# A WEB-BASED District Metering Area (DMA) Profiling with an Anomaly Detection SYSTEM

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**ABSTRACT**

Non-Revenue Water (NRW) remains a significant financial and operational challenge for water utilities worldwide. This study details the development of a web-based system designed to automate Minimum Night Flow (MNF) anomaly detection and streamline District Metering Area (DMA) profiling for the Davao City Water District (DCWD). Utilizing a Waterfall Software Development Life Cycle, the system was developed to replace labor-intensive manual spreadsheet reviews with a centralized database and automated alert mechanism. Results from multi-level testing demonstrated that the system successfully identifies flow irregularities and meets operational requirements. User Acceptance Testing (UAT) conducted with operational staff yielded high levels of satisfaction and perceived usefulness, underscoring the system's reliability in monitoring network anomalies. This research underscores the potential of digital solutions to bridge the gap between raw data collection and operational response, fostering more sustainable and efficient water distribution.

**KEYWORDS:** *Information System, non-revenue water, district metering area, minimum night flow, anomaly detection.*

## INTRODUCTION

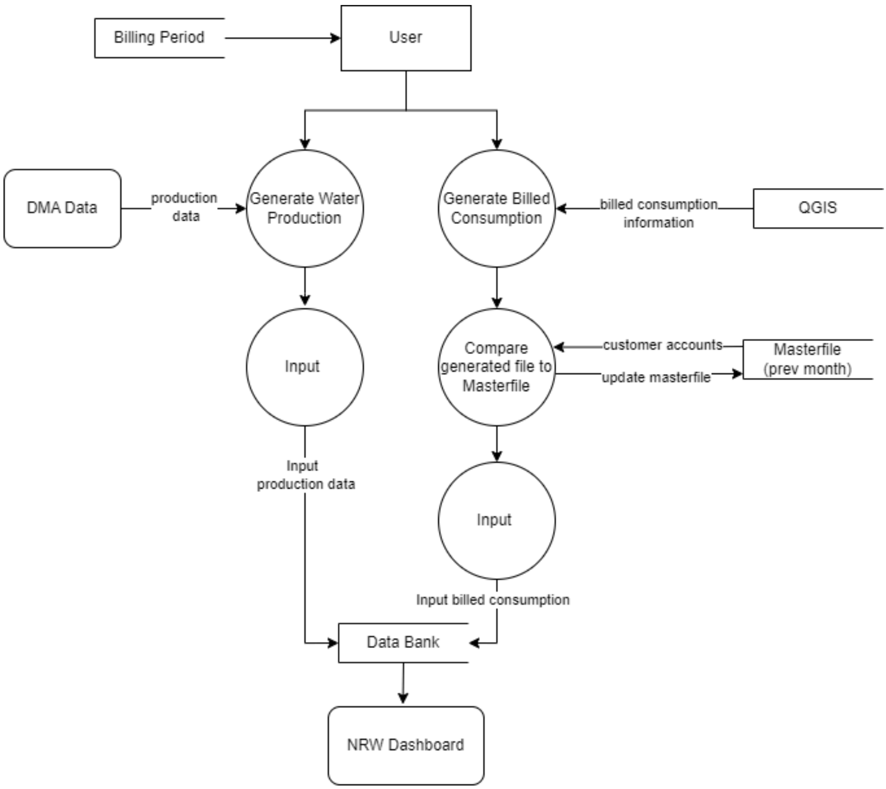
Non-Revenue Water (NRW) is defined as the difference between the total water volume pumped into a supply system and the volume that reaches the consumer. High levels of NRW hinder a utility's ability to meet consumer demand and sustain affordable pricing, as significant volumes of water yield no revenue. Industry standards, supported by recent assessments, target an acceptable NRW rate of 15 percent by volume. NRW comprises physical losses from leaks, commercial losses due to meter inaccuracies or theft, and unbilled authorized consumption for operational use.

To effectively combat these losses, water utilities are increasingly implementing District Metering Areas (DMAs) to isolate sections of the distribution network for more precise monitoring. The National Economic and Development Authority (NEDA), in its Philippine Water Supply and Sanitation Master Plan (2024), highlights that implementing such programs is critical to meeting national performance standards. DMAs allow utilities to assess NRW volume monthly, prioritize leak detection, and monitor the Minimum Night Flow (MNF), thereby reducing the time required to detect a new leak from months to mere days. However, while the benefits of DMAs are well documented, current monitoring methods often require more advanced automation to accelerate and improve the precision of leak localization.

