



# Conceptual Engineering Design of a High-Head, Low-Flow Community-Based Clean Water Supply System in Galiukir Indigenous Village, Bali

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**Abstract.** Clean water supply in Galiukir Indigenous Village, Bali, is constrained by a large elevation difference, a long transmission pipeline, limited source yield, and inadequate existing pump head. This study develops a conceptual engineering design for a community-based high-head, low-flow water supply system serving 150 households or approximately 600 residents. Based on a domestic water consumption of 60 L/person/day and an assumed 1% water loss, the average design demand is 36.36 m<sup>3</sup>/day (0.421 L/s). The primary source yield of 0.27 L/s is insufficient to meet this demand, whereas the combined primary and secondary sources provide approximately 0.47 L/s or 40.61 m<sup>3</sup>/day. The hydraulic analysis was performed using the Darcy–Weisbach method for a PE100 DN/OD63 SDR11 PN16 transmission pipe with a length of approximately 910 m and a static elevation head of 136 m. At an upper conceptual flow of 0.50 L/s, the calculated major and minor head losses are approximately 1.55 m and 0.03 m, respectively, resulting in a steady-state total dynamic head of approximately 137.58 m. A 15% conceptual equipment-selection allowance gives a preliminary pump-selection head of approximately 158–160 m. Preliminary water-hammer screening indicates a peak pressure of approximately 14.21–14.33 bar, which remains below the nominal PN16 pressure class but requires further transient verification. The proposed configuration therefore adopts a variable-speed high-head multistage centrifugal pump supported by pressure monitoring, non-slam check valve, dry-run protection, air-release and washout valves, and reservoir-level control. The proposed design provides a technically quantified basis for subsequent detailed design, pump-curve verification, transient hydraulic analysis, and field commissioning.

**Keywords:** Community-Managed Rural Water Supply, High-Head Pumping, Hydraulic System Curve, PE100 Pressure Pipeline, Source-Limited Water Supply

## 1 Introduction

Access to clean water is an essential requirement for public health, sanitation, household activities, and community welfare. In rural areas, clean water distribution is commonly constrained by source availability, topography, pipeline length, pressure losses, reservoir capacity, water quality, technology suitability, and community-based

operation capacity. Previous studies on rural water supply systems emphasize that planning should integrate source discharge, pumping method, pipe network configuration, reservoir function, technology selection, and community participation to ensure service reliability and long-term sustainability (Prasetiyowati & Indrawati, 2021; Wigati et al., 2023; Wispriyono et al., 2022)

To ensure technical compliance and operational safety, system planning must align with established regulatory frameworks and standard specifications. In Indonesia, the regulatory basis for Drinking Water Supply Systems (SPAM) is governed by Government Regulation (PP) No. 122/2015, alongside Ministry of Public Works and Housing (PUPR) Regulations No. 27/PRT/M/2016 and No. 4/2020 concerning implementation standards and standard operating procedures. Technical design of distribution networks and overall SPAM planning refer to SNI 7509:2011 and SNI 7831:2012, respectively. Furthermore, piping material specifications for polyethylene (PE) pipes and fittings must comply with the relevant SNI series and ISO 4427, while performance validation of rotodynamic pumps adheres to ISO 9906:2012. Recent literature underscores the importance of advanced modeling in rural network design; for instance, Urszula & Deska (2025) demonstrated the application of hydraulic modeling for the conceptual planning and reconstruction of rural water supply networks, whereas (Sradomski et al., 2025) highlighted the necessity of transient and water hammer analysis in rising pipelines to ensure structural reliability under dynamic operating conditions.

Galiukir Indigenous Village, located in a hilly area of Kebon Padangan Village, Pupuan District, Tabanan Regency, Bali, relies on an existing clean water supply system comprising local water sources, a lower reservoir, a pump, transmission piping, and an upper reservoir. The system is designed to serve approximately 150 households (600 residents at 4 persons per household) with an average design demand of 36.36 m<sup>3</sup>/day (0.421 L/s), calculated from a domestic unit demand of 60 L/person/day (36.0 m<sup>3</sup>/day) and an assumed 1% water loss; however, water distribution remains unstable across several service areas. These performance issues align with broader rural water supply challenges documented in previous studies, where service reliability is frequently compromised by inadequate infrastructure, limited source discharge, insufficient pressure, seasonal water scarcity, and weak management capacity (Kartikasari & Nafi'iyah, 2019; Utama, 2021).

