Urban Utilities Planning: Water Supply, Sanitation and Drainage
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Module - 05
Water supply Distribution system and Plans
Lecture - 25
Distribution Network Design

Welcome back. In lecture 25, Distribution Network Design will be covered.

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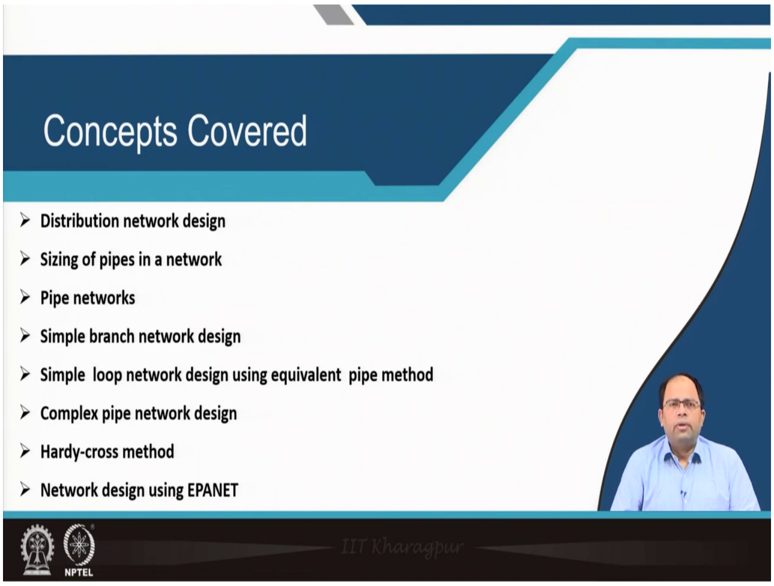

The contents covered in the lecture include

- Distribution network design
- Sizing of pipes in a network
- Pipe networks
- Simple branch network design
- Simple loop network design using equivalent pipe method
- Complex pipe network design
- Hardy-cross method
- Network design using EPANET

Distribution Network design

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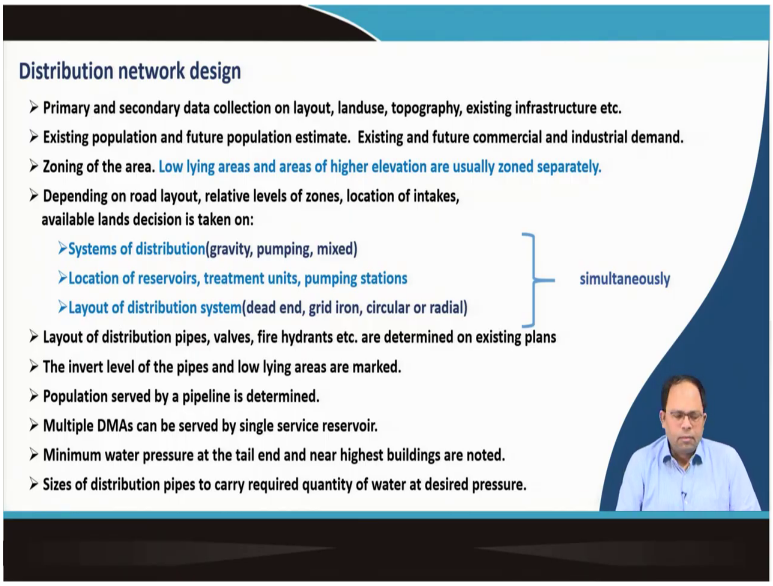

The first step is to define the zones or the DMAs; the different techniques to design the DMAs for a particular area has also been discussed. A lot of data is required.

- Primary and secondary data on layout, land use; layout, topography, existing infrastructure etc., has to be acquired.
- Existing population and future population estimate. Existing and future commercial and industrial demand. The future population has to be determined on the basis of multiple factors and has to be done separately. This helps in understanding the quantity of water supply which would be needed.
- Zoning has to be done. Low lying areas and areas of higher elevation have to be zoned separately.
- Depending on road layout, relative levels of zones, location of intakes,
  available lands decision is taken on (three steps have to be decided simultaneously):
  1. Systems of distribution (gravity/pumping/mixed)
  2. Location of reservoirs, treatment units, pumping stations – has to be fixed initially; however, changes can be done in case cost can be reduced etc.

3. The layout of the distribution system (dead-end/gridiron/circular/radial)

- The next step is to design the layout or the proposed layout of the distribution network in terms of the pipelines, valves, the location of fire hydrants etc.
- The invert level of pipes and the low lying areas are marked as that influences the head
- The next step is to know the population served by particular pipelines of systems which may be dead end type, loop type etc.

- Multiple DMAs can be served by a single service reservoir or vice versa.

- It is necessary to check whether there is minimum pressure available at the endpoints of the distribution network because of the frictional losses. Similarly, it is important to check whether adequate pressure is available in high demand areas such as near tall buildings. Every node point has to be checked similarly. Based on the results, modifications can also be made in the pipeline designs

- The size of distribution pipes to carry a required quantity of water at desired pressure needs to be determined. If sufficient pressure is not achieved, modifications can be done.

These are the various steps involved in distribution network design. Some of the steps are to be done sequentially, and some are done simultaneously. Few are iterative as well. Once these are completed, the system can be optimized by reducing cost by changing pipe diameters, location of pump houses etc.

Sizing of pipes in a network:

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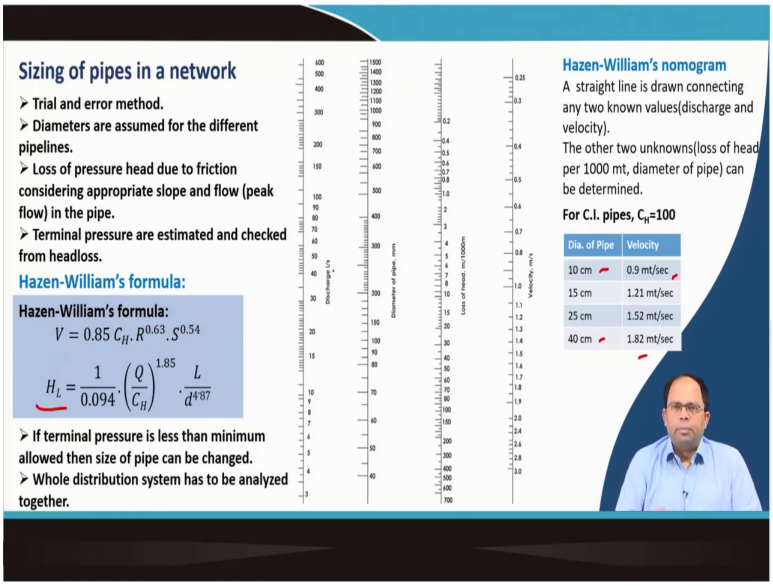

Hazen-Williams formula and the modified Hazen-William's formula are the most commonly used formulas. Even after designing a network, factors such as whether the determined diameter is suitable to serve a particular area with sufficient head may not be assured; trial and error are involved, and recomputation may be needed, which is challenging. So, diameters are assumed for different pipelines and terminal pressure is estimated considering the loss of pressure rate due to friction considering appropriate slope and flow (peak flow) in the pipe. Once the required velocity is determined and evaluated considering a particular slope (range), it is the diameter that is adjusted.

Hazen-Williams's formula is the most commonly used formula in pipe network design and pressure pipe pressure concrete design. The formula is given as:

$$V = 0.85\, C_H . R^{0.63} . S^{0.54}$$

where, S is the slope and R is the hydraulic radius and 0.85 is the constant and C_H is the coefficient. The formula can be rewritten by substituting S instead of H_L/L as:

$$H_L = \frac{1}{0.094} \cdot \left(\frac{Q}{C_H}\right)^{1.85} \cdot \frac{L}{d^{4.87}}$$

If the head loss is more, the pipeline's diameter can be increased to reduce head loss as evident from the above equation, which implies if there is no adequate pressure in the pipeline, then the pipe diameter has to be increased. So, if terminal pressure is less than the minimum level which is allowed, the size of the pipe can be changed, and whole distribution system has to be analyzed together. This results in the complete recomputation of the entire pipe network and is challenging.

Hazen-William's nomogram is a tool used by designers before the emergence of software tools. The nomogram has four lines representing discharge, the diameter of the pipe, velocity, and the head loss. If any two of these are known, a line connecting the values corresponding to the parameters intersecting the two other lines shows their corresponding values. If the discharge and velocity is known, the other two parameter values can be determined by drawing a straight line. Corresponding to a specific change in diameter, this nomogram can be used to recompute for all the other pipe or nodes or all the other pipe sections in a network.

For C I pipes, the C_H values = 100.

The following table shows the suggested velocities corresponding to different pipe diameters.

Dia. of Pipe	**Velocity**
10 cm	0.9 mt/sec
15 cm	1.21 mt/sec
25 cm	1.52 mt/sec
40 cm	1.82 mt/sec

Pipe Networks:

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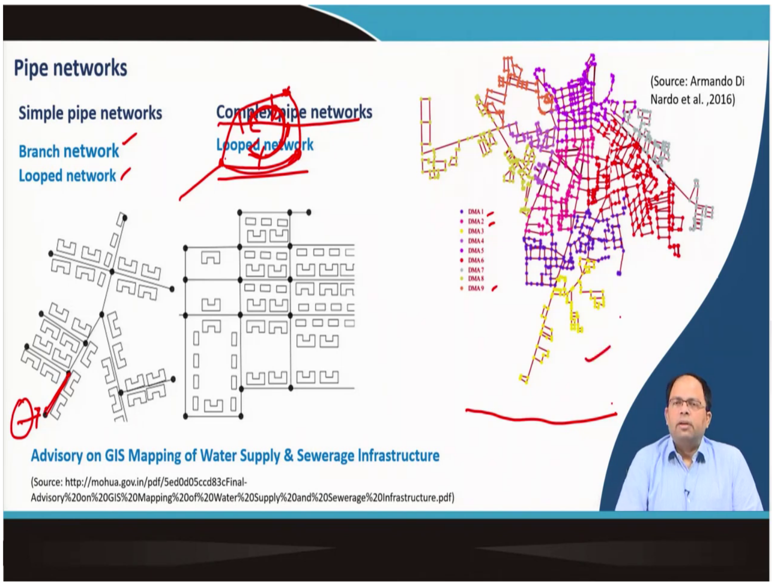

Pipe networks could be simple such as the branch network and loop network given in the left portion of the figure or complex as given in the right image of the figure. In the case of a dead-end system, calculations are relatively easier than the loop system. If the flow rate and the velocity is known for a portion, the diameter can be known. However, these calculations become relatively difficult in a loop system because of water flow from multiple directions. If anyone parameter such as the flow is changed, all the other factors may get changed.

In the case of complex networks, many DMAs may be there (as shown in the right figure) getting served by their designated overhead tanks. In a city-level layout, the pipe network may get complex when it gets laid out following the road network.

