User manual

JalTantra: A System for Design and Optimization of Water Distribution Networks

Version 0.1

June 2020

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JalTantra was developed by Nikhil Hooda and Prof. Om Damani, as part of Nikhil's PhD thesis at the Department of Computer Science and Engineering, Indian Institute of Technology Bombay.

We acknowledge the helpful inputs and suggestions of Nikhil Hooda,Prof. Om Damani and Deepak Karwa towards preparation of this document.

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1 Introduction

JalTantra is a system for design and optimization of water distribution networks. Design and verification of distribution networks [11, 12] is an important component for sustainability, coverage and service delivery of drinking water schemes. Design of water systems has several aspects --- scale (single-village, multi-village, rural-regional, urban), energization options (grid vs. solar), service delivery options (24x7,. intermittent), and several design options (demand driven, pressure driven, centralized, decentralized infrastructure [2]).

Jaltantra is used to design water distribution networks based on the following assumptions,

- The network has a single source which provides a steady head no matter what the demand
- This manual focuses on branch network alone. Next version of Jaltantra will also optimize loop networks.

Network solving in JalTantra means determining the optimum diameters for pipes of the water distribution network being designed. In addition it can allocate and size other components of the network---Elevated Storage Reservoirs (ESRs) and pumps, as per demand requirements. The objective function of the optimization is to minimize the capital and operational cost of the network while satisfying all inputs and hydraulic constraints [1].

This manual is about designing and optimizing the **branched** distribution network of a single village / multi village schemes (one ESR and a distribution network) [9]. Design of the transmission network (MBR, multiple ESRs) [8] and allocation of pumps have not been covered in this document.

Features of JalTantra

- No network size limitation
  Capable of handling networks having as high as 1000 nodes, solving the optimization in a few seconds.

- Best cost optimization capability
  Proven optimal algorithm for branch networks.

- Extensible and customizable
  Can be easily customized based on feedback from field trials and practical experiences.

- Several input and output file formats
  - Can load files in three formats: BRANCH, XML or EXCEL
  - Can save input files as XML or EXCEL
  - Can save output file as EXCEL
  - Sample input/output files provided under the HELP section
  - Output can be extracted into .inp file(Suitable for EPANET simulations)

- New technology developed in Java, platform independent.
  https://www.cse.iitb.ac.in/jaltantra

Inputs, outputs and objective function of JalTantra

- **Inputs**

  Source node: Head of source (Elevation + Staging height)
  Node: Elevation, {demand}, {minimum pressure requirement}
  Pipe: Start/end node, length, {roughness}, {diameter}, {parallel allowed}
  Cost of commercial pipes with different diameters
  Commercial Pipes: Diameter, Cost, {roughness}
  Note: Variables marked {} are optional

- **Outputs**

  Diameters of pipes in the distribution network

- **Objective function**

  Minimize total cost of pipes in the network

Accessing JalTantra

- JalTantra is free to use and publicly available at: https://www.cse.iitb.ac.in/jaltantra [4].

- A local version for Windows is available at:
  https://www.cse.iitb.ac.in/jaltantra/Local_JalTantra(2.2.2.0).zip

  Note: Local version can be used without an internet connection.

2 Overview and use of system

On the top-left side of the JalTantra interface, there is a sidebar which displays all the panels for design parameters of the water distribution system [4].
The four primary options are:

- Network Description, which contains the input forms to provide information about the network.
- Optimize Network, from where you tell the system to optimize the network and where the results are displayed.
- Load/Save files, from where you can load input files or save input/output files.
- The Help section, from where you can get additional information about the system.

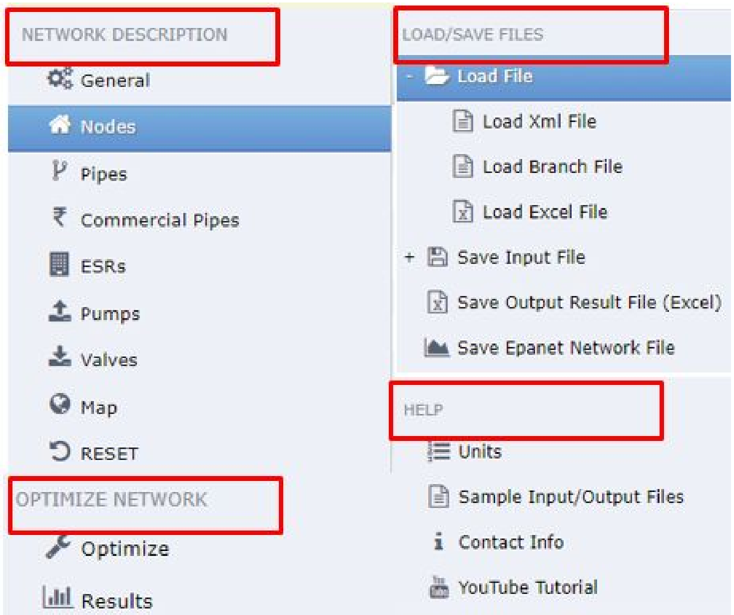


Figure 1. Four options and each panel under every option in JalTantra.

Figure 1 shows all options in the sidebar and panels under these options. In further sections, we will learn how to use all options and fields under them.

For a better understanding, we will design an example network "**sample network".** In this network, given all node demands & elevations, layout, pipe lengths and other hydraulic constraints, **we need to decide the optimum value of pipe diameters with minimum cost of network layout.** The sample network details are shown in **Figure 2**.

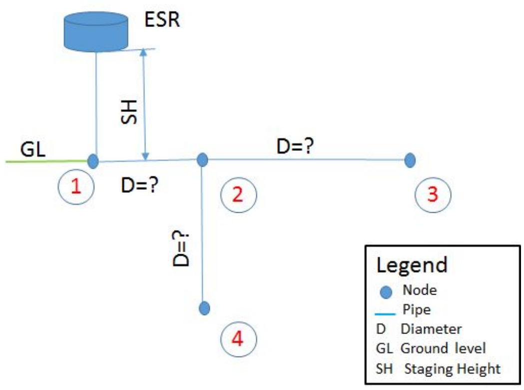
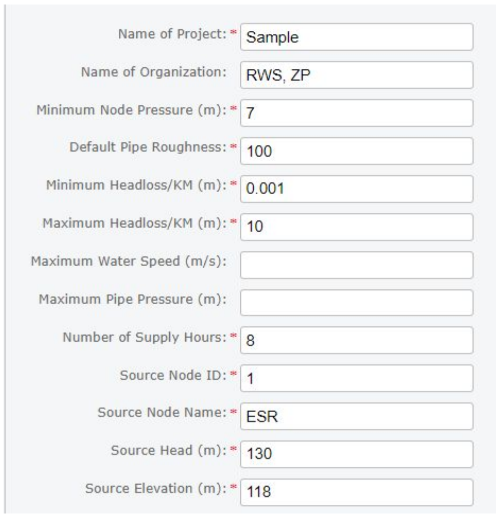


Figure 2. A sample network with the ESR, nodes of the network and distances between them.



Name of Project: *	Sample
Name of Organization:	RWS, ZP
Minimum Node Pressure (m): *	7
Default Pipe Roughness: *	100
Minimum Headloss/KM (m): *	0.001
Maximum Headloss/KM (m): *	10
Maximum Water Speed (m/s):	
Maximum Pipe Pressure (m):	
Number of Supply Hours: *	8
Source Node ID: *	1
Source Node Name: *	ESR
Source Head (m): *	130
Source Elevation (m): *	118

Figure 3. Various fields under the "General" panel.

2.1 Setting up network layout and properties

The first option is Network description. This contains the various panels, using which all the network information is provided. All these panels [4] are described one by one in the following sections.

2.1.1 General

The first panel is the "General" panel which contains **input fields** for the general information of a network. All input fields are shown in **Figure 3** for our sample network (**Figure 2**).

Following are the various fields:

- **Name of the project: N**ame it '***Sample***'.
- **Minimum node pressure:** This is the minimum pressure in meters that must be maintained at all nodes by default. We can override this and give different values for different nodes, but this is the default value.
  Use a value **of 7 meters** [10] for our sample project.
- **Default pipe roughness:** For measuring head loss in pipes we use the Hazen-williams head loss equation[1]. This is the roughness coefficient used in the formula.
  This is the default value used for all pipes, but can be overridden with different values for specific pipes.
  Use a typical value of **100** [Appendix A]**.**
- **Minimum and maximum head loss per Km in pipe:** This is the minimum and maximum head loss in meters that is allowed per kilometer for each pipe in the network.
  Use typical values of **0.001** meters and **10** meters respectively for the two fields.
- **Number of supply hours:** This is the number of hours in a day for which the source provides water. This determines the peak factor for the flow in the network.
  For example, if the number of supply hours is 12, then water demand for the entire day

[1] **$S = h_f/L = 10.67*Q^{1.852} / (C^{1.852} * d^{4.8704})$** where,
S = Hydraulic slope, h_f = head loss in meters (water) over the length of pipe, L = length of pipe in meters, Q = volumetric flow rate, m^3/s (cubic meters per second), C = pipe roughness coefficient, d = inside pipe diameter, m (meters)

must be satisfied in 12 hours. This is equivalent to having a peak factor of 2 i.e. nodes have an effective demand that is double their stated demand.
For our sample project, use a value of 8 hours. That means the peak factor is 3 and the demand will be 3 times the stated demand.