The previous feasibility assessment primarily identified the hydraulic inadequacy of the existing system, particularly the mismatch between the approximately 80 m pump head and the approximately 136 m static elevation difference. However, it did not translate these findings into an integrated engineering configuration considering community demand, daily source yield, storage, hydraulic losses, operating schedule, pressure safety, control philosophy, and community-based maintenance. The present study therefore addresses this gap by developing a conceptual engineering design that converts the feasibility findings into an integrated and technically assessable system configuration.

The expected outputs therefore include the design basis, demand–source water balance, preliminary hydraulic calculations, system configuration, preliminary equipment specifications, pressure-control philosophy, alternative configuration

screening, conceptual drawings, pumping schedule, and community operation and maintenance framework. Final construction drawings, vendor-certified equipment data, detailed bill of quantities, and construction cost estimates remain outside the present conceptual design scope.

## 2 Methodology

This study applied a community-based technical assistance approach within a conceptual engineering design framework, integrating field assessment, preliminary engineering analysis, system configuration, and operation and maintenance planning. Community participation was incorporated to ensure compatibility with local operating capacity and existing infrastructure. Similar approaches in rural water supply planning combine field surveys, source assessment, community discussion, technical design, technology selection, and operational planning to identify appropriate infrastructure solutions (Prasetiyowati & Indrawati, 2021; Wigati et al., 2023; Wispriyono et al., 2022). The conceptual engineering design was developed through seven sequential stages: (1) field-system characterization; (2) service-demand assessment; (3) source-yield and storage water-balance analysis; (4) steady-state hydraulic calculation of the transmission line; (5) preliminary pump and pressure-pipe selection; (6) comparative screening of alternative pumping configurations; and (7) development of the operating, protection, and community-maintenance philosophy.

Field measurements were conducted in June 2026. Elevation was measured using an elevation application with 98% accuracy, while source discharge was measured five times using a 5-L container. Pipe dimensions and pressure ratings were verified from the measured outer diameter and manufacturer markings. Field observations covered the water sources, reservoirs, pump, control panel, piping arrangement, valves, pipeline route, pipe size, and safety devices. The existing SHIMGE BLT16-8 multistage centrifugal pump has a 7.5 kW motor, operates at 2900 rpm with a 380 V three-phase supply, and provides an estimated head of 80 m with a nominal discharge of approximately 16 m<sup>3</sup>/h.

Technical problem identification was performed by comparing the existing system condition with the actual field requirements. The main parameters considered were elevation difference, pipe length, pipe diameter, source discharge, pump head, reservoir capacity, pipe pressure rating, and safety protection. The lower reservoir or source collection point is located at approximately 544 m above sea level, while the upper reservoir is located at approximately 680 m above sea level. Therefore, the static elevation difference is approximately 136 m. The total pipeline distance from the lower reservoir to the upper reservoir is approximately 910 m. The existing transmission line was represented in the conceptual engineering calculation by a PE100 DN/OD 63 mm, SDR11, PN16 polyethylene pipe complying with the SNI 4829/ISO 4427 piping-system series. With a nominal outside diameter of 63 mm and wall thickness of approximately 5.8 mm, the hydraulic internal diameter adopted for calculation was approximately 51.4 mm.

The design concept emphasized a community-friendly system that could be locally implemented and maintained. Hydraulic planning considered flow rate, pipe diameter, pressure requirements, reservoir function, head loss, and distribution reliability (Intansari & Susanto, 2021; Kartikasari & Nafi'iyah, 2019). Hydraulic simulation and design evaluation were also used to assess pipe velocity, head-loss gradient, pressure, and service coverage against planning criteria (Abriani et al., 2021; Muflih et al., 2024)

