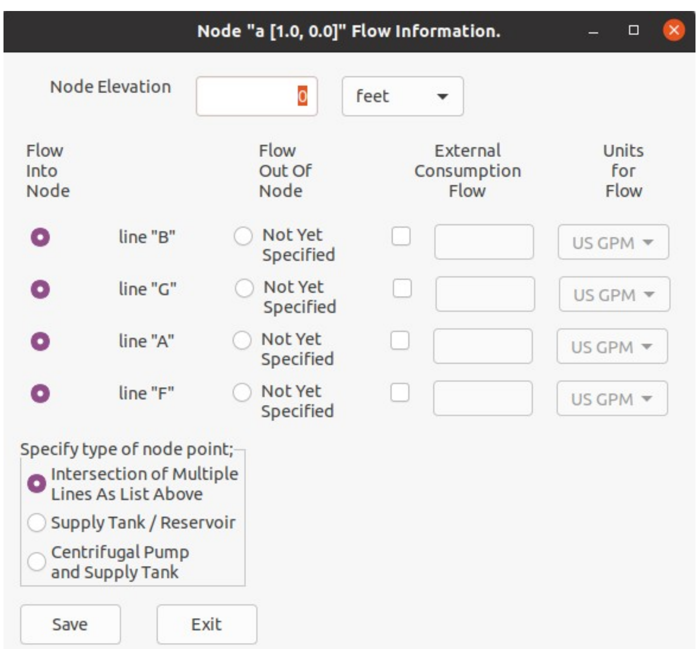
This page like the remaining 5 is for the entry of the fittings which maybe on the pipe line, you merely enter the number of fittings present. In some cases such as reducers or welded elbows you will need to specify more details, but I have confidence you'll get it.
If the fittings form is greyed out and does not allow data entry it is because the 'General Pipe Information' has not been entered. You must have a pipe diameter and length entered to proceed with the fittings selection.

NOTE: Once all the data is entered into all the various pages you **must** click the 'File' menu button and select 'Data Complete' to properly save your changes. You will also note a change to the grid area of the main form. The line that was selected will now be high-lighted green indicating the information has been entered and completed for this line.



Now the node information entry form. This gets a little trickier, first I added some more points to my graphics to help explain, it now look like this:

Define the Intersection Nodes

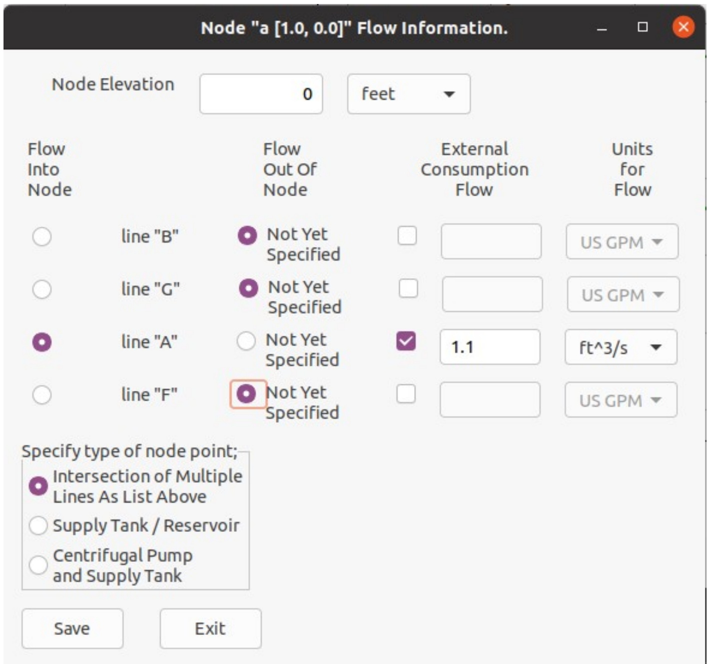


Lines ‘A’, ‘D’,’I’ and ‘H’ at corners of the graphics will be used as consumption lines, ‘A’ & ‘I’ will supply a fluid flow and ‘D’ & ‘H’ will consume or drain the fluid flow. So lets first select node ‘a’ to get the node entry form.

At the top of the Node form is the node and its coordinates, next is the elevation of the node, you can select the units in the drop down box on the right.

The selection below lets you specify the direction of flow into the node along the line specified. Don’t worry if you guess wrong for the flow direction, the program will correct it, during calculaion. If it is a consumption flow check the check box then input the flow and specify the units of flow.

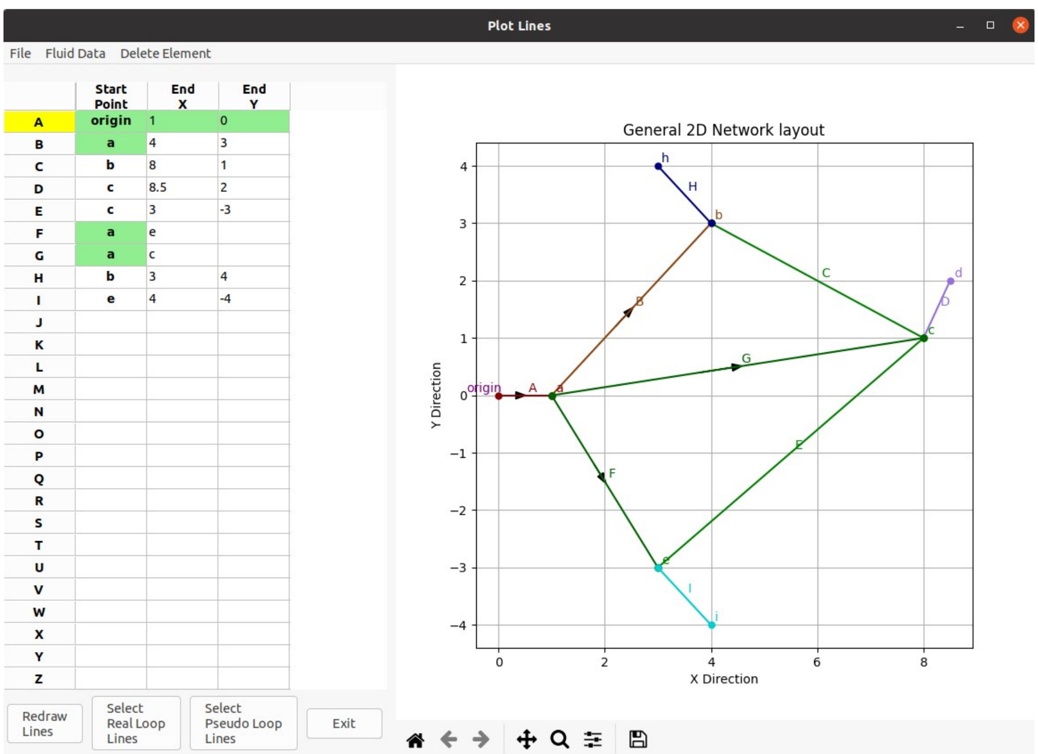
The lower box area is where you indicate if the node is just a junction point, a pump/tank supply point or a reservoir tank. The next figure shows how this form can be completed and the changes it makes to the graphics.



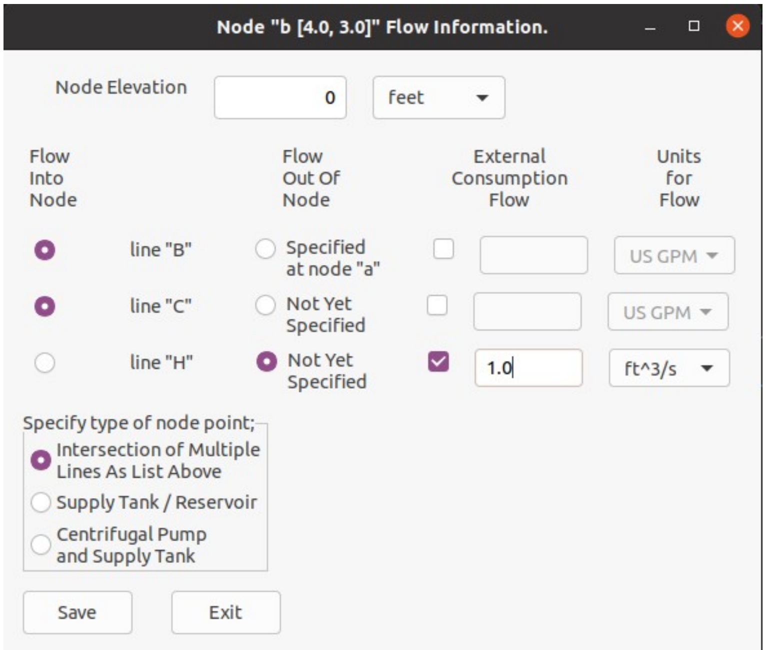
OK so a lot happened once the data was entered into the node form and the Save button was clicked.

In the grid the cells containing the coordinates for point ‘a’ and any cell containing the node letter ‘a’ where high-lighted green. Since the consumption line ‘A’ has been specified as such it was high-lighted in yellow.

The lines in the graphics have had arrow heads attached to indicate the direction of flow.



Lets repeat the process for point ‘b’. The node form for the ‘b’ is completed as shown.
You will notice when the form is opened that line ‘A’ flow has already been “Specified at node ‘a’ ”.
You need only specify those which are ‘Not Yet Specified’.



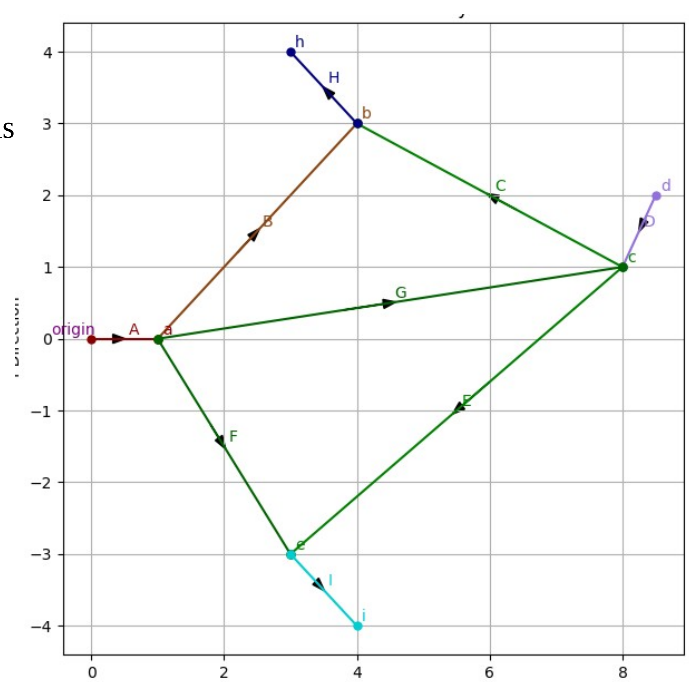
Once ‘Saved’ the grid section will look like this and the graphics will update to show arrow heads on lines ‘H’ and ‘C’. Remember line ‘H’ is a consumption and is high-lighted yellow.

	Start Point	End X	End Y
A	origin	1	0
B	a	4	3
C	b	8	1
D	c	8.5	2
E	c	3	-3
F	a	e	
G	a	c	
H	b	3	4
I	e	4	-4

	Start Point	End X	End Y
A	origin	1	0
B	a	4	3
C	b	8	1
D	c	8.5	2
E	c	3	-3
F	a	e	
G	a	c	
H	b	3	4
I	e	4	-4

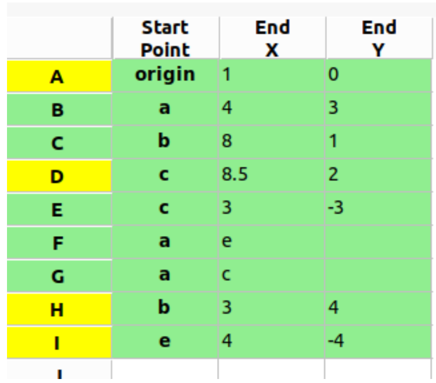
Lets finish up the last nodes actually the last node flow into node ‘c’ is set at 1.0 ft^3/s and flow out of node ‘e’ is set at 1.0 ft^3/s. The last node need only be opened and confirmed, this step is there to confirm the node elevation. The grid section should now look like this;