Simple branch network design

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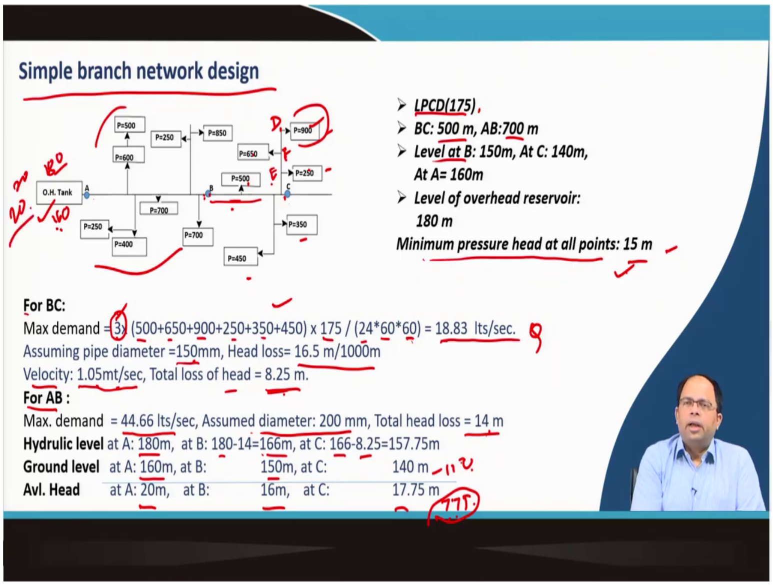

The overhead tank location can be observed from the above figure. Lines AB and BC constitute the main lines. CD is a branch line serving multiple lines at the locations (E and F). If the line FD is considered, it can be seen that it has to serve a population of 900. Section EF serves the population of (650+900) because the water that flows through F serves both 900 and 650. Similarly, if BC is considered, a population of (450+350+500+650+250+900) is served. The pipelines and the nodes must be adequate to serve the designated population and should have adequate thickness and capacity too handle pressure.

Assume the LPCD as 175, the length of BC pipeline as 500 meters and AB as 700 meters. Invert levels at B = 150m, at C=140 m and at A=160m. The level of the overhead reservoir is 180 meters. At point A, the ground level is 160 m, and hence the head available is (180-160) is 20 m. This head serves the entire area and is achieved by the height at which the OHT is located.

It is important to make sure that the minimum pressure head at all points should be 15 meters. All points along the main lines of the entire network should have a pressure of at least 15 meters. Endpoints such as D can have 5 or 7 m.

Firstly, it is needed to determine the maximum demand for a particular pipeline for a pipe section. For the pipe section BC, the maximum demand for BC is three times the total demand. Total demand for BC is the product of (450+350+500+650+250+900) and 175 lpcd. This is the total population served multiplied by LPCD 175. If per second demand is considered, it becomes 18.83 litres per second. This value is multiplied by a factor of 3 to represent the peak demand. Other factor values can also be applied based on its suitability.

Assuming pipe diameter as 150 mm using the Hazen-William's nomogram and having the discharge Q, the head loss would be 16.5 meters per 1000 meters as derived from the nomogram. Actual head loss is half of 16.5 m because the pipe length for BC is 500 meters. Based on the nomogram, the velocity of flow along the pipeline is 1.05 meters per second which is adequate. Unlike this, ideal pipe size could be derived from an assumed velocity and the Q rate to determine from the nomogram. However, the pipeline diameter is usually assumed first based on which the velocity and loss of head are determined and checked for whether it is appropriate. The pipeline AB serves the entire population.

Similar to the calculations for BC, Peak demand is determined for AB as 44.66 liters per second. Assuming a diameter of 200 mm, the total head loss is found as 14 meters in the particular pipeline.

The design has to be checked on whether it is right.

The hydraulic level	at A: 180m,	at B: 180-14=166m,	at C: 166-8.25=157.75m
Ground-level	at A: 160m,	at B: 150m,	at C: 140 m
Avl. Head	at A: 20m,	at B: 16m,	at C: 17.75 m

If the ground level was also 150 mm at C, the head would have been just 7.75 meters which fails. In that case, pipeline diameter has to be changed to achieve head loss and also pumping may have to be employed to increase pressure.

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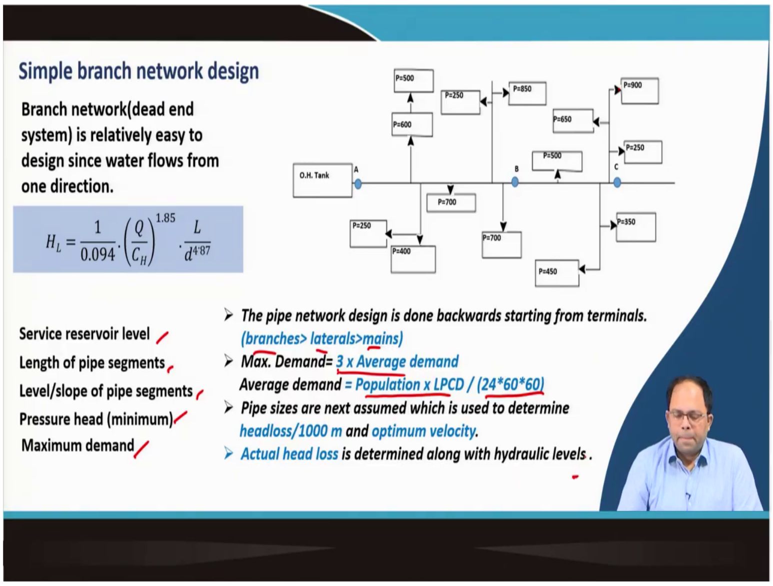

The branch network or dead-end system is relatively easy to design since water flows from one direction and service. In a dead-end system, it is essential to know the following.

- Service reservoir level
- Length of pipe segments
- The slope of pipe segments
- Minimum pressure head that is required at different points
- Maximum demand.

- The pipe network design is done backwards, starting from terminals followed by the branches and laterals and then the mains
- Maximum demand is 3 times average demand; this can be changed it laterals or branches are designed.
- Average design = population x LPCD/total seconds in a day.
- Pipe size a next assumed, which is used to determine head loss per 1000 meters and optimum velocity
- Actual head loss is determined along with the hydraulic level.

These are the different steps to follow.

Simple looped network design using equivalent pipe method

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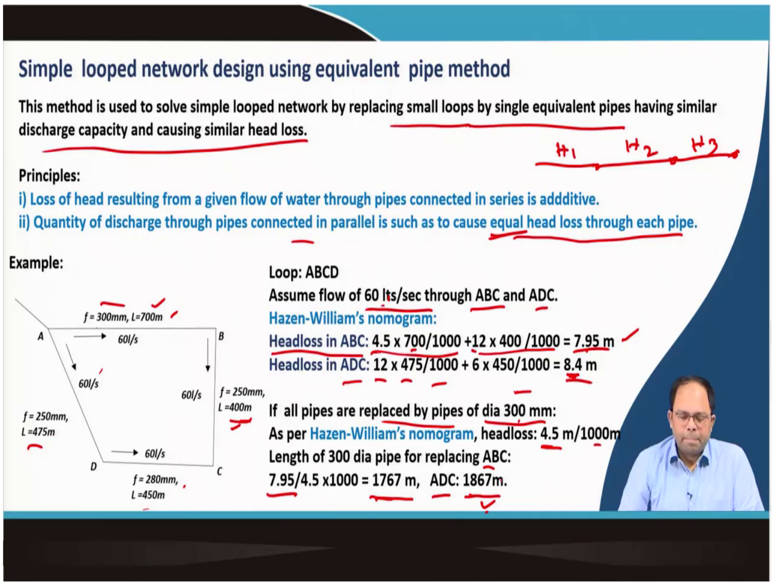

This method is used to solve a single simple loop network by replacing small loops and by single equivalent pipes having similar discharge capacity and causing similar head loss. Small loops are replaced with a single pipe (equivalent pipe) to make the overall network easier to solve. The pipe would have similar discharge capacity and cause similar head loss and should have the capacity to supply the population served by the loop.

Basic principles to follow includes:

Loss of head resulting from a given flow of water through pipes connected in series is additive. The quantity of discharge through pipes connected in parallel is such as to cause equal head loss through each pipe. As shown in the example, the headloss across ADC and ABC will remain the same; however, the quantity of discharge, pipeline diameter and length would be different.

<u>Example:</u>

Considering the layout shown in the above figure, it can be observed that ABC is longer than ADC. Consider the assumption that flow is 60 litres per second through ABC and ADC. Using Hazen-William's nomogram, the head loss can be determined from pipe diameter and the flow. Head loss in ABC is equal to the sum of head loss in AB and head loss in BC. From the nomogram, the head loss for this flow is obtained as:

Headloss in ABC: 4.5 x 700/1000 +12 x 400 /1000 = 7.95 m

Headloss in ADC: 12 x 475/1000 + 6 x 450/1000 = 8.4 m

In actual, the equal headloss assumption is not same.

So, these are the two head losses in two pipelines, but as we know from the principle that the head losses would be actually equal, so that means the flow would be different.

To find an equivalent pipe to replace this particular loop, it can be assumed that the four pipes AB, BC, AD and DC are replaced by one pipe of diameter 300 mm. Many such assumptions and recomputation may be required.

As per Hazen-William's nomogram, headloss: 4.5 m/1000m
Length of 300 dia pipe for replacing ABC:
7.95/4.5 x1000 = 1767 m,   ADC: 1867m.

In order to replace ABC, a pipeline length of 1767 is needed. In case of ADC, it is 1867 m.

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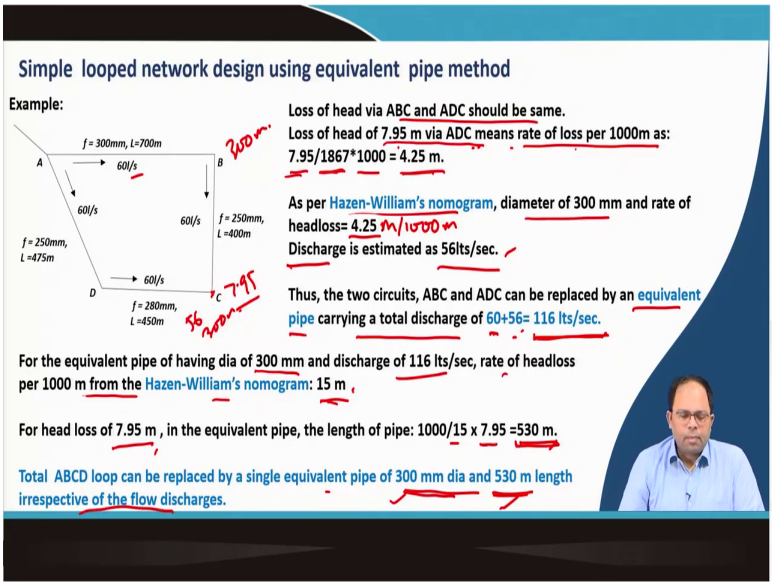

Loss of head via ABC and ADC should be same.

Loss of head of 7.95 m via ADC means rate of loss per 1000m as: 7.95/1867*1000 = 4.25 m.

As per Hazen-William's nomogram, the diameter of 300 mm and rate of headloss= 4.25:

Discharge is estimated as 56lts/sec.

Thus, the two circuits, ABC and ADC, can be replaced by an equivalent pipe carrying a total discharge of 60+56= 116 lts/sec.

For the equivalent pipe of having dia of 300 mm and discharge of 116 lts/sec, rate of headloss per 1000 m from the Hazen-William's nomogram: 15 m

For head loss of 7.95 m, in the equivalent pipe, the length of pipe: 1000/15 x 7.95 =530 m.

Total ABCD loop can be replaced by a single equivalent pipe of 300 mm dia and 530 m length irrespective of the flow discharges.

