

## **CHAPTER 14**

### **14.Automation of Water Supply Systems**

## CHAPTER 14: AUTOMATION OF WATER SUPPLY SYSTEMS

### 14.1 Introduction

Water supply is a basic necessity for people; the gap between demand and supply is growing day by day. This imposes the need to practise optimum utilisation of water through the use of information technology at source, treatment, transmission, and distribution till it reaches the consumer's end. This implies continuous supervision of the water supply process in order to allow any problem that could appear to be isolated, analysed, and resolved, and at the same time, to maintain normal functioning parameters to the best possible level. Proper solutions imply effective point/stage wise monitoring with automation architectures including a supervision and control system for the real time sensing of various parameters, programmable logic controllers-based control system with basic functions (communication, adjusting, measuring, etc.) libraries, communication systems, standard interfaces or dedicated ones connected with sensors, electrical drive elements, measuring devices, etc.

The informatics systems present the possibility of monitoring, analysing and processing the data, leading to an optimum functioning of the stage as well as the entire water supply system. This chapter presents a philosophy of automation system for the monitoring, control, and predictive analysis of the process parameters in the water supply system for efficient energy usage, reduction of water losses and optimum administration of the water supply system.

### 14.2 Purpose and Objective

Application of new technology and 'smart (real-time process parameter measurement)' devices are well-established in all type of works for sustainable services, including water supply networks. Remote and online monitoring is one of the easiest ways to control flow and pressure among other water-related process parameters in water supply networks. In order to reduce losses in the network, online monitoring and controlling is more than a necessity. Water loss reduction is one of the biggest challenges today in the water supply system.

The automatic and electronic devices will help monitor and control leakages in the water supply systems. The application of these new technologies in water supply system eliminates not only water wastage but also provides continuous water flow at predetermined pressure range. The methodology involves automation with minimum human intervention leading to effective and efficient network distribution, cost effectiveness and maintaining safe drinking water quality parameters.

The sensor-based monitoring is not only to monitor key performance indicators viz., flow, pressure, leaks, residual chlorine, etc., but also to ensure early detection of faults/deviations from set routines, enable quick response, minimise service delivery outage, minimise water loss, optimise efficiency, and monitor the quantity and quality on sustainable basis. The additional advantage of this data would be to analyse the demand pattern of user groups over time and use this information for demand management at appropriate level, minimise non-revenue water, ensure proper management and effective operation, and maintenance of water supply systems in the ULBs.

A combination of sensors, automation systems, and a cloud-based Internet of Things (IoT) system will be the most appropriate to provide a comprehensive and robust smart online water management system.

### 14.3 Instruments and Control Systems

Instrumentation and control refer to the analysis, measurement, and control of process variables using process control instruments and software tools through an automatic control system. Some of the more common process variables measured in a water distribution system includes flow, pressure,

level, chemical dosage, water quality, energy, and temperature. Instrumentation should be selected, installed, commissioned, and maintained properly ensuring the data that it can provide is invaluable to the water management authority/body.

The control system may be manual or automatic or a combination thereof. Regardless, the system should be designed to promote energy efficiency, conserve water, and reduce waste while meeting the treated water quality standards and demands under all anticipated conditions.

### 14.3.1 Methods of Control

The key characteristic of control is to interfere, to influence, or to modify the process. This control function or the interference to the process is introduced by an organisation of parts (including operators in manual control) that, when connected together, is called the control system. Depending on whether a human body (the operator) is physically involved in the control system, they are divided into manual control and automatic control (SCADA). Due to its efficiency, accuracy, and reliability, automatic control is widely used.

#### i. Manual

Manual Control system is an open loop control system. This type of system needs an external effort to adjust and correct the errors. Manual control system is less reliable. Manual controls are applicable when judgment and discretion are required. Additional risks arise with the use of manual controls as they can be more easily overridden, susceptible to human error, and are inherently less consistent than automated controls.

#### ii. SCADA

Supervisory control and data acquisition or SCADA is a type of process control system architecture that uses computers, networked data communications, and graphical human-machine interfaces (HMIs) to enable a high-level process supervisory management and control.

SCADA is a collection of hardware and software components. Plant floor devices such as pumps, valves, and transmitters transfer real-time data to processors such as remote terminal units (RTUs) or programmable logic controllers (PLCs). That data is then disseminated to various devices within the network such as HMI terminals, servers, and computers. Images of these processes are presented to operators for various types of interaction.

Generally, SCADA is done by relying on simple indicators such as lamps, analogue meters, or alarms. Along with the development of computer technology, the computer becomes an important component used in designing SCADA. However, an IoT system is more suitable for web-based monitoring and control for several reasons. These reasons are elaborated in the next sections.

In SCADA system, HMI is used as a display of connecting SCADA system between man and machine. HMI displays data to the operator and provides the input medium used to control the process by the operator. Without using HMI, the process of supervision and control will be more difficult and require more time.

The hardware components consist of pumps and motors, valves, switches, and transmitters. These components will communicate with a processor which, in turn, will allow the components to be viewed, graphically, on the SCADA system.

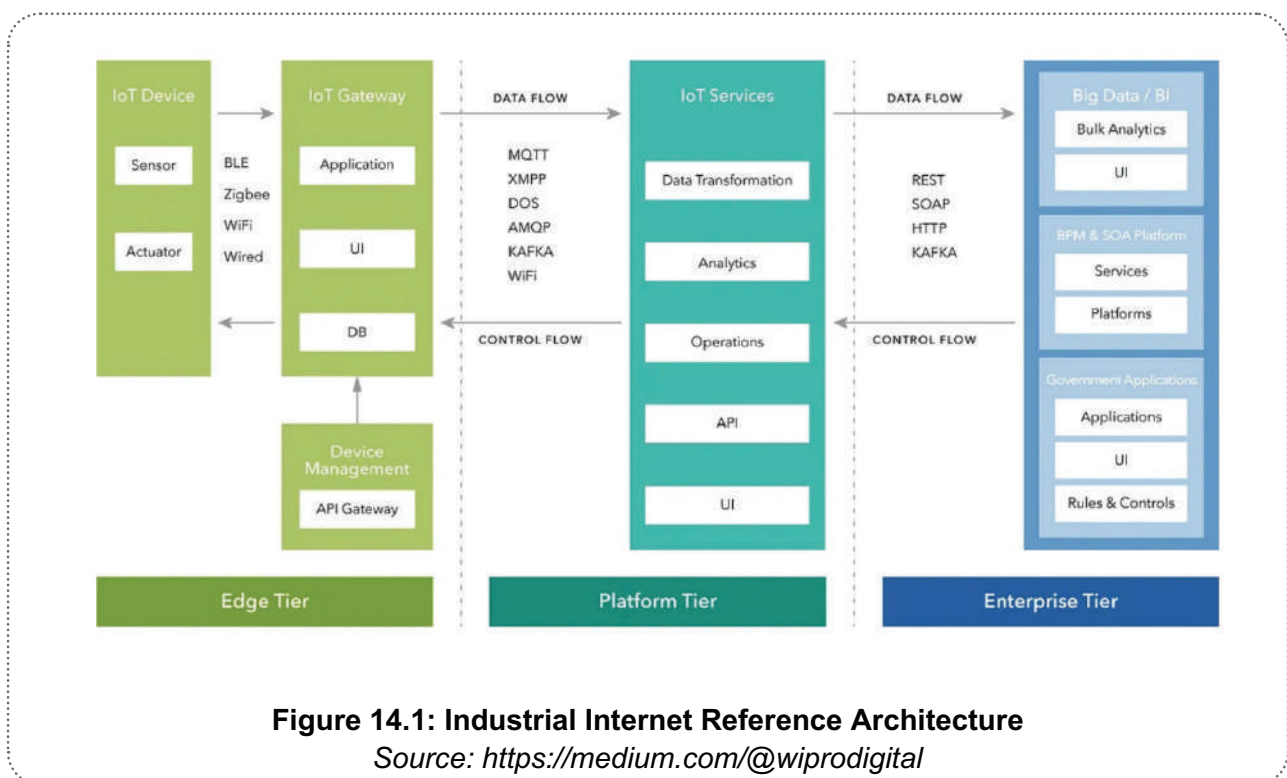
### 14.4 Internet of Things (IoT) System

Important advancements in computing, storage, networking, and sensor technologies over the last decade or so has given rise to IoT.

At a high level, IoT is a network of interrelated intelligent devices, computers, machines, and objects that are capable of transferring data without requiring human-to-human or human-to-computer interaction. The application of IoT in water distribution refers more specifically to interconnected control systems, sensors, instruments, industrial assets, computers, and people. IoT enables intelligent operations using advanced data analytics, resulting in transformational business outcomes. The scale and span of IoT can be massive, easily resulting in deployments reaching into the thousands, if not tens of thousands of individual endpoints. When properly utilised and optimised, it can be one of the largest enablers for smart systems.

#### 14.4.1 IoT Architecture

As depicted in Figure 14.1, there are three tiers in an IoT system – Edge, Platform and Enterprise Application.



##### 14.4.1.1 Edge tier

The Edge tier consists of IoT devices and the IoT gateway. The architectural characteristics of this tier, including its breadth of distribution and location, depend on the specific use cases of the enterprise. It is common for IoT devices to communicate using a relatively short range and specialised proximity network, due to power and processing limitations. The IoT gateway contains a data store for IoT device data, one or more services to analyse data streaming from the IoT devices or from the data store, and control applications. The IoT gateway provides endpoints for device connectivity, facilitating bidirectional communication with the enterprise systems. It also implements edge intelligence with different levels of processing capabilities.

##### 14.4.1.2 Platform tier

This typically resides in cloud or some sort of internet/intranet and uses a web server or similar infrastructure. It provides foundational services to Edge tier and Enterprise tiers. Some services

provided by platform are data processing and storage, stream analytics engine, alarm and alerts module, AI/ML engine, among others.

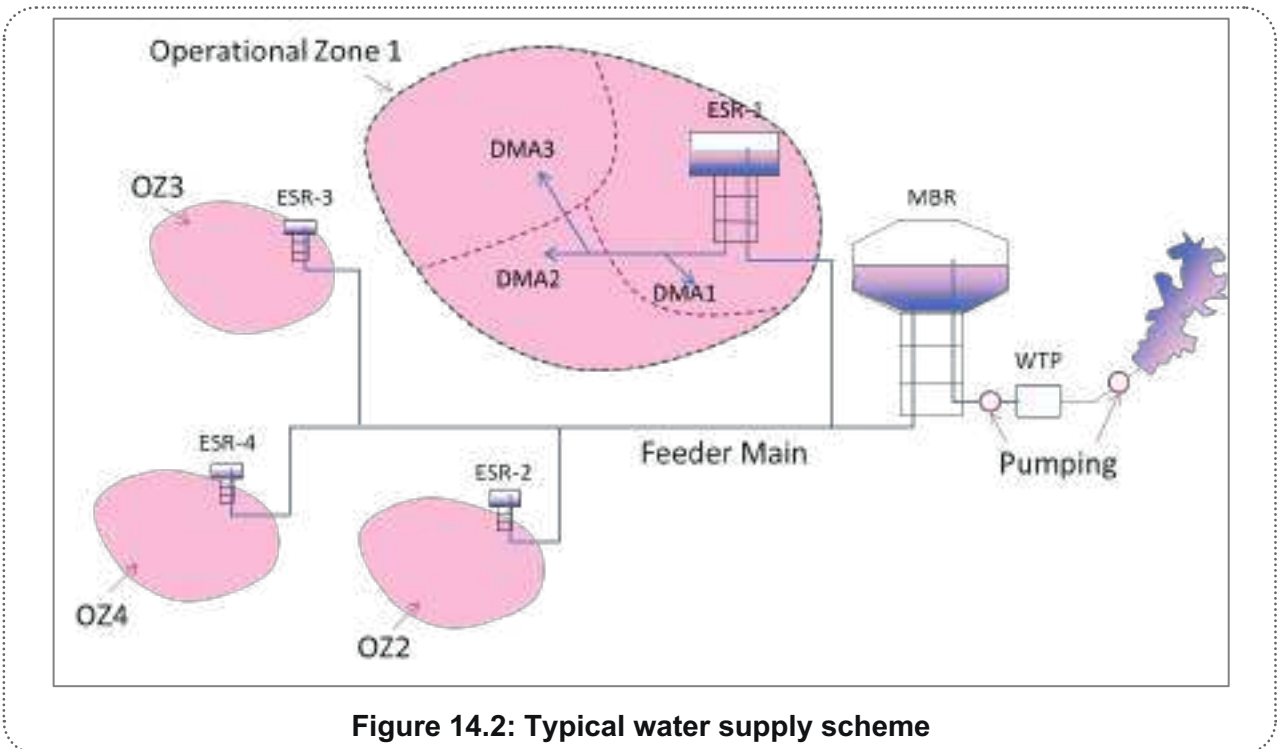
**14.4.1.3 Enterprise/Application tier**

This tier resides on top of the platform and shares platform services and data storage. It has the application for a specific requirement, e.g. CMS. It provides user interface and application specific analytics, dashboards, reports. It runs real-time analytics on the data and gives actionable alerts to users. Industrial control systems like SCADA and DCS are suitable for time-critical (microseconds latency) primary control of a process. In water distribution domain, WTP is an example of such a process. For other components like pumping stations, ESR, FCV, time-critical control is not required. Control logic of such components may be based on data from other parts of the network in addition to the component being controlled. Thus, an IoT system where data from all parts of the network is processed is suitable for non-time-critical control.

In short, IoT working on top of automation systems and integrated with technologies like AI/ML is an ideal digital platform for distributed water management system. To ensure every drop of water gets meaningfully utilised, India must embark on the journey to digitalise water distribution. The beginning of the transition to a centrally monitored water supply distribution and management system is the most important. It involves:

- a. the monitoring and control requirements of the existing system;
- b. understanding how available instruments/technology along with control systems can be used to achieve a real-time monitoring and control;
- c. understanding the upgradations that needed in the existing water supply system; and
- d. working on a cost-effective final solution for the utility.

**14.5 Automation at Various Components of Water Supply System**



**Figure 14.2: Typical water supply scheme**

A typical water supply scheme is shown in Figure 14.2. The following components of a water supply system can be considered for the purpose of automation, real-time monitoring, and centralised control:

- 1) Water pumping systems
- 2) Water treatment plants (WTPs)
- 3) ESR/MBR/GSR
- 4) Key points in Distribution System

SCADA is suitable for the control of a plant (e.g., WTP, ESR, etc.) but not for distribution systems. IoT platform with a water distribution application is more suitable compared to SCADA. In a distribution system each device, each node, and each facility needs to be stitched together, and these will be very large numbers.

### 14.5.1 Water Pumping Systems

As shown in Figure 14.2, pumping is generally required from source to WTP and again from WTP to a clear water master balancing reservoir (MBR).

Water pumping systems can and need to be monitored for the parameter such as water level, pressure, incoming and outgoing flow, energy consumed by the pumping systems, water quality parameters, among others.

#### Monitoring and Control using SCADA

(i) **Monitoring:** Monitoring location and parameters are shown in Table 14.1.

**Table 14.1: Monitoring location and parameters**

Location	Parameter	Method	Per
River Source	Level	Ultrasonic/Radar Level Sensor	Take Off Point
Pump House	Level	Ultrasonic/Radar Level Sensor	Underground Reservoir
	Flow	Electromagnetic Flowmeter	Individual Delivery of the Pump
	Flow	Electromagnetic Flowmeter	Common Header from the Pump House
	Energy	Electronic Energy Meter	Common LT/HT Line to the Pump House
	Energy	Electronic Energy Meter	LT/HT Line feeding the individual Pumps at Pump House

(ii) **Control:** Control location and parameters are shown in Table 14.2.

**Table 14.2: Control location and parameters**

Location	Parameter	Method	Per
River Source	Flow	Electric Actuated Gate/Valves	Off Take Point
Pump House	Priming System	Electric Actuated Valves/Solenoid valves	Pump at Inlet line
	Flow	Electric Actuated Gate/Valves	Individual Delivery of the Pump

Location	Parameter	Method	Per
	Flow	Electric Actuated Gate/Valves	Common Header from the Pump House

'Per': suggests the location of installation,  
 All parameters must be available as 4–20 mA inputs to the monitoring and control system in real time for proper management of the system.

### 14.5.2 Water Treatment Plants (WTP)

All water supply systems will involve raw water being picked up from a source (river/check dam/canal, etc.). The source is generally a distance away from the town or the city which is being fed by the water supply system. C&I scheme for a WTP is shown in figure 14.3.

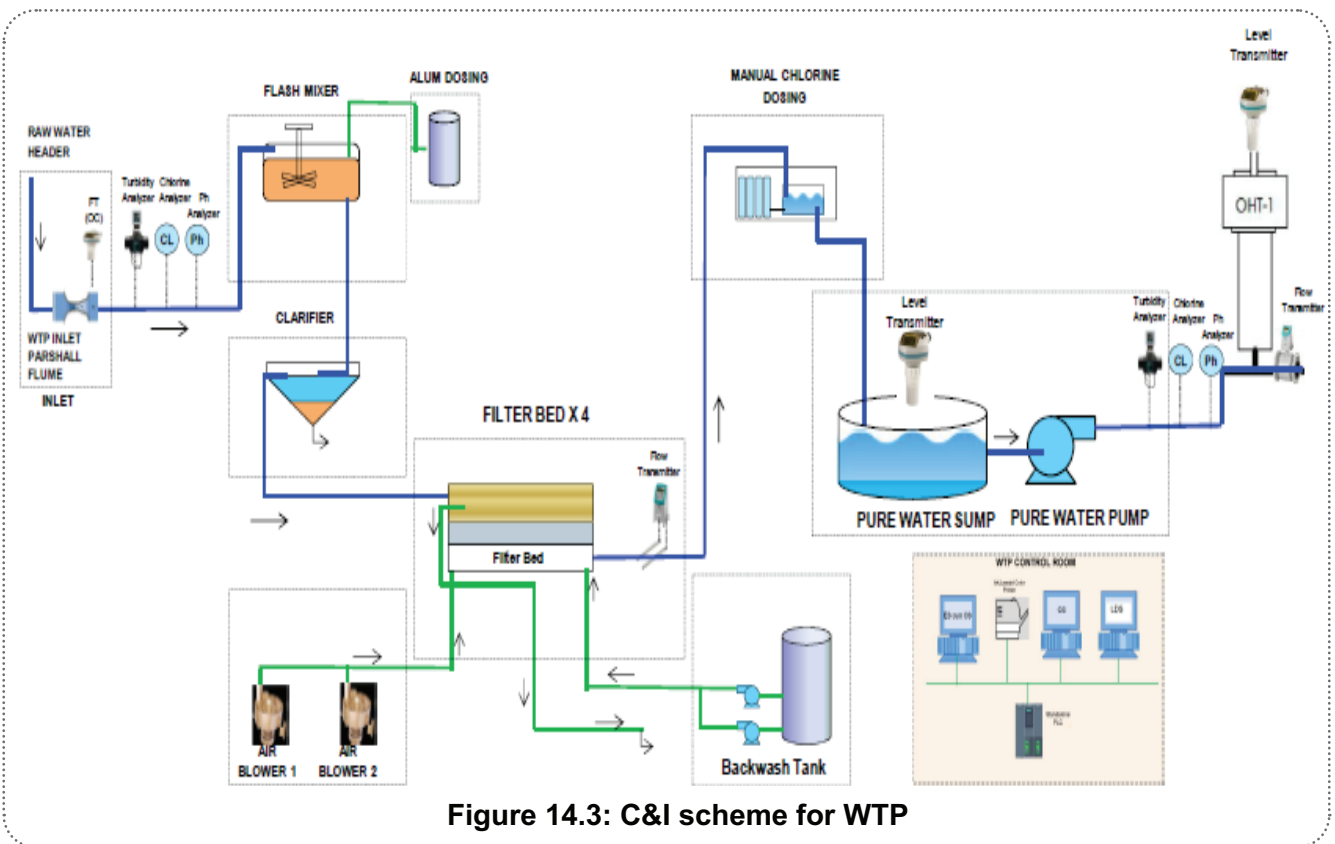


Figure 14.3: C&I scheme for WTP

The following table provides a list of parameters that can be considered for the purpose of real time and SCADA base monitoring.

**Monitoring:** The parameters to be monitored at each stage shall be considered as shown in Table 14.3.

Table 14.3: Monitoring location and parameters in WTP

Location	Parameter	Method	Per
Aerator	Flow	Electromagnetic Flowmeter	Aerator Inlet
Flash Mixer	Water Quality: pH and Turbidity	Online Sensors	Per Flash Mixer
Alum/PAC Dosing	Flowmeter of Alum/PAC	Electromagnetic Flowmeter	Per Dosing Pump
Clarifier	Water Quality: pH and Turbidity	Online Sensors	Per Clarifier Outlet

<b>Location</b>	<b>Parameter</b>	<b>Method</b>	<b>Per</b>
Filter Beds	Level	Ultrasonic Level Sensor	Filter Bed (multiple in case of multiple outlets in filter bed)
	Pressure	Differential Pressure Sensor	Filter Bed
Back Wash System	Level	Ultrasonic Level Sensor	ESR
	Pressure	Pressure Transmitter	At inlet line to the Filter Bed
Backwash Water Recirculation System	Level	Ultrasonic Level Sensor	Recirculation Sump
	Pressure	Pressure Transmitter	At outlet line from the pumping system
	Flow	Electromagnetic Flowmeter	At inlet to the recirculation sump/recirculation line to the pre clarifier stage
Chlorine Dosing System	Residual Chlorine	Online Sensors	Per Pure Water UGR
Pure Water Pumping System	Pressure	Pressure Transmitter	At outlet line from the pumping system
	Level	Ultrasonic Level Sensor	Sump
	Flow	Electromagnetic Flowmeter	At outlet line from the pumping system

(ii) **Control:** The parameters to be controlled at each stage are shown in Table 14.4.