- **Source node id:** Source id is any integer.
  Keep source id ‘**1**’
- **Source name:** Can be ESR, GSR, well, etc.
  Name source as ESR.
- **Source elevation** is the elevation of the ground level of the source in meters.
  Enter elevation as 118 meters.
- **Source head** is the constant head provided by source in meters no matter what the demand of the network.
  In this example, the source head is at 130 m (adding 12 m of staging height to source elevation).

2.1.2 Nodes

Now, in the “Nodes” panel enter all the information regarding the nodes of our network.
The nodes information is displayed as a table with the following columns:

- Node ID: This is the unique integer identifier for each node.
- Node Name: The name of a node. Note that this field is optional.
- Elevation: Elevation of the node in meters.
- Demand: The water demand of the node in litres per second. This field is optional, if left empty a zero demand is assumed. For example if there is an intermediate node with zero demand, then the demand field can be left empty.
- Minimum Pressure: This is the minimum pressure in meters that must be maintained at that node. If left empty it uses the default minimum node pressure value from the general information panel.

Sample project (**Figure 2**) has node details as given in **Figure 4**.

All Fields | Add New | Delete

Node ID	Node Name	Elevation (m)	Demand (lps)	Min. Pressure (m)
2		120	2.00	
3		118	1.00	
4		116	3.00	

Figure 4. Node details of sample project.

To add a node simply click on the “Add New” button at the top as shown in **Figure 4**. **As you can see it has already given a node id number of 2 since 1 is already used for source**.
If needed, overwrite this and use any integer greater than equal to 1.
To edit any value, double click on the cell.

2.1.3 Pipes

Now use “Pipes” panel. The functionality of this panel is very similar to the nodes panel.
As before, there is a table with the pipe information and similar tasks like add, delete and search can be performed.
See the columns for the pipe table:

- Pipe ID: Just like the node id, this is the unique integer identifier for each pipe in the network.
- Start Node: This is the node id of the node at the start of the pipe.
- End Node: Similarly, this is the node id of the node at the end of the pipe.
- Length: This is the length of the pipe.

- Diameter: Normally diameter is calculated by the optimization and this field is left empty but if the pipe is using some existing diameter then the value can be set here.
- Roughness: This is the hazens-williams roughness coefficient for the pipe. This needs to be provided if an existing diameter is being used. If left empty it takes the default value provided in the general screen.
- Parallel Allowed: If the pipe has an existing diameter, then this option can be enabled to allow a parallel pipe to be placed in case the primary pipe is not enough to serve the demand.

Sample project (**Figure 2**) has node details as given in **Figure 5**.

All Fields | Add New | Delete

Pipe ID	Start Node	End Node	Length (m)	Diameter (mm)	Roughness	Parallel Allowed
1	1	2	500			☐
2	2	3	600			☐
3	2	4	650			☐

Figure 5. Pipe details of sample project.

To add a pipe, simply click on the "Add New" button at the top as shown in **Figure 5**. To edit any value double click on the cell.

2.1.4 Commercial pipes

Use the commercial pipe section. This is where the data for the commercially available pipe and its cost is entered.

- Each row in the table is simply the diameter of the pipe, its head loss roughness coefficient and the cost per meter of the pipe.
- If the roughness value field is kept blank, it will take the default value of roughness from the general screen.

Sample project (**Figure 2**) has node details as given in **Figure 6**.

All Fields | Add New | Delete

Diameter (mm)	Roughness	Cost (Rs)
80		94
100		105
125		108
200		120
250		134

Figure 6. Commercial pipe information for sample project.

2.1.5 Reset

After entering all the relevant data for our network and can move onto optimization.
If you want to clear all the data, click on the reset button.
Make sure you save before resetting or all of the data will be lost.

2.1.6 Map

Typically, node details are entered manually which come from surveys, but using this option you can directly draw a network in Google map . Using this feature network details such as elevation, distance etc. are automatically queried and used from the map for network setup. Usage of this feature is discussed in Section 2.6.

2.2 Solving for the network

After completely filling the network information part, move to the ‘optimize’ panel.
Open the optimize network menu and click on “Optimize”.
While the system is optimizing the pipe diameters, a “optimizing... please wait” popup will appear.
Once done, the system popup “done” will appear if successful or “could not solve network” if the network cannot be solved.

Results:
For our sample network a “done” message was shown. This means it is successful. Then it goes to the results screen where the nodes, pipes and cost details are shown in different tabs.

In the nodes tab the head at each node is shown (see **Figure 7**).

Nodes Pipes Cost ESR Cost Pump Cost

All Fields

Node ID	Node Name	Demand (lps)	Elevation (m)	Head (m)	Pressure (m)	Min. Pressure (m)
1	ESR	0.00	118.00	130.00	12.00	0.00
2		6.00	120.00	128.43	8.43	7.00
3		3.00	118.00	125.00	7.00	7.00
4		9.00	116.00	123.00	7.00	7.00

Figure 7. Result nodes tab for sample network.

In the pipes tab the diameter of the pipe chosen, the head loss in each pipe and the cost of each pipe can be seen (See **Figure 8**). Also, note that Pipe ID2 has been optimized in such a way that it has been divided in two pipes of different diameters in order to minimize the network cost at the same time satisfying all hydraulic constraints. Same is the case for Pipe ID3.

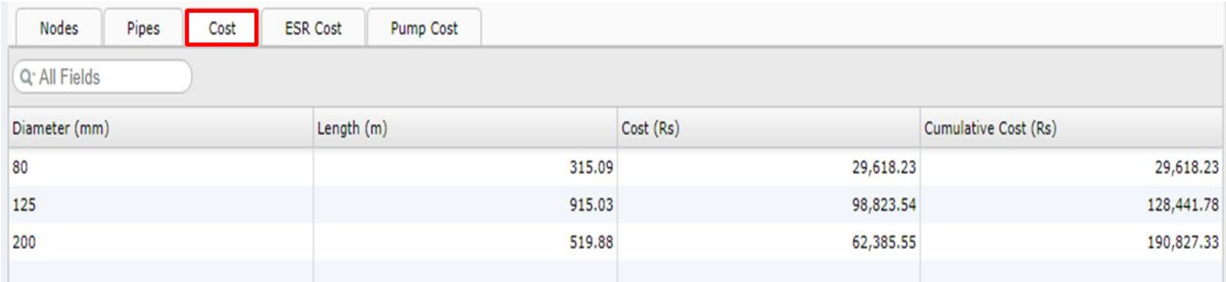
Nodes Pipes Cost ESR Cost Pump Cost

All Fields

Pipe ID	Start Node	End Node	Length (m)	Flow (lps)	Speed (m/s)	Diameter (mm)	Roughness	Headloss (m)	Headloss per KM (m)	Cost (Rs)
1	1	2	500.00	18.00	0.57	200.00	100.00	1.57	3.14	60,000.00
2	2	3	315.09	3.00	0.60	80.00	100.00	3.11	9.87	29,618.23
2	2	3	284.91	3.00	0.24	125.00	100.00	0.32	1.12	30,770.54
3	2	4	630.12	9.00	0.73	125.00	100.00	5.41	8.59	68,053.00
3	2	4	19.88	9.00	0.29	200.00	100.00	0.02	0.87	2,385.55

Figure 8. Result pipes tab for sample project.

In the cost tab the cost for each pipe diameter and the overall cost is shown (see **Figure 9**).



Diameter (mm)	Length (m)	Cost (Rs)	Cumulative Cost (Rs)
80	315.09	29,618.23	29,618.23
125	915.03	98,823.54	128,441.78
200	519.88	62,385.55	190,827.33

Figure 9. Results-cost tab for sample project.

2.3 Importing and exporting data and results

Now that entry of so many input details is done and got the result, someone would like to save this information for future use.
Click on the load/save files option to expand the options (See **Figure 1**.) These options are explained further.

2.3.1 Save input file

To save the input, click on the plus sign next to “Save Input File” (click on the + sign next to Save Input File).
By double clicking this option can be maximized and the input can be saved as an XML or Excel file.

Similarly, output information can be saved as an MS Excel file.

2.3.2 Load input file

In the Excel file, all the information that was entered earlier can be seen.
To load this file open a fresh session of JalTantra by opening the site in a new tab.
To load the file maximize the “LOAD/SAVE FILES” tab and then maximize the load file option (see **Figure 1**).

