GIS-Integrated Hydraulic Modelling for the Regency Township Water Supply Project WaterGEMS-Based Design and Performance Assessment, Kalyan-Dombivli India

Ganesh A. Mangaonkar[1], Manjusha N. Sarnobat[2], Ashish Machhi[3], Rajesh Panandikar[4]
[1,2]Department of Civil and Environmental Engineering, Kolhapur Institute of Technology's College of Engineering, Kolhapur, (Empowered Autonomous) Maharashtra, India
[3,4]Waternet Consulting Services Pvt. Ltd., Maharashtra, India

***Abstract*—Rapid growth of peri-urban residential townships increases the technical risk of under-designed water distribution networks, particularly where static layouts are prepared without hydraulic verification. This study develops and evaluates a GIS-integrated hydraulic model for the proposed water supply system of Regency Township under Kalyan-Dombivli Municipal Corporation, Maharashtra, India. Spatial inputs were prepared using Google Earth, QGIS and AutoCAD, and the final network geometry was modelled in WaterGEMS using pipes, junctions, elevated service reservoirs and associated hydraulic attributes. Demand assessment and performance thresholds were aligned with current Indian urban water-supply guidance and service-security priorities. The system was divided into two elevated service reservoir zones: ESR-01 with 1.0 ML storage and ESR-02 with 2.0 ML storage. DI K-9 pipes of 150-400 mm diameter were adopted with a Hazen-Williams coefficient of 140. The simulated pressure range was 13.56-20.02 m H_2O in ESR-01 and 14.90-16.83 m H_2O in ESR-02, exceeding the adopted minimum residual pressure of 7 m. Main carrier pipes near the ESRs conveyed higher flows at velocities of 1.27-1.60 m/s, within the preferred 0.60-2.0 m/s design envelope. Some low-demand branch pipes produced velocities below 0.60 m/s, and selected pipes showed comparatively higher head loss gradients, indicating locations for detailed design review. The findings confirm that WaterGEMS-based pre-implementation modelling can strengthen pipe sizing, pressure adequacy checks, ESR operation and operational risk identification in township-level water supply planning.**

***Index Terms*—WaterGEMS; water distribution network; hydraulic modelling; GIS; township water supply; CPHEEO; pressure management; Kalyan-Dombivli**

I. INTRODUCTION

Safe and reliable drinking-water distribution is a core public-health and urban-service requirement. International public-health guidance identifies safe and readily available water as essential for drinking, domestic use, food production and wider health protection [1]. In India, urban water-supply planning has increasingly shifted from source creation alone toward service reliability, functional taps, distribution efficiency and water security under the AMRUT 2.0 framework for 2021-2026 [2]. Recent national guidance on water supply and treatment systems also gives renewed attention to engineering planning, demand assessment, service delivery, storage, distribution design and operation [3].

Kalyan-Dombivli Municipal Corporation (KDMC) lies within the rapidly urbanizing Mumbai Metropolitan Region, where residential townships create rising demands on municipal water-supply infrastructure. Regency Township is a developing residential area requiring a distribution network that can satisfy present demand, accommodate future growth and maintain adequate residual pressure at consumer points. Without hydraulic verification, township systems may experience low pressure, excessive head loss, uneven zoning, avoidable energy use, stagnation in low-flow pipes and increased dependence on groundwater or tanker supply.

Water distribution network (WDN) design involves hydraulic interactions among pipe diameter, pipe roughness, length, elevation, storage level, nodal demand, pump head and network topology. These interactions are difficult to judge from a two-dimensional layout alone. Modern modelling platforms therefore support engineers by translating drawings and spatial data into hydraulic systems whose pressure, flow, velocity and hydraulic grade behavior can be tested before construction. WaterGEMS provides geospatial model-building, hydraulic simulation, scenario management, optimization and asset-management capabilities for water-distribution systems [4].

The present manuscript upgrades the design-stage project report into a journal-oriented applied case-study article. The study is not framed as a conventional narrative review; it is a project-based hydraulic assessment supported by current standards, peer-reviewed literature and WaterGEMS simulation outputs. The paper demonstrates how GIS, AutoCAD and WaterGEMS can be combined to design and assess a township-scale water supply network under Indian urban conditions.

