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Analysis and Design of Water Distribution Network for Jabalpur Cantonment Board Area

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ABSTRACT

In this research paper focuses on studying and improving the water distribution network in the Jabalpur Cantonment Board Area. Water distribution networks are crucial infrastructures for ensuring reliable water supply to communities. However, many areas, including Jabalpur Cantonment, face challenges related to water distribution efficiency, reliability, and equitable access. The study begins with a comprehensive analysis of the existing water distribution network in the Jabalpur Cantonment Board Area. Factors such as network layout, pipe material, age of infrastructure, and water demand patterns are thoroughly examined to identify existing inefficiencies and areas for improvement. Using advanced engineering tools such as WaterGems and methodologies, an optimized design for the water distribution network is proposed. This design considers factors such as hydraulic efficiency, pressure management, and resilience to minimize water losses and ensure consistent water supply to consumers. Furthermore, the study incorporates considerations for future growth and development in the Jabalpur Cantonment Board Area. By employing sustainable design practices and incorporating modern technologies, the proposed water distribution network aims to meet the present and future water needs of the community while minimizing environmental impact. By implementing the proposed design improvements, the Jabalpur Cantonment Board can achieve a more sustainable, efficient, and reliable water supply network, ultimately improving the quality of life for its residents.

Keywords- Water distribution network, Jabalpur Cantonment Board, Hydraulic modelling, Sustainability, Water loss

1.INTRODUCTION

The provision of potable water is an essential service for sustaining life and supporting societal development. In urban areas, water distribution networks play a pivotal role in ensuring reliable and equitable access to clean water. The Jabalpur Cantonment Board (JCB) area, like many urban regions in India, faces challenges in its water distribution system due to factors such as population growth, aging infrastructure, and unpredictable demand patterns. This research article presents a comprehensive analysis and design of the water distribution network within the Jabalpur Cantonment Board area. The study aims to address existing issues, optimize network performance, and propose sustainable solutions to meet present and future water demand. The Jabalpur Cantonment Board area is a unique urban environment characterized by its distinct topography, demographic distribution, and infrastructural constraints. As such, designing an efficient water distribution network requires a nuanced understanding of these factors to ensure the delivery of safe and reliable water to all residents and stakeholders.

Key challenges facing the water distribution network in the JCB area include:

1. **Water Losses:** Aging pipelines and leakages contribute to significant water losses, reducing the efficiency of the distribution system and exacerbating water scarcity issues.
2. **Uneven Distribution:** Disparities in water access across different neighborhoods within the JCB area highlight the need for equitable distribution strategies to ensure social equity and inclusivity.
3. **Infrastructure Resilience:** The network must be resilient to natural disasters, such as floods or earthquakes, to minimize disruptions and ensure continuous water supply during emergencies.
4. **Sustainability:** With growing concerns over water scarcity and environmental degradation, designing a sustainable water distribution network involves incorporating conservation measures and exploring alternative water sources.

To address these challenges, this research employs advanced techniques in hydraulic modeling, optimization algorithms, and Geographic Information Systems (GIS) to analyze, design, and propose improvements for the water distribution network in the Jabalpur Cantonment Board area. The findings of this study are expected to provide valuable insights for policymakers, urban planners, and water utility managers in enhancing the efficiency, reliability, and sustainability of water supply infrastructure in the JCB area. By optimizing the distribution network, it is envisaged that the quality of life for residents will improve, ensuring access to clean water remains a fundamental right for all inhabitants of the Jabalpur Cantonment Board area. In subsequent sections, this article will delve into the methodologies employed, data analysis conducted, results obtained, and recommendations proposed to address the identified challenges and optimize the water distribution network for the Jabalpur Cantonment Board area.

2. DESIGN CRITERIA

Design Period:

All design criteria adopted as per CPHEEO Manual:

The design year of project is considered as 30 years. The base year is taken as 2025 considering period required to sanction and execution of project. Thus, the design year to design various components is assumed as follows,

Base Year = 2025

Intermediate Year = 2040

Ultimate Year = 2055

Population:

Population projection for ultimate year 2055 for Project Area is considered as explained in the earlier chapter.