And the graphics area should look like this

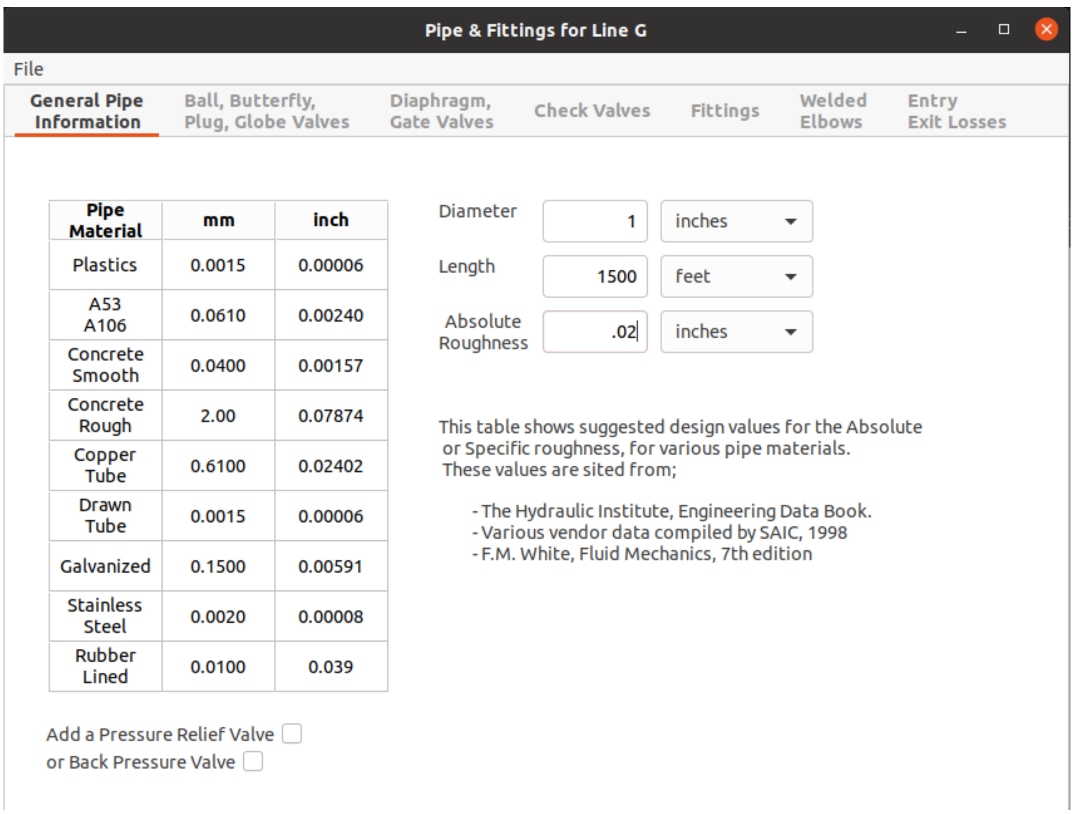


The cells for lines ‘B’,’C’, ‘E’, ‘F’, and ‘G’ are not high-lighted yet as the piping has not been defined. As each is defined it will be high-lighted. Go ahead and enter the line data as follows:
Simple click on each line label and eneter the data as shown then remember to click the menu item “File” --> “Data Complete” to save it. The grid should now look like this:

Line	Pipe ID	Length	Absolute Roughness
B	6”	1000’	.02”
C	6”	800’	.02”
E	6”	2000’	.02”
F	6”	1000’	.02”
G	1”	1500’	.02”

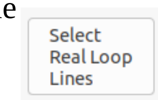


	Start Point	End X	End Y
A	origin	1	0
B	a	4	3
C	b	8	1
D	c	8.5	2
E	c	3	-3
F	a	e	
G	a	c	
H	b	3	4
I	e	4	-4

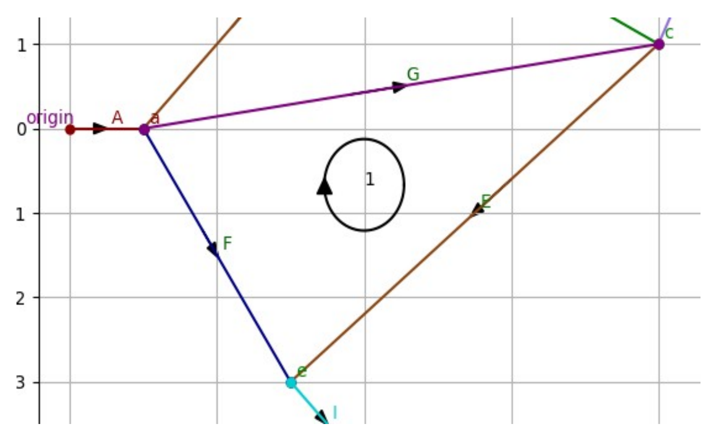


Define the Closed Loops (or energy equations)

The last step in defining our model is to define the closed energy loops, in this example there are 2 potential loops. In this example there are 5 line flows to be determined, there are 4 junction nodes which have already been defined; however, of the 4 node equations only 3 are independent. The 4 junction nodes provide 3 independent equations and the as yet undefined loops provide 2 more equations.

Let’s define the loop defined by lines ‘E’, ‘F’ and ‘G’.
First initiate the process by clicking the 

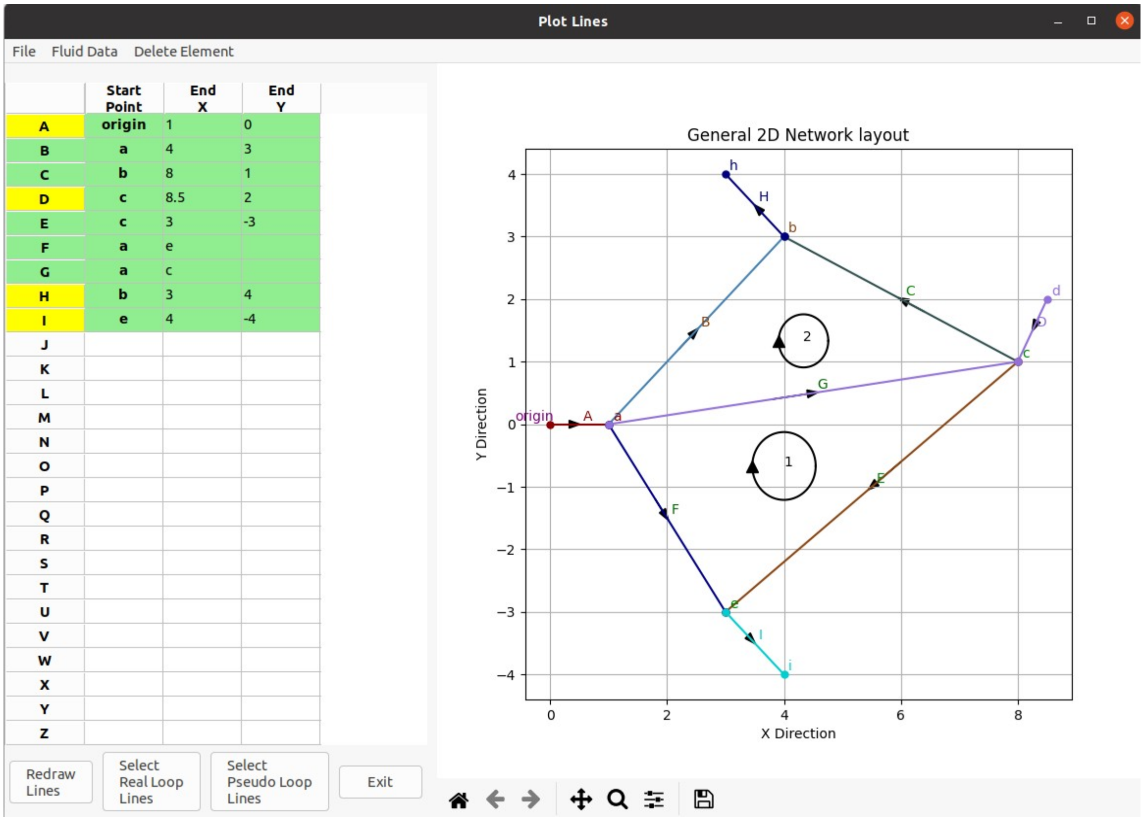
button, it will change to 



Now all you need do is select the lines by clicking on the line label for each line. When the line is selected it’s colour well change to black. Once the last or loop closing line is selected, the lines will revert to coloured and a circular arrow will appear with a number defining the loop. The order in which the lines are selected does not matter the program will arrange them into an order which is clockwise. Do the same for loop ‘B’, ‘C’, ‘G’. You could have selected the lines ‘B’, ‘C’, ‘F’ and ‘E’ instead but it is recommended that you keep the loops small and repeat as few lines as possible.

If all has gone well your screen should look something like this:

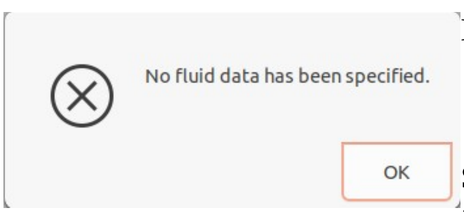
1. a
l
l



the cell defining the node coordinates should be shaded green

2. all the lines which have undefined flows and which have had the diameter, length and roughness defined will be shaded green
3. any line which is just a consumption point will be shaded yellow

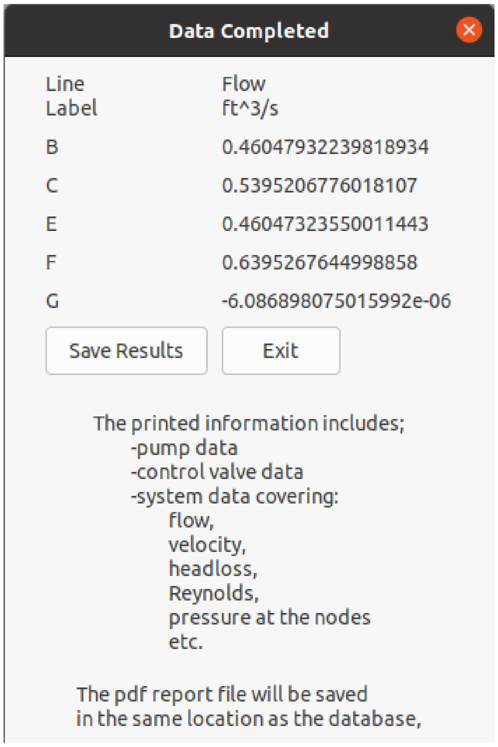
You form should now show 2 loops as a minimum and the cells shaded as above. Now you can click the menu item File --> Calculate. But first you should use the File -->Save to Database menu item.



Now because the fluid is not defined you just get:

So click the menu item Fluid Data --> Fluid Properties, just accept the default for water by clicking the Save button.

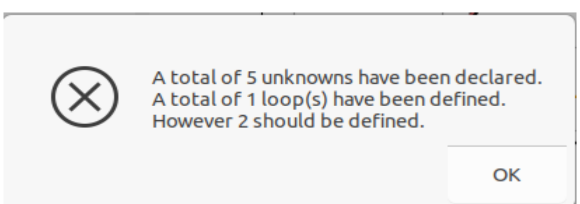
Now go ahead and click the File --> Calculate menu option. One of two things could happen, the good thing is you will see this screen:



It shows the line labels and the line flows in ft^3/s. You can elect to save the results or exit the form and make changes to the graphics.

The flow for line 'G' shows as a negative this means that the direction shown in the graphics is wrong and is reversed. If you go to the graphics and select either node 'a' or 'c' and reverse the direction of flow for line 'G', then rerun the calculation the flows will be the same except line 'G' will no longer be negative.

If you didn't get the above screen, the second thing which may happen is not too bad and can usually be fixed.
(NOTE: for this example one of the 2 loops was deleted to force this message).
It looks like this;



It means that you have not fully defined your data. The program tries to take a best guess at the problem. In this case it says you should have 2 loop defined, but only 1 has been shown.

But sometimes it just indicates a warning;

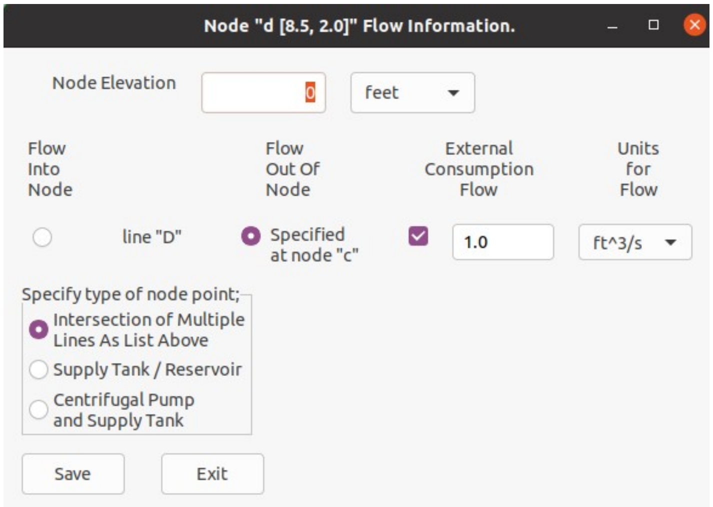
'Unable to iterate network to a solution, total number of iterations completed = #.
Based on presented information system cannot be solved.'

This is not good and it means there is something wrong with the data entered i.e. you screwed up. You will need to go through the forms/data and try to determine what went so terribly, terribly wrong. Sometimes this can be repaired by using the menu item File --> Reread Database.

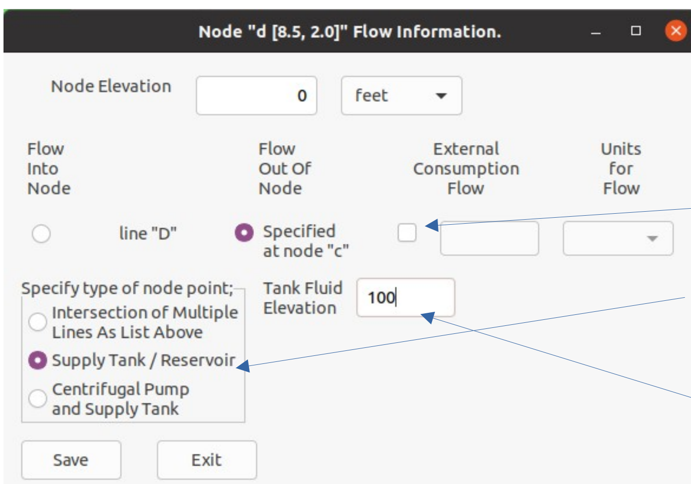
Ok on a high point we can now continue on with other features of the program, pumps and tanks.

Entering Pumps and Tanks

You define a pump or tank using the node form at a specified node, the only stipulation is that the node must be at the end of a single line, i.e. it cannot be at a node with multiple intersecting lines. Lets start with a simple tank and locate it at node ‘d’. Open the node definition screen by clicking on the new node ‘d’. Define the items as shown;



Change the original Node form for node ‘d’ to look like this.