Complex pipe network design

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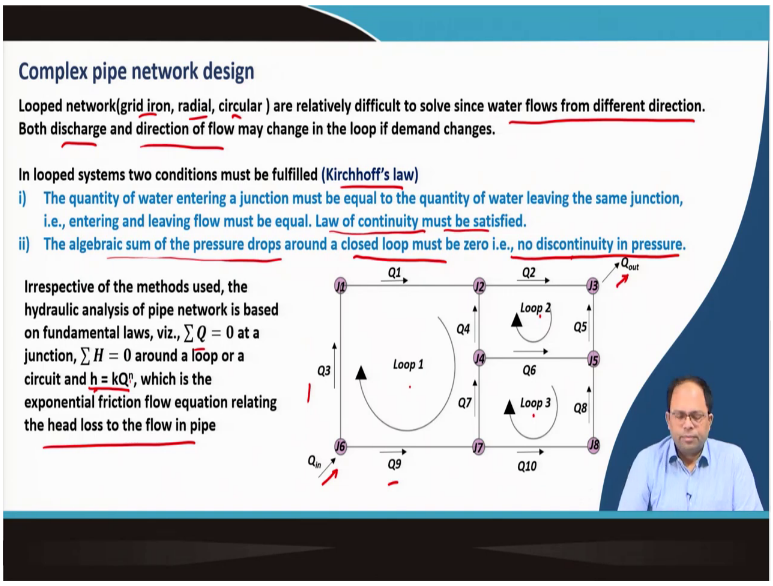

Looped network (grid iron, radial, circular) are relatively difficult to solve since water flows from different direction. Both discharge and direction of flow may change in the loop if demand changes. If there is a change in the demand across different times of the day, then, the direction of flow in the loop will also change. Entry and exit of water is marked in the above figure.

The different loops and the direction of flow (may be different) assumed is shown in the figure . Flow directions can change with the different demand as well. In looped systems two conditions must be fulfilled as per Kirchhoff's law (From electrical engineering)

1. The quantity of water entering a junction must be equal to the quantity of water leaving the same junction. So that means, Q_{in}, the water that is coming in at junction J6 must be equal to Q9 and Q3 which are the water going out of junction J6.

$Q_{in} = Q9 + Q3$

2. The algebraic sum of the pressure drops around a closed loop must be 0. So, there is no discontinuity in pressure.

These two law helps to solve such networks.

Irrespective of the methods used, the hydraulic analysis of pipe network is based on fundamental laws, viz., $\sum \boldsymbol{Q} = \mathbf{0}$ $\sum \boldsymbol{Q} = \mathbf{0}$ at a junction, $\sum \boldsymbol{H} = \mathbf{0}$ $\sum \boldsymbol{H} = \mathbf{0}$ around a loop or a circuit and $h = kQ^n$, which is the exponential friction flow equation relating the head loss to the flow in pipe. This is the head loss equation which can be found using one of the formulas such as the Darcy-Weisbach equation

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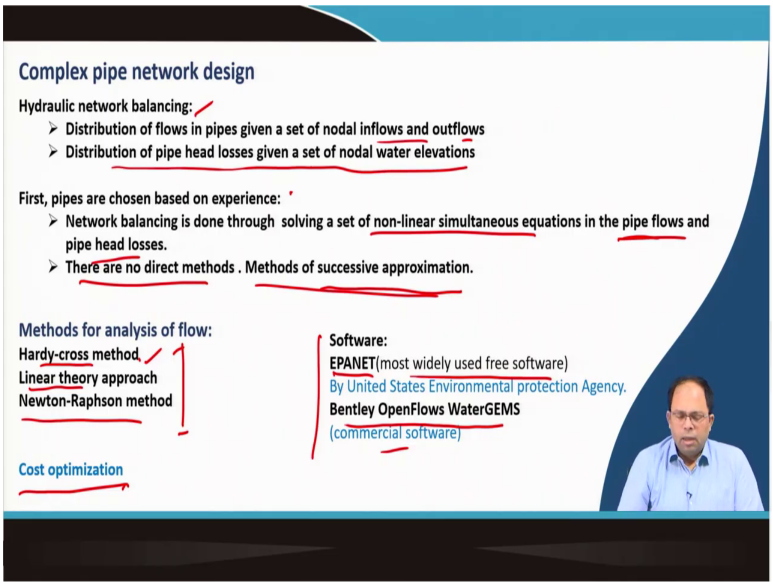

Hydraulic network balancing - Distribution of flows in a pipe given a set of nodal inflows and outflows

Distribution of pipe head losses given a set of nodal water elevations.

Pipe diameters are chosen based on experience. Network balancing is done through solving a set of non-linear simultaneous equation together in the pipe flows and the pipe head losses. Two equations involving H and Q are considered. So, multiple equations are formed corresponding to the different nodes and has to be solved simultaneously. And there is no direct method, there is method of successive approximation.

Methods for analysis of flow involves:

Hardy-Cross method
Linear theory approach
Newton-Raphson method.

These are the different methods to solve non-linear simultaneous equations involving both pipe flows as well as head losses. These are based on the method of successive approximation that is different iterations are performed with adjustments

Hardy cross method will be explained

Software that are used in solving such complex pipe network are EPANET by the Environmental Protection Agency of US. It is widely used and is a free software.

Bentley open flow water gems (commercial software) is another example.

Network design checks various components and involves cost optimization by changing some parameters.

Hardy Cross method:

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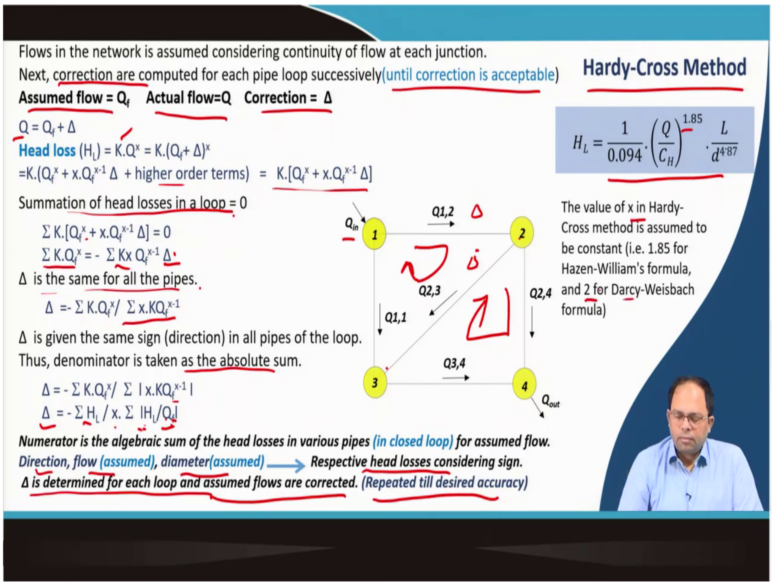

Flows in the network is assumed considering continuity of flow at each junction.

Next, correction are computed for each pipe loop successively (until correction is acceptable)

Assumed flow = Q_f Actual flow=Q   Correction = Δ

$Q = Q_f + \Delta$

Head loss (H_L) = $K.Q^x = K.(Q_f + \Delta)^x$

$= K.(Q_f^x + x.Q_f^{x-1}\,\Delta\ + \text{higher order terms}) \;=\; K.[Q_f^x + x.Q_f^{x-1}\,\Delta]$

Summation of head losses in a loop = 0

$\Sigma\, K.[Q_f^x + x.Q_f^{x-1}\,\Delta] = 0$

$\Sigma\, K.Q_f^x = -\ \Sigma\, Kx\, Q_f^{x-1}\,\Delta$

Δ is the same for all the pipes.

$\Delta = -\Sigma\, K.Q_f^x / \ \Sigma\, x.KQ_f^{x-1}$

Δ is given the same sign (direction) in all pipes of the loop.

Thus, denominator is taken as the absolute sum.

$\Delta = -\ \Sigma\, K.Q_f^x / \ \Sigma\ |x.KQ_f^{x-1}|$

$\Delta = -\ \Sigma\, H_L / x.\ \Sigma\ |H_L/Q_f|$

Numerator is the algebraic sum of the head losses in various pipes (in closed loop) for assumed flow. Direction, flow (assumed), diameter (assumed)

Respective head losses considering sign. Δ is determined for each loop and assumed flows are corrected. (Repeated till desired accuracy)

Network design using EPANET

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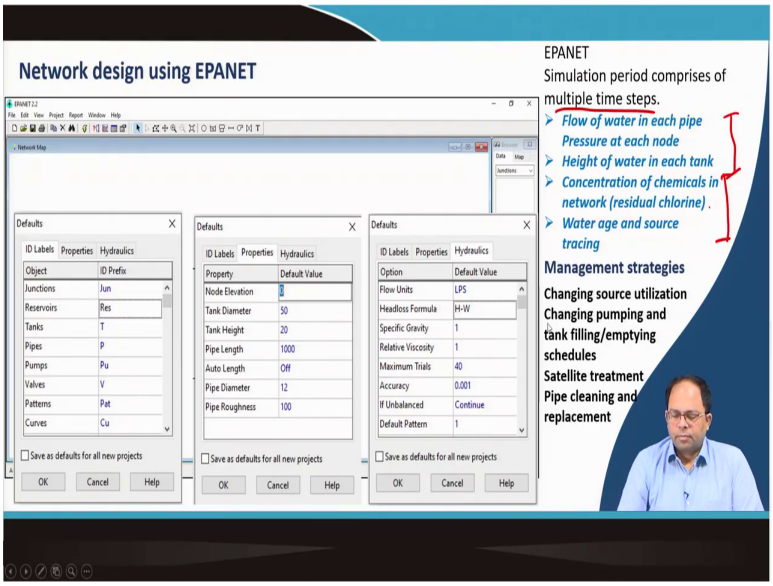

The above figure shows the interface of the network design software EPANET. Using simulation, the pipe network is solved and it is done using multiple time steps.

The flow of water in each pipe and pressure at each node has to be determined. Similarly, height of water in a tank can also be determined. The concentration of chemicals in the network residual chlorine, water age and source tracing could also be achieved.

Using the software, the effects caused for the following can be known.

- Changing source utilization
- Changing pumping and tank filling/emptying schedules
- Satellite treatment
- Pipe cleaning and replacement

Various defaults has to be entered while starting the design such as the tank diameter, tank height, pipe length etc. Similarly, defaults corresponding to properties and Hydraulics should also be set.

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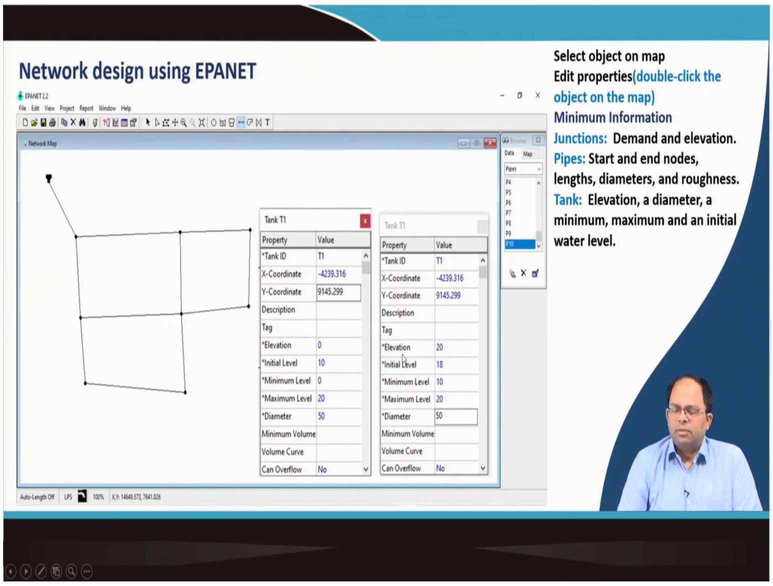

Pipes, junctions and tanks can be drawn or located. Demand (population x lpcd x demand factor) and elevation for each junction has to be marked.

