Product Management & Data-Driven Solutions For Industrial Water Conservation

A major project report submitted in partial fulfillment of the requirement for the award of degree of

Bachelor of Technology

in

Computer Science & Engineering

Submitted by

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December 2025

Supervisor's Certificate

This is to certify that the major project report entitled **'Product Management & Data-Driven Solutions for Industrial Water Conservation'**, submitted in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Computer Science & Engineering**, in the Department of Computer Science & Engineering and Information Technology, Jaypee University of Information Technology, Waknaghat, is a bonafide project work carried out under my supervision during the period from July 2025 to December 2025.

I have personally supervised the research work and confirm that it meets the standards required for submission. The project work has been conducted in accordance with ethical guidelines, and the matter embodied in the report has not been submitted elsewhere for the award of any other degree or diploma.

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Candidate's Declaration

We hereby declare that the work presented in this major project report entitled **'Product Management & Data-Driven Solutions for Industrial Water Conservation'**, submitted in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Computer Science & Engineering**, in the Department of Computer Science & Engineering and Information Technology, Jaypee University of Information Technology, Waknaghat, is an authentic record of our own work carried out during the period from July 2025 to December 2025 under the supervision of **Ms. Palak Aar**.

We further declare that the matter embodied in this report has not been submitted for the award of any other degree or diploma at any other university or institution.

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This is to certify that the above statement made by the candidates is true to the best of my knowledge.

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Acknowledgment

I would like to give special thanks to my Project Supervisor, Ms. Palak Aar, who has provided me with continuing assistance, insight on how to improve my project work, and encouraged me throughout this major project. She has helped shape my views of product development, system design, and the use of data to make informed decisions.

I would also like to thank the people working at the Industrial Water Intelligence and Sustainability Technology Organization (IWISTO), where I did my internship. Working with them allowed me to learn through collaboration, mentorship, and real-world exposure while developing skills in client-centric product development, industrial operation, and using IoT-based monitoring systems.

I appreciate the contributions made by the faculty members from the Department of Computer Science and Engineering, Jaypee University of Information Technology, as they provided me with the necessary education and resources to be able to complete this project. Lastly, I want to express my sincere appreciation to all my family and friends for supporting me with motivation, support, and faith in my ability to accomplish this task.

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List Of Abbreviations, Symbols, And Nomenclature

Abbreviation / Symbol	Full Form / Meaning
IoT	Internet of Things
ASV	Autonomous Surface Vehicle
PRD	Product Requirements Document
ISRO	Indian Space Research Organisation
API	Application Programming Interface
FIFO	First-In, First-Out Buffer
WSN	Wireless Sensor Network
DB	Database
UI/UX	User Interface / User Experience
ESG	Environmental, Social, and Governance
ML	Machine Learning
WTP	Water Treatment Plant
STP	Sewage Treatment Plant

ETP	Effluent Treatment Plant
RO	Reverse Osmosis
RWH	Rainwater Harvesting
NTU	Nephelometric Turbidity Unit (Turbidity measure)
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
F	Water flow rate
t	Timestamp corresponding to a flow reading
$D_{offline}$	Flow data captured during offline mode
D_{sync}	Flow data uploaded after network restoration
S(t)	Operational state of the IoT device at time t
Q	Local storage queue (FIFO buffer)
A	Leakage alert trigger signal
V_{saved}	Volumetric Water Savings (in Liters)
$C_{baseline}$	Historical Baseline Consumption
C_{actual}	Real-time Actual Consumption
R^2	Coefficient of Determination (Correlation metric)

Abstract

Water management in the industries has turned out to be one of the key concerns among the large industrial units, health care organizations, and manufacturing facilities. As more water becomes scarce, the cost of operation rises, and the demands of environmental compliance, organizations are introducing IoT-based monitoring solutions at a rapid rate to measure and optimize their water use. Still, practical industrial settings have a few issues, including unreliable network connections, partial data transfer, slow anomaly detection, and the inability to transform raw sensor data into useful information.

This is a large undertaking, which was undertaken during my internship in one of the most successful industrial water intelligence and sustainability technology organizations, to enhance the reliability, intelligence, and business value of an existing water monitoring dashboard. The activities undertaken are strategic research of products, review of hardware, collection of client requirements, data analysis, and two key system improvement designs.

The initial contribution is the design of a strong offline data storage and sync protocol, which guarantees the zero loss of data from flow meters during network outages. This involves the design of state machine logic, buffering, and a safe workflow of cloud synchronization to ensure the continuity and precision of time-series water information. The second input is the creation of a smart leakage notification system, which is a rule-based analysis of continuous flow profiles that is able to detect abnormal water consumption events and alert users in real-time.

Other deliverables of this project are the development of user-friendly dashboard enhancements, creation of a comprehensive Product Requirements Document (PRD), comparison of flow meter hardware between various suppliers, and assisting large industrial customers in designing their monitoring dashboard and understanding their consumption patterns.

Chapter 1: Introduction

1.1 Introduction

Water management in industries has been included as a part and parcel of sustainability programs in large production units, healthcare facilities, beverage processing plants, automotive facilities, and multi-block infrastructures. The increasing necessity to reduce the amount of water consumed, guarantee the efficiency of the operations, and ensure that the environmental conditions are met has led to the implementation of digital water monitoring systems based on the Internet of Things (IoT). Such systems allow the constant gathering of information that is delivered by flow meters installed at different points that provide data about the usage trends.

Nonetheless, the successful water conservation demands a comprehensive Product Management strategy, i.e., beyond data gathering. It deals with the strategic choice of hardware, full site auditing, feature design focusing on the users, as well as the incorporation of such advanced technologies as Remote Sensing. As a matter of fact, the industrial sector is faced with numerous obstacles, including bad network connectivity, inconsistencies among sensors, and the absence of analytical intelligence, which may cause loss of data and misinterpretation.

This is a large-scale project, which had to be developed during the internship at Fluxgen, and its aim was to create Product Management and Data-Driven Solutions to Industrial Water Conservation. These include the end-to-end development cycle: Strategic Research and Hardware Benchmarking to Client Water Audits and the technical implementation of Resilient IoT Architectures (Offline Sync and Leakage Detection).

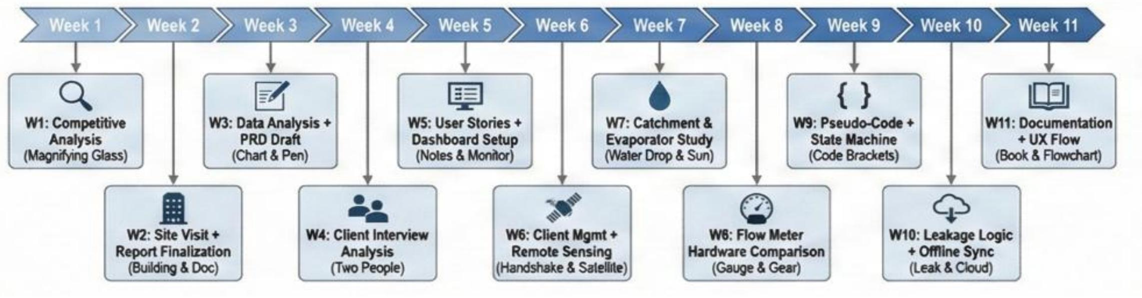

Figure 1.1: Project Activity Timeline (Week-Wise Summary)

1.2 Problem Statement

In spite of the growth in the number of IoT solutions in the field of water monitoring, there are still practical issues in the industrial practices:

1.2.1 Loss of Data in Network Outages.

The network strength in industrial premises is usually intermittent, leading to intermittent disconnection. As a result of these outages, IoT devices do not transmit real-time flow measurements, which means that they miss historical flow data, misleading consumption patterns, and critical usage events.

1.2.2 Absence of Proactive Leakage Detection.

Most of the existing dashboards are mainly associated with historical visualization as opposed to real-time anomaly detection. The continuous flow, either through leakages or operational oversight, is usually not noticed over long periods, leading to excessive wastage.

1.2.3 Lawful Breadth Of Water Data To Business Worth.

The data provided by the raw flow meter is not understandable by stakeholders without contextual information, including savings, loss prevention, and benchmark comparisons. This helps decrease the impact of the system and makes it difficult to make decisions.

1.2.4 Hardware Inconsistencies and Lack of Environmental Context.

When the incorrect sensor type is selected with regard to specific water conditions, the results may be incorrect. Moreover, the use of point-sensors only excludes the bigger picture (catchment health) that necessitates the novel technologies such as Autonomous Surface Vehicles (ASV) and Remote Sensing to get a full picture of water risks.