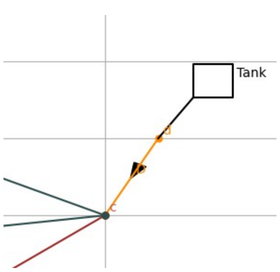


2) Specify a fluid level in the tank

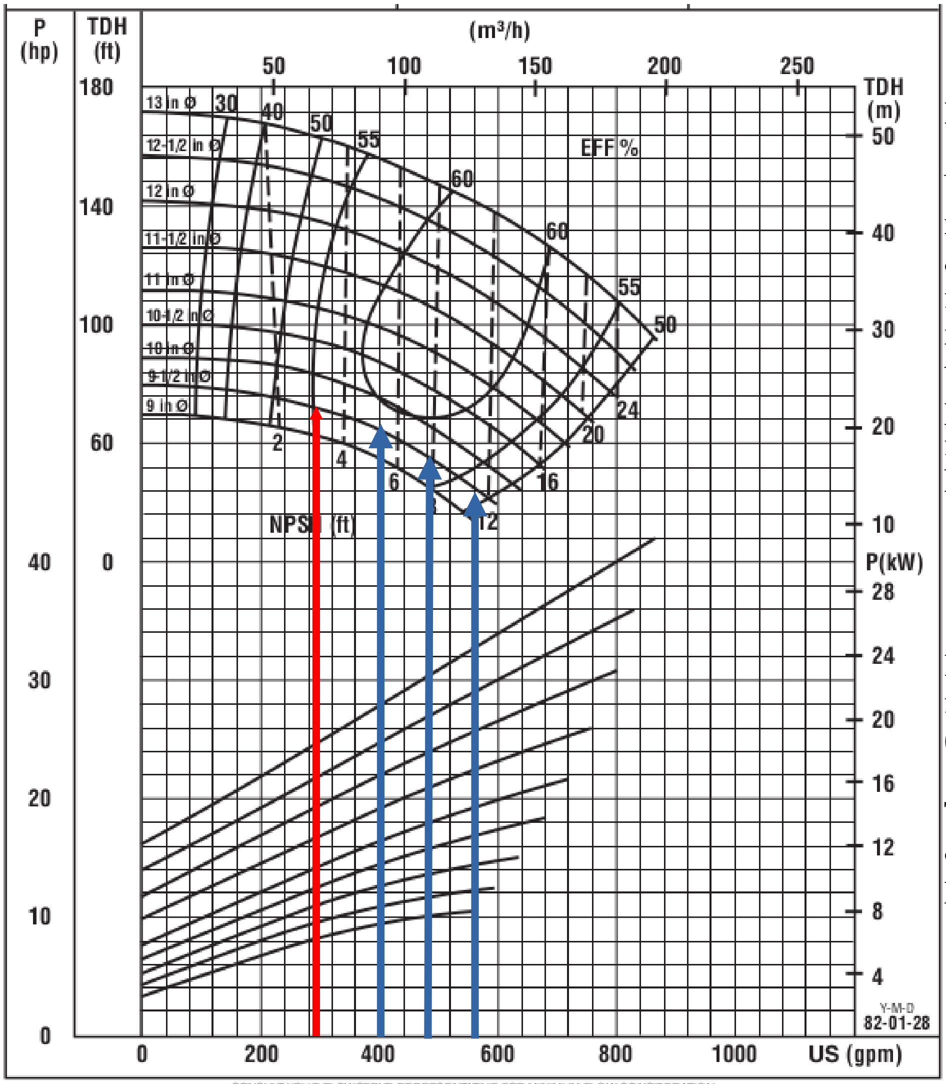
3) make sure the flow direction is selected in this case I elected it to flow into the circuit

1) remove the consumption flow by clicking the check box
2) select the bullet next to ‘Supply Tank / Reservoir
3) The ‘Tank Fluid Elevation’ text box will appear and you can enter the fluid elevation.

The Pipe and Fittings form for line ‘D’ well need to be changed to include a pipe size of 6” with a length of 200’ and a roughness of .02”



You will note that apart from the flow arrow appearing on the graphics a tank figure has been added.



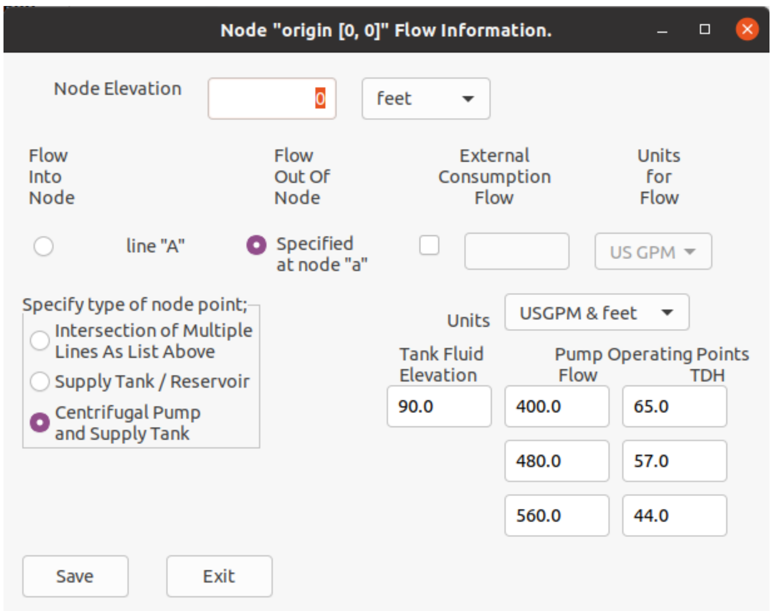
Next lets change node ‘origin’ to include a pump, but first some pump data is needed. In order to proceed a pump curve will be needed for a constant speed and set impeller size. You will need to select 3 points from the pump curve which define flow and corresponding head.

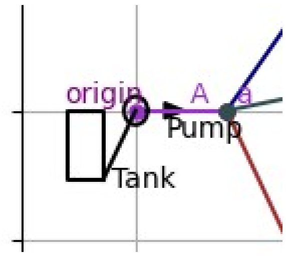
Reading 3 arbitrary points for a 9-1/2” dia impeller (blue arrows).

The red arrow reveals the actual calculated operating point.

Flow (USGPM)	TDH (ft)
400	65
480	57
560	44

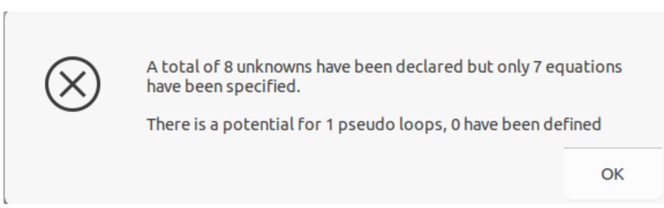
Click on the node 'origin' label and modify the node form by clicking the Centrifugal Pump and Supply Tank bullet. Doing so pops up the text boxes for the added information. Specify the data from the pump curve and add a fluid level to the tank. Make sure the flow direction is correct that is out of the pump node. This time when you save the node data a small pump and tank will be drawn on the graphics.





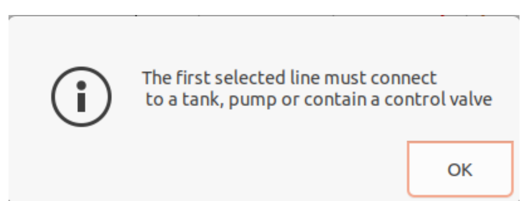
You will also need to specify the line information for the pump discharge line 'A', 6" diameter, 1000' long and roughness of .02". You will know this because the cell for line 'A' initially is yellow, but once the diameter, roughness and length are defined it will revert to green.

If you try to run the calculation at this point you will get the warning;

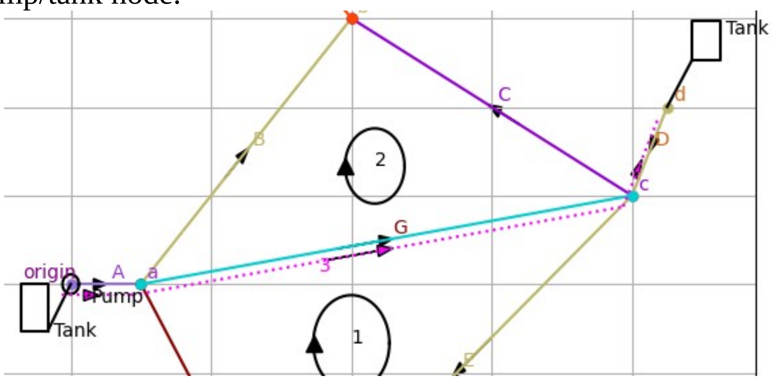


When you add a pump to the system you introduce and added unknown. This is where the pseudo loop comes to play. Selecting a pseudo loop is the same as a closed loop except you click the 'Select Pseudo Loop' button. A pseudo loop needs to run between two supply points (tank, pump or Control Valve). If there was only one tank, pump/tank of control valve in the system you would not be able to select a pseudo loop.

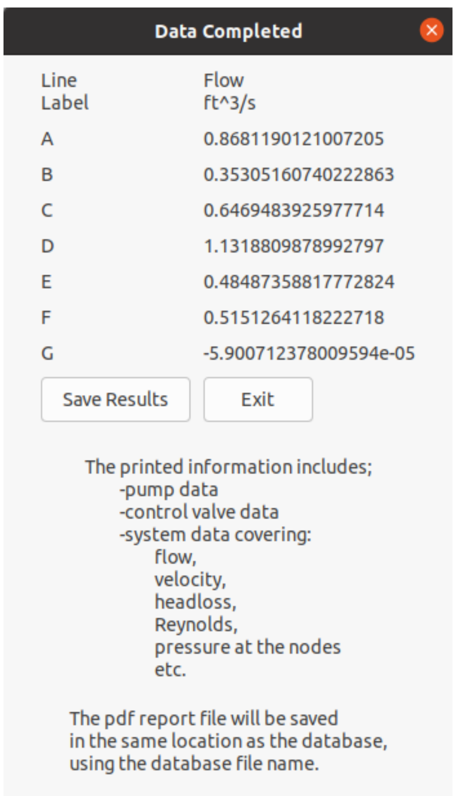
Once you have clicked the 'Select Pseudo Loop' a warning about pseudo line selection pops up. It just means you have to start the selection at a pump or tank discharge line. (Control valves come later.)



Select lines ‘A’ , ‘G’, and ‘D’. When you select the last line with the pump/tank or tank connected to it the lines revert to colour and the dotted loop arrow line is drawn. Again the pseudo loop must start and end with a tank or pump/tank node.



You can now run the calculation.



When you do if all is good you will get the form to the left. The numbers may vary depending on the values you entered for: elevations, pipe roughness, etc.

PRV and BPV Entry

First some information regarding **P**ressure **R**elief **V**alves (not safety valve) and **B**ack **P**ressure **V**alves.

A PRV's purpose is to maintain a constant pressure on its downstream side, independent of upstream pressure. Only two exceptions to the maintenance of this downstream pressure exist:

1. if the upstream pressure becomes less than the valve setting. If this occurs, the valve has no effect on flow conditions except to create a local loss; generally its effect is then like a globe valve in dissipating additional head beyond the friction loss in that line.
2. if the downstream pressure exceeds the pressure setting of the valve so that flow would occur in the upstream direction if the PRV were not present. Occurrence of this and PRV acts as a check valve, preventing a reverse flow in the line. Then the PRV allows the pressure immediately downstream from the valve to exceed its pressure setting.

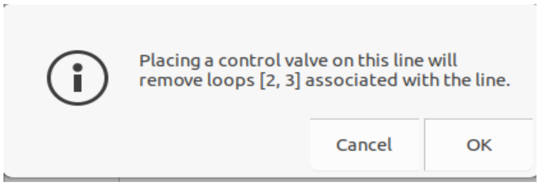
A BPV's purpose is to maintain a constant pressure upstream, independent of the value of the downstream pressure. This type of valve can be used at higher elevations of a network to maintain pressure in that area. Again there are exceptions

1. should the upstream pressure become less than the pressure setting, the valve can not maintain the pressure setting and it will shut down the flow in its line.
2. should the flow want to reverse direction from the positive flow direction through the valve, the valve opens completely and acts as a local loss device.