- Here are the options to load files in three options xml, branch and excel.
  - XML and Excel.
  - Branch file format is for those network files that were previously used in the Branch software. They have the extension .bra
- How to load the excel file saved previously.
  - Click on “Load Excel File”. Again there is a warning message “Any unsaved information will be lost, continue?”.
  - Click “Yes”, a typical dialog box for file selection will be shown
  - Choose the file that was just saved and click open.
  - Now all the information from the excel file has been loaded into the different screens.
  - You can click on the optimize button again and check if the same results are the same as before.

2.4 Tips for using tool

The HELP option provides useful information and tips for some common usage scenarios.

The units used for various parameters are mentioned.

- Elevation, Head, Minimum Pressure and Length are specified in *meters*.

- Demand is specified in *liters per second*.
- Pipe diameters are specified in *millimeters*.

The section has links to a few sample input and output files for reference and as examples. Click them to download to study details.

For more information, queries, suggestions or comments on JalTantra, please use the contact information mentioned in this listing.

2.5 Various common cases in optimization

2.5.1 Missing information

If some information is missing as part of the input then the system generates **an appropriate warning message**.

Suppose, supply hours missed to be entered as input in the field “Number of Supply Hours” in “General” panel (see **Figure 10**) and try optimizing.

The warning message saying “Please enter Number of Supply Hours” is generated (see Figure 10.

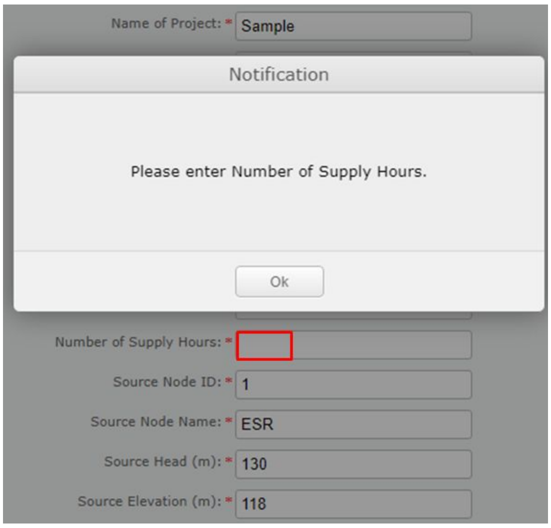


Figure 10. Missed information of supply hours and appropriate message generated while optimizing

2.5.2 Infeasible network

Infeasibility of the network means Jaltantra can not solve the optimization for the specified constraints (minimum node pressure, min/max head loss in pipes) and inputs parameters of the network (source head, elevations, pipe lengths, commercial pipe diameters, etc.) given.

a) If the network is infeasible, a “Head loss can not be set within min/max values” message may be displayed.
For the sample project, look up the field “Minimum Headloss/KM (m)” in the ”General” panel (see **Figure** 3). The minimum head loss value has been set to 0.001 m/Km, change it to 4 m/Km.

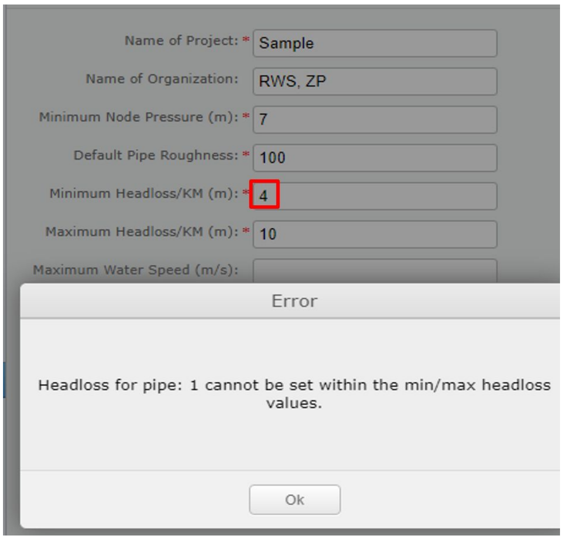


Figure 11. Minimum head loss value changed to 4m from the original value of 0.001 m resulted in error.

On solving for this network, a “Head loss can not be set within min/max head loss values” (see **Figure 11**) message appears.

This message indicates that for the given demand requirements and commercial pipes available, the head loss in pipe 1 can not be in the range of 4 m/Km to 10 m/Km and in this case could be lower.

b) The "Failed to solve network" message.

In our sample project, look up the source head, which is set to 130 m.
Change the value of source head to 124 m, considering staging height of ESR 6m instead of 12 m. Use the "General" panel and change the source head as 124 m (See **Figure 12**).

Now try optimizing this network.
A "Failed to solve network" message is shown in **Figure 12**.

This implies that the source head is insufficient to solve the network for given commercial diameters and hydraulic constraints like residual pressure, etc.

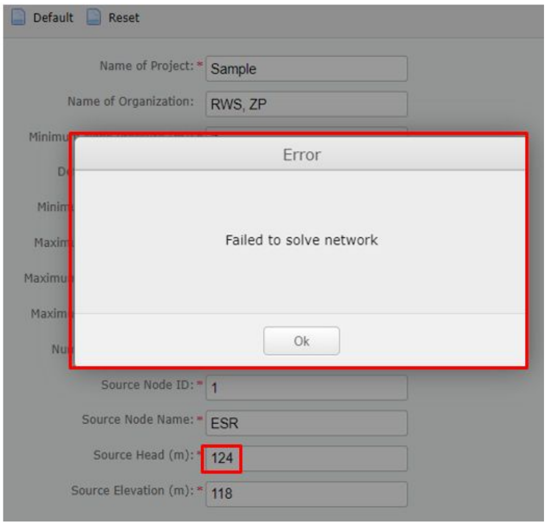


Figure 12. Source head changed to 6 m which results in inability to solve the network.

2.5.3 Parallel pipes

Consider a scenario where an existing pipe of the network has to be used as part of the redesign of the distribution network. Further, assume that the demand in the downstream of the pipe has changed and it is likely that the diameter of the pipe may not be able to meet desired demand requirements. A possible solution is to add a pipe in parallel to an existing pipe to increase capacity of the network.

Consider in our original sample network, pipe1 (from node 1 to node 2) is an old pipe with diameter 100 mm. Therefore, in the "Pipes" input panel, add 100 mm diameter for pipe1 (see **Figure13)** and try to optimize the network. The error "Headloss for pipe: 1 cannot be set within min/max headloss values" will appear. This implies that the 100 mm diameter for pipe1 is not sufficient to solve the network.

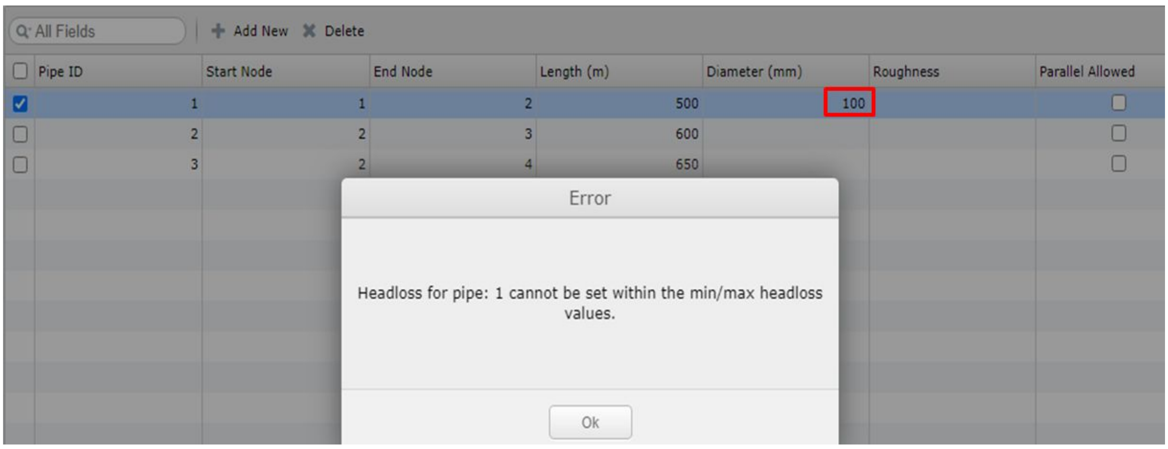


Figure 13. Existing pipe1 of 100 mm which results in infeasibility of network .

Here for pipe 1, the system can be asked to allow parallel pipes by clicking "Parallel Allowed" (See **Figure 14**).

Pipe ID	Start Node	End Node	Length (m)	Diameter (mm)	Roughness	Parallel Allowed
1	1	2	500	100		☑
2	2	3	600			☐
3	2	4	650			☐

Figure 14. Parallel pipe allowed to pipe1.