Specifically, at the Davao City Water District (DCWD), the Investigations and Data Analysis Unit (IDAU) is responsible for managing data across approximately 141 DMAs. This process is currently manual and labor-intensive; seven staff members must daily access individual brand-specific portals and spreadsheets to check for flow irregularities—a task that consumes approximately two hours per person every day. If a staff member is absent, the workload for others increases, potentially delaying the identification of critical leaks. This manual data flow, as illustrated in Figure 1, from production data portals to Excel master files and NRW dashboards, creates operational bottlenecks that hinder timely decision-making. The current manual NRW reporting workflow requires staff to aggregate production data from disparate cloud portals and billed consumption data from QGIS into Excel-based databases. This labor-intensive process involves manual cross-referencing with customer master files to update NRW dashboards, which is prone to data entry errors and results in significant operational delays. Consequently, there is an urgent need to centralize these disparate data streams, eliminate manual touchpoints, and streamline the reporting cycle

**Figure 1**

*NRW Report Data Flow Diagram*




Despite the clear need for optimization, a significant research gap exists in developing localized, automated anomaly detection systems seamlessly integrated with operational NRW profiling. While previous studies have addressed the general benefits of establishing DMAs, they often lack specific functional integrations for utility-specific workflows, such as the transition from raw data logging to automated NRW computation and alert notification. This study fills these gaps by developing a tailored web-based system that automates these manual processes, thereby improving operational efficiency and reducing response times.

**Objectives of this study**

1. Develop a web-based system to centralize DMA data and automate functionalities such as anomaly detection, alerts, and NRW calculation;
2. Conduct an acceptability test among target users using the Technology Acceptance Model (TAM);
3. Create an implementation plan for integrating the system into water utility operations. The scope focuses on monitoring DMA-level data via CSV uploads and providing real-time visualization and reporting tools for utility staff

## METHODOLOGY

*System Design.* To transition from manual workflows to a digital infrastructure, the system's development followed the Waterfall Software Development Life Cycle (SDLC), a model chosen for its structured, linear progression, which ensured that requirements were fully defined before moving into design and implementation. During the initial phase, requirements were gathered through interviews with the Investigations and Data Analysis Unit (IDAU) to map existing manual workflows into digital processes. For system architecture, the Structured System Design method was employed, utilizing Data Flow Diagrams (DFDs) to visualize data movement and Entity-Relationship Diagrams (ERDs) to model the underlying data structure. To maintain conciseness for publication, technical descriptions of the SDLC phases focus on operational applications rather than generic definitions.

Building upon this architectural foundation, a multi-tier testing strategy consisting of unit, integration, and user acceptance testing was used to ensure functional accuracy. Unit testing was performed by developers to verify individual modules in isolation. To validate the anomaly detection logic, manual verification was conducted using a series of standardized formulas. The system determines the Average Minimum Night Flow (MNF) by dividing the sum of daily low-flow readings by the number of days observed (n). To establish a baseline for alerts, an MNF Threshold is set to Average MNF × 1.3. Furthermore, to quantify the scale of irregularities, the Deviation Percentage is calculated as follows:

$$Deviation\ Percentage = \left(\frac{Detected\ MNF\ Value - Set\ MNF\ Average}{Set\ MNF\ Average}\right) x\ 100$$

These manual computations were compared against system-generated outputs to confirm the correctness of the computational logic.

Following unit testing, Integration testing was conducted to identify defects in the interaction between combined modules, such as the relationship between CSV uploads and the graph-view visualization interface. It is acknowledged that this phase was conducted primarily by the researcher; while this ensured architectural alignment, the potential for researcher bias is noted and was mitigated by subsequent independent testing sessions.

Parallel to these technical evaluations, User Acceptance Testing (UAT) was conducted on-site at the Davao City Water District (DCWD) with actual operational users. Because of the unit's specialized nature, the sample size (n=3) was specifically targeted to include the primary decision-makers, such as administrators and operators from the IDAU responsible for the DMA monitoring workflow. This evaluation used an adapted Technology Acceptance Model (TAM) to assess perceived usefulness and ease of use, ensuring the system met the staff's specific daily task requirements. Evaluation was conducted using a 5-point Likert scale.