Some of the requirements for adding a valve to the graphics;

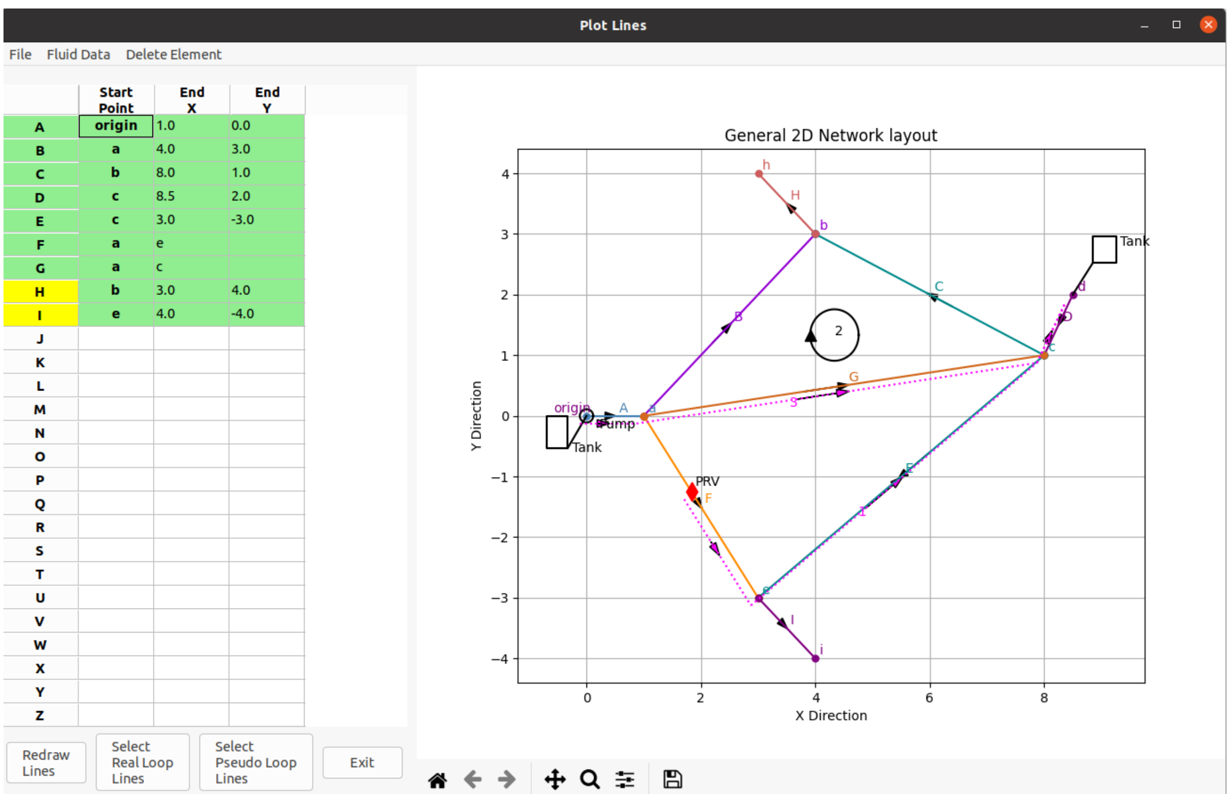
1. if you add a valve to a line which is associated with either a closed loop(s), the loop(s) will be removed. PRV and BPV cannot be part of a closed loop.
2. If you try to add a valve to a line which is part of a pseudo loop(s) the loop(s) will be removed. PRV and BPV are usually part of a pseudo loop but flow direction is important in selecting the pseudo loop.
3. As mentioned flow direction is important in selecting pseudo loops containing a valve. In the case of a PRV the pseudo loop arrow must approach the valve from the downstream direction. In the case for BPV the direction must approach from the upstream side. No worries the program will prompt you with a node which must be on the next line selected, it will also let you know if your selection is wrong.

Lets add a PRV to the line ‘F’ by opening the Pipe and Fitting form, by clicking on line label ‘F’. Now select the check box to ‘Add a Pressure Relief Valve’ and a few things will happen;

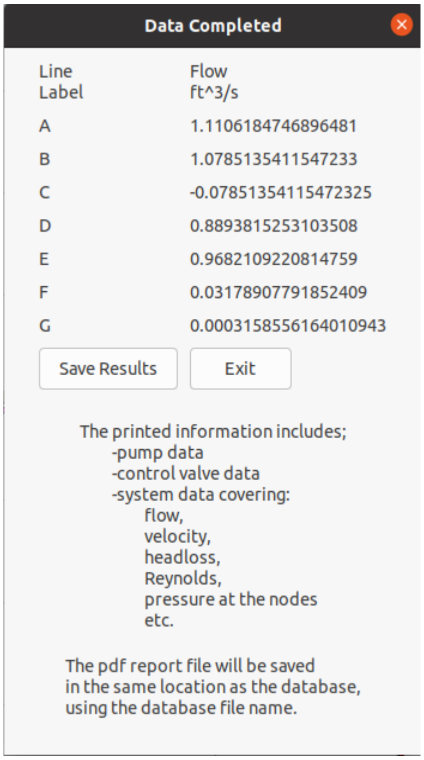


this warning will appear and after clicking ‘OK’ the one loops will be removed from the graphics, and some text boxes will appear on the Pipe and Fittings form.

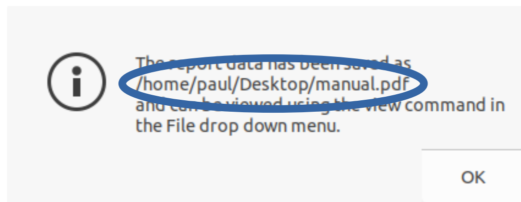
Specify the valve set pressure say 55’ and the length of pipe downstream call it 500’. Select the ‘File’ --> ‘Data Complete’ and try to rerun the calculations. You get a warning information is missing, that’s because a loop was removed and something needs to replace it. Lets start with the valve pseudo loop, click ‘Select Pseudo Loop Lines’ and select line ‘F’ after acknowledging the warning about having to select the line containing the valve. You are informed that the next line selected must terminate at node ‘e’, acknowledge this warning and select line ‘E’. This loop must end with a tank or pump as any pseudo loop so select line ‘D’ as the final line. A new pseudo line from the valve to the tank should appear. You have now replaced the deleted closed loops and your final screen should look like this;



The final test comes when you select the File --> Calculate menu item and get this window and then save the results.



To save the report click the ‘Save Results’ button and you will see the following message, it tells you where your report has been saved, it should be the same name and location as the database file you entered at the start of this example, with a .pdf extension.



The Final Report

The attached report is divided into 10 areas over 3 tables;

- Line data table;

1. this is the information entered by you for each line label
2. the final calculated flows in three different units
3. the total line loss for the given flow
4. head loss converted to psig based on fluid density
5. the fluid velocity in the line

- Node data table;

6. node label
7. node head
8. node pressure based on fluid density

- Pump data table

9. The pump information is based on the theoretical calculation of the pump curve and may not be an exact point on the pump curve, but as you see here it is only off by a few feet of TDH for the calculated flow. The curve indicates about 70' TDH for the flow of 290 USGPM (see red arrow on previous pump curve).

- Control Valve data table

10. When a control valve is introduced its information will appear here. For PRV valves the downstream pressure should approximate the set pressure and for BPV the upstream pressure should be the same as the set pressure.

- Fittings data table by Line Label

11. When fittings as specified in the Pipe and Fittings form the information will appear here, if there are no fittings specified for a line then the table will not be shown.

Calculated Data for expl_2.db

Line Label	Pipe Dia inches	Pipe Length	Flow			Head Loss		Pressure Drop psig	Velocity	
			ft^3/s	USGPM	m^3/s	feet	meters		ft/s	m/s
A	6.0	1000.0	1.114	499.83	0.032	27.311	8.324	11.8	5.66	1.73
B	6.0	1000.0	1.075	482.44	0.03	25.459	7.76	11.0	5.47	1.67
C	6.0	800.0	-0.075	-33.61	-0.002	0.117	0.036	0.05	0.38	0.12
D	6.0	200.0	0.886	397.83	0.025	3.476	1.059	1.5	4.51	1.37
E	6.0	2000.0	0.968	434.68	0.027	41.418	12.624	17.89	4.93	1.5
F	6.0	1000.0	0.032	14.15	0.001	0.03	0.009	0.01	0.16	0.05
G	1.0	1500.0	0.007	3.25	0.0	25.575	7.795	11.05	1.33	0.4

1 2 3 4 5

Node Label	Elevation		Head		Pressure	
	feet	meters	feet	meters	psig	kPa
origin	0.0	0.0	149.039	45.43	64.4	443.68
a	50.0	15.15	121.728	37.1	52.6	362.38
d	0.0	0.0	100.0	30.48	43.21	297.69
c	50.0	15.15	96.153	29.31	41.55	286.24
e	20.0	6.06	54.735	16.68	23.65	162.94
b	50.0	15.15	96.27	29.34	41.6	286.59

6 7 8

9

Pump Node	Head		Flow	
	feet	meters	USGPM	m^3/hr
origin	59.039	17.995	499.798	113.524

10

Line Label	Valve Type	Set Pressure			Upstream Pressure			Downstream Pressure		
		feet	psig	kPa	feet	psig	kPa	feet	psig	kPa
F	PRV	55	23.76	163.85	121.73	52.53	362.18	54.73	23.62	162.85

11

Fittings for line B	Quantity
Ball Valve Full Port	1
Ball Valve Reduced Port	3
Plug Valve 3-Way Straight	6

APPENDIX I

FORTRAN PROGRAM

Data type

```
INTEGER JN(40.5), NN(40), JB(20), IFLOW(40), LP(8,20), JC(50)
REAL D(50), L(50), A(50.51), QJ(20), E(50), KP(50), V(2), Q(50),
      EXPP(50), AR(50), ARL(50)
```

Read in data

```
30    READ(5,110,END=99) NP, NJ, NL, MAX, NUNIT, ERR, VIS, DELQ1
110   FORMAT(515.3F10.5)
```

Variable definitions

```
NN – number of nodes
JN – number of pipes at node
JB – unknown
INFLOW – consumption flow rate
LP – unknown
JC – to do with solution of linear equations

D – pipe diameter
L – pipe length
A – flow
QJ – unknown
E – initial absolute roughness
      converted to relative roughness
V – velocity
Q – flow in pipe
KP – Kp value for pipe
EXPP – n exponent in equation hf = Kp * Q^n
AR – pipe x-sectional area
ARL – coefficient in equation Kp = a * (L / (2 * g * D * A^2))
```

Used in equations 2-15 to 2-18 Ref 1

```
# NP - NO. OF PIPES.
# NJ - NO. OF JUNCTIONS,
# NL - NO. OF LOOPS,
# MAX - NO. OF ITERATIONS ALLOWED,
# ERR – allowed error in calculated flows before accepting results
# VIS – kinematic viscosity
# DELQ1 – deviation used to calculate Q1 and Q2 from average Flow
# IF NUNIT=0 D AND E IN INCHES AND L IN FEET,
# IF NUNIT=1 D AND E IN FEET AND L IN FEET,
# IF NUNIT=2 D AND E IN METERS AND L IN METERS,
# IF NUNIT=3 D AND E IN CM AND L IN METERS.
```

The 100 series line numbers reference formatting only and are not addresses here.

```
100   FORMAT(1615)
      NPP = NP + 1
      NJI = NJ - 1
      READ(5,101) (D(I), I=1, NP)
      READ(5,101) (L(I), I=1, NP)
      READ(5,101) (E(I), I=1, NP)
101   FORMAT(8FI0.5)
      DO 48 I=1, NP
48    E(I) = E(I) / D(I)
      IF(NUNIT-1) 40, 41, 42
40    WRITE(6.102) D(I), I=1, NP)
102   FORMAT('PIPE DIAMETERS (INCHES)'./,(1H, 16F8.1))
      DO 43 I=1, NP
43    D(I) = D(I)/12
      GO TO 44
41    WRITE(6.112) (D(I), I=1, NP)
112   FORMAT('PIPE DIAMETERS (FEET)'./,(1H, 16F8.3)
44    WRITE (16.103) L(I), I=1, NP)
103   FORMAT('LENGTH OF PIPE (FEET)'./,(1H, 16F8.0)
```

Convert absolute roughness to relative roughness

Based on units selected, convert dia and length to feet or meter

```
      G2 = 64.4
      GO TO 50
42    IF (NUNIT .EQ. 2) GO TO 45
      DO 46 I=1, NP
46    D(I) = .01 * D(I)
45    WRITE(6.113) (D(I), I=1, NP)
113   FORMAT('PIPE DIAMTERS (METERS)',/,(1H.16.F8.4))
      WRITE(6.114) (L(I), I=1, NP)
114   FORMAT('LENGTH OF PIPE (METERS)',/,(1H, 16F8.0)
      G2=19.62
      WRITE(6.115) (E(I), I=1, NP)
115 FORMAT('RELATIVE ROUGHNESS OF PIPES',/,(1H, 16F8.6)
```

NOTE
Undefined

Length and dia convertion cont'd

```
# INFLOW - IF 0 NO INFLOW,
      IF 1 THEN NEXT CARD GIVES MAGNITUDE IN GPM
      IF 2 NEXT CARD GIVES MAGNITUDE IN CFS
      IF 3 NEXT CARD GIVES MAGNITUDE IN CMS.
# NNJ - NO. OF PIPES AT JUNCTIONS POSITIVE FOR INFLOW
  NEGATIVE FOR OUTFLOW.
# JN - THE NUMBER OF PIPES AT JUNCTION,
      IF FLOW ENTERS MINUS
      IF FLOW LEAVES THE PIPE NUMBER IS POSITIVE.
```

Variables for nodes

```
      DO 70 I=1, NP
      AR(I) = .78539392 * D(I)**2
70    ARL(I) = L(I) / (G2*D(I) * AR(I)**2)
      II = I
      DO 1 I=1, NJ
      READ(5,100) IFLOW(I), NNJ, (JN(I,J),J=I,NNJ)
      NN(l)=NNJ
      IF(IFLOW(I)-1) 1.2,3
2     READ(5,101) QJ(II)
      QJ(II) = QJ(II)/449.
      JB(II)=1
      GO TO 4
3     READ(5, 101) QJ(II)
      BJ(II) = 1
4     II = II + 1
1     CONTINUE
```

Pipe x-sect area
Coefficient for Kp - equation 2-28 Ref 1

Determine the coefficient for the variables in the node equation same as: Calc_Network.py.node_matrix

```
# NUMBER OF PIPES IN EACH LOOP (SIGN INCLUDED)
      DO 35 I=1, NL
      READ(5,100) NNJ, (LP(J,I), J=1 ,NNJ)
35    LP(8,I)=NNJ
      DO 5 I=1, NP
      IF(NUNIT .GT. 1) GO TO 66
      KP(I)=.0009517 * L(I) / D(I)**4.87
      GO TO 5
66    KP(I) =.00212 * L(I) / D(I)**4.87
5     CONTINUE
      ELOG = 9.35 * ALOG10(2.71828183)
      SUM=100
      NCT=O
20    II = 1
      DO 6 I=1, NJI
      DO 7 J=1, NP
7     A(I,J) = O
      NNJ = NN(I)
```

Calculate initial Kp based on Chw = 100 – equation 2-22 Ref 1

Set constants to be used further on in iteration loop.