II. RESEARCH PROBLEM AND STUDY SIGNIFICANCE

The central engineering problem is whether the proposed Regency Township distribution system can supply water with adequate pressure and acceptable velocity across two ESR-fed zones. In developing residential areas, the major risk is not only water availability at the source but also hydraulic delivery at the consumer interface. A system may have sufficient source volume but still fail operationally if pipe diameters, junction demands, ESR levels or pressure zones are not properly balanced.

Recent WDN research shows that digital modelling improves the ability to test pressure sufficiency, identify vulnerable pipes, evaluate performance deterioration and support pressure-management decisions [5,6]. GIS-supported model compilation is especially useful where spatial alignment, elevations and service areas must be converted into usable hydraulic elements [7]. In township projects, this integration is valuable because roads, blocks, ESR locations and tapping points can be georeferenced before hydraulic simulation.

The significance of this study lies in its practical contribution to township infrastructure planning. Instead of relying on isolated demand calculations or manual pipe sizing, the study evaluates the complete network through hydraulic outputs. It identifies pressure adequacy, velocity compliance, high-head loss segments, low-demand branch lines and ESR performance. Such evidence is useful for design consultants, municipal engineers and academic researchers working on decentralized urban water supply systems.

III. OBJECTIVES

1. To estimate and operationalize the water distribution requirements of Regency Township and associated demand points through a hydraulic modelling framework.
2. To prepare a technically consistent water distribution layout using GIS, AutoCAD and WaterGEMS workflows.
3. To evaluate pressure, flow, velocity, hydraulic grade and head loss behavior in ESR-01 and ESR-02 zones.
4. To demonstrate the usefulness of software-based hydraulic modelling for sustainable township water supply planning.

IV. LITERATURE REVIEW

4.1 Urban water supply modelling and service reliability

Urban WDN performance is generally evaluated through pressure sufficiency, velocity compliance, flow continuity, head loss control, storage adequacy and operational reliability. The policy importance of these parameters has grown because continuous and safe water delivery is central to public health, urban equity and water security [1]. In India, AMRUT 2.0 sets a service-oriented direction for urban water security and universal household tap coverage in statutory towns [2]. Revised national water-supply guidance provides a contemporary design reference for planning, demand, storage, transmission and distribution systems [3].

In engineering terms, WDN reliability is not achieved by oversizing all pipes. It requires a balance between pressure adequacy, economic pipe sizing, acceptable velocities, leakage control and operational maintainability. Excessively high pressure may aggravate leakage and pipe failure, whereas insufficient pressure undermines service quality and public trust. Recent pressure-management literature therefore recommends system-specific evaluation rather than uniform pressure assumptions [6].

4.2 GIS-integrated model development

GIS-based workflows help transform spatial data into hydraulic model inputs. A methodological QGIS-EPANET study demonstrated that spatial processing, topology checks and engineering judgment can be integrated to create usable WDN models [7]. This is directly relevant to township settings where alignment data must pass through several stages before becoming a hydraulic network.

A further QGIS-EPANET design application demonstrated the usefulness of open-source spatial tools for pipe-sizing and pressure assessment in distribution-system planning [8]. Although the present study uses WaterGEMS rather than EPANET as the simulation platform, the underlying methodological principle is similar: spatial layouts are first prepared and cleaned, then converted into model elements with attributes such as length, diameter, elevation and nodal demand.

4.3 Hydraulic simulation platforms for WDN analysis

Hydraulic modelling tools simulate pressurized pipe networks by solving continuity and energy relationships across pipes, nodes, tanks, pumps and valves. EPANET remains a widely used open-source benchmark, and the 2020 EPANET 2.2.0 update expanded modelling capabilities for utilities and the water community [9]. GIS-supported hydraulic studies using platforms such as WaterCAD further demonstrate the value of coupling spatial data with network simulation [10]. Commercial platforms such as WaterGEMS provide additional interoperability, scenario management and model-building functions for practical design review [4].

Recent research increasingly connects hydraulic modelling with digital twins, machine learning, pressure sensors and operational analytics. State-estimation, smart-water and water-sector digital-twin studies show how hydraulic models can be extended from design verification toward continuous monitoring and operation [11-13]. These developments do not replace conventional hydraulic models; rather, they strengthen their use as calibrated decision-support tools.