Since it is already known that a 100 millimeter pipe is not enough the system will try and place a pipe in parallel to satisfy the network.
Now try optimizing again.
This time network got solved.
See the "Results-->Pipes" tab to know what happened.

Pipe ID	Start Node	End Node	Length (m)	Flow (lps)	Speed (m/s)	Diameter (mm)	Roughness	Headloss (m)	Headloss per KM (m)	Cost (Rs)
1	1	2	500.00	2.50	0.32	100.00	100.00	1.19	2.38	0.00
1	1	2	500.00	15.50	0.49	200.00	100.00	1.19	2.38	60,000.00
2	2	3	358.63	3.00	0.60	80.00	100.00	3.54	9.87	33,710.88
2	2	3	241.37	3.00	0.24	125.00	100.00	0.27	1.12	26,068.35
3	2	4	650.00	9.00	0.73	125.00	100.00	5.58	8.59	70,200.00

Figure 15. Results of parallel pipes.

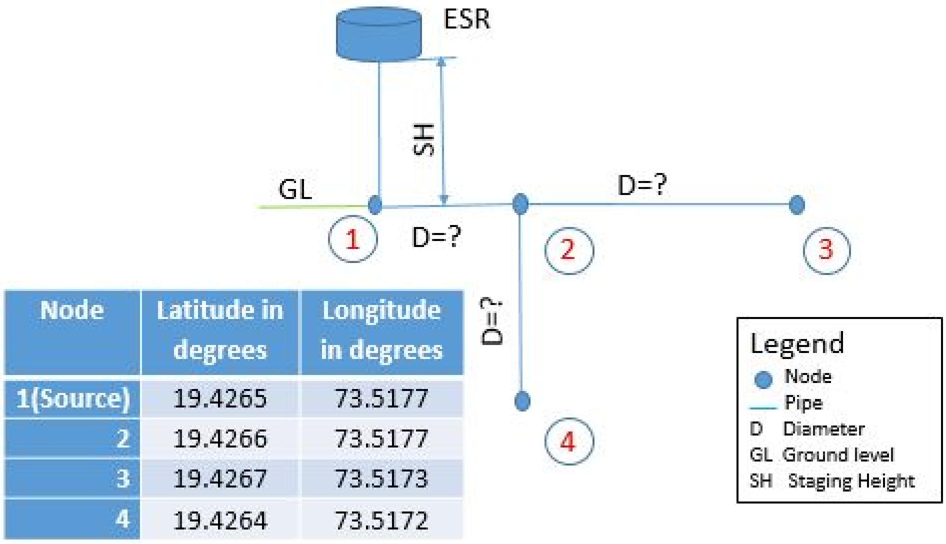
The system added a 200 millimeter pipe in parallel for pipe id 1 (see **Figure 15**).
The two pipes, 100 mm and 200 mm in parallel are able to satisfy the network where a single pipe could not.
Note that the original 100 millimeter pipe does not contribute to the total cost since it is an existing pipe.

2.6 Using Map/GIS

Entering all the nodes and pipe data can be very time consuming, especially for a large network.
Also data like node elevations and pipe lengths needs to be found either via surveys or through some GIS tool.
Rather than manually entering all this data **the map tool can be used**.
The system uses Google Maps and allows adding nodes by **directly selecting nodes on the map** or by **entering latitude and longitudes** of node locations and joining nodes for pipes as per the layout of the network decided. After that all the details can be exported so that the node and pipe tables can be seen as earlier.

Note: This option can be used whenever there is internet connection available

Solve one sample pipe network for getting familiar with this feature of JalTantra.



Node	Latitude in degrees	Longitude in degrees
1(Source)	19.4265	73.5177
2	19.4266	73.5177
3	19.4267	73.5173
4	19.4264	73.5172

Figure 16. A sample pipe network with four nodes and an ESR.

Solve the network shown in **Figure 16** which has one source (ESR) node and four demand nodes. Latitude and longitudes and demands of all nodes are given in the figure. The other parameters of the scheme are: Staging height = 12m, minimum node pressure = 7m, default pipe roughness = 100, and minimum and maximum head loss in pipe as 0.001 and 10 m/km, respectively.

Following are the steps to solve this network,

Step1: Adding source node

In the “Map” panel, click on “Add node” (see **Figure 17**). Name the Node 1 as ESR and it is marked as “source” as this is source node. Copy the latitude and longitudes of the node into respective boxes. Google will take elevation automatically.

(Note: Nodes can be of three types---source, ESR or demand/non-demand nodes. In our example **Node1 is marked as source node and others as demand nodes).**

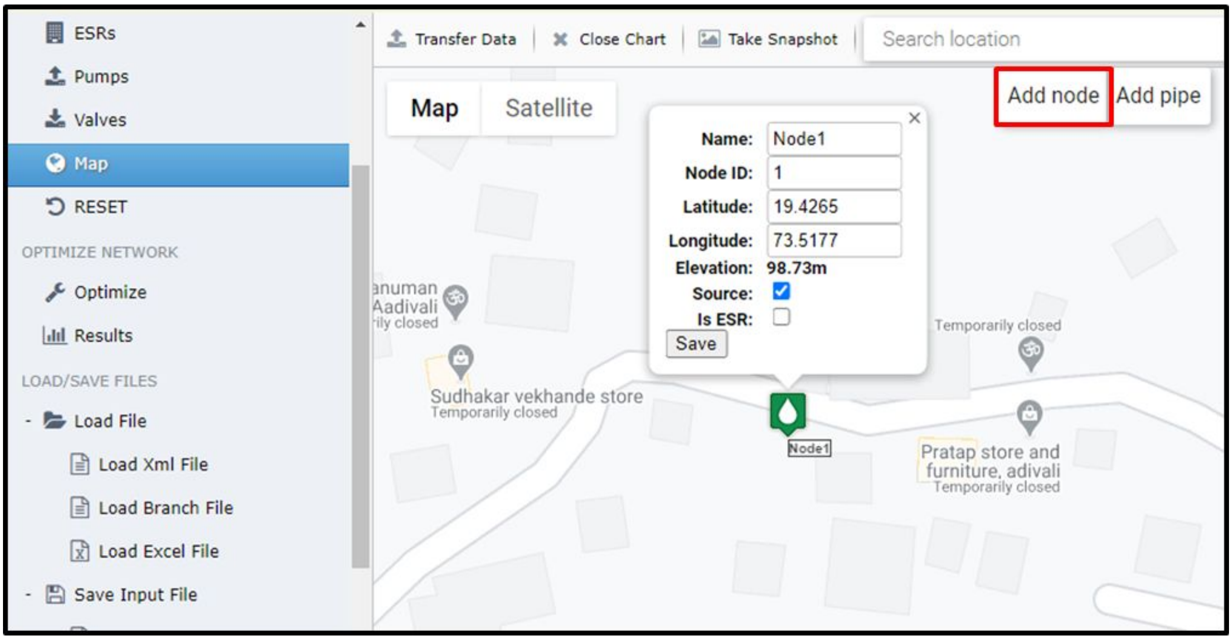


Figure 17. Adding nodes in the Google map interface.

Step2: Adding other (demand) nodes

Similarly enter other node details by adding nodes**. Please note that other nodes have not been marked as source or ESRs.**

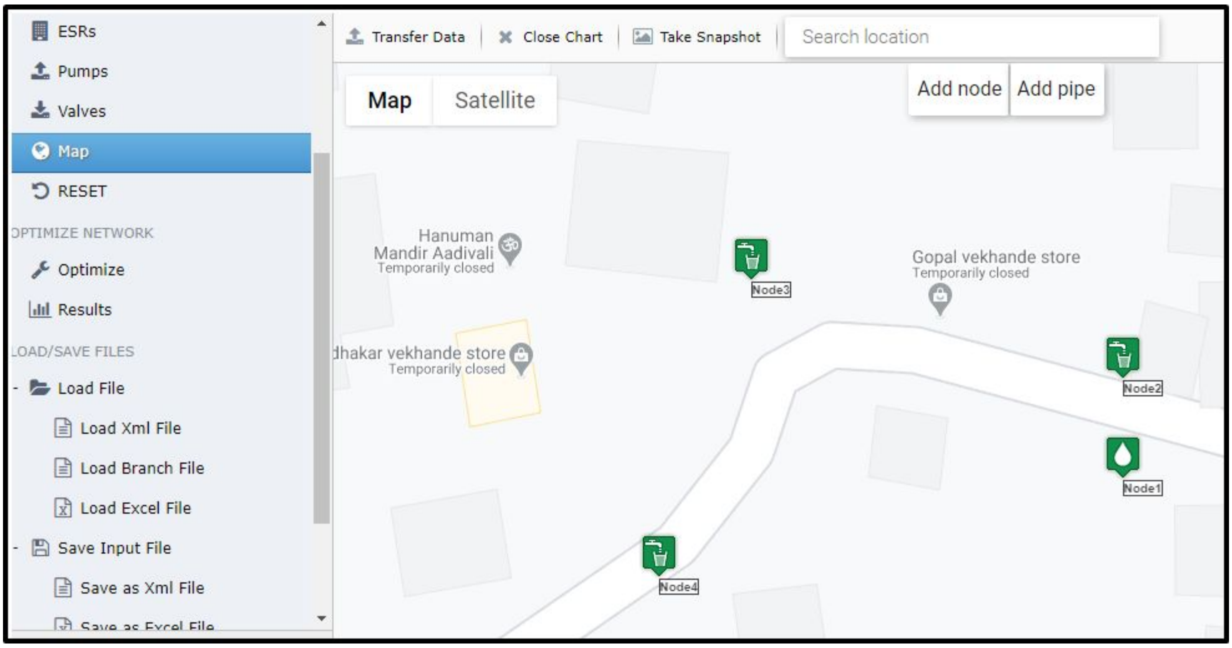


Figure 18. View after adding details of all nodes.