LPCD Rate and Losses:

Urban sectors are proposed to be designed without sewerage system, 135 LPCD rate is adopted for water supply design (Ref- CPHEEO Manual Table 2.1 Pg. No.11). For Ideal water supply scheme, the permissible system losses are 15%. Hence same are adopted in the design of water supply system for the project. The breakup of same is as follows,

Raw Water Transmission Mains = 1%

Pure Water Transmission Mains = 1%

Water Treatment Plant = 3%

Distribution System = 10%

Nodal Population & water Demand:

Method used for calculating population at Node & water Demand is unit line pattern. (Population –Density method)

Peak factor:

For intermittent water supply: Peak factor for distribution system design is taken as shown in Table 1

Population	Peak factor for intermittent supply	
< 50000	3	As per Guidelines given in Para 10.3.1, CPHEEO manual on water supply and treatment; Ed 1999.
50000 to 200000	2.5	
>200000	2	

Note: As the project area is still developing, the distribution network is designed for intermittent supply with a peak flow factor of 3.0.

Governing Levels:

For Distribution Network: Lowest supply levels (L.S.L.) of respective Existing or proposed ESR/GSR of are considered as governing levels for Hydraulic calculations and residual head is measured above Ground level of node point.

However Following levels are considered while hydraulic designing of system.

- Minimum Water level in UGR and FSL of OHT for Pump design.
- Minimum and maximum level UGR and OHT for mass balancing
- Pump Floor level / pump centre RL to calculate suction head and delivery head.

Residual Pressure:

For Water Distribution Network, minimum residual head of 12 m is considered above the G.L. of design node point in the command area. (As per Guidelines given in Table 2.1, of AMRUT guidelines for planning, design, and implementation of 24x7 water supply systems)

However, in exceptional case due to higher elevation in localized area, residual head at node may vary between 7.0 to 12.0 m.

Formula for head loss calculation:

The design of the Distribution network is based on the Hazen William (H/W) head loss formula.

Q = 1.292 x 10 (-5) x C x d 0.63 x S 0.54

Where,

Q = Discharge in cubic meter/hour

D = diameter of pipe in mm

S = slope of hydraulic gradient.

C = Hazen-William coefficient.

Hazen William Constant for Different Pipe Material:

The H/W co-efficient of roughness of pipe (C-value of pipe) is adopted as shown in Table .

Pipe material	Status	C value
MS pipe (with lining)	New	140
Ductile iron	New	130
HDPE	New	140
PVC	Old	145

Maximum Head Loss:

Distribution Network is so designed that rate of head loss (m/km) for respective type of pipe shall not exceed 5.0 m/km for design peak flow. (As per AMRUT guidelines for planning, design, and implementation of 24x7 water supply systems, Chapter 5, 5.5).

Velocity:

Velocity in of pipelines is restricted to **Minimum 0.3 m/sec to maximum of 2.1 m/sec**. In exceptional it may be lesser to fulfil criteria minimum pipes dia.

Pipe Material:

For Pure Water Transmission mains, generally M.S. pipe or D.I pipe is used considering the techno-economy.

In Distribution mains HDPE pipes are now generally preferred (for Dia up to 315 mm) over DI pipes due to their cost effectiveness and have long term cost advantages, physical properties, leak free joints and reduced maintenance costs. HDPE pipes with fusion welded joints, eliminating infiltration problems experienced with pipe joints of DI pipe at every small length. Similarly, DI K-9 pipe are preferred than CI pipe to its techno- commercial feasibility.

Hence for proposed pipe following pipe material is considered, for transmission main & distribution Network.

DI- K-9 (IS 8329:2000) =200 to 450 mm ND (Pumping Mains)

DI- K-7 (IS 8329:2000) =200 to 450 mm ND (Gravity flow)

HDPE PE-100 (IS 4984: 2016) = 110 to 3150 mm ND

Adequacy of Storage:

Generally, OHT / GSR capacity is taken as 33% to 50% of the total demand for intermittent supply or with Mass balance. In continuous supply system, the tank capacity is works out from Mass balance of surplus and deficit in tank Volume considering rate of hourly inflow, out flow. Storage Capacity of tank and its phasing, depends upon the water demand in intermediate & ultimate phase. The tank capacity and its phasing are considered accordingly.

Staging Of Elevated Service Reservoir: The Maximum staging height of OHT should not be more than 30m as per Amrut 2.0 guidelines Similarly, Min staging height of tank should meet the criteria of required residual head at node considering ultimate stage demand

3. NETWORK PERAMETERS

To evaluate potable water demand, population data sourced from the Census was used. The potable water distribution pipe networks from the Cantonment Board office were then exported for hydraulic simulation using WaterGems (Update 3-10.03.05.05). This software requires essential information about nodes, pipes, tanks, pumps, and storage reservoirs for the hydraulic simulation process:

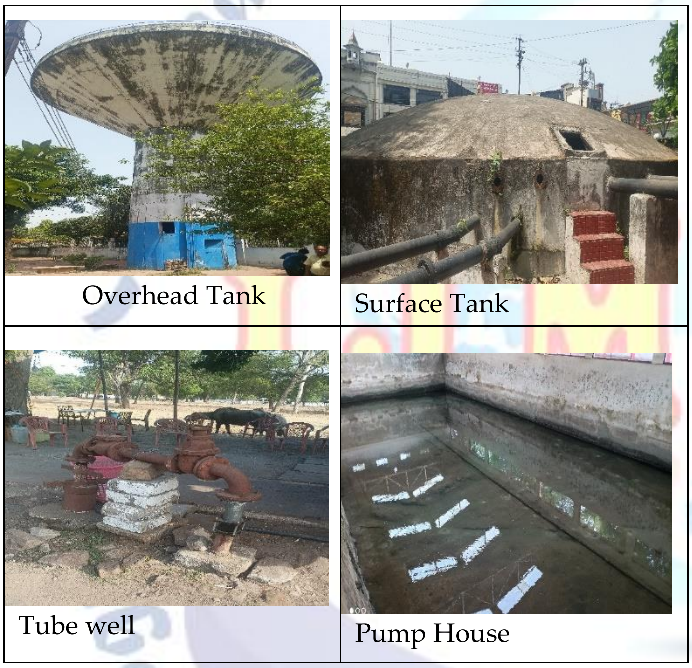


Figure 3.1: Field Data Collection

Nodes:

The data required for each node in the simulation of the potable water distribution network is:

Node ID:

The program automatically assigns this parameter, but you can customize it by accessing the main window Project/Defaults. From there, you can specify the desired nomenclature for each element in the network, including nodes, pipes, tanks, pumps, and valves.

Coordinates of the node:

To accurately map out the pipe network, it is essential to have the coordinates for each node. These coordinates enable us to determine the latitude and longitude of each section of the pipe. Thankfully, this information is automatically captured during the creation of the pipe network, as it is drawn and established using a geo-coded base image.

Demand in the node:

Upon obtaining the design population for the Jabalpur Cantonment Board Area, the next step is to estimate the demand for potable water. This estimation considers the type of buildings within the area. Additionally, it is crucial to factor in the future residents' water demand, which amounts to 18.30 million litters per day (MLD). This significant change will inevitably impact the current distribution pattern.

Demand Statement of Jabalpur Cantonment Board

Sr. No.	Details	2021	Base Year 2025	2030	Intermediate Year 2040	2050	Ultimate Year 2055
A	**Population (Souls) incl. Slum Population**	**80885**	**84334**	**88646**	**97270**	**105894**	**110206**
B	Rate of water supply (LPCD)	135	135	135	135	135	135
C	**DEMAND @ 135 LPCD**	10.92	11.39	11.97	13.13	14.3	14.88
D	Institutional demand @ 2.5%	0.27	0.28	0.3	0.33	0.36	0.37
E	Commercial demand @ 2.5%	0.27	0.28	0.3	0.33	0.36	0.37
	Industrial Demand @ 5%	0	0	0	0	0	0
F	**Total (C+F+G)**	**11.46**	**11.95**	**12.57**	**13.79**	**15.02**	**15.62**

G	**Demand with 10% distribution losses @ ESR**	**12.61**	**13.15**	**13.83**	**15.17**	**16.52**	**17.18**
H	Demand with Pure Water Transmission losses @ 1%	12.74	13.28	13.97	15.32	16.69	17.35
I	Demand with WTP losses @ 3%	13.13	13.69	14.4	15.79	17.21	17.89
J	Demand with Raw Water Transmission losses @ 1%	13.26	13.83	14.55	15.95	17.38	18.07
K	**Total (MLD)**	**13.39**	**13.97**	**14.7**	**16.11**	**17.56**	**18.25**

Table 1.*1* : Water Demand of Jabalpur Cantonment Board

Elevation:

Garmin GPS equipment was utilized to determine the elevation at various points within the Jabalpur Cantonment Board Area. This elevation data, along with a Digital Elevation Model (DEM), was then incorporated into the simulation.

Demand pattern:

The maximum water demand previously calculated represents the highest request for water in the area, but it typically does not exceed 100% throughout the day. For the network simulation within the Board area, a specific pattern has been chosen to represent the maximum hourly demand, which equates to an average daily water consumption of 60% for this area. This pattern has been assigned to the networks being evaluated.

Pipes:

The data required for in each pipe for the simulation of the water distribution network is:

Pipe ID:

The program automatically generates a parameter for each pipe in the network. To customize the nomenclature for each pipe, you must access the main window project and input your desired labels.