MAIN LOOP

Calculation of the energy equations for closed loops and pseudo loops same as Calc_Network.py loop_matrix and pseudo_matrix

Calculation of the energy equations cont'd

```
      DO 8 J=1, NNJ
      IJ = JN(I,J)
      IF(IJ .GT. 0) GO TO 9
      IIJ = ABS(IJ)
      A(I,IIJ) = -1.
      GO TO 8
9     A(I,IJ) = 1
8     CONTINUE
      IF(IFLOW(I).EQ.O)GO TO 10
      A(I,NPP) = QJ(II)
      II = II + 1
      GO TO 6
10    A(I,NPP) = O.
6     CONTINUE
      DO 11 I=NJ, NP
      DO 22 J=I, NP
22    A(I,J)=O.
      II = I-NJI
      NNJ = LP(8,II)
      DO 12 J=I, NNJ
      IJ = LP(J,II)
      IIJ = ABS(IJ)
      IF(IJ .LT. 0) GO TO 13
      A(I,IIJ )=KP(IIJ)
      GO TO 12
13    A(I,IIJ) = -KP(IIJ)
12    CONTINUE
11    A(I,NPP) = O.
      V(I) = 4.
```

MAIN LOOP uses the new Kp and n exponent calculated in the lower iteration loop with the code above to rebuild the energy equations. This will continue until the allowed error is reached or the number of allowed iterations is exceeded.

```
# SYSTEM SUBROUTINE FROM UNIVAC MATH PACK TO SOLVE LINEAR SYSTEM OF EQ.
      CALL GJR(A, 51, 50, NP, NPP, $98, JC, V)
```

Replaced with numpy solver

```
      IF (NCT .GT. 0) SUM=O.
```

Resetting setting of SUM

```
      DO 51 I=1, NP
      BB = A(I,NPP)
      IF(NCT) 60,60,61
60    QM = BB
      GO TO 62
61    QM = .5 * (Q(I) + BB)
      SUM = SUM + ABS(Q(I)-BB)
62    Q(I) = QM
      DELQ = QM * DELQ1
      QM = ABS(QM)
      VI = (QM - DELQ) / AR(I)
      IF(VI .LT. .001) V1=.002
      V2 = (QM + DELQ) / AR(I)
      VE = QM / AR(I)
      REI = V1 * D(I) / VIS
      RE2 = V2 * D(I) / VIS
      IF(RE2 .GT. 2.1E3) GO TO 53
      F1 = 64./RE1
      F2 = 64./RE2
      EXPP(I) = 1.
      KP(I) = F2 * (Lgth+Le) / Dia
      KP(I) = 64.4 * VIS * ARL(I) / D(I)
      GO TO 51
53    MM = O
      F = 1 / (1.14 - 2 * ALOG10(E(I)))**2
```

1st iteration QM = initially calculated Q, all others use last 2 calculated Qs for QM. BB is previous Q

Iteration loop to calculate the Kp and n exponent for the energy equations based on previous values of Q. For first iteration use Q1 and DELQ. Afterwards use the previous Q and newly calculated Q. Reassign the new Kp and n exponents in the energy equations.

Laminar Flow

NOTE; the original laminar KP equation was replaced with the equation 3-15 from Crane C-410 paper.

```
      PAR = VE * SQRT(.125 * F) * D(I) * E(I) / VIS
      IF(PAR .GT. 65.) GO TO 54
      RE = RE1      120
57    MCT = 0
52    FS = SQRT(F)
      FZ = .5 / (F*FS)
      ARG = E(I) + 9.35 / (RE * FS)
      FF = 1./FS - 1.14 + 2.*ALOG10(ARG)
      DF = FZ + ELOG *FZ / (ARG * RE)
      DIF = FF / DF
      F = F + DIF
      MCT = MCT + 1
      IF(ABS(DIF) .GT. .00001 .AND. MCT .LT. 15) GO TO 52
      IF(MM .EO. I) GO TO 55
      MM = I
      RE = RE2
      F1 = F
      GO TO 57
55    F2 = F
      BE = (ALOG(F1) - ALOG(F2)) / (ALOG(QM + DELQ) - ALOG(QM - DELQ))
      AE = F1 * (QM - DELQ)**BE
      EP = 1 - BI:
      EXPP(I) = EP + 1
      KP(I) = AE * ARL(I) * QM**EP
      GO TO 51
54    KP(I) = F * ARL(I) * QM**2
      EXPP(I) = 2
51    CONTINUE
17    NCT = NCT + 1
      IF(SUM .GT. ERR AND NCT .LT. MAX) GO TO 20

      IF(NCT . EQ. MAX) WRITE(6,108) NCT,SUM
108   FORMAT('DID NOT CONVERGE IN 15 ITERATIONS SUM OF DIFFERENCES')

      IF(NUNIT ,LT. 2) GO TO 63
      WRITE(6.127) (Q(I), I=1, NP)
127   FORMAT('FLOWRATE IN PIPES IN CMS',/,(1H, 131.10.4))
      DO 64 I=1, NP
64    KP(I) = KP(I) * ABS(Q(I))
      WRITE(6, 139) (KP(I), I=1, NP)
      GO TO 30
63    WRITE(6,107) (Q(I), I=1, NP)
107   FORMAT('O FLOW RATES IN PIPES IN CFS'./.(IH.13F10,3))
      DO 21 I=1, NP
      KP(I) = KP(I) * ABS(Q(I))
21    Q(I) = 449. * Q(I)
      WRITE(6,138) (KP(I), I=1, NP)
138   FORMAT(' HEAD LOSSES IN PIPES',/,(IH ,13FI0.3))
      WRITE(6,105) (Q(I), I=1, NP)
105   FORMAT('FLOW RATES (GPM)',/,(IH ,13FI0.1))
      GO TO 30

98    WRITE(6,106) JC(1),V
106   FORMAT('OVERFLOW OCCURRED -- CHECK SPECIFICATIONS FOR REDUNDANT EQ.
      RESULTING IN SINGULAR MATRIX',15,2F8.2)
      GO TO 30
99    STOP
      END
```

PAR is proportional to velocity high par allows for higher pipe velocity. Recommend PAR <= 120

Loop is equivalent to Calc_Network Iterate_Flow

Equation 2-25 to 2-28 in Ref 1

MAIN LOOP

Ouput Kp and Q

Beginning of program

Beginning of program

Beginning of program

REFERENCE 1 ‘Steady Flow Analysis of Pipe Networks An Instructional Manual.pdf’

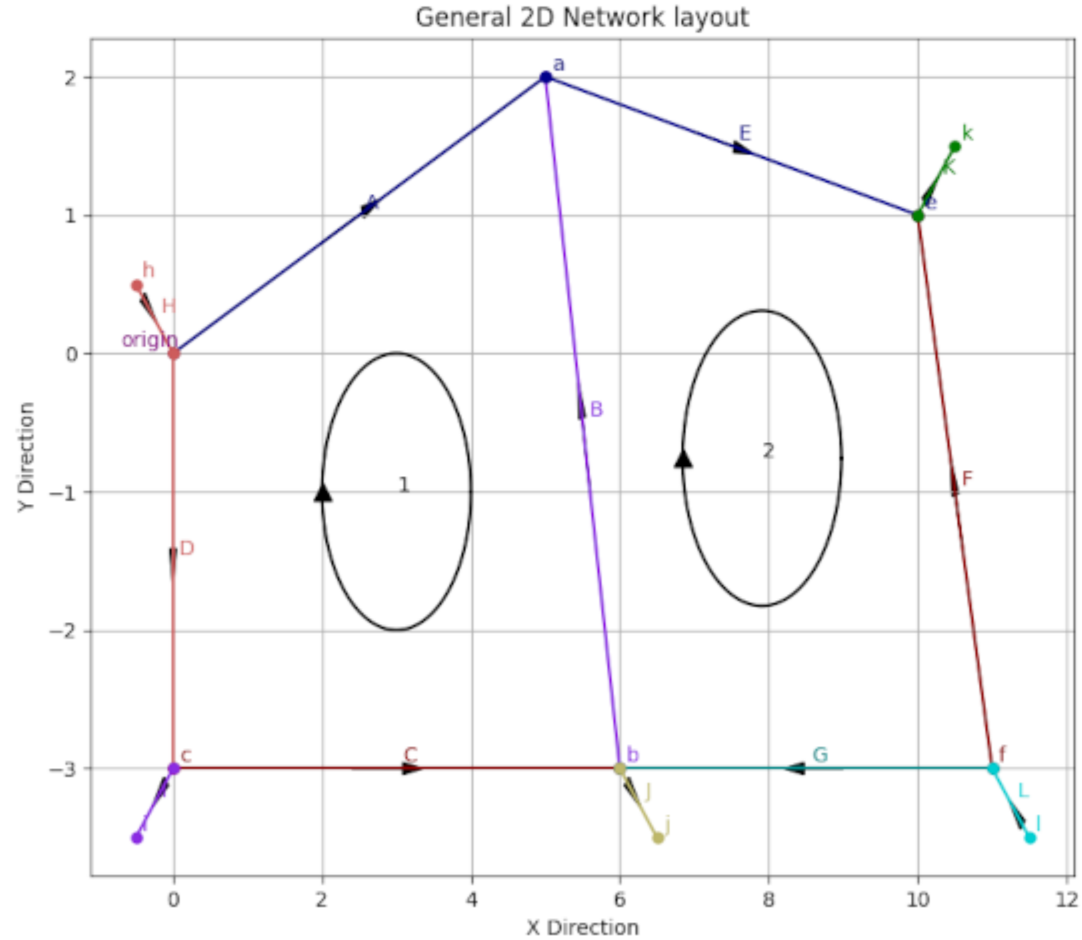
APPENDIX II

EXAMPLES

Plot Lines

File Fluid Data Delete Element

	Start Point	End X	End Y
A	origin	5.0	2.0
B	a	6.0	-3.0
C	b	0.0	-3.0
D	origin	c	3.0
E	a	10.0	1.0
F	e	11.0	-3.0
G	b	f	6.0
H	origin	-0.5	0.5
I	c	-0.5	-3.5
J	b	6.5	-3.5
K	e	10.5	1.5
L	f	11.5	-3.5
M	d	11.0	4.0
N	i	3.0	4.0
O	e	9.0	5.0
P			
Q			
R			
S			
T			
U			
V			
W			
X			
Y			
Z			



Redraw Lines

Select Real Loop Lines

Select Pseudo Loop Lines

Exit

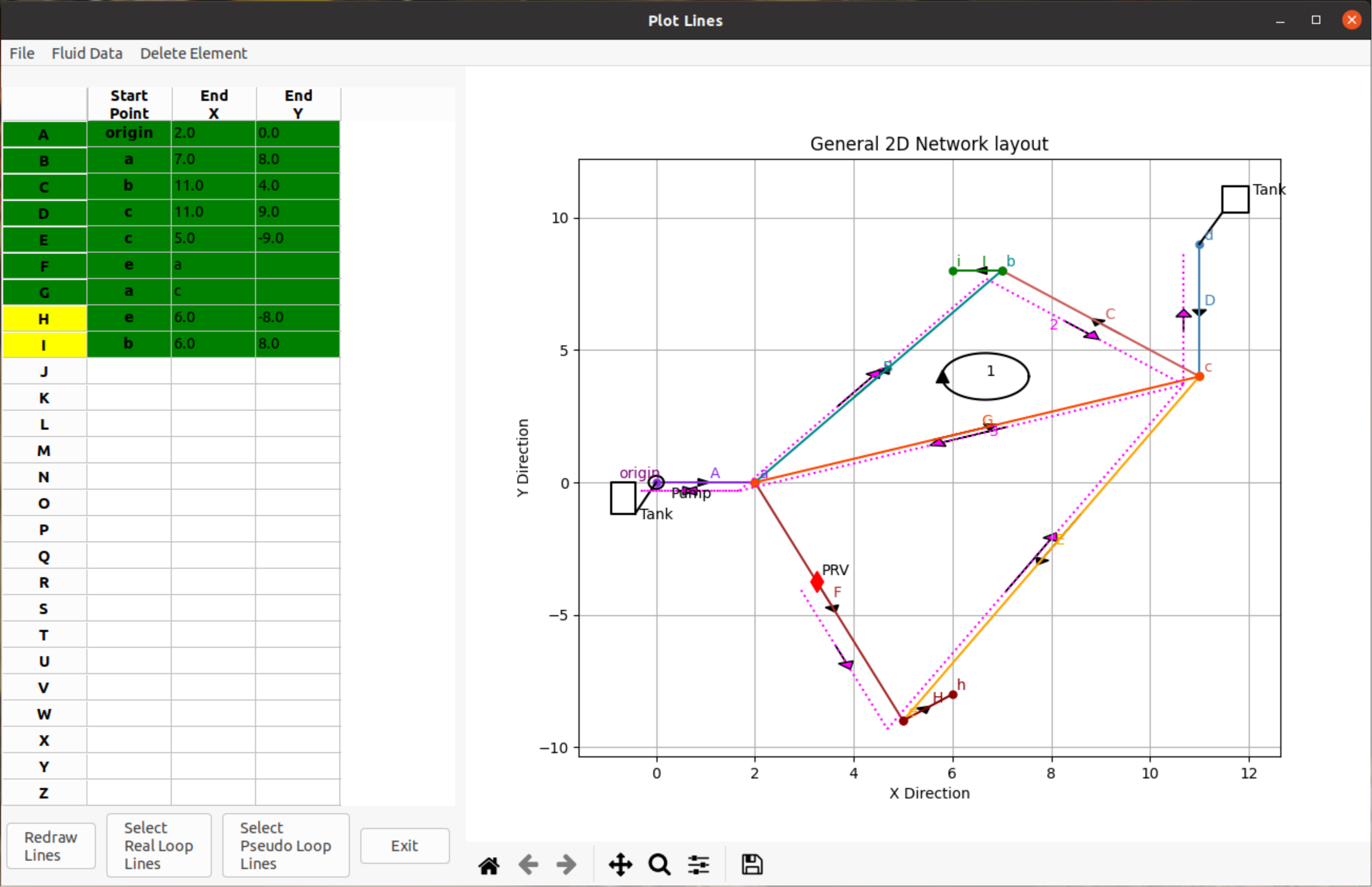
Calculated Data for expl_1.db

Line Label	Pipe Dia inches	Pipe Length	Flow			Head Loss		Pressure Drop psig	Velocity	
			ft^3/s	USGPM	m^3/s	feet	meters		ft/s	m/s
A	8.0	1072.82	1.044	468.5	0.03	4.93	1.503	2.13	2.99	0.91
B	12.0	731.09	0.645	289.68	0.018	0.171	0.052	0.07	0.82	0.25
C	10.0	1000.0	1.186	532.39	0.034	1.875	0.571	0.81	2.17	0.66
D	12.0	500.0	3.416	1533.28	0.097	2.884	0.879	1.25	4.34	1.32
E	10.0	1222.84	1.689	758.18	0.048	4.554	1.388	1.97	3.09	0.94
F	6.0	600.0	1.656	743.16	0.047	30.321	9.242	13.12	8.42	2.57
G	8.0	800.0	2.804	1258.62	0.079	25.596	7.802	11.08	8.02	2.45