Pipes have start and end nodes. The length of the pipeline, the diameter of the pipeline and the roughness coefficient of the pipeline has to be entered.

For tanks, elevation, diameter, minimum, maximum and an initial water level has to be given. This helps to know the head available based on that the calculations can be done.

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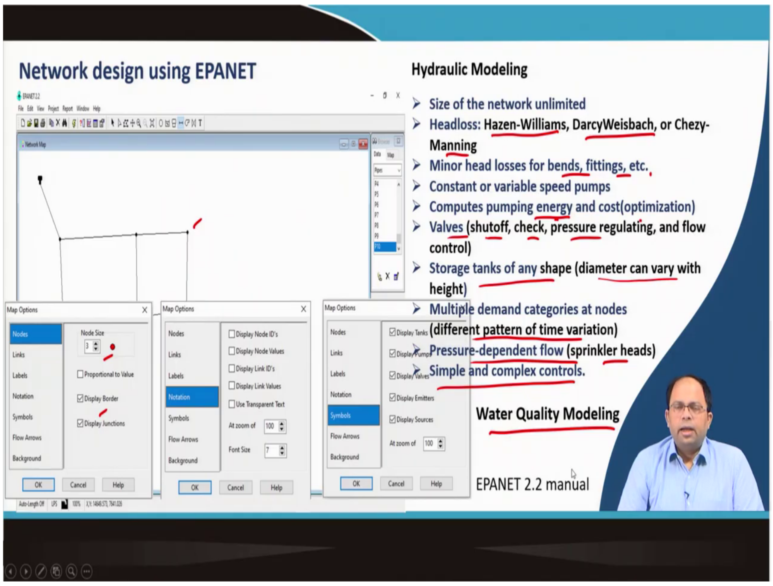

Hydraulic modeling

- Size of the network for the software solve is unlimited
- The different head loss formulas that could be utilized is Hazen-Williams, Darcy-Weisbach or Chezy-Manning.
- Then minor head losses for bends fittings can be incorporated
- Constant or variable speed pumps can be used
- Computes pumping energy and cost for optimization purposes
- Valves (shutoff, check, pressure regulating, and flow control)
- Storage tanks of any shape (diameter can vary with height)
- Multiple demand categories at nodes (different pattern of time variation). The factor to convert the average demand has to be given for all the hours.
- Pressure-dependent flow (sprinkler heads)
- Simple and complex controls for different systems could be incorporated.

EPANET 2.2 manual can be followed.

A video explaining the various components and functions will be shown.

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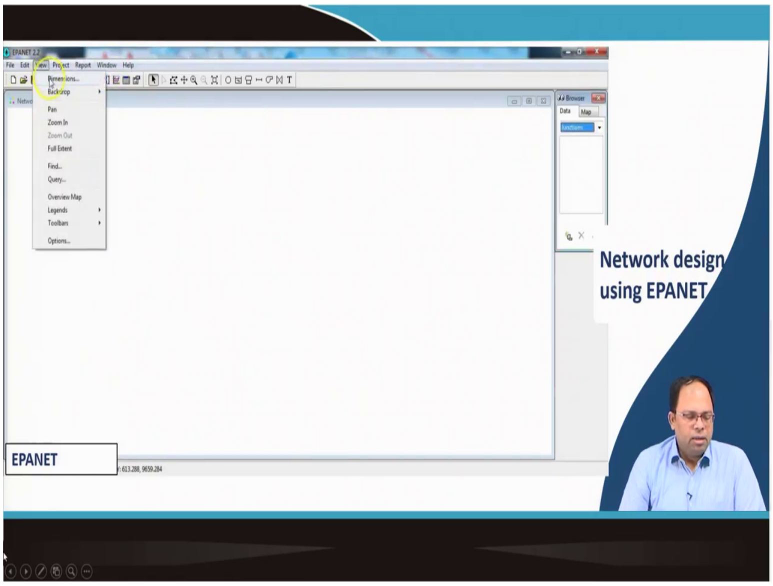

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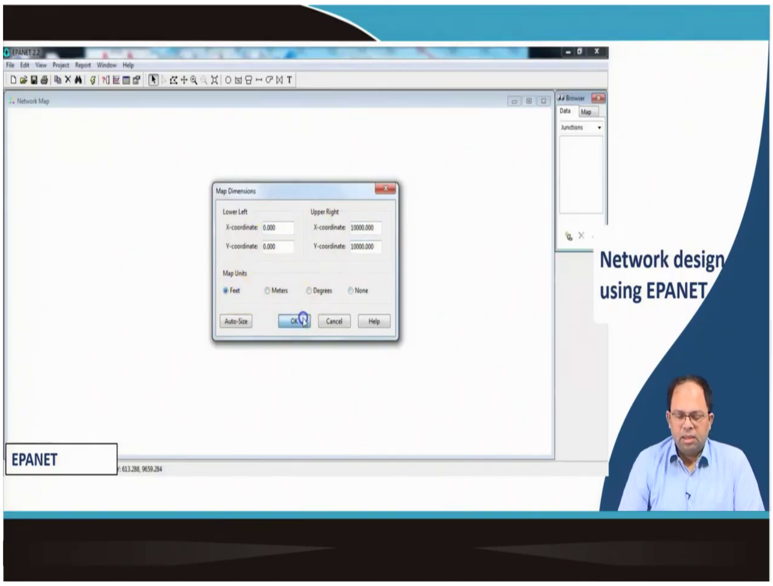

The dimension unit has to be set firstly such as the metres or feet.

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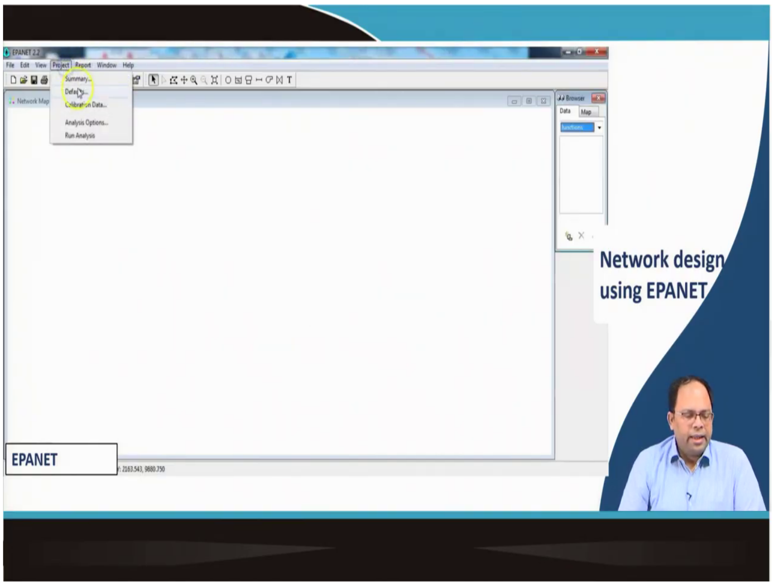

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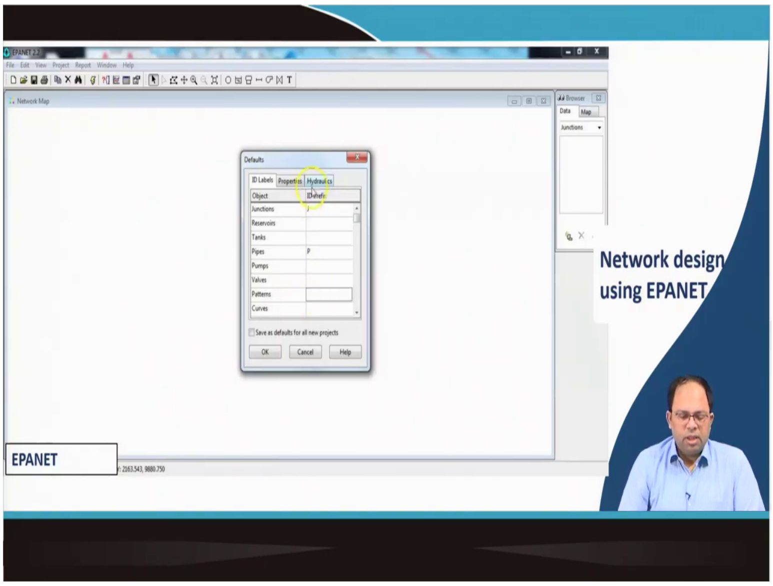

Defaults can be modified as shown in the figure.

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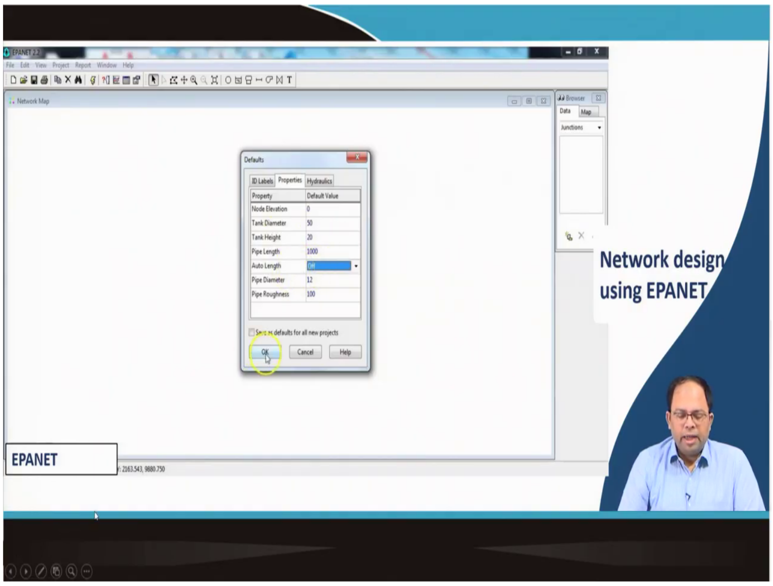

The properties can be adjusted.

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Nodes, pipe lengths etc can be added.

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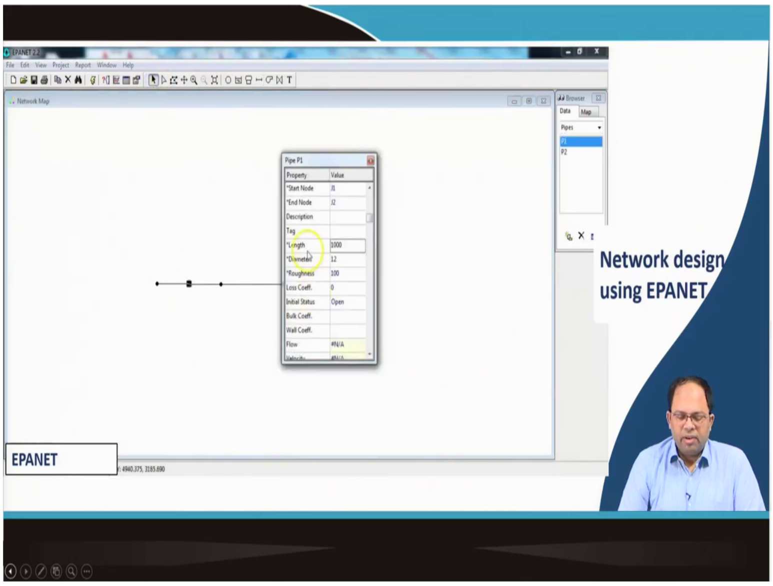

Properties of the pipes can be modified.