Hydraulic losses were evaluated using the Darcy–Weisbach equation, with the friction factor estimated using the Swamee–Jain correlation (Al-zaidi et al., 2023). The calculation adopted a PE100 DN/OD 63 mm SDR11 PN16 pipe ( $D_i = 51.4$  mm), an equivalent roughness of 0.007 mm, and a design flow of 0.50 L/s. Minor losses were estimated using a lumped coefficient of  $\Sigma K=10$ , representing valves, bends, entrance/exit effects, and other fittings at the conceptual-design stage. The resulting major and minor losses were approximately 1.55 m and 0.03 m, respectively. With a static head of 136 m, the steady-state TDH was approximately 137.58 m. A 15% allowance was applied for preliminary pump selection, giving a selection head of approximately 158–160 m.

$$h_f = f \frac{L}{D} \frac{v^2}{2g} \quad (1)$$

$$h_m = \Sigma K \frac{v^2}{2g} \quad (2)$$

$$H_{TDH} = \Delta z + h_f + h_m \quad (3)$$

For  $Q = 0.5$  L/s,  $D_i = 51.4$  mm,  $\mathcal{E} = 0.007$  mm,  $f = 0.0295$ , and  $\Sigma K = 10$ , the calculated major loss, minor loss, and TDH were 1.55 m, 0.03 m, and 137.58 m, respectively; a 15% conceptual pump-selection allowance increased the preliminary selection head to approximately 158–160 m.

### 3 Results and Discussion

#### 3.1 Conceptual Design Basis Derived from the Feasibility Assessment

The conceptual engineering design was developed from the initial feasibility assessment, which identified the system as a low-flow, high-head pumping system due to the large elevation difference between the lower and upper reservoirs and the limited source discharge. This design basis is consistent with rural water supply studies highlighting topography, source discharge, pipeline length, reservoir location, technology suitability, and community management as key factors in system selection (Prasetyowati & Indrawati, 2021; Utama, 2021; Wigati et al., 2023)

The system is designed to serve 150 households or approximately 600 residents. Based on a domestic consumption of 60 L/person/day and an assumed 1% water loss, the average design demand is approximately 36.36 m<sup>3</sup>/day, equivalent to 0.421 L/s. The primary source provides approximately 23.33 m<sup>3</sup>/day (0.27 L/s), which is insufficient to meet the daily demand. When the secondary source of 0.20 L/s is included, the combined source yield increases to approximately 40.61 m<sup>3</sup>/day (0.47 L/s), providing

a nominal surplus of approximately 4.25 m<sup>3</sup>/day. The 9 m<sup>3</sup> lower reservoir acts as a source buffer, while the 90 m<sup>3</sup> upper reservoir provides storage equivalent to approximately 2.5 days of average demand. At a conceptual pumping rate of 0.50 L/s, approximately 20.2 h/day of cumulative pump operation is required to transfer the daily design demand.

The service-demand and source-capacity relationship forming the principal water-balance basis of the conceptual design is summarized in Table 1.

**Table 1.** Linkage between feasibility findings and conceptual design responses

| Parameter         | Value                     |
|-------------------|---------------------------|
| Population served | 600 persons               |
| Demand            | 36.36 m <sup>3</sup> /day |
| Source yield      | 40.61 m <sup>3</sup> /day |
| Storage           | 9 + 90 m <sup>3</sup>     |
| Pumping condition | 0.50 L/s                  |

Based on these findings, the conceptual design should prioritize a balanced system in which pump operation is matched with source availability, reservoir capacity, hydraulic requirements, pressure safety, and local operating capacity. The system should not be designed merely to maximize pumping discharge, but to match pump operation with source availability, reservoir capacity, and pipe pressure safety.

### 3.2 Preliminary Hydraulic Design for the Low-Flow, High-Head Pumping System

At the upper conceptual flow of 0.50 L/s, the calculated velocity in the PE100 DN/OD 63 mm SDR11 pipe ( $D_i = 51.4$  mm) is approximately 0.241 m/s. Using the Darcy–Weisbach method, the major and minor head losses along the 910 m transmission line are approximately 1.55 m and 0.03 m, respectively. Therefore, the steady-state total dynamic head is 137.58 m. Applying a 15% conceptual pump-selection allowance gives approximately 158.2 m, which is rounded to 160 m. The 160 m value therefore represents a preliminary pump-selection envelope rather than the continuous operating head of the pipeline.