Length:

In ArcGIS 3.3, this parameter is automatically calculated based on the coordinates of each node. This allows for the easy determination of the length between each element. In this simulation, length is expressed in meters.

Diameter:

This parameter introduces the diameter of each pipe section. The diameters used in this work are as specified in the plan provided by the board, ranging from 110 millimetres to 315 millimetres.

Roughness of pipe:

The roughness of the potable water distribution network is influenced by the material chosen for the pipes. In this case, the existing pipes are made of Galvanized Iron, which has a roughness value of 120 as per design specifications.

Tanks

The data required for each tank in the simulation of the potable water distribution network is:

Tank ID:

The program automatically generates this parameter, which specifies the nomenclature for each tank in the network. To customize it, navigate to the main window project/defaults and input the desired nomenclature for each tank.

Elevation:

The elevation parameter in WaterGems (Update 3-10.03.05.05) is distinct from the elevation in the nodes. Unlike the latter, which is automatically determined, this parameter must be manually inputted. It serves to incorporate the elevation of both the tank and the surrounding land, as indicated in Table.

Pump:

The data required in each pump for the simulation of the potable water distribution network is:

Pump ID:

The program automatically provides this parameter. To customize it, navigate to the main window project/defaults and specify the desired nomenclature for each pump element in the network.

Pump Curve:

Utilizing both total demand and geographical data, we determined the diameters of the pumping pipes, the pumping level, and the elevation. These parameters allowed us to calculate the Flow and Head values necessary for simulation in WaterGems. The specifications for each pump are detailed in Table.

Label	Elevation (m)	Status (Calculated)	Status (Initial)	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (MLD)	Pump Head (m)
PMP-1	394.1	On	On	390.96	457.96	15.253	67

