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Control & Automation – Technical Report

Application of Automation in Wastewater Treatment

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Abstract

Instrumentation, Control and Automation (ICA) play a crucial role in modern wastewater treatment systems, by improving operational efficiency, reliability and environmental compliance. Wastewater treatment facilities deal with large variations in flow, pollutant loading and weather conditions, so relying on manual operation is inefficient and introduces unnecessary risk. This report examines the development and application of ICA in wastewater treatment, focusing on sensors, actuators, controllers and control systems, all of which help to improve process stability. The historical evolution of automation is also explored, alongside modern advancements such as artificial intelligence (AI), SCADA and the Internet of Things (IoT). A case study of Dŵr Cymru Welsh Water is included to demonstrate real-world application. The report concludes that while ICA significantly enhances wastewater treatment performance, challenges such as cybersecurity, maintenance and cost must be addressed.

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1 Introduction

Wastewater treatment is essential for safeguarding public health and protecting the environment by removing impurities and from wastewater or sewage, before it reaches natural bodies of water or aquifers (Nathanson and Ambulkar, 2018). If wastewater is not treated properly, it can cause serious environmental damage, harm aquatic ecosystems, spread disease and cause major public health risks. Traditionally, wastewater treatment resulted in inefficiencies and inconsistencies in treatment performance due to the reliance on manual monitoring and operator intervention, to respond to changing conditions (Mahajan and Yadav, 2024). The routine inspection approach worked on a basic level; however, it was limited by delays in response time, human error and difficulty maintaining optimal control across larger and more complex plants. The integration of Instrumentation, Control and Automation (ICA) has transformed these systems into highly efficient and reliable operations.

ICA systems enable continuous monitoring and automatic control of key process variables such as flow rate, pH, dissolved oxygen and chemical concentrations. These systems combine sensors, actuators, controllers and supervisory platforms to ensure treatment processes are optimal and compliance with environmental standards (Olsson et al, 2013). Automation not only improves efficiency but also ensures compliance with increasingly stringent environmental regulations.

This report investigates the application of ICA in wastewater treatment, including its historical development, key components, regulatory requirements and emerging technologies with a particular focus on practical implementation in Wales.

2 Historical Development

The development of wastewater treatment automation has evolved in parallel with advancements in industrial control systems. The first known successful wastewater management was wastewater drainage during the Neolithic Age, around 6500 BC (Fatma et al, 2014). The ancient Greeks are considered the forerunners of modern sanitation systems, with findings showing the presence of sophisticated sewage systems dating from 2700 to 1450 BC (Angelakis, Capodaglio and Dialynas, 2022).

During millennia, untreated wastewater was discharged into water bodies such as rivers and lakes and alternatively applied to fields to dispose of it, contaminating crops of vegetables. This remained prominently active well into the 20th century and is still practiced in underdeveloped countries today (Salgot and Folch, 2018). In the mid-20th century, a major breakthrough occurred with the

development of electronic control systems. Feedback control mechanisms, particularly Proportional-Integral-Derivative (PID) controllers, enabled automatic regulation of key variables such as chemical dosing and aeration (Åström and Murray, 2008). This marked the transition from manual to semi-automated systems.

In recent decades, digital technologies have revolutionised wastewater treatment. The introduction of Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems have enabled full automation (Avinash et al, 2018). These systems allow for real-time monitoring, remote control and data analysis which significantly improves plant efficiency and reliability (Kamilko, 2024).

According to Worku et al (2025), advancements in wastewater treatment now include complex scientific methods such as electrocoagulation, bioremediation and advanced oxidation to break down harmful chemicals in water.