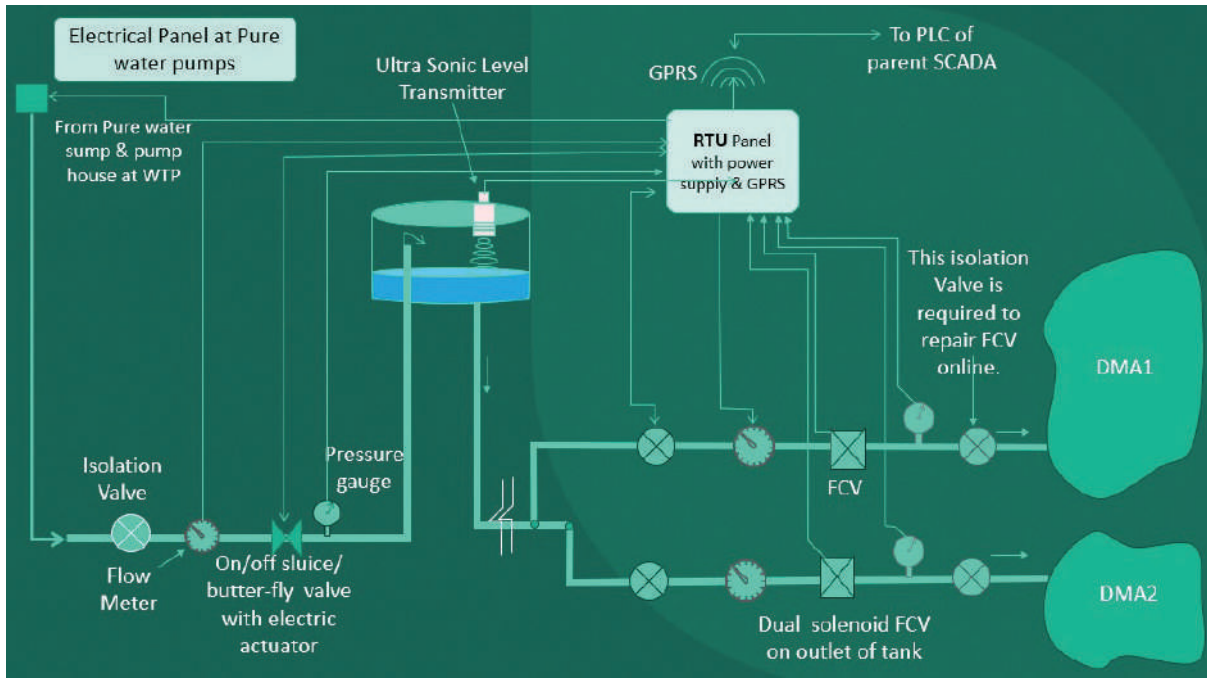
**Table 14.4: Control location and parameters in WTP**

<b>Location</b>	<b>Parameter</b>	<b>Method</b>	<b>Per</b>
Aerator		PLC based flow monitoring local panel	
Flash Mixer	Mixer Operations	PLC controlled local panel	Per Flash Mixer
Alum/PAC Dosing	Flow of Alum/ PAC	PLC controlled local panel operating Dosing Pump	Per Dosing Pump
Clarifier	Clarifier Operations	PLC controlled local panel	Per Clarifier
Filter Beds	Filter Bed Operations of Regular, Backwash and Drain Modes	PLC controlled local panel	Filter Bed
	Flow	Electric Actuated Gate/Valves	Individual Inlet/Outlet/Backwash

Location	Parameter	Method	Per
			and Drain of the Filter Bed
Back Wash System	Priming System	Electric Actuated Valves/Solenoid valves	Pump at Inlet line
	Flow	Electric Actuated Gate/Valves	Individual Delivery of the Pump
	Pressure	Pressure Transmitter	At outlet line from the pumping system
	Flow	Electromagnetic Flowmeter	At inlet to the recirculation sump/recirculation line to the pre-clarifier stage
Chlorine Dosing System	Residual Chlorine	Online Sensors	Per Pure Water UGR
Pure Water Pumping System	Pressure	Pressure Transmitter	At outlet line from the pumping system
	Level	Ultrasonic Level Sensor	Sump
	Flow	Electromagnetic Flowmeter	At outlet line from the pumping system

### 14.5.3 ESR/MBR/GSR

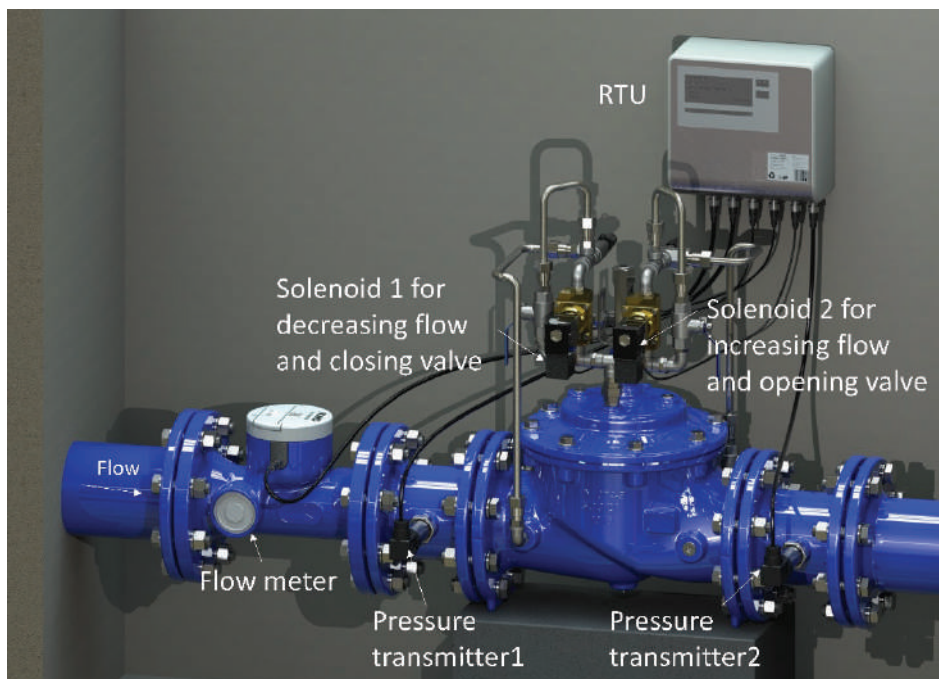
ESR/MBR/GSR systems need to be monitored for parameters such as water level, pressure, incoming and outgoing flow, water quality parameters among others. A typical inlet and outlet arrangement at service reservoir is shown in Figure 14.4. This arrangement is only for a sump/clear water reservoir pumping water to the ESR. However, for a gravity/pumping main supplying water to multi-ESRs, the pressure gauge as shown in Figure 14.4 will be replaced by a pressure transmitter which will be connected to RTU. In addition to this, the on/off sluice/butterfly valve shall be replaced by the dual solenoid FCV.



**Figure 14.4: Typical inlet and outlet arrangement at service reservoir**

A typical FCV is shown in Figure 14.5. FCVs are used to rationalise (less quantity in non-peak hours and more quantity at peak hours) distribution of water from ESRs to DMAs. Normally, with hydraulic model, the design of pipelines is so made that the DMAs can get water as per their demand. However, the tank practically gets empty (on sloppy side) when the flow starts. However, with FCV, the flow can be regulated in such a way that the water will flow as per the actual demand in the DMA and there will be backward pressure available which will help to maintain water level in the service tank.

During pipe breakages or burst in the DMA, the FCV at the entry of DMA can close the flow. Here, the pressure transmitter shall send the signal and accordingly, the PLC shall control the FCV through its solenoids.



**Figure 14.5: Typical FCV with solenoids, RTU, pressure transmitters and flowmeter.**

In order to maintain the nodal pressure of 21 m, if VFD pump is installed on the outlet of the ESR, then FCV may not be necessary.

**Monitoring and Control by IoT System**

**Monitoring:** The parameters to be monitored are shown in Table 14.5.

**Table 14.5: Monitoring location and parameters in ESR/ UGR/ pump house**

Location	Parameter	Method	Per
Elevated Service Reservoir	Level	Ultrasonic/Radar Level Sensor	Reservoir
Pump House	Level	Ultrasonic/Radar Level Sensor	Underground Reservoir
	Flow	Electromagnetic Flowmeter	Individual Delivery of the Pump
	Pressure	Pressure Transmitter	Individual Delivery of the Pump
	Flow	Electromagnetic Flowmeter	Common Header from the Pump House
	Pressure	Pressure Transmitter	Common Delivery of the Pumps
	Energy	Electronic Energy Meter	Common LT/HT Line to the Pump House
	Energy	Electronic Energy Meter	LT/HT Line feeding the individual Pumps at Pump House

**Control:** The parameters to be controlled are shown in Table 14.6.

**Table 14.6: Monitoring location and parameters in ESR/ UGR/ pump house**

Location	Parameter	Method	Per
ES Reservoir/UG Reservoir	Flow	Electric Actuated Gate/Valves	Inlet, Bypass and Outlet
Pump House	Priming System	Electric Actuated Valves/Solenoid valves	Pump at Inlet line
	Flow	Electric Actuated Gate/Valves	Individual Delivery of the Pump
	Flow	Electric Actuated Gate/Valves	Common Header from the Pump House

‘Per’: suggests the location of installation, All parameters must be available as 4–20mA inputs to the monitoring and control system in real time for proper management of system.

#### 14.5.4 Key points in Distribution System

In addition to the above systems/subsystems, every water supply distribution system has some key notes where it is important to measure various parameters such as pressure, flow, water quality to ascertain that the water supply system is working within normal and allowed limits. Such key locations are at the entry of each DMA and the strategic spots such as highest and lowest ground elevations and farthest node in the operational zones. It becomes key to be able to get these feedbacks from predefined locations as they are litmus test for the proper functioning of the overall system.

Over a period of time, these key points may lose/gain importance for parameter measurement in the overall water supply system.

In addition to the pre identified key points as the water supply system expands and evolves over time, there may be a requirement to add or reduce key points in the water distribution set up.

The following sections deal with a broad outlook on the requirement of parameter monitoring in the various subsystems and gives an insight into what may be considered by the various utilities/boards of corporations for incorporation in their individual water supply system.

**Monitoring:** The parameters to be monitored are shown in Table 14.7.

**Table 14.7: Monitoring location and parameters**

Location	Parameter	Method	Per
Entry of DMA	Flow, pressure	Ultrasonic/Electromagnetic Flowmeter and Pressure Transmitter	Inlet
Strategic points such as highest and lowest elevations and farthest node in operational zone	Pressure	Pressure Transmitter	As per the topography
Strategic Points	Water Quality Parameters	Water Quality Analyser	As per the criteria given in Chapter 8 of the Part B manual

**Control:** The parameters to be controlled are shown in Table 14.8.

**Table 14.8: Controlling parameters**

Location	Parameter	Method	Per
Entry point of DMA and sub-DMA	Flow	Electric Actuated Gate/Valves	Key Point

'Per': suggests the location of installation

All parameters must be available as 4–20mA inputs to the monitoring and control system in real time for proper management of system.

The control systems and all of the above subsystems would comprise of PLC/RTU-based control panels with accessories and relevant switchgear as per the system requirement that can be programmed to operate the control systems in a pre-programmed fashion. In addition, as required and as per site conditions, the PLC/RTU panels will have the capability to provide localised communication on technologies such as OFC, ethernet, wireless CAN, and on wireless technologies like GPRS, satellite communication, LoRaWAN, etc.

Control and monitoring elements should further be enabled to communicate the status of their individual locations to an IoT based centralised monitoring and control centre (CMS) that enables the water supply system to be monitored from one single location for the entire state/city/town.

Controls and instrumentation should be planned as per the projected requirement viz., appropriate plant size, complexity, and number of staff and their skills for each plant. To achieve this, the designer should develop a control philosophy that will enable the plant staff to effectively monitor and control the plant and major equipment, the water supply system.

**14.6 SCADA and IoT Comparison in Water Distribution Systems**

Main characteristics of a water distribution system are:

1. Large areas coverage with seamless and very low-cost connectivity;
2. Large data crunching;
3. Real-time monitoring and data analytics;
4. Historical data context;
5. Making data available to other systems.

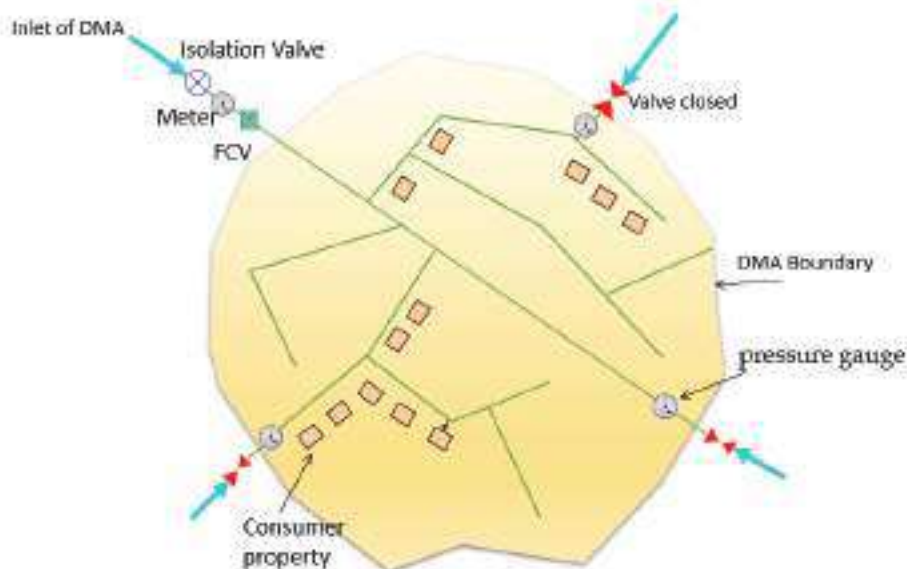
**Table 14.9: Comparison of SCADA and IoT**

SN	IoT/Digital Platform	SCADA
1.	Designed for web-based monitoring of multiple devices/processes	Designed for primary control of a process
2.	A web-based system suitable for cloud deployment	A standalone system with web interface
3.	ISA-95 level 3 system. Can connect to SCADA for data collection	ISA-95 level 2 system
4.	Main focus is various value-added features using collected data. Has capability of control functions like start/stop pump or open/close valve, etc. Latency is in seconds/minutes depending on network latency	Main focus is operations and real-time control. Time-critical controls with milliseconds latency are possible
5.	Multi-user system with different user roles and elaborate access right allocation	Multi-user system. Access rights allocation is limited
6.	Used by all user levels up to management	Mainly used by plant operators, engineers and supervisors
7.	Core features are dashboards, reports and analytics on data collected directly from plant/process. Also, notifications to users for real-time actions	Core features are monitoring and control of plant/process
8.	Can be integrated with other enterprise systems like billing system, GIS	Difficult to integrate with enterprise systems

### 14.7 District Metering Areas (DMA) or Sub-DMA Monitoring and Control

A District Metered Area (DMA) is a subzone within operational zone of a water distribution network that can be hydraulically isolated and for which water consumption is measured using water meters. Bulk flowmeters are installed at the entry points of the DMAs, and all user connections are properly metered for recording the consumption.

The main purpose of DMA is to identify and prioritise leak identification and repair programme by computing NRW values. Another important purpose of DMA is to rationally distribute the water rationally according to the needs with equal pressure. A typical hydraulically discrete single DMA is shown in Figure 14.6.



**Figure 14.6: Typical hydraulically discrete single DMA**

The isolation valve, meter, and the flow control valve (FCV), at the entry point of the DMA, should be connected to the SCADA/IoT.

#### 14.7.1 Criteria for DMAs

- Size of DMA (e.g. number of connections – generally between 500 and 3000 in plain areas)
- Number of valves that must be closed to isolate the DMA
- Number of flowmeters to measure inflows and outflows (the fewer the meters required, the lower the establishment costs)
- Ground-level variations and, thus, pressures within the DMA (the flatter the area the more stable the pressures and the easier to establish pressure controls)
- Easily visible topographic features that can serve as boundaries for the DMA, such as rivers, drainage channels, railroads, highways, etc.

To divide a large open system into a series of DMAs, it is essential to close valves to isolate a certain area and install flowmeters. This process can affect the system's pressures, both within that particular DMA as well as its surrounding areas. The water utility, therefore, must ensure that the water supply to all customers is not compromised in terms of pressure and supply hours. The following aspects of the DMA are to be recorded and maintained by the engineer at site for effective management of water supply.

**Table 14.10: Aspects of the DMA are to be recorded and maintained**

S. No	Description	Remarks
1	Area of a DMA	
2	Source of water	
3	Point of inlets and outlets	
4	Total length of pipeline network as diameter-wise	
5	Age of pipeline network	
6	Total number of HSCs	
7	Total number of bulk connections	
8	Base line leakage levels	
9	Number of valves and its location	
10	Valves to be operated to deliver water for the entire DMA	
11	Supply hours and supply zones	
12	Low pressure region of the DMA	
13	Population of the DMA	

**14.7.2 Boundary demarcation (Natural and artificial)**

Using a calibrated hydraulic network model of the supply system to simulate possible DMA designs will enable analyses of system pressures and flows without affecting supply to customers. However, many water utilities/municipalities/water boards do not have existing calibrated hydraulic network models. The boundary demarcation shall factor in railway crossings/Nallah/river/NHAI crossings such that the DMA does not extend along these features. Also, the terrain within the DMA shall not be too undulating. The most important factor governing the DMA demarcation is to ensure that the ELSR/OHT is located at a significantly higher elevation within the DMA.

**14.7.3 DMA Isolation**

DMA's in network areas should be easily isolated, i.e. areas with a separate supply zone. In establishing a DMA, the water utility should limit the number of inflows, which also helps to reduce the cost of flowmeter installation. To achieve this, it is necessary to close one or more boundary valves, which must remain shut permanently to ensure that any flow data accurately represents the total inflow for the DMA. Understanding district meter areas utility managers will ensure that all pipes into and out of the DMA are either closed or metered by performing an isolation test as follows:

1. Close all metered inlets.
2. Check whether the water pressure within the DMA drops to zero since no water should now be able to enter the area.

If the pressure does not drop to zero, then it is likely that another pipe is allowing water into the area and therefore needs to be addressed.

Once the DMA has been established, it becomes an operational tool for monitoring and managing both of the major components of NRW, physical and commercial losses. The calculation for NRW within a DMA is defined as follows:

$$\text{DMA NRW} = \text{Total DMA Inflow} - \text{Total DMA Consumption}$$

After flowmeters are installed on all inlets to the DMA, the Total DMA Inflow can be measured using the increase in the totaliser, or the meter counter measuring the volume of water passing through the meter, for the calculation period. The total DMA consumption will depend on the customer meter coverage. If the DMA has a 100% domestic meter coverage, meaning all customers within the DMA

have a meter, then the total DMA consumption can be calculated through a simple summation of all meter measurements for the calculation period.

The RTU Panel shall be installed with GSM-GPRS-LTE-NB LTE unit to transfer the field process and non-process parameters to the cloud server or centralised monitoring and control centre or web/mobile-based information retrieval system. Process parameters include:

- Real time – Upstream – Downstream – Pressure
- Real time – Flow rate
- Real time – Flow quantity
- Real time – Pressure – Flow control – Open/Close
- Real time – Pressure – Flow – Proportional control

**14.7.4 Monitoring DMA inflows and pressures is used for calculation of:**

- System input volume (SIV).
- Minimum night flow (MNF).
- Supply pressure at inlet point and at critical and average pressure point of the DMA.
- Online bottom-up water balance including leakage, water demand estimation.
- Detection of bursts events.
- Water loss performance Indicators: including leakage per service connections/per length of pipes, and the infrastructure leakage index (ILI).

**14.7.5 DMA Operation may be controlled for:**

- Setting supply pressure at DMA inlet point.
- Controlling isolating valves to control supply in case of failure or shortage or to manage supply for sub-DMAs in case of intermittent supply.

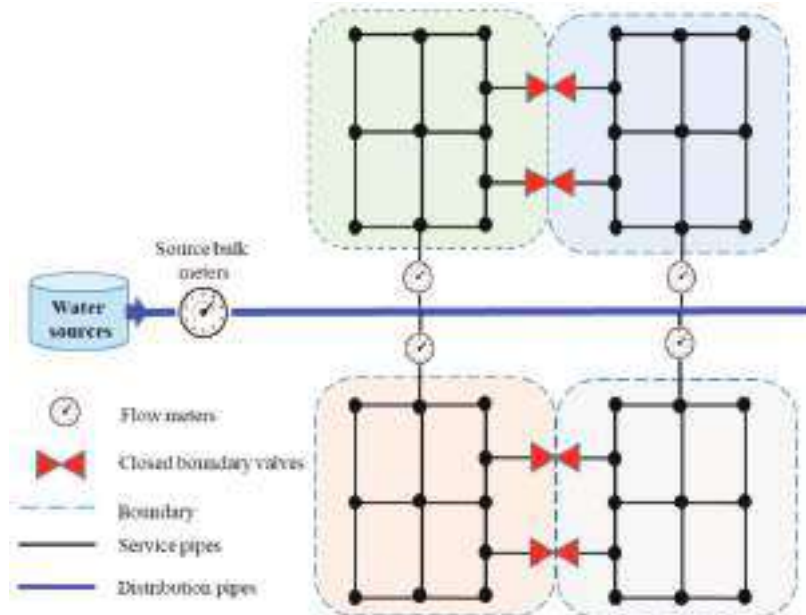
This information is used to score DMAs based on their situation, set targets, and prioritise activities. A typical District Metered Area schematic diagram is shown in Figure 14.7.