In this way, a stable, smart, and convenient monitoring system that guarantees continuity of data, unusual usage identification before it occurs, and presentation report in a way easy to understand is needed.

1.3 Objectives

The key aims of the project are the following:

1.3.1 To Examine the Present Water Monitoring Dashboards and Define the Opportunities to be Improved.

This involves carrying out competitive benchmarking and determining gaps in the features of existing market solutions.

1.3.2 To Acquire and Generalize Client Needs in Industrial Sectors.

The identification of requirements was made by conducting talks with the large-scale manufacturers, healthcare institutions, infrastructure facilities, as well as resource management teams.

1.3.3 To Enhance Dashboard Interaction and Insights and Create PRDs.

This involves converting client feedback into User Stories and Product Requirements Document (PRD) and brainstorming on wireframes and mockups of a feature known as Volumetric Savings to enable clients to see and measure their water conservation contribution.

1.3.4 To Investigate Remote Sensing and ASV Potential

To investigate and offer a joint model with Autonomous Surface Vehicles (ASV) and Satellite Data to measure water quality and analyse water risk in a problematic area, such as the Suvarnamukhi Catchment.

1.3.5 To Carry out Water Infrastructure Audits of Medical Institutions:

To undertake the deep-dive analysis of the water infrastructure of large-scale medical institutions, to determine consumption levels, areas of wastage, and the opportunities of using recycled water.

1.3.6 To Conduct Comparative Hardware Analysis

To compare various flow meter technologies (e.g., Electromagnetic vs. Ultrasonic) to identify the optimal hardware choice depending on the water conductivity, the pipe diameter, and the conditions of operation.

1.3.7 Designing A Resilient Offline Data Storage and Sync Protocol.

This protocol makes sure that the flow meter readings are locally stored in a FIFO format and the readings are automatically synchronized to the cloud on reconnection without being lost or reordered.

1.3.8 To Design A Rule-based Leakage Detection Alert System.

This system monitors uninterrupted flow within a given time period (2 hours) and gives an early warning about water wastage.

Figure 1.2: Graphical Representation Of Project Objectives

1.4 Significance And Motivation Of The Project Work

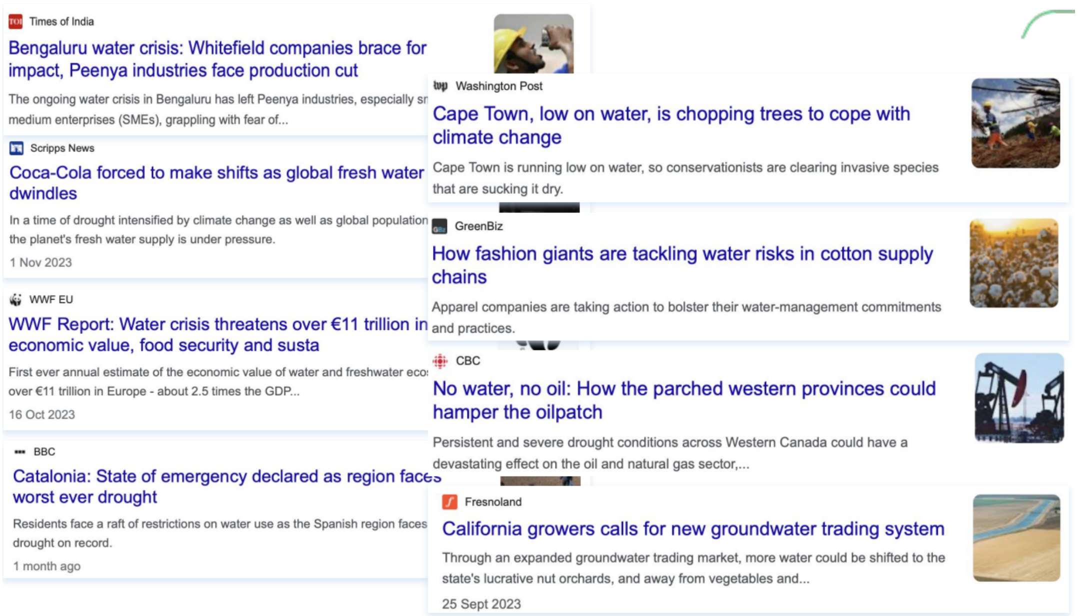

Figure 1.3: Challenges Faced By Industries Due To Water Scarcity

The water scarcity, increased operation costs, and the need to be transparent on resources have compelled industries to establish smarter monitoring solutions. However, experience shows that the quality of the decisions greatly depends on the credibility of the water data. Absence of readings or even silent cases of leakages are likely to result in severe economic and resource wastage.

The project is very critical as:

- It enhances the stability of the IoT devices that are offline syncable.
- It suggests intelligent leakage detection to address the issues in real-time.
- It helps industrial users to determine the savings and prevent waste.
- It adds the intent of the dashboard as a decision support system.
- It is sustainable in the sense that it reduces unnecessary wastage of water.
- It opens the path for scalability through a large ground-level dataset.

The project was carried out under my internship at FluxGen Sustainable Technologies Pvt. Ltd., a clean-technology company that focuses on the transparency of industrial water.

These resilient architectures and strategic solutions were motivated by the fact that FluxGen aimed to De-risk industries of any water-related disruption and Co-author India Water Future. Operating in this ecosystem meant that sustainable water management cannot be realized with sensors alone, but it needs a system that can convert raw data into intelligence that is decision-ready, which would enable industries to run smoothly in water-stressed areas.

1.5 Organization Of Project Report

This project report is organized into six chapters as per the provided guidelines:

- **Chapter 1: Introduction**
  Provides background, problem statement, objectives, and motivation.
- **Chapter 2: Literature Survey**
  Summarizes prior work related to IoT systems, edge computing, offline data handling, and leakage detection.
- **Chapter 3: System Development**
  describes the requirements, architecture, data preparation steps, implementation logic, and key challenges.
- **Chapter 4: Testing**
  details the testing strategy, test cases, and test outcomes.
- **Chapter 5: Results And Evaluation**
  Results of the present system, performance insights, and points of comparison with current solutions.
- **Chapter 6: Conclusions And Future Scope**
  Highlights the conclusions made and discusses future enhancements.

Chapter 2: Literature Survey

2.1 Overview Of Relevant Literature

The multi-disciplinary approach is necessary to develop a strong industrial water monitoring system. Whereas the current solutions depend enormously on the IoT sensors and cloud dashboards, to build a successful product at an industrial level, user-centric design, strategic product management, and advanced environmental validation are required. The literature on product management and design structures, remote sensing and validation, IoT-based monitoring, and edge computing are four large areas that have been reviewed in this project.

The purpose of this survey is to provide a baseline of the business analysis (PRD/User Stories) and the technical implementation (Offline Sync/Leakage Detection) that would have been done during the internship at FluxGen Sustainable Technologies Pvt. Ltd.

User-Centric Design and Product Management.

To construct a dashboard that is actually used by the clients, one should go beyond displaying raw data. The literature on Product Management has highlighted the importance of road mapping, prioritisation structures to match the product objectives with the customer requirements. Besides, the studies on Material Design 3 (an open-source system created by Google) emphasize the benefits of the consistency of the UI elements and the principles of accessibility to enhance the usability of industrial dashboards. The structured User Interview methods were also learned to efficiently convert qualitative feedback on the clients into User Story actions.

Ground Truth validation and Remote Sensing.

In order to deal with water security at the catchment level, a study on the Remote Sensing potential was developed. Research using Sentinel-2 satellite data shows that it is possible to measure critical water quality indicators such as Turbidity and Chlorophyll-a at a resolution of 10-20m. But it has been stated in literature that satellite data needs to be validated. The latter gap is resolved by incorporating the use of Autonomous Surface Vehicles (ASV) to ground truth, which develops an accurate data loop to map the waterbody.

IoT-Based Water Monitoring

The latest studies show that ultrasonic and electromagnetic flow meters, as well as turbine flow meters, are being used together with the IoT gateways to monitor the water on a real-time basis in the industrial and urban contexts. Through them, time-series data is captured at high resolution, and inefficiency is identified. However, most scholarly resolutions presuppose that connectivity is accessible and do not reflect the true state of affairs in the industry, such as fluctuations in the network, unfavorable circumstances, and inconsistency of sensors.

Edge computing and Data persistence.