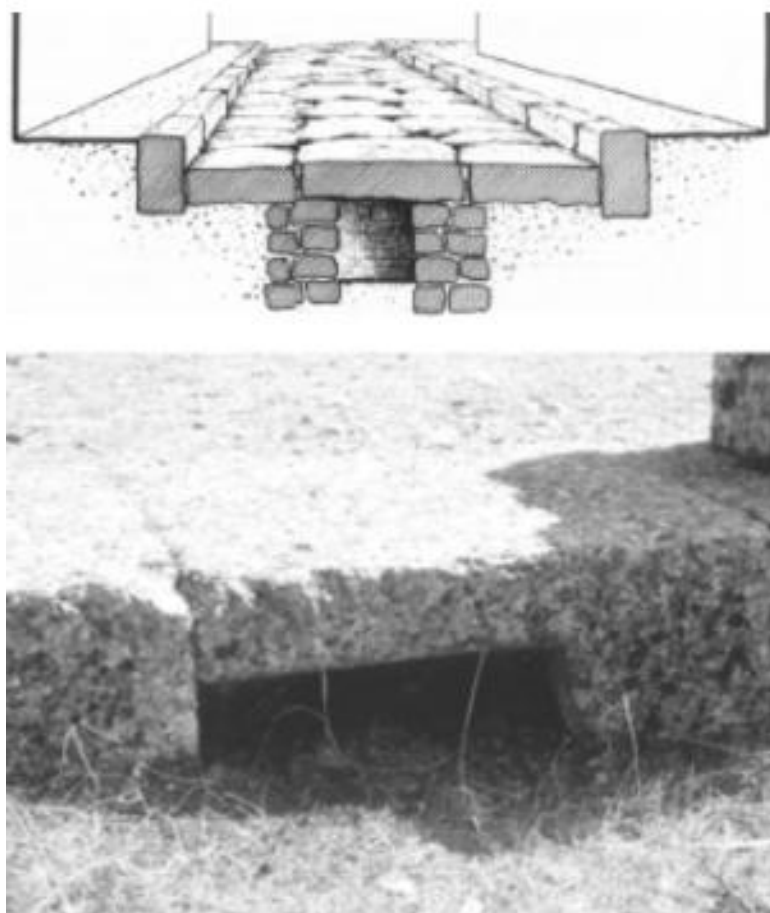


Figure 1 Sketch of an Ancient Greek stone masonry sewer (Segovia, 2021).

3 Wastewater Treatment Process Overview

Wastewater treatment is typically divided into several stages: preliminary, primary, secondary and tertiary. Each stage requires precise monitoring and control (Idrica, 2022).

3.1 Preliminary Treatment

Preliminary treatment involves the removal of large debris using screens and grit chambers to protect downstream equipment from being damaged (Oakley, 2019). Flow sensors are used to monitor the incoming wastewater rates (Sun et al, 2021), while level sensors are used to prevent overflow conditions (Reyes et al, 2026).

3.2 Primary Treatment

This stage of the process allows sewage to slowly pass through a basin where heavy solids settle at the bottom, while lighter solids float to the surface and are removed (YASA ET, 2025). Sedimentation tanks remove suspended solids through gravitational settling while automation ensures sludge removal and flow rates are optimised to maximise efficiency (Britannica, 2019). Primary treatment removes about 60-70% of suspended solids from wastewater systems (Smith, 2025).

3.3 Secondary Treatment

Secondary treatment is a vital part of the process, removing organic substances, nutrients and harmful bacteria from wastewater before it is released or reused (El Baradei, Basiouny and Hazem, 2025). It is a biological process involving the oxidation of dissolved organic material by micro-organisms. These micro-organisms break down the matter in aeration tanks, requiring precise control of dissolved oxygen (DO) levels. DO sensors and aeration control systems are critical in maintaining optimal microbial activity (OpenLearn, n.d.).

3.4 Tertiary Treatment

Tertiary treatment is the final stage of wastewater treatment. It disinfects water to extreme standards. This is an essential stage to the process for producing water to specification and to treat wastewater for public water systems (Membracon, 2021). Advanced processes such as filtration, nutrient removal and disinfection using chlorine are included at this stage. Automated chemical dosing systems ensure the correct application of the disinfectants (Zagklis and Bamos, 2022).

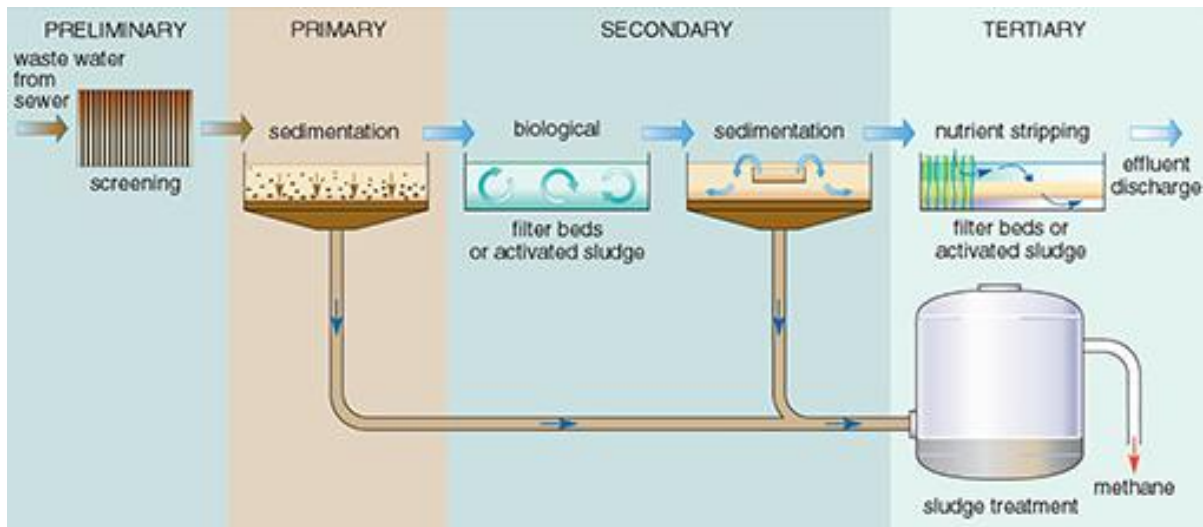


Figure 2 Flow diagram showing the different stages of treatment in a sewage treatment plant (OpenLearn, n.d.).

4 Sensors in Wastewater Treatment

Sensors form the foundation of ICA systems by providing real-time data for process monitoring and control. They have become essential instruments for identifying and measuring wastewater contaminants (Weerasinghe, Jayathilaka and Vithanage, 2025).

Common sensors include:

- Flow Sensors: Measure influent and effluent flow rates, ensuring a balanced operation.
- Level Sensors: Maintain appropriate liquid levels in tanks.
- pH Sensors: Monitor acidity and alkalinity for optimal chemical and biological treatment.
- Turbidity Sensors: Assess water clarity and treatment effectiveness.

(Wellaware, 2021).

(Icon Process Controls, 2023).

Other important sensors include suspended solids sensors, ammonia and nitrate analyser, temperature sensors, chemical oxygen demand sensors and chlorine residual sensors.

(Zeroinstrument, 2025).

Despite their importance, sensors are susceptible to fouling (expocontrols, 2025), calibration drift (Ahmad, 2024) and environmental damage. Therefore, it is crucial that sensors receive regular maintenance and calibration.



Figure 3 Turbidity sensor (rshydro, 2026).

5 Process Controllers

Once process data has been measured, it must be interpreted and acted upon. This is the role of the controller. In wastewater treatment, controllers range from simple local loop controller to complex plant-wide PLC and SCADA systems.

PID control remains on the most widely used techniques. Its popularity comes from its simplicity, proven performance and sustainability for continuous regulation (Du, Yan and Qiao, 2020). In wastewater treatment, PID loops are often used to regulate dissolved oxygen, tank level, chemical dosing rate and pressure (Sanchez, 2025). The proportional term responds to the current error, the integral term corrects the accumulated offset, and the derivative term anticipates future change (National Instruments, 2023). When tuned correctly, PID control provides stable and responsive operation.

PLCs have become the standard platform for sequencing and interlocking plant operations. A PLC can receive signals from many field devices, apply programmed logic and output commands to pumps, valves, motors and alarms (Ghifary, 2026). In a wastewater plant, PLCs may control pump duty and standby arrangements, screen cleaning sequences, sludge removal timing, chemical dosing systems and fault handling (PLC Programming Expert, 2025). Their ruggedness and flexibility make them well suited to harsh industrial environments (Rowse, 2023).

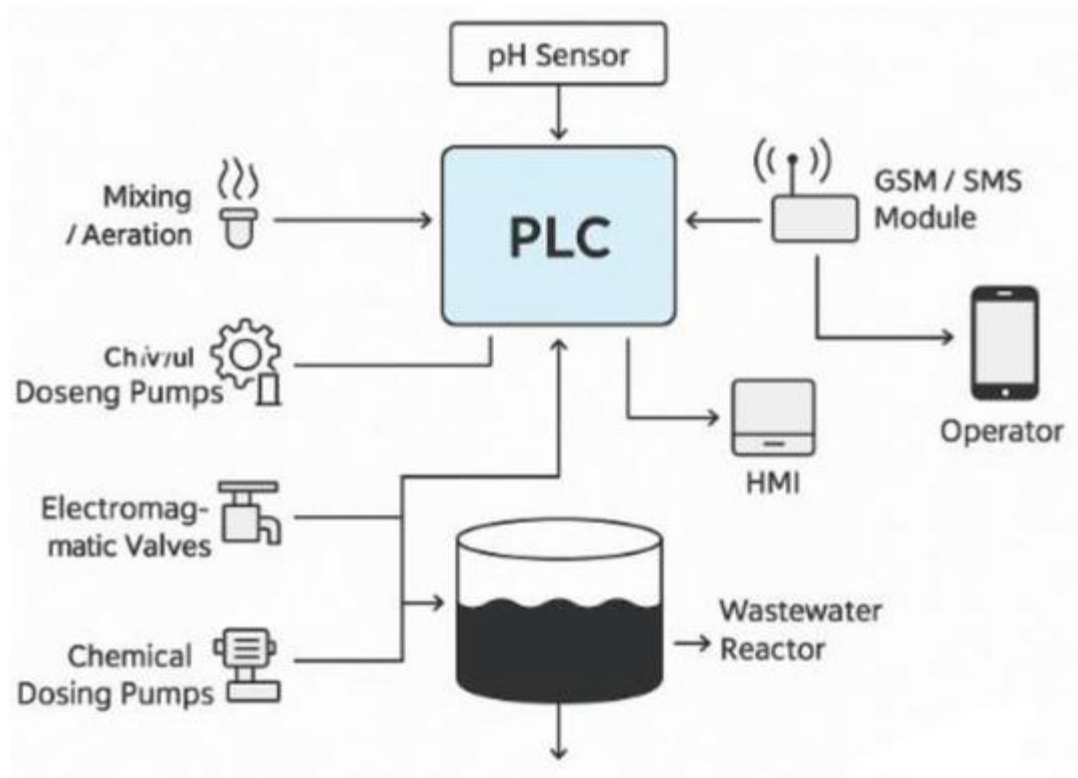


Figure 4 Example diagram of a PLC in a wastewater treatment system (Iljinas et al, 2025).

Larger treatment works may also use more advanced control architectures, including distributed control systems and advanced process control algorithms (Selişteanu et al, 2018). These allows multiple control loops to work together rather than independently. For example, aeration control can be linked to ammonia concentration, flow loading and energy tariffs so that the plant optimises both treatment quality and running cost (Medinilla et al, 2020).

A key point is that automation is not simply about replacing people, but rather that good control design supports operators by making routine decisions automatically while leaving humans responsible for supervision, maintenance and exceptional circumstances.

6 Actuators in Wastewater Treatment

Actuators are devices that convert control signals into physical action (Bong, 2026). If sensors provide the eyes of the system and controllers provide the brain, then the actuators provide the muscles. In wastewater treatment, common actuators include pumps, valves, blowers, mixers and mechanical drives (Tchobanoglous, Burton and Stensel, 2003).

Pumps are used throughout wastewater treatment plans to transport influent, sludge and chemical streams (An Pump, 2025). These systems are typically controlled using level-based setpoints, flow targets and automatic on/off scheduling. In many cases, variable speed drivers are implemented to allow pump output to match incoming flow conditions, improving efficiency and reducing energy consumption (Fecarotta, Martino and Morani, 2019).

Control valves regulate fluid and air flow (Luo et al, 2024). They may be electrically, pneumatically or hydraulically actuated, depending on the application. In chemical dosing systems, actuated valves help to maintain accurate reagent delivery (ipsflowsystems, 2026). In aeration systems, modulating valves distribute air to different treatment lanes (APG-Neuros, 2024).

Blowers are especially important in activated sludge systems as they supply the oxygen required by microorganisms for biological treatment. Aeration enables bacteria to break down organic pollutants, making it a critical process in wastewater treatment (Byrne, 2019). Furthermore, aeration systems are one of the largest energy consumers in treatment plans, often accounting for over half of the total energy usage (Muloiwa, Dinka and Nyende-Byakika, 2022).

Mixers, scrapers and conveyors are also frequently automated. These machines are essential for maintaining suspension, removing settled solids and transferring waste materials (Kato and Kansha, 2024).

Actuator reliability is vital because a well-designed control strategy can become useless if the final control element cannot respond correctly. For this reason, wastewater plants often include standby units, fault alarms, manual override facilities and preventative maintenance schedules (Strong, 2026).

7 Supervisory Control and SCADA Systems

At plant level, automation is coordinated by supervisory systems, most commonly SCADA. SCADA allows operators to see the entire treatment works through a central human-machine interface. Instead of walking from one unit process to another, operators can view measurements, trends, alarms and equipment status from a control room or even from remote locations (Upadhyay and Sampalli, 2020).

The main benefit of SCADA is visibility. Operators can see whether pumps are running, dissolved oxygen is failing, chemical storage is low or if discharge limit is at risk. This makes fault detection a lot quicker (Khan, Yeun and Byun, 2023).

SCADA supports alarm management, event logging and reporting (Inductive Automation, 2018). In a compliant wastewater plant, records are important because operators must demonstrate that the plant is being managed properly.

However, SCADA also creates dependencies. If communications fail or cyberattacks occur, then plant supervision may well be disrupted (Mingo and Burrell, 2023). For that reason, modern automation must include secure network design, user access control, backups and incident response planning. In other words, autonomy must be balanced with resilience (McDonnell, 2021).

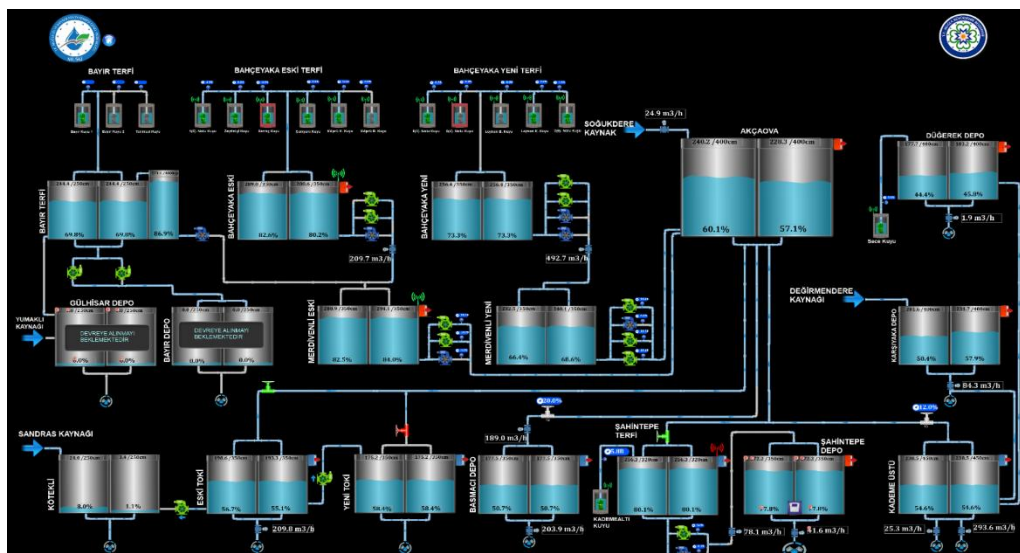


Figure 5 Example of a SCADA system in wastewater treatment (Mikrodev, 2026).

8 Regulations and Standards

Wastewater treatment must be heavily regulated as poor performance can have direct environmental and public health consequences. In the UK, wastewater treatment operators must comply with environmental permits that set discharge limits for key parameters such as biochemical oxygen demand (BOD), suspended solids, ammonia, nitrogen and phosphorus. These limits are regulated by the Environment Agency to ensure that treated effluent does not cause any environmental harm (Environment Agency, 2016; Environment Agency, 2018; UK Parliament, 1998; UK Parliament, 2025).

Automation helps plants meet these requirements by making compliance a continuous process, rather than an occasional manual check. For example, online sensors can detect if pH is drifting, if final turbidity is increasing or if aeration is insufficient. Controllers can then respond immediately, before permit limits are breached (Dharmarathne, 2025).

Regulation also affects safety and system design. Wastewater sites may contain hazardous chemicals, confined spaces, explosive atmospheres and biological hazards (Atlantic Pumps, 2025). Automated shutdowns, interlocks, gas detection and alarm systems therefore contribute not only to process performance but also employee safety.

Additionally, standards relating to electrical equipment, control panels, instrumentation accuracy and cyber resilience are increasingly relevant. This means that the wastewater engineer must understand both process engineering and wider regulatory context in which autonomy is applied.

9 Advanced Technologies in Wastewater Automation

Modern wastewater automation is increasingly moving beyond conventional control, towards data-driven intelligence. One major development is in the use of the Internet of Things (IoT), where connected devices transmit data across networks (Karim, Rodgers and Hossain, 2024). This allows utilities to monitor remote sites more effectively and compare performance across multiple assets.

Artificial Intelligence (AI) and Machine Learning (ML) are also becoming more important. These tools can analyse large amounts of operational data, identify hidden patterns and make predictions that human operators struggle to detect manually (Surur et al, 2025). For example, AI may predict blower maintenance needs, detect abnormal influent conditions or optimise dosing rates based on changing load patterns.

Another major development in advanced technologies is digital twins. A digital twin is a virtual model of a physical process that updates using real plant data. In wastewater treatment, this can be used to test control changes, predict performance under storm conditions or analyse energy-saving opportunities without disrupting real operation (Wang et al, 2024). Figure 6 shows a diagram of a digital twin concept to a water reclamation process.

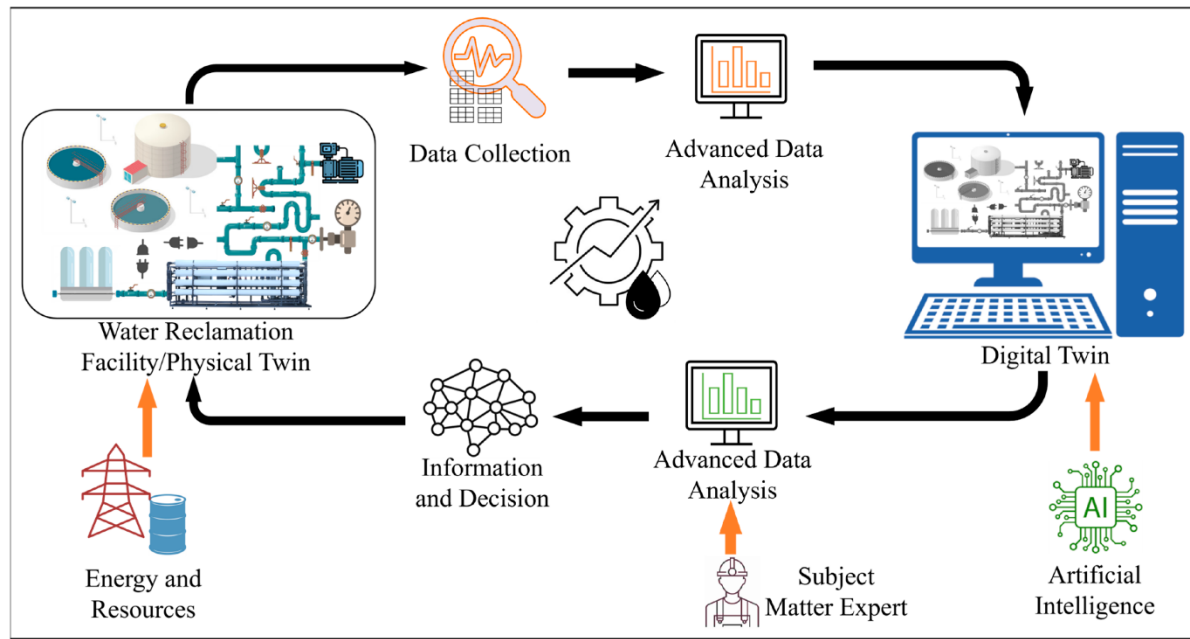


Figure 6 An illustration of a digital twin concept applied to a water treatment plant (Bam et al, 2025).

Smart sensors with self-diagnostics are also improving reliability by warning operators when calibration is drifting or when fouling is affecting measurements (Majumdar et al, 2025).

Although these advanced technologies offer strong potential, it is critical that they are adopted carefully. Wastewater plants need robust and understandable systems, not just advanced technological ones. These technologies have the potential to create complexity without adding real operational value.

10 Case Study: Dŵr Cymru Welsh Water

A useful example in Wales is Dŵr Cymru Welsh Water (Dŵr Cymru Welsh Water, n.d.), which operates many wastewater treatment assets across Wales. This creates a strong need for reliable remote monitoring and standardised control systems, because sites vary from large urban works to smaller rural facilities.

Automation within Welsh Water supports resilience during difficult operating conditions, including storm events that sharply increase influent flow and hydraulic loading Gill, Stable and Ghuman, 2023). Telemetry and SCADA systems allow operators to monitor multiple sites in real time, prioritise alarms and respond quickly when conditions deteriorate. This is especially import in Wales, where geography and weather can make site access challenging.

At larger sites, automation is used to control biological treatment, pumping systems, sludge handling and energy recovery. Variable speed drives, PLC logic and remote diagnostics help improve efficiency and reduce unnecessary energy consumption. Upgrades to older sites show how legacy infrastructure can still benefit from modern control integration without complete plant replacement (E Tech Group, 2025).

The Welsh Water example shows that automation is not only about efficiency in normal conditions, but also about resilience, environmental protection and maintain service continuity across a distributed network of assets.

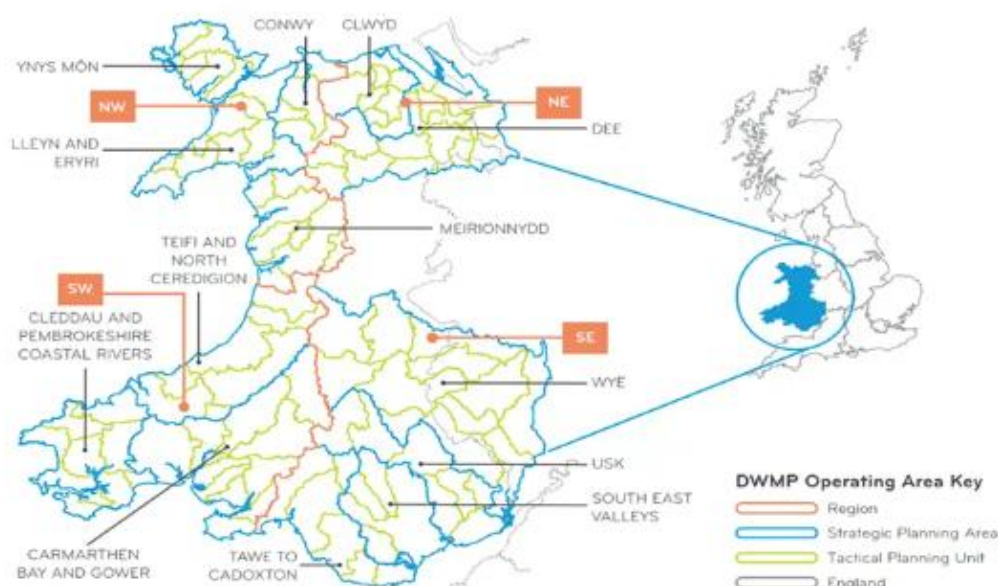


Figure 7 A mapped plan of where Welsh Water will be operating in Wales to improve drainage and wastewater management (Dŵr Cymru Welsh Water, n.d.).

11 Critical Analysis

Overall, the application of ICA in wastewater treatment provides major benefits to the process. It improves process stability, reduced operator workload, supports regulatory compliance, optimises energy use and enable rapid response to defects. It can also improve treatment quality beyond anything that manual control could achieve alone.

However, automation is not instantly successful just simply because the technology has been installed. Poorly maintained sensors, badly tuned control loops or over-complex systems can create new problems rather than fixing old ones. There is also a risk that operators become over-reliant on automated systems and lose understanding of the process. Another key issue with automation is cost. Advanced instrumentation, controller and communications infrastructure require significant investment which for smaller sites may make the business case for sophisticated automation, weaker. Therefore, the most effective approach is not for automation to take over but rather be applied appropriately. Systems should match plant size, process risk, operator skill and regulatory need.

12 Conclusion

To conclude, ICA has fundamentally improved wastewater treatment from a largely manual utility service, into a highly monitored and increasingly autonomous engineering operation. By combining technologies such as sensors, controllers, actuators and SCADA systems, treatment plants can respond continuously to changing flow, load and environmental conditions. This improves the efficiency of the process, reduces operational costs and helps utilities meet strict environmental standards.

The historical development of automation in wastewater treatment shows a clear movement from manual observation to real-time digital control. Modern-day plants now depend on ICA, not only for basic operation, but also for energy management, safety, compliance and resilience. The Welsh Water case study demonstrates how these systems are practiced within Wales, particularly across geographically dispersed plants and under tough weather conditions.

Future developments such as AI, IoT and digital twins are likely to expand the capability of wastewater automation to another level. Even so, successful implementation will depend on reliable instrumentation, good maintenance, appropriate design and skilled human oversight. ICA is therefore best understood not as a replacement, but a powerful tool to assist engineering judgement and allow wastewater treatment to be carried out more safely, efficiently and sustainably.

13 References