MODELLING AND OPTIMIZATION OF WATER DISTRIBUTION SYSTEM SITE: NAGPUR

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ABSTRACT

Modelling and Optimization of water distribution system is addressed in this paper by WaterGEMS and EPANET. A water distribution network is used to show the algorithm performance and the obtained results are compared with those given by using dynamic programming to solve the same problem under the same conditions. The work presented in this thesis has been driven by the need for reduced, while at the same time suitably accurate, models to imitate the complex and nonlinear nature of water distribution systems to optimize their operation. WaterGEMS and EPANET are software that models the water transmission and distribution piping system. It is used to build a hypothetical model which is simulated and run to observe the performance of the network. Nagpur transmission network was designed and modelled for this study. The model is built from source- Pench Dam to the MBR in seminary hills. The models are later divided in 3 zones with assumed population. This system is optimized for diameter and pressure.

Keyword *Modelling;Optimization; EPANET;WaterGEMS*

1. INTRODUCTION

Water is vital for all forms of life and it covers seventy one percent of earth, of which nearly three percent is fresh water. Only half a percent of fresh water sources are rivers, lakes etc. With the growing population, it has become difficult to get a regular supply of fresh water. Approximately two and a half billion people on earth do not have access to safe drinking water. The acute crisis of water that is looming on the ever-growing world, it is important to optimize the supply and reduce losses. Urban water distribution systems have the vital purpose of delivering. There are various software's that industries are using as Winder, WaterGEMS, Synergy, SWMM etc., This report gives modelling and optimization of Nagpur water distribution system

2. WATER DISTRIBUTION SYSTEM

1.1 Water Distribution System

The important aspect of water supply after treatment is safe and adequate distribution. It is a network of pipeline to distribute water to the population. The system is designed to give adequate supply for Domestic, commercial, industrial, and firefighting process. A water distribution system should satisfy the following criteria:

- Adequate Pressure at the consumers tap for specific rate of flow.
- It should have adequate pressure to meet the firefighting demands
- The water hygiene should be maintained throughout the distribution
- It should be economical and cost-effective
- There should be supplementary supply in case of pipe bursting/repairing.

1.2 Design of water distribution system

Sources:

Ground water: It is utilized by digging a borewell. Artesian wells may have water that is confined below a rock foundation so that the water is under pressure. When an auger breaks through the rock foundation, there might be

sufficient water under pressure to force the water to the surface from where it is then pumped to the treatment facility and then it goes to finished water storage or driven directly into the distribution system. In majority places, the ground water in India is utilized directly without treatment. It is major source in village areas where the municipal supply is not connected or is intermittent.
Surface water: This is the supply taken from above ground sources as lakes, rivers. The water in these supplies were reserved by artificial dams. It has been discussed further in the sections below.

Water distribution methods:
Gravity system: The water flows under gravity from high gradient to low gradient areas. This is typically used for wastewater network. In water system gravity systems can be used in main line as and when possible. It is economical than pressure system. In this type of system, adequate pressure is available because of gravity to uphold water pressure in the mains for domestic consumption and fire service demand. This is the most dependable method of distribution if the piping leading from the treated water source
Pressure system with elevated storage: Pumps are used for transmission of water from reservoirs to the treatment plant to storage reservoir to distribution. Different types of pumps are used based on the requirement, economics, and site. A combination of gravity flow and one or more pumping stations to transport the water from the source point to all the water demand points on the distribution system. Through the use of pumps and elevated storage, the surplus water pumped during periods of low consumption is stored in elevated tanks or reservoirs (ESR). During periods of high consumption, the stored water supplements the water being pumped. This method allows fairly uniform flow rates and pressures throughout the water system. Thus, this method usually is economical because the pumps may be operated at their rated capacity. Since the stored water supplements the supply used for fires and system breakdowns, this method of operation is fairly dependable.