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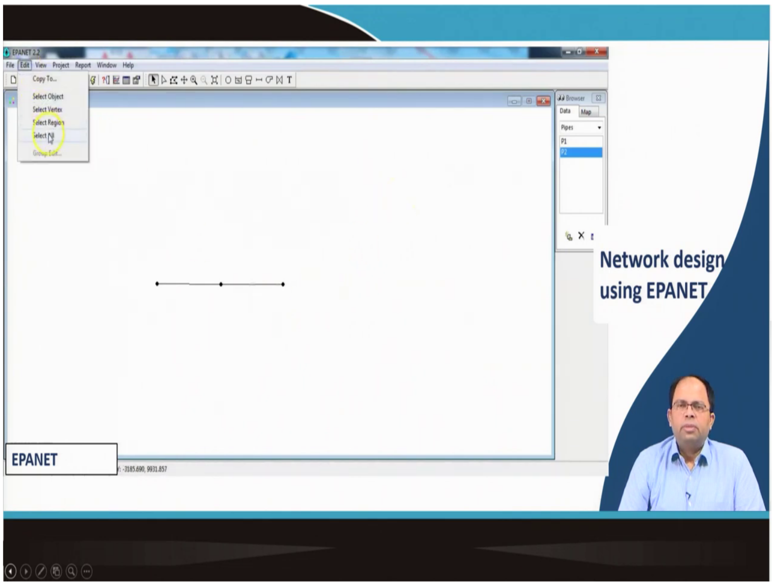

The default values have to be modified for all the components drawn.

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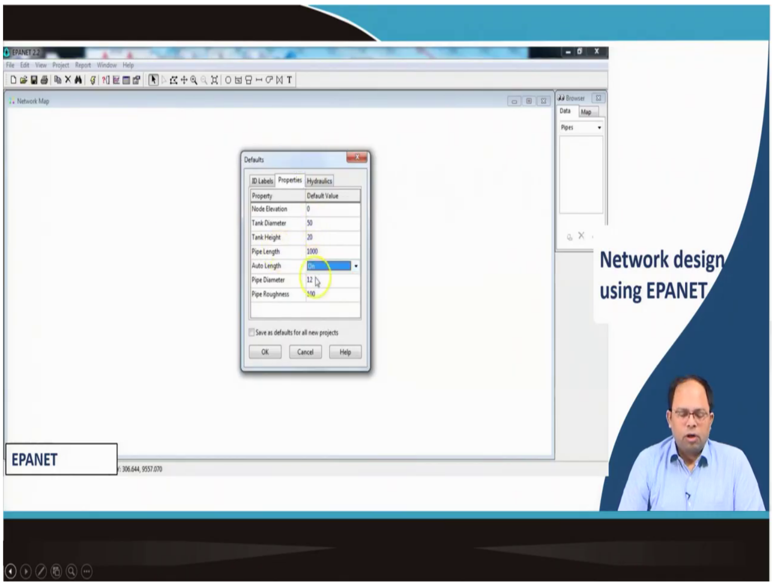

Auto length can be enabled; that means, whatever length which is drawn is considered. The nodes are connected with pipelines.

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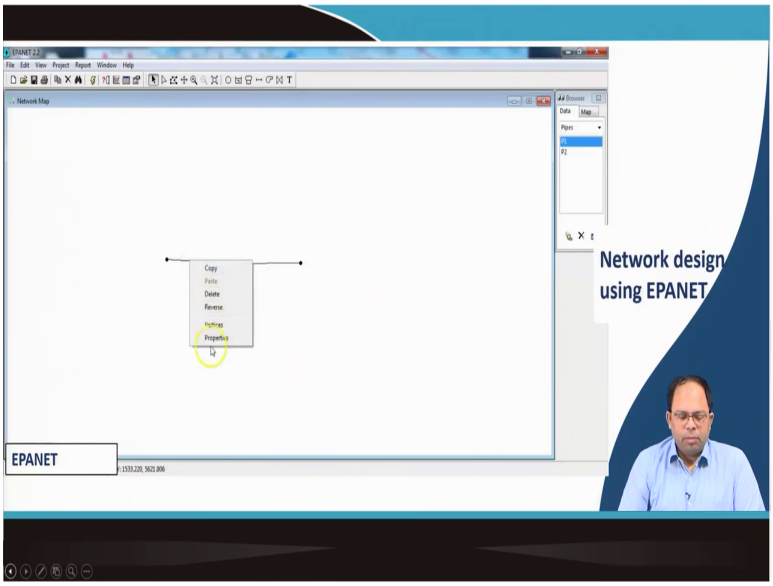

Properties are checked.

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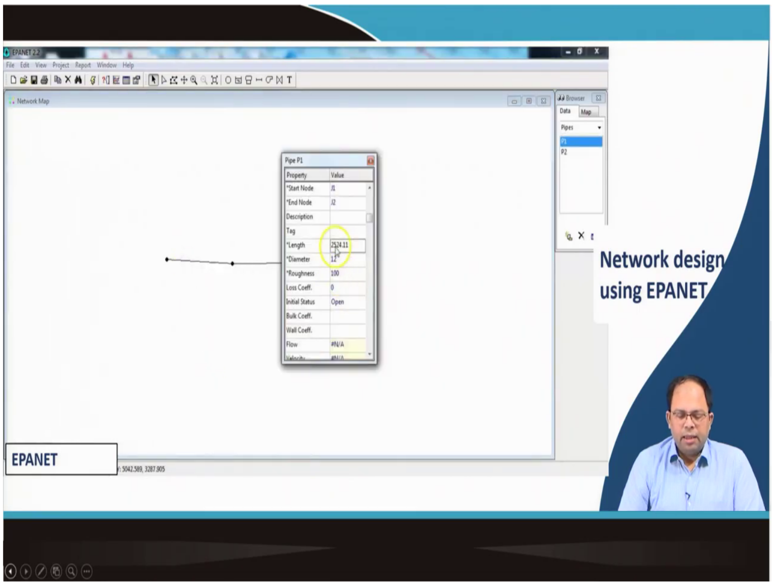

The length automatically updated can be changed as well

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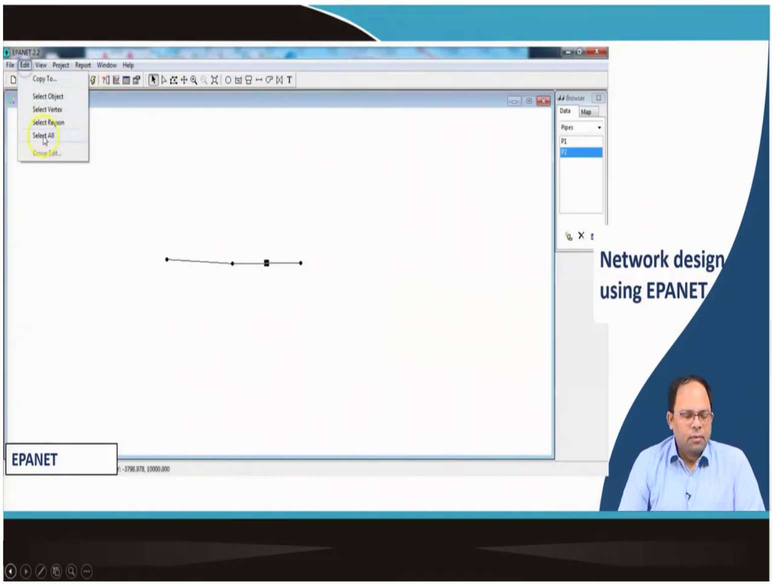

Components can be deleted also while doing editing.

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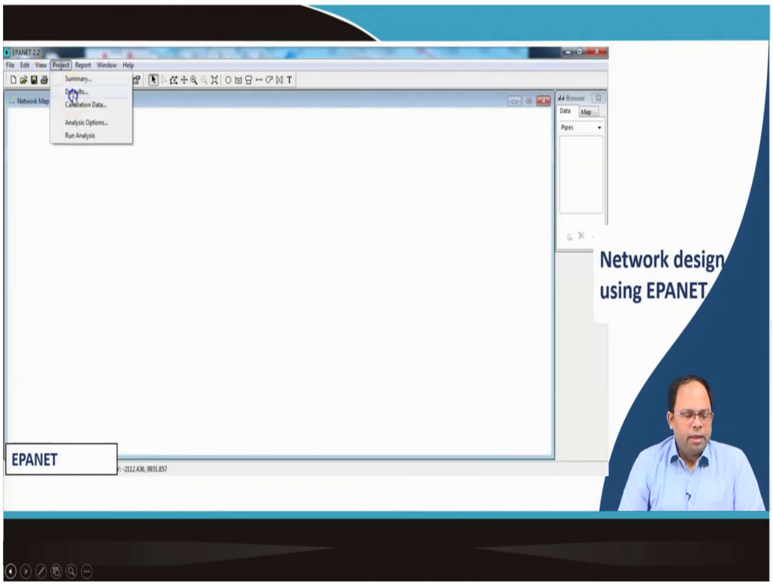

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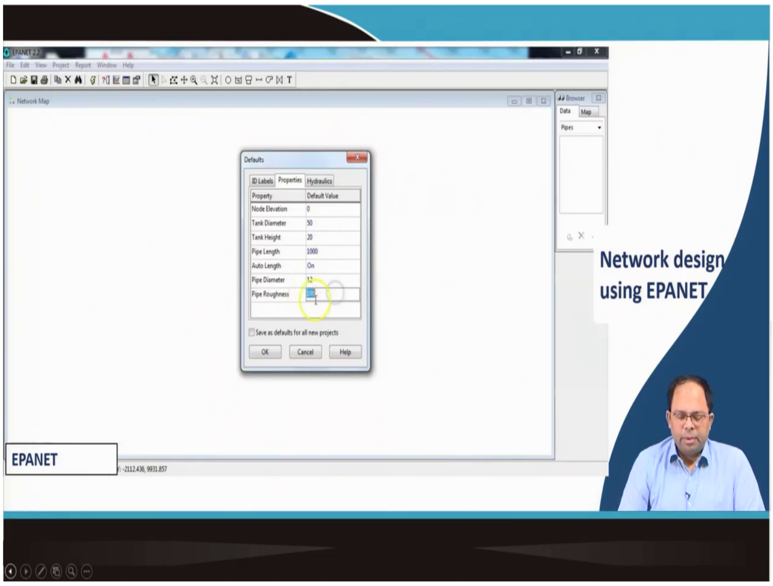

Properties of various pipes such as the diameter and the roughness can be changed.