4.4 Pressure, leakage and performance-oriented management

Pressure and leakage are strongly linked in distribution operation. While the present case study focuses on design-stage hydraulic adequacy rather than leakage calibration, recent literature shows that pressure management, leak detection and customer-oriented performance indicators are now central to WDN assessment [5,14,15]. These studies support a broader interpretation of the present results: identifying low-pressure nodes and high-head loss pipes during design can reduce later operational failures.

The literature also shows that hydraulic optimization is not restricted to software output reporting. Simulation-based optimization can improve pipe selection and network economics [16], while probabilistic state estimation can support uncertainty-aware WDN operations [17]. Reliability and isolation-valve studies further indicate that network resilience should be considered during detailed design and operation [18]. Therefore, the present WaterGEMS outputs should be treated as a design-stage baseline that can later be strengthened through calibration, extended-period simulation, leakage modelling and operational data integration.

V. MATERIALS AND METHODS

5.1 Study area and system configuration

The study area is the Regency Township Water Supply Project located within the administrative context of Kalyan-Dombivli Municipal Corporation, Maharashtra, India. The township is a growing residential development requiring a planned distribution system that can deliver potable water with adequate pressure and balanced flow. The proposed design is divided into two elevated service reservoir zones: ESR-01 with 1.0 ML storage capacity and ESR-02 with 2.0 ML storage capacity.

The network consists of DI K-9 pipes, junctions, branch lines, main lines, ESRs and associated hydraulic links. Pipe diameters used in the model range from 150 mm to 400 mm. The Hazen-Williams roughness coefficient for DI pipes is taken as 140, consistent with the design assumptions used in the source project data.

5.2 Data preparation workflow

The model preparation followed a sequential workflow. First, Google Earth and QGIS were used to identify the township boundary, route alignments, key locations, possible pipeline paths and spatial reference points. KML/KMZ information supported mapping and spatial review. Second, AutoCAD was used to prepare and clean the water-supply layout. Unnecessary objects, duplicate lines and irrelevant layers were removed so that the geometry could be imported into the hydraulic model. Third, the cleaned drawing was exported in a compatible DXF or shape file format for model building.

After importing the layout into WaterGEMS, hydraulic elements were checked and assigned. Pipes were attributed with length, diameter, material and Hazen-Williams coefficient. Junctions were attributed with elevation and demand. ESRs were assigned storage and level data, and hydraulic simulation was used to calculate pressure, flow, velocity, hydraulic grade and head loss gradients. The combined workflow is shown in Figure 1.

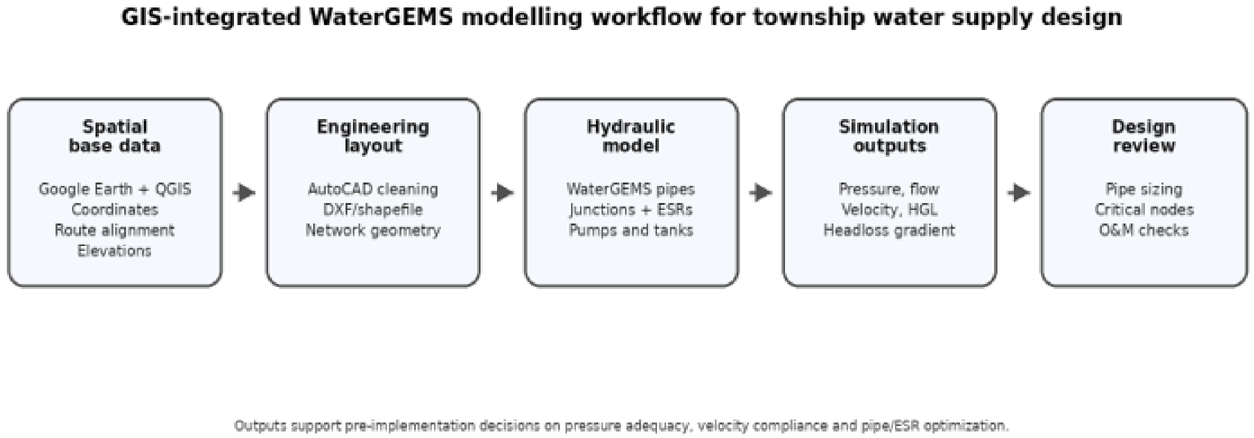

Figure 1. GIS-integrated workflow for WaterGEMS-based hydraulic modelling of the Regency Township Water Supply Project.