*Ethical Considerations.* Alongside these methodological procedures, and in strict alignment with publication standards, ethical protocols were maintained throughout the study. Institutional permission was obtained from DCWD management, and informed consent was secured from all participants prior to their involvement in testing or surveys. To ensure data privacy and confidentiality, all survey responses were anonymized, and the system implements role-based authentication to protect sensitive utility infrastructure data and restrict access to authorized personnel only.

## RESULTS AND DISCUSSION

The system successfully addresses the functional requirements identified by the IDAU, most notably secure user authentication and automated anomaly detection. To maintain operational security, the platform implements the role-based access levels defined in Table 1, distinguishing between Administrators—who possess full permissions for user and water rate management—and Regular Users, whose access is restricted to assigned DMAs.

**Table 1**
*User Roles*

| Module / Feature | Admin | Regular User |
|---|---|---|
| Dashboard Access | Yes | Yes |
| View DMA Statistics | Yes | Yes |
| View Alert Logs | Yes | Yes |
| Add DMA | Yes | No |
| Update DMA | Any DMA | Assigned DMAs only |
| Upload Billing Data | Yes | No |
| User Management | Yes | No |
| Update Water Rates | Yes | No |
| Generate Reports | Yes | No |

Beyond these access controls, the overarching data flow is visualized through the Context Diagram and Level 0 Data Flow Diagram (DFD) presented in Figures 2 and 3. These illustrations demonstrate how raw data is transformed into actionable alert information within the central database.

**Figure 2**
*Context Diagram*

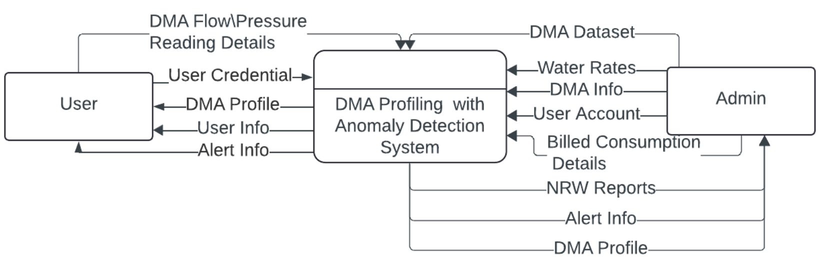
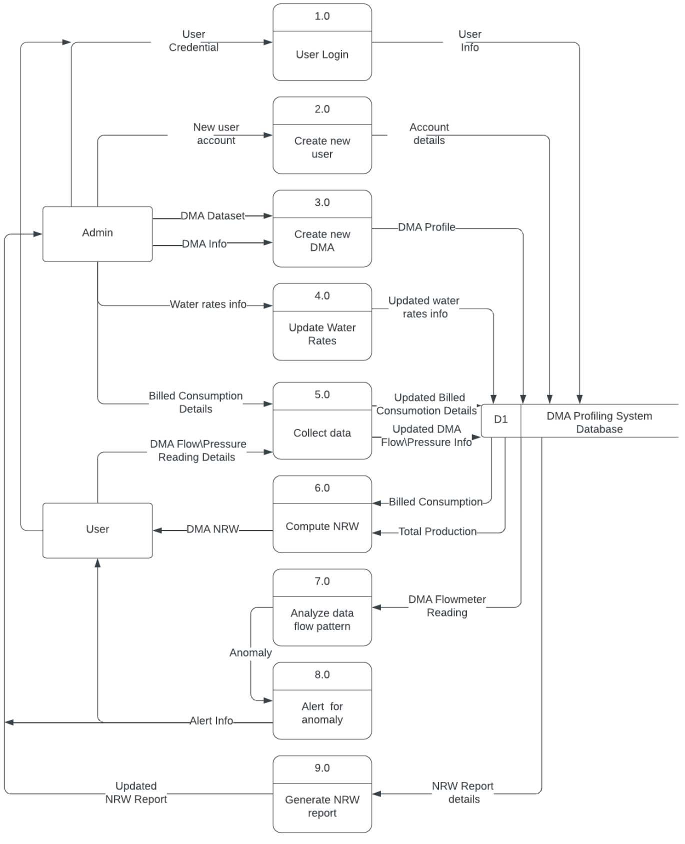