1.3 Water Demand:
The bureau of Indian standard IS: 1172-1993 has set minimum water supply of 200 liters per capita per day for domestic use. The consumption of water is based on size of city, characteristics of population and standard of living, Industries and commerce, climatic condition and metering

Sr No.	Classification of Town/City	Recommended Maximum Water Supply Levels (lpcd)
1	Town provided with piped water supply but without sewerage system	70
2	Cities provided with water supply where sewerage system exists	135
3	Metropolitan and Mega cities provided with piped water supply where sewerage system exists	150

TABLE 1: Domestic Water Consumption

3. CASE STUDY

Nagpur city is center of India. It is the third largest city and winter capital of Maharashtra. It is one of the proposed smart cities in Maharashtra. Nagpur's location on the convergence of several transportation routes that has contributed to the huge share of employment generation in the trade and transportation sector. Transportation sector employs 17.6 percent of the total working population. Manufacturing also has a significant presence in Nagpur with 15.4 percent of the working population involved in this sector.

As of the 2011 census, Nagpur municipality has a population of 2,405,665. The total number of slums number 179,952, in which 859,487 people reside. This is around 35.73% of the total population of Nagpur. The urban agglomeration has a population of 2,497,870 with 1,274,138 males and 1,223,732 females.

Water supply to Nagpur City was drawn from five surface sources viz. Ambazari tank, Gorewada Tank, Kanhan River, Wunna Irrigation Tank, and Pench canal. Out of these, Ambazari Tank is presently supplying water to MIDC area and Wunna Irrigation Tank is used only to meet the needs of defense area and surroundings. Hence City gets water only from Gorewada Tank, Kanhan River, and Pench Canal. Gorewada Tank Source was developed in the year 1911. As city grew and the need for water increased, Gorewada Tank source became inadequate. As augmentation to Gorewada was not possible due to site constraints, surface water source from river Kanhan was developed. The irrigation department, Govt. of Maharashtra executed a storage dam across river Pench in 1976 for hydro-electric project at Totaladoh and pickup dam at Navegaon Khairy, wherein reservation of 190 Mm3 was made for water supply to Nagpur City.

Old Gorewada Source

This source was found in 1911, it has earthen bund across river Pili which is located nearly 8km towards North East of Nagpur. This source has capacity of nearly 8.82 Mm3 gross storage and 7.92 Mm3 live storage. There is a treatment plant with capacity of 16 MLD.

Kanhan Water Source

This source is nearly 14km from Nagpur city, near the confluence of river Kolar and river Kanhan constructed in 1940. A dam was constructed across Kanhan River -500mtr upstream of the Kanhan head works with capacity of 7.80Mm3. Kanhan Water Supply Scheme was commissioned in four phases during the years 1940 - 1970. The first phase capacity in 1940 was 27.3 MLD which was augmented to 63.6 MLD in 1954. The capacity was further augmented to 86.3 MLD in 1966 and finally to 109 MLD in 1970. There are two intake well at the river bed and two dry wells in the right bank. The water is treated to a conventional treatment plant of 109MLD capacity. The treated water is then pumped to GSR of capacity 2 ML in government house through a 600mm-900mm dia parallel rising mains of length 15.24km.

Pench Source

113.5 MLD water is drawn from Pench right bank canal by gravity to the Mahadulla pumping station. The raw water is pumped to the B.P.T. of capacity 5.7 lakhs liters through 1606 mm dia M.S. Rising Main of length 5624 m. from B.P.T. water is taken to the Gorewada balancing tank through 700 mm dia duplicate C.I. gravity mains each of length 400 m. from Gorewada Tank it is drawn to the conventional treatment plant of capacity 113.5 MLD through 1200 mm dia M.S. gravity main. The filtered and chlorinated water from the treatment plant is pumped to Seminary Hills G.S.R. of capacity 20.43 ML and Gittikhadan G.S.R. of capacity 5.94 ML. Sitabuldi G.S.R. is fed from Seminary Hills G.S.R. through 700 mm dia M.S. Feeder Main of length 4000 m.

