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Application of automation in wastewater treatment

Control & Automation (ACMA5001)

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1 Introduction

1.1 Background to Wastewater Treatment and ICA

Wastewater treatment is an essential public health and environmental service. Municipal wastewater treatment works (WWTWs) must run continuously and deal with large changes in flow and pollution load, while still meeting strict discharge limits. Trying to manage this entirely by hand would be slow, unreliable and difficult to sustain in practice. For that reason, instrumentation, control and automation (ICA) has become a key part of modern wastewater treatment. It brings together sensors to measure what is happening in the process, controllers to compare those measurements against target conditions, and actuators to make physical changes within the plant. This allows treatment systems to respond to changing conditions with much less direct operator intervention. Over time, ICA has moved from being a specialist addition to becoming a normal part of wastewater engineering, mainly because treatment standards have become tighter and plants are expected to run more efficiently and consistently (Olsson et al., 2014).

1.2 Objectives of the Report

This report examines how ICA is applied in municipal wastewater treatment and how its use has developed over time. It focuses on the main technical elements of an automated treatment works, namely sensors, controllers, actuators, and supervisory systems, and also considers the importance of regulations and recent developments in advanced automation. The discussion is limited to municipal sewage treatment works rather than drinking water systems or sewer network control.

2 Wastewater Treatment Processes and Key Variables

2.1 Overview of Typical Wastewater Treatment Stages

A municipal WWTW normally treats wastewater in a number of stages, with each stage designed to remove a different type of contaminant. In the preliminary stage, screens and grit removal units take out large solids and abrasive material so that downstream equipment is protected from blockage and wear. The wastewater then moves into primary treatment, where settlement tanks remove heavier suspended solids and floating grease. This reduces the loading on the later biological stages. The secondary stage is usually based on biological treatment, most often the activated sludge process, where microorganisms break down dissolved and fine organic matter. In many modern works, this stage also includes nitrification and denitrification so that nitrogen can be removed before discharge. Finally, tertiary treatment is used where a higher effluent standard is required, for example through filtration, phosphorus removal or disinfection (Metcalf and Eddy et al., 2014).

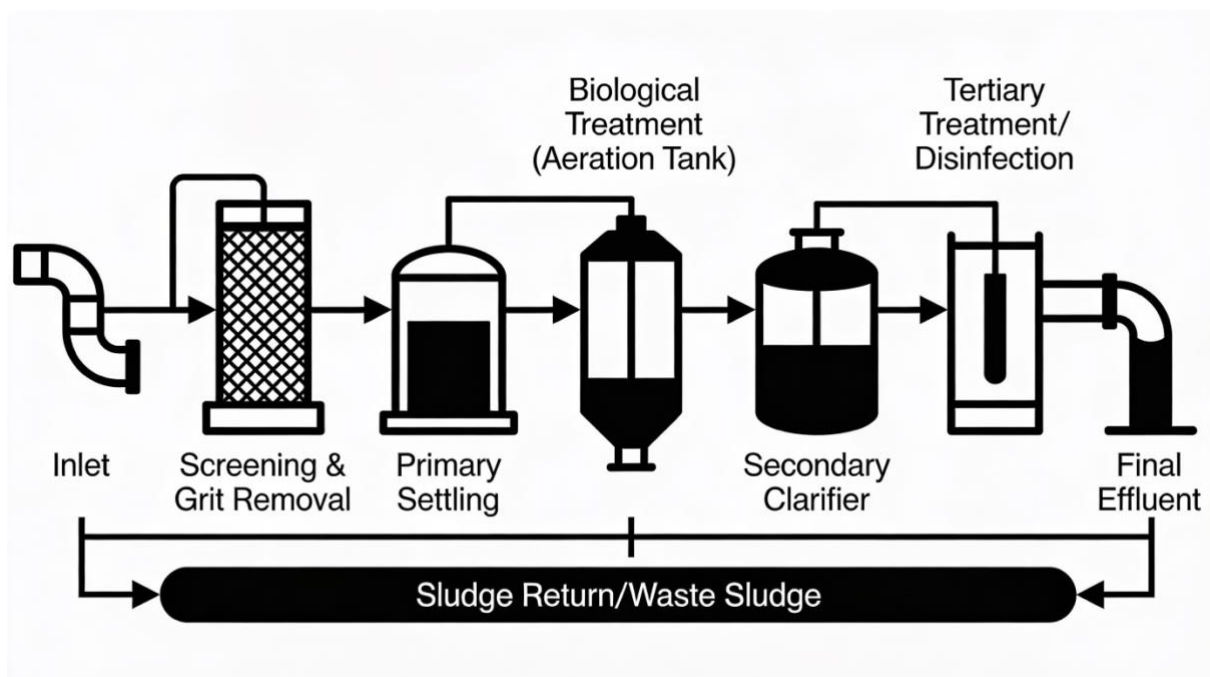


Figure 1: Figure 1. Wastewater treatment process diagram. Generated by Perplexity AI, 2026

ICA is important across the whole plant, but it is especially important in parts of the process where conditions can change quickly or where tight control directly affects final effluent quality. Typical examples include inlet pumping, aeration tanks, final clarifiers, chemical dosing systems and sludge handling processes (Olsson et al., 2005).