**Pressure Control**

Pressure reduction is highly efficient in reducing and controlling leakage. Pressure is usually modulated by installation of pressure reducing valve (PRV) at the DM inlet chamber to control the downstream pressure.

**Three PRV control types are enabled:**

1. Fixed pressure control: PRV is set to control one fixed downstream pressure.
2. Two-point control: PRV set point changes between day and night times.
3. Dynamic pressure control: Downstream pressure is controlled according to flow, time or pressure at remote point, typically the DMA's critical point.



**Figure 14.7: District Metered Area schematic diagram**

## 14.8 Monitoring of NRW in 24×7 Water Supply System at DMA Level

### 14.8.1 Monitoring of NRW at DMA level and communication technologies (IoT)

The purpose of DMA formation is to monitor the water supply into DMA and measure the consumption of water at household level to monitor and control NRW in a gradual manner as explained in Chapter 2 of Planning, Investigations, Design, and Implementation of Part A Manual. This will also facilitate to conduct regular water audit and take measures to bring down the NRW to the desired level. In order to monitor the NRW at DMA level, the prerequisite is to provide flowmeter at the entry of DMA and 100% House service connections with water meters and proper communication technologies. The frequency of monitoring of NRW and accuracy depends on the type of water meters and communication technologies adopted in the 24×7 water supply distribution system at DMA level.

The different water meters with communication technologies for water meter data transmission to the servers to assess the NRW audit are discussed as under with merits and demerits.

#### 14.8.1.1 Consumer Meter and Data collection

The specifications of the bulk and consumer metering determine the framework of meter reading methodology. There are four types of meter data transfer to collect and analyse the supply and consumption of water.

- MultiJet non-AMR meters
- AMR compatible meters
- AMR meters
- Smart water meters – electromagnetic and ultrasonic types

#### Meter Reading and Management requirements

- During DMA study, readings from all consumer water meters of selected DMA consumers are to be recorded in accordance with requirements.
- Develop a monitoring programme of random spot-checks to ensure the accuracy of the meters and the meter reading process to be carried out by the ULB.
- Develop and implement a plan which would ensure

- All consumer meters are in working condition
- All consumer meters are accurate,
- All consumer meters are read,
- All consumer meters are in suitable and easily approachable locations,
- Problems related to unprotected and unsealed consumer meters are resolved,
- Develop and implement a programme to estimate consumption in circumstances where metering problems exist and provide advice as to methods to improve the meter reading process to ensure greater accuracy.
- Identify consumer meters which have not been read.

#### 14.8.2 Type of Smart Meters available with Communication Technologies

There are various types of water meters that are being used in WS&D projects. They are classified based in principle of operation namely:

- **Mechanical type Water Meter – Single Jet, MultiJet**

This type of water meter works on the principle of turbine rotation with respect to flow of water through the water meter. When the water passes through the flow tube, a small turbine inside the water meter rotates and a magnetic pulse will be generated from the magnetic pickup installed in the turbine. The name single jet or MultiJet is based on the number of water jet inside the flow tube. In a single jet meter, water will hit the turbine in single nozzle or jet, whereas in MultiJet, the water will divide multiple jets and hit the turbine. MultiJet meters are more accurate and long-term use compared to single jet meters. These meters will not have any facility to communicate.

- **MultiJet Manual/Non-AMR Water Meter**

These water meters will record the reading of volume ( $m^3$ ) in the form of mechanical registers or electronic registers. These meters will not have any facility to communicate. Hence, the meter reader has to go personally to the meter location, open, read, and enter the reading manually in the reading register (paper or electronically). This is mainly for mechanical meters that do not have remote reading facilities.

- **MultiJet AMR Compatible Water Meter**

These water meters are like manual water meters except with an additional provision of external communication provision. These meters can have the facility of pulse output or serial output, which can be sensed by an external device and converted into electronic media and to be communicated through radio/GSM/GPRS networks. Note that these mechanical types of meters have only the facility of integrating the conversion and communication the reading.

- **Electromagnetic Type Water Meter**

Electromagnetic water meters function on the principle of electromagnetism, called Faraday's induction law, to measure the velocity of the water passing through it. In an electromagnetic meter, a magnetic field is created across the pipe. When water, which is an electrical conductor, moves through the magnetic field, a voltage is induced which is detected by electrodes in the body of the meter. The voltage is directly proportional to the flow velocity, which is used to calculate the volume. Electromagnetic water meters are accurate within their measuring range. Normally, DN15 to DN40 are referred to as domestic electromagnetic water meter, while meters from DN50 to DN300 are referred to as bulk electromagnetic meter.

- **Ultrasonic Type Water Meter**

Ultrasonic water meters utilise the properties and behaviour of sound waves passing through moving water. The ultrasonic water meters are designed on the transit time principle. A transit time ultrasonic meter has two sound transducers mounted on opposite sides of the pipe at an

angle to the flow. Each of these sound transducers will, in turn, transmit an ultrasound signal to the other transducer. The differences in the transit times of the signals determine the velocity, and the volume is derived from the velocity. The measuring principle is called 'bidirectional ultrasound technique based on the transit time method', which is a proven, long-term, stable, and accurate measuring principle.

- **Automated Meter Reading (AMR) Water Meter**

Mechanical water meters are an updated version of mechanical AMR compatible water meters. These meters are fitted with an electronic device, which can pick up the reading from the water meter. For electromagnetic and ultrasonic water meter, AMR facility is in-built, making them 'smart meters'.

In AMR, meter readings are automatically collected through radio frequency media without manual intervention. This metering data is then transferred to a central computer through a cellular network for analysis and billing purposes. Readings from AMR can be obtained by a simple walk-by or drive-by method, where the meter reader either walks or drives down the street while automatically downloading the meter data.

- **Walk-By Method:**

The meter reader has to carry a meter reading device and walk through the service area (Figure 14.8). The meter reading device will automatically pick up the water meter readings of water meters around. These reading devices also have software facilities to identify the meters which are not responding or are faulty. Once the meter reader travels through the designated route, the readings are transferred to a central server via the cloud using GSM/GPRS mode.

- **Drive-By Method:**

The procedure is as same as the walk-by method, except that the reading device shall be mounted on a vehicle (bike or van) with high-gain antennas mounted on top of the vehicle (Figure 14.8). The reading, once taken, will be transferred to a central server through GSM/GPRS mode.

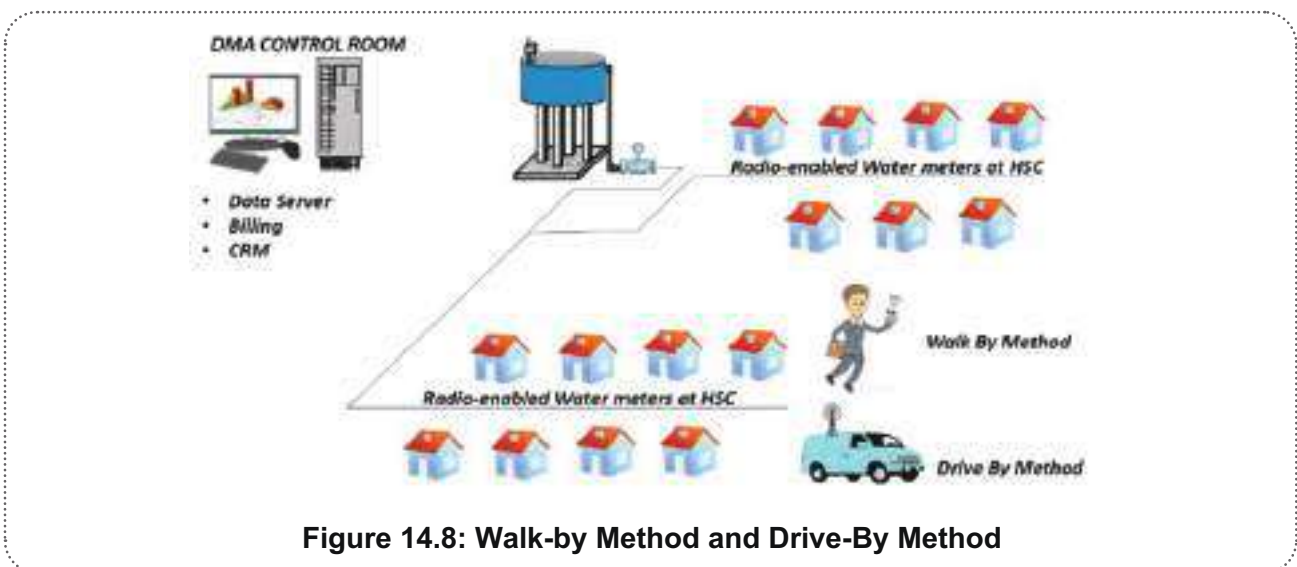


Figure 14.8: Walk-by Method and Drive-by Method

- **Automated Metering Infrastructure (AMI) Meter:**

Advanced Metering Infrastructure (AMI) is the collective term to describe the whole infrastructure from smart meter to two-way communication network to control centre equipment and all the applications that enable the gathering and transfer of energy usage information in near real time. This is an AMI and differs from automatic meter reading (AMR) in that it enables frequent reading

of the meters. Communications from the smart water meter to the network is always through wireless communication.

AMI refers to an infrastructure of fixed network for monitoring and collecting the reading from water meters. Currently, there are two common infrastructure facilities available for data transfer through AMI.

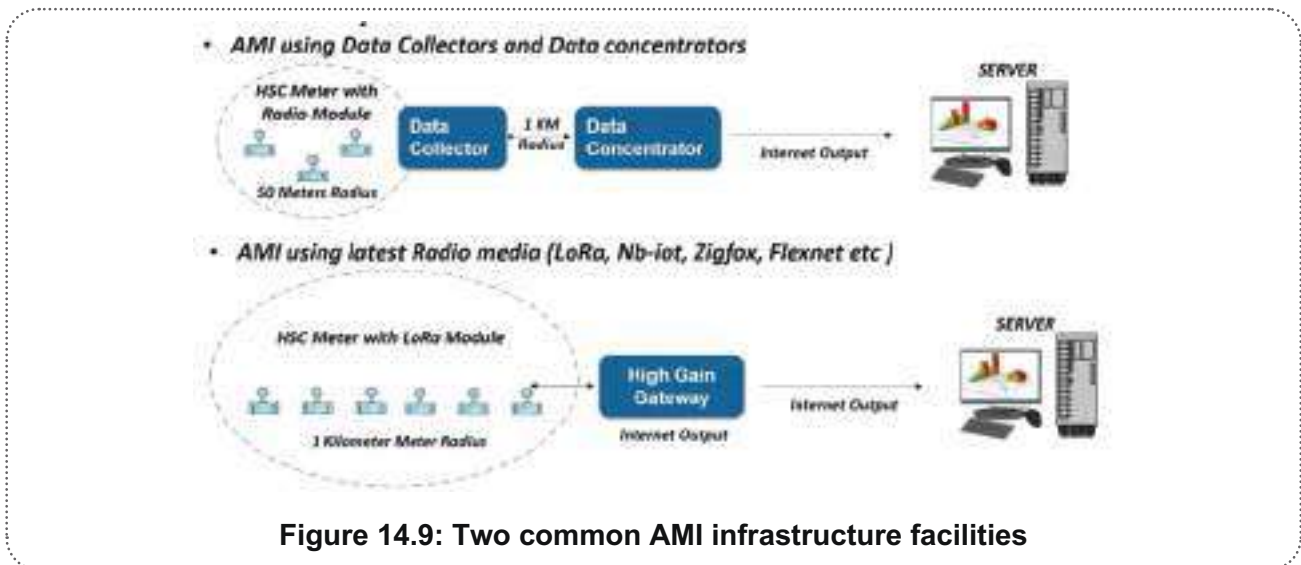


Figure 14.9: Two common AMI infrastructure facilities

\*Range depends upon radio performance with various obstacle, LOS, data packet size.

The comparison between different water metering and communication technologies is provided in Table 14.11.

Table 14.11: Comparison in Between Different types of smart meters

Characteristics	Mechanical Meters	Mechanical Meters	Mechanical Meters	Ultrasonic Water Meters	Electromagnetic Water Meters
	Non-AMR	AMR	Advanced AMR	AMI	AMI
Approx Cost per meter	X	3X	3.5X	4.5X	4.5X
				(Composite Body) 6X	(Composite Body) 6X
				(Brass/Bronze Body)	(Brass/Bronze Body)
Approx Lifetime of product (Considering Brass/Copper Alloy Body and Register version)	5 years	5 years	5 Years	10–12 Years	10–12 years
Accuracy	± 5%	± 5%	± 5%	± 2%	± 2%
Battery Life (Based on One Communication per Month)	NA	5 Years	5 Years	12 Years	12 Years
Battery Life	NA	5–6 Years	5-6 Years	10 Years	10 Years

Part A- Engineering

Characteristics	Mechanical Meters	Mechanical Meters	Mechanical Meters	Ultrasonic Water Meters	Electromagnetic Water Meters AMI
	Non-AMR	AMR	Advanced AMR	AMI	
(Based on One Communication per Day)					
Battery Life					
(Based on One Communication per hour)	NA	4–5 Months	5 Months	10 Years	10 Years
Consumption Index Storage Frequency	NA	Daily Index available while fetching data through AMR	Hourly Index available	Daily Index and Hourly Index	Daily and Hourly Index
Consumption index recording capability during Minimum Night Flow (MNF) study	NA	Daily Index recording can be converted to Hourly but affects battery	Yes (15 mins index recording possible for 4 hours per day)	Hourly Index recording can be possible	Hourly Index recording can be possible
Interoperability (Capability to convert AMR to AMI and vice versa)	NA	Not possible	Yes	Yes	Yes
Dynamic Operating Range (R=Q3/Q1) As per MID certification	Up to R50	Up to R 80	Up to R 80	Up to R 400	Up to R 400
Minimum accountability (15 MM)	50 Litre/Hour	30 Litre/Hour	30 Litre/Hour	6 Litre/Hour	6 Litre/Hour
AMR Dataset capability to do online high-resolution water balance and leak estimation	NA	Daily Water Balance Possible, Leak estimation not possible	Hourly Water Balance Possible and Leak Estimation Possible	Hourly Water Balance Possible and Leak Estimation Possible	Hourly Water Balance Possible and Leak Estimation Possible

Characteristics	Mechanical Meters	Mechanical Meters	Mechanical Meters	Ultrasonic Water Meters	Electromagnetic Water Meters
	Non-AMR	AMR	Advanced AMR	AMI	AMI
Reverse Flow Detection through AMR (Reverse flow detection dataset can be used to detect probable sources of contamination in water network)	No	Yes	Yes	Yes	Yes
Pressure Rating (in Bar)	PN16	PN16	PN16	PN16	PN16
Environmental Consideration (Recyclability of Product at end of life)	Yes	Yes	Yes	No	No
				(Composite Body)	(Composite Body)
				Yes (Brass/Bronze Body)	Yes
					(Brass/Bronze Body)
<b>Communication Technology:</b>					
Available options	No	Radio Frequency (RF)	RF,	RF,	RF,
			LoRaWAN,	LoRaWAN,	LoRaWAN,
			NB-IoT	NB-IoT	NB-IoT
Metering Index Technology	Analogue	Analogue	Analogue	Digital	Digital
Pulse Reader to convert data from Analogue to Digital	NA	Required	Required	Not Required	Not Required
Communication Module	NA	Required	Required	Required	Required
RF Technology	NA	Drive-by/Walk-by	Drive-by/Walk-by	Drive-by/Walk-by	Drive-by/Walk-by
LoRa/LoRa WAN	NA	Drive-by/Walk-by	Drive-by/Walk-by/Fixed Private Network	Drive-by/Walk-by/Fixed Private Network	Drive-by/Walk-by/Fixed Private Network

Characteristics	Mechanical Meters	Mechanical Meters	Mechanical Meters	Ultrasonic Water Meters	Electromagnetic Water Meters
	Non-AMR	AMR	Advanced AMR	AMI	AMI
NB-IoT	NA	NA	Fixed Network provided by Cellular Company	Fixed Network provided by Cellular Company	Fixed Network provided by Cellular Company
Daily Reading/NRW Audit	NA	NA	Possible	Possible	Possible
Changing of Communication Interval	NA	NA	Possible	Possible	Possible
Two-way Communication	NA	Not possible	Possible	Possible	Possible

\*\* The battery consumption shall be depended on the communication intervals, so it is advised to minimise the same if not required, to ensure the life of battery.

The key to an effective NRW reduction is to develop a better understanding of the causes for NRW and its components. This is to be established as a part of the water audit through a diagnostic approach by establishing network characteristics and understanding operation and management practices.

## 14.9 Sensor Systems

### 14.9.1 Mechanical

Mechanical system can be used to measure, record, and trend variations in process parameters, such as pressure, flow, or temperature. In most cases, the instrument will convert mechanical displacement or movement of its sensor into a corresponding proportional movement of a pen or gauge.

Control of mechanical systems involves using:

- (i) Sensors to monitor:
  1. the input;
  2. the mechanisms in the process part of the system;
  3. the output motion and force.
- (ii) Feeding the information to:
  1. analogue or digital displays so that a human operator may act on the information; and/or
  2. controlling devices that act on the input and/or process parts of the system to achieve a desired output.

### 14.9.2 Pneumatic

A pneumatic system is a system that uses compressed air to transmit and control energy. Pneumatic components are resistant to continuous loads and maintenance-free over their entire service life. They are very easy to install and are cheaper than comparable electrical solutions, particularly when implementing complete system solutions. Pneumatic components also have benefits when it comes

to safety. Compressed air continues to be available even during a power failure. An air reservoir is always available along with a compressor for generation and preparation purposes. Apart from end-position sensing and monitoring the compressed air supply, it doesn't need to be monitored and checked. It follows the 'fit and forget' principle.

Pneumatic actuators only require electricity for the control and generation of compressed air; the movement itself is triggered by the compressed air. Whereas electric actuators require gearboxes, which are responsible for most of the power losses as well as electrical heat losses, pneumatic actuators act directly on the shut-off device. They only require a piston and drive shaft to convert the 'linear' compressed air force into a swivel motion.

### **14.9.3 Electrical**

Electrical instrumentation is about the design, realisation, and use of electric or electronic systems for the measurement of electrical and non-electrical quantities. Strongly related fields are measurement science and data acquisition. A control system that uses an electric current, either direct current (DC) or current shuttle (AC) as a source of supply. Electrical systems require:

- (i) electricity (DC) or (AC);
- (ii) input elements (switches, sensors, transducer, valves, electronic components, etc.);
- (iii) output elements (motor, lights, etc.);
- (iv) extension cable.

This system of instrumentation and control is simple and widely used.

### **14.9.4 Electro-pneumatic**

Electro-pneumatic control consists of electrical control systems operating pneumatic power systems. In this, solenoid valves are used as interface between the electrical and pneumatic systems. Devices like limit switches and proximity sensors are used as feedback elements. Electro-pneumatic control integrates pneumatic and electrical technologies and is more widely used for large applications. In electro-pneumatics, the signal medium is the electrical signal either AC or DC source is used. Working medium is compressed air. Operating voltages from around 12 V to 220 V are often used. The final control valve is activated by solenoid actuation.

In electro-pneumatic controls, mainly, three important steps are involved:

- (i) Signal input devices – Signal generation such as switches and contactor, various types of contact and proximity sensors;
- (ii) Signal processing – Use of combination of contactors of relay or using programmable logic controllers;
- (iii) Signal outputs – Outputs obtained after processing are used for activation of solenoids, indicators or audible alarms.

Seven basic electrical devices commonly used in the control of fluid power systems are:

- (i) manually actuated push button switches;
- (ii) limit switches;
- (iii) pressure switches;
- (iv) solenoids;
- (v) relays;
- (vi) timers;
- (vii) temperature switches.

Other devices used in electro-pneumatics are:

- (i) proximity sensors;

(ii) electric counters.

The greatest advantage of electro-pneumatic is the integration of various types of proximity sensors (electrical) and PLC (Programmable Logic Controller) for a very effective control. As the signal speed with electrical signal can be much higher, cycle time can be reduced, and signal can be conveyed over long distances.

### 14.9.5 Hydro-pneumatics

The hydro-pneumatic system provides water automatically at defined pressure and quantities at many locations from a single pumping system. This system operates on variety of differential pressures. It operates automatically by sensing the pressure within the preset pressure range. Hydro-pneumatic systems are used to supply water at designed pressure and quantity from a single source.

### 14.9.6 Level Measurement

Level measurement is categorised into the top-down and bottom-up level, the top-down measurement is not susceptible to leakage, or it can be considered as less leakage process. The top-down measurement could make a contact with the fluid or sometimes it won't, while the bottom-up type makes contact with the process fluid.