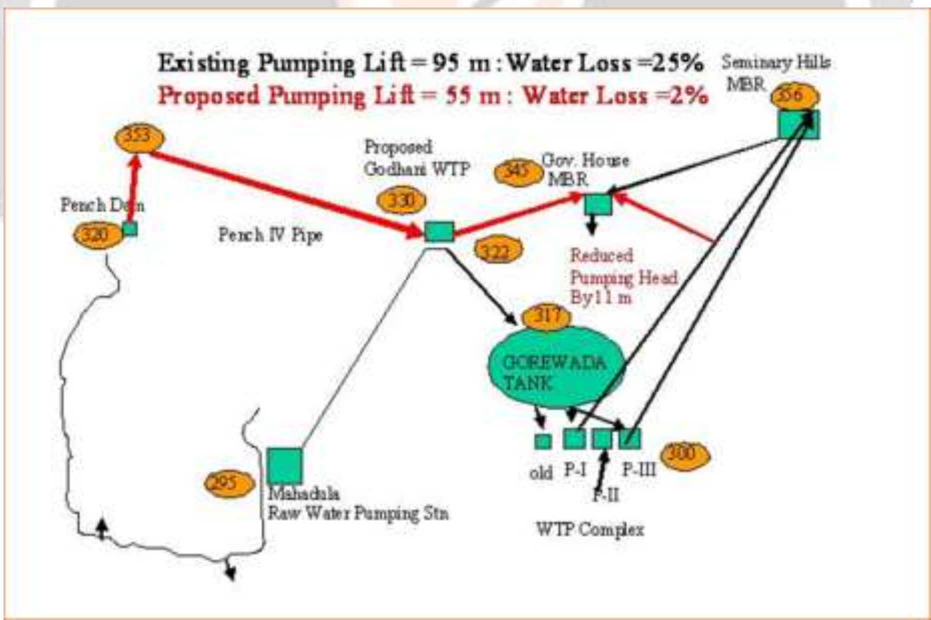

Fig 1- Nagpur Transmission system

In year 2000, NMC had appointed M/s Tata Consulting Engineers Ltd. (TCE) for preparation of Master Plan for water supply to Nagpur city. Population projections were carried out during these studies, which are reproduced below:

Years			
2001	2011	2021	2031
18, 36,145	20, 47,538	22, 58,931	24, 70,325

Water Demand

As per CPHEEO manual on water supply and treatment (Third edition (May 1999) revised and updated) the recommended 'Maximum' water supply in liter / capita / day (LPCD) is as follows:

Provided with piped water supply where sewerage system is existing / contemplated- 150 LPCD

4. DESIGN OF NAGPUR WATER DISTRIBUTION SYSTEM

The components covered under this part are, -

- The intake facilities at Pench (Navegaon Khairi) reservoir at Pench river course. The units are designed for total intake capacity of 756 MLD. This will include pumping facility of 756 MLD raw water up to Break Pressure tank having total head as 43 meters, in two phases, each of 378 MLD along with the necessary electrical sub-station of appropriate capacity.
- Sixty meters long raw water pumping main from the pumping station to break pressure tank, located near Head Work Site comprising of 2134 mm (OD) M.S., pipeline of 25 mm shell thickness. The same line will cater for Phase-II flow of 378 MLD.
- Construction of circular break pressure tank on hillock near H/W site with following features.

i)Inner Diameter of Tank	10m
ii)Bed level of Tank	353.000 m
iii)Top level of Tank	363.000 m
iv)Inlet to Tank	2032 mm (O.D.) M.S. pipe
v)Outlet from tank	1930 mm (O.D.) M.S. pipe
vi)Overflow	Combination of 1930 mm (MS) and 2000 mm (id) RCC NP-3 pipe

•The unit is designed for 756 MLD flow

• Raw Water Transmission Main from BPT to bifurcation point at Mahadulla of 2134 mm (O.D.) mild steel with shell thickness of 10 mm, 20 mm CC out coating and 12 mm CC in lining, for the length of about 27 km for Phase I

•Duplication of the same pipe is proposed for Phase – II

•Bifurcation arrangement at Mahadulla, to bifurcate the incoming 315 MLD of flow in two branches. One branch carrying 115 MLD of flow up to proposed WTP location at Godhani and second branch will get connected to existing raw water transmission main of 1626 mm (O.D.) MS pipeline feeding Gorewada. In Phase II, tapping arrangement at Mahadulla will be provided for cargo Hub (MIHAN) project for the flow of 115 MLD and remaining flow to 200 MLD will get carried by existing transmission main of 1626 mm (O.D.) to Gorewada.

•Raw water transmission main from bifurcation point at Mahadulla to proposed WTP location of length approximately of 2600 m and 1422 mm (O.D.), 10 mm thick size carrying 115 MLD of discharge.