5.3 Design criteria and hydraulic checks

The design checks were aligned with contemporary water-supply planning principles, national water-supply design guidance and the source project's adopted thresholds [3]. The minimum residual pressure considered for the main line and UG tank level was 7 m. The preferred velocity range was 0.60-2.0 m/s. The head loss gradient was interpreted against a general design expectation of lower values in transmission or feeder mains and acceptable higher values in distribution sections, with careful review of pipes showing comparatively higher losses.

The model was assessed under the available design condition. The analysis focused on whether the system could maintain adequate pressure at all reported junctions, whether pipe velocities remained within or near the preferred design envelope, whether selected pipes produced excessive head loss, and whether the ESR levels provided adequate hydraulic grade for downstream supply.

Table 1. Model-development workflow, data inputs and hydraulic outputs.

Stage	Tool/Platform	Primary inputs	Hydraulic/design output
Spatial identification	Google Earth, QGIS	Township location, route alignments, coordinates, ESR and source locations	Mapped network base and spatial reference
Layout preparation	AutoCAD	Cleaned distribution layout, pipeline alignment, junction locations	DXF/shape file for model import

Stage	Tool/Platform	Primary inputs	Hydraulic/design output
Hydraulic model building	WaterGEMS	Pipes, nodes, ESRs, diameter, material, length, elevation, demand	Connected hydraulic network
Simulation and review	WaterGEMS outputs	Design criteria for pressure, velocity and headloss	Critical pipes, junction pressures, ESR outflows and optimization points

VI. RESULTS

6.1 Pipe network characteristics

The proposed distribution network uses DI K-9 pipes with diameters between 150 mm and 400 mm. In ESR-01, pipe diameters of 150, 200, 250, 300, 350 and 400 mm are used. Smaller diameters serve branch distribution sections, whereas 350-400 mm pipes carry higher flow near the ESR and main distribution paths. Pipe P-65 from T-1 ESR to J-47 is a 400 mm pipe carrying 163 L/s at 1.30 m/s with a head loss gradient of 3.408 m/km. Pipe P-66 from J-47 to J-12 is also a 400 mm pipe carrying 160 L/s at 1.27 m/s with a head loss gradient of 3.289 m/km.

In ESR-02, diameters of 150, 250, 300, 350 and 400 mm are used. Pipe P-53 from J-37 to T-2 ESR is a 400 mm pipe carrying approximately 201 L/s at 1.60 m/s with a head loss gradient of 5.020 m/km. Pipe P-52 from J-35 to J-37 is a 350 mm pipe carrying 146 L/s at 1.52 m/s with a head loss gradient of 5.325 m/km. These results show that the larger main pipes near ESR-02 carry higher flows while remaining within the velocity criterion.

Some negative flow signs appear in the WaterGEMS output. These values do not indicate hydraulic failure; they show that the computed flow direction is opposite to the direction in which the pipe was drawn. This is a normal interpretation issue in hydraulic model reporting and should be checked through network arrows or flow-direction symbols during final review.

Table 2. WaterGEMS-simulated pipe hydraulic outputs for selected critical pipes.

Zone	Pipe	Diameter (mm)	Flow (L/s)	Velocity (m/s)	Head loss gradient (m/km)	Design interpretation
ESR-01	P-65	400	163	1.30	3.408	Acceptable velocity; moderate head loss.
ESR-01	P-66	400	160	1.27	3.289	Acceptable velocity; moderate head loss.
ESR-01	P-62/P-63	150	3	0.18	0.265	Low velocity; review flushing/water age.
ESR-01	P-67	300	97	1.37	5.293	Higher head loss; check peak demand.
ESR-02	P-53	400	201	1.60	5.020	Acceptable velocity; review head loss.
ESR-02	P-52	350	146	1.52	5.325	Review head loss during final sizing.
ESR-02	P-54	150	6	0.35	0.965	Low flow; operational review.