Table 2 : Pump specification

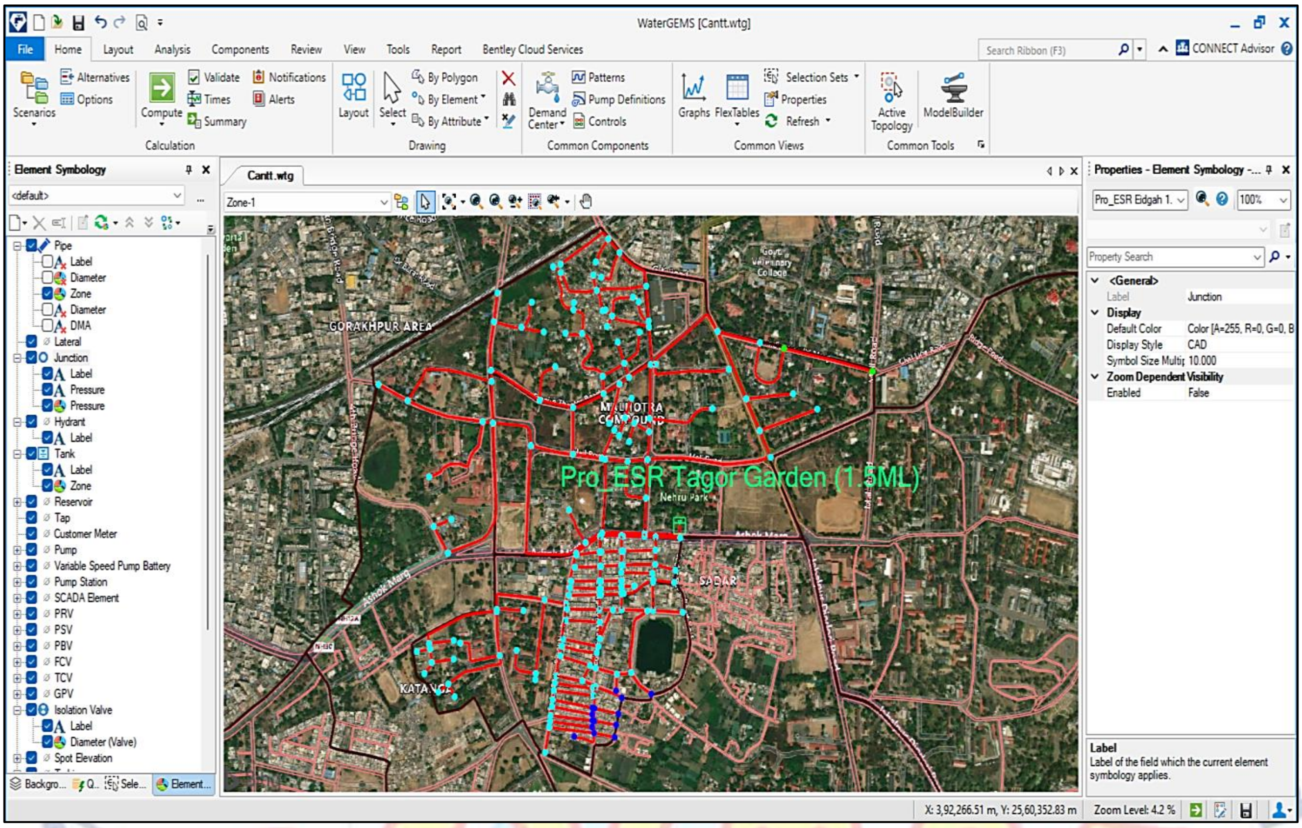
4. RESULTS AND DISCUSSION

Table 4.1: Pipe Length Summary Of Dist. Network (Zone-1-5)

Sr. No.	Pipe Sizes (mm)	Length (M)					TOTAL (ZN-1 to 5)
		ZONE-1	ZONE-2	ZONE-3	ZONE-4	ZONE-5	
1	110 HDPE	12928	4323	6964	694	3641	28549
2	140 HDPE	2707	2338	4153	1541	429	11167
3	160 HDPE	1561	1350	1529	1415	476	6330
4	180 HDPE	1574	79	331	-	435	2419
5	200 HDPE	694	432	216	-	259	1600
6	225 HDPE	382	-	570	-	-	952
7	250 HDPE	9	-	238	-	268	515
8	280 HDPE	-	74	419	-	-	493
9	315 HDPE	154	25	507	119	385	1190
Grand Total		**20008**	**8621**	**14925**	**3769**	**5893**	**53215**