•An ultra-modern state of art water treatment plant of nominal capacity of 115 MLD capacity of Godhani.

•Pure water rising main from WTP at Godhani to existing MBR at Governor House of size 1422 mm □, MS 12 mm thick and length about 7500 m.

•Strengthening & extension of existing distribution network including ESR's and distribution mains.

5. MODELLING

With developing technology, new mathematical model build technology are available. The day to day water system handling is done by the skilled staff. Usually this process is repetitive so the controller is well aware of it, and they use their experience to adjust control elements as pumps and valve to ensure customer demands. Modelling is being undertaken as a proactive management strategy. Hydraulic modelling provides in depth analysis of water supply and water distribution system elements and their functionalities. Modelling can be done for normal and emergency conditions. The analysis can be performed for both existing and future expansion. It provides capability to mathematically replicate the non-linear dynamics of water distribution network by solving the governing set of quasisteady state hydraulic equations that include conservation of mass and conservation of energy elements.

Hydraulic models are often used to validate the design of the rehabilitated or new pipelines. Modelling is also used to verify the system capacity or to analyze the effect of modified infrastructure within the context of the entire water distribution system or its sub-system.

Water modelling can be done to analyze:

- Steady-state analyses

- Extended period analyses
- Fire flow analyses
- Hydraulic transient analyses
- Water quality analyses
- Development of scenarios
- Pressure optimization
- Existing and future demand scenarios
- Operational optimization
- Existing and emergency water supply analyses

EPANET

EPANET is software that models water distribution piping systems. EPANET carry out extended period simulation of the water movement and quality behavior within pressurized pipe networks. Pipe networks consist of pipes, nodes (junctions), pumps, valves, and storage tanks or reservoirs. EPANET tracks:

- The flow of water in each pipe,
- The pressure at each node,
- The height of the water in each tank,
- The type of chemical concentration throughout the network during a simulation period,
- Water age
- Source
- Tracing

EPANET Application

EPANET is one of the most widely used software. It can be used for following analysis:

- Model build and Calibration
- Model the movement of a non-reactive tracer material through the network over time
- Model the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) over time
- Model the age of water throughout a network
- Track the percent of flow from a given node reaching all other nodes over time
- Model reactions both in the bulk flow and at the pipe wall
- Allow growth or decay reactions to proceed up to a limiting concentration
- Employ global reaction rate coefficients that can be modified on a pipe-by-pipe basis
- Allow for time-varying concentration or mass inputs at any location in the network

WaterGEMS

One of the most sophisticated software in water network modelling is WaterGEMS. It provides with a comprehensive decision-support tool for water distribution networks. WaterGEMS can do fire flow, water quality simulations.

WaterGEMS provides numerous software tools for:

Intelligent planning for system reliability: WaterGEMS, can effectively identify potential problem areas, accommodate service area growth, and plan capital improvements. The capability of the water network to adequately serve its customers must be evaluated whenever system growth is anticipated.

Optimized operations for system efficiency: Realistically modelling the operation of complex water systems can be difficult. With WaterGEMS, model pump accurately, optimize pumping strategies, and plan shutdowns and routine operations to minimize disruption.

Reliable asset renewal decision support for system sustainability: WaterGEMS tools such as Pipe Renewal can be used to analyze and compare a wide range of variables to prioritize renewal decisions.

6. RESULTS

WaterGEMS

Label	Elevation (m)	Demand (m^3/s)	Hydraulic Grade (m)
J-2	310	4	325.20
J-3	300	2	320.67
J-35	330	0.09	323.65
J-36	328	0.08	321.88
J-37	324	0.06	321.83
J-38	327	0.13	325.02
J-39	326	0.11	323.39
J-40	328	0.13	325.09
J-41	328	0.15	321.81
J-42	324	0.06	322.04
J-43	328	0.08	321.47