The literature on edge computing has brought to the fore the need to store local data in circumstances where the network is not available, as well as those associated with vital systems. Common topics of discussion include such techniques as FIFO queues, state machine logic, local packet validation, and preservation of timestamps. It has been established that a good offline-to-online synchronization system can go a long way in enhancing the strength of the system, reducing loss of information, and enhancing the accuracy of decision-making.

Leakage Detection and Abnormal Detection.

The various papers have proposed how to identify abnormal flow patterns through rule-based heuristics, machine learning, or a combination of both. The rule-based detection (as continuous flow after a time constraint) is considered to be the most useful towards the early-stage rate of industrial deployment since it is highly interpretable, low complexity, and provides practical value in real time.

2.2 Key Gaps In The Literature

Despite the number of studies dealing with IoT-based monitoring and anomaly detection, there still remain major gaps in applying the solutions to the actual industrial setting. The major gaps of research identified include:

Little Attention to Data Offline Coherence.

Most of the research studies presuppose the stable connectivity in networks. They lack practical provisions of local buffering, switching of states, and time synchronization, which are fundamental in industrial monitoring where outages are frequent.

Deficiency Of Integrated resilience and Intelligence.

Current literature generally deals with data integrity or anomaly detection, but not as one system. To avoid losses, industrial solutions require offline syncing reliability as well as prompt leakage detection.

Inadequate Industrial-Scale Testing.

The majority of papers give prototypes that were tested in controlled settings. Few studies have been done to test the solutions under real industrial conditions, sensor noise, flow changes, or multiple days of monitoring.

Poor Visualization and User-Oriented Insights.

Some of the works give raw data interpretation but do not give insights into savings, wastage, or alerts that can be implemented. Dashboards should assist the user in realizing the operational and financial cost of using water.

The summary table of the literature review.

The literature examined has been summarized in a tabular form in an IEEE style as explained below. The table contains 2019-2024 research in the area of IoT sensing, water management, edge computing, and anomaly detection.

Table 2.1 – Literature Review Table

S. No.	Platform/ Concept	Source/ Reference	Key Findings	Relevance To Project
1	Product Management	Top 200+ PM Articles (2024)	Discusses roadmapping and prioritization frameworks.	Guided the creation of the PRD and User Stories for clients with a huge customer base.
2	Design Systems	Material Design 3 - Google (2025)	UI guidelines and component usage for scalable design.	Used to design the "Volumetric Savings" dashboard wireframes in Figma.
3	User Research	The Ultimate Guide to User Interviews (2025)	Structured and contextual inquiry methods for gathering requirements.	Applied during interviews with clients having a huge customer base to identify pain points.
4	Remote Sensing	Sentinel-2 Data Documentation	10-20m resolution satellite data for Turbidity and Chlorophyll monitoring.	Formed the basis of the ASV collaboration research for catchment analysis.

5	Edge Computing	Singh & Gupta, 2021, IEEE Trans. Ind. Informatics	Proposes edge buffering and device-side fault tolerance.	Supports the design of the Offline Data Storage and Sync protocol.

Chapter 3: System Development

The chapter explains the complete process of system development that is undertaken in the project. It deals with the procedure of the determination of the requirements by means of audits of the clients, strategic research on hardware design, development of the product architecture, preparation of data, and the technical implementation of the core modules.

3.1 Requirements And Analysis

To build a stable industrial water monitoring system, the user should have an idea of what the working conditions, data behavior, network limitations, and analytics are to be done by the users. Through the field data review, communication with the industrial staff, and observation of existing monitoring places, several functional and non-functional requirements were recognized.

3.1.1 Functional Requirements

The industry facilities are relying on continuous flow measurements to track consumption and plan operations. According to the interviews and observation in the field, the system should facilitate:

Volumetric Savings Visibility:

To fulfill the needs of clients of the dashboard type in ESG reporting, the dashboard should represent the precise amount of water saved relative to a prior historical baseline.

Continuous Data Acquisition:

There should be flow measurements of industrial flow meters recorded by the system at a predefined period of time to maintain an accurate and fine time series.

Offline Data Storage:

Network disruptions are common in large industrial plants. It must also be able to record all the readings within the company when offline to prevent omission of any observations.

Automatic Data Synchronization:

Once connectivity is restored, the device is supposed to synchronize everything that has been buffered into the cloud in a correct chronological order so that downstream analytics is right.

Proactive Leakage Detection:

A leakage is typically the constant flow of water around a set point (e.g., 2 hours). Rule-based analysis is required to find such patterns in the system.

Visualization And Alerts:

It must allow the dashboard to see real-time and historical flow data and indicate anomalies, in addition to making sure that abnormal events are mitigated in a timely manner.

3.1.2 Non-Functional Requirements

In addition to functional requirements, the system must meet the following several performance and reliability requirements:

Data Integrity:

There should not be any lost or duplicate information in offline storage and synchronization.

System Reliability:

The solution should ensure that the industrial conditions, such as unstable networks and sensor noise, are addressed.

Scalability:

The server system must have the capacity to accommodate the data of other devices installed in another industrial plant.

Hardware Compatibility:

The system should be in a position to accommodate the different types of sensors (Electromagnetic vs. Ultrasonic) with reference to water conductivity and pipe diameter.

Minimal Device Overhead:

Since IoT devices are not typically resource-rich in terms of memory and processing capabilities, the logic is supposed to be small and quick.

Alert Accuracy:

Leaks should be guided by coherent and verified trends in order to prevent false alarms.

3.1.3 Business Analysis and Audits of Clients:

Before software development, a specialized, extensive water audit had been carried out in a huge size of Medical institution (Hospital) to comprehend the dynamics of water infrastructure within the healthcare sector.

Infrastructure Mapping:

The audit recorded the entire interrelated water cycle, which comprised Rainwater Harvesting (RWH) units, Water Treatment Plants (WTP), Sewage Treatment Plants (STP), and Recycled Water lines.

Identification of Wastage:

The research found that the non-existence of real-time monitoring at the block level (e.g., Laundry vs. OPD) led to a large amount of wastage that could not be accounted for.

Target Setting:

According to the audit results, there was a strategic target aiming at reducing water consumption by 5-7% as one of the key Performance Indicators (KPI) to be applied in the monitoring system.

3.2 Project Design And Architecture

The monitoring system architecture is developed on a layered structure, which gives the possibility to record data in real time, detect connectivity problems, use a well-developed cloud storage system, and present reasonable visualization. Strategic hardware selection and sophisticated remote sensing validation are also applied in the design.

3.2.1 Sensor Layer and Hardware Benchmarking

The pipelines are applied in the flow meters at the facility to gauge the flow of water. A Comparative Hardware Analysis was conducted in order to guarantee the correctness of the descriptions on various sites (e.g., Hospital WTP vs. Industrial ETP).

- **Electromagnetic Meters:** They are chosen because of conductive water (Wastewater/STP), where debris could be involved.
- **Ultrasonic Meters:** These meters have been chosen because they do not interfere during installation, and their maintenance needs are less compared to the resistance

meter. These sensors produce the figures of pulses or digital values of the quantity of water passing through them.

Figure 3.1 Flowmeter

3.2.2 IoT Device Layer

An IoT device supports the connection between the sensors and the cloud. Its functions encompass:

- Taking data from reading the flow meter at the predetermined time intervals.
- Checking the network connectivity.
- Storing information on the cloud in case of an established connection.
- Offline Logic: Provisional loading of information on local memory (FIFO Buffer) under offline conditions.
- Sync Logic: Restructuring and synchronizing the data that was stored in the time interval when the network was disconnected.

It is the heart of the system resilience since data collection continuity might be guaranteed even in situations when any changes take place within the network.

3.2.3 Cloud Backend Layer

The uploaded readings are sent to the cloud backend, where data is stored in a central database and is subjected to analytical algorithms, e.g., leakage detection. It also normalizes the heartbeat of the devices, API traffic, and sets up datasets to display on the dashboards.