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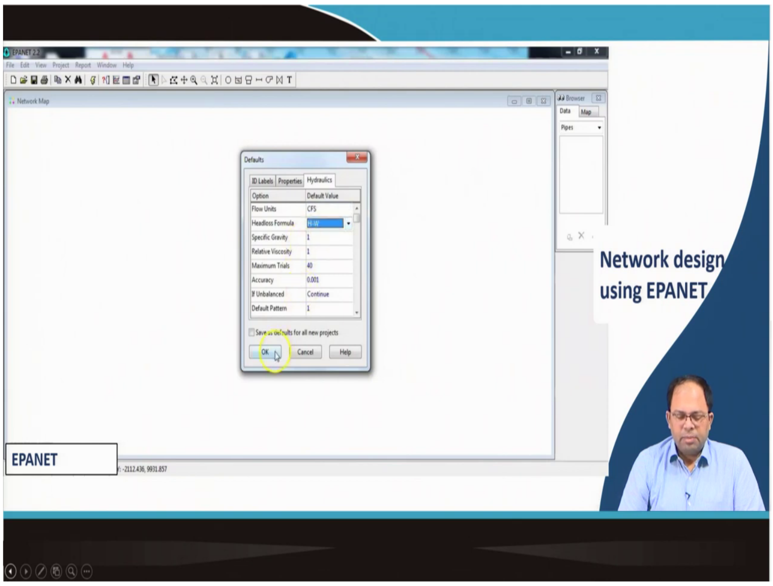
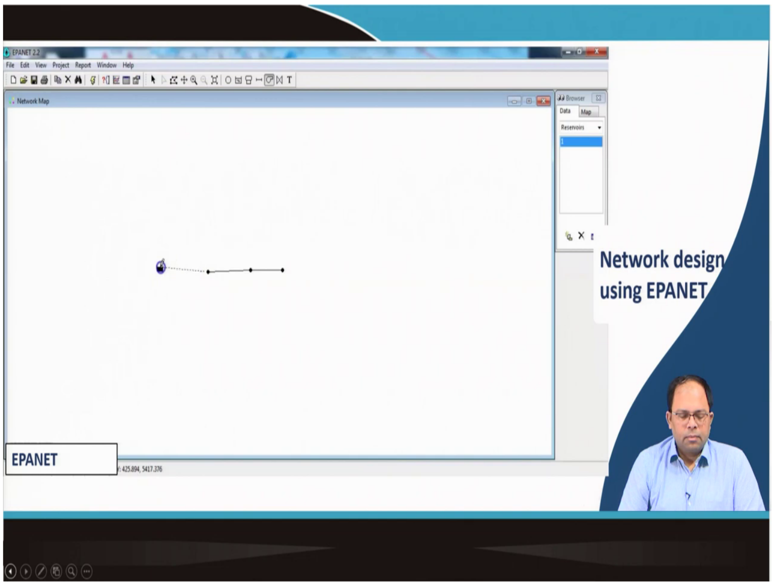


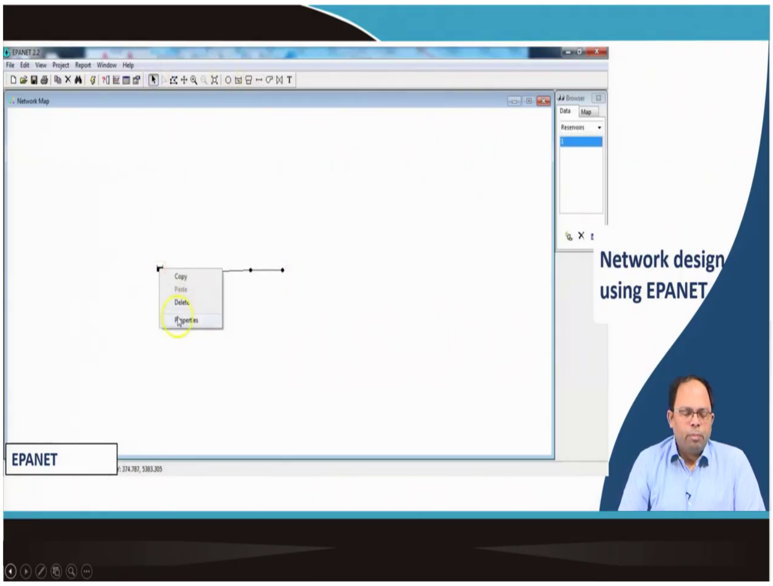
Then flow could be cubic feet per second. Head loss formula could be Hazen-William's Specific gravity can be set.

(Refer Slide Time: 62:30)



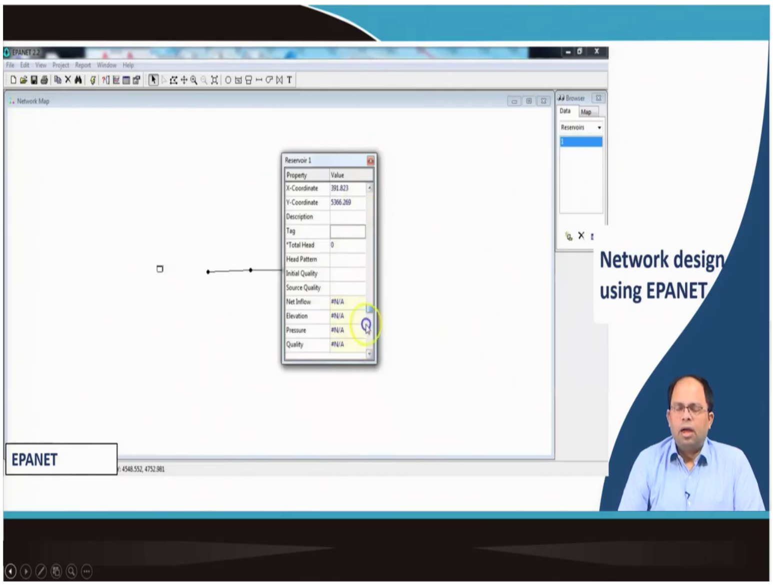
Aa reservoir, nodes and pipelines are drawn.

(Refer Slide Time: 62:40)



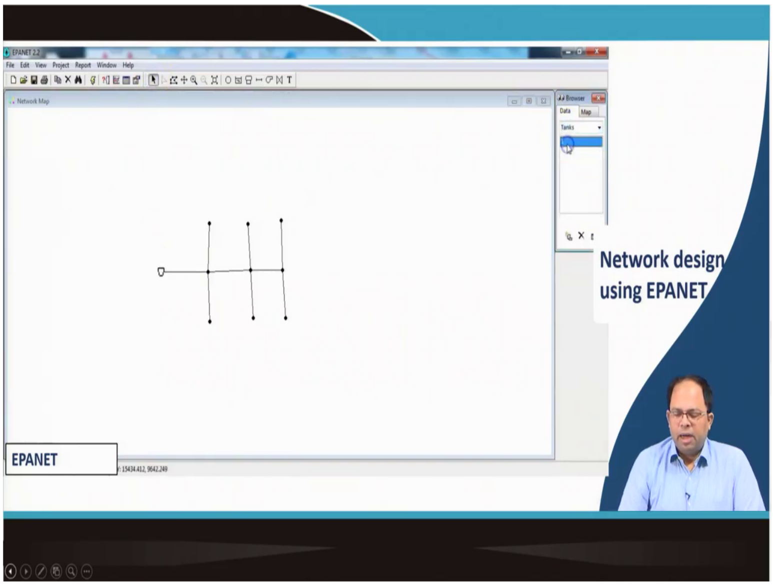
Pump is required.

(Refer Slide Time: 62:43)



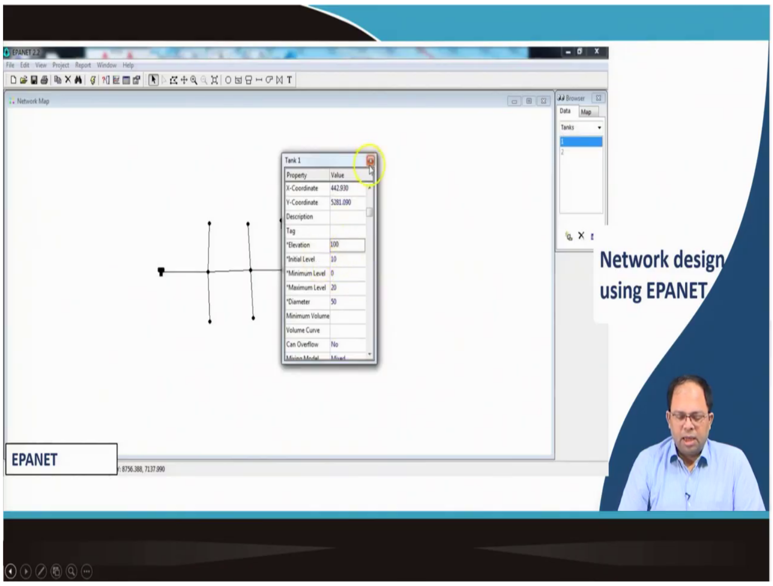
The total head available is 0 at the particular reservoir drawn/located, hence, a pump is required to pump the water from this reservoir to the network. Pump can be added and pump cuves can also be added

(Refer Slide Time: 63:22)



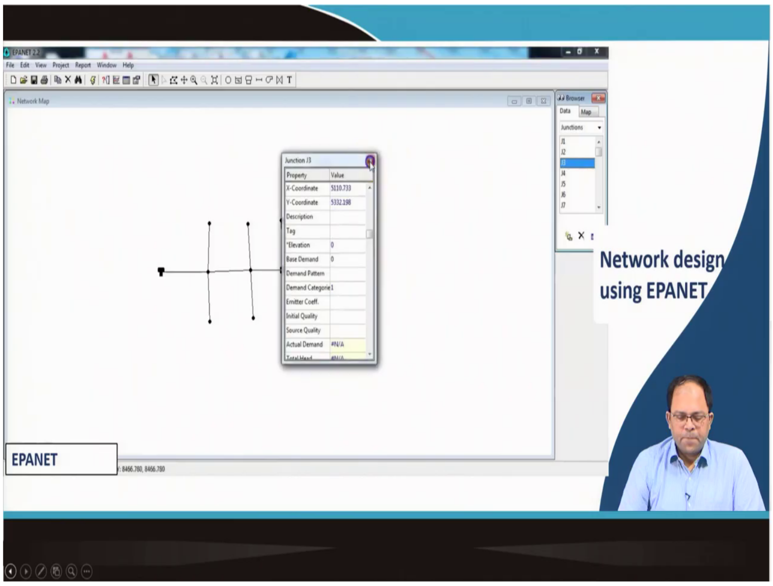
An overhead tank is located to expand the network. Atree system of layout is drawn.