Table 2-Manholes Results

Label	Length (Scaled) (m)	Diameter (mm)	hw (m)	Flow (m^3/s)	Velocity (m/s)
P-9	17	1600	110	2	1.15
P-51	38	750	110	1	3.17
P-52	33	750	110	2	3.93
P-53	30	750	110	1	3.31
P-54	20	300	110	0.083	1.23
P-55	26	250	110	0.7	1.53
P-56	28	200	110	0.058	1.99
P-57	22	400	110	0.099	1.04
P-58	23	300	110	0.1	1.56
P-59	21	400	110	0.99	1.04
P-60	20	350	110	0.13	1.56
P-61	17	200	110	0.04	1.91
P-62	20	250	110	0.07	1.63
P-1	25	2600	110	9	1.65
P-2	46	2000	110	9	2.79
P-4	13	1400	110	1.3	0.89
P-5	25	1400	110	1.3	0.89
P-7	46	1900	110	5	1.71

Table 3-Pipes Results

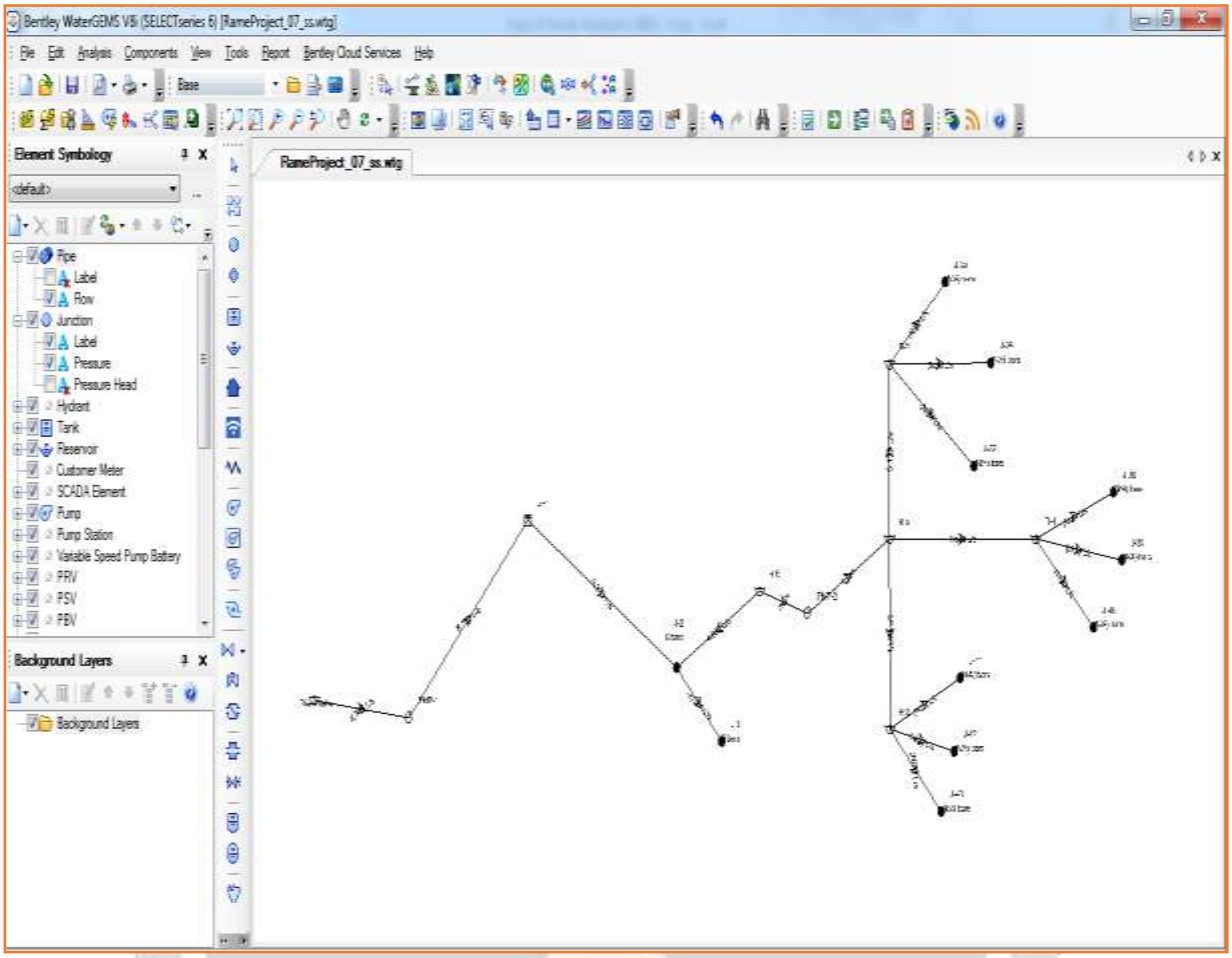

Fig 2 -WaterGEMS model

EPANET

Node ID	Elevation	Demand	Head
	m	LPS	m
Junc J-2	310	3645	325.20
Junc J-3	300	2314	320.67
Junc J-35	330	86.81	323.65
Junc J-36	328	75	321.88
Junc J-37	324	63	321.83
Junc J-38	327	130.	325.02
Junc J-39	326	110	323.39
Junc J-40	328	130	325.09
Junc J-41	328	150	321.81
Junc J-42	324	60	322.04
Junc J-43	328	80	321.47

Table 4 EPANET Nodes Results

Link ID	Length (m)	Diameter(mm)	Roughness	Flow(LPS)	Unit Headloss(/s)	Friction Factor(m/km)
Pipe P-1	10	2600	130	8755.01	1.65	0.69
Pipe P-2	60	2000	130	8755.01	2.79	2.46
Pipe P-5	2600	1400	130	1201.02	0.03	0.00
Pipe P-7	27360	1900	130	6011.02	2.12	1.58
Pipe P-9	5350	1600	110	2314.00	1.15	0.85
Pipe P-51	1000	750	110	370.00	3.12	13.00
Pipe P-52	800	750	110	290.00	3.80	18.75
Pipe P-53	1000	750	110	224.00	3.25	14.00
Pipe P-54	200	300	110	86.81	1.23	6.74
Pipe P-55	250	250	110	75.00	1.53	12.49
Pipe P-56	120	200	110	62.50	1.99	26.43
Pipe P-57	280	400	110	130.21	1.04	3.52
Pipe P-58	250	300	110	110.00	1.56	10.45
Pipe P-59	260	400	110	130.21	1.04	3.52
Pipe P-60	250	350	110	150.00	1.56	8.76
Pipe P-61	80	200	110	60.00	1.91	24.5
Pipe P-62	180	250	110	80.00	1.63	14.08