The calculated velocity of approximately 0.241 m/s is relatively low and results from the limited source yield combined with the existing DN/OD 63 mm transmission pipe. Although this condition produces low friction losses, it may increase the potential for sediment deposition, trapped air at pipeline high points, and increased hydraulic residence time. The low velocity is therefore considered a source-constrained operating condition rather than an optimum design velocity. Air-release valves at local high points, washout valves at low points, and periodic flushing are consequently included in the conceptual design to mitigate these operational risks. (Intansari & Susanto, 2021; Kartikasari & Nafi'iyah, 2019; Prasetyowati & Indrawati, 2021). The preliminary hydraulic design basis for the proposed conceptual system is presented in Table 2.

**Table 2.** Preliminary Hydraulic Design Parameters and Calculated Performance

| Parameter                 | Value / design basis          | Design implication                 |
|---------------------------|-------------------------------|------------------------------------|
| Lower reservoir elevation | 544 m a.s.l.                  | Pump suction reference             |
| Upper reservoir elevation | 680 m a.s.l.                  | Delivery elevation                 |
| Static head               | 136 m                         | Dominant hydraulic load            |
| Transmission length       | 910 m                         | Head-loss calculation              |
| Pipe specification        | PE100 DN/OD63 SDR11 PN16      | Pressure transmission line         |
| Wall thickness            | 5.8 mm                        | Pipe geometry                      |
| Internal diameter         | 51.4 mm                       | Hydraulic calculation              |
| Upper conceptual flow     | 0.50 L/s                      | Calculation condition              |
| Flow velocity             | 0.241 m/s                     | Source-constrained low velocity    |
| Reynolds number           | $\approx 1.23 \times 10^4$    | Flow regime                        |
| Darcy friction factor     | $\approx 0.0295$              | Darcy–Weisbach calculation         |
| Major head loss           | 1.55 m                        | Pipe friction                      |
| Minor head loss           | 0.03 m                        | Local fittings                     |
| Steady-state TDH          | 137.58 m                      | Required hydraulic head            |
| Maximum steady pressure   | $\approx 13.49$ bar           | Near pump discharge                |
| Pump-selection allowance  | 15%                           | Conceptual equipment margin        |
| Pump-selection envelope   | $\approx 158$ – $160$ m       | Preliminary pump selection         |
| Surge pressure increment  | $\approx 0.72$ – $0.84$ bar   | Preliminary water-hammer screening |
| Screening peak pressure   | $\approx 14.21$ – $14.33$ bar | PN16 verification basis            |

### 3.3 Proposed Conceptual System Configuration and Components

Three conceptual pumping arrangements were considered. A single multistage pump requires approximately 137.6 m TDH at 0.50 L/s. Two pumps operating in series at the lower station could theoretically share the required head at approximately 69 m per pump; however, the combined head and maximum downstream pipeline pressure would remain essentially unchanged while the number of pumps and controls would increase. Alternatively, a two-stage system with an intermediate break-pressure reservoir located approximately halfway through the elevation rise could reduce the required static lift to approximately 68–69 m per stage, but would require an additional reservoir, second pump set, electrical supply, control system, land, and maintenance. Therefore, a single variable-speed multistage pump is retained as the preferred conceptual configuration because it provides the simplest community-operated arrangement, subject to final verification of pipeline pressure and transient conditions.

The conceptual system consists of an integrated arrangement featuring a lower reservoir or source collection tank, a variable-speed high-head multistage centrifugal pump, PE/HDPE transmission piping, isolation and non-slam check valves, control valves, pressure and flow monitoring, air release and washout valves, dry-run protection, reservoir level controls, and a simplified electrical control panel, as summarized in Table 3. This configuration aligns with established rural water supply and SPAM expansion planning practices that integrate pumping units, pipelines, reservoirs, flow/pressure control devices, and treatment units into a functional system to enhance service reliability (Intansari & Susanto, 2021; Prasetyowati & Indrawati, 2021; Utama & Ariyadi, 2022). Hydraulically, the pump is specified for a normal target flow of approximately 0.45–0.47 L/s and an upper calculation flow of 0.50 L/s at 138–145 m Total Dynamic Head (TDH), operating with a preliminary 2.2–3.0 kW motor