Fittings for line A	Quantity
Globe Valve Y-Pattern	1
Globe Valve Right Angle	1

Fittings for line B	Quantity
Plug Valve 2-Way	1

Fittings for line E	Quantity
Globe Valve Y-Pattern	2
Globe Valve Right Angle	1



Plot Lines
File
Fluid Data
Delete Element
Start Point
End X
End Y
A origin 2.0 0.0
B a 7.0 8.0
C b 11.0 4.0
D c 11.0 9.0
E c 5.0 -9.0
F e a
G a c
H e 6.0 -8.0
I b 6.0 8.0
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
Redraw Lines
Select Real Loop Lines
Select Pseudo Loop Lines
Exit
General 2D Network layout
Tank
Tank
Pump
PRV
origin
1
2
3
Y Direction
X Direction

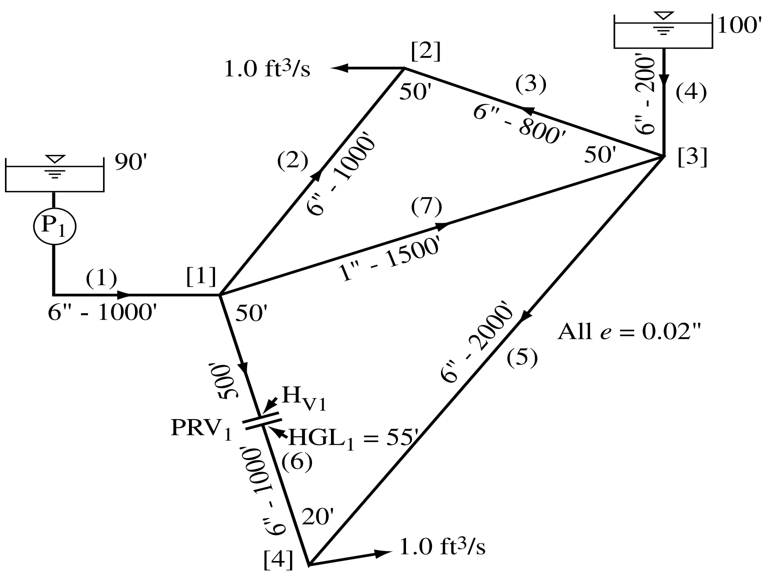
i.e., determine whether the PRV's and BPV's are operating in their normal modes or in one of their exceptional modes. Methods for adding such devices into network analyses are described in these sections. The discussion begins with pressure reduction valves.

Underlying the writing of the three systems of equations described in Section 4.2 is the basic assumption that a relation exists between the magnitude of the discharge in a pipe and the amount of the head loss, or head difference, between the ends of this pipe. Such a relation does not exist if a PRV (or a BPV) is present in the pipe. Therefore a pipe with a PRV in it should not appear in a normal energy loop equation. However, in the usual mode of operation for a PRV a constant head is maintained at its downstream end; in this way it behaves like a reservoir. Furthermore, regardless of its mode of operation the discharge at the upstream node of a pipe containing a PRV will be the same as the discharge at the downstream node of this pipe. The details of developing a proper system of equations to describe a network containing one or more PRV's are different, depending upon whether a system of Q-equations, H-equations, or ΔQ-equations are desired. Therefore, each of these will be described in a separate section.

4.3.1. *Q*-EQUATIONS FOR NETWORKS WITH PRV'S/BPV'S

The procedure for developing the Q-equation system for a network containing PRV's is as follows: (1) write the junction continuity equations in the usual manner, ignoring the PRV's; (2) replace each PRV with an artificial reservoir which has a water surface elevation equal to the HGL-elevation that is the sum of the pressure head set on the PRV and its elevation in the pipeline; finally (3) write the energy equations around the loops of this modified network. The resulting equations describe the normal mode of operation.

Let's try this procedure on the seven-pipe network shown in Fig. 4.6, in which a PRV exists in pipe 6, located 500 ft. downstream from node 1, the upstream end of this pipe. Since a PRV is a directional device, we must always identify the upstream and downstream



Q ft³/s	Head ft.
1.0	60
1.5	55
2.0	48

Figure 4.6 A seven-pipe network.

ends of the pipe containing it. The system of Q-equations for this network consists of four junction continuity equations and three energy loop equations. According to the usual rules, an independent junction continuity equation can be written for each of the four junctions since there are two supply sources for this network. These junction continuity equations are

$$\begin{aligned} F_1 &= -Q_1 + Q_2 + Q_6 + Q_7 = 0 \\ F_2 &= 1.0 - Q_2 - Q_3 = 0 \\ F_3 &= Q_3 - Q_4 + Q_5 - Q_7 = 0 \\ F_4 &= 1.0 - Q_5 - Q_6 = 0 \end{aligned} \tag{4.21}$$

These continuity equations are unaffected by the presence or absence of a PRV in the network. We next modify the network so the upstream portion of the pipe containing the PRV is removed and the PRV is replaced by a reservoir with a water surface elevation equal to the HGL of the pressure setting of the PRV (see Fig. 4.7). Of the three loops that exist in this modified network, only one is a real loop which traverses pipes 2, 3, and 7. Two pseudo loops also exist. One pseudo loop connects the two original supply sources. This loop can start at the reservoir and end at the source pump so it includes pipes 4, 7, and 1. The second loop must extend from the artificial reservoir created by the PRV to one of the other supply sources (or another artificial reservoir, if two or more PRV's exist in the network). The shortest path for this second pseudo loop will traverse pipes 4, 5, and 6. In writing the head loss in pipe 6, only that portion of the pipe downstream from the PRV is used. A modified loss coefficient K' will be used to denote this change in the exponential formula. The new coefficient K' equals the K for the pipe containing the PRV, multiplied by the ratio of the pipe length from the PRV to the pipe's downstream end divided by the total pipe length, or

$$K' = K(L_d / L) \tag{4.22}$$

or in this example $K_6' = K_6(500/1000) = 0.5K_6$.

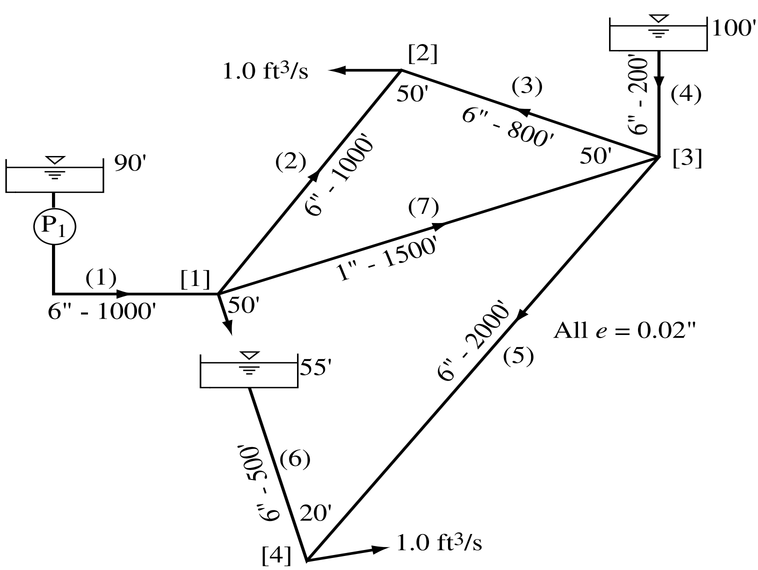


Figure 4.7 The modified seven-pipe network.

The energy equations are

$$F_5 = K_2 Q_2^{n_2} - K_3 Q_3^{n_3} - K_7 Q_7^{n_7} = 0 \;\; (real \;\; loop)$$
$$F_6 = K_4 Q_4^{n_4} - K_7 Q_7^{n_7} - K_1 Q_1^{n_1} + h_{p1} - 100 + 90 = 0 \;\; (pseudo \;\; loop) \qquad (4.23)$$
$$F_7 = K_4 Q_4^{n_4} + K_5 Q_5^{n_5} - K_6' Q_6^{n_6} + 55 - 100 = 0 \;\; (pseudo \;\; loop)$$

The head produced by the pump h_{p1} can be defined by a second-order polynomial passing through three points of the pump curve, or

$$h_{p1} = A Q_1^2 + B Q_1 + C \qquad (4.24)$$

We have now formed seven independent equations that contain the seven unknown discharges $Q_1, Q_2, \ldots, Q_7$. In this example the real loop that was lost by having a PRV in pipe 6 is replaced by an additional pseudo loop. We see that the number of equations again equals the number of unknown discharges.

To obtain a solution for this network by using the computer program NETWK, the input data can be prepared (see the NETWK user manual for input data requirements or the condensed description of this input on the CD) as listed in Fig. 4.8. The solution tables from NETWK are reproduced in Fig. 4.9. A study of this output will show that the PRV is operating in its normal mode of operation.

```
Example of a network containing a PRV
/* 6 1 4 1000
PIPES
1 0 1 1000 6 0.02
2 1 2
3 3 2 800
4 0 3 200
5 3 4 2000
RESER
7 1 3 1500 1
NODES
1 0 50
2 1
3 0
4 1 20
4 100
PUMPS
1 1 60 1.5 55 2 48 90
VALVE
6 500 55
RUN
```

Figure 4.8 Input data for the network shown in Figs. 4.6 and 4.7.

This solution indicates that the PRV is operating in its normal mode of maintaining the set pressure at its downstream end because the reported downstream HGL-elevation equals the value specified in the input data. If this had not been the case, the solution from NETWK would have indicated either that the PRV had shut off the flow in pipe 6 or that it was completely open and replaced by a minor loss. In solving the network equations, if the discharge in pipe 6 had been negative, then the program would have noted that the PRV would act as a check valve, preventing a reverse flow. If this situation should occur, then the network problem would be altered so it would only have six pipes instead of seven (pipe 6 would not exist in this modified network). The equations describing the flows in

```
LOSSES DUE TO FLUID FRICTION IN ALL PIPES
POWER LOSS   =   11.51 H.P.   =   8.585 KWATTS.
ENERGY LOSS   =   206.0   KWHRS/DAY

PUMPS:
PIPE    HEAD      Q    HORSEPOWER    KILOWATT    KWATT-HRS/DAY
 1      59.1    1.11     7.43          5.54         133.0
ELEVATION OF HGL UPSTREAM AND DOWNSTREAM OF PRVS:
```

Figure 4.9 Output tables from NETWK.

```
   PIPE    UPSTREAM  DOWNSTREAM
              HGL       HGL
    6       121.79     55.00
  UNITS OF SOLUTION ARE:
  DIAMETER,     inch
  LENGTH,       feet
  HEAD,         feet
  ELEVATION,    feet
  PRESSURE,     lb/in^2
  DISCHARGE,    ft^3/s
  DARCY-WEISBACH FORMULA USED FOR COMPUTING HEAD LOSSES
```

PIPE DATA

PIPE NO.	NODES FROM	TO	L ft.	DIA. in	e x10^3 in	Q ft^3/s	VEL. ft/s	HEAD LOSS ft.	HLOSS/ 1000
1	0	1	1000	6.0	20.0	1.11	5.65	27.28	27.28
2	1	2	1000	6.0	20.0	1.07	5.43	25.26	25.26
*3	2	3	800	6.0	20.0	0.07	0.34	0.10	0.12
4	0	3	200	6.0	20.0	0.89	4.54	3.55	17.74
5	3	4	2000	6.0	20.0	0.96	4.91	41.47	20.74
6	1	4	1000	6.0	20.0	0.04	0.18	0.04	0.04
7	1	3	1500	1.0	20.0	0.01	1.31	25.56	17.04

AVE. VEL. = 3.19 ft/s, AVE. HL/1000 = 15.46, MAX. VEL. = 5.65 ft/s, MIN. VEL. = 0.18 ft/s
*Flow direction is reversed from input data.