6.2 Junction pressure and hydraulic grade

The junction pressure results indicate that both ESR zones satisfy the adopted minimum residual pressure of 7 m under the analyzed condition. In ESR-01, simulated pressure ranges from 13.56 m H_2O at J-42/Village to 20.02 m H_2O at J-8. Other representative values include 17.83 m H_2O at J-1, 15.71 m H_2O at J-2, 16.54 m H_2O at J-6, 19.00 m H_2O at J-44/Village and 14.12 m H_2O at J-50/Village. In ESR-02, simulated pressure ranges from 14.90 m H_2O at J-39 to 16.83 m H_2O at J-37. Representative values include 16.03 m H_2O at J-15, 16.15 m H_2O at J-16, 16.55 m H_2O at J-21, 15.69 m H_2O at J-24, 15.46 m H_2O at J-28 and 16.02 m H_2O at J-38

Regency Onyx. These values show adequate pressure distribution, but the lower-pressure junctions should still be checked under peak demand and low-tank-level scenarios.

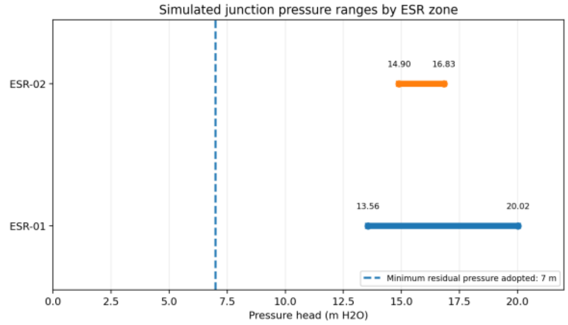

Figure 2. Junction-pressure ranges for ESR-01 and ESR-02 compared with the adopted minimum residual pressure threshold of 7 m.

Table 3. Pressure-performance summary by ESR zone.

Zone	Elevation range (m)	Pressure range (m H_2O)	Minimum pressure junction	Maximum pressure junction	Compliance status
ESR-01	14.35-19.80	13.56-20.02	J-42/Village	J-8	Above 7 m residual pressure
ESR-02	19.85-22.06	14.90-16.83	J-39	J-37	Above 7 m residual pressure

6.3 Velocity and head loss behavior

Velocity in ESR-01 ranges from 0.18 m/s to 1.37 m/s, while ESR-02 ranges from approximately 0.35 m/s to 1.60 m/s in the available output. Most pipes fall within the preferred 0.60-2.0 m/s design envelope. Low velocities occur in selected terminal or low-demand branches where minimum diameter constraints and small assigned demand produce slow flow. Such pipes may remain hydraulically acceptable but should be examined for stagnation, flushing requirements and water-age implications in future extended-period analysis.

Head loss gradients vary according to pipe length, diameter and flow. Most reported values remain acceptable for a distribution network. However, P-3, P-52, P-53, P-67 and P-69 show values around or above 5 m/km. These pipes should be treated as design-review points because excessive headloss can reduce downstream pressure when demands increase or ESR levels decline.

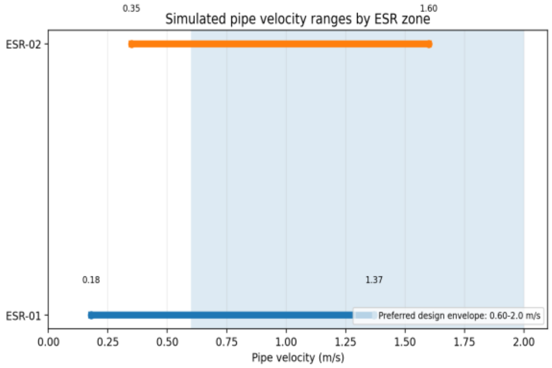

Figure 3. Pipe-velocity ranges for ESR-01 and ESR-02 compared with the preferred 0.60-2.0 m/s design envelope.