(Refer Slide Time: 64:03)



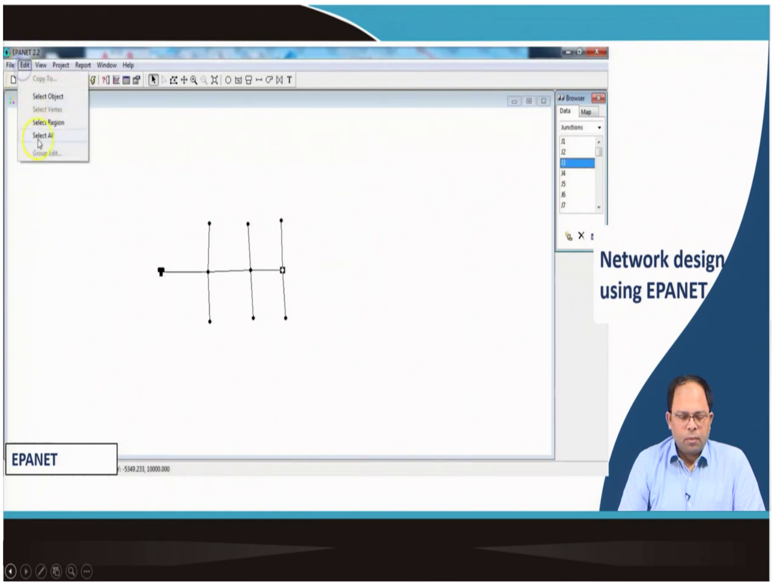
Properties of the tank can be modified. (elevation is modified as 100)

(Refer Slide Time: 64:19)



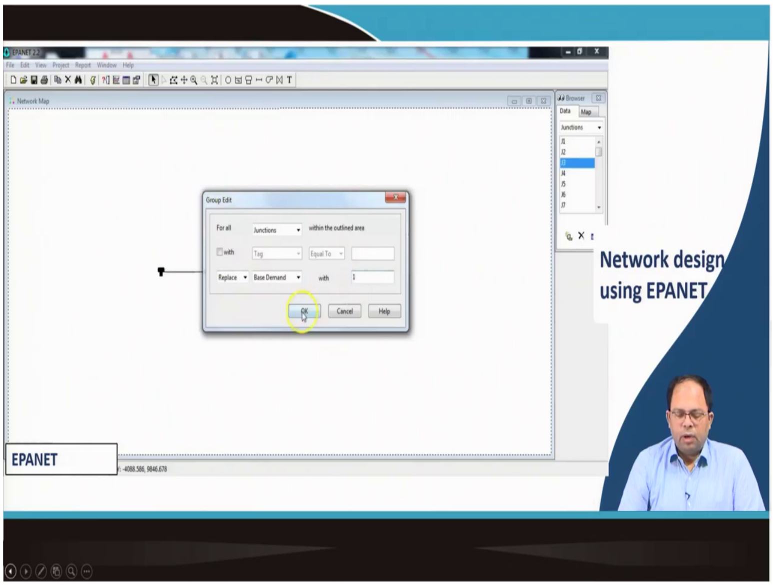
Then, For each demand, a base demand is given to make sure it works.

(Refer Slide Time: 64:33)



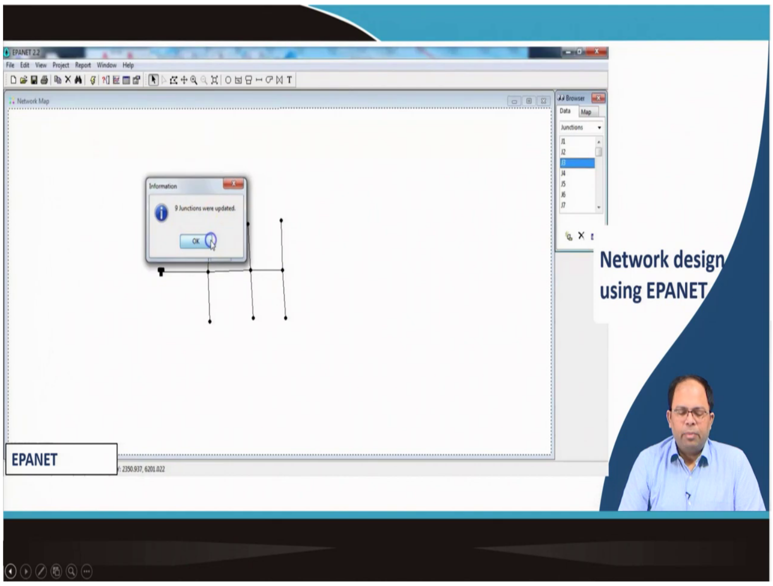
All the nodes can be selected and edited together.

(Refer Slide Time: 64:38)

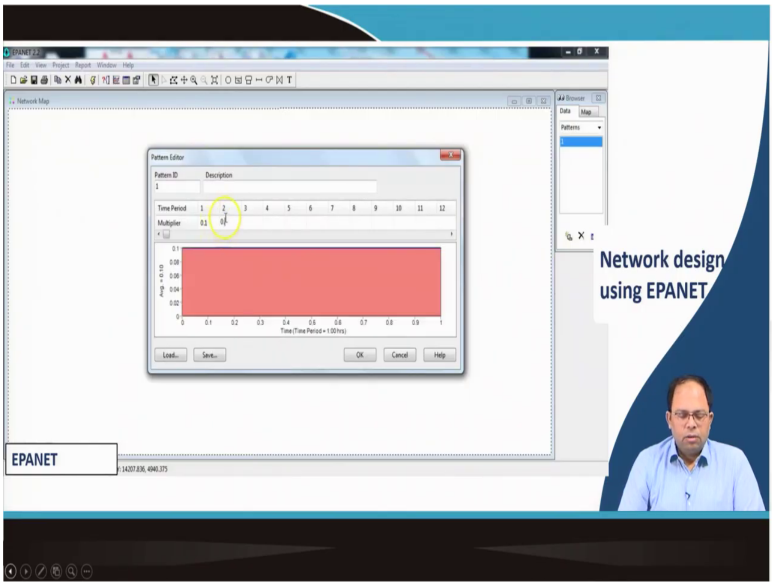


All the 9 junctions can be updated in terms of its base demand at once.

(Refer Slide Time: 64:46)

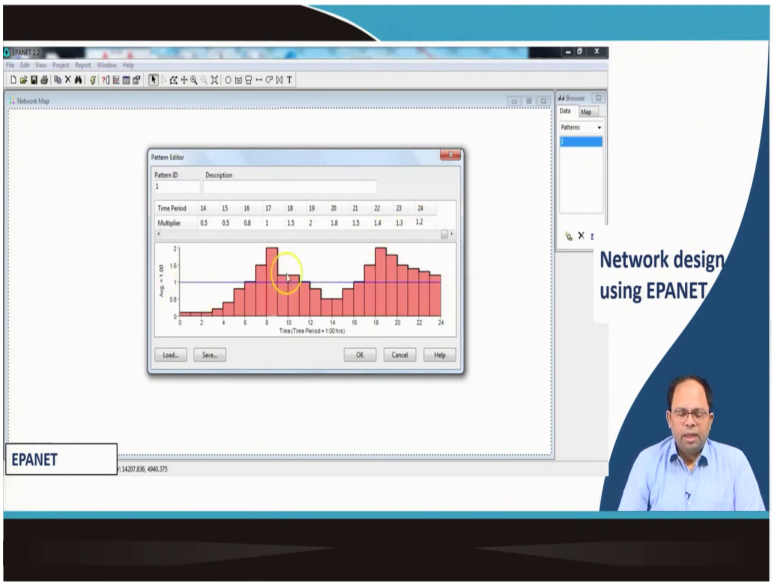


(Refer Slide Time: 64:52)



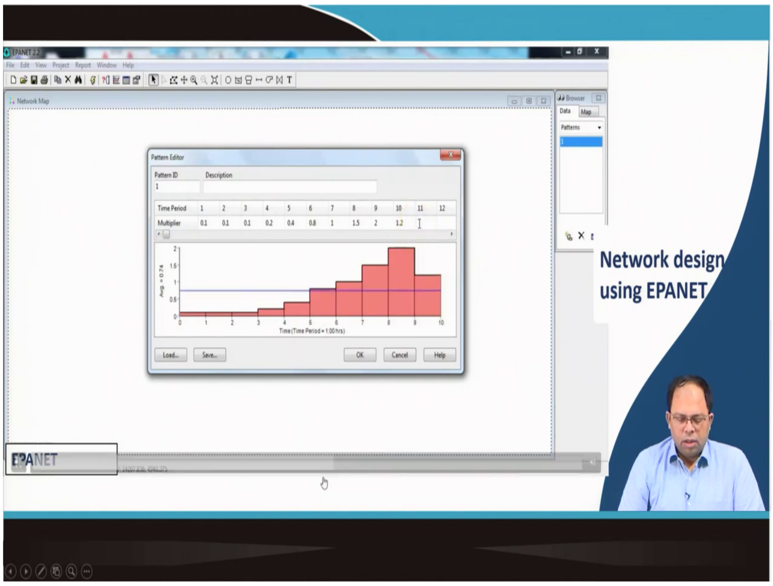
The pattern of distribution is designed. A pattern is added.

(Refer Slide Time: 65:00)



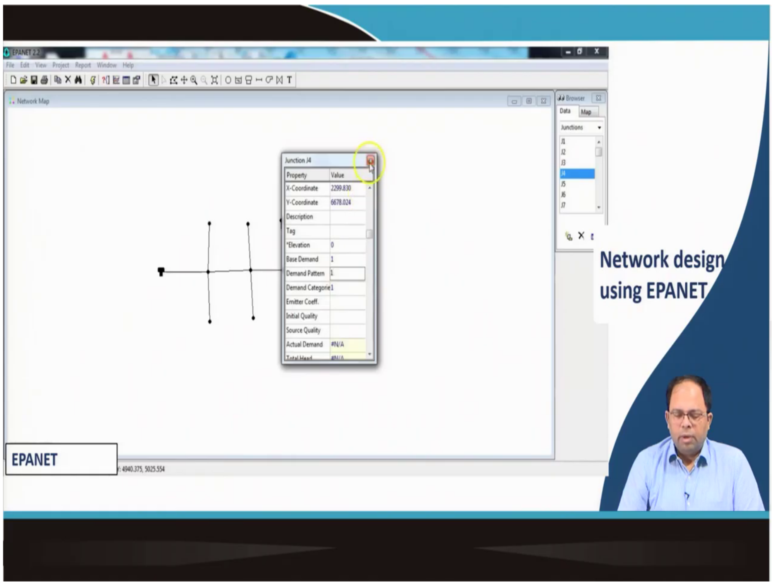
So, the first hour is 0.1 of average, second hour is also 0.1. So, for every hour, a flow rate has to be given to give a pattern for the entire day. So, at 8 o’clock in the morning can be considered 1.5 times, the 9 o’clock as 2 times, 10 o’clock as 1.2 times and so on.

(Refer Slide Time: 65:35)



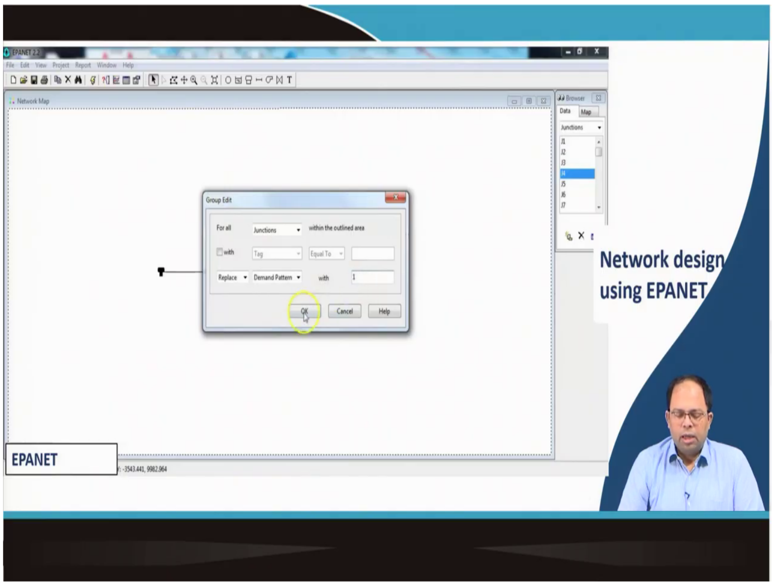
The pattern is decided.