NODE DATA

NODE	DEMAND ft^3/s	gal/min	ELEV. ft.	HEAD ft.	PRESSURE lb/in^2	HGL ELEV. ft.
1	0.00	0.0	50.	71.81	31.1	121.81
2	1.00	448.8	50.	46.55	20.2	96.55
3	0.00	0.0	50.	46.45	20.1	96.45
4	1.00	448.8	20.	34.98	15.2	54.98

AVE. HEAD = 49.95 ft., AVE. HGL = 92.45 ft.
MAX. HEAD = 71.81 ft., MIN HEAD = 34.98 ft.

Figure 4.9, concluded. Output tables from NETWK.

this modified network would consist of the original equations with the last one omitted. If the HGL elevation at node 1 had been lower than the HGL setting of the PRV, then it would be known that the PRV would not be able to sustain its pressure setting, and the network problem must then be solved by using equations that replace the PRV with a minor loss device. For this last mode of operation the last energy equation would be replaced by a real loop equation traversing pipes 5, 6, and 7. Pipe 6 would contain a minor loss device to represent the PRV as being fully open.

The procedure for writing the system of Q-equations should now be apparent for back-pressure valves (BPV's) in networks. As with PRV's, the junction continuity equations are written ignoring the presence of BPV's. The junction continuity equations are unaffected by the existence of a BPV. In writing the energy equations, the upstream side of each BPV is replaced by an artificial reservoir; in each case the pipe segment from the downstream end of the BPV to its downstream node is then removed, and the energy equations are written for this revised network.

Calculated Data for expl_2.db

Line Label	Pipe Dia inches	Pipe Length	Flow			Head Loss		Pressure Drop psig	Velocity	
			ft^3/s	USGPM	m^3/s	feet	meters		ft/s	m/s
A	6.0	1000.0	1.114	499.83	0.032	27.311	8.324	11.8	5.66	1.73
B	6.0	1000.0	1.075	482.44	0.03	25.459	7.76	11.0	5.47	1.67
C	6.0	800.0	-0.075	-33.61	-0.002	0.117	0.036	0.05	0.38	0.12
D	6.0	200.0	0.886	397.83	0.025	3.476	1.059	1.5	4.51	1.37
E	6.0	2000.0	0.968	434.68	0.027	41.418	12.624	17.89	4.93	1.5
F	6.0	1000.0	0.032	14.15	0.001	0.03	0.009	0.01	0.16	0.05
G	1.0	1500.0	0.007	3.25	0.0	25.575	7.795	11.05	1.33	0.4

Node Label	Elevation		Head		Pressure	
	feet	meters	feet	meters	psig	kPa
origin	0.0	0.0	149.039	45.43	64.4	443.68
a	50.0	15.15	121.728	37.1	52.6	362.38
d	0.0	0.0	100.0	30.48	43.21	297.69
c	50.0	15.15	96.153	29.31	41.55	286.24
e	20.0	6.06	54.735	16.68	23.65	162.94
b	50.0	15.15	96.27	29.34	41.6	286.59

Pump Node	Head		Flow	
	feet	meters	USGPM	m^3/hr
origin	59.039	17.995	499.798	113.524

Line Label	Valve Type	Set Pressure			Upstream Pressure			Downstream Pressure		
		feet	psig	kPa	feet	psig	kPa	feet	psig	kPa
F	PRV	55	23.76	163.85	121.73	52.53	362.18	54.73	23.62	162.85

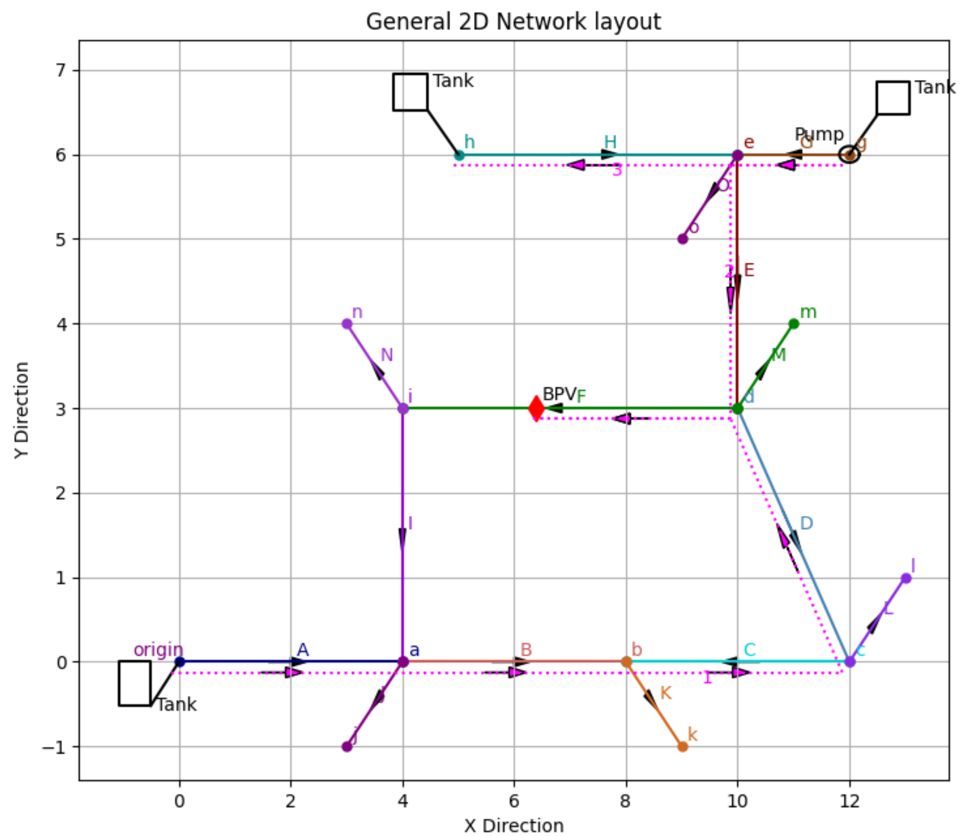
expl_3.db

Data Input / Output Comparison to Hydraulics of Pipeline Systems (figure 4.10)

Plot Lines

File   Fluid Data   Delete Element

	Start Point	End X	End Y	Calc vs Paper m^3/s	
A 9	origin	4.0	0.0	.007	.014*
B 6	a	8.0	0.0	.015	.015
C 7	b	12.0	0.0	.035	.035
D 8	c	10.0	3.0	.065	.065
E 3	d	10.0	6.0	.098	.091
F 4	d	i		.012	.006*
G 1	e	12.0	6.0	.11	.102
H 2	e	5.0	6.0	.002	.004*
I 5	a	4.0	3.0	.003	.009*
J	a	3.0	-1.0		
K	b	9.0	-1.0		
L	c	13.0	1.0		
M	d	11.0	4.0		
N	i	3.0	4.0		
O	e	9.0	5.0		
P					
Q					
R					
S					
T					
U					
V					
W					
X					
Y					
Z					



Redraw Lines   Select Real Loop Lines   Select Pseudo Loop Lines   Exit

Confirmation of Variables and Equations

A = 9, B = 6, C = 7, D = 8, E = 3, F = 4, G = 1, H = 2, I = 5
a = 4, b = 5, c = 6, d = 2, e = 1, i = 3

[0, -1.0, -1.0, 0, 0, 0, 0, 0, 0, 0],	-0.7056	F5	.02 m^3/s = 0.706293 ft^3/s
[-1.0, 1.0, 0, 0, 0, 0, 0, 0, -1.0, 0],	-0.7056	F4	
[0, 0, 1.0, -1.0, 0, 0, 0, 0, 0, 0],	-1.0584	F6	.03 m^3/s = 1.05944 ft^3/s
[0, 0, 0, 1.0, -1.0, 1.0, 0, 0, 0, 0],	-0.7056	F2	
[0, 0, 0, 0, 1.0, 0, -1.0, -1.0, 0, 0],	-0.5292	F1	.015 m^3/s = 0.52972 ft^3/s
[0, 0, 0, 0, 0, -1.0, 0, 0, 1.0, 0],	-0.5292	F3	
[0, 0, 0, 0, 0, 0, -1, 0, 0, 1],	0.883	Pump Transition Eq	
[96.9294, 116.3153, -145.3941, -35.8175, 0.0, 2.65173, 0.0, 0.0, 0.0, 0],	-196.79	F9	135 - 195=-60 m = -196.8 ft
[0.0, 0.0, 0.0, 0.0, 3.31466, 2.65173, 9.6657, 0.0, 0.0, 0.5259],	75	F8	180-195+38=23 m = 75 ft
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 9.6657, -193.8589, 0.0, 0.5259]]	58.6	F7	180-200+38=18 m = -59 ft

Pump Equation (based on ft^/s);

A = -0.53
B = -0.93
Ho = 124.64

ho = 124.2 (38 m) => based on (Ho – B/4*A)
coef for transition eq = .877 => based on (B/(2*A))

based on a flow of .102 m^3/s = 3.602096 ft^3/s
TDH = -.53(3.6)^2 - .93(3.6)+124.64
= 114.4 ft = 34.88 m
agrees with answer in documentation therefore A, B, Ho are acceptable.

Hydraulics of Pipeline Systems Figure 4.10

The writing of a system of Q-equations will be illustrated with the network in Fig. 4.10, which has 9 pipes and 6 nodes, is supplied by a source pump and has two tanks

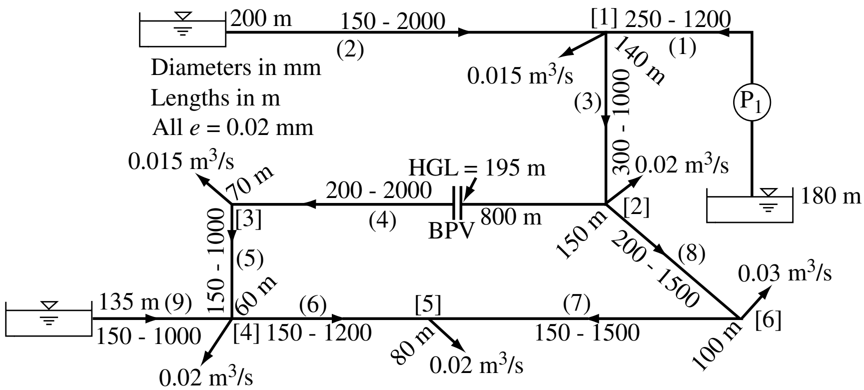


Figure 4.10 A 9-pipe, 6-node network.

(reservoirs) connected to it. Without a BPV (or some other device) this network would cause the lower reservoir at the end of pipe 9 to overflow. There are six junctions in this network. The corresponding six junction continuity equations are

$$
\begin{aligned}
F_1 &= 0.015 - Q_1 - Q_2 + Q_3 = 0 \\
F_2 &= 0.020 - Q_3 + Q_4 + Q_8 = 0 \\
F_3 &= 0.015 - Q_4 + Q_5 = 0 \\
F_4 &= 0.020 - Q_5 + Q_6 - Q_9 = 0 \\
F_5 &= 0.020 - Q_7 - Q_6 = 0 \\
F_6 &= 0.030 - Q_8 + Q_7 = 0
\end{aligned}
\tag{4.25}
$$

Before forming the loops around which the energy equations are written, an artificial reservoir is placed on the upstream side of the BPV with a water surface elevation equal to the HGL resulting from the pressure setting of the valve. The pipe downstream from the BPV is removed. When these changes are completed, the network appears as in Fig. 4.11, and energy equations can next be written around the loops of this modified network. Three loops are needed, since NL = NP - NJ = 9 - 6 = 3. These are all pseudo loops and may be

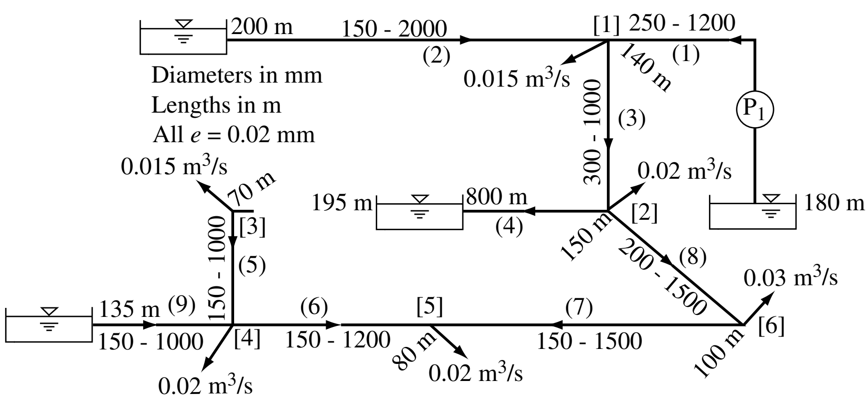


Figure 4.11 The modified 9-pipe, 6-node network.

composed in the following way: the pipes in loop 1 are 1 and 2; the pipes in loop 2 are 1, 3, and 4 (upstream portion); and the pipes in loop 3 are 9, 6, 7, 8, and 4 (upstream portion). It is incorrect to write a loop through pipes 9, 5, and 4 (the upstream portion) because a BPV sets the pressure on its upstream side. Hence the energy equations in the Q-equation system are the following:

$$F_7 = K_1 Q_1^{n_1} - h_{p1} - K_2 Q_2^{n_2} - 180 + 200 = 0$$

$$F_8 = K_1 Q_1^{n_1} - h_{p1} + K_3 Q_3^{n_3} + K_4^{'} Q_4^{n_4} - 180 + 195 = 0 \tag{4.26}$$

$$F_9 = K_9 Q_9^{n_9} + K_6 Q_6^{n_6} - K_7 Q_7^{n_7} - K_8 Q_8^{n_8} + K_4^{'} Q_4^{n_4} - 135 + 195 = 0$$

One possible input file to NETWK for the solution of this problem is presented in Fig. 4.12, and the resulting solution tables are presented in Fig. 4.13.

```
Network Containing BPV
/* 2 .02 140
$SPECIF NFLOW=3,NPGPM=3,NUNIT=4 $END
PIPES
1 0 1 1200 250 .02
2 0 1 2000 150
3 1 2 1000 300
4 2 3 2000
5 3 4 1000 150
6 4 5 1200
7 6 5 1500
8 2 6 1500 200
9 0 4 1000 150
NODES
1 .015 140
3 .015 70
4 .02 60
5 .02 80
6 .03 100
RESER
2 200
9 135
PUMPS
1 .1 35 .15 32 .2 28 180
BPVALVE
4 1200 195
RUN
```

Figure 4.12 The input data file to NETWK for the 9-pipe, 6-node network.