Table 4.2: Over Head Tank Table

Proposed Over Head Tanks	Zone	Elevation (Base) (m)	Elevation (Minimum) (m)	Elevation (Initial) (m)	Elevation (Maximum) (m)	Flow (Out net) (MLD)	Hydraulic Grade (m)
Pro_ESR Tagor Garden (1.5 ML)	Zone-1	408.1	426.1	428.6	431.1	8.575	428.6
Pro_ESR Eidgah (1.1ML)	Zone-2	403.14	421.14	423.64	426.14	5.66	423.64
Pro_ESR Katanga School (1.7ML)	Zone-3	409.2	430.2	432.7	435.2	9.537	432.7
Pro_ESR Gora Bazar (1.5ML)	Zone-4	404.85	422.85	425.35	427.85	12.5	425.35
Pro_ESR Karondi (1.3 ML)	Zone-5	413.75	428.75	431.25	433.75	7.123	431.25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SADAR
KATANGA
Ashok Marg
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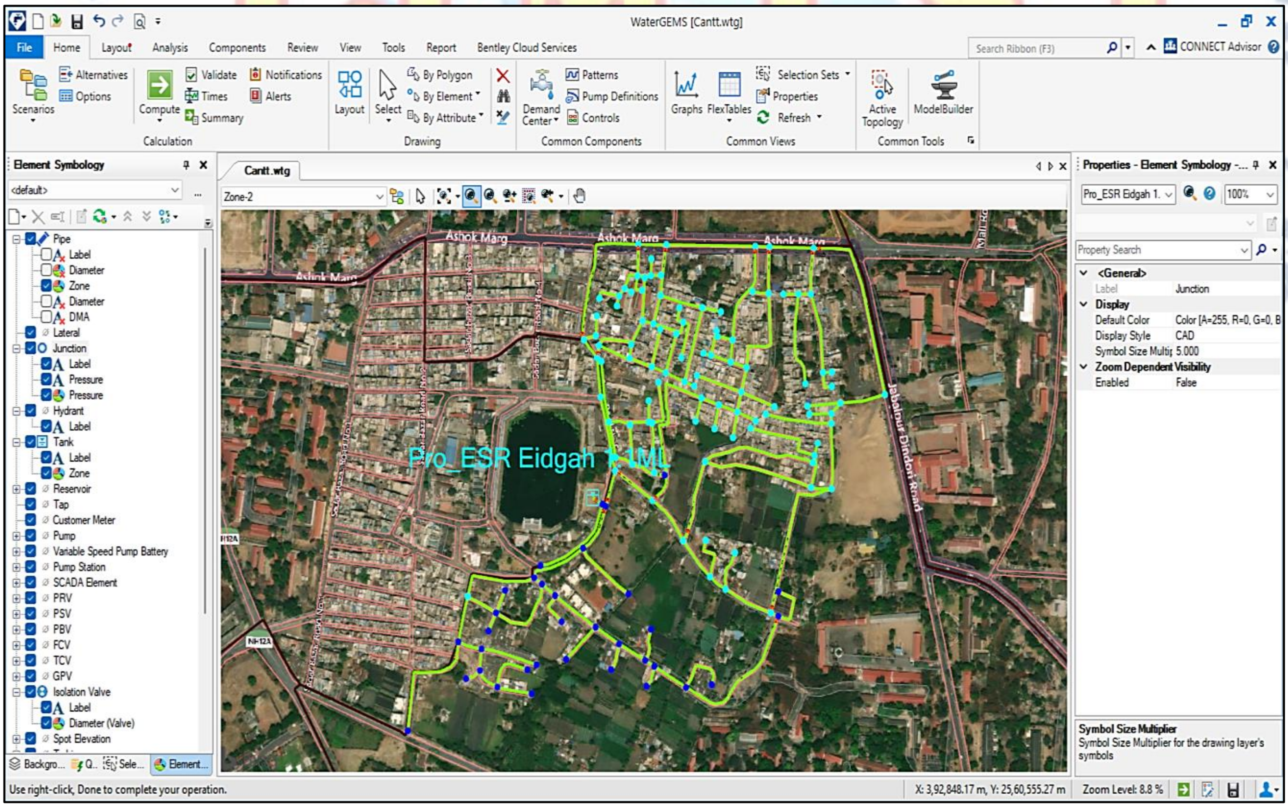
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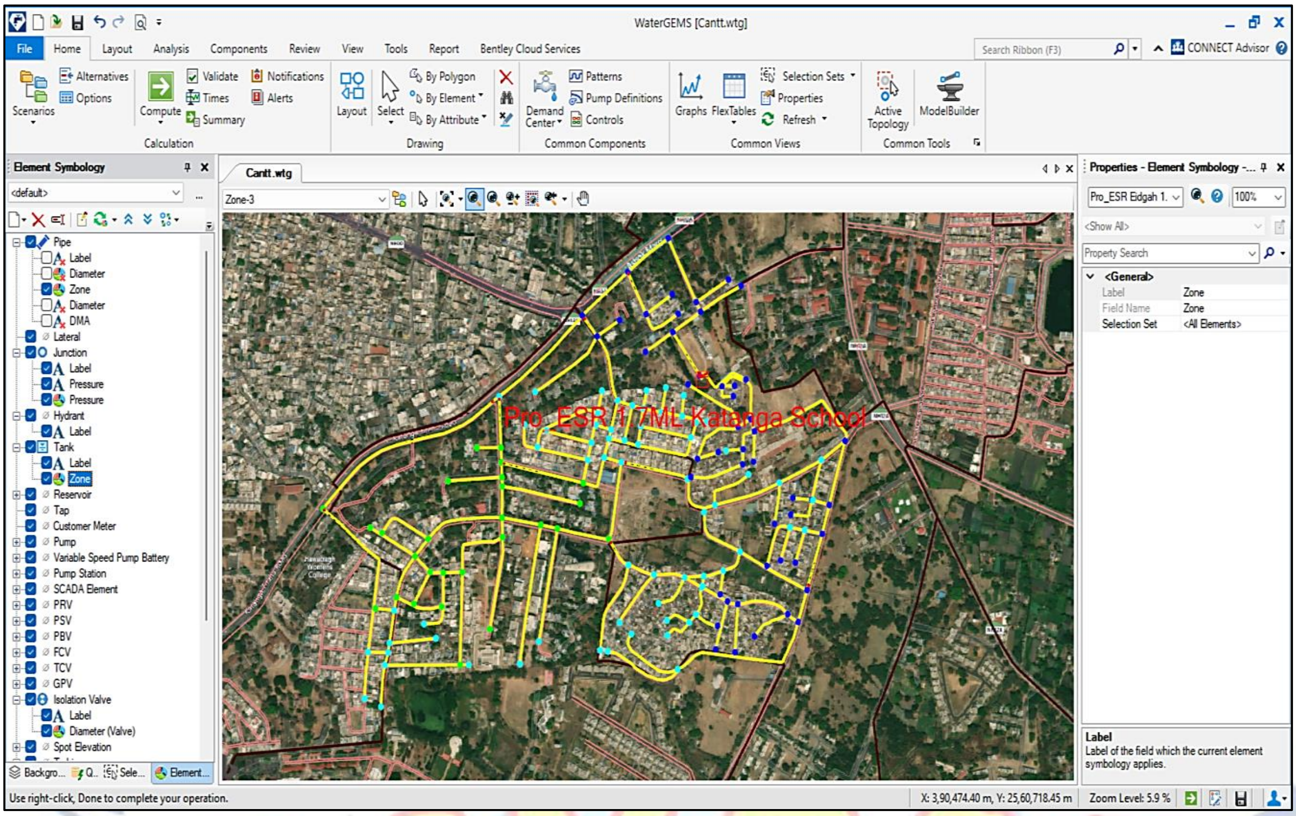
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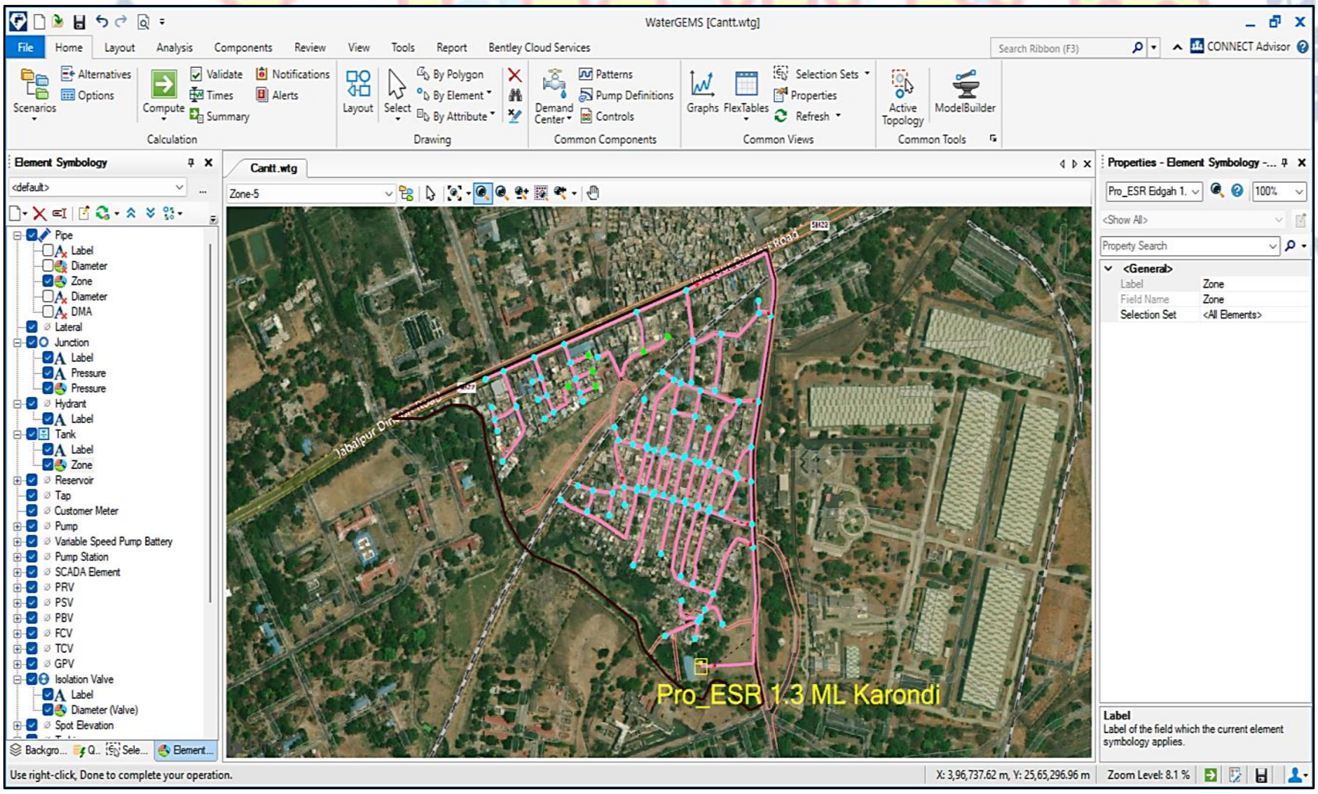
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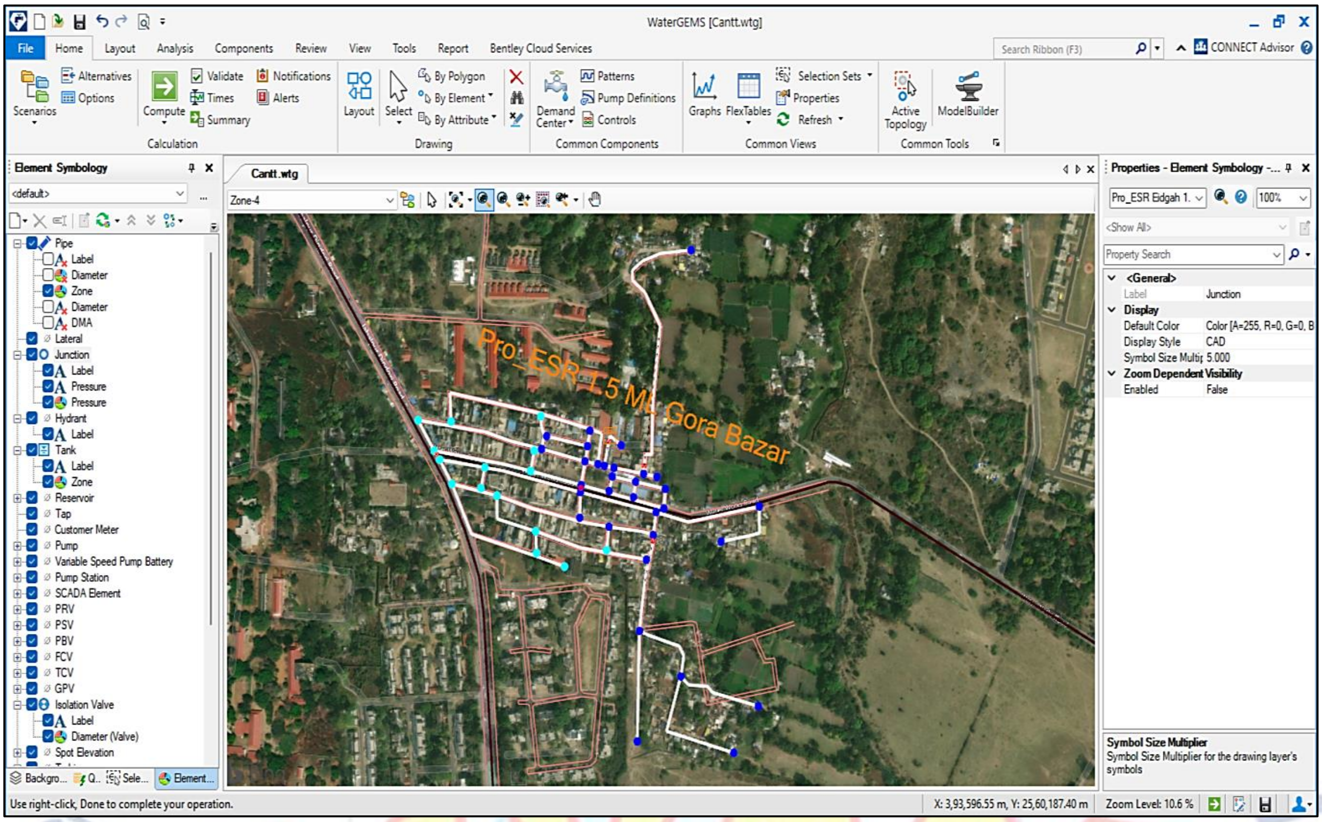