Step3: Adding pipes of the network

Click on "Add pipe" and select any two nodes, it will add a pipe which will have a zig-zag **path** (See pipe P1 in **Figure 19**). This layout of pipe is not straight because it takes the path along the road.

For straight pipes (connecting directly selected nodes and not along the road), right click on a map anywhere, select "Add a direct pipe" and then click on the nodes one by one. It will give a straight pipe (See pipe P2 in **Figure 19**).

Note: While joining nodes for pipe, it should be joined in the direction of flow. In our sample network, the flow direction is from node3 to node4.

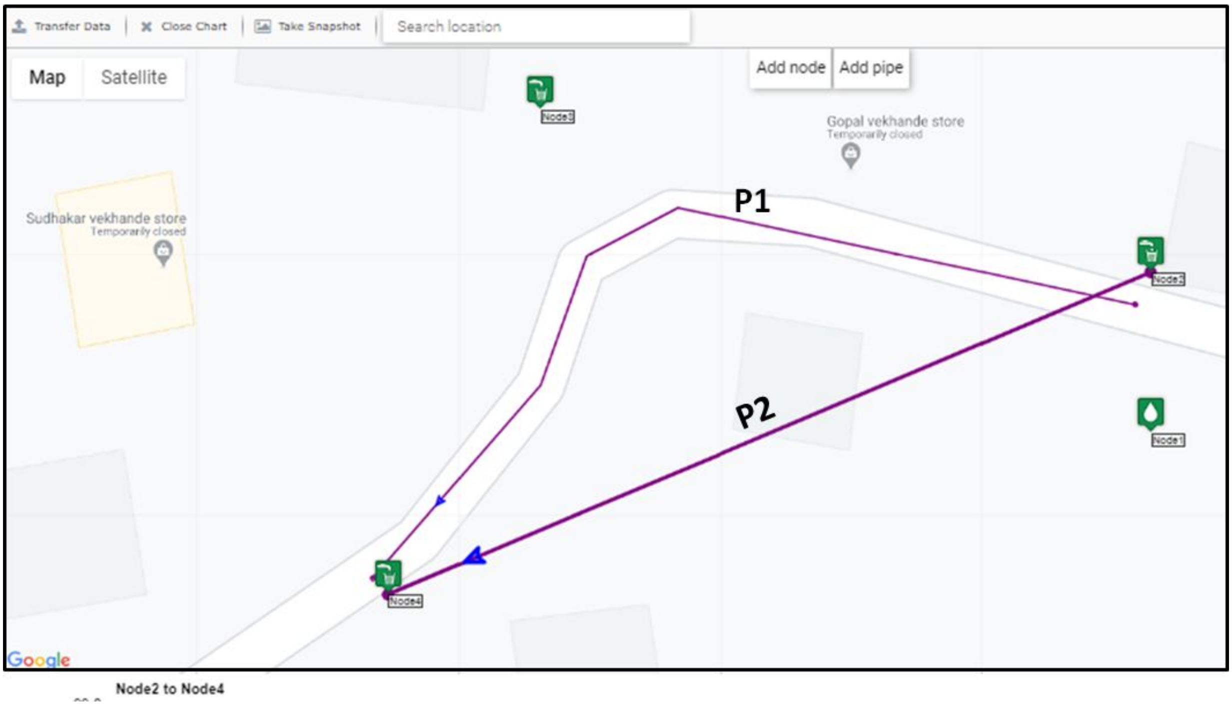


Figure 19. Examples of a direct pipe and a zig zag pipe.

Similarly add all pipes for our sample network as direct pipes, while considering flow, from node 1 to node 4 sequentially (See **Figure 20**)

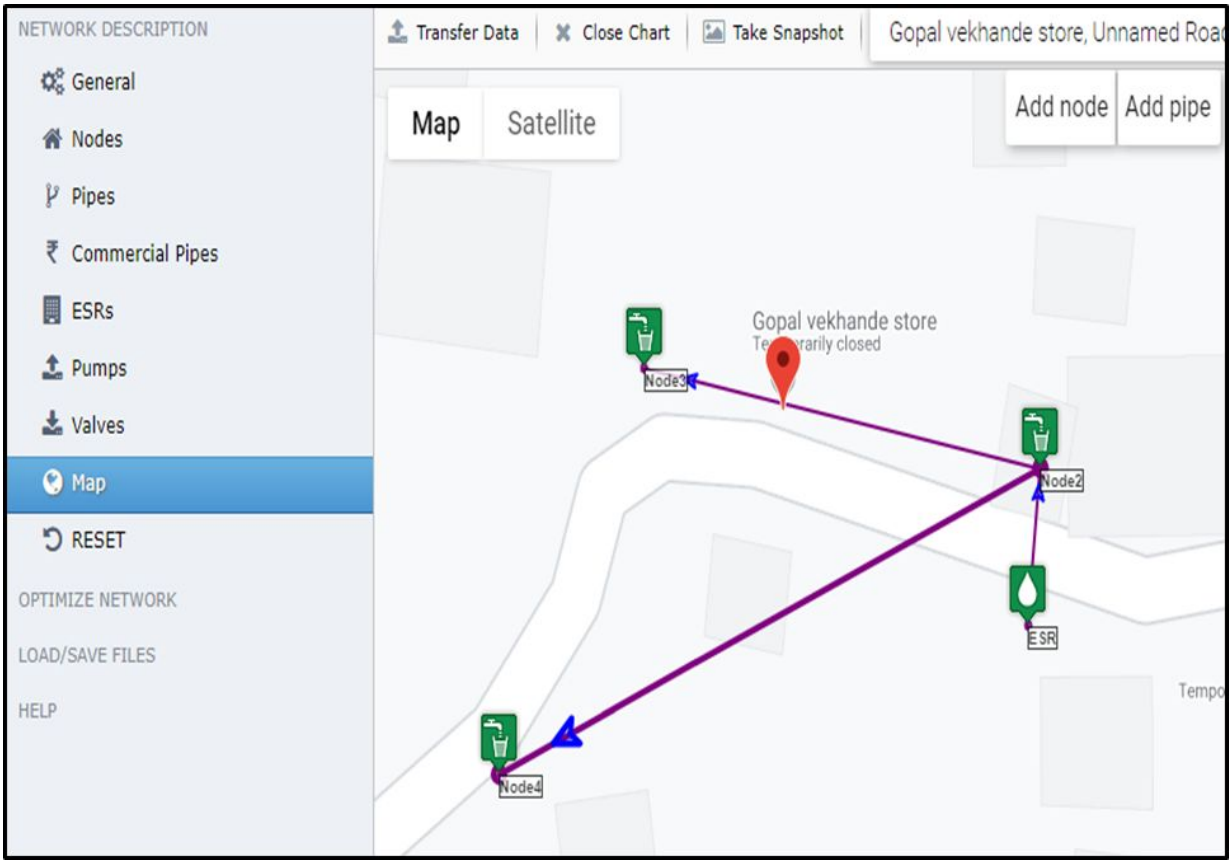


Figure 20. View with pipes added for sample network.

Step 4: Transfer data

Now click on the “Transfer Data” command (highlighted command in **Figure 20**). This will transfer details such as node elevations, source elevation, pipe lengths to the respective panels.

Now apply this command to our sample project. The node names, elevation and lengths of pipes will automatically be generated into the respective tabs.

Further, follow steps discussed in Sections 2.1.1, 2.1.2, 2.1.3 and 2.1.4. to optimize the network.

2.7 Valves

The “Valves” panel allows to manually add Pressure Reducing Valves (PRVs at different pipe IDs. The purpose of this valve is to reduce unwanted extra pressure at a node by adding PRV to the pipe which connects that node.