Level measuring instruments are suitable to measure the level of water and it could be done directly or indirectly which would be done according to the application. A level measuring instrument would act as an indicator that shows the level of the water and this information would be carried in the form of AC signals, and this is done for the control purpose. The level switches would monitor if the liquid is at a high level or low level according to the set point.

The direct level measurement is an easy process. This measurement is based on physical principles such as fluid motions, floats, and thermal properties. There are many types of level measurements under this category including sight glass, float-operated, dipstick, dip rods, and lead lines. So, basically, the direct level measurement is taken by defining the position of the interface, and the density of the measured material is not a constraint.

The indirect level measurement is done by measuring other quantities like volume. So, this method measures level by determining some other parameters such as pressure, weight, or temperature.

### 14.9.7 Essential instruments

#### i. Ultrasonic Tank Level Sensors

Ultrasonic level sensors measure the distance between the transducer and the surface. Using the time required for an ultrasound pulse to travel from a transducer to the fluid surface and back (TOF). These sensors work without the need to touch the medium being measured. Ultrasonic sensors are ideal for difficult liquids such as wastewater. Ultrasonic level sensors are also ideal for continuous level measurement. While float switches and other sensors are adept at measuring when liquid levels are above or below a certain point. The nature of ultrasonic level measurement is such that levels can be sensed and displayed in real time.

#### ii. Hydrostatic level transmitters

These transmitters help in determining fluid contents of a container by measuring the pressure of the resting body of the fluid within it. The greater the force of liquid, the greater the volume of fluid. The measured static pressure of a liquid is proportional to the height of the liquid. And the static pressure is converted into an electrical signal. The exquisite structure, simple adjustment, and flexible installation methods provide convenience to use.

### iii. Radar Level Sensors

Radar level transmitters, also called radar level gauges which can undertake a Non-contact continuous level measurement in liquids and solids with free space radar sensors. Whereas, Non-contacting radar, based on microwave technology, detects only surfaces that reflect energy. These transmitters work on the principle of a radar by using radio wave emissions. Mounted at the top of a tank filled with liquid, these transmitters send a radar signal into the liquid and receives a reflection of the signal. The transmitters then analyse the current fill level of the tank based on the time taken by the transmitted signal to return.

### iv. Capacitance Level Transmitters

Capacitance level detectors, also known as capacitance level transmitters. Capacitance level transmitter offers continuous and point level detection in liquids with capacitance probes. These transmitters use liquid stored in a tank or container as a dielectric medium between two or more electrodes. The energy capacity of the capacitor circuit increases when there is more liquid and decreases if there is less liquid. Measuring the variations in the capacitance value, capacitance level transmitters calculate the level of the tank.

### v. Float level transmitters

Float level gauge is mainly composed of magnetic float, sensor, and transmitter. The magnetic float ball changes with the liquid level and floats up and down along the catheter. The magnetic steel in the float ball attracts the reed switch at the corresponding position in the sensor, which changes the total resistance (or voltage) of the sensor. The transmitter then converts the changed resistance (or voltage) signal into a current signal output.

## 14.10 Flow Measurement

Flowmeter is a device that can be used to measure the amount of liquid that passes through it. It is an instrument which is used to conduct the flow measurement. Flowmeters measure the flow by two methods, some flowmeters measure the flow as the amount of the liquid passes through the flowmeter during a period of time, while other flowmeters measure the flow by measuring the total amount of fluid that has passed through the flowmeter.

Flowmeter consists of devices such as a transducer and a transmitter. The transducer is responsible for sensing the fluid passing through the primary device, while the transmitter receives a signal from the transducer and converts it into a usable flow signal. So, a flowmeter can be considered as the combination of these physical devices.

Flowmeters can be classified into differential pressure meters, variable area meters, positive displacement meters, magnetic, turbine, ultrasonic, and vortex. In differential pressure meters, a restriction is used to create a pressure drop. The flow rate can be determined by measuring the pressure drop across the restriction. In positive displacement meters, the measuring process takes place by precision-fitted rotors as flow measuring elements. The selection of flowmeter depends upon flow conditions and flow range, process conditions like pressure and temperature, and size of pipe.

### 14.10.1 Filter Flow Control

An operational control system, including media configuration, underdrain system, and backwash process, is an important consideration because it determines how water flow is controlled through the filter. Four basic types of operational control systems are used in gravity filtration, with some variances from plant to plant.

- (i) **Effluent rate of flow:** This type of system controls the rate of treatment through a cell on the filter's discharge. Basic components include a flow-sensing device, rate controller, and

modulating valve. A wide variety of flow-sensing devices may be used, including direct reading meter systems and indirect reading systems such as venturi or orifice plates. The rate control design also varies considerably, depending on the flow-sensing device and modulating valve design. Signals from the flow sensor, rate controller, and valve may be pneumatic, electric, mechanical, or a combination of these.

- (ii) **Influent flow splitting:** An influent flow splitting filter system has an adjustable weir positioned at the entrance of each filter cell. The influent weir is the system's main component. A feed pipe or flume common to all filter cells carries the water to the individual weirs. The inlet weirs are adjustable so each can be positioned at the same elevation to obtain uniform flow splitting. Ancillary equipment often includes an influent control valve and an effluent hydraulic control point to maintain a minimum water level in a filter cell. The influent control valve is used to stop incoming flow if the cell needs to be removed from service, such as during a backwash event. The effluent hydraulic control point may consist of a downstream weir or upturned loop in the effluent pipe.
- (iii) **Constant level:** This type of filter control uses a level-sensing device in each filter cell to communicate with a control valve in the effluent line. The communication method can take various forms, including mechanical linkage, pneumatic pressure, electrical signal, or a combination of these. A variety of level-controlling devices may be used. The most common is a butterfly valve equipped with an appropriate actuator to position the valve disc. Valve size selection is critical for operation, and selection should be made such that a small change in disc position doesn't drastically change the flow through the valve.
- (iv) **Declining rate:** Declining rate filtration is one of the oldest and simplest methods of filter control. It is used with multiple filter cells – the greater number of cells, the better the performance. The system's main component is the filter media. To limit the maximum rate of filtration through a cell, a flow restriction may be placed in the effluent pipe or, in some special cases, on the influent side. The flow restriction may simply be an orifice plate. This flow restriction is used to limit the initial flow passing through the filter – essentially a speed limit for the filter. A two-position control valve may also be used where the valve is partially closed directly after a backwash to restrict flow of the cleanest cell.

### 14.10.2 Filter Flow Control Valve

All filters have either five or six valves associated with the filter bay, depending on the type of backwash procedure. The control valves associated with a filter are influent, effluent, drain and backwash. The fifth valve is either an agitator water supply valve or an air valve, depending on whether a surface agitator wash system or an air/water system is used.

In the filtration mode, treated water enters the filter box through influent piping or channel and fills the box. Water flow is down through the media, through the underdrain support system, and out through the effluent piping where flow is measured and controlled by a rate of flow controller. The rate of flow controller is commonly a venturi meter, a flow transmitter and a filter effluent valve. As the loss of head across the filter increases, the filter effluent valve must modulate to a more open position to maintain the set point of the flow. Filtered water flows through the rate of flow controller to the clear well. The filter media used in a filter is commonly thought to trap the suspended materials. However, filtration is a combination of both physical and chemical mechanisms. As water passes through the media, large particles are trapped, and suspended particles become stuck to the surface of the grains of filter media and to other particles previously adsorbed by the media. Filter run time is dependent on how many particles are present in the water supply to the filter, and the initial cleanliness of the filter following the backwash sequence. Run times can vary from as short as 15

hours or less to over 100 hours. In the filtration mode, grains of filter media tend to stick together forming mud balls because of sticky floc. Unless backwashing removes this material, mud balls can sink into the media and clog the filter. As the filtration process progresses, the filter media becomes more restrictive to flow, causing an increased head loss through the media. If allowed to progress too far, negative pressures can be produced in the effluent piping that can cause air binding. A loss of head transmitter is a transmitter that senses the differential pressure between the head of water in the filter bay and the pressure in the effluent piping. In an automatic backwash system, high loss of head is one of the signals used to alarm or start a backwash sequence.

Automatic filter backwash control provides a consistent process of cleaning, and in the case of multimedia filters, proper re-stratification of the media. Air-water backwash control is extremely critical. An automatic backwash control system provides all interlocks to control the pumps, blowers, and valves to provide a safe and reliable operation. In some cases, the automatic control system is designed to adjust the backwash flow rate based on temperature or viscosity of the water and terminate the backwash sequence based on time or the turbidity of the backwash water. In the automatic mode, all sequencing is done by the control system. The backwash procedure is started automatically after the control system receives a high loss of head alarm, a high turbidity alarm, or a preset filter run time has been reached.

### 14.10.3 Rate of Flow of Chemicals

#### (i) Liquid Chemical Feed

The chemical dose rate should be flow paced to the plant flow in the part of the process that the chemical is to be injected into. Two methods are typically used to achieve this: metering pump, or flowmeter and flow control valve on the chemical feed. In metering pump, positive displacement type (diaphragm, peristaltic or progressive cavity) pump should be used. The output of the pump is directly controlled by a 4–20 mA signal from the flow transmitter on the plant flowmeter. On plant shutdown, the flowmeter (usually the raw water flowmeter) will signal the metering pump to stop and a solenoid on the dilution water to close. A load cell or pressure (level) transmitter on the chemical storage tank should provide warning signals when chemical supply is low and should have an alarm and initiate plant shutdown when the level becomes critically low (low-low level). In case of flowmeter control, the chemical feed rate is controlled by an in-line flow control valve. A PLC receives a 4–20 mA signal from the flow transmitter on the plant flowmeter. Using this dose rate set point, the controller will look at the flowrate on the chemical feed flow transmitter and signals the in-line flow control valve to a position that will control the feed rate to the established set point. On plant shutdown, the controller will signal the in-line control valve to close. Depending on the range of feed rates, multiple flowmeters and control valves may be required. As with the metering pump system, low and low-low level alarms/shutdown should be provided on the chemical storage tank.

#### (ii) Dry Chemical Feed

Dry chemical feed systems typically include a packaged bulk storage combination feeder and mixer. The feeder can be gravimetric or volumetric and will be controlled by a 4–20 mA signal from the flow transmitter on the plant flowmeter. The chemical feeder discharges to a dissolving tank where it is mixed with plant service water to form a solution (slurry) suitable for dosing. Plant service water flowrate is manually set and monitored by a flow indicator. The rate needs to be suitable for the range of anticipated chemical feeds and its solubility; the rate may need to be manually adjusted seasonally. For a specific plant service water flowrate, the variation in chemical feed rate creates a corresponding variation in solution strength fed to the process water. The solution is fed via a hydraulic injector (if into a pipeline under pressure), or directly by gravity into open channels or tanks. On plant shutdown a signal from the raw water flowmeter will call for the dry feeder to stop and a solenoid valve on the

plant service water feed to the dissolving tank to close. If an injector is used, a solenoid valve on the plant service water will also close.

### 14.11 Pressure Measurement

Pressure may be simply indicated on a gauge or transmitted by a transmitter. Pressure gauges are available to read both differential and single-ended pressure. By far, the most common measurements are single-ended, although differential gauges are used to read head loss on water and air filters.

- (i) Where a pressure gauge is reading a pressure produced by a pump (normally required) the gauge should be protected from vibration by filling it with either silicone liquid or glycerine. Silicone should be used if the ambient temperature will fall below  $-30^{\circ}\text{C}$ .
- (ii) The range of the gauge should be chosen so that it will normally operate at one-half to two-thirds of scale at normal design pressure; the gauge should not be operated full-time near the top end of the scale. This will provide some safety margin on overpressure as well as prolonging the life of the gauge.
- (iii) The gauge should be installed where the lens will not get damaged and where it can be read easily. Choose a gauge with a top-mounted stem where it will be installed near the ceiling so that the dial will read right-side up.
- (iv) For water applications (both raw water and treated), a bronze or 316 stainless steel bourdon tube mechanism should be used. For applications on chemical lines, the manufacturer should be consulted for compatibility between the process and the gauge material.
- (v) On corrosive liquids and processes containing solids, or where the gauge material is not compatible with the process, an isolating diaphragm should be used between the process sense line and the gauge to protect the gauge.
- (vi) A block and bleed valve should be installed between the process and the gauge, or between the process and the diaphragm, to take the gauge out of service.

Pressure transmitters are available to read either differential or single-ended pressures. The single-ended type may read either gauge pressure (the pressure relative to the atmosphere) or absolute pressure (relative to a vacuum). Absolute pressure measurements are not common. Differential measurements are commonly used to determine when a filter needs washing. The range of the transmitter should be chosen so that it will normally operate at one-half to two-thirds of scale at normal design pressure; the transmitter should not be operated full-time near the top end of the scale. This will provide some safety margin on overpressure as well as prolonging the life of the sense element in the transmitter. For water applications (both raw water and treated), a bronze or 316 stainless steel sensing diaphragm should be used. A block and bleed valve should be used between the process and the transmitter, or between the process and the isolating diaphragm, to take the transmitter out of service, and to facilitate calibration. Where a pressure gauge is not installed on the same line as the transmitter, an integral display should be provided on the transmitter for local indication.

### 14.12 Water Quality

A set of automatic measuring, storing and display systems of water quality helps in resolving the limitations in manual monitoring. A sensor is an ideal detecting device to solve these problems. It can convert non-power information into electrical signals. It has many special advantages such as good selectivity, high sensitivity, fast response speed, and so on. Water treatment and distribution process with sampling points is shown in figure 14.10.

The general precautions in the Bureau of Indian Standards, i.e. IS-3025/1622 and/or Standard Methods for the Examination of Water and Wastewater – latest edition [Published jointly by American

Public Health Association (APHA), and American Society for Testing and Materials (ASTM)] shall be referred to for detailed information on sampling and testing procedures.



**Figure 14.10: Water treatment and distribution process with sampling points**

Sampling points and sampling schedule is shown in Table 14.12.

**Table 14.12: Sampling points and sampling schedule**

Sampling points	Sampling Schedule	Test Analysis	Critical Parameters for Process efficiency
1	Daily	Jar Test, Turbidity, pH, Colour, Coliform, Iron	pH 7.0 – 8.0, MPN of Coliform/100 ml ≤ 160000
2	Daily	Turbidity, pH, Colour, Coli form	Turbidity 2 – 6 N.T.U, pH 7.0 – 7.8, Coliform - ≤1600
3	Daily	Turbidity, pH, Colour, Coliform	Turbidity ≤ N.T.U, pH 7.0–7.6, Colour ≤5 Hazen, Coliform - ≤500 CFU, Aluminium ≤0.2 mg/L, Iron ≤0.3 mg/L
4,5,6 and 7	Daily	Turbidity, Free Chlorine, pH, Colour, Coliform, Aluminium, Iron	Turbidity ≤1 N.T.U, Free Chlorine 0.7 – 0.9 mg/L (WTP), ≥0.2 ppm (consumer tap) pH 7.0–7.6, Colour ≤ 5 Hazen, Coliform – absent, Aluminium ≤ 0.2 mg/L, Iron ≤ 0.3 mg/L

### 14.13 Quality Sensors

The most widely used water quality sensors in monitoring installations are temperature, specific conductance, dissolved oxygen (DO), pH, and turbidity. Sensors are also available to measure oxidation-reduction potential, water level, depth, salinity, ammonia, nitrate, chloride, and chlorophyll.

The sensors needed to measure these properties are available as single instruments or in various combinations. A group of sensors configured together is commonly referred to as a sonde, which typically has a single recording unit or electronic data logger to record the output from the multiple sensors.

#### Types of Monitor Configuration

In general, three types of configurations are used for water quality monitors:

- 1) The flow through monitoring system generally has a pump that delivers water to the sensor(s) mounted in a shelter;
- 2) The sensors are placed in situ (immersing a field measurement sensor directly into the water); and
- 3) The self-contained sensor and recording system that requires no external power and are placed in situ. Each configuration has advantages and disadvantages in relation to site location and data quality objectives.

### 14.14 Optional Instrumentation and Controls

#### 14.14.1 Level

A level switch can be described as a device that can sense the level of a liquid in a process tank. A level switch is also used to control valves and pumps so that it can maintain the fluid level at a set value and also that it can prevent the tanks from overflowing. So, we can see a level switch in measurement and control applications, level switch can indicate the high and low levels in process tanks. There are various level switches, and the most common types of level switches are thermal, inductive, ultrasonic, etc.

#### 14.14.2 Flow

Flow switches are used to detect the flow of the fluid, these switches are used to determine if the required flow is available or not. So, if the required flow is not available, then it could damage the system. There are different types of flow switches, and we can choose the flow switches according to the line size.

#### 14.14.3 Pressure Switch Applications

Pressure switch is a device that monitors pressure and provides an output when a set pressure is reached. The specific pressure that opens and closes the switch is called the set point. Pressure switches are commonly associated with well pumps.

Pressure switches are comprised of several components including an adjustment screw, diaphragm, lever, and contacts. The adjustment screw sets the spring pressure. This can be adjusted to change the on and off pressure range that the switch operates at. The standard range of a pressure switch is usually located on the unit itself. It relies on water pressure to do all the work. The change in pressure that activates the switch is provided via the water from the well. The pressure moves up through the diaphragm which presses against a piston and spring, which in turn opens or closes the contacts. Open contacts are located within the switch, closes when pressure drops. This completes an electrical circuit, which in turn, activates the pump. When the set pressure is reached, this allows the contacts to open again which turns off the pump. It is used to operate as a safety valve, which vents out pressure when the pressure exceeds the upper limit.

#### 14.14.4 Filter Console

Filter control console provides continuous and discrete controls that are necessary for a typical surface or bulk filter in a WTP. This device can be used for standalone operation or it can be integrated into a plant-wide SCADA network. The PLC in the system eliminates the need for items such as timers, relays, and PID controllers. It also provides documented configuration that can be adapted by users to suit the unique needs for a given situation.

### 14.14.5 Clarifier Desludging

The control system associated with the clarifier consists of the mobile bottom valve hydraulically movable in the bowl; the control water feed, the control water valve system with the solenoid and manually controlled valves for automatic and manual control, and the programme control system. The control system is operated in normal operation by a preselected desludging programme. Any required full desludge operation can be controlled semi- automatically by the valve control cabinet. In the case of current failure or other possible defects, putting the control cabinet or the electrical control valves out of operation, the separation process can be brought to an end by operating the manually operated valves.

### 14.15 Instrument cum Control Panel

These panels are useful to monitor and control process parameters like temperature, pressure, flow, etc., and also to control the power to the final driver like motor pumps, heaters, etc. Various interlocks and safety audio visual alarms are provided through PLCs. A total process simulation can be shown on the mimic. Starters for motors, heaters, pumps are provided in the panel.

### 14.16 Online Measurement Instrumentation

#### 14.16.1 Level Measurement

Whenever water parameters are considered, both water quantity and water quality must be given equal weightage. Instrumentation facilitates the co-ordination of various water parameters, that are essential for the optimisation of water supply and treatment plants. One of the important parameters among them is water level measurement, which is carried out at various locations viz., water reservoir, inlet chamber, open channel, alum feeding tank, lime tank, filter beds, air vessel, sump well, etc.

Maintenance of pressure instruments is essential for their proper working and accurate reading. It also improves the life and reliability of the instruments.

#### 14.16.2 Radar Level Transmitters

They provide a non-contact type of level measurement in case of liquids in a metal tank. They make use of EM, i.e. electromagnetic waves usually in the microwave X-band range which is near about 10 GHz. Hence, they can be also known as microwave level measurement devices. However, there are some differences between radar and microwave types. They are:

- (i) power levels in the case of radar systems are about  $0.01 \text{ mW/cm}^2$  whereas, in the case of microwave systems, these levels range from  $0.1$  to  $5 \text{ mW/cm}^2$ ;
- (ii) microwaves can work at higher energy levels; hence, they are competent enough to endure extra coating as compared to radar level detectors.

A radar level detector (Table 14.13) includes:

- (i) a transmitter with an in-built solid-state oscillator;
- (ii) a radar antenna;
- (iii) a receiver along with a signal processor and an operator interface.

The operation of all radar level detectors involves sending microwave beams emitted by a sensor to the surface of the liquid in a tank. The electromagnetic waves after hitting the fluid's surface return back to the sensor which is mounted at the top of the tank or vessel. The time taken by the signal to return back, i.e. time of flight (TOF) is then determined to measure the level of fluid in the tank.

Table 14.13: Radar Level Transmitter

Radar – Microwave type level transmitter	Service: Raw Water (Non-Contact Type)
<b>Transmitter</b>	
Type	Microwave level measurement
Principle	Pulse Time of Flight
Output	4–20 mA HART Current
Housing	Die-Cast Aluminium
Electromagnetic compatibility	Interference Immunity to EN 61326, Annex A (Industrial) and NAMUR
Ingress protection	IP65/IP 66/IP 67
Accuracy	±3 mm
Area classification	Non-Hazardous
Display	4-line LCD Display. Menu guided operation. Display of Envelope Curve.
Configuration	Using the keypad on display
<b>Sensor</b>	
Range	Liquids 0 to 5 m and 0 to 10 m depending on tank size
Temperature range	-40 °C ... +80 °C
Max pressure	3 bar abs
Materials	Sensor: PVDF Seal: EPDM
Antenna seal	FKM Viton
Process connection	Threaded or universal flange dependent on model selection
Degree of protection	IP65

In water works, various treatment processes are carried out to supply potable water. The parameters of the water which are normally used for monitoring are as follows:

- (i) turbidity;
- (ii) pH;
- (iii) residual chlorine.