5. CONCLUSION

In concluding the hydraulic design for the Jabalpur Cantonment Board area, it is evident that a comprehensive approach has been undertaken to address the water supply needs of the community. Through meticulous analysis, innovative methodologies, and adherence to established engineering principles, this design aims to provide sustainable and resilient water infrastructure for the region. The design process began with a thorough assessment of the existing water supply system, including infrastructure, demand patterns, and potential challenges. By leveraging advanced modeling techniques and data analysis, key areas of improvement were identified, laying the foundation for targeted interventions. Throughout the design process, emphasis was placed on optimizing system efficiency, ensuring equitable distribution, and enhancing resilience to external factors such as population growth and climate variability. Innovative solutions, such as the integration of smart technologies and sustainable practices, have been incorporated to maximize the effectiveness and longevity of the water supply infrastructure. Furthermore, community engagement and stakeholder collaboration have been integral to the design process, ensuring that the needs and preferences of the local population are adequately addressed. By fostering a participatory approach, this design not only meets technical requirements but also reflects the aspirations and priorities of the community it serves. Looking ahead, it is essential to recognize that the implementation of this hydraulic design is just the beginning of a long-term commitment to water resource management in the Jabalpur Cantonment Board area. Continuous monitoring, evaluation, and adaptive management will be necessary to address evolving challenges and opportunities, ensuring the sustainability and effectiveness of the water supply system over time.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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