Table 5 EPANET Pipes Results

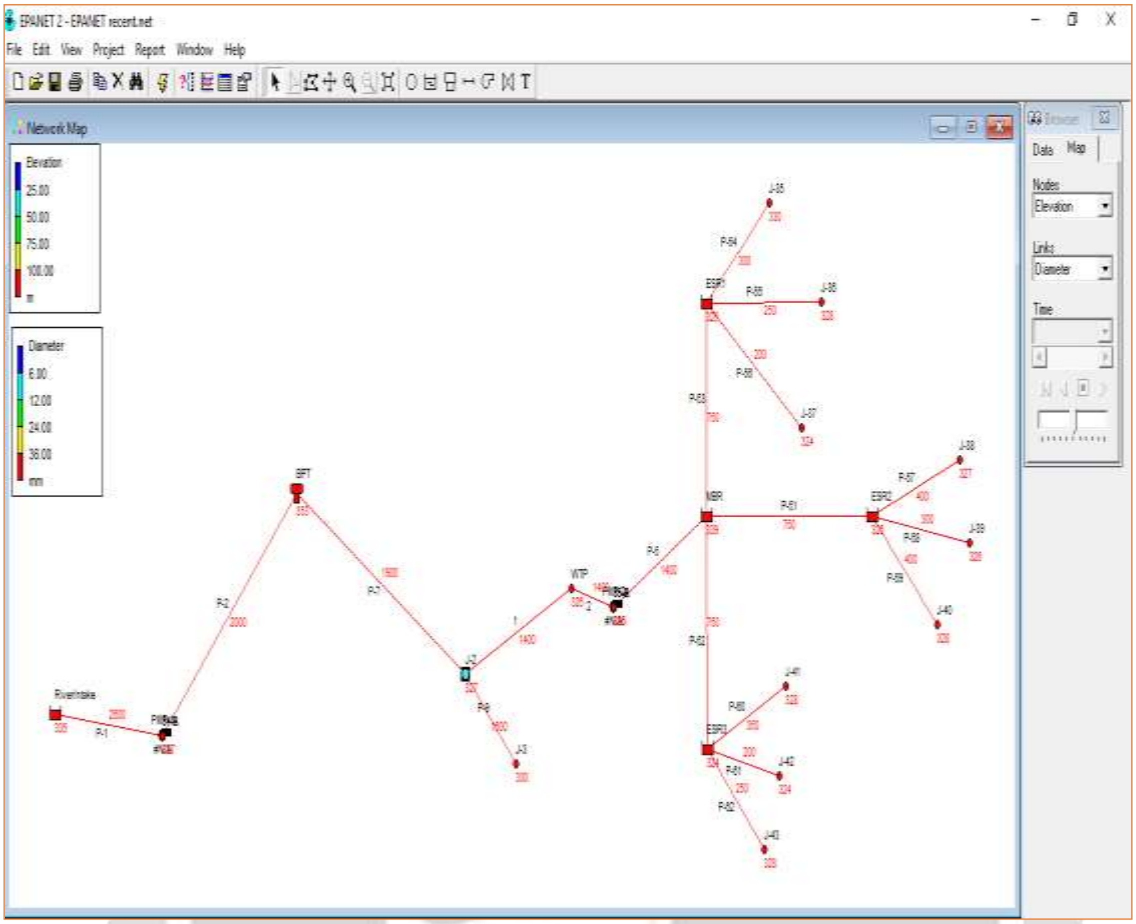

FIG 3- EPANET model

7. OPTIMISATION

In simple terms optimization is using find the best possible solution to a problem statement in various iterations and combinations. It is finding the most cost-effective solution or highest achievable performance under the given constraints Optimization originated in the 1940s, when George Dantzig used mathematical techniques for generating "programs" (training timetables and schedules) for military application. Since then, his "linear programming" techniques and their descendants were applied to a wide variety of problems, from the scheduling of production facilities, to yield management in airlines. Today, optimization comprises a wide variety of techniques from Operations Research, artificial intelligence, and computer science, and is used to improve business processes in practically all industries.

There are lot complexities in the design of a water distribution system, basically due to non-linear head loss relationship and discrete nature of pipe sizes. Nevertheless, due to its huge cost, the least cost design of WDN has always been the focus area for research. Also, the optimal allocation of the available water to the demands of service reservoirs remains a trial and error approach. Therefore, the problem comprises of three optimal requirements-

Firstly, optimal allocation of available water at different sources to meet the demands of the service reservoirs.

Secondly, the optimal route to transport the allocated water quantity from these sources to the respective service reservoirs.

Lastly, the optimal selection of pipe sizes for the selected routes for the transporting the allocated water quantity meeting the hydraulic requirement that governs the levels of the resources and the service reservoirs.

Head losses

When a real fluid flows through a pipe, part of the total energy of the fluid is spent in maintaining the flow. The used-up energy is converted to thermal energy due to internal friction and turbulence. Such a conversion, which is the loss of energy as far as its utility is concerned, is usually expressed in the form of head of liquids and therefore termed head loss.