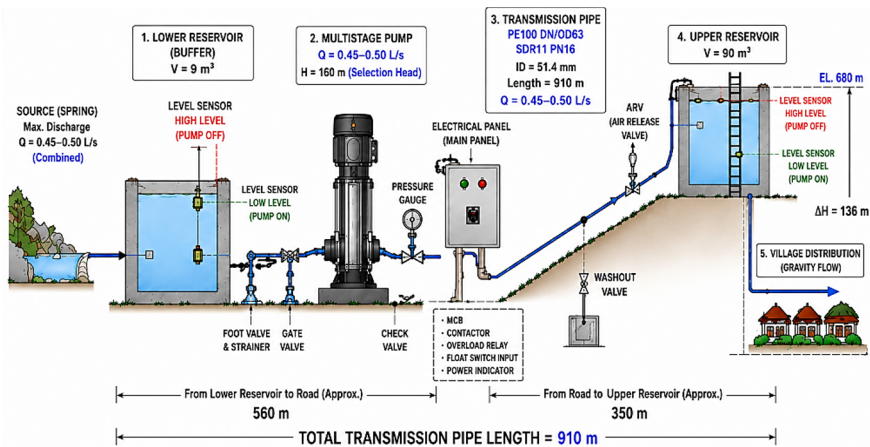
rating subject to the final manufacturer curve. The transmission line utilizes PE100 DN/OD 63 mm, SDR11, PN16 piping complying with the SNI 4829/ISO 4427 series, equipped with a pump discharge assembly consisting of DN50 isolation/check valves, a 0–25 bar pressure gauge, flow monitoring, air-release valves at local high points, and washout valves at low points. Serving as the primary storage before gravity-based distribution to service areas, the upper reservoir operates alongside lower-reservoir level control logic-conceptually stopping the pump at 20–25% lower-reservoir usable level and enabling restart above 40%, while stopping near 90% and restarting at 60–70% in the upper reservoir, subject to final commissioning adjustments. The Preliminary system component specifications and control settings are summarized in Table 3.

**Table 3.** Preliminary System Component Specifications And Control Settings

| Component               | Preliminary specification                       | Location / control function     |
|-------------------------|-------------------------------------------------|---------------------------------|
| Lower reservoir         | Existing, 9 m <sup>3</sup>                      | Source buffer                   |
| Pump                    | Vertical multistage centrifugal, VFD-controlled | Lower reservoir pump station    |
| Normal pump flow        | 0.45–0.47 L/s                                   | Match combined source yield     |
| Upper calculation flow  | 0.50 L/s                                        | Hydraulic design case           |
| Required operating TDH  | ≈137.6–145 m                                    | Pump duty region                |
| Pump-selection envelope | ≈158–160 m                                      | Preliminary equipment selection |
| Motor                   | ≈2.2–3.0 kW                                     | Subject to manufacturer curve   |
| Transmission pipe       | PE100 DN/OD63 SDR11 PN16                        | 910 m transmission line         |
| Isolation valve         | Approx. DN50                                    | Pump maintenance isolation      |
| Non-slam check valve    | Approx. DN50                                    | Pump discharge                  |
| Air-release valve       | At local high points                            | Air removal                     |
| Washout valve           | At local low points                             | Sediment flushing               |
| Electrical control      | VFD + overload/phase protection                 | Pump station                    |

*Note : All specifications and control set points are preliminary conceptual values and shall be verified during detailed design*

A preliminary water-hammer screening was performed using the Joukowsky relationship (Kandil et al., 2024). For the calculated flow velocity of 0.241 m/s and a conceptual PE wave-celerity sensitivity range of 300–350 m/s, an instantaneous reduction of flow velocity to zero produces a surge-head increment of approximately 7.37–8.60 m, corresponding to approximately 0.72–0.84 bar. When added to the calculated maximum steady pressure of approximately 13.49 bar, the preliminary peak pressure becomes approximately 14.21–14.33 bar. This value remains below the nominal PN16 pressure class; however, PN16 is retained only as the conceptual baseline because the final transient response also depends on pump shut-off head, actual pipe condition, valve-closure characteristics, pump inertia, temperature effects, and the detailed elevation profile. Final pipe-class acceptance therefore requires manufacturer pump-curve verification and transient hydraulic analysis (Intansari & Susanto, 2021; Prasetyowati & Indrawati, 2021). A variable-frequency drive, non-slam check valve, pressure monitoring, and controlled pump acceleration/deceleration are therefore recommended to reduce transient-pressure risk. The design concept is shown in Figure 1.