**Figure 3**

*DFD Level 0*

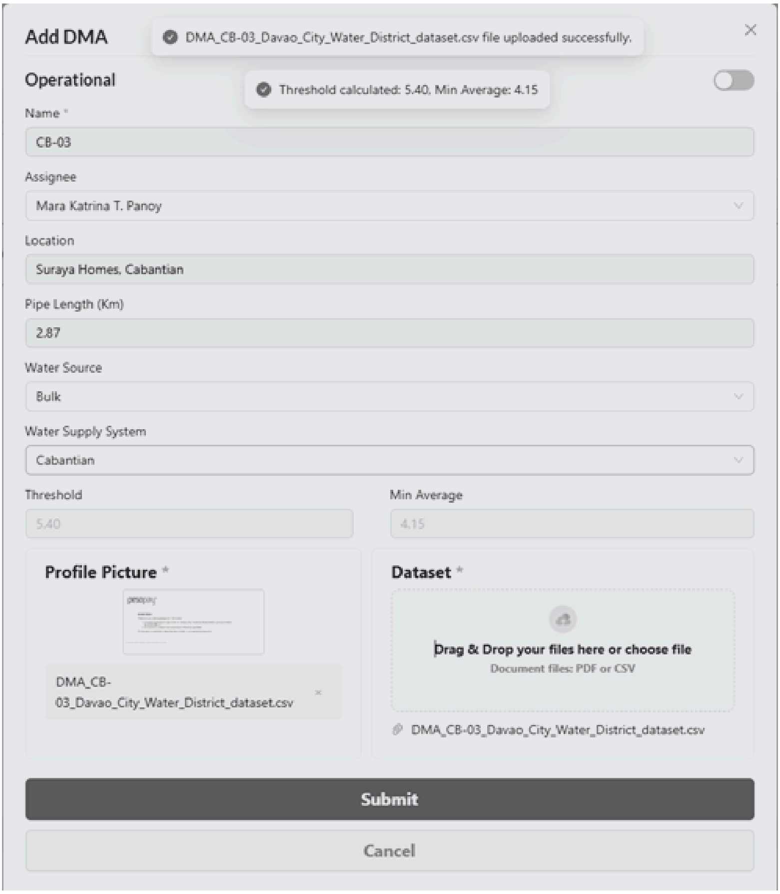



Specifically, Figure 3 provides a granular technical overview of the system's nine primary subprocesses, ranging from initial login to the generation of consolidated NRW reports, to highlight the platform's internal logic. Ultimately, this structured approach ensures that the system remains scalable, capable of handling an increasing volume of datasets as more DMAs are onboarded into the digital infrastructure.

Beyond structural design, the system's technical reliability was verified through a multi-tier testing strategy. Initial unit testing focused on the computational logic of the anomaly detection module using data from DMA code CB-03. As illustrated in Figure 4, the system automatically parsed a seven-day dataset to calculate an average Minimum Night Flow (MNF) of 4.15 m³/h and an alert threshold of 5.40 m³/h.