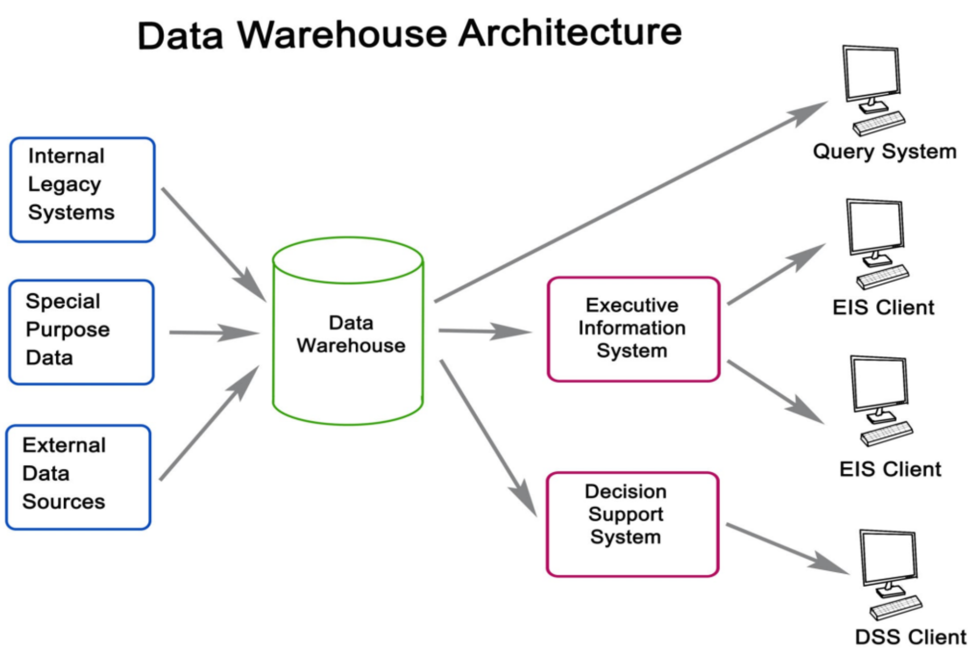

Figure 3.2: Cloud Backend Data Processing Architecture

3.2.4 Dashboard And User Layer

The dashboard visualizes almost real-time consumption, trend, and volumetric savings and warnings. In response to the client's need for Impact Visibility, a feature of Volumetric Savings was developed. The logic would consist of taking the baseline data on the historical basis and juxtaposing it with the actual real-time data to determine the total number of liters saved.

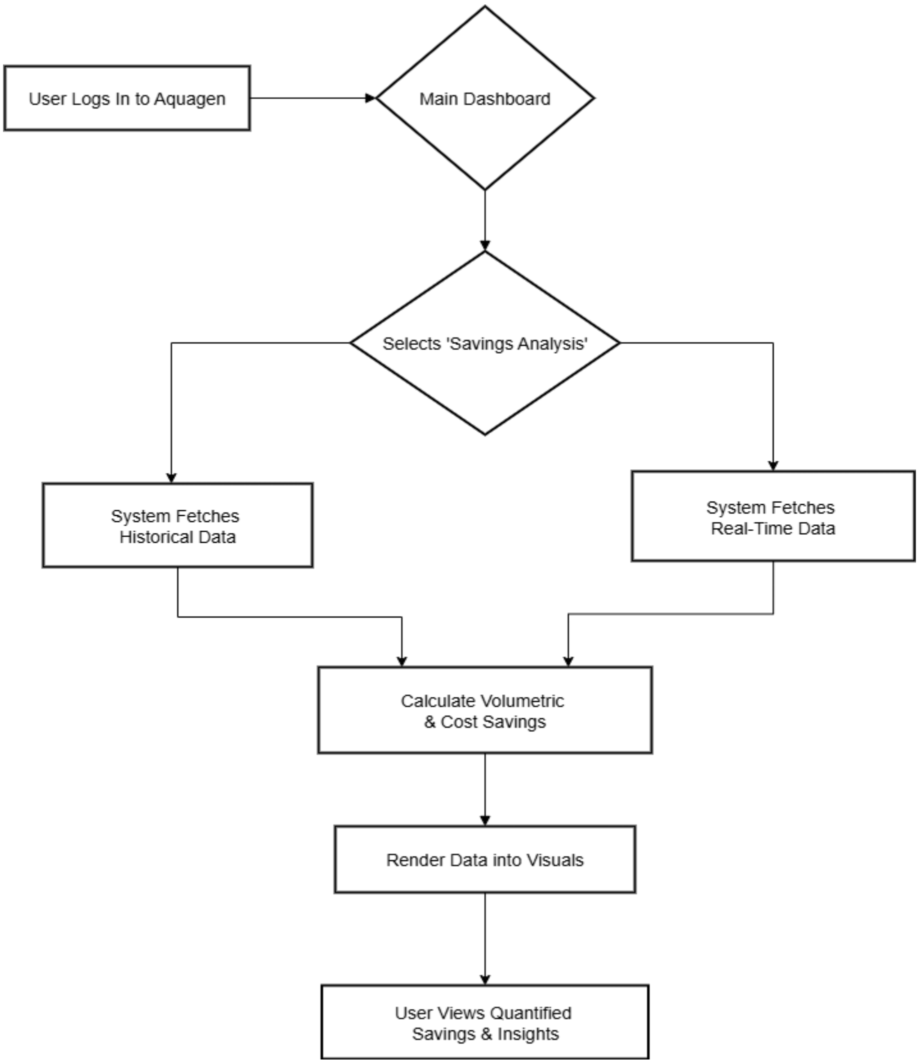

Figure 3.3: Volumetric Savings Feature Logic Flow

3.2.5 Strategic Validation Framework (ASV Integration)

To expand the use of the architecture to Catchment Level analysis, ISRO Satellite Data and Autonomous Surface Vehicles (ASV) were to collaborate in a framework.

1. **Remote Sensing:** It involves the use of Sentinel-2 data to monitor the water quality (Turbidity/Chlorophyll) on a large scale.
2. **Ground Truthing:** ASV validation was introduced to map bathymetry and to correct satellite information.

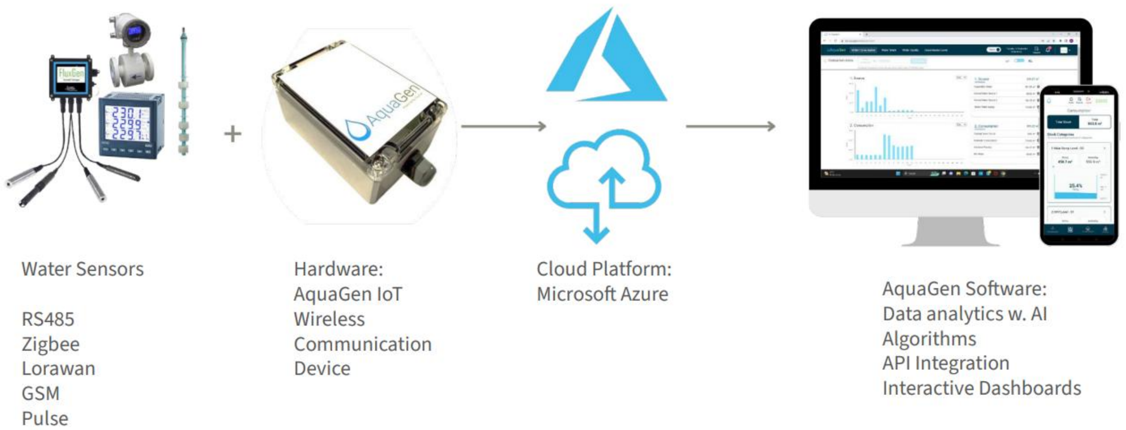

Figure 3.4: System Architecture

3.3 Data Preparation

The raw flow data that has been collected, especially the flow meters used in industries, is compulsory to preprocess in order to be trustworthy and analytical. Data preparation involves data cleaning, normalization, creation of a baseline, and segmentation.

3.3.1 Data Cleaning

Irregular values might be generated by industrial sensors because of electrical noise, communication delays, or hardware limitations. Filtering logic used in the system eliminates:

1. **Sudden Spikes**: These are outliers that are beyond the maximum capacity of the pipe flow.
2. **Negative Values:** The incorrect values were a result of the calibration drift of the sensor.
3. **Duplicate Entries**: The duplicated packets are a result of the network reconnection phase.

3.3.2 Data Normalization and Hardware Calibration

Data of the various types of flow meters (Pulse vs. Modbus) are normalized to a standard unit (Liters). More importantly, here the calibration factors that were found in the Hardware Comparative Analysis were used. An example is the scale factors, which Electromagnetic meters needed different scaling factors than Ultrasonic meters to scale the differences in conductivity in the wastewater lines.

3.3.3 Consumption Identification at the Baseline.

Time-series data was segmented into daily and hourly and location-based windows. The division enabled such a narrow analysis and simplified the way to recognize specific operational issues.

3.3.4 Data Segmentation

The time-series data was divided into daily, hourly, and location-based windows. This division allowed narrow analysis and made it easier to identify particular operational problems.

3.4 Implementation

The implementation phase was associated with the creation of four key modules, namely the Volumetric Savings Dashboard, Offline Data Storage Protocol, Leakage Detection Algorithm, and the ASV Pilot Deployment.