**Figure 1.** Conceptual configuration of the proposed high-head, low-flow water supply system.

### 3.4 Conceptual Operation, Safety Control, and Community Maintenance Strategy

At a pump flow of 0.50 L/s (1.80 m<sup>3</sup>/h), approximately 20.2 h/day of cumulative pump operation is required to deliver the average design demand of 36.36 m<sup>3</sup>/day. Because the combined source yield is approximately 0.47 L/s, the pump should operate in level-controlled cycles rather than as an uncontrolled continuous system. The 9 m<sup>3</sup> lower reservoir provides sufficient buffering between source inflow and the slightly higher pump discharge. Conceptually, the daily pumping period may be divided into two or more cycles totaling approximately 20 h/day, with pump shutdown at approximately 20–25% usable lower-reservoir level and restart after recovery to at least 40%. The upper-reservoir level provides the second control condition, with pump stop at approximately 90% full level and restart at approximately 60–70%. The combined source provides approximately 40.61 m<sup>3</sup>/day, giving a nominal daily margin of only 4.25 m<sup>3</sup>/day above the calculated demand; therefore, source-level monitoring and dry-run protection are essential during seasonal low-flow periods. The operation, safety control, and community maintenance scope is summarized in Table 4.

**Table 4.** Community-based Operation and Preventive Maintenance Plan

| Frequency / trigger | Activity                                                                                 | Responsible personnel         | Purpose                  |
|---------------------|------------------------------------------------------------------------------------------|-------------------------------|--------------------------|
| Daily               | Check reservoir levels, pump pressure, leakage, abnormal noise, operating hours          | Local operator                | Early fault detection    |
| Weekly              | Inspect intake, strainer, visible pipeline and valves                                    | Local operator                | Prevent blockage/leakage |
| Monthly             | Inspect pressure gauge, level sensors, check valve, ARV, washout valve and control panel | Operator / trained technician | Verify safety devices    |

|                               |                                                                             |                                       |                             |
|-------------------------------|-----------------------------------------------------------------------------|---------------------------------------|-----------------------------|
| Every 3–6 months              | Check electrical protection, pump vibration, sensor operation and terminals | Qualified technician                  | Prevent equipment failure   |
| Annually                      | Reservoir cleaning and pump performance evaluation                          | Technical team                        | Restore system performance  |
| As required                   | Pipeline flushing through washout valves                                    | Local operator                        | Remove sediment             |
| Continuous                    | Maintain logbook and operating-hours record                                 | Local operator                        | Troubleshooting/history     |
| After training / periodically | Operator competency assessment                                              | Community management / technical team | Verify operating competence |

Previous community-based water supply programs indicate that practical training, local participation, simple operating procedures, and appropriate technology selection can improve ownership, user satisfaction, and system sustainability (Wigati et al., 2023; Wispriyono et al., 2022).

#### 4. Conclusion

This paper presents a Conceptual engineering design planning concept for a community-based clean water distribution system in Galiukir Indigenous Village, Bali. The planning was developed as a follow-up to feasibility findings showing that the existing system was hydraulically inadequate due to insufficient pump head, high elevation difference, limited source discharge, and the need for pipe pressure verification.

The proposed operating flow of approximately 0.45–0.50 L/s, the calculated steady-state TDH of approximately 137.6 m, and the preliminary pump-selection envelope of approximately 158–160 m should be regarded as conceptual design values rather than final equipment specifications. Final pump selection and pipe-pressure verification require confirmation using manufacturer-certified pump curves, detailed hydraulic and transient simulation, the verified longitudinal pipeline profile, and field flow-pressure testing during commissioning.

Therefore, the present study provides a technically quantified Conceptual Engineering Design basis for subsequent detailed design and implementation rather than a final construction-level hydraulic specification.

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