These parameters are monitored either by means of online instruments or by analytical laboratory instruments or both. Their relative advantages and disadvantages are as follows:

### 14.16.3 Turbidity Meter

Table 14.14: Advantages and Disadvantages of Turbidity Meter

Online	Laboratory Type
<b>Advantages</b>	
<ul style="list-style-type: none"> <li>i. Turbidity continuously monitored</li> <li>ii. Can be hooked up for automation</li> <li>iii. Can be set for giving an alarm if minimum and maximum limits of turbidity are exceeded.</li> <li>iv. Human error in sampling is eliminated</li> </ul>	<ul style="list-style-type: none"> <li>i. Low cost</li> <li>ii. Simple to use</li> <li>iii. Portable</li> <li>iv. Easy maintenance</li> </ul>
<b>Disadvantages</b>	
<ul style="list-style-type: none"> <li>i. High cost</li> <li>ii. High maintenance is required</li> </ul>	<ul style="list-style-type: none"> <li>i. Does not monitor continuously</li> <li>ii. Human error may encounter</li> </ul>

Online	Laboratory Type
iii. Periodical calibration is required iv. It is not portable	iii. Low accuracy
<b>Maintenance</b>	
i. Clean chamber and lens with fresh water ii. Microprocessor-based instrument has a self-calibration facility which is useful for periodical calibration iii. Clean sources of light	i. Clean sampling tube with fresh water ii. Bulb, standard sample tubes, and lens should be cleaned with soft cotton iii. Calibrate before carrying out the measurement iv. Calibrate with standard samples of 100 NTU, 10 NTU, and 1 NTU or calibrate with Formazin standard solution

#### 14.16.3.1 Typical Specification for Online Measurement of Turbidity

Online sensor (Table 14.15) based on Nephelometric 90 degree scattering light method as per ISO 7027. The sensor must be an easy plug and play with digital communication based on inductive energy transfer with IP68 rating suitable for measuring range 0 to 9999 FNU/NTU with an accuracy of <2% of measured value or 0.1 FNU/NTU. The sensor shall store on-board all the calibration data and other diagnostic information. The sensor must have provision to store at least five user calibration points. The offered transmitter shall be four-wire digital with the possibility of connecting multiple sensor inputs for additional parameters – referred to as multichannel/multi-parameter type. The transmitter shall be suitable for outdoor installation with IP66/67 rating.

**Table 14.15: Online Turbidity Meter**

<b>Turbidity Measurement</b>	
<b>Transmitter</b>	
Type	Turbidity and suspended solids transmitter
Principle	Nephelometric measuring principle 90° NIR scattered light according to ISO EN 27027
Output	4–20 mA HART current
Supply voltage	100/115/230 V AC +10/–15%, 48 ... 62 Hz; 24 V AC/DC +20/–15%
Material	Field Housing: ABS PC Non-corrosive type
Display	LC display, two lines, with status indicators
Electromagnetic compatibility	interference emission and interference immunity acc. to EN 61326-1:1998
Protection class of field housing	IP 65
Ambient temperature	– 20 to 60 °C
Self-Diagnostic feature	Required
<b>Sensor</b>	
Measurement range	0 – 9999 FNU/0 – 3000 ppm/0 – 3.0 g/L
Material	Sensor shaft: PVC/PPS GF40 Optical window: sapphire Cable: TPEO
Max Process temperature	50 °C
Max Process pressure	10 bars
Temperature sensor	Integrated NTC temperature sensor
Connection	Fixed cable connection
Ingress protection	IP68

<b>Turbidity Measurement</b>	
Additional Certifications	Calibration certification
Resolution	0.001 FNU, 0.01 ppm, 0.1 g/l, 0.1%
Measurement error	<2% of meas. value (min. 0.02 FNU)

14.16.4 pH Meter

**Table 14.16: Advantages and Disadvantages of pH Meter**

<b>Online</b>	<b>Laboratory Type</b>
<b>Advantages</b>	
<ul style="list-style-type: none"> <li>i. Continuously monitored</li> <li>ii. Can be hooked up for automation</li> <li>iii. Can be set for giving alarm for specified limits</li> <li>iv. Human error in sampling is eliminated</li> </ul>	<ul style="list-style-type: none"> <li>i. Low cost</li> <li>ii. Simple to use</li> <li>iii. Portable</li> <li>iv. Easy maintenance</li> </ul>
<b>Disadvantages</b>	
<ul style="list-style-type: none"> <li>i. High cost</li> <li>ii. Periodical calibration is required</li> <li>iii. High maintenance cost (replacement of electrodes)</li> <li>iv. It is not portable</li> </ul>	<ul style="list-style-type: none"> <li>i. Does not monitor continuously</li> <li>ii. Human error may encounter</li> <li>iii. Low accuracy</li> </ul>
<b>Maintenance</b>	
<ul style="list-style-type: none"> <li>i. Clean electrode with soap water or clean with 5% concentrated H<sub>2</sub>SO<sub>4</sub> and 6% concentrated H<sub>2</sub>O<sub>2</sub></li> <li>ii. Calibrate periodically with a standard solution of pH 4 and pH 7</li> <li>iii. Replace electrodes if dried up</li> </ul>	<ul style="list-style-type: none"> <li>i. Clean sampling electrode with distilled water</li> <li>ii. Calibrate the instrument with three standards samples, i.e. pH 4, pH 7, and pH 9.2</li> <li>iii. Prepare standard samples from readily available capsules</li> <li>iv. Calibration may last from 4 days to 7 days</li> </ul>

**14.16.3.2 Typical Specification for Online Measurement of pH**

Online pH (Table 14.17) sensor is based on potentiometric measurement using a glass sensor. The sensor shall have digital communication based on inductive energy transfer. The sensor shall have in-built memory to store calibration data and other additional diagnostic information. The offered transmitter shall be four-wire digital with the possibility of connecting multiple sensor inputs for additional parameters – referred to as multichannel/multi-parameter type. The transmitter shall be suitable for outdoor installation with IP66/67 rating.

**Table 14.17: Online pH Meter**

<b>Transmitter</b>	
Type	Glass electrode
Principle	Glass electrode with dirt repellent PTFE diaphragm
Output	4–20 mA HART current
Supply voltage	100/115/230 V AC +10/–15%, 48...62 Hz; 24 V AC/DC +20 /–15%
Material	Field Housing: ABS Polycarbonate non-corrosive
Display	LC display, two lines, with status indicators

Electromagnetic compatibility	Interference emission and interference immunity acc. to EN 61326: 1997/A1: 1998
Protection class of field housing	IP 68
Ambient temperature	-20 ... +60 °C
Diagnostic feature	Required
<b>Sensor</b>	
Measurement range	pH 0–14
Material	Glass
Max Process temperature	130°C
Max Process pressure	6bar
Temperature sensor	NTC/ Pt100
Connection	Inductive digital connection with transmitter
Ingres protection	IP68
Additional Certifications	FM, ATEX, CSA
Resolution	pH 0.01, Temp 0.1 °C
Measurement Error	±0.5% of Measuring range

#### 14.16.4 Residual Chlorine Meter

**Table 14.18: Advantages and Disadvantages of Chlorine Meter**

Online	Laboratory Type (Lovibond Type)
<b>Advantages</b>	
<ul style="list-style-type: none"> <li>i. Continuously monitored</li> <li>ii. Can be hooked up for automation</li> <li>iii. Can be set for giving alarm for specified limits</li> <li>iv. Human error in sampling is eliminated</li> </ul>	<ul style="list-style-type: none"> <li>1. Low cost</li> <li>2. Simple to use</li> <li>3. Portable</li> <li>4. Easy maintenance</li> </ul>
<b>Disadvantages</b>	
<ul style="list-style-type: none"> <li>i. High cost</li> <li>ii. Periodical calibration is required</li> <li>iii. High maintenance cost (replacement of membrane)</li> <li>iv. It is not portable</li> <li>v. It requires electricity of battery or solar</li> </ul>	<ul style="list-style-type: none"> <li>i. Does not monitor continuously</li> <li>ii. Human error in sampling may encounter</li> <li>iii. Low accuracy</li> </ul>
<b>Maintenance</b>	
<ul style="list-style-type: none"> <li>i. Clean membrane if it gets clogged</li> <li>ii. If the membrane is damaged replace it with the new one</li> <li>iii. Fill up/ DPD membrane /electrolyte if necessary</li> <li>iv. Calibrate it using Potentiometric electrode</li> </ul>	<ul style="list-style-type: none"> <li>i. Clean tubes with distilled water</li> <li>ii. Calibration is not required as it is a comparator</li> </ul>

##### 14.16.4.1 Typical Specification for Online Measurement of Chlorine

Online chlorine analyser (Table 14.19) is based on Amperometric (membrane-based measurement of active chlorine converted to free chlorine by means of pH compensation)/DPD Colorimetric method for Free Chlorine monitoring. The sensor shall have digital communication based on inductive energy/RS485 transfer which will withstand moisture, corrosion, and ensures reliable data transmission. The complete measuring system includes chlorine sensor, pH sensor/in-built pH compensation/pH buffer with suitable flow assembly for mounting these sensors along with the transmitter. The offered transmitter must be IP65, Interference emission and immunity as per EN

61326-1:2006.

**Table 14.19: Online Chlorine Meter**

<b>Transmitter</b>	
Type	Free chlorine
Principle	Amperometric/DPD Colorimetric measurement of free chlorine
Output	4–20 mA/MODUBUS/PROFIBUS HART
Supply voltage	100/115/230 V AC +10/–15%, 48 ... 62 Hz; 24 V AC/DC +20/ –15%
Material	Field housing: ABS PC Fr
Display	LC display, two lines with status indicators
Electromagnetic compatibility	Interference emission and interference immunity acc. to ISO EN 61326: 1997/A1: 1998
Protection class of field housing	IP 65
Ambient temperature	-20....+60 °C
<b>Sensor</b>	
Measurement range	0.01 – 5ppm free chlorine
Material	Sensor Shaft: PVC
	Membrane: PTFE
	Membrane cap: PBT (GF30); PVDF
Process temperature	+2°C.....+45 °C
Max process pressure	1 bar
Temperature sensor	NTC/ Pt100 for Amperometric method
Connection	Inductive digital connection with transmitter
Ingress protection	IP 68
Resolution	0.01 mg/L
Measurement error	±5% of measuring range

#### 14.16.5 Total Dissolved Solids/Electrical Conductivity

The amount and composition of TDS in water is linked to the electrical conductivity of the water. As such, of the most effective ways of measuring TDS in water is by measuring the conductivity of the water itself. Electrical, or specific, conductivity of water is directly related to the concentration of dissolved ionised solids in the water. Ions from the dissolved solids in water create the ability for that water to conduct an electric current, which can be measured using a conventional conductivity meter or TDS meter.

##### 14.16.5.1 Typical specification for online measurement of TDS/EC

Conductivity measurements are used routinely in several applications as a fast, inexpensive, and reliable way of measuring ionic content in a solution. The measurement of product conductivity is a typical way of monitoring and continuously trending the performance of water purification systems. Ions from the dissolved solids create the ability for water to conduct an electrical current, which is measured by the online TDS analyser, and immediately displayed as sodium chloride ppm or mg/L or  $\mu\text{S/cm}$  conductivity.

Online conductivity/TDS analyser has specifications to measure analyse and control conductivity, TDS, and temperature:

- (i) three programmable on/off relays: two for conductivity and one for temperature;
- (ii) accepts 2-wire or 4-wire conductivity cells for K=0.1, K=1 and K=10 cell constants for improved flexibility and accuracy;
- (iii) displays three selectable conductivity and TDS ranges per cell constant for a total of 18 ranges;
- (iv) automatic temperature compensated (ATC) conductivity readings.
- (v) programmable temperature coefficient;
- (vi) simultaneous display of conductivity, temperature, cell constant, temperature coefficient, relay status and transmitter current mA output;
- (vii) convenient one-point calibration and calibration data are stored in memory and is ready for use on power up;
- (viii) standard ¼ DIN size;
- (ix) performs self-diagnostic at power up to ensure proper operation.

### **14.17 Leakage reduction and continuity of supply**

There are multiple causes for loss of water in transmission pipelines which include leakage, metering errors, public usage such as firefighting, and theft. The most critical route for losses is a leak, as they are considered to contribute an estimated of 70% of water loss in water transmission systems, this value is expected to become higher in undermanaged networks.

The two classes of leak detection system can be defined as follows:

- (i) Static leak detection systems: are systems that rely on sensors and data collectors that are placed within the water network and on valves and are capable of transmitting periodical data to the network management office. This data can be used to identify, localise, and pinpoint leaks.
- (ii) Dynamic leak detection systems: are systems that rely on moving leak detection devices to suspected leakage area to perform an investigation. Therefore, they rely initially on suspicion of an existing leak. Another approach is performing regular surveys around cities to identify leaks as soon as possible. Those systems can confirm the existence of leaks and immediately localise and pinpoint them.

The main distinction between the two classes is that static leak detection systems can inform the water network management of the existence of a leak almost immediately, whereas dynamic leak detection systems are required to have information of a leak possibility so that they can be mobilised for investigation. On the other hand, dynamic leak detection systems can pinpoint the exact location of a leak almost immediately under ideal operating conditions, whereas static leak detection systems will provide a location within a certain area, and they are also more prone to false alarms. The two classes encompass a wide variety of technologies to provide an accurate leak detection system, but the technologies are not limited to one class. For example, acoustic technologies, specifically noise loggers, can be dynamic and be moved from one location to the another periodically, or they can be left in the network to detect leaks.

Identification of leakage is performed by a PIC microcontroller to automate the process. Leakage and suction of water are identified by the pattern of water flow rate, which is monitored continuously by the processor and if the same goes beyond a predefined threshold level, suitable alarms or annunciators are triggered to notify the leakage or theft. The flow rate is sensed by the signal conditioning unit when the water is passed through the pipeline. The sensor operates under certain pretend value. When there is a sudden drop in the water flow due to leakage or any pumping of water through motor, it will be detected by the water flow sensor. The signal conditioning unit is used to

give the desired input signal of the ADC. The analogue signals generated due to variation in the flow of water sensed by the water flow sensor are converted into digital signals using analogue to digital convertor (ADC) and this digital signal is given to the microcontroller. This microcontroller enables the transmitter signal for intimation to water supply personnel. At the same time, they enable the driver unit to close the solenoid valve.

### 14.18 Telemetry and IoT Systems

IoT and telemetry work in tandem to provide a combination of data acquisition, analysis, storage, and reporting. Additionally, IoT systems allow operators to monitor and control system command functions from a remote location. It's a powerful blend of hardware and software technologies that improve efficiency, cost, and productivity. IoT is a web-based platform for real-time monitoring and analytics of geographically distributed systems. Telemetry is a technology which allows the remote measurement and also, reporting of information of interest to the system designer.

#### 14.18.1 Geographical Information System (GIS)

The Geographic Information System (GIS) is a software system with which location-based mapping and characterisation of the geographic features can be integrated into a Decision Support System (DSS) for planning, execution, and management of any spatial both the manmade and natural features. GIS will play an important role in mapping, monitoring, and operation of water supply schemes under AMRUT on IoT based sensors. The areas in which GIS can be used in the water supply system from planning to operation and management monitoring are mentioned below:

- (i) mapping of surface and ground water sources and Infrastructure including mapping of IoT sensors;
- (ii) water resources availability estimation and determining carrying capacity through GIS;
- (iii) water budgeting and audit at different levels of hierarchy;
- (iv) planning of Water supply infrastructure up to home;
- (v) management of system (resources, assets, functionary);
- (vi) Use in day-to-day effective maintenance management by locating the areas for trouble shooting in pipe network and infrastructure through GIS-based simulated hydraulic models;
- (vii) real-time monitoring of services using IoT based sensors and analytical tools with GIS linkage for water quantity, quality, operations, and maintenance. Dissemination of information to beneficiaries/public and system management group;
- (viii) GIS-based Consumer Relations Management (CRM) using geospatial database of consumers and using several electronic media like mobile, e-mails, social media, etc.;
- (ix) monitoring of the CRM and grievance redressals in relation to KRAs of concerned official;
- (x) nation, state, ULB level visualisation of status of services through GIS enabled dashboards in the map form;
- (xi) DSS development on daily and seasons basis for policy makers. In the present context of IoT sensors-based monitoring in AMRUT.

GIS can be used for mapping and geocoding of water supply schemes, its sources, geographical boundaries of beneficiary areas, IoT based sensors deployed for the scheme for monitoring, areas under influence of a sensor. This shall, after analytics, display visually on the GIS map-based dashboards about the quantity and quality of water supply in an area under the influence of geocoded sensor.

The data from geocoded ground water level measurement sensors and its GIS-based analysis will have to be projected on the maps as dashboard for use of water scarcity management measures and DSS for the different administrative units.

Development of modules for use of the geospatial IoT sensor-based available data for effective

operations management of individual water supply system by mapping the entire transmission and distribution network and using GIS-based simulated hydraulic models with real-time flow and pressure data inputs through sensors.

### 14.18.2 Telemetry

Telemetry is the automatic recording and transmission of data from remote or inaccessible sources to an IT system in a different location for monitoring and analysis. Telemetry data may be relayed (Figure 14.11) using radio, infrared, ultrasonic, GSM, satellite, or cable, depending on the application.

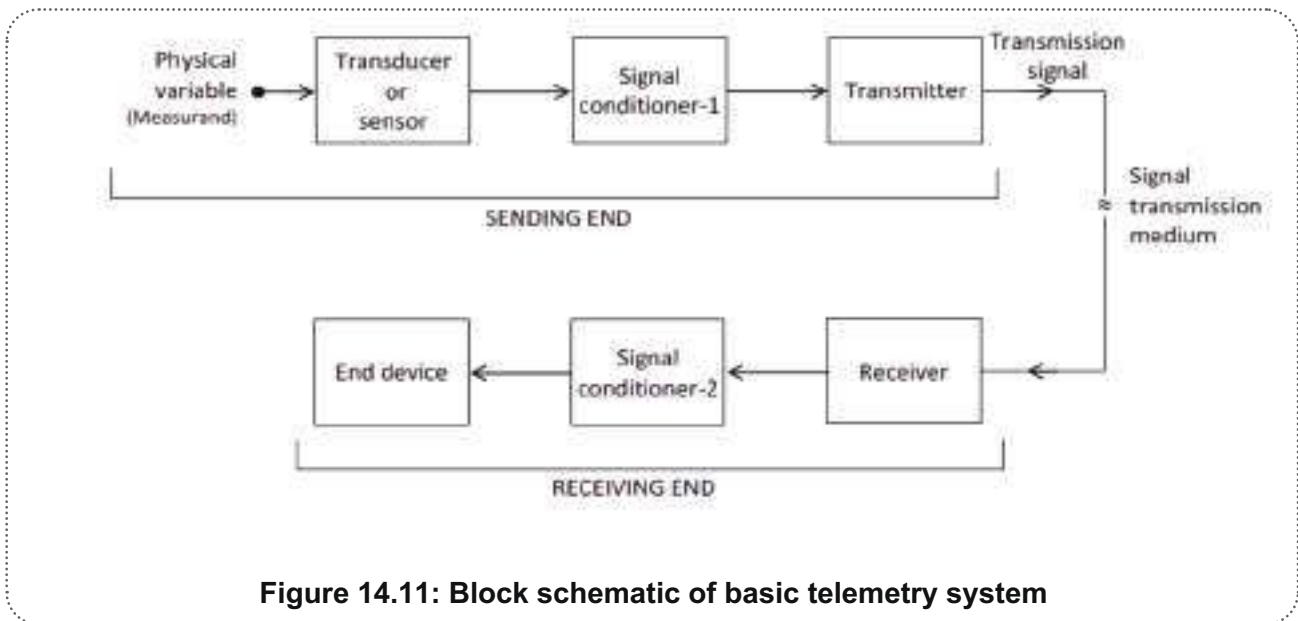


Figure 14.11: Block schematic of basic telemetry system

A high-level solution has to be described as shown in Figure 14.12.