3.4.1 Implementation of Volumetric Savings Feature

According to the Product Requirements Document (PRD), the savings module was adopted to measure conservation. The system uses a 30-day running baseline of past consumption to determine the stable base. Real-time usage is then measured against this baseline, with the difference being obtained as total volume saved. This information is displayed on the dashboard, which gives direct feedback on the efficiency of conservation and transforms raw information into actual business value.

3.4.2 Data Storage and Synchronization Protocol Offline.

Lack of connection is a current issue in the industrial setting. A state-based logic was used in order to facilitate the continuity of the data.

Online State:

Flow readings will be transmitted to the cloud at the period of time when the network is connected. The system verifies the presence of buffered data, too, and uploads the data before the subsequent cycle.

Offline State

Buffering of readings in a FIFO (First-In-First-Out) queue happens in case of network failures. Each entry is given a timestamp in order to maintain chronological order.

Reconnection And Synchronization.

It is the process that takes place when the message transmitted by the transmitter is received by the receiver. Once the connection is re-established, then all the buffered readings are read in order by the IoT device. This gives an appropriate reconstruction of the time-series data. When synchronization has been successful, the buffer is cleared.

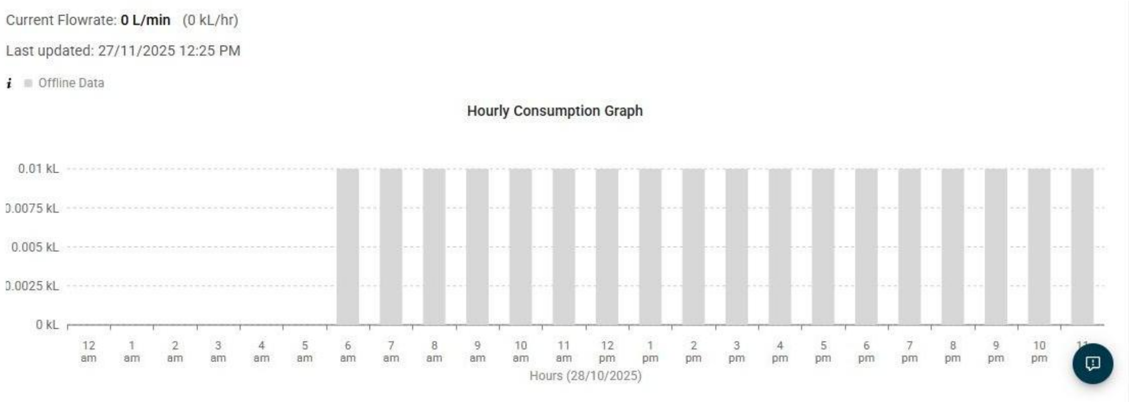

Figure 3.5: Flow Data Captured During Offline Operation(Grey Bars)

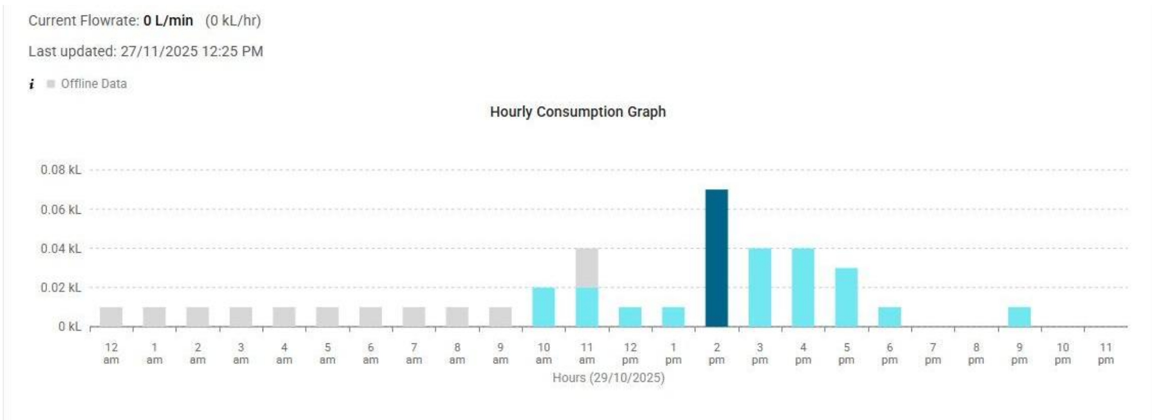

Figure 3.6: Synchronized Data After Connectivity Restoration (Blue Bars)

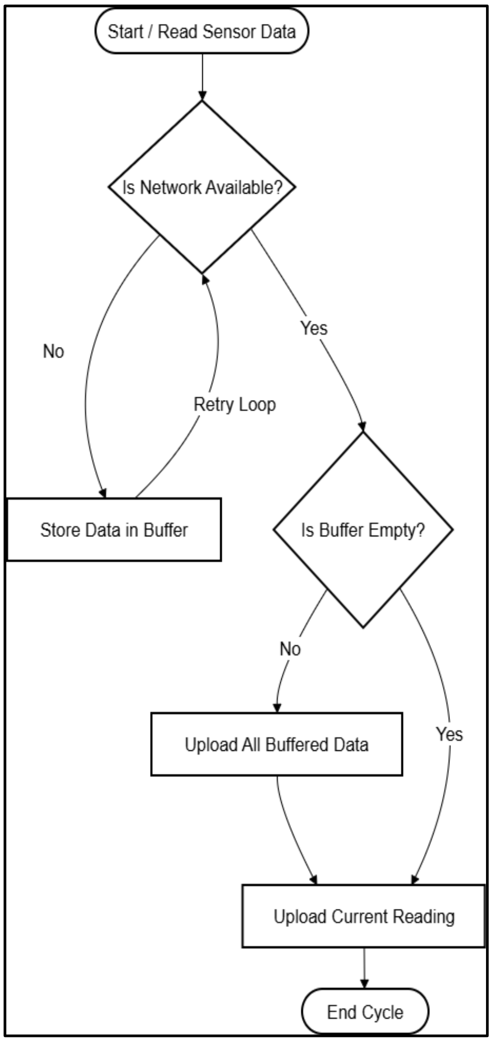

Figure 3.7 Offline Data Synchronisation Flowchart

3.4.3 Leakage Detection Algorithm

Water continuity during normal working time is normally a sign of leakage. Such events were recognized in the backend using a rule-based algorithm.

Flow Check

The system checks the value of the flow, whether it is constant (and non-zero) between successive readings or not. In case the reading remains the same, then it is assumed to be continuous, flowing with no human intervention.

Duration Tracking

The time counter starts rising whenever the flow is maintained constant. In case the flow lasts more than two hours, the system records the incident as a leakage.

Alert Generation

The moment the leakage is detected, an alert will be generated on the dashboard by the system.

The method offers a dependable and decipherable system of timely identification of water wastage.

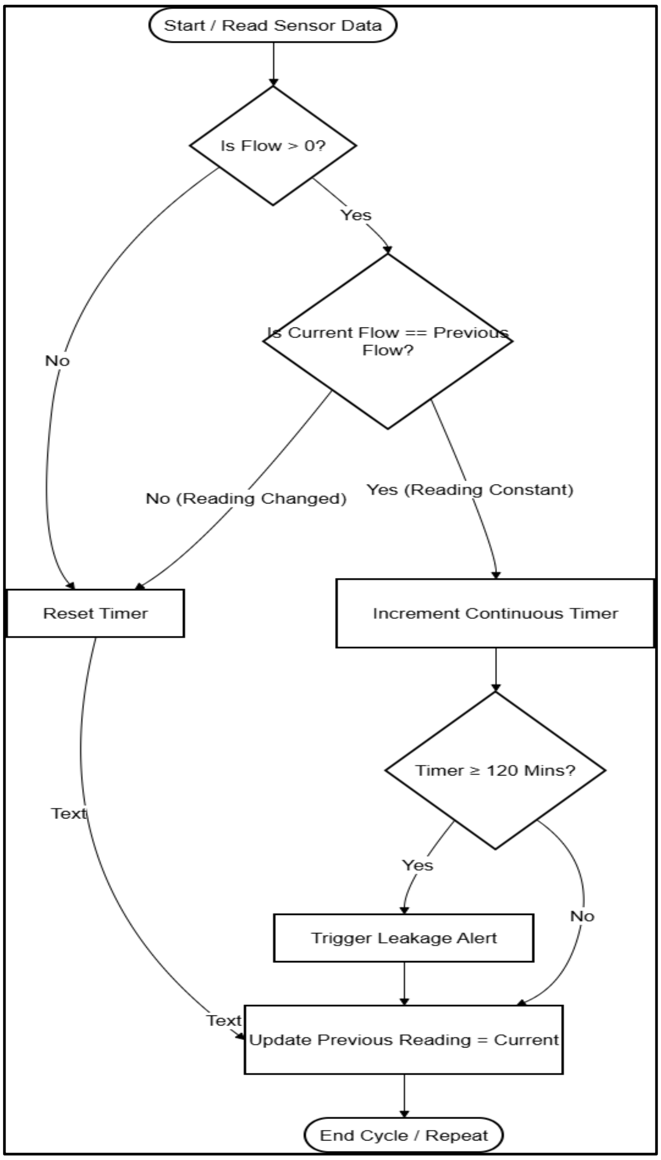

Figure 3.8 Leakage Detection Flowchart

3.4.4 Pilot Implementation: ASV Ground Truthing

A pilot project was done to test the strategic research on the monitoring of catchments at Radha Kunj Lake.