6.4 ESR and storage performance

The tank output indicates that both ESRs were modelled with a base elevation of 18 m, a minimum elevation of 38 m, an initial elevation of 38.15 m and a maximum elevation of 43 m. The hydraulic grade for both ESRs is 38.15 m under the reported condition. T-1 ESR of 1.0 ML shows a net outflow of 162.96 L/s, while T-2 ESR of 2.0 ML shows a net outflow of 200.86 L/s. The higher flow from ESR-02 reflects its larger storage capacity and connected demand zone.

The ESR levels directly influence downstream pressure. If the tank level falls substantially, pressure at critical downstream or higher-elevation nodes may reduce. Therefore, the reported steady output should be complemented during detailed design by extended-period simulation, operational pattern testing and low-level tank scenarios.

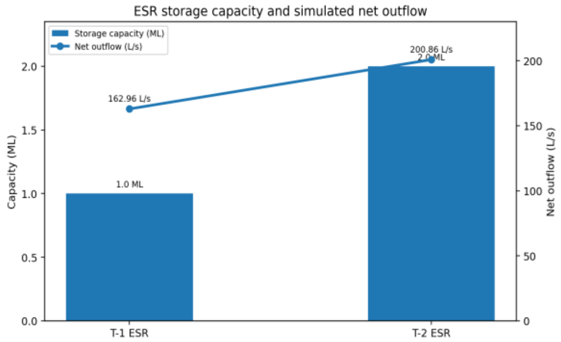

Figure 4. ESR storage capacity and simulated net outflow for T-1 and T-2.

Table 4. ESR hydraulic-output summary.

ESR	Capacity (ML)	Base elevation (m)	Minimum level (m)	Initial level (m)	Maximum level (m)	Net outflow (L/s)
T-1 ESR	1.0	18	38	38.15	43	162.96
T-2 ESR	2.0	18	38	38.15	43	200.86

VII. DISCUSSION

7.1 Hydraulic adequacy of the proposed network

The results show that the proposed water distribution system is hydraulically workable under the analyzed design condition. Both ESR zones maintain pressure values above the adopted 7 m residual pressure threshold. This is a positive finding for the feasibility of the proposed layout. The pressure margins are stronger in ESR-01 than in ESR-02, but both zones remain within a functional range. The lowest-pressure points, J-42/Village and J-50/Village in ESR-01 and J-39 in ESR-02, should be priority nodes during final scenario testing.

The main pipes near ESR outlets are sized to carry high flows at velocities that remain within the preferred range. P-65, P-66, P-52 and P-53 demonstrate that the selected main diameters are capable of transmitting the required flows without exceeding the upper velocity limit. This is important because velocities above the recommended range can increase head loss, transient risks and operational stress.

7.2 Low-velocity branches and operational implications

The major caution emerging from the model concerns low-velocity branch lines. Pipes P-62 and P-63 in ESR-01 and P-54 in ESR-02 show velocities below the preferred lower limit. Low velocity is not automatically a design failure, particularly where minimum pipe diameter is used for constructability, future demand or local regulations. However, sustained low velocity can contribute to water-age concerns, sediment deposition and inadequate turnover. Contemporary WDN performance literature increasingly recognizes that hydraulic adequacy should include customer-oriented and pipe-level indicators rather than pressure alone [5].

For Regency Township, the low-velocity pipes should be reviewed through extended-period simulation with diurnal demand patterns. If low turnover persists, design options may include local demand reassignment, loop closure, staged diameter optimization, terminal flushing arrangements or future-demand justification.

7.3 Head loss and final pipe optimization

Head loss gradients around 5 m/km in selected pipes should be interpreted carefully. In distribution networks, such values may still be acceptable, but they indicate sections where friction loss is relatively higher. P-3, P-52, P-53, P-67 and P-69 should be checked under peak factor, lower ESR levels and future demand. If downstream pressures remain adequate in these scenarios, the design may be retained. If pressures fall close to the threshold, upsizing, route adjustment or zoning revision may be needed.

This result is consistent with simulation-based optimization literature, which shows that pipe sizing should balance pressure adequacy and economic efficiency rather than simply maximizing diameters [16]. A practical design should therefore treat WaterGEMS outputs as a screening layer for engineering judgment.

7.4 Contribution to sustainable township water management

The study contributes to sustainable township water management by demonstrating a pre-implementation verification procedure. Reliable municipal supply can reduce unnecessary dependence on groundwater extraction and tanker delivery, both of which may carry social, environmental and cost burdens. The use of model-based planning also helps identify design risks before construction, reducing rework and supporting more accountable infrastructure decisions.