From this solution we see that the BPV dissipates 65.88 m of head to sustain the upstream HGL setting of 195 m. This value is obtained by subtracting the downstream HGL from the BPV setting. It is a worthwhile exercise to begin with the head losses in the PIPE DATA table and verify the HGL elevations reported in the NODE DATA table; it will lead to a better understanding of the BPV and its effect on pressures and discharges in this network as the BPV operates in its normal mode. If the solution had shown a negative flow through pipe 4, then the downstream pressure would actually be larger than the BPV setting, and the valve would open up completely. For this occurrence the BPV must be re-placed by a minor loss device, and then this modified network problem could be studied. If the HGL at node 2 (the node immediately upstream from the BPV) were less than the HGL established by the BPV setting, then the BPV would close completely. The pipe

```
LOSSES DUE TO FLUID FRICTION IN ALL PIPES
POWER LOSS  =  65.18 H.P.  =  48.63 KWATTS.
ENERGY LOSS  =  1167.0  KWHRS/DAY

PUMPS:
PIPE   HEAD     Q   HORSEPOWER   KILOWATT   KWATT-HRS/DAY
 1     34.88   10.0    46.9        35.0        839.8
HGL DOWNSTREAM AND UPSTREAM FROM BPV
 4     129.12        195.00
```

Figure 4.13 The output tables from NETWK for the 9-pipe, 6-node network.

PIPE DATA

PIPE NO.	NODES FROM	TO	L m	DIA. mm	e x10³ mm	Q m³/s	VEL. m/s	HEAD LOSS m	HLOSS/ 1000
1	0	1	1200	250	20.0	0.102	2.09	15.58	12.98
2	0	1	2000	150	20.0	0.004	0.21	0.75	0.37
3	1	2	1000	300.	20.0	0.091	1.29	4.28	4.28
4	2	3	2000	300.	20.0	0.006	0.08	0.06	0.03
5	4	3	1000	150.	20.0	0.009	0.52	1.90	1.89
6	5	4	1200	150.	20.0	0.015	0.86	5.69	4.74
7	6	5	1500	150.	20.0	0.035	2.00	33.11	22.07
8	2	6	1500	200.	20.0	0.065	2.08	25.25	16.83
9	0	4	1000	150.	20.0	0.014	0.79	4.03	4.03

AVE. VEL. = 1.10 m/s, AVE. HL/1000 = 7.47, MAX. VEL. = 2.09 m/s, MIN. VEL. = 0.08 m/s

NODE DATA

NODE	DEMAND m³/s	DEMAND ft³/s	ELEV. m	HEAD m	PRESSURE kPa	HGL ELEV. m
1	0.015	0.53	140.0	59.25	580.7	199.25
2	0.020	0.71	140.0	55.02	539.2	195.02
3	0.015	0.53	70.0	59.08	579.0	129.08
4	0.020	0.71	60.0	70.97	695.6	130.97
5	0.020	0.71	80.0	56.66	555.3	136.66
6	0.030	1.06	100.0	69.78	683.8	169.78

AVE. HEAD = 61.79 m, AVE. HGL = 160.13 m
MAX. HEAD = 70.97 m, MIN. HEAD = 55.02 m

Figure 4.13 (Concluded) The output tables from NETWK for the 9-pipe, 6-node network.

containing the BPV should then be removed from the network, and the problem could then be solved by using the equations for this modified network; then the BPV could not maintain the pressure setting, and it would simply prevent any flow from passing through the pipe in which it is installed.

4.3.2. *H*-EQUATIONS FOR NETWORKS WITH PRV'S/BPV'S

The procedure for writing the *H*-equations for a network that contains PRV's and/or BPV's is described here. First, view the HGL resulting from the pressure setting of the device as a reservoir, since under normal operation the HGL is fixed by the device. Second, place an additional unknown variable on the other side of the device to represent the elevation of the HGL there. We will denote this variable by H_{vi}, in which i is the number of the device. For the first PRV or BPV $i = 1$, for the second $i = 2$, etc. For a PRV the value of H_{vi} is the HGL-elevation immediately upstream from the valve, whereas H_{vi} is the HGL-elevation immediately downstream from the valve for a BPV. Third, the junction continuity equations are written in the usual way, with the difference between the upstream and downstream HGL-elevations, divided by K for this pipe, all raised to the reciprocal of the discharge exponent n, i.e., $Q_k = \{(H_i - H_j)/K_k\}^{1/n_k}$. Finally, since an additional unknown is introduced for each PRV or BPV, one additional equation must be added to the system of continuity equations for each device. These additional equations are obtained by noting that the head losses in the upstream and downstream portions of the pipe containing the device are proportional to these two lengths. For a PRV this equation is

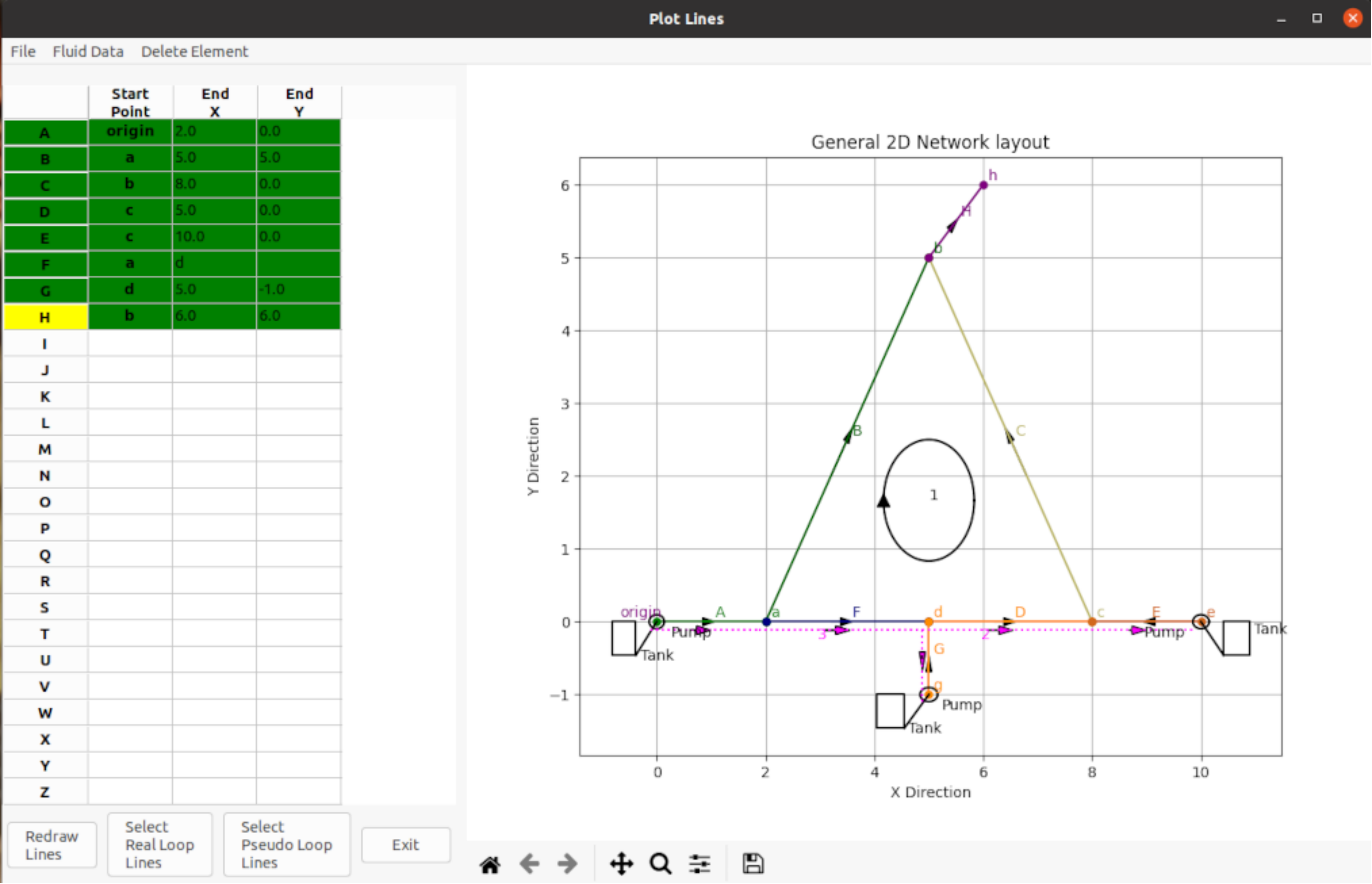
Calculated Data for expl_3.db

Line Label	Pipe Dia inches	Pipe Length	Flow			Head Loss		Pressure Drop psig	Velocity	
			ft^3/s	USGPM	m^3/s	feet	meters		ft/s	m/s
A	5.91	3281.0	0.26	116.53	0.007	3.932	1.198	1.7	1.36	0.42
B	5.91	3937.2	-0.535	-240.12	-0.015	17.528	5.342	7.58	2.81	0.86
C	5.91	4921.5	1.241	556.82	0.035	103.657	31.595	44.85	6.51	1.99
D	7.87	4921.5	2.299	1031.86	0.065	79.308	24.173	34.32	6.79	2.07
E	11.81	3281.0	3.445	1546.12	0.098	15.261	4.652	6.6	4.52	1.38
F	11.81	6562.0	0.44	197.57	0.012	0.722	0.22	0.31	0.58	0.18
G	9.84	3937.2	3.902	1751.22	0.11	56.738	17.294	24.55	7.38	2.25
H	5.91	6562.0	0.072	32.42	0.002	0.807	0.246	0.35	0.38	0.12
I	5.91	3281.0	-0.089	-39.95	-0.003	0.583	0.178	0.25	0.47	0.14

Node Label	Elevation		Head		Pressure	
	feet	meters	feet	meters	psig	kPa
g	0.0	0.0	703.389	214.39	304.4	2097.31
e	462.0	140.0	199.193	60.71	86.2	593.94
origin	0.0	0.0	135.0	41.15	58.42	402.53
a	198.0	60.0	131.068	39.95	56.72	390.81
h	0.0	0.0	200.0	60.96	86.55	596.34
d	495.0	150.0	183.932	56.06	79.6	548.43
b	264.0	80.0	148.596	45.29	64.31	443.07
i	231.0	70.0	130.485	39.77	56.47	389.07
c	330.0	100.0	104.624	31.89	45.28	311.96

Pump Node	Head		Flow	
	feet	meters	USGPM	m^3/hr
g	112.989	34.439	1751.106	397.745

Line Label	Valve Type	Set Pressure			Upstream Pressure			Downstream Pressure		
		feet	psig	kPa	feet	psig	kPa	feet	psig	kPa
F	BPV	639.6	84.39	581.87	183.93	79.5	548.13	130.49	56.4	388.85



Plot Lines
File
Fluid Data
Delete Element
Start Point
End X
End Y
A origin 2.0 0.0
B a 5.0 5.0
C b 8.0 0.0
D c 5.0 0.0
E c 10.0 0.0
F a d
G d 5.0 -1.0
H b 6.0 6.0
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
Redraw Lines
Select Real Loop Lines
Select Pseudo Loop Lines
Exit
General 2D Network layout
Y Direction
X Direction
origin
a
b
c
d
e
g
h
A
B
C
D
E
F
G
H
1
2
3
Pump
Tank

Calculated Data for expl_5.db

Line Label	Pipe Dia inches	Pipe Length	Flow			Head Loss		Pressure Drop psig	Velocity	
			ft^3/s	USGPM	m^3/s	feet	meters		ft/s	m/s
A	8.0	1000.05	0.842	377.92	0.024	3.125	0.952	1.35	2.41	0.73
B	6.0	2000.1	0.666	299.08	0.019	17.49	5.331	7.57	3.39	1.03
C	8.0	2000.1	1.334	598.58	0.038	15.309	4.666	6.62	3.81	1.16
D	8.0	1000.05	0.579	259.75	0.016	1.512	0.461	0.65	1.66	0.5
E	6.0	1000.05	0.755	338.83	0.021	11.168	3.404	4.83	3.84	1.17
F	6.0	1000.05	0.176	78.83	0.005	0.669	0.204	0.29	0.89	0.27
G	6.0	1000.05	0.403	180.92	0.011	3.285	1.001	1.42	2.05	0.62

Node Label	Elevation		Head		Pressure	
	feet	meters	feet	meters	psig	kPa
origin	0.0	0.0	117.299	35.75	50.76	349.75
a	0.0	0.0	114.174	34.8	49.41	340.44
e	0.0	0.0	123.48	37.64	53.44	368.18
c	0.0	0.0	112.312	34.23	48.61	334.88
g	0.0	0.0	116.748	35.58	50.52	348.11
d	0.0	0.0	113.505	34.6	49.12	338.44
b	0.0	0.0	96.684	29.47	41.84	288.28

Pump Node	Head		Flow	
	feet	meters	USGPM	m^3/hr
origin	17.325	5.281	377.89	85.834
e	18.52	5.645	338.806	76.956
g	21.773	6.636	180.904	41.09