2.2 Key Process Variables and Why They Matter

The success of any automated treatment works depends on the quality of its measurements. Flow is one of the most important variables because it affects loading across the whole

plant, from inlet pumping to chemical dosing and final effluent reporting. Level is also critical in wet wells, tanks and channels, where poor control may cause flooding, overflow or pump damage. pH must be monitored because biological treatment and chemical dosing both depend on it remaining within an acceptable range. If pH moves too far from the target range, process performance can quickly fall away. Temperature affects the speed of biological reactions and can influence oxygen demand and treatment efficiency.

Among all measured variables, dissolved oxygen (DO) is one of the most important in activated sludge systems. If DO is too low, the biological process becomes unstable and treatment quality drops. If it is too high, the plant wastes energy through excessive aeration. Turbidity, suspended solids and sludge-related measurements help operators and control systems assess clarifier performance and biomass condition. Nutrient variables, especially ammonia, nitrate and phosphate, have become increasingly important as discharge standards have tightened. Online monitoring of these variables allows more direct control of nutrient removal rather than relying only on laboratory testing (Olsson et al., 2014). Taken together, these measurements allow the plant to run safely, efficiently and in line with consent conditions.

3 Historical Development of ICA in Wastewater Treatment

3.1 Early Manual Operation and Basic Instrumentation

Before automation became common, wastewater treatment depended heavily on manual operation. Plant staff relied on visual checks, local gauges, manual sampling and laboratory results to decide whether pumps, valves and weirs needed adjusting. This meant that most process changes were reactive rather than immediate. If a problem developed between samples, there was often a delay before it was noticed. Early instrumentation was limited and usually local, such as float switches for level detection or pressure gauges fixed to individual assets. There was little opportunity for remote monitoring and almost no way to coordinate the plant as one integrated system. This made operation labour-intensive and placed a great deal of responsibility on operator experience rather than on continuous process data (Olsson, 2012).

3.2 From Basic Feedback Control to Digital Systems

A major shift began when electronic instruments and analogue controllers started to be introduced during the 1960s and 1970s. Standardised signal transmission, especially 4–20 mA systems, made it possible to send measurements from field instruments to local controllers and use them in basic feedback loops. This supported applications such as level-based pump operation, flow-paced dosing and early dissolved oxygen control. The first specialist conference on ICA in wastewater treatment was held in London in 1973, which is often taken as a key point in the development of the field as a recognised engineering discipline (Olsson et al., 2014).

As technology improved, programmable logic controllers (PLCs) replaced many isolated analogue controllers and gave engineers greater flexibility in how control logic was set up. Later, SCADA systems and distributed control platforms allowed data from across the site to be brought together in one place. This improved alarm handling, plant visibility and historical data storage. By the early 2000s, better sensors, cheaper computing and improved communications made it possible to move from isolated automatic loops towards plant-wide automation. This has led to the modern WWTW, where many routine functions are handled automatically, while operators focus more on supervision, fault response and performance improvement (Olsson, 2012; Olsson et al., 2014).

4 Instrumentation: Sensors and Measurement Systems

4.1 Sensors and Instrumentation in WWTPs

Instrumentation is the starting point of every control strategy in wastewater treatment. If the plant does not measure the right things accurately, it cannot control them properly. Sensors therefore provide the real-time information needed for both automatic control and operator decision-making. In wastewater treatment this is not always easy, because sensors must work in difficult conditions that include fouling, corrosion, suspended solids and changing temperatures (Olsson et al., 2005).

Flow measurement is required at the inlet, between process stages and at the final effluent outfall. Open channels often use flumes or weirs with level-based measurement, while closed pipes commonly use electromagnetic flow meters. Level sensors are widely used in tanks, wells and channels to control pumping and to raise alarms when conditions become unsafe. Water quality sensors are equally important. pH and temperature probes are standard across most treatment works and are especially useful where biological or chemical treatment needs to be tightly controlled. Dissolved oxygen sensors are particularly important in aeration tanks because oxygen supply has a direct effect on treatment performance and power use. In many activated sludge works, DO control is one of the main ways energy use is managed (Henze et al., 2008).

Other instruments measure suspended solids, mixed liquor concentration and sludge blanket depth, helping staff and control systems judge the condition of the biological process and the performance of clarifiers. Nutrient analysers for ammonia, nitrate and phosphate are also becoming more common, especially where stricter nutrient consents apply. These instruments make it possible to adjust the process in near real time instead of waiting for lab results. Even so, practical issues remain. Sensors must be cleaned, calibrated and maintained regularly, and poor maintenance can lead to drift, false readings and poor control performance (Olsson, 2012).