Recent reviews and digital-operation studies link WDN modelling with digital transformation, including leak analytics, digital twins, sensor networks and data-driven operations [13,14,19]. The present study provides a baseline model that can evolve into an operational model if calibrated with field pressure, flow, pump and tank-level data.

VIII. PRACTICAL DESIGN RECOMMENDATIONS

1.Conduct extended-period simulation using realistic diurnal demand patterns, pump operation schedules and minimum/maximum ESR levels.
2.Priorities detailed review of low-pressure junctions: J-42/Village, J-50/Village and J-39.
3.Review higher-head loss pipes P-3, P-52, P-53, P 67 and P-69 under peak demand and future-growth scenarios.
4.Assess low-velocity branches P-62, P-63 and P-54 for water age, flushing requirement and future demand justification.
5.Calibrate the model after commissioning using field-measured pressure, flow and ESR-level data.
6.Integrate leakage monitoring, pressure management and periodic hydraulic model updating into the township's operation and maintenance plan.
7.Maintain a GIS-linked asset database so that future repairs, extensions and demand changes can be reflected in the hydraulic model.

IX. LIMITATIONS AND FUTURE SCOPE

This manuscript is based on the available design-stage WaterGEMS output. It does not include field calibration, measured pressure logging, leakage estimation, water-quality simulation, pump energy optimization or transient/surge analysis. The results should therefore be interpreted as a design-stage hydraulic adequacy assessment, not as a full operational validation of the completed network.

Future work should include extended-period simulation, demand pattern development, pressure-dependent demand analysis, water-age modelling, leakage scenario testing, pump energy assessment, high-frequency pressure-sensing diagnostics and calibrated comparison with field data after commissioning [20]. A further publication could compare WaterGEMS outputs with EPANET or another hydraulic solver to strengthen methodological reproducibility.

X. CONCLUSION

The GIS-integrated WaterGEMS analysis of the Regency Township Water Supply Project demonstrates that the proposed distribution network is hydraulically workable under the analyzed design condition. The network is divided into two ESR zones with 1.0 ML and 2.0 ML storage capacities. DI K-9 pipes of 150-400 mm diameter provide the primary distribution infrastructure, and the main carrier pipes near the ESRs convey high flows at velocities within the preferred design range.

The pressure results are satisfactory. ESR-01 maintains 13.56-20.02 m H_2O and ESR-02 maintains 14.90-16.83 m H_2O, both above the adopted 7 m residual pressure threshold. The velocity analysis also shows general compliance, although selected low-demand branch pipes fall below 0.60 m/s and should be reviewed during final design. Head loss gradients are mostly acceptable, but pipes with values around or above 5 m/km should be checked under peak and future-demand scenarios.

Overall, the study supports software-based hydraulic modelling as a practical and publishable approach for township water supply design. By integrating GIS, AutoCAD and WaterGEMS, engineers can test pressure adequacy, pipe sizing, ESR performance and operational risks before implementation. The approach is especially relevant for rapidly urbanizing Indian townships where reliable municipal supply is necessary to reduce groundwater and tanker dependence and to improve long-term water security.

XI. DECLARATIONS

Funding: No external funding information was provided in the source manuscript.

Conflict of interest: The authors should declare any institutional or consultancy interests before submission. No conflict statement was provided in the source manuscript.

Data availability: The hydraulic summary data used in this manuscript are reported in the tables and figures. The WaterGEMS model, GIS files and AutoCAD layouts should be made available by the corresponding author upon reasonable request, subject to client and institutional permissions.

Ethics approval: Not applicable. The study uses engineering design and hydraulic modelling data and does not involve human participants or animal subjects.

Author contributions: Ganesh A. Mangaonkar contributed to data collection, layout preparation, WaterGEMS modelling, hydraulic analysis and manuscript preparation. Manjusha N. Sarnobat supervised the academic methodology and reviewed the manuscript. Ashish Machhi and Rajesh Panandikar provided industry inputs and technical review for practical water supply design. All authors should review and approve the final version before submission.

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