The head loss in a pipe is classified into two categories:

Head loss due to friction, i.e., frictional head loss

Head loss due to minor appurtenances, i.e., minor head loss.

The frictional head loss in a pipe is due to the viscosity of the fluid and the turbulence of the flow and is present throughout the length of the pipe. As the frictional head loss in a long pipe is relatively larger than other head losses, the frictional head loss is also termed as major head loss.

When there is a sudden or gradual change in the boundaries of the fluid or when there is a local obstruction to flow, the flow pattern changes. This results in a change in the magnitude, direction or distribution of the velocity of flow. Such a change introduces additional head loss which is of a local nature and is usually much less than the frictional head loss in a long pipe. It is therefore termed minor head loss.

Darcy-Weisbach Formula

The frictional head loss hf for incompressible flow in a pipe depends on the fluid properties such as the density ρ and viscosity μ, the flow characteristic such as the average velocity V, the pipe characteristics such as the length L and the internal diameter D, the pipe wall roughness characteristics such as the size of the roughness projections e (dimensions, L), arrangement or spacing of the roughness projections e' (dimensions, L), and a dimensionless form factor m depending upon the shape of the individual roughness elements. Using dimensional analysis, it can be shown (Streeter and Wylie 1984) that

$$hf = \frac{L}{D} \cdot \frac{V^2}{2g} \cdot \Phi\left(\frac{VD\rho}{\mu}, \frac{e}{D}, \frac{e'}{D}, m\right)$$

in which Φ represents a function of. As it is extremely difficult to quantitatively consider the effect of e' and m, their effect is either ignored or is included indirectly by considering equivalent size e. Therefore, Eq. (5.1) can be reduced to

$$hf = L/D.V^2/2g.\Phi(VD\rho/\mu, e/D)$$

The term VDρ/μ is the Reynolds number Re. The dimensionless parameter e/D is known as the relative roughness.