**Figure 4**

*DMA Profile Configuration and Automated Threshold Calculation Interface*

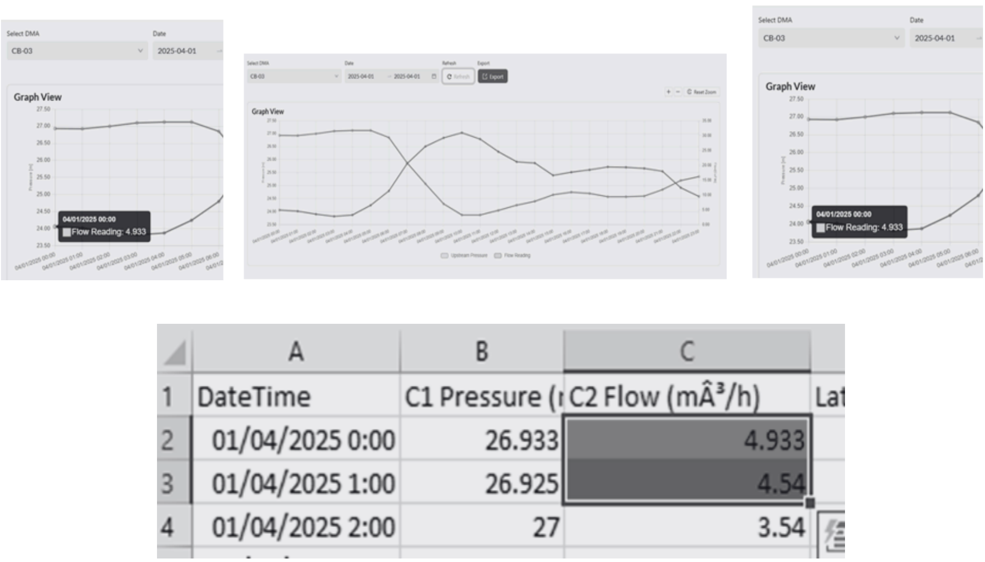



To verify these automated outputs, the raw data readings (3.92, 3.73, 4.38, 3.85, 4.16, 5.30, and 3.71) were manually verified. This comparison confirmed that the system achieved a 100% accuracy rate in its computational logic, successfully applying the 1.3x multiplier required for alert triggering. Building on this computational validation, subsequent integration testing demonstrated the system's ability to map these datapoints. into a functional

Graph View, as shown in Figure 5, enabling users to visualize flow trends in real time.

**Figure 5**

*Graph View Interface for Integrated DMA Flow Meter Readings*




To evaluate the anomaly detection and notification features, a simulation was conducted for DMA CL-01 using modified flow readings intended to exceed the 35.22 m³/h threshold. Figure 6 illustrates the simulated dataset, while Figure 7 displays the resulting alert notification.

**Figure 6**

*Simulated Flow Dataset for Anomaly Detection Performance Validation*

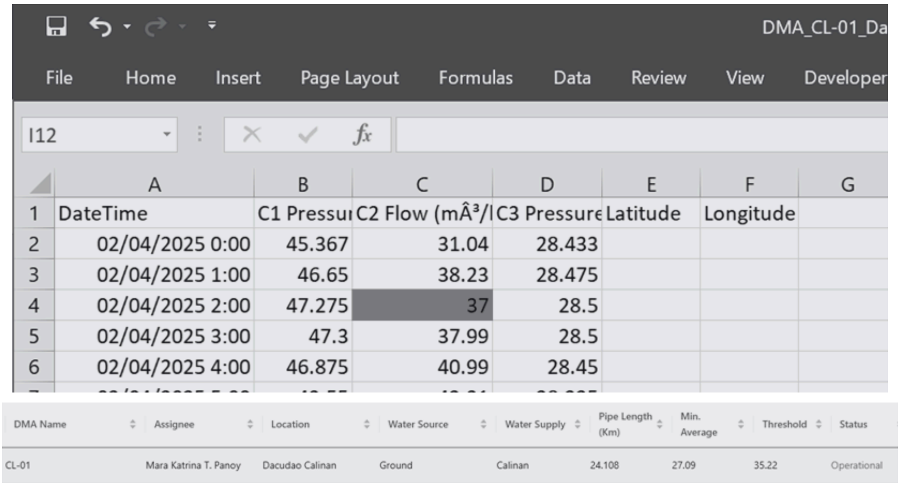
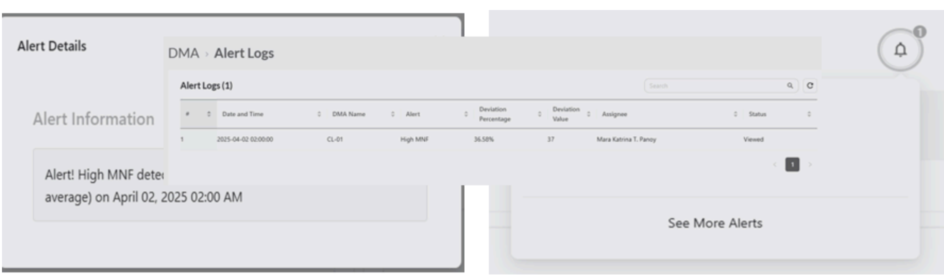



**Figure 7**

*Sample Alert Notification and Alert Logs Details Result from the system*




The system successfully identified a 36.58% deviation from the average, triggering an immediate alert. This performance metric is critical for publication, as it demonstrates that the system eliminates the delay inherent in manual reviews, providing a proactive rather than reactive tool for leak detection.