Consider a scenario of our sample example. The results of which (no parallel allowed case) are shown in **Figure 21.**

Node ID	Node Name	Demand (lps)	Elevation (m)	Head (m)	Pressure (m)	Min. Pressure (m)
1	ESR	0.00	118.00	130.00	12.00	0.00
2		6.00	120.00	128.43	8.43	7.00
3		3.00	118.00	125.00	7.00	7.00
4		9.00	116.00	123.00	7.00	7.00

Figure 21. Results of Sample network showing nodes and pressures at nodes

After solving the sample network the pressure at node2 was found to be 8.43m. The minimum node pressure has already been set to 7m. Now, if the pressure at node2 is to be reduced to 7m then go to the “Valves” panel, add a pipe ID and number it as “1” as node2 is connected to Pipe ID1 (See **Figure 22**).

Note that the PRV valve is fitted to pipe.

Now, enter an amount of pressure which needs to be reduced (in this case it is 1.44m) under the option “valve pressure reducing setting (m)” in “Valve” panel (See **Figure 22**.)

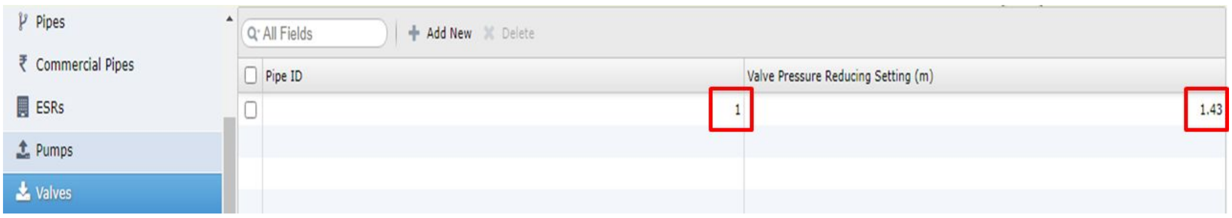


Figure 22. Adding PRV to Pipe ID1 with setting of 1.43m reduction of pressure at node2.

Now, optimize the network. It can be noted that after adding PRV for the setting of reducing pressure by 1.43 m at node2, the pressure at node2 is 7m (See **Figure 23)**.

Nodes | Pipes | Cost | ESR Cost | Pump Cost

All Fields

Node ID	Node Name	Demand (lps)	Elevation (m)	Head (m)	Pressure (m)	Min. Pressure (m)
1	ESR	0.00	118.00	130.00	12.00	0.00
2		6.00	120.00	127.00	7.00	7.00
3		3.00	118.00	125.00	7.00	7.00
4		9.00	116.00	123.00	7.00	7.00

Figure 23. Results after adding PRV to Pipe ID1 with setting of 1.43m reduction of pressure at node2.

Note: Even if you enter more amount of pressure to be reduced i.e. more than 1.43m, after optimization, you will find the pressure at node2 is 7m only and can not be reduced beyond it since in "General" panel we have set minimum pressure at every node 7m.

2.8 Practice problems

I. Find the pipe diameters that result in a minimum cost of the distribution network of Khairapada Piped Water Supply System (PWSS). The details of the network are given below.

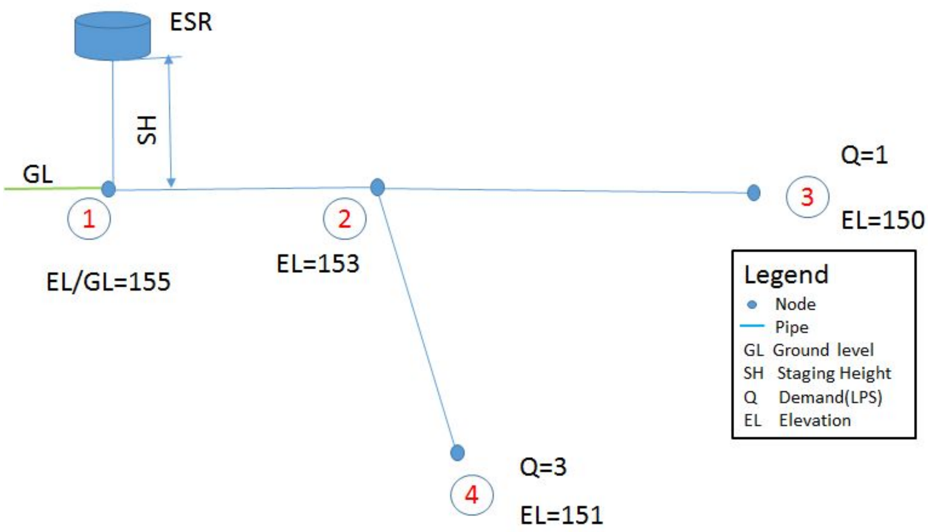


Figure 24. Details of nodes, elevations, demands forJamsar distribution network

The pipe and commercial pipe details are as shown in **Table1**.

Table 1. Pipe and commercial pipe details.

Pipe details				Commercial pipe details	
Id	**Start node**	**End node**	**Length (m)**	**Diameter(mm)**	**Cost(Rs/m)**
1	1	2	400	80	455
2	2	3	750	100	649
3	2	4	600	125	884
				150	1039

Following are parameters of the network: minimum residual head = 7m, minimum & maximum head loss = 0.001 m/Km & 10 m/Km, pipe roughness = 100 and supply hours = 8 hour, Staging Height of ESR = 12 m.

Compare your solution with the cost shown in **Figure 25**.

Nodes | Pipes | Cost | ESR Cost | Pump Cost

All Fields

Diameter (mm)	Length (m)	Cost (Rs)	Cumulative Cost (Rs)
80	750.00	341,250.00	341,250.00
125	600.00	530,400.00	871,650.00
150	400.00	415,600.00	1,287,250.00

Figure 25. Optimized network cost of Jamsar network

II. Find the pipe diameters that result in a minimum cost of the distribution network of Khairapada Piped Water Supply System (PWSS). The details of the network are given below.

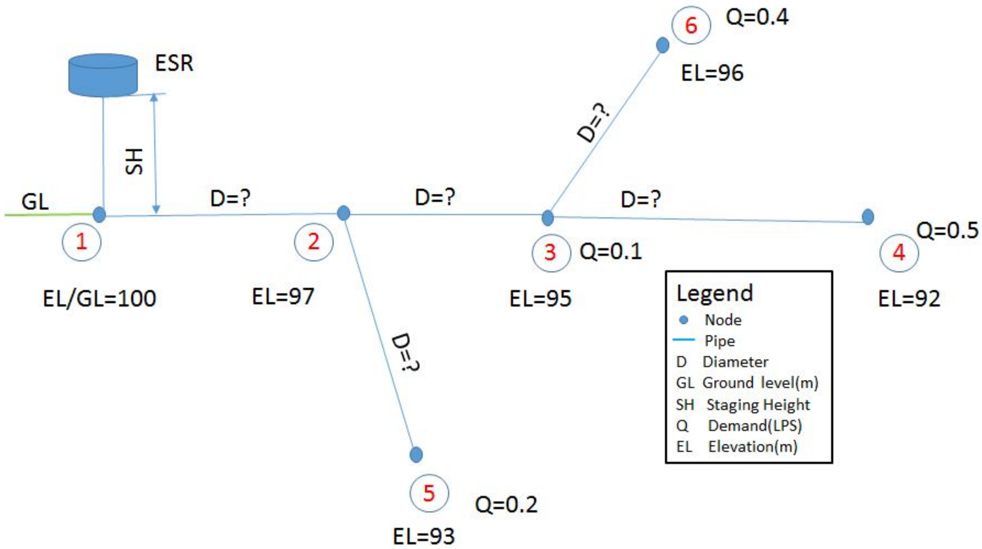


Figure 26. Details of nodes, elevations, demands for Kondhale distribution network

The pipe and commercial pipe details are as shown in **Table2**.

Table 2. Pipe and commercial pipe details.

Pipe details				Commercial pipe details	
Id	**Start node**	**End node**	**Length (m)**	**Diameter(mm)**	**Cost(Rs/m)**
1	1	2	500	50	273
2	2	3	450	65	346
3	3	4	550	80	455
4	3	6	560	100	649
5	2	5	600	125	884
				150	1039

Following are parameters of the network: minimum residual head = 7m, minimum & maximum head loss = 0 m/Km & 5 m/Km, pipe roughness = 100 and supply hours = 8 hour, Staging Height of ESR = 6m.

Compare your solution with the results shown in **Figure 27**.