(Refer Slide Time: 66:29)



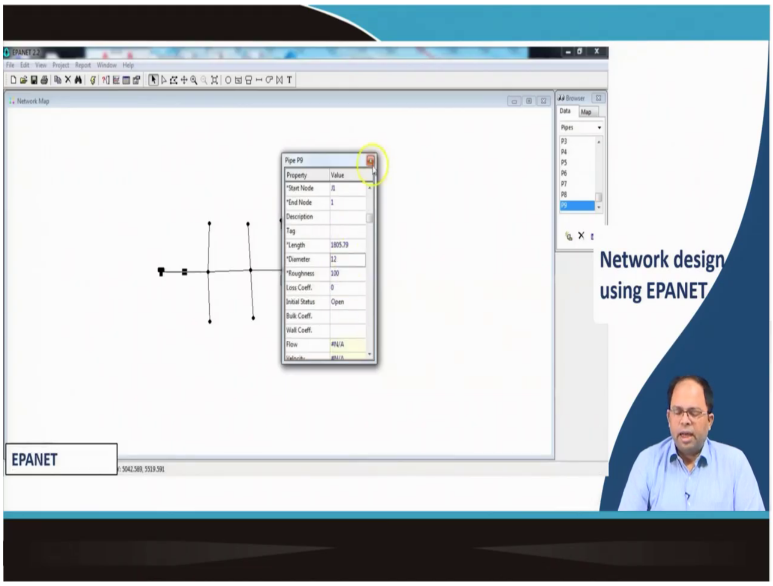
The pattern is designed for each of the nodes. Different demand patterns can be named and multiple nodes may be set with same pattern.

(Refer Slide Time: 66:50)



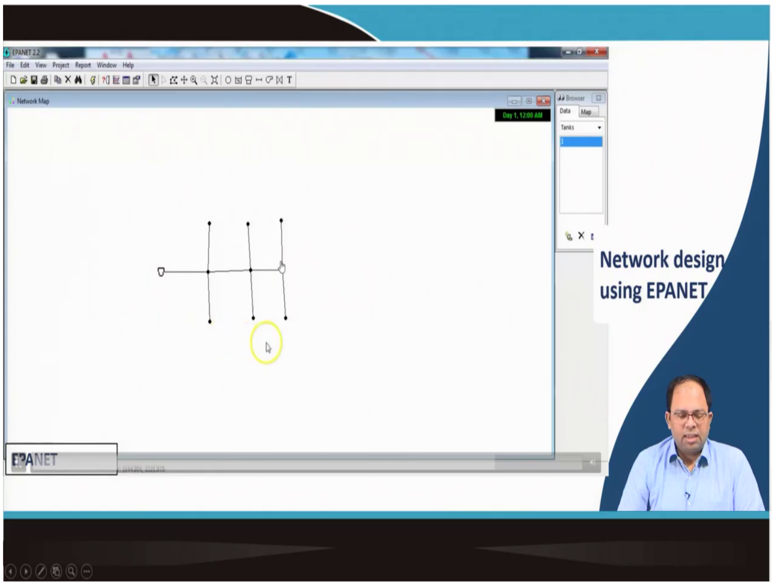
The total demand as well as the demand pattern is given. Thus all the values are given.

(Refer Slide Time: 67:26)



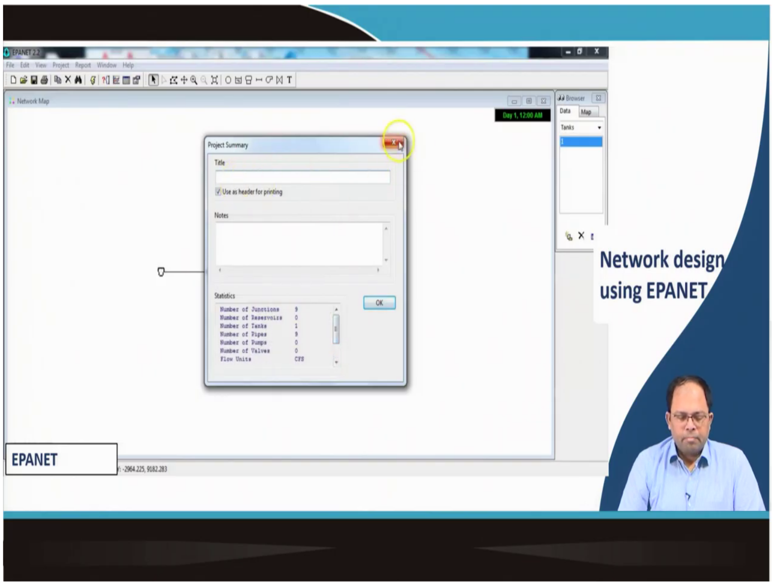
The different parameters needs to be checked. Simulation can be done to achieve this. Accordingly, properties can be done and the correct values can be determined.

(Refer Slide Time: 67:45)



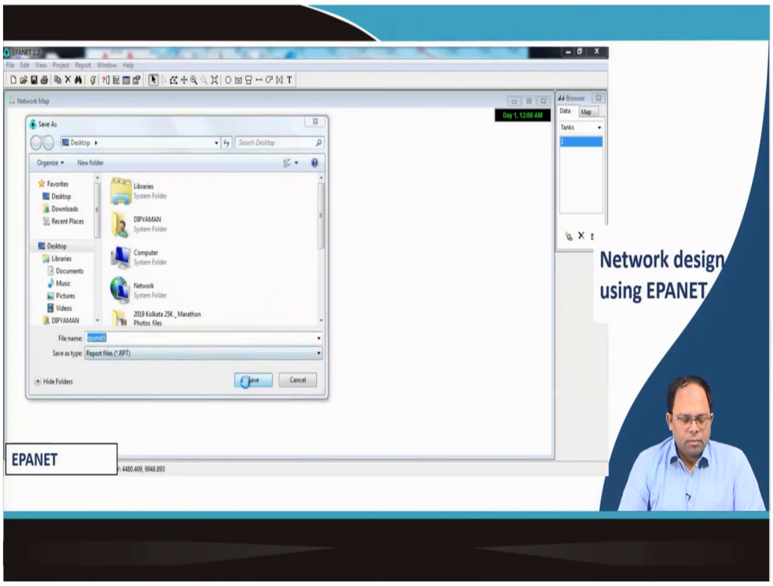
Summary of the simulation is shown.

(Refer Slide Time: 67:57)



Reports can be made from summary.

(Refer Slide Time: 68:07)

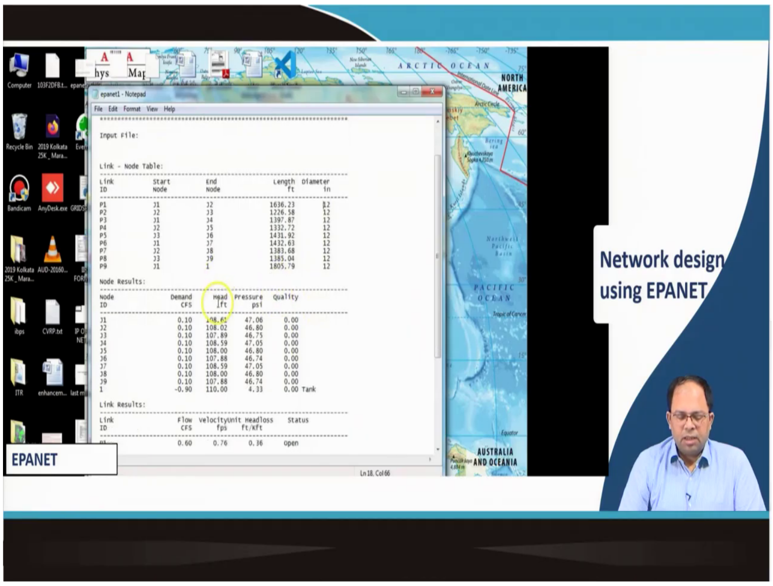


(Refer Slide Time: 68:24)

The report can be saved and opened.

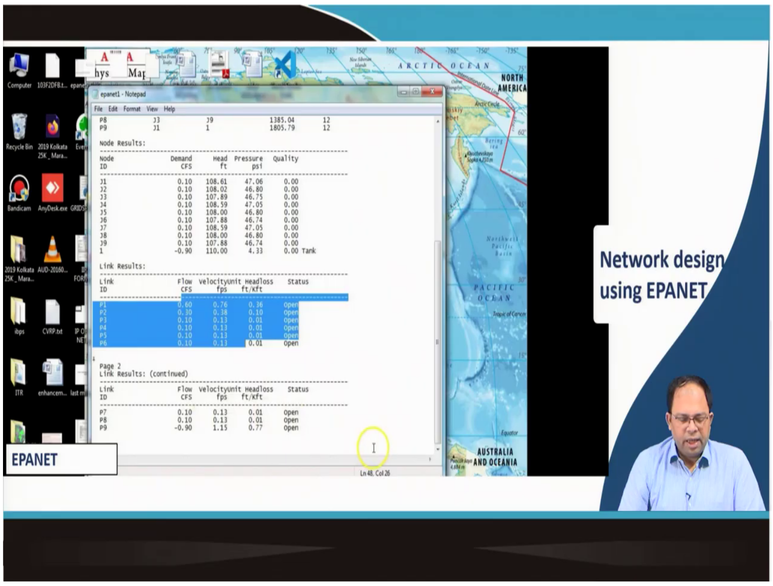
(Refer Slide Time: 68:31)

(Refer Slide Time: 68:32)



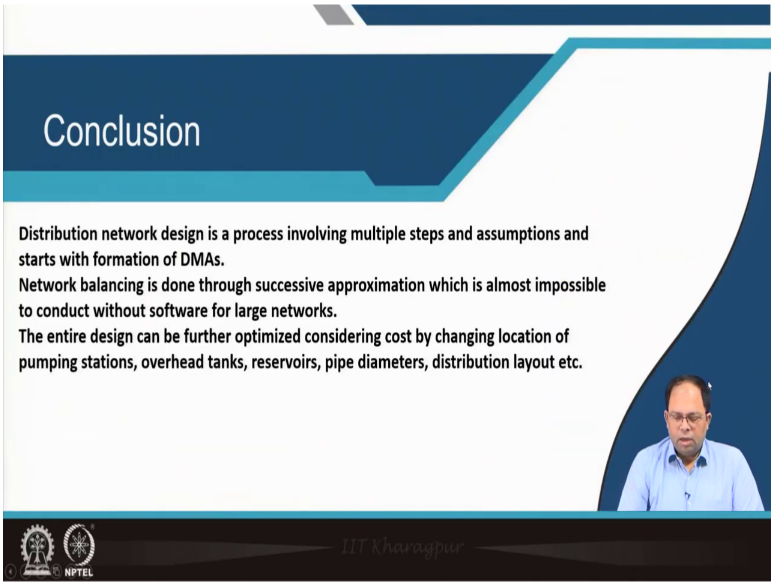
In a report, the parameter values are given for all the components. The flow and head is also computed. Pressure in the pipes and water quality can also be checked.

(Refer Slide Time: 68:55)



Based on the values of various components, the correctness of the design can be checked

(Refer Slide Time: 69:20)



These are the steps to follow to do design in the softwares.

Conclusion:

Distribution network design is a process involving multiple steps and assumptions and starts with formation of DMAs.

Network balancing is done through successive approximation which is almost impossible to conduct without software for large networks.

The entire design can be further optimized considering cost by changing location of pumping stations, overhead tanks, reservoirs, pipe diameters, distribution layout etc.

References:

(Refer Slide Time: 69:58)