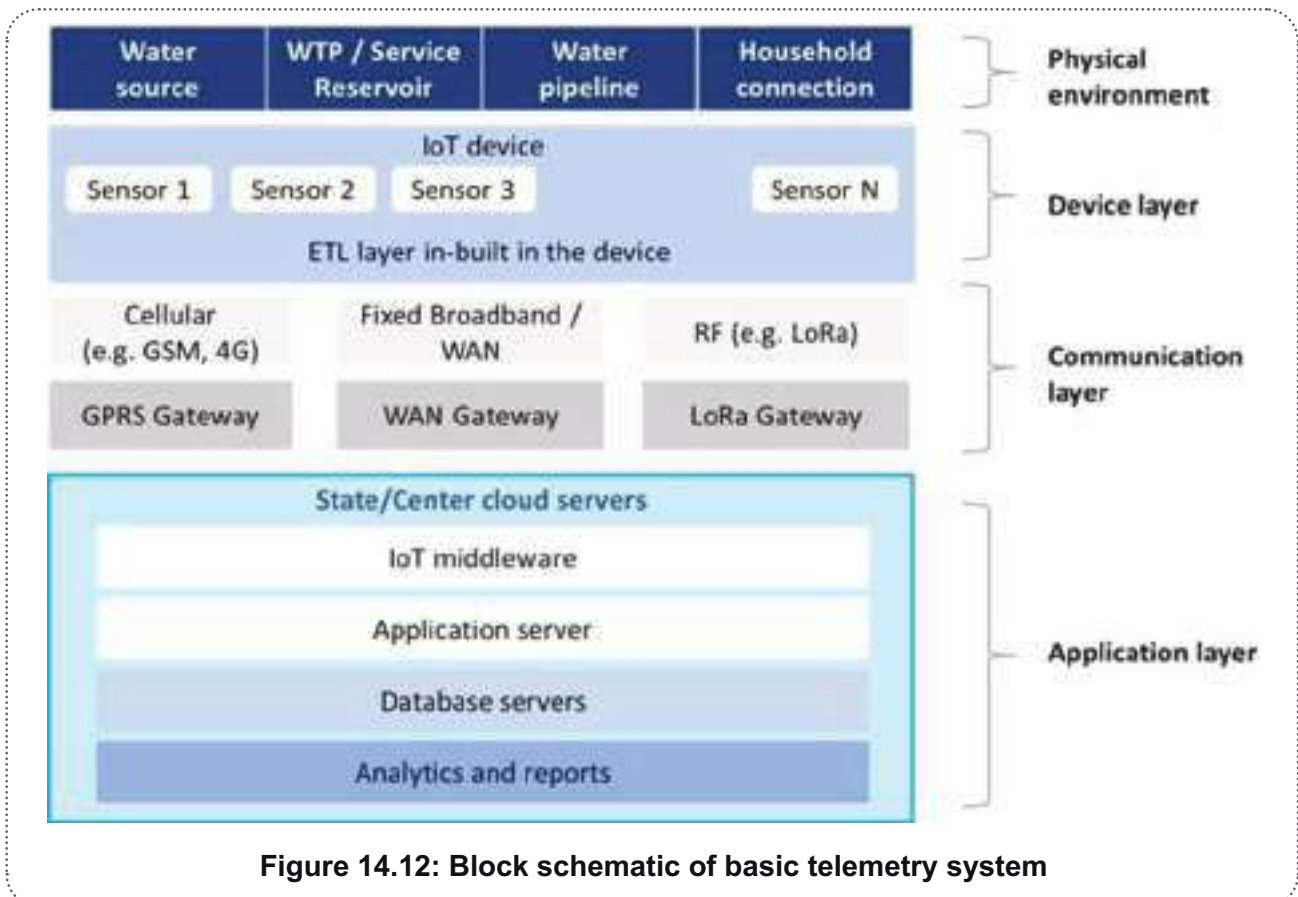


Figure 14.12: Block schematic of basic telemetry system

### Networking and communication standards

The solution design should adhere to open standards and be technology neutral. It can use a variety of networking technologies as per local conditions and availability of services, such as fixed broadband/Wi-Fi, local area RF (e.g. Lo Ra), and/or cellular technologies (2G/3G/4G/5G and NB-IoT). The communications to cloud can be done via several IoT-compatible and specialised protocols.

### Data for collection by Telemetry

Telemetry works through sensors at the remote source which measures physical (such as pressure or temperature) or electrical (such as current or voltage) data. This is converted to electrical voltages that are combined with timing data. They form a data stream that is transmitted over a wireless medium, wired or a combination of both.

### Processing data from Telemetry

At the remote receiver, the stream is disaggregated, and the original data displayed or processed based on the user’s specifications.

### 14.18.3 Cloud-Based IoT System

As elaborated in earlier sections, IoT systems are enterprise systems that utilise the latest technologies like internet, cloud, AI/ML, among others. In these systems, the system’s infrastructural cost is reduced by implementing IoT through cloud computing. Maintaining, as well as integrating these systems, is easy as compared to others.

In real time, the condition of these systems can be reported through cloud computing. Therefore, the implementation of algorithms like intricate control can be done that are frequently used on usual PLCs. Here are some key features of cloud-based IoT systems explained in Figure 14.13.

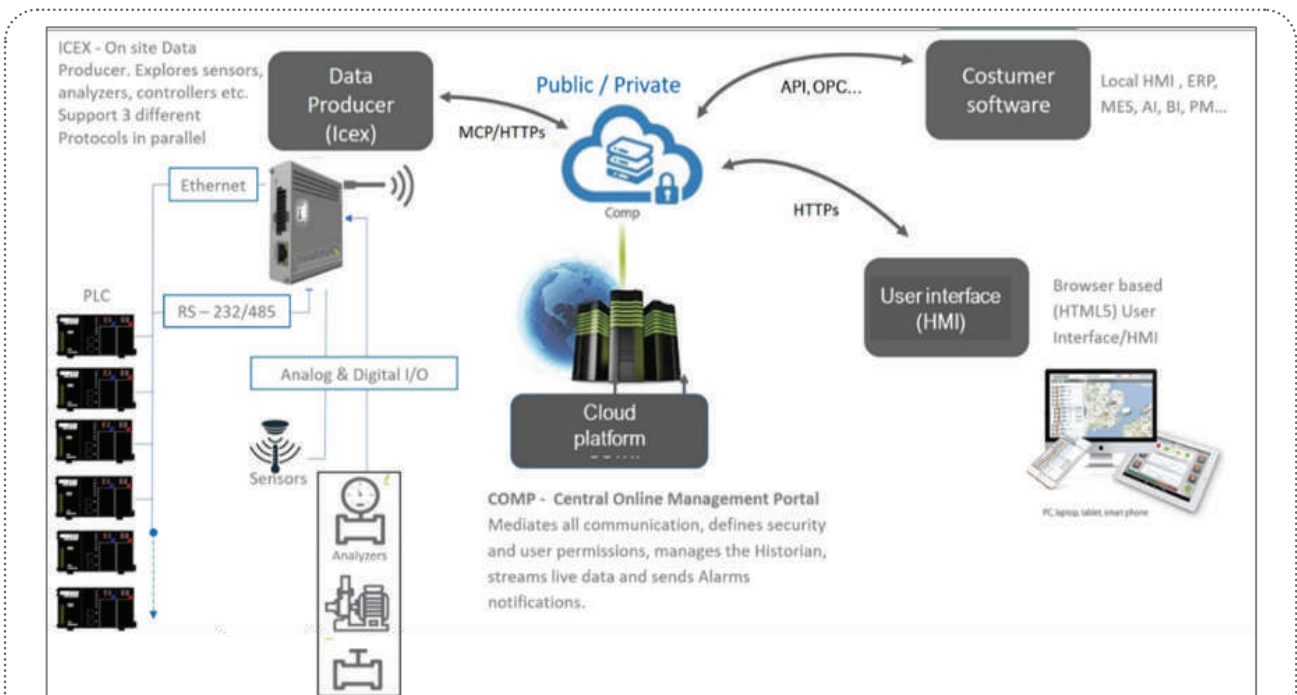


Figure 14.13: Cloud-based IoT systems

1. Cloud-based architecture: A cloud-based IoT system uses cloud computing technologies to store and process data, rather than relying on local servers. This allows for scalability and flexibility,

as well as cost savings since companies don't need to invest in expensive hardware and maintenance.

2. **Communication protocols:** Cloud-based IoT systems use a variety of communication protocols to connect to sensors, controllers, and other devices. These may include OPC UA, MQTT, and others such as MCP propriety protocol.
3. **Security:** With the increasing use of cloud technologies in industrial settings, security is a top priority. Cloud-based IoT systems use a variety of security measures to protect data and systems from cyber threats, such as firewalls, encryption, and access control.
4. **Analytics:** Cloud-based IoT systems can leverage the power of cloud-based analytics to provide real-time insights into operation processes. This can include predictive maintenance, anomaly detection, energy management and other machine learning algorithms.
5. **Mobility:** Cloud-based IoT systems can be accessed securely from anywhere, using any device with an internet connection. This allows operators and managers to monitor and control processes and assets from anywhere in the world.

### **Cloud-based IoT comparing to legacy SCADA.**

There are several reasons why cloud-based IoT systems are considered better, more secure, and more open for the future than legacy SCADA solutions.

1. **Security:** Cloud-based IoT systems have better security measures in place compared to legacy SCADA solutions. The cloud service providers invest heavily in securing their systems, implementing strict access controls, encryption, and monitoring to prevent unauthorised access and data breaches.
2. **Scalability:** Cloud-based IoT systems are highly scalable and can easily accommodate changes in the number of devices or users. They can also handle a larger volume of data and processing requirements, making them suitable for larger and more complex systems.
3. **Accessibility:** Cloud-based IoT systems provide remote access to data and control systems, allowing operators to monitor and control the system from anywhere in the world with an internet connection.
4. **Interoperability:** Cloud-based IoT systems are built with open standards and protocols that make them more interoperable with other systems and technologies. This makes it easier to integrate them with other systems, such as IoT devices, AI, and machine learning algorithms.
5. **Cost effectiveness:** Cloud-based IoT systems are more cost-effective than legacy SCADA solutions as they require less hardware and software investment. Also, maintenance and support costs are significantly lower as the cloud service provider takes care of most of the maintenance and updates.

### **Interfacing IoT with GIS**

IoT systems can interface with a GIS to provide location-based data and visualisation. Here are some examples of how IoT can interface with GIS:

**Asset management:** to provide a map-based view of assets, such as equipment and infrastructure. This can enable more efficient asset management, such as tracking maintenance activities, optimising routes, and identifying areas for improvement.

**Real-time monitoring:** to display real-time monitoring data on a map. This can provide a visual representation of the data, making it easier to identify trends, patterns, and anomalies.

**Incident management:** to provide a map-based view of incidents, such as alarms, faults, and other events. This can enable faster response times and improve incident management.

Environmental monitoring: to monitor environmental factors, such as air quality, water quality, and weather patterns. This can enable more proactive environmental management, such as identifying potential hazards and mitigating risks. By interfacing with GIS, IoT system can provide a powerful tool for managing and optimising processes. This can enable more efficient decision making, reduce costs, and improve overall system performance. Details of facility, control type, etc. are shown in Table 14.20.

**Table 14.20: Details of facility, control type, etc.**

Facility	Control Type	Control Parameters	Control Mode	Source
Pump / Pump Station	Pressure Control	Discharge Pressure	Local / Remote	Automation Program
	Level Control	Discharge Reservoir/Tower Level	Local / Remote	Automation Program
	Time Control	Day Time	Local	Automation Program
	Power Consumption Optimization	Demand,Pumps Characteristics,Network Topology, Power Tariffs	Remote	Optimization Algorithm
Puimp - Variable Speed Drive	Speed Control	Diacharge Flow/Pressure	Local	VFD setup
Controlled Valve	Status Control	Status	Local / Remote	Automation Program
Pressure Reducing Valve (DMA,PMA)	Fixed Pressure	Discharge Pressure	Local	Controller
	2 points Pressure	Discharge Pressure , Time	Local	PLC / Valve Pilot
	Dynamic Pressure	Discharge Pressure , Time/Flow	Local / Remote	PLC / Valve Pilot
Flow Control Valve	Fixed Flow	Discharge Flow	Local	Controller
Storage : Resrvooir/Tank valve	Level Control	Water Level	Local	PLC / Controller

**14.19 Smart Water Management**

Smart water management is the use of data and technology to optimise water usage, reduce waste, and improve overall efficiency. SCADA and IoT systems including digital twin can play a critical role in smart water management by providing real-time monitoring and control of water systems. Here are some examples of how a cloud-based SCADA and IoT systems including digital twin can be used for smart water management:

1. Real-time monitoring: It can monitor water systems in real time, including water quality, flow rates, pressure, and other key metrics. This can provide valuable insights into system performance and enable early detection of issues before they become significant problems.
2. Leak detection and NRW: It can detect leaks and non-revenue water (NRW) issues in water systems by monitoring and comparing pressure changes and flow rates. This can enable quick identification and repair of leaks, reducing water waste and minimising damage to infrastructure.
3. Energy management: It can monitor energy usage in water systems, optimising energy consumption and reducing energy costs.
4. Remote control: It can provide remote control of water systems, enabling operators to adjust system settings, turn pumps on or off, and monitor performance from anywhere with a secured internet connection.

For efficient operation and maintenance with no downtime in services, an IoT-based real-time data collection, analysis, reporting, command and control system with online sensors installed across the city network is implemented.

This includes real-time surveillance to ensure quality water supply to every home, real-time data analysis and decision making for uninterrupted water supply, data capture for preventive maintenance of water supply assets, reduction of NRW through leakage detection and control, efficient incidence management and quick resolution of issues, effective complaint redressal for enhanced customer satisfaction, mobile responsive real-time flow, pressure and quality monitoring of water supply, GIS-based assets and consumer mapping and real-time dashboard.

The smart water management has emerged as a transparent, cost-effective and user-friendly system with real-time water quality monitoring without human intervention, automated pump and pressure control compared to manual operation and on the spot automated testing and chemical dosing compared to manual practice, thus reducing the manpower requirement to a large extent. This also has lessened the issue identification and resolution time from days to a few hours, resulting in high-level customer satisfaction. Further, since the system can now be operated remotely, it has become disaster resilient and during natural calamities such as cyclones, the services will no longer be disrupted. The DMA should have digital inlet pressure with a pressure transmitter, inlet electromagnetic flowmeter, altitude pilot control valve with necessary ESR level transmitter, including mechanical gauge. The delivery of the ESR should be divided into required numbers of header depending upon hydraulic gradient of the sub-DMA and consumption. The sub-DMA should have an electromagnetic flowmeter and dynamic control valve along with the pressure transmitter at required point as per desired. The above instruments should be connected to DMA level PLC panel through data cable and the back-up power supply should have a DG of required capacity including emergency chlorine dosing VFD driven chlorine dosing pumps.

The distribution network of each sub-DMA should have online chlorine analyser and connected to DMA level PLC by optical dark fibre. The lane, bye-lane, street and commercial/official should have individual flowmeter along with digital online pressure transmitter which should be connected to main PLC by optical fibre through a street side PLC panel. Each DMA PLC should be connected through the dark fibre optic in star topology. Typical Command Centre and DMA Monitoring of WATCO, Puri are shown in Figure 14.14 & 14.15.

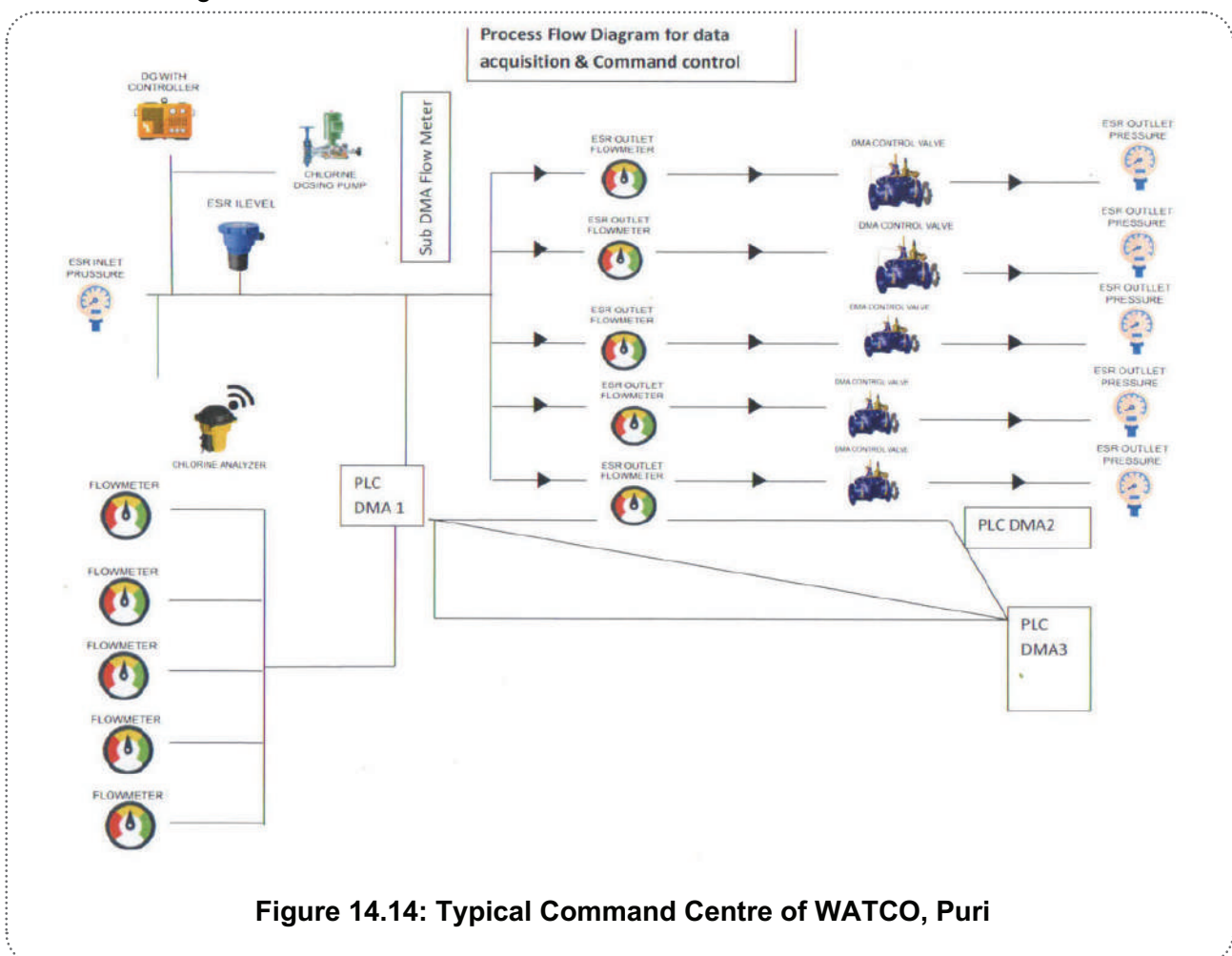
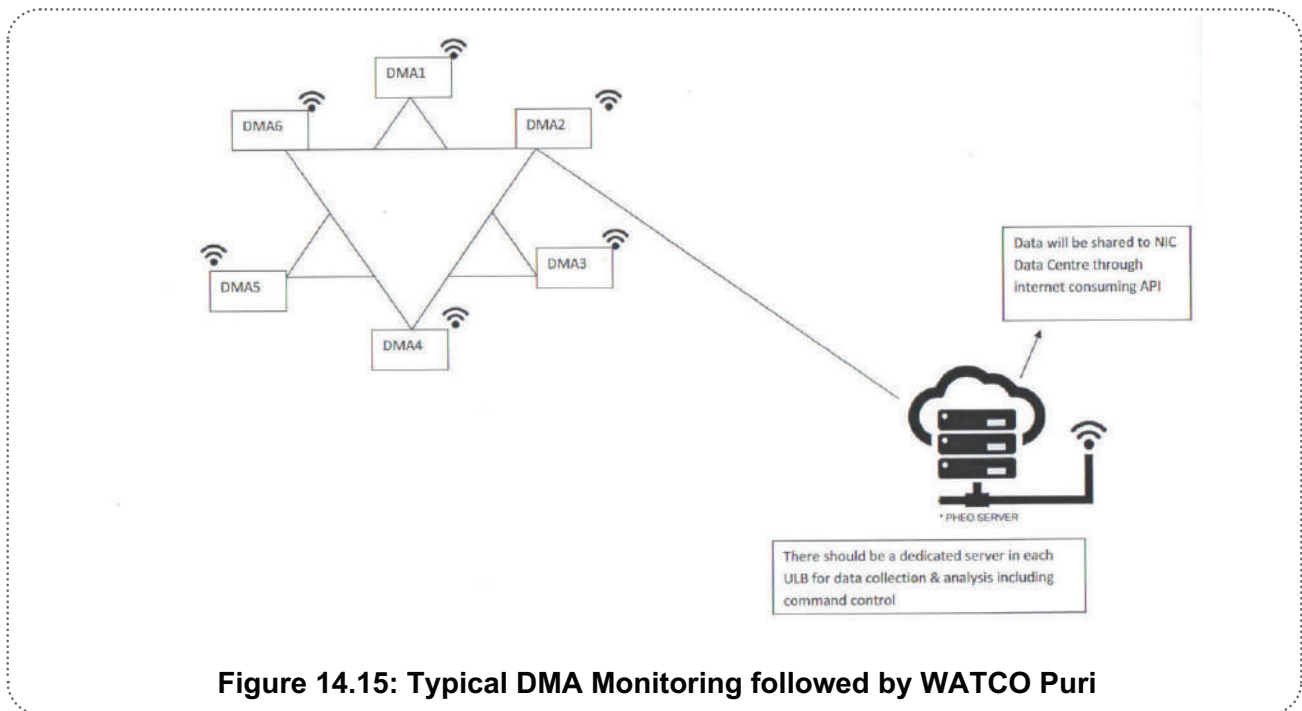


Figure 14.14: Typical Command Centre of WATCO, Puri



**Figure 14.15: Typical DMA Monitoring followed by WATCO Puri**

All DMA data should be captured in the server each at interval of 20 milliseconds per instrument round the clock. A graph and alert are generated accordingly for its monitoring and in case of emergency all functional instruments can be controlled from the command control room.