**Table 2**

*Summary of User Acceptance Test (UAT)*

| Category | Test Case IDs | Scenarios Included | Status |
|---|---|---|---|
| Authentication & Security | TC-01-03, 17, 22 | Login, profile updates, session timeouts, and role-based access. | Passed |
| DMA Management | TC-04-07, 20, 23 | Profile creation, image updates, status changes, and scalability. | Passed |
| Data Processing | TC-08, 13, 15 | CSV imports, water rate updates, and threshold setting. | Passed |
| Analysis & Reporting | TC-09-12 | NRW charts, line graphs, and top high-NRW DMA dashboards. | Passed |
| Anomaly Detection | TC-14, 21 | Accurate detection of MNF increases and alert triggering. | Passed |
| General Performance | TC-16, 18, 19 | 24/7 availability, network accessibility, and browser compatibility. | Passed |

To validate the operational readiness of these automated features**,** User Acceptance Testing (UAT) was conducted on-site at the Davao City Water District (DCWD) with actual operational users from the Investigations and Data Analysis Unit (IDAU) to validate the system's readiness for deployment. As summarized in Table 2, the evaluation encompassed 23 predefined test cases covering critical functional and non-functional requirements, ranging from secure role-based authentication to automated NRW computation and scalability. All 23 test cases met the 100% success acceptance criterion, demonstrating that the system's architecture is robust and aligned with the unit’s specialized daily workflows

Building upon this functional validation, a key highlight of the testing phase was validating the anomaly detection module through a controlled simulation. By intentionally modifying flow readings to exceed the predefined threshold, the system achieved 100% detection accuracy, identifying a 36.58% deviation from the Minimum Night Flow (MNF) average and triggering an alert within seconds. This performance metric is significant for publication as it provides technical evidence that the system successfully replaces the two-hour manual review process with an automated mechanism. Overall, the participants reported a positive experience, specifically noting the system's reliability and consistency, which underscores its potential to shift utility operations from reactive monitoring to a proactive, data-driven leak detection strategy.

Complementing these technical performance metrics, a user acceptability survey involved the specialized operational staff of the IDAU (n=3), a sample size justified by the unit's unique role as the primary decision-makers for DMA monitoring. As illustrated in Table 3, the results indicate strong positive perceptions across all Technology Acceptance Model (TAM) categories.

**Table 3**
*User Acceptability TAM Results Summary*

| Category / Item | Mean | SD | Description |
|---|---|---|---|
| **Perceived Usefulness** | | | |
| 1. Improve job performance | 4.00 | 0.00 | Agree |
| 2. Improve productivity | 4.67 | 0.58 | Strongly Agree |
| 3. Enhance effectiveness | 4.33 | 0.58 | Agree |
| 4. Useful in job | 4.33 | 0.58 | Agree |
| **Perceived Ease of Use** | | | |
| 5. Easy to learn | 4.33 | 0.58 | Agree |
| 6. Easy to control system outputs | 3.67 | 0.58 | Agree |
| 7. Easy to become skillful | 4.00 | 0.00 | Agree |
| 8. Easy to use | 4.67 | 0.58 | Strongly Agree |
| **Behavioral Intention to Use** | | | |
| 9. Intention to continue use | 4.33 | 0.58 | Agree |
| 10. Recommend to others | 4.33 | 0.58 | Agree |
| 11. Enthusiastic about features | 4.33 | 0.58 | Agree |
| 12. Rely on the system for tasks | 3.67 | 0.58 | Agree |
| **User Satisfaction** | | | |
| 13. Satisfied with overall experience | 4.00 | 0.00 | Agree |
| 14. Meets functionality expectations | 4.00 | 0.00 | Agree |
| 15. Value relative to effort | 4.33 | 0.58 | Agree |
| 16. Reliability and consistency | 5.00 | 0.00 | Strongly Agree |

Under Perceived Usefulness, the high score for improved productivity (Mean: 4.67) directly supports the study's objective of replacing labor-intensive manual reviews with automated workflows. While Perceived Ease of Use was generally high (Mean: 4.67), a lower score for system control (Mean: 3.67) suggests a minor learning curve as users transition from familiar spreadsheet-based processes. Similarly, while Behavioral Intention to continue using and recommending the system is strong (Mean: 4.33), the lower score for task reliance (Mean: 3.67) indicates that full operational trust is still developing—a common trend when implementing new digital solutions alongside legacy systems.