Pipe ID	Start Node	End Node	Length (m)	Flow (lps)	Speed (m/s)	Diameter (mm)	Roughness	Headloss (m)	Headloss per KM (m)	Cost (Rs)
1	1	2	500.00	3.60	0.29	125.00	100.00	0.79	1.57	442,000.00
2	2	3	315.40	3.00	0.38	100.00	100.00	1.05	3.33	204,693.93
2	2	3	134.60	3.00	0.24	125.00	100.00	0.15	1.12	118,987.32
3	3	4	550.00	1.50	0.30	80.00	100.00	1.50	2.73	250,250.00
4	3	6	560.00	1.20	0.24	80.00	100.00	1.01	1.81	254,800.00
5	2	5	600.00	0.60	0.31	50.00	100.00	2.96	4.94	163,800.00

Figure 27. Optimized network results of Kondhale network

III. Find the pipe diameters that result in a minimum cost of the distribution network of Khairapada Piped Water Supply System (PWSS). The details of the network are given below.

General Information

- Peak factor: 3
- Supply hours: 24/3 = 8
- Head loss : 0 to 10 m/km
- 'C' value for HDPE pipe: 140
- Minimum node pressure: 7m

Commercial pipe data			
Diameter	Cost	Diameter	Cost
96	311	175	1,040
109	403	196	1,337
122	539	218	1,647
140	701	245	2,066
157	844		

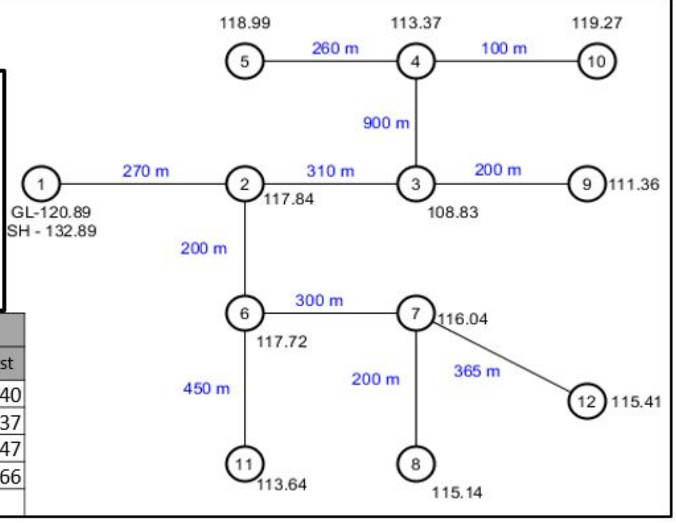


Figure 28. Khairapada network details and other required inputs.

(Please note GL is elevation of source node(ESR) and SH is source head (GL+Staging Height))

Node details of the network are shown in **Table 3.**

Table 3. Node details of Khairapada PWSS.

Node	Elevation (m)	Demand (LPS)	Node	Elevation (m)	Demand (LPS)
1 (ESR)	120.89	0	7	116.04	0
2	117.84	0	8	115.14	0.87
3	108.83	0	9	111.36	1.3
4	113.37	0	10	119.27	0.67

5	118.99	0.95	11	113.64	1.6
6	117.72	0	12	115.41	0.88

Compare your solution with the results shown in **Figure 29.**

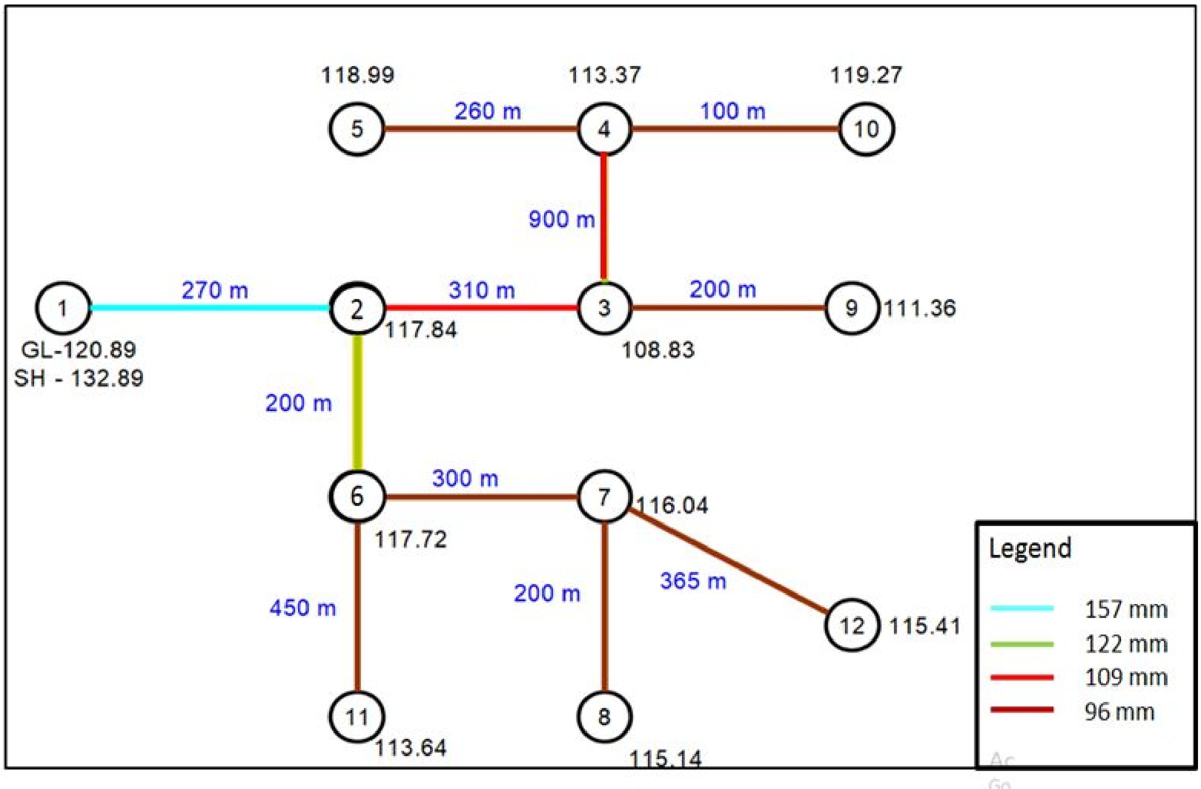


Figure 29. Optimized pipe diameters of Khairapada PWSS.

II. Find the pipe diameters that result in a minimum cost of distribution distribution network. The details of the network are given below.

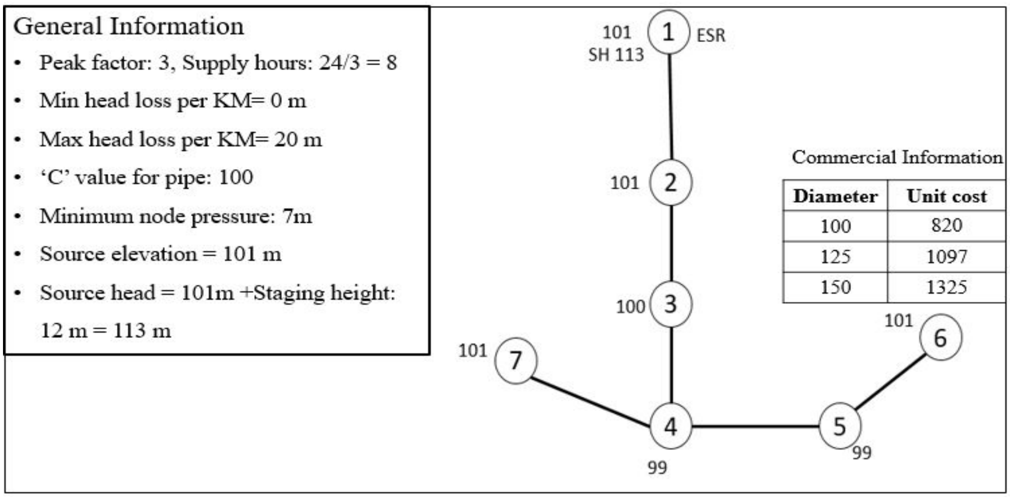


Figure 30. Network details and other required details.

The pipe and node details are as shown in **Table4**.

Table 4. Node details of Khairapada PWSS.

Pipe details				Node details		
Id	**Start node**	**End node**	**Length (m)**	**Id**	**Elevation (m)**	**Demand(LPS)**
1	1	2	79	1 (ESR)	101	0
2	2	3	103	2	101	0.65
3	3	4	38	3	100	1.2
4	4	5	51	4	99	0.95
5	4	7	39	5	99	0.92
6	5	6	53	6	101	0.86
				7	101	0.55

Compare your solution with the results shown in **Figure 31**.