### 14.20 Instrumentation Matrix for Water Supply

Components, field instrumentation, electrical inputs, control system and communication technologies at various locations of the water supply system are explained in detail in the matrix below:

INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)					
S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
1	<b>Intake pumping station (RWPS)</b>	Pressure Transmitter at Pump individual at Inlet Level Transmitter at Intake well Flow Transmitter at Pump outlet command discharge Temperature scanner at pumps. Vibration sensor at X Y Axis of pump Reverse rotation switch for VT pump, Pump Monitoring system Controlling and monitoring of Integral type Motorised actuator valves/gates. It is advised to select smart actuator to achieve digitalised Plant communication system: PA, EPABX and CCTV Automated lighting system (Solar/EB power)	a) VFD/soft starter from LT and HT panels connected to PLC via ethernet/RS 485 Modbus/TCP IP for Energy monitoring and demand-based operation b) All multi-frequency modulation connected via Modbus communication for energy monitoring. c) Energy management d) Control and monitoring of incomer, bus coupler, individual drives, DG set e) Transformer monitoring f) Intelligent motor control centres-based panels to acquire more electrical insights	a) Automation through PLC/SCADA b) DNP3 and HART over IP protocols are mandatory for wireless communication/field instrumentation for health diagnostics and remote parameterisation c) To achieve digital plant protocols like MQTT, MODBUS shall also be used only for specific areas d) Hot Standby CPU, redundant power supply, redundant communication-based PLC system shall be used. e) UPS with suitable battery and other sets.	Option 01 – VSAT-based wireless communication Option 02 – Multi-label based switching fibre optic cable communication via service provider
2	<b>Raw water Rising main (if Applicable)</b>	Battery operated Electromagnetic flowmeter at tapping point Transient pressure Acoustic Transmitter (TPAT)/Online Noise sensor for continuous monitoring	-	Data logger with in-built data storage and data transfer via dual GPRS communication	Software-driven WAN-based GPRS communication with alternate service provider for redundant communication
3	<b>Water Treatment Plant (WTP)</b>	<b>Pre-settlement treatment</b> – pH analyser, Turbidity analyser and Residual Chlorine Analyser at inlet, Full Bore electromagnetic	a) VFD/soft starter from LT and HT panels connected to PLC via ethernet /RS 485 Modbus/transmission	a) Automation through PLC/SCADA b) DNP3 and HART over IP protocols are mandatory for	Option 01 – VSAT-based wireless communication with NMS service.

INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)					
S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
		<p>flowmeter at inlet pump of WTP</p> <p><b>Filter Bed:</b> a) Loss of Head Transmitter for individual filter bed level measurement and Rate of Flow Transmitter at outlet of filter bed.</p> <p>b) SMART Filter bed automation (Wireless)</p> <p><b>Chemical Dosing and Sludge Treatment:</b> Pressure instrument at each pump, Level Transmitter at each tank and Flowmeter at common discharge pump.</p> <p><b>Post treatment</b> – pH analyser, Turbidity analyser and Residual Chlorine Analyser at outlet , Full Bore electromagnetic flowmeter at outlet pump of WTP.</p> <p><b>Plant communication system:</b> public address, EPABX and CCTV Automated plant lighting system (Solar/EB power)</p> <p>Controlling and monitoring of Integral type Motorised actuator valves/gates. it is advised to select smart actuator to achieve digitalised</p> <p>Note: It is advised to select</p>	<p>control IP for Energy monitoring and demand-based operation</p> <p>b) All Multi-frequency modulation connected via Modbus communication for Energy monitoring.</p> <p>c) Energy management</p> <p>d) Control and monitoring of incomer, bus coupler, individual drives, DG set</p> <p>e) Transformer monitoring</p> <p>f) intelligent motor control centre based panels to acquire more electrical insights</p>	<p>wireless communication/ instrumentation for health diagnostics and remote parameterisation</p> <p>c) To achieve digital plant protocols like MQTT message queuing telemetry, MODBUS shall also be used only for specific areas</p> <p>d) HOT Standby CPU, redundant power supply, redundant communication-based PLC system shall be used.</p> <p>e) UPS with suitable battery and other sets.</p>	<p>Option 02 – MPLS-based FO cable communication via service provider SD WAN Connection technology (applicable for central control room and unified operation centre).</p> <p>Option 03 – combination of both MPLS and VSAT communication.</p>

**INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)**

S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
4	<b>Clear water Pumping station (CWPS)</b>	Wireless Instruments within WTP campus for digitally enabled plant. Pressure Transmitter at Pump Inlet Level Transmitter at tank measurement Flow Transmitter at Pump outlet command discharge Temperature scanner at pumps. Vibration sensor at X Y Axis of pump. Pump Monitoring system Controlling and monitoring of Integral type Motorised actuator valves/gates. it is advised to select smart actuator to achieve digitalised Note: It is advised to select Wireless Instruments within pumping station campus for digitally enabled plant Plant communication system: PA, EPABX and CCTV Automated lighting system (Solar/EB power)	a) VFD/soft starter from LT and HT panels connected to PLC via ethernet/RS 485 Modbus/TCP IP for Energy monitoring and demand-based operation b) All MFM connected via Modbus communication for Energy monitoring. c) Energy management d) Control and monitoring of incomer, bus coupler, individual drives, DG set e) Transformer monitoring f) IMCC based panels to acquire more electrical insights	a) Automation through PLC/SCADA b) DNP3 and HART over IP protocols are mandatory for wireless communication/ field instrumentation for health diagnostics and remote parameterisation c) To achieve digital plant protocols like MQTT, MODBUS shall also be used only for specific areas d) HOT Standby CPU, redundant power supply, redundant communication-based PLC system shall be used. e) UPS with suitable battery and other sets.	Option 01 – VSAT-based wireless communication Option 02 – MPLS-based FO cable communication via service provider
5	<b>Clear water Rising Main (CWRM)</b>	Battery operated Electromagnetic flowmeter at tapping point Transient pressure Acoustic Transmitter (TPAT)/Online Noise sensor for continuous monitoring		Data logger with in-built data storage and data transfer via dual GPRS communication	SD WAN-based GPRS communication with alternate service provider for

INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)					
S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
6	<b>Intermediate Booster Pumping Station (IBPS)</b>	Pressure Transmitter at Pump individual at Inlet Level Transmitter at tank measurement Flow Transmitter at Pump outlet common discharge Temperature scanner at pumps. Vibration sensor at X Y Axis of pump Pump Monitoring system Controlling and monitoring of Integral type Motorised actuator valves/gates. it is advised to select smart actuator to achieve digitalised plant. Plant communication system: PA, EPABX and CCTV Note: It is advised to select Wireless Instruments within pumping station campus for digitally enabled plant Automated lighting system (Solar/EB power)	a) VFD/soft starter from LT and HT panels connected to PLC via ethernet /RS 485 Modbus/TCP IP for Energy monitoring and demand-based operation b) All MFM connected via Modbus communication for Energy monitoring. c) Energy management d) Control and monitoring of incomer, bus coupler, individual drives, DG set e) Transformer monitoring f) IMCC based panels to acquire more electrical insights	a) Automation through PLC/SCADA b) DNP3 and HART over IP protocols are mandatory for wireless communication/ field instrumentation for health diagnostics and remote parameterisation c) To achieve digital plant protocols like MQTT, MODBUS shall also be used only for specific areas d) HOT Standby CPU, redundant power supply, redundant communication-based PLC system shall be used. e) UPS with suitable battery and other sets.	redundant communication Option 01 – VSAT-based wireless communication Option 02 – MPLS-based FO cable communication via service provider
7	<b>Master Balancing Reservoir (MBR)</b>	Pressure Transmitter at Pump individual at tank Level Transmitter at top of all reservoir tank Flow Transmitter at Pump inlet and outlet of tank	-	RTU with DNP3, HART over IP and MQTT protocols	a) Data logger with in-built data storage and data transfer via dual GPRS communication b) SD WAN-based

## INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)

S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
		Water quality Analyser at outlet of tank Instrumentation for online dosing chlorine system (Level sensor, solenoid valve and stroke pump adjustment) Controlling and monitoring of Integral type Motorised actuator valves/gates. it is advised to select smart actuator to achieve digitalised plant. Plant communication system: CCTV system Note: It is advised to select Wireless Instruments within MBR campus for digitally enabled plant			GPRS communication with alternate service provider for redundant communication
8	<b>Clear water Pumping Main (CWPM)</b>	Battery operated Electromagnetic flowmeter at tapping point Transient pressure Acoustic Transmitter (TPAT)/Online Noise sensor for continuous monitoring	-	Data logger with in-built data storage and data transfer via dual GPRS communication	SD WAN-based GPRS communication with alternate service provider for redundant communication
9	<b>Elevated Service Reservoir (ESR)</b>	Pressure Transmitter at Pump individual at tank Level Transmitter at top of all reservoir tank Flow Transmitter at Pump inlet and outlet of tank	-	RTU with DNP3, HART over IP and MQTT protocols (Rugged RTU for remote location considering temperature and other factors)	a) Data logger with in-built data storage and data transfer via dual GPRS communication b) SD WAN-based GPRS

INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)					
S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
10	<b>ULB Transfer Chamber – UTC</b>	Water quality Analyser at outlet of tank Instrumentation for online dosing chlorine system (Level sensor, solenoid valve and stroke pump adjustment) Controlling and monitoring of Integral type Motorised actuator valves/gates. it is advised to select smart actuator to achieve digitalised plant. Plant communication system: CCTV system	-	Battery operated Data logger	a) Data logger with in-built data storage and data transfer via dual GPRS communication b) SD WAN-based GPRS communication with alternate service provider for redundant communication
11	<b>District Metered Area – DMA</b>	Pressure Transmitter at Inlet of each DMA Flow Transmitter at inlet of each DMA with data logger	-	Battery operated Data logger	a) Data logger with in-built data storage and data transfer via dual GPRS communication

**INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)**

S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
12	<b>Sub-DMAs</b>	Pressure Transmitter at Inlet of each sub-DMA Pressure Transmitter at critical pressure points at low, medium and High pressure Flow Transmitter at inlet with data logger at critical pressure points Battery operated digitalised Online chlorine measurement sensor at zone-wise (Data can be directly transfer to central control room and respective OHSR without any transmitter in sensor as an alternative technology)	-	Battery operated Data logger	b) SD WAN-based GPRS communication with alternate service provider for redundant communication a) Data logger with in-built data storage and data transfer via dual GPRS communication b) SD WAN-based GPRS communication with alternate service provider for redundant communication
13	<b>House service connection/ commercial connection</b>	Option 01 – AMR Water meter at inlet of individual house service connection Option 02 – AMI Water meter at inlet of individual house service connection Option 03 – NB-IoT/LORA/RF others Water meter at inlet of individual house service	-	-	Option 01 – AMR Water meter at inlet of individual house service connection Option 02 – AMI Water meter at inlet of individual house service connection Option 03 – NB-

INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)					
S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
		<p>connection Option 04 – Direct GPRS (E SIM enabled/plastic sim) Water meter at inlet of individual house service connection</p> <p>Option 05 – Dual communication Water meter at inlet of individual house service connection <b>1. GPRS</b> (E SIM enabled/plastic sim) <b>2.</b> During GPRS technical issue – Data can be accessed via through walkway drive method also (using suitable radio communication)</p> <p>Note: Suitable protocol can be used (MQTT, DNP3, CSV file format).</p>			<p>IoT/LORA/RF others Water meter at inlet of individual house service connection Option 04 – Direct GPRS (E SIM enabled/plastic sim) Water meter at inlet of individual house service connection Option 05 – Dual communication Water meter at inlet of individual house service connection <b>1. GPRS</b> (E SIM enabled/plastic sim) <b>2.</b> During GPRS technical issue – Data can be accessed via through walkway drive method also (using suitable radio communication)</p>
14	<b>Surge Control system</b>	Required field instrumentation shall be provided for monitoring and controlling.	-	Via WTP PLC/RTU	SD WAN-based GPRS communication with alternate service provider for

INSTRUMENTATION MATRIX FOR WATER SUPPLY PROJECT (AI BASED DIGITAL PLANT)					
S. No	Components	Field Instrumentation	Electrical Inputs	Control System	Communication
15	<b>Command Control Centre (UOC)</b>	Both control and monitoring of complete plant from Intake to HSC		a) Higher end FEP server, blade server, application server, Historian server, Disaster recovery management, OT/IT server, web server, HART server, LVS and redundant machines. b) Required furniture's with air condition c) DG and UPS supply d) Hybrid cloud management	redundant communication Option 01 – VSAT-based wireless communication Option 02 – MPLS-based FO cable communication via service provider

### **14.21 Use of Information Technology (IT) and IT-Enabled Services (ITES)**

Information technology (IT) and IT-Enabled Services (ITES) have the potential to help improve water supplies and address the systemic problems faced by the water sector. IT has great potential to provide timely information on the level of services delivered and the performance of service providers. Although snapshot baseline maps of water supplies can be created with mobile phones or GPS units, these maps often do not track core issues over time. Applied appropriately to monitoring, IT can do more to trace these issues over time and allow previous data points to be updated easily. A second use of IT is providing data management tools in areas and improving the quality of monitoring information so that it is taken seriously. Accuracy requires reviewing and validating information during data collection and reducing data entry errors. With IT, data can be checked by an expert in a utility's office even as surveys are being conducted in the field. Data do not need to be transcribed if they are entered into a phone during data collection. Validated data improve the ability of stakeholders to learn and adapt to new challenges. Additionally, data collected by different agencies can be shared for cross-validation and co-ordination. If the data are known to be accurate, broken infrastructure can be fixed in a timely manner, sector regulations can be enforced, and external support can be provided when necessary. Finally, the implementation of IT can lower the costs of existing monitoring activities by speeding up data collection, management, and analysis while reducing travel distances and costs. The cost of internet access, phones, computers, and software is decreasing dramatically while the benefits continuously improve.

ITES, is defined as outsourcing of processes that can be enabled with information technology and covers diverse areas like revenue claims processing, legal databases, content development, payrolls, logistics management, GIS, web services, etc. Information technology that enables the process by improving the quality of service is IT-enabled services. The most important aspect is the value addition of IT-enabled service. The value addition could be in the form of customer relationship management, improved database, speedy complaint redressal, etc. This radically reduces costs and improves service standards.

### **14.22 Application of IoT and Artificial Intelligence (AI)**

The IoT is a dynamic wireless network infrastructure that integrates various communication technologies and solutions to enable the interaction between people and things/objects. This remarkable technology opens opportunities for the development of distinct applications for the cities. For instance, in the context of water management, the use of IoT allows for monitoring and controlling water supply systems in real time.

IoT systems are fourth-generation systems. In these systems, the system's infrastructural cost is reduced by implementing IoT through cloud computing. Maintaining as well as integrating these systems is easy as compared to others. In real time, the condition of these systems can be reported through cloud computing. Therefore, the implementation of algorithms like intricate control can be done that are frequently used on typical PLCs.

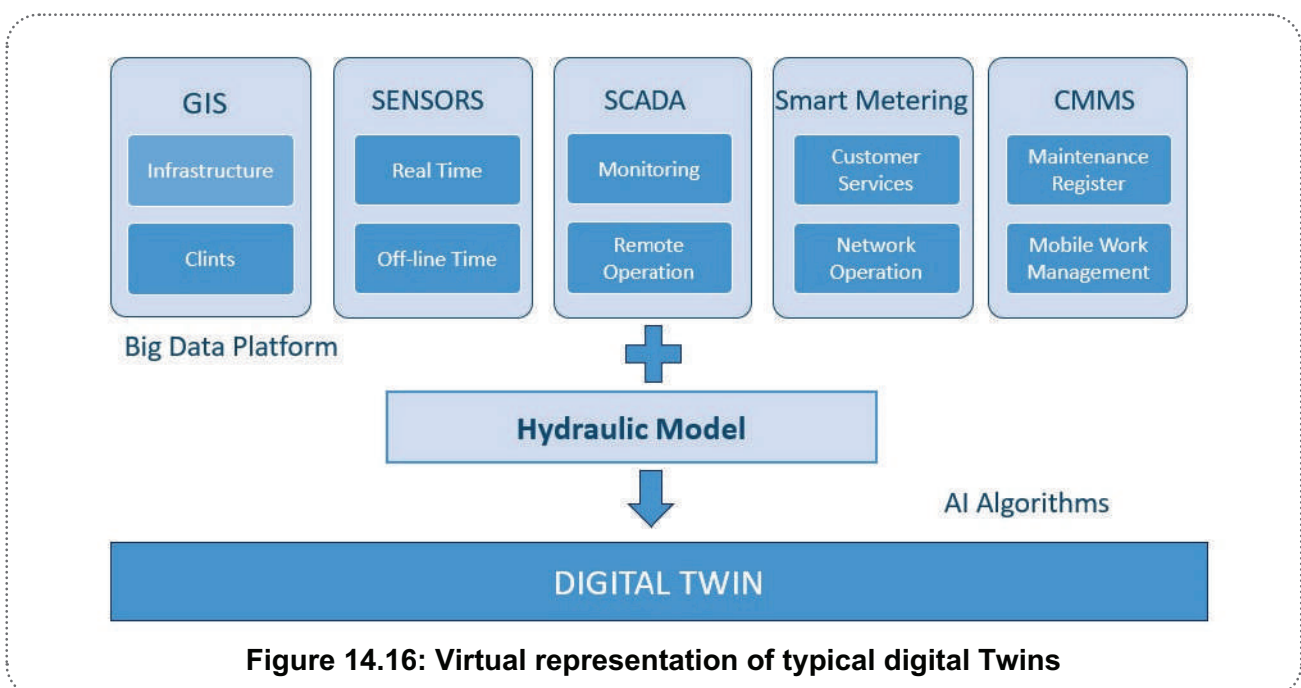
Artificial intelligence (AI) comprises 'a branch of computer science dealing with the simulation of intelligent behaviour in computers'. In the context of delivering efficient water supply, AI or machine learning is mainly applied to decision-making tasks: how water utilities can maximise information and data available to make better decisions while enhancing service delivery; optimising capital investment; and reducing operating costs, including social and environmental externalities.

AI in water management might come off as a huge revelation but it can change the way we treat and manage water sources around us. AI can make the process of water management easier with data analytics, regression models, and algorithms. These cutting-edge technologies help in building

efficient water systems and networks. AI can be used to build water plants and get the status of water resources. Water managers and government bodies can use AI to build a smart water system that can build efficient infrastructure for water management and adapt to changing conditions. These systems will be cost-effective and sustainable that can optimise all water management solutions and predict potential damages. Physical water leak detection techniques are based on combining special equipment (acoustic sensors, gas tracers, etc.) with human skills. A current trend is to incorporate AI in some of this hardware to replace humans in interpreting the data (water leak noises). With the advances in numerical modelling of the hydraulics of water distribution networks, it is now possible to detect potential leaking pipe sectors through numerical methods, as long as the hydraulic models are fed with a sufficient amount of calibrated field data such as pressure, flow, and node consumptions.

### 14.23 Digital Twins

Digital twin is a technology that creates a virtual representation (Figure 14.16) of a water supply system. In other words, digital twin creates a virtual replica of the real-world water supply system.



**Figure 14.16: Virtual representation of typical digital Twins**

Digital twin brings WTP, transmission pipeline, service reservoir, SCADA, GIS, hydraulic modelling, flowmeters, control valves and consumer meter information into a connected data environment, delivering cost-effective operations strategies in real time.

#### 14.23.1 Objective of Digital Twin

Many times, water supply system of the towns and cities are suddenly hit by ‘unexpected’ events such as pump failure, pipe burst, low pressures, or the failure of ageing assets. On occurrence of such instances, we react only to solve the present issue. The reality is that most such events are not truly ‘unexpected’. In many cases, they are predictable, we just fail to plan and prepare. Digital twins help us, and above situation no longer remains unpredictable. With real-time data and data analytics, digital twin makes predictive analysis. For example, the flow and pressure in pipelines are continuously shown on the screen in real time with 95% confidential ratio. If we observe a sudden dip into the pressure, we can immediately know that there is a burst or heavy leakage in the system.

### 14.23.2 Digital Twin in addition to IoT

The purpose of the digital twin is to integrate the existing IoT solution, engineering data (e.g. hydraulic model) and IT data (GIS for example) and any other systems. The digital twin should be evergreen, live, and constantly represent the real performance of all assets and predict the behaviour of the system.

IoT systems alone provide just visibility and analytics in few points in the network. They cannot extrapolate for the whole system nor simulate the complete behaviour of the system.

The digital twin with the simulation capabilities of network software simulate the full behaviour of the systems and can ingest IoT data as initial/boundary conditions to analyse IF-ELSE scenarios, respond to emergencies (e.g. shut-off of valves, electricity failure, leakages, etc.). In addition, the digital twin technology enables detecting of events and anomalies into the network.

Digital twin can also integrate with other enterprise systems such as work order management. The digital twin solution has a capital planning module inside to help understand critical parts of the system and direct/prioritise further investment. The digital twin solution integrates analytical platforms such as PowerBI (or similar). The digital twin solution can ingest any GIS data available through Web Map Service (WMS) service to provide full context of the project and also the water networks.

### 14.23.3 Benefits of Going Digital

Virtual representation of water supply system of a city using digital twin spans its lifecycle. It is updated from real-time data, and uses simulation, machine learning and reasoning to help decision making. It serves as system simulation, integration, testing, monitoring, and maintenance.

The performance data of the real world of city's water supply system is taken to the virtual reality where the performance data is processed and continuously made available to the system's manager.

Digital twin provides an environment using which the utility's engineer can have access to their critical system. On observation from measurements and analytically derived results, he gets performance information of his assets. This would enhance skills of operations, maintenance, and decision making.

With real-time data and data analytics, digital twin makes predictive analysis. During O&M, if a city witnesses any problem due to pipe breakages, bursts, leakages, etc., then digital twin immediately alarms the utility and guides to take corrective measures. For example, a sudden dip is observed into real-time pressure, it indicates that there is a burst or heavy leakage in the system. Hence, the ground team can be engaged to address the issue at the site.