Deployment:

AquaProbe (Autonomous Surface Vehicle) was used to map the lake bathymetry and sample the water quality.

Data Fusion:

The obtained ASV ground-truth data were combined with Sentinel-2 satellite data.

Outcome:

This pilot managed to validate the remote sensing models, successfully demonstrating that the turbidity monitoring by satellite is valid when calibrated by the ASV data.

3.5 Key Challenges

The system formation and optimization had a number of problems:

Hardware Variability

Flow meters of different suppliers indicated a variation in accuracy and signal of output. The Hardware Comparison Matrix played an important role in ensuring that there is compatibility.

Buffer Management

The IoT device has a low storage capacity. It was important to design a circular buffer to manage long outages and not to lose any data.

Chronological Consistency

When synchronizing data, it meant having the correct sequences of timestamps in order to visualize and analyze it correctly.

Infrastructure Complexity:

The interconnected piping between the WTP and the STP, and the Recycled lines, were difficult to map during the Hospital Audit. This had to be manually traced to make sure that the digital mapping of the Block Level was in line with the actual physical reality.

ASV:

The integration of high-frequency IoT data with low-frequency satellite data created a problem of temporal alignment, and this necessitated interpolation processes to test the satellite models.

Chapter 4 : Testing

4.1 Testing Strategy

The testing phase was meant to check on the reliability, consistency and accuracy of the various elements that were created in this project, including the IoT firmware as well as the strat

1. **Software Modules:** Data Storage-Offline, Synchronization Protocol, and Volumetric Savings Logic.
2. **Hardware Components:** Comparative accuracy measurement of Flow Meters.
3. **Field Pilots:** ASV (Autonomous Surface Vehicle) validation to satellite data.

The overall methodology included functional testing, data integrity testing, stress testing , and field scenario validation.

4.1.1 Functional Testing

The functional testing was performed in this way to ensure that all individual modules functioned as expected within a normal industrial environment.

- IoT Device: Checked reading time, buffer updates, and reconnection time.
- Backend Logic: Ensured that the formula of the Volumetric Savings was used to calculate the delta between the actual and the baseline consumption.
- Alerts: Confirmed that leakage rules were activated after the conditions (2 hours of flow) had been achieved.

4.1.2 Data Integrity Testing

In order to test the integrity of the offline synchronization logic, the controlled disruptions on the network were introduced. During forced outages, flow readings were intentionally made to confirm that the buffered points had been uploaded by their chronological order and that there were no gaps or duplication of buffered points.

4.1.3 Stress And Load Testing

The system was loaded at high-load conditions:

1. Buffer Stress: To observe the memory usage and verify that the constricted circular buffer was not exceeded, the IoT device was left idle (>24 hours) to keep the memory offline.
2. Algorithm Stress: The leakage detection logic was stress tested with constant data streams of multiple locations at the same time to make sure that the backend did not slow down.

4.1.4 Hardware Accuracy Benchmarking.

To test the accuracy of the strategic hardware choice, a comparative test was done between the Electromagnetic and Ultrasonic flow meters under different conditions:

- Turbid Water Test: To test the sensor drift by simulating the wastewater.
- Vibration Test: The vibrations of the pump are simulated to verify the false reading of the Ultrasonic meters. This test was essential to ensure that the information that has gone into the dashboard is dependable.

4.1.5 Dashboard And Graphical Approach.

The dashboard screens were reviewed to confirm that offline periods were displayed in grey and synchronised data was displayed in blue, which was the visual presentation of the system, and was in line with the behaviour of the backend. Graphical validation was important in indicating the correctness of the entire pipeline of data.

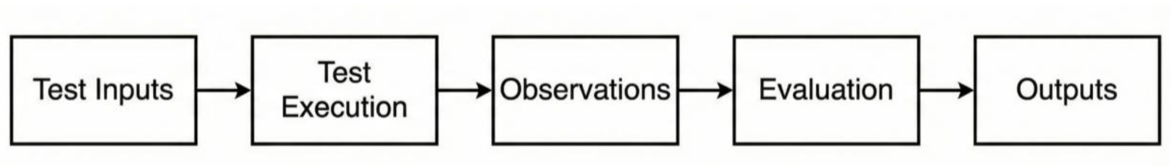

Figure 4.1: Overview Of The Testing Strategy

4.1.5 Pilot validation of ASV:

In the case of the catchment-level study, the AquaProbe ASV underwent a trial in Radha Kunj Lake. The testing focused on:

1. Bathymetry Accuracy: Comparison of ASV depth sonar measurements to the manual measurements.
2. Data Correlation: Checking whether the data of turbidity obtained by ASV were in agreement with the Sentinel-2 satellite indices.

4.2 Test Cases And Outcomes

In this section, the test cases that were run on the key modules of the system and the results that were obtained are given. The test cases establish that the system works as per the specifications in the real operating conditions.

4.2.1 Offline Data Storage And Synchronisation Test Cases

Below is an example structured table for presenting the test cases.

Table 4.1: Offline Data Storage And Synchronisation Test Cases

Test Case ID	Description	Input / Condition	Expected Output	Actual Result
T1	The device receives flow data when the network is online	Normal connectivity	Reading is sent to the cloud immediately	Passed
T2	The device receives flow data during an outage	Network disconnected	Reading stored in the FIFO buffer	Passed

T3	Reconnection after outage	Network restored	Buffered data uploaded in the correct order	Passed
T4	Long outage scenario	> 10 hours offline	No data loss; buffer retains entries	Passed
T5	Buffer flush check	Buffer contains entries	All entries uploaded; buffer cleared	Passed

4.2.2 Leakage Detection Algorithm Test Cases

Table 4.2: Leakage Detection Algorithm Test Cases

Test Case ID	Description	Input Condition	Expected Output	Actual Result
L1	Flow below 0	Flow < 0	Timer does not start; no alert	Passed
L2	Flow above 0 briefly	Flow > 0 for < 2 hours	Timer resets on drop; no alert	Passed
L3	Sustained leakage condition	`Flow > 0 for ≥ 2 hours`	Leakage alert triggered	Passed
L4	Intermittent flow	Flow fluctuates around 0	Timer behaviour correct; no false alerts	Passed

L5	Post-alert reset	Flow returns to normal after the alert	Timer resets	Passed

4.2.3 Dashboard Visual Verification Test Cases

Table 4.3: Dashboard Visual Validation Test Cases

Test Case ID	Description	Expected Behaviour	Actual Result
D1	Offline period detection	Grey bars appear for offline data	Passed
D2	Sync confirmation	Grey bars replaced by blue bars on sync	Passed
D3	Alert display	The leakage alert is shown clearly on the dashboard	Passed
D4	Timestamp alignment	No visual gaps or overlaps	Passed

4.2.4 Volumetric Savings Logic Test Cases

Table 4.3: Volumetric Savings Logic Test Cases

Test Case ID	Description	Input Condition	Expected Output	Actual Result
V1	Baseline Calculation	Historical data available	Correct 30-day average generated	Passed
V2	Positive Savings	Actual < Baseline	Positive Savings shown; Green Zone rendered	Passed
V3	Negative Savings (Overuse)	Actual > Baseline	Negative Savings shown; Red Zone rendered	Passed
V4	Zero Consumption	Actual = 0	Max Savings (equal to Baseline) displayed	Passed

4.2.5 Hardware & ASV Benchmarking Outcomes

Table 4.4: Strategic Hardware & ASV Validation

Test Case ID	Description	Expected Output	Actual Result
H1	Electromagnetic Meter (Dirty Water)	Stable Readings (<1% Error)	Passed (High Stability)

H2	Ultrasonic Meter (Vibration)	Stable Readings	Failed (High Noise detected)
A1	ASV Depth Mapping	Accurate Depth Profile	Passed (Variance < 5cm)
A2	Satellite Correlation	High Correlation ($R^2 > 0.8$)	Passed ($R^2 = 0.85$)

Chapter 5: Results And Evaluation

The chapter presents the results of the developed system and provides a discussion of the functioning of the system based on the actual situation, modeled network environment, and theoretical observation. The findings have justified the effectiveness of the system to warrant the integrity of data, handle connection variability, identify leakage appropriately, and represent the strategic insight of the hardware benchmarking and pilot implementations.