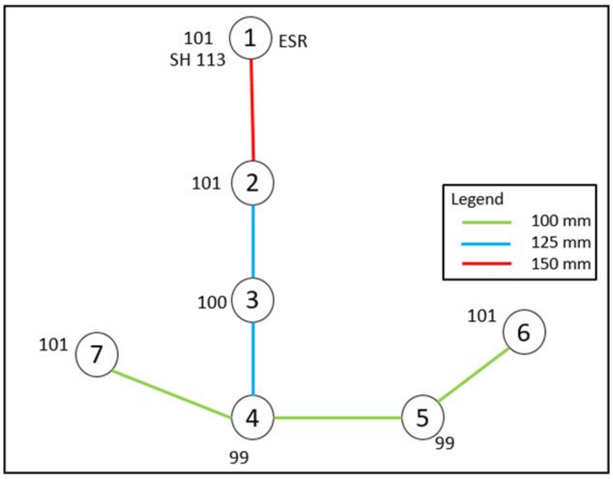


Figure 31. Optimized pipe diameters of Khairapada PWSS

III. Find minimum cost for the Patil Pada PWSS distribution network layout for 4 household clusters. The demands & elevations for clusters, staging height of ESR and lengths of pipe of the network are shown in **Figure 32.**.

Figure 32 Network details of Patil Pada PWSS

Following are parameters of the network: minimum residual head = 7m, minimum & maximum head loss = 0.001 m/Km & 10 m/Km, pipe roughness = 100 and supply hours = 8 hour.

For commercial pipe rates, refer to **Table 5.**

Table 5. Commercial pipe data

Diameter (mm)	Cost (Rs./m)
50	273
65	346
80	455
100	649
125	884
150	1039

IV. Design and estimate the cost of a distribution network for a region with 4 household clusters shown in **Figure 33**. The figure also shows the number of households in each cluster, the average elevation of the cluster, elevation of some sample locations or non demand nodes (that can be used by pipes of the distribution network). Note that you can try with multiple pipe layouts of the distribution, pick one which yields the lowest cost.

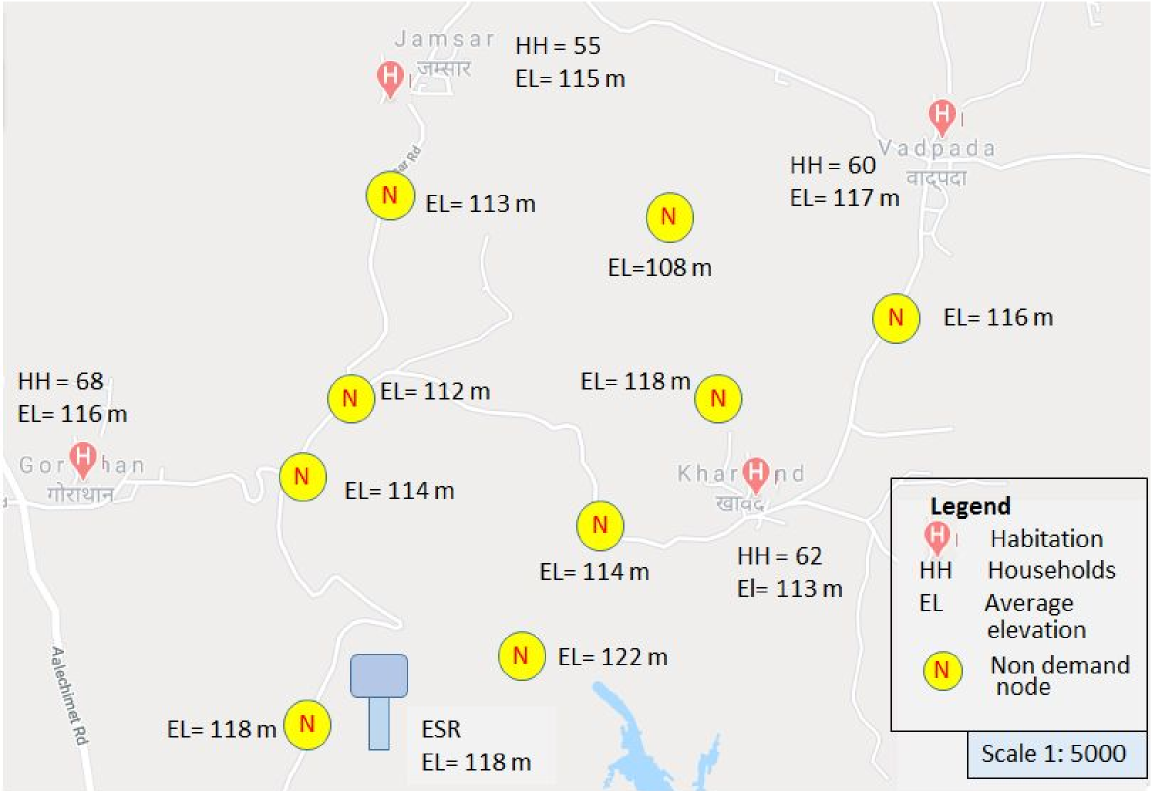


Figure 33 Road layout and habitation details of Jamsar village

There are four habitations in the village and the distribution network is to be designed for supplying water to these habitations from the ESR.

Other information,

- Liters Per Consumer Per Day (LPCD): 70
- Consumers per HH: 6
- Demand = LPCD*Consumer pe HH*HH/(24hr*3600s) LPS e.g. 70*6*62/(24*3600) = 0.30 LPS
- Use non demand nodes/sample locations to layout the pipe network. No two demand nodes should be directly connected, meaning they have to interconnect via the non-demand nodes.
- Pipe lengths can be approximated from the map using scale. e.g. if approximate distance from GL/EL of ESR to nearest non demand node in **Figure 33** is 1.5 cm (along road and not straight line), then the actual length of pipe = 1.5*5000 = 7500 cm = 75 m since scale is 1:5000.
- Residual pressure: 7m, Min-Max head loss in pipe: 0.001 m/Km & 10 m/Km, pipe roughness: 100, supply hours: 8 hours
- ESR staging height: 12 m
- For commercial pipe data, refer to **Table 5**.

2.9 JalTantra and beyond

Jaltantra solves for an output for the distribution network, i.e. **optimum pipe diameters satisfying the hydraulic constraints** of head loss range, residual pressure at each node.

The current system is designed for branch networks only, but it is being expanded to optimize networks with loops as well. The next version of Jaltantra will also feature a Geographical Information System (GIS) based demand allocation, data management and result visualization. The current capabilities of JalTantra through sample case study are discussed in [3].

The optimization solution assumes steady state conditions---constant average demand (no volumetric constraints at nodes), constant head at ESR, etc. and optimization is done allocating different diameters for all pipes satisfying hydraulic constraints for the network.

There are several operational and runtime aspects of a distribution network that cannot be captured by and solved using JalTantra.

Following are some such scenarios,

I. **Impact of varying demand pattern**
A water supply system will not operate always at peak demand. The demand in the network will vary with a particular pattern over the day as per the consumption of water by consumers, e.g. @8am demand = 2.5*average demand, @1pm demand = 0.8*average demand etc. This fluctuating demand pattern will cause all parameters such as pressure at a node, velocity and head loss in pipes, pumping hours, and tank level/volume to vary at different times of the day and affect service levels.

II. **Effect of changes to network parameters on service levels**
During the lifetime of a water supply system various changes may happen---change in demand, addition of new demand nodes, change in physical condition of pipes (friction loss), leakages and losses, disconnections of pipes etc. Quantifying the impact of these changes is important to determine the service delivery of the distribution network.

III. Effect of flow control valves and pressure regulating valves
- As we design networks for demand of ultimate period (e.g., 15 years) So, initially, after commissioning the scheme, demands/flows have to be lower than the designed flows. This can be done through different valve operations and the required flows can be adjusted.
- In a network, if there are few nodes where residual pressure is considerably higher than the average pressure, then the network will have to be simulated using pressure regulating valves for pressure balance.

For many such cases we can not use JalTantra. As a result, for simulation and analysis, other tools and simulation software such as **EPANET** [6,7] are required.

3 Appendix

A. Pipe roughness coefficients

Table 4. Pipe material and roughness coefficient

Pipe material	Hazen-Williams coefficient (value of C)
Cast Iron, Ductile Iron	100
Mild Steel	100
Galvanised Iron (above 55 mm dia)	100
Galvanised Iron (below 55 mm dia)	55
RCC-spun concrete, Prestressed concrete (up to 1200 mm dia)	140
RCC-spun concrete, Prestressed concrete (above 1200 mm dia)	145
PVC, GRP, HDPE and other plastic pipes	145

[Source:Page No. 87, Technical Data Book (4th Edition, 2007), India Water Works Association]

B. Hazen-Williams equation of head loss

Hazen Williams equation is an empirical relationship which relates flow of water with physical properties of pipe and head loss due to friction.

The Hazen-Williams equation for head loss is

$$S = h_f/L = 10.67 * Q^{1.852} / (C^{1.852} * d^{4.8704})$$ [13].

where,

S = Hydraulic slope(m/Km), h_f = head loss in meters (meters of water column) over the length of pipe, L = length of pipe in meters, Q = volumetric flow rate, m^3/s (cubic meters per second), C = pipe roughness coefficient, d = inside pipe diameter (meters).

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