### 14.23.4 Digital Twin Setup

It is needed to configure the digital twin by assigning the data. As shown in Figure 14.17, the information is put in various silos. For example, the shape files are put in the GIS silo, while sensors and customers' information are placed in the silos allotted for them.

The hydraulic model of a city is fed to the digital twin software. For that, we must share the hydraulic model file and the GIS shape files with the support team of the digital twin. This team feeds the files to cloud platform (Figures 14.18 and 14.19) and the system automatically uploads the file and set up the model.



Figure 14.17: Performance data of the real world



Figure 14.18: Data uploading from city to cloud platform and response



Figure 14.19: Data uploading from 500 AMRUT cities to cloud platform, processing, and response.

#### 14.23.5 Working of Digital Twin

The working of digital twin is shown in Figure 14.20.

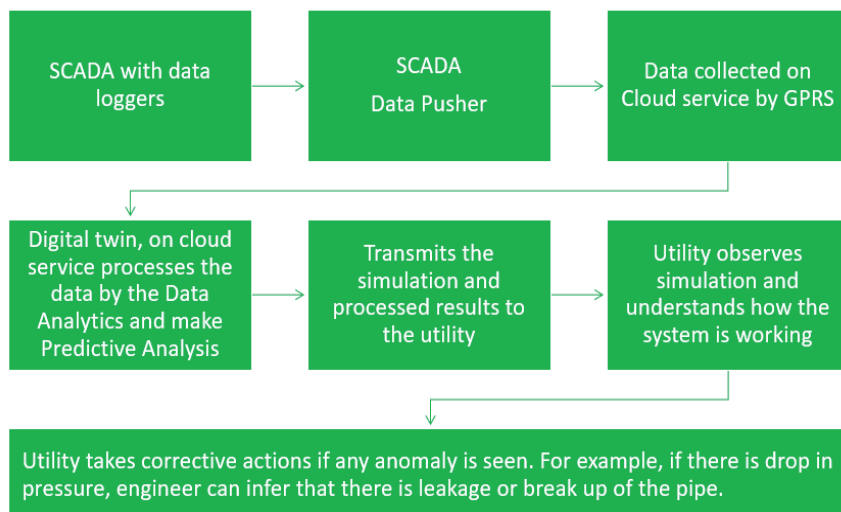


Figure 14.20: Working of digital twin.

The digital twin operation begins after the SCADA system generates data. Data pusher is inserted into the PLC of the SCADA which sends the data to cloud service. This data is accessed by the digital twin software on cloud.

Real-time simulation of the network: Once the digital twin is configured, the digital twin shows the sensors in network, pipes, service tanks, valves, etc. It shows the real-time animation of flow through pipes as shown in Figure 14.21.

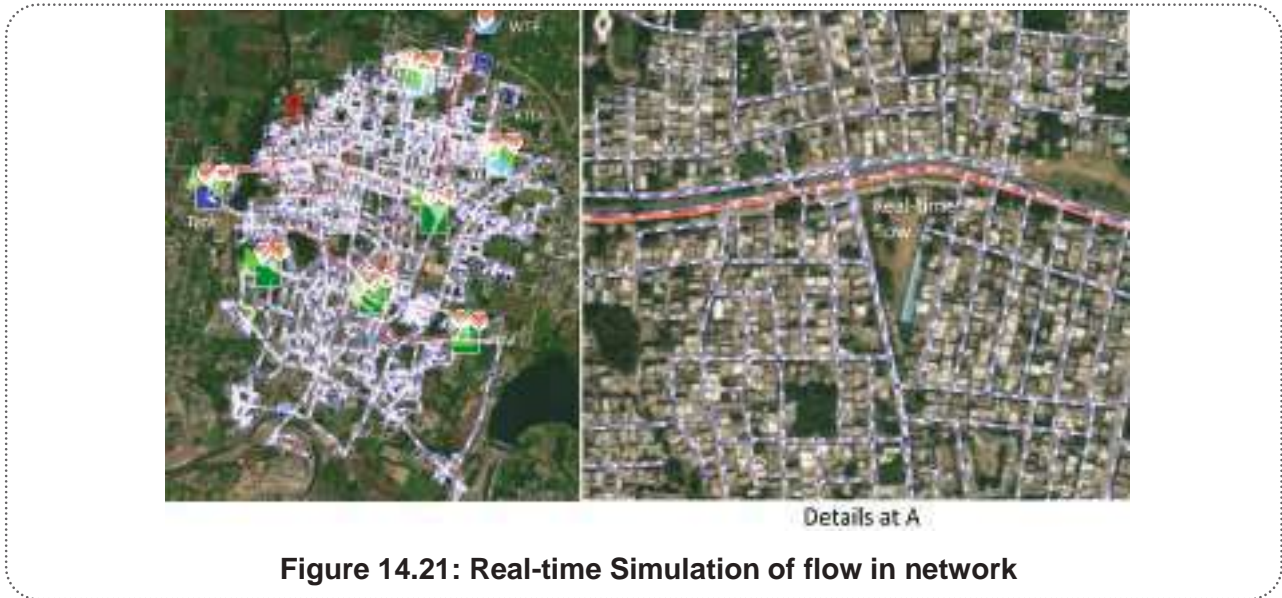


Figure 14.21: Real-time Simulation of flow in network

On configuration, the digital twin shows the machine-learned forecast and real-time results with statistical data, data analytics, and predictive analysis.

### Water Audit

For real-time water audit, the customer’s information is fed into the silo (Figure 14.17) earmarked for customers. The software installed on the server of the cloud platform makes data analytics and computes system inflow, consumption, and losses and the NRW is computed. The results are shown in Water Balance table which is shown in Figure 14.22.

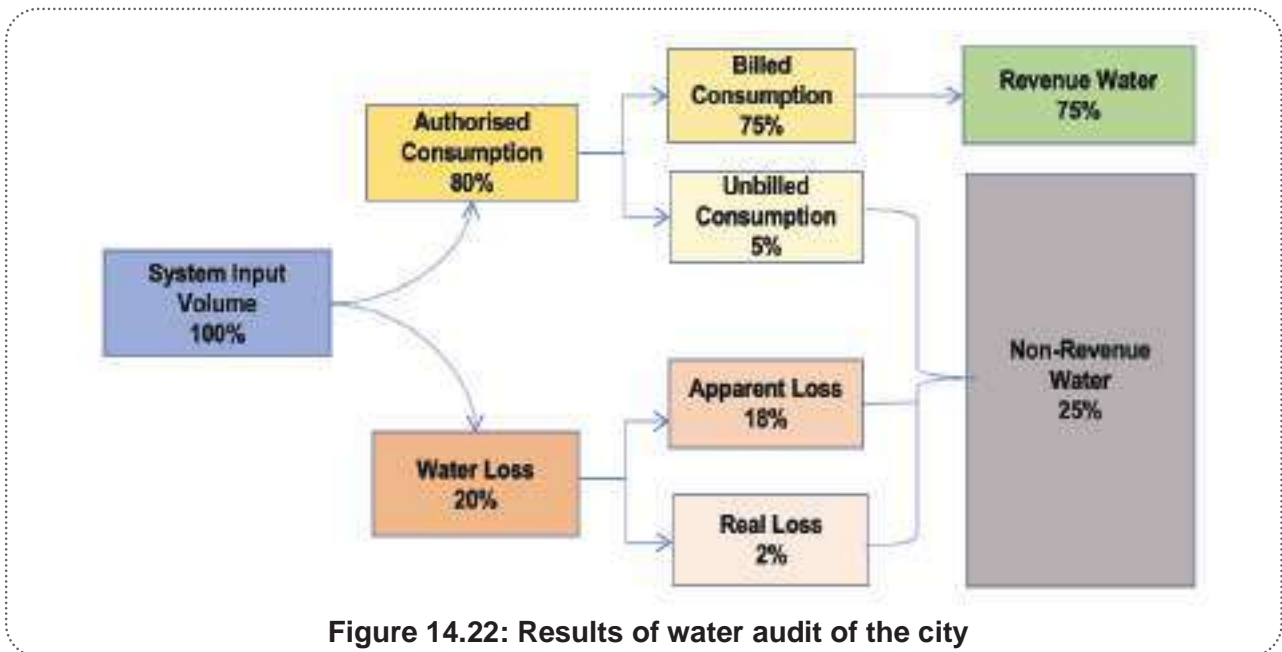


Figure 14.22: Results of water audit of the city

Digital twin produces the water balance series for different months, its graphs are shown in Figure 14.23.

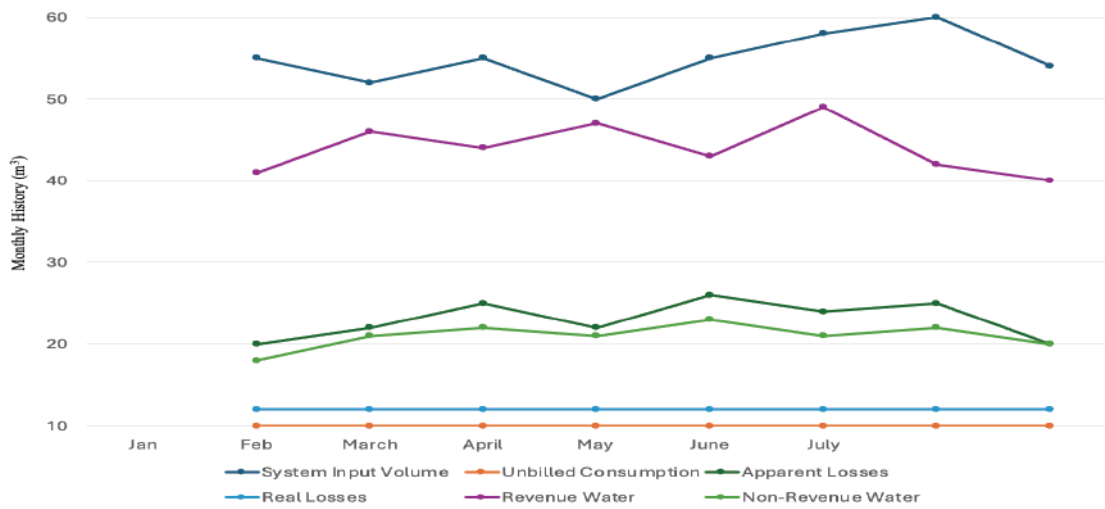


Figure 14.23: Results of water balance series for different months

Digital twin also produces water balance bar charts for various operational zones of the system as shown in Figure 14.24.

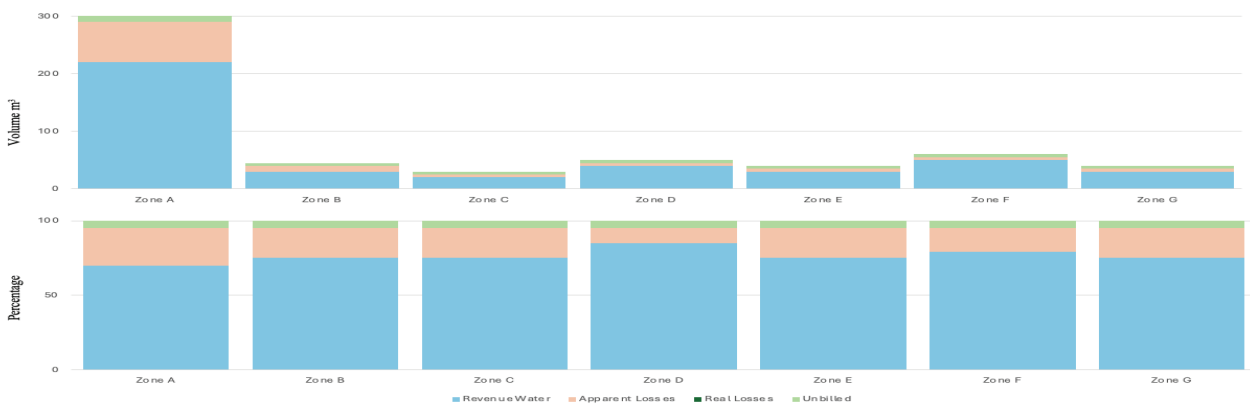


Figure 14.24: Results of water balance bar charts

Digital twin also generates minimum net night flow (MNF) values of the system as shown in Figure 14.25.

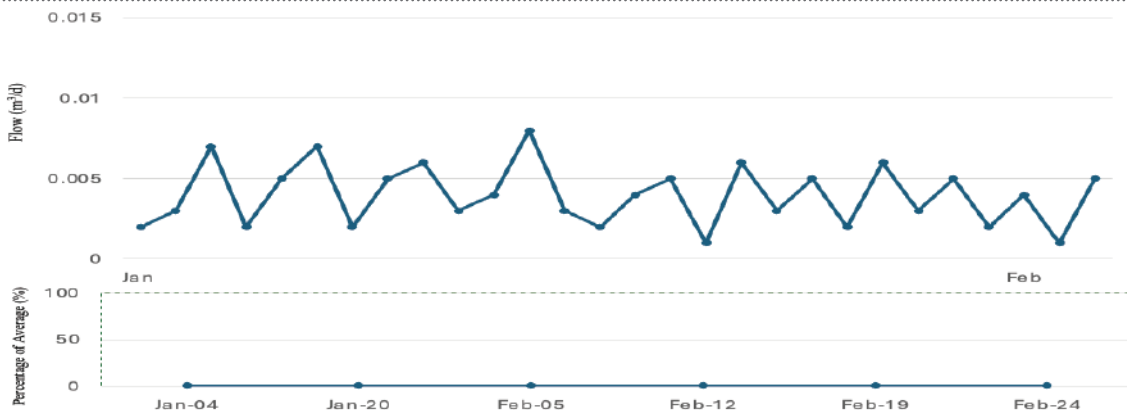


Figure 14.25: Results of minimum net night flow (MNF) of the system

### **Actionable Insights for the Entire Utility**

It shall integrate combined data spread across multiple systems with the power of real-time analysis. The digital twin shall connect all data sources and create a continuous, consistent digital representation of operated assets. The solution's browser-based portal shall provide an easy framework to visualise and communicate with stakeholders from any device. It shall be possible that the entire team can quickly identify system inefficiencies and anomalous events, track system performance over time, make more informed decisions, and drive high-quality, consistent, and cost-effective service levels immediately as well as in the future.

### **Moving Beyond SCADA Results**

The features allow to readily monitor various parameters at any point in the system. The digital twin visualises current data in the context of historical trends. Thematic displays provide visual cues on the normal operating ranges as well as indicate when recorded data points are outside of normal operation.

With the digital twin, it shall be possible to investigate the real-time performance for each asset using an embedded hydraulic model that is continually updated with boundary conditions from sensors. Any parameter that can be computed with the hydraulic model can therefore be simulated and monitored in real time without the need to separately open, set up, and run hydraulic modelling software. This enables graphical indication of current pressure, velocity, and other characteristics for every asset in the system, providing instant detection of areas in need of intervention to improve service levels or minimise potential issues.

### **Proactive Network Management**

The digital twin can compute up to one week of demand forecasts for each sensor or district metered area by combining machine learning algorithms with advanced data analytics. Zone demand forecasts, along with other initial conditions from other sensors, can also be used as boundary conditions for the model runs, empowering more reliable insights and support toward a more proactive system operation.

### **Identification of Where Water is Going and at What Cost**

The digital twin shall help to reduce NRW using live water audit calculations. It shall be possible to compare overall production against metering data to estimate how much water was lost, both in quantity and percentage. The application shall perform automated evaluation of nightly minimum flows, enabling identifying the location and quantity of NRW. This auditing shall be available for individual zones or the entire network, which allows you to detect when a problem occurred or determine the effectiveness of mitigative actions. The features shall also improve energy efficiency by leveraging real-time analyses of each pump and tank, with alerts that tell you when performance is outside of service thresholds.

### **Early Warning and Emergency Management**

Digital twin shall improve awareness of anomalous network events such as leaks, bursts, and meter failures, contributing to reduced response times and subsequent operational cost reduction. By incorporating a real-time anomaly detection system, the digital twin automatically triggers alerts whenever real data is outside the expected operational behaviour. Volumes lost in each event need to be automatically computed, allowing to manage those events with status updates, category classifications, and comments. The features shall facilitate to evaluate current network performance as well as various what-if scenarios when quick decisions are needed due to a fire, pipe break, pump

outage, or other time-critical events, and demonstrate the impact of actions to service levels and customers throughout the network.

### **Connected Data Environment**

The digital twin leverages a connected data environment that provides a cloud-provisioned open framework for collaboration and asset information management throughout the lifecycle of water infrastructure. The connected data environment shall ensure the accuracy and availability of system data at every stage of the asset lifecycle, allowing faster project start-up, streamlined workflows, improved standard adherence, reduced risk, more informed decisions, and increased asset performance.

### **Water Audit**

Digital twin can perform the following activities:

- IWA/AWWA water balance diagram – Monthly water audit by pressure zone based on production data from SCADA and customer consumption from billing data.
- NRW analysis – Automatic derivation of real and apparent losses (based on minimum nightly flow analytic).
- NRW visualisation – Graphical comparisons of the water balance components for multiple zones (historical trend series and bar charts).
- NRW key performance indicators (KPIs) – Minimum nightly flow (MNF) per connection and ratio between minimum and average flow.

### **Pump Performance and Energy Management**

- Pump operational analytics – Individual pump and/or total pump station performance evaluations in terms of best operation point, energy efficiency, and energy cost including comparisons over historical time periods (constant and variable speed pumps).
- Pump power cost KPIs – key performance indicators including total pump power cost and pump 'inefficiency' cost.

### **Tanks assessment**

- Historical trend analysis – Comparative trends in tank operation (level, hydraulic grade line, and volume).
- Total Storage Assessment – Real-time storage volume assessment.
- Alerts – Low- and high-level alert notification.

### **Event Management and Emergency Response**

- Intelligent alerts – Automatic alerts generated for sensors or zones based on user-defined rules and patterns.
- Pipe break volume KPI – Automatic calculation of pipe break volume using calculated DMA flow volume exceedance above the pattern prediction.
- Events management – User updatable status, category, and edit workflow comments; ability to add manual events.
- Operational event simulation – Define and analyse impacts of events such as: valve closure/opening, pipe breaks, fires, and pump shutdowns.

### Background Real-time Network Simulation

Digital twin can make following simulations:

- 1) 'Heartbeat' model – Re-occurring automatic background run of hydraulic model (user-defined interval such as one hour) using real-time boundary conditions, control overrides, and/or demand overrides from SCADA data derived calculations.
- 2) Map thematic and graphical display – 'heartbeat' modelling results for hydraulic grade line (HGL), pressure, flow, velocity, water quality, and other characteristics displayed in map view and chart views including preconfigured symbology templates and flow direction simulator on map.
- 3) Hindcast/Forecast simulation – Real-time model simulation of hindcast (up to 24 hours) with optional control and demand override and forecast (up to 24 hours) based on model's inherent control logic.
- 4) Trend chart – Display SCADA vs. Model simulation results in chart.
- 5) Demand forecasting – Automatic calculation and adjustment of demand patterns for forecast model simulation.
- 6) Desktop alternative – Ability to upload and download hydraulic model for offline analysis.
- 7) Alerts configuration – Set alerts for anomalous conditions defined based on absolute value or pattern, by individual sensor or zones, duration, and magnitude (absolute value or %); also flag lost signal or repeating values.
- 8) User configuration – User can incorporate new sensors, pumps, tanks, or zones into the system, configure alerts, routinely add customer billing data, and upload the most up-to-date hydraulic model as needed.
- 9) User settings and KPIs – Customisable settings such as production and customer water costs, pressure level of service requirement, pump efficiency, or energy tariff information.
- 10) User credentials – Manage users and access to cloud application.
- 11) Global settings – Customisable definition of thematic displays for all users.
- 12) External data connections – Refresh/modify links to external data.
- 13) Power BI integration – Integration and visualisation of user-customisable reports done in Power BI.
- 14) LoF and CoF factors – Define the factors that define the likelihood and consequence of failure (LoF and CoF).
- 15) LoF and CoF decision tree – Logic based decision tree interface to easily create simple or more complex LoF and CoF analysis; create queries across multiple datasets.
- 16) Risk matrix scenarios – Combine LoF and CoF using a user-defined risk matrix to create various scenarios for analysis and comparison.
- 17) Risk calculation – Automatically performs LoF, CoF, and risk score calculation for each pipe asset.
- 18) Visualisation – Tabular and map display of the assets based on low, medium and high risk (or user defined); side by side comparison of different risk scenarios.
- 19) Capital plan – Define the performance parameters that can influence capital planning decisions; define intervention plans based on risk and performance.

#### 14.24 Conclusion

Implementation of various solution/tools such as sensors, smart meters, advanced communication tools coupled with IoT platforms can bring about real-time database and information management and thus improving the performance of Urban Local Bodies (ULBs) and water utilities.

Smart technologies are likely to benefit both, the water utilities and the consumers, thus promoting efficient use of water both at the supply and demand side. Additionally, it shall improve the credibility

of the utilities thus improving revenue collection and reducing NRW. The ability to monitor water supply and distribution system on a real-time basis shall enable quick identification, prediction and prevention of potential problems such as a burst water main, a slow leak, a clogged drain or a hazardous sewage overflow/contamination. It shall thus ultimately ensure water conservation and reduction in losses and UFWs. Such systems can improve the efficacy of water supply system.