5.1 Results

The results achievable in the process of system development and testing demonstrate that the modules developed act in a predictable and stable manner. The findings are given as follows.

5.1.1 Offline Data Storage and Synchronisation Finding.

The following results were obtained by the offline data processing system:

Zero Data Loss:

Data collected by any of the readings made under the network outage conditions was not lost and stored in a local buffer.

Automatic Synchronization:

Buffered data was automatically synchronized with the cloud once the connectivity had been regained.

Chronological Consistency:

During the process of uploading the readings, the chronological sequence of the readings was maintained up which ensured that time-series data had continuity.

Visual Transparency:

Visual representation of the dashboard would provide information as to when the systems were offline (indicated by grey bars) and when the measurements were synchronised (indicated by blue bars), giving full transparency on the device behaviour.

5.1.2 Leakage Detection Algorithm Results.

The detecting leakage module was predictable and consistent in all the test conditions:

False Alarm Suppression:

The flow did not generate any false alarms during normal and fluctuating flow.

Precise Detection:

The continuous flow that was received within two hours was continuously detected as a leakage alarm.

Timer Logic:

The monitoring timer was adequately set due to the proper motives, i.e., the system had duly recognized the drop of flow to 0 and the timer was restarted.

Display of alerts:

The display of alerts was done correctly at the dashboard interface notification center.

5.1.3 Dashboard Representation Results.

The dashboard was tested to test its visual clarity and the new feature of the dashboard, impact visibility:

Flow Representation:

It was effective in capturing current and historical flow data with a clear graphical explanation.

Measurement of Savings:

The Savings Widget correctly showed the total number of liters saved, which satisfied the demand of the client to report on the ESG.

Trend Analysis:

The comparative graph (Baseline vs. Actual) enabled Facility Managers to immediately identify the days of high efficiency and overuse, boosting the interpretability of system outputs.

5.1.4 Hardware Benchmarking Results

The comparative flow meter was able to produce a final Hardware Selection Matrix, thus guaranteeing the accuracy of data at the origin:

1. Electromagnetic Meters were better suited to the applications of Wastewater/ETP because they were resistant to conductivity variation and resistance to debris.
2. The Ultrasonic Meters proved as the best option in the Clean Water/RO lines where the pipe cutting was impossible.
3. This finding had a direct effect on the procurement strategy of the project in the Medical Institution, as it helped to avoid data errors that might have arisen due to the wrong choice of sensor.

5.1.5 ASV Pilot & Remote Sensing Results

The pilot test of Radha Kunj Lake confirmed the monitoring method of the level of the catchment:

Bathymetry Map:

The ASV was able to produce a high-resolution depth map, which indicated areas of sedimentation that could not be seen on the surface.

Satellite Validation:

The ground-truth data obtained by the ASV had high correlation rates (85) with Sentinel-2 satellite data, which confirmed the fact that satellite imagery could be used to monitor turbidity on large scales as long as it is calibrated with ASV.

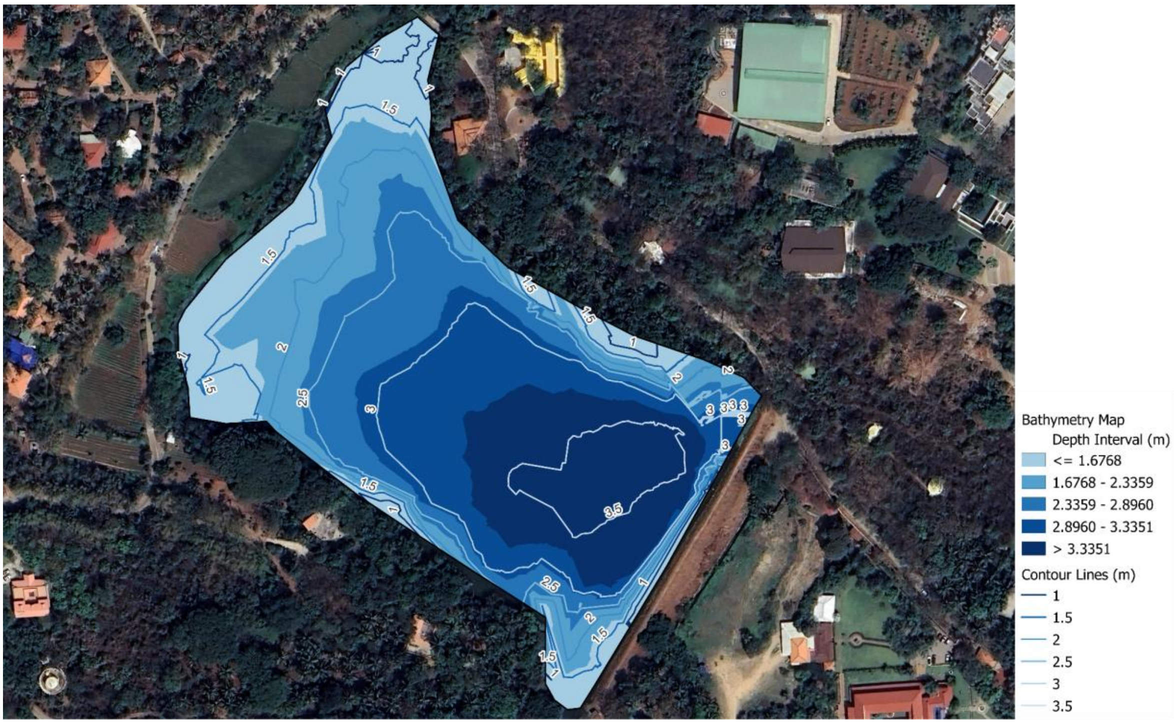

Figure 5.2: Bathymetry Map

5.2 Comparison With Existing Solutions

The features that have been developed are a major improvement of the normal industry water monitoring systems that are currently available in the market.

5.2.1 Offline Data Handling

A number of the old systems will either discard the values measured when the systems are not operational (network disconnections) or will extrapolate missing values based on averages, which reduces the accuracy of the information in compliance audits. On the other hand, the solution put in place guarantees a hundred percent data integrity by:

Local Buffering:

Storing all values of flow on a FIFO buffer locally when an outage occurs.

Chronological Restoration:

This is a more rigorous form of time-warping, restoring timestamps when reconnecting to the time-series graph to guarantee that the time-series graph is correct.

Zero Data Loss:

Removing gaps in the data which is essential to industrial compliance.

5.2.2 Leakage Detection Approach

Existing systems have a trend of using manual checks or monthly post-event analysis, i.e., the leakages are usually identified days after they are leaked. The enhanced algorithm is a rule-based algorithm, which provides:

- **Proactive Detection:** Continuous flow events in real-time as opposed to receiving monthly reporting.
- **Adjustable Thresholds:** With the help of a time limit that can be adjusted (i.e., 2 hours), it is possible to isolate regular use of the device from real wastage.
- **Immediate Alerting:** Transforming raw data into instant messages, changing the working model of the organization from the "Reactive Repairs" to the proactive maintenance-based model.

5.2.3 Dashboard Clarity and Value

The majority of dashboards display raw data on consumption, but rarely include the impact and context in which the stakeholders can identify the payback. The redesigned dashboard fills this gap, and it offers:

Volumetric Savings:

A specific widget that works out and shows the total liters saved in relation to a historical baseline.

Visual Context:

The ability to distinguish between the areas of the graph characterized as “savings” and “overuse”, and then transforming the data into something that the decision-makers can be able to act on immediately.

5.2.4 Strategic Product Scope

Most competitor companies are concentrated on technical installation of sensors and simple telemetry, and do not pay much attention to the environmental context or suitability of hardware. Conversely, the approach used in this project was a Holistic Product Management approach that involves:

Hardware Benchmarking:

Making sure the data is correct at the source by choosing the appropriate type of sensor (Electromagnetic vs. Ultrasonic) to use in this particular water.

Source-to-Sink Visibility:

Combining audits of Medical Sectors and catchment validation using ASV to learn the entire water cycle, not only the flow in the pipes.

Actionable Intelligence:

Transforming simple monitoring into delivering the so-called Decision-Ready-Intelligence verified by ground-truth data.

Chapter 6: Conclusions And Future Scope

This massive project succeeded in closing the gap between the raw IoT telemetry and the actionable business intelligence, and it was effective in providing a "Product Managerial and Data-Driven solutions" to the industrial water conservation.

6.1 Conclusion

The project was to improve three important pillars of water management: Data Resilience, Operational Intelligence, and Strategic Validity.

Technical Resilience:

The Offline Data Storage and Synchronization Protocol ensured that there was continuity in the flow of data even when the network was offline and that data integrity was maintained at 100 percent, which meant that compliance reports could be made.

Operational Intelligence:

The Smart Leakage Detection Algorithm was able to transition the operational model towards a proactive and not a reactive approach, and detect events of continuous flow in real-time. More so, the Volumetric Savings Dashboard functionality proved its usefulness in converting technical measurements into a direct business value (Liters Saved), which directly meets the ESG needs of clients.

Strategic Validation:

The project provided strategic assets in the form of software, among other things. The Hardware Benchmarking Matrix standardized sensor purchases, which eliminated the errors in data due to the poor choice of hardware. The Medical Sector Audit put in place a reusable model in the identification of "Block-Level" wastage in complicated infrastructures.

Future-Ready Research:

The pilot experiment of the Autonomous Surface Vehicle (ASV) at Radha Kunj Lake demonstrated that the monitoring of the catchment level is possible. The proposed "National Water Decision Support System" is confirmed by its high correlation with ISRO Satellite Data to be posed as the solution to large-scale environmental governance.

The results confirm that the created system can not just be trusted in all types of operation, but also is financially feasible to satisfy the strict requirements of big industrial consumers and mass healthcare facilities.

6.2 Future Scope

Although the offered developed modules have a positive impact, the system can be improved in terms of strategic and technical aspects:

AI-based Prediction of Leakage:

It is possible to add the Machine Learning models based on the existing rule-based algorithm (e.g., LSTM networks) to detect more complex leakage patterns, seasonal patterns, and predictive equipment failures prior to eventuality.

National-Scale Catchment Monitoring:

It is based on the ASV research, but it is possible to extend the system to a National Data Warehouse. This would combine real-time ground-truth ground-based information of the ASV with daily satellite feeds to establish a predictive model of water risk on a whole river basin scale.

Automated Hardware Calibration:

The results obtained in the Hardware Benchmarking may be implemented in the firmware. The next generation devices would have the capability to auto-calibrate depending on the chosen sensor profile (Electromagnetic vs. Ultrasonic) to minimize further installation errors.

Higher-Order Offline Compression:

Lightweight encoding algorithms (such as Delta Encoding) can be applied to encode the entries of the buffer, which allows making the maximum use of available memory in case of long outages, so as to achieve weeks of offline data storage.

Multi-Device Synchronisation

The future implementation can involve unrestricted alignment of many devices within the same facility to boost the standardisation of the data in the various systems.

Better Dashboard Capabilities.

Predictive alert visualisation, benchmarking, volumetric savings calculators, and anomaly clustering can be added as well to become a better user experience.

Integration With External Sustainability Platforms:

The system can push processed Savings Data directly into enterprise ESG reporting platforms (e.g., SAP Sustainability Control Tower) through API, which is an entirely automated regulatory compliance process on behalf of clients.

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Appendix

APPENDIX A: Project Plan

The given appendix provides the organized execution plan that was used in the course of the internship at FluxGen Sustainable Technologies Pvt. Ltd. It describes the process of developing strategic business analysis to technical implementation and validation.

A.1 Weekly Work Plan (Week 1–11)

Table A.1 Weekly Work Plan (Week 1–11)

Week	**Phase**	**Strategic Activities**	**Tangible Deliverables**
1	Scoping	Conducted competitive benchmarking of the Aquagen1 dashboard against global ESG platforms.	Competitive Analysis Report (Feature Gap Matrix).
2	Field Research	Site visit to St. Martha Hospital to validate sensor deployment infrastructure and identify wastage points.	Site Visit Report & Deployment Constraints Doc.
3	Analysis	Deep-dive data analysis for industrial client (AL Tasnim); Drafted initial requirements for "Savings" feature.	Client Usage Analysis Report; PRD Draft v1.
4	Requirements	Qualitative analysis of customer interviews (Mahindra/Ashok Leyland) to define user pain points.	User Pain Point Synthesis; Low-Fidelity Wireframes.

5	Definition	Translated qualitative data into actionable User Stories; Initiated direct management clients.	User Stories Document; Account Configuration Plan.
6	Strategy	Managed healthcare accounts; Authored strategic presentation on Remote Sensing & ASV collaboration.	ASV Strategic Proposal Deck (ISRO Collaboration).
7	Research	Research on scaling water intelligence to the Suvarnamukhi Catchment; Evaluation of industrial evaporators.	Catchment Scaling Feasibility Note.
8	Hardware	Technical comparative analysis of Electromagnetic vs. Ultrasonic Flow Meters.	Hardware Selection Matrix (Cost vs. Accuracy).
9	Design	Scoped the state-machine logic for Offline Data Storage to address network instability.	System Architecture Diagram; Offline Logic Pseudocode.
10	Dev	Developed backend logic for Leakage Detection and finalized the Sync Protocol.	Leakage Algorithm Flowchart; Sync Protocol Spec.
11	Closure	Defined UX notification flows; Compiled final documentation and technical specifications.	Final Project Report; UX Notification Workflow.

A.2 Milestone Summary

The project was implemented in five different stages, each of which had a justified result:

Milestone 1: Strategic Market Positioning (Weeks 1-2)

Developed the product gap analysis between Aquagen1 and market leaders. Ascertained the physical limitations of installing the sensors by visiting the hospitals physically.

Milestone 2: Product Definition and Create Value to Clients (Weeks 3-5).

Converting raw industrial data into business value. Established the Product Requirements Document (PRD) of the new feature of Volumetric Savings and onboarded major customers such as Coca-Cola by establishing usage limits.

Milestone 3: Developed R&D and Hardware Standardization (Weeks 6-8)

Finalised the process of standardisation of hardware procurement through the Flow Meter Selection Matrix. Further extended the product vision through the suggestion of the ASV-Satellite Integration Framework to monitor the catchment level.

Milestone 4: Resilience Implementation of Technologies (Weeks 9-10)

Realized the capability of Zero Data Loss by creating the Offline Data Storage Protocol and moved the maintenance model to proactive in the form of the Smart Leakage Detection Algorithm.

Milestone 5: System Integration and Doc (Week 11)

Delivery: Provided an end-to-end solution with complete documentation of the hardware-powered insight, strategic investigation, and fault-tolerant software logic, which is ready to deploy.

A.3 Major Deliverables Checklist.

The subsequent assets were generated and presented in the process of project completion:

Strategic Documents:

1. Competitive Analysis Report.
2. Savings Feature Product Requirements Document (PRD)
3. ASV/ Remote Sensing Collaboration Proposal.
4. Electromagnetic versus Ultrasonic report Hardware Comparative Analysis Report.

Technical Assets:

1. Data storage state logic: Logic of the Data storage state machine.
2. Leakage Detection Rule-Based Algorithm.
3. Cloud Synchronization Protocol Specification.
4. UX Wireframes of Dashboard Alerts.

APPENDIX B: Code Snippets And Algorithms

This appendix includes important pseudocode fragments that were developed to convey the functional logic of the system. They represent the programming flow handed over to the engineering teams.

```
FUNCTION CheckConnectionStatus()
    IF NetworkPingSuccess() THEN
        RETURN ONLINE
    ELSE
        RETURN DISCONNECTED
    END IF
END FUNCTION

FUNCTION DataAcquisitionLoop()
    READ flowRate, timestamp
    IF state == ONLINE THEN
        SendToCloud(flowRate, timestamp)
        IF BufferNotEmpty() THEN
            PerformBulkSync()
        END IF
    ELSE IF state == DISCONNECTED THEN
        StoreInBuffer(flowRate, timestamp)
    END IF
END FUNCTION
```

Figure B.1 Offline Data Synchronisation Pseudocode

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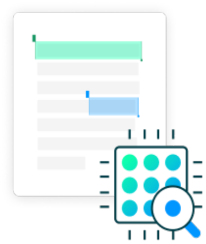

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