Introducing a coefficient of friction f such that

$$f = \Phi(Re, e/D)$$

Equation (5.2) can also be written as

$$hf = fL/D.V^2/2g$$

Weisbach (1855) was the first to write a resistance equation for pipes in the form of Eq. (5.4). As Darcy carried out considerable work on pipe flow, his name is also associated with Eq. (4) is now commonly known as Darcy-Weisbach formula.

For noncircular pressure conduits, D in Eq. (5.4) is replaced by 4R in which R is the hydraulic radius defined as the ratio of the cross-sectional area of flow A, and the wetted perimeter P, i.e., R = A/P.

Sometimes, it is more convenient to use the Darcy-Weisbach formula in a form in which hf is given in terms of the discharge Q rather than the average velocity V. Replacing V by Q/A and taking A = πD2/4 for circular pipes, Eq. (5.4) on simplification becomes

$$hf = (16fLQ^2)/(\pi^2\ 2gD^5) = (8fLQ^2)/(\pi^2\ gD^5)$$

Taking g = 9.81 m/s2, Eq. (5.5) can further be simplified to

$$hf = (fLQ^2)/(12.1D^5)$$

The following table gives optimization of pumping main and gravity mains modelled in the network with respect to cost and pressure.

Pipe line	Discharge (Q) l/s	Nominal diameter (m)	Hf+10% extra(m)	Cost of pipe w.r.t length	Selected Diameter
Node ESR1 to J35	87	0.225	6.01	117800	250mm
	87	0.250	3.60	143800	
	87	0.300	1.48	242600	
Node ESR1 to J36	75	0.225	5.73	147250	250mm
	75	0.250	3.43	179750	
	75	0.300	1.41	303250	
Node ESR1 to J37	63	0.225	1.96	70680	225mm
	63	0.200	3.48	86280	
	63	0.300	0.48	145560	
Node ESR2 to J38	130	0.250	10.68	201320	300mm
	130	0.300	4.39	339640	
	130	0.400	1.08	580720	
Node ESR2 to J39	110	0.250	6.98	179750	300mm
	110	0.300	2.87	303250	
	110	0.350	1.36	406500	
Node ESR2 to J40	130	0.250	9.92	186940	300mm
	130	0.300	4.08	315380	
	130	0.400	1.01	539240	
Node ESR3 to J41	150	0.300	5.10	303250	350mm
	150	0.350	2.41	406500	
	150	0.400	1.26	518500	
Node ESR3 to J42	60	0.15	8.74	21920	200mm
	60	0.200	2.15	36800	
	60	0.225	1.21	47120	
Node ESR3 to J43	80	0.200	8.26	82800	250mm
	80	0.250	2.79	129420	
	80	0.300	1.15	218340	

Table 6-Optimization of Water Distribution System

8. CONCLUSIONS

Modelling and optimization of water distribution system is today's progressive worlds need. Modelling, by replicating the site condition gives a realistic approach to the design. There are lot of factors modelling is dependent on, and every factor affects the result and can be different than site. Models produce information. They do not produce decisions.

In this project for future yr. 2031, Nagpur conveyance system was designed and modelled in WaterGEMS and EPANET. Both the modes were run for stable condition. There is minor difference in the results obtained from this two software's. For each ESR, 3 zones were modelled with assumed population and the pressure was at the end nodes.

The model was later optimized for cost and pressure at the end of the distribution.

There are a few challenges in modelling of water distribution system:

- Input Data accuracy
- Design accuracy
- Needs proper understanding of the output required in the project
- There are many possible methods of getting desired solutions, best possible solution needs to be identified.
- Software availability
- Time constraints

Further more detail designing and modelling is required the scope of project only covered comparing results from EPANET, WaterGEMS and optimization of the distribution system.

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