Expanding on these categorical results, the most significant finding is a perfect score for User Satisfaction regarding system reliability and consistency (Mean: 5.00), confirming the platform's dependability for critical anomaly detection. Furthermore, the lack of qualitative feedback suggests that the current features meet the immediate functional requirements of the staff, with no significant operational barriers identified during the initial rollout. These findings collectively demonstrate that the system is strategically and technically aligned with the utility's goal of improved operational efficiency.

Despite these positive evaluations, the analytical interpretation of the user acceptability results reveals that while staff are highly enthusiastic about the system's ease of use and reliability, full operational reliance is a developing process. This transition is managed through a phased implementation strategy designed to ensure operational continuity as we move from legacy, spreadsheet-based workflows. Currently, the system and spreadsheets are used in parallel; this dual approach is a practical necessity because the initial version focuses on core DMA-level functionalities while tasks such as system-wide NRW aggregation and pressure profiling remain to be digitized.

To begin this transition, Phase 1 focuses on the core modules that have been successfully validated through User Acceptance Testing (UAT), including manual CSV data uploads, automated Minimum Night Flow (MNF) anomaly detection, and real-time alerts. Even in this initial stage, the system has demonstrated a significant practical contribution by reducing the daily manual review time for the Investigations and Data Analysis Unit (IDAU) from approximately two hours per staff member to a near-instantaneous automated process.

Looking toward future integration, Phase 2 addresses the broader technical scope required for full operational integration and the eventual elimination of manual spreadsheets. A primary objective is to integrate the billing system and DMA data loggers via an API, transitioning the system from periodic manual updates to a continuous, fully automated monitoring platform. Furthermore, Phase 2 will expand the system's computational logic beyond isolated DMAs to include system-wide NRW analysis and comprehensive pressure profiling, tracking critical metrics such as maximum, minimum, and average pressure values (PSI). The strategic roadmap for these enhancements, including the API development timeline and network-wide rollout, is detailed in Table 4. This phased approach ensures that the Davao City Water District maintains high operational standards while adopting a more robust, centralized digital infrastructure

**Table 4**

*Strategic Roadmap for Phase 2 Enhancements and Full Operational Integration*

| Aspect | Objectives | Strategies | Person Involved | Budget /Materials | Source of Budget | Time Frame | Actual Accomplishment |
|---|---|---|---|---|---|---|---|
| Development & enhancement | API Integration, NRW expansion, Pressure Profiling | Implement API for both the Billing System and DMA Data Loggers | Researcher, System Analyst, Developers, QA Team, Data Logger Manufacturers | Software Tools<br><br>Php 50,000 | Institutional Grants and External Funding | Months 3-6 | System completed and tested. User Manual |
| Training & Orientation | Equip users with skills to operate the enhanced system | Create a user training plan. | System Developers, End Users | Training materials, Venue, and food<br><br>Php 5,000 | Institutional Grants and External Funding | Months 6-7 | Training conducted. |
| Deployment | Ensure the successful rollout of the system | Create a deployment plan | Developers, IT Admin, End Users | Php 5,000 | Institutional Grants and External Funding | Months 6-7 | Deployment initiated and monitored |
| User Acceptance | Validate system readiness and usability | Conduct user acceptance testing sessions | QA Team, End Users, Project Leads | Feedback forms | None | Months 6-7 | UAT completed with signed approvals |

| **Aspect** | **Objectives** | **Strategies** | **Person Involved** | **Budget /Materials** | **Source of Budget** | **Time Frame** | **Actual Accomplishment** |
|---|---|---|---|---|---|---|---|
| Post-Deployment Feedback Meetings | Gather user feedback for improvement | Conduct feedback meetings | Project Manager, End Users, System Developers | Form, Venue, food<br><br>Php 2,000 | Institutional Grants and External Funding | Months 7-8 | Accomplished feedback forms |

This study successfully developed a web-based DMA profiling system that automates MNF anomaly detection and NRW calculation. Key findings demonstrate that the system achieves high accuracy and is well accepted by operational users.

Theoretical and Conceptual Contributions: Conceptually, this research provides a framework for phased digital transformation in water utilities, demonstrating how localized automation can be integrated into legacy spreadsheet-based workflows. Theoretically, it validates the application of TAM in small, specialized utility units, proving that even a limited user base can provide significant insights into the operational viability of new technology. Future enhancements (Phase 2) will focus on full API integration with billing systems and data loggers to achieve a completely automated, system-wide NRW management platform.

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