



APPLICATION OF AUTOMATION IN WASTEWATER TREATMENT

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Executive Summary

Over the past 40–50 years, UK wastewater treatment plants have evolved from manual operations to highly automated systems. Advanced technologies—including sensors, programmable logic controllers (PLCs), PID controllers, and SCADA systems—enable real-time monitoring, precise process control, and regulatory compliance. Emerging technologies such as AI, machine learning, and digital twins offer opportunities for predictive maintenance, improved energy efficiency, and overall operational optimisation. With careful integration, these innovations can create fully optimised, sustainable, and resilient wastewater treatment facilities.

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Table of Contents

Executive Summary.....	1
List of Figures.....	2
Introduction.....	3
History of ICA and Implementation into Wastewater Treatment	3
Components of ICA in Wastewater Treatment	5
Sensors.....	5
Actuators	7
Process Controllers	8
Supervisory Control	10
Regulations and Standards	11
Emerging Technologies.....	12
Conclusion	13
Bibliography.....	14

List of Figures

Figure 1 - Population of Wales 1800 - 2000 (Office for National Statistics, 2003)	4
Figure 2 - History of UK population with projections (MigrationWatch UK, 2024)	4
Figure 3 - Types of electrode (HORIBA, n.d.).....	5
Figure 4 - Clarke Type DO sensor (Yartsev, 2023)	6
Figure 5 - Electric Solenoid Valve (Control and Instrumentation, 2022)	7
Figure 6 - Types of Positive Displacement Pumps (Michael Smith Engineers, n.d.)	7
Figure 7 - Centrifugal pump diagram (Michael Smith Engineers, n.d.).....	8
Figure 8 - Ladder Logic Example (Ladder Logic World, 2021).....	9
Figure 9 - SCADA interface of water treatment plant (Trihedral Engineering Limited, 2025)	10
Figure 10 - SCADA Interphase on specific areas of plant (Trihedral Engineering Limited, 2025)	11
Figure 11 - Czinger Brake Node (Ars Technica, 2023)	12

Introduction

Health and safety are fundamental to modern society, particularly as growing populations place increasing demands on infrastructure and resources. In the United Kingdom, high population density in urban areas intensifies the challenges of disease prevention, pollution control, and waste management (ONS, 2023). For example, despite significant improvements in water quality since the 1960s, the River Thames continues to face pressures from sewage discharges and urban runoff (Environment Agency, 2021). Similarly, coastal areas such as Ogmore-by-Sea in South Wales have experienced beach closures following untreated sewage releases, highlighting that such issues are not confined to densely populated cities (BBC News, 2022).

Access to clean water is central to public health, making wastewater treatment a key area of environmental regulation. In the UK, frameworks such as the Water Industry Act 1991 and the Environmental Protection Act 1990 establish strict requirements for wastewater management, overseen by bodies including the Environment Agency and Ofwat (UK Government, 1991; UK Government, 1990). Increasingly, these obligations are supported by Instrumentation, Control and Automation (ICA), which enables real-time monitoring and automated adjustment of treatment processes. ICA systems incorporate technologies such as sensors, programmable logic controllers (PLCs), and supervisory control and data acquisition (SCADA) systems, allowing treatment plants to maintain compliance while reducing reliance on manual intervention (Galloway et al., 2017). These innovations are essential in managing the unprecedented scale of waste generated by today's population, ensuring efficiency, consistency, and safety that would be unmanageable through manual processes alone (Environment Agency, 2021).

The aim of this report is to investigate the application of Instrumentation, Control and Automation (ICA) in wastewater treatment facilities, examining its historical development, key components—including sensors, controllers, actuators, and supervisory systems—and its role in enabling safe, efficient, and largely autonomous plant operation. The report will also evaluate the regulations that govern wastewater treatment in the UK and consider recent technological advancements that are shaping the future of automation in this sector.

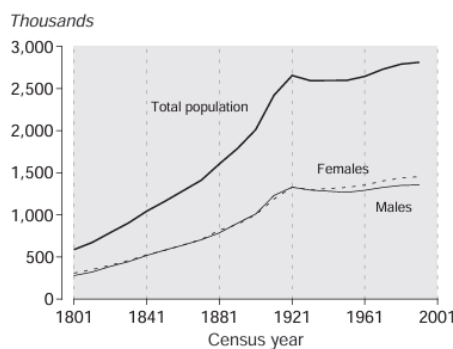
History of ICA and Implementation into Wastewater Treatment

The origins of Industrial Control Automation (ICA) can be traced to the Industrial Revolution, when advances in manufacturing, energy production, and chemical processing created a need for greater precision and consistency. Early process industries, such as chemical manufacturing and power generation, relied on mechanical systems like spring-and-weight mechanisms and pneumatic controllers to regulate pressure, flow, and temperature, enabling safer and more efficient production (Bennett, 1993). By the mid-20th century, developments in electrical instrumentation introduced analogue sensors and control panels, shifting industry away from purely mechanical systems. A major turning point came in the late 1960s with the first Programmable Logic Controller (PLC), the Modicon 084, designed for General Motors to replace hardwired relay logic in automotive assembly lines (Bolton, 2015). PLCs offered flexible, programmable digital control and soon became central to industrial automation. At the same time, Supervisory Control and Data Acquisition (SCADA) systems enabled centralised monitoring of large-scale processes, particularly in oil, gas, and power sectors (Hughes, 2018). These technologies laid the foundation for application in environmental sectors.

In the early 1800s, organised waste management in the UK was largely absent, with urban areas relying on cesspits and drains discharging untreated waste into rivers. This inadequate infrastructure fuelled repeated cholera outbreaks in the 1830s–1850s, prompting urgent public health reforms (Hamlin, 2009). The construction of large-scale sewer systems, most notably Joseph Bazalgette’s London network (1859–1865), marked a turning point in sanitation, later replicated nationwide (Halliday, 2001). Decades later, ICA technologies enabled effective monitoring and control of environmental processes where variables could be measured and regulated. Wastewater treatment facilities proved particularly suited to these methods, allowing more efficient and reliable operation. The demand for automated control accelerated in the 20th century, driven by population growth (Figure 1 & 2) and tightening regulatory standards, which made manual management of large wastewater systems increasingly impractical. volumes increasingly impractical, which is why within a 10 to 20 years of ICAs being created they were implemented in water treatment facilities (Olsson et al., 2014).

THE POPULATION AND AREA SIZE OF WALES

This table and chart show the various increases and decreases in area size and population, and numbers of males and females. There have been many boundary changes within Wales over the 200 years, which made it impractical to carry out this analysis at a lower geographical area. There have been a number of minor boundary changes between Wales and bordering counties in England, but these should not be significant in terms of analysing the growth in population over the 200 years.



Year	Area Size (Acres)	Total Population	Males	Females
1801	na	587,128	279,351	307,777
1811	na	673,337	322,335	351,002
1821	na	789,271	387,765	401,506
1831	na	904,312	445,658	458,654
1841	5,076,310	1,045,958	518,313	527,645
1851	5,092,885	1,163,139	581,840	581,299
1861	5,102,885	1,286,413	641,652	644,761
1871	5,090,222	1,412,583	706,048	706,535
1881	5,082,631	1,604,821	786,322	818,499
1891	5,121,013	1,788,639	900,955	887,684
1901	5,126,491	2,012,876	1,011,458	1,001,418
1911	5,127,734	2,420,921	1,231,739	1,189,182
1921	5,130,022	2,656,474	1,329,994	1,326,480
1931	5,130,086	2,593,332	1,293,805	1,299,527
1951	5,130,107	2,596,850	1,269,278	1,327,572
1961	5,130,107	2,644,023	1,291,764	1,352,259
1971	5,139,922	2,731,204	1,327,507	1,403,697
1981	5,131,854	2,790,500	1,352,000	1,438,500
1991	5,131,328	2,811,865	1,356,886	1,454,979

na = not available

Figure 1 - Population of Wales 1800 - 2000 (Office for National Statistics, 2003)

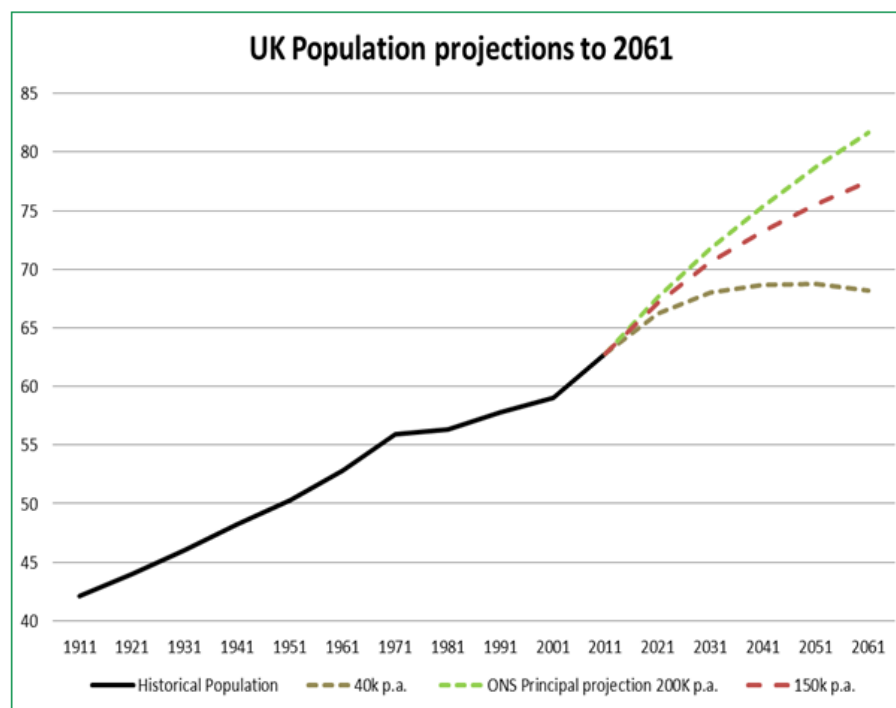


Figure 2 - History of UK population with projections (MigrationWatch UK, 2024)

Components of ICA in Wastewater Treatment

ICA systems in wastewater treatment plants rely on four core elements: sensors, actuators, process controllers, and supervisory control. Each plays a vital role in enabling real-time monitoring, decision-making, and process adjustment, thereby ensuring that facilities can operate efficiently, safely, and in compliance with environmental regulations.

Sensors

Sensors form the foundation of ICA by converting physical, chemical, or biological process conditions into measurable signals. In wastewater treatment, they provide real-time monitoring of variables that determine treatment performance, examples of these sensors are:

pH probes

Monitoring pH levels of wastewater is an effective way to assess the water and subsequently treat it with optimal chemicals to optimise conditions for microorganisms and ensure efficient biological and chemical treatment processes. This is normally achieved using combination electrodes, which is essentially glass electrode and reference electrode built into one electrode as shown in figure 3.

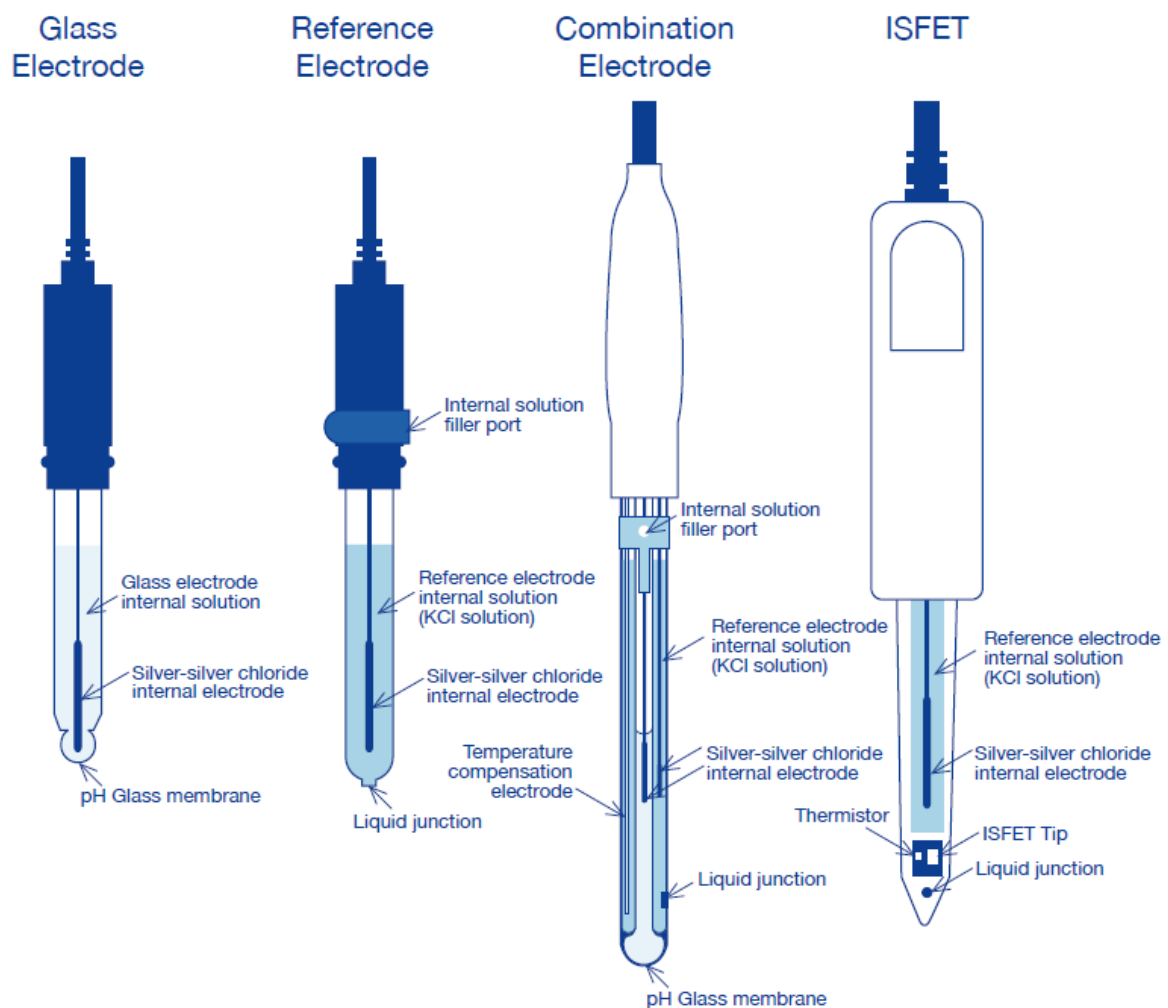


Figure 3 - Types of electrode (HORIBA, n.d.)

These electrodes determine variations in pH by measuring the voltage difference between the glass electrode and the reference electrode within the combination electrode. This difference in voltage is

then interpreted by a pH meter, which converts it into a pH value, reflecting the acidity or alkalinity of the solution (Atlas Scientific, n.d.).

Flow Meters

Flow meters provide real-time measurements of volumetric flow, enabling wastewater treatment plants to operate within their designed capacity. These measurements allow for precise control of chemical dosing to ensure that treatment processes achieve the required water quality standards. Additionally, flow meters monitor the effluent discharge, supporting compliance with regulatory limits (Quantum Controls, n.d.).

Dissolved Oxygen Sensors

Dissolved oxygen (DO) sensors measure the saturation of oxygen in wastewater, enabling treatment facilities to ensure that oxygen levels are sufficient to support aquatic life following discharge. These sensors also help sustain the microorganisms responsible for breaking down organic matter during wastewater treatment. Clark-type electrodes are commonly employed in DO sensors, functioning as amperometric biosensors in which the current generated at an electrode is directly proportional to the concentration of the analyte. As oxygen diffuses to the platinum cathode, the electrode facilitates the measurement of dissolved oxygen in wastewater. A typical configuration of a DO sensor is illustrated in Figure 4.

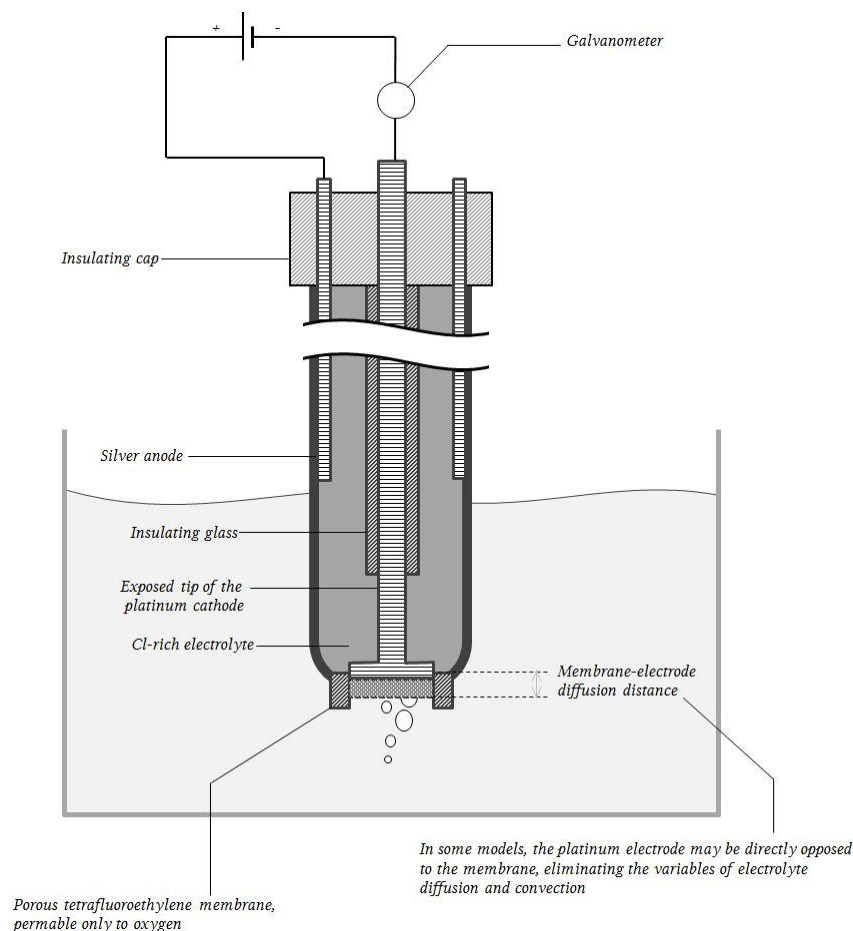


Figure 4 - Clarke Type DO sensor (Yartsev, 2023)

Actuators

Actuators enable the precise control of the movement of liquids and gases within a system. For example, pumps are used to transport fluids, while valves regulate flow, allowing the system to deliver accurate volumes when required and to stop fluid movement as necessary. Alongside sensors and programmable logic controllers (PLCs), actuators enable precise control over wastewater treatment processes.

Valves

Valves regulate fluid flow and can be electronically controlled. In a solenoid valve (Fig. 5), an electrical signal retracts the plunger to open flow, which closes again once the signal stops.

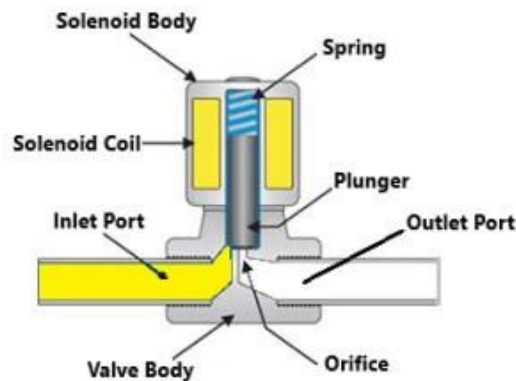


Figure 5 - Electric Solenoid Valve (Control and Instrumentation, 2022)

Pumps

Pumps, powered by motors, move fluids using mechanisms such as impellers, gears, pistons, or diaphragms. Centrifugal pumps (Fig. 7) handle large water volumes, while positive displacement pumps (Fig. 6) deliver precise doses, ideal for chemical dosing applications (DAE Pumps, 2024).

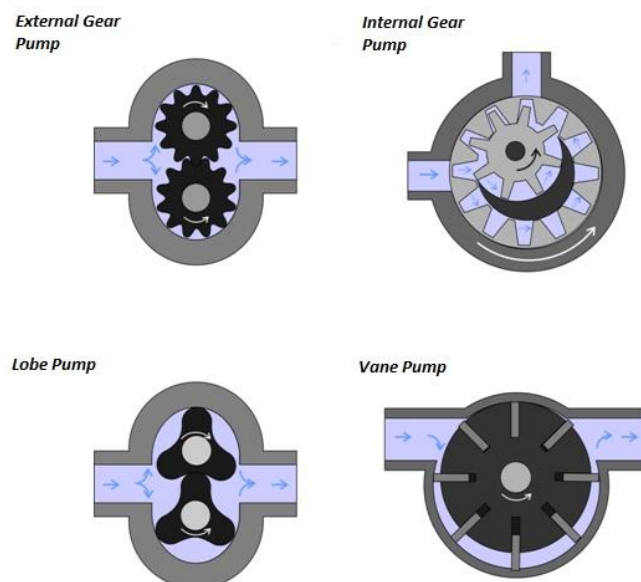


Figure 2. Rotary positive displacement pump designs

Figure 6 - Types of Positive Displacement Pumps (Michael Smith Engineers, n.d.)

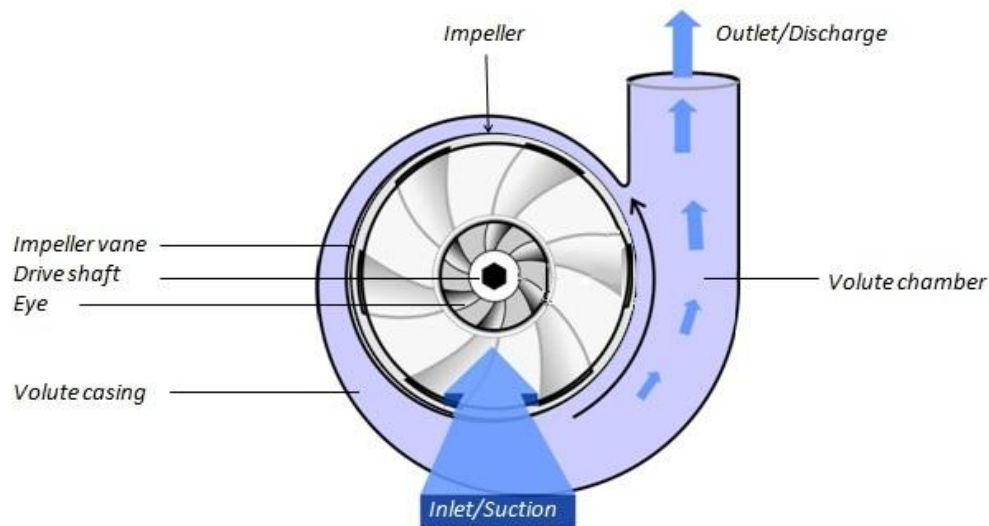


Figure 2. Volute case design

Figure 7 - Centrifugal pump diagram (Michael Smith Engineers, n.d.)

Process Controllers

Programmable Logic Controllers

Process controllers, such as programmable logic controllers (PLCs), have enabled automation across many industries, including water treatment (Automation Community, 2023). In simple terms, a PLC is pre-programmed to read data from sensors — such as dissolved oxygen (DO), flow, or pH sensors — and process this information according to predefined instructions that will action actuators (PLC Technician, 2023). For example, if a pH sensor reports a reading of 8.5 (alkaline), the PLC can trigger a dosing pump connected to a chemical storage tank to release a calculated amount of neutralizing chemical. Using input from a flow meter, the PLC determines the correct volume of chemical to achieve the target pH, typically around 7 (Control Engineering, 2011). This capability allows for streamlined and accurate treatment within water treatment facilities. Prior to PLCs, manual adjustments to water treatment processes had to be made by staff after receiving measurements manually or visually through a pH reader (PLC Department, 2023).

PLCs are commonly programmed using ladder logic, a graphical programming language that represents control processes in the form of “rungs,” analogous to the steps of a ladder. Each rung evaluates specific input conditions and produces a corresponding output when the predetermined conditions are met (Ladder Logic World, 2021). Figure 8 illustrates a simple ladder logic diagram comprising two inputs and a single output, in which the output is activated only when both input conditions are satisfied. In the context of water treatment, parameters such as flow rate may serve as continuous variables used for external calculations rather than as direct true/false inputs within the ladder. Conversely, a pH sensor can be integrated as a discrete input: when the pH deviates from the target value of 7, the PLC energizes a dosing pump to correct the level, and once the desired pH is reached, the input condition becomes false, resulting in the de-energization of the pump. This structured logic enables precise and automated control over process variables, reducing the reliance on manual intervention.

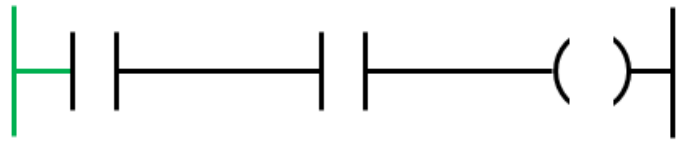
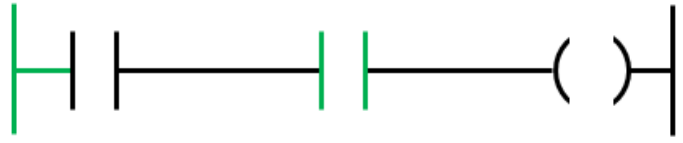
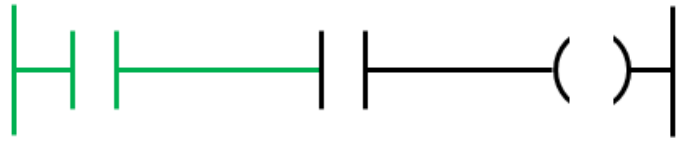
	INPUTS		OUTPUT
	A	B	Y
A= FALSE B= FALSE Y= FALSE			
A= FALSE B= TRUE Y= FALSE			
A= TRUE B= FALSE Y= FALSE			
A= TRUE B= TRUE Y= TRUE			

Figure 8 - Ladder Logic Example (Ladder Logic World, 2021)

In practice, ladder logic within industrial facilities is considerably more complex, enabling real-time visualisation of operational processes as the system autonomously responds to input data from the water treatment process.

Proportional-Integral-Derivative (PID) Control

A Proportional-Integral-Derivative (PID) controller functions as a self-correcting system, continuously monitoring process variables and comparing sensor readings to predefined target values. This continuous assessment allows the system to adjust process inputs in real time to maintain the variable near its nominal value. For instance, in the previous PLC example, the pH level rises to 8.5, a PID controller does not simply operate an on/off dosing pump; rather, it modulates the chemical dosage dynamically to maintain the pH near the target value of 7, so it may activate the dosing system at pH 7.1 depending on its set parameters. The PID controller achieves this through three distinct components:

1. Proportional (P): Determines the response magnitude based on the current deviation from the setpoint; larger deviations trigger stronger corrective actions.
2. Integral (I): Accounts for cumulative error over time, adjusting the control output to eliminate any persistent offset from the target value.
3. Derivative (D): Reacts to the rate of change of the process variable, mitigating rapid fluctuations and preventing overshoot by anticipating future deviations (National Instruments, 2025).

By integrating these three control actions, PID controllers enable precise, continuous regulation of process variables, providing smoother and more accurate control than simple binary (on/off) systems.

Supervisory Control

Supervisory Control and Data Acquisition (SCADA) Systems

SCADA (Supervisory Control and Data Acquisition) systems function as the central control and monitoring platforms for industrial facilities, including water treatment plants (Inductive Automation, 2025). These systems interface with PLCs and PID controllers to collect process data and present it via a graphical user interface, as illustrated in Figure 9. This real-time visualization enables operators to monitor equipment and sensor outputs continuously and to adjust operational parameters as required. In addition to process oversight, SCADA systems serve a critical safety function by detecting abnormal conditions or system malfunctions and generating alarms—both visual and auditory—to alert personnel, thereby facilitating rapid intervention. The data acquisition capabilities of SCADA further allow process data to be recorded and stored over time, supporting performance analysis and optimization. In the context of water treatment, such historical data can inform predictive insights, such as anticipated flow rate changes following heavy rainfall, or help identify periods of lower demand when maintenance activities can be scheduled more efficiently (Prometheus Group, 2024; OnLogic, 2024).

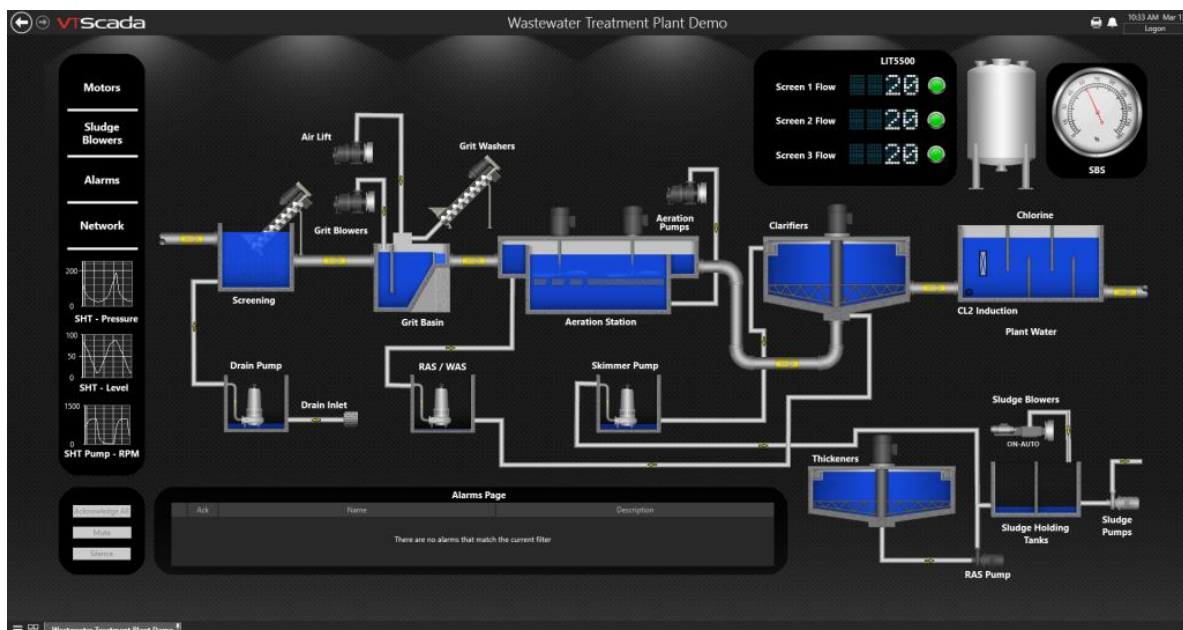


Figure 9 - SCADA interface of water treatment plant (Trihedral Engineering Limited, 2025)

Figure 9 illustrates the comprehensive overview of a water treatment plant. However, with advancements in technology and enhanced user interfaces, SCADA systems are no longer confined to a single fixed display. As demonstrated in Figure 10, the same SCADA software allows operators to navigate into specific pumps and individual treatment stages within the facility, allowing for general oversight and area specific analysis/control.

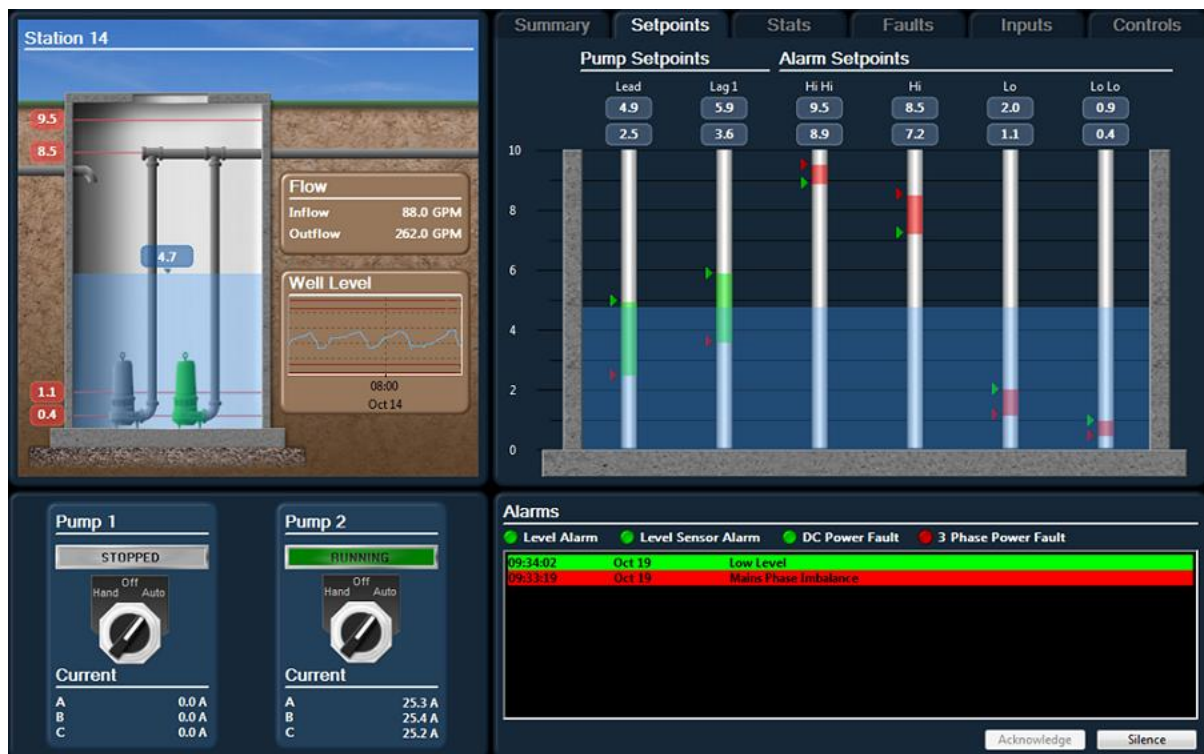


Figure 10 - SCADA Interphase on specific areas of plant (Trihedral Engineering Limited, 2025)

Regulations and Standards

Wastewater treatment in the UK is governed by a system of legislation, regulatory bodies, and standards that ensure plants protect public health and the environment. Maintaining compliance is critical to prevent spread of diseases, safeguard ecosystems, and ensure operational efficiency. ICA systems play a critical role by enabling continuous monitoring, automated control, and reliable documentation to demonstrate compliance. Failure to adhere to system can result in environmental harm, financial penalties, and reputational damage for water companies.

The Water Industry Act 1991 defines the responsibilities of water companies, while the Environmental Protection Act 1990 established controls on pollution and discharges (UK Government, 1990; UK Government, 1991). In practice, the Environment Agency (EA) monitors wastewater treatment plants and enforces compliance with these legislative requirements to ensure that facilities operate to high environmental and public health standards (Environment Agency, 2021). Alongside statutory regulation, ICA systems employed in wastewater treatment plants are also governed by international engineering and environmental standards. The IEC 61131 standard establishes programming languages for Programmable Logic Controllers (PLCs), providing consistency and reliability in automation across facilities (International Electrotechnical Commission, 2013).

Emerging Technologies

While wastewater treatment plants have become substantially more autonomous over the past 40–50 years, there remains considerable potential for further automation through emerging technologies such as Artificial Intelligence (AI), machine learning (ML), and digital twins

AI and Machine Learning

Artificial Intelligence (AI) is among the most widely recognised emerging technologies, demonstrating the ability to undertake highly specialised tasks that traditionally require extensive human expertise, such as computer programming. AI has shown potential to surpass human capabilities in complex domains, including design. A notable example is the Czinger brake node, developed through the integration of AI and 3D printing, which resulted in a high-performance component that is 40% lighter than a conventional braking assembly, while maintaining functionality and significantly reducing material waste (Ars Technica, 2023)



Figure 11 - Czinger Brake Node (Ars Technica, 2023)

These developments highlight AI's potential to transform and optimise manufacturing processes. When integrated into wastewater treatment facilities, AI can improve operational efficiency by extending plant lifespans, reducing carbon emissions, increasing treatment capacity, and supporting sustainability initiatives. Additionally, AI facilitates predictive maintenance through machine learning – collecting data and scanning for patterns in performance, allowing predictions on how to keep performance optimal.

Digital Twins

Digital twins are digital replicas of physical systems, they can be used for predictive maintenance, enabling the simulation of real-world conditions to forecast component failures or schedule routine servicing, thereby maintaining optimal performance (McKinsey, 2024).

Conclusion

Over the past 40–50 years, wastewater treatment plants have evolved significantly, transitioning from manual operations to highly automated systems through Instrumentation, Control, and Automation (ICA). Advances in sensors, programmable logic controllers (PLCs), PID controllers, and SCADA systems have enabled real-time monitoring, precise control of process variables, and compliance with regulatory standards. These innovations have allowed facilities to operate more efficiently, safely, and consistently, addressing the challenges posed by growing urban populations and increasingly stringent environmental regulations. Nevertheless, further improvements are still required to prevent incidents such as the release of untreated sewage into the Ogmore by the sea in 2022 (BBC News, 2022).

Emerging technologies, including Artificial Intelligence (AI), machine learning (ML), and digital twins, present opportunities to further optimise wastewater treatment processes. AI and ML can analyse complex datasets to enhance operational efficiency, extend plant lifespans, reduce carbon emissions, and support predictive maintenance, thereby reducing the need to expand facility capacity by increasing treatment turnover times. Digital twins offer virtual replicas of treatment systems, allowing operators to simulate real-world conditions, predict component failures, schedule maintenance, and evaluate plant performance prior to physical construction.

Challenges to implementing these technologies may include incompatibility with older machinery, which may require substantial overhauls, and increased cybersecurity risks as plants become more connected online. Despite these hurdles, adopting these innovations is expected to improve plant performance and support global efforts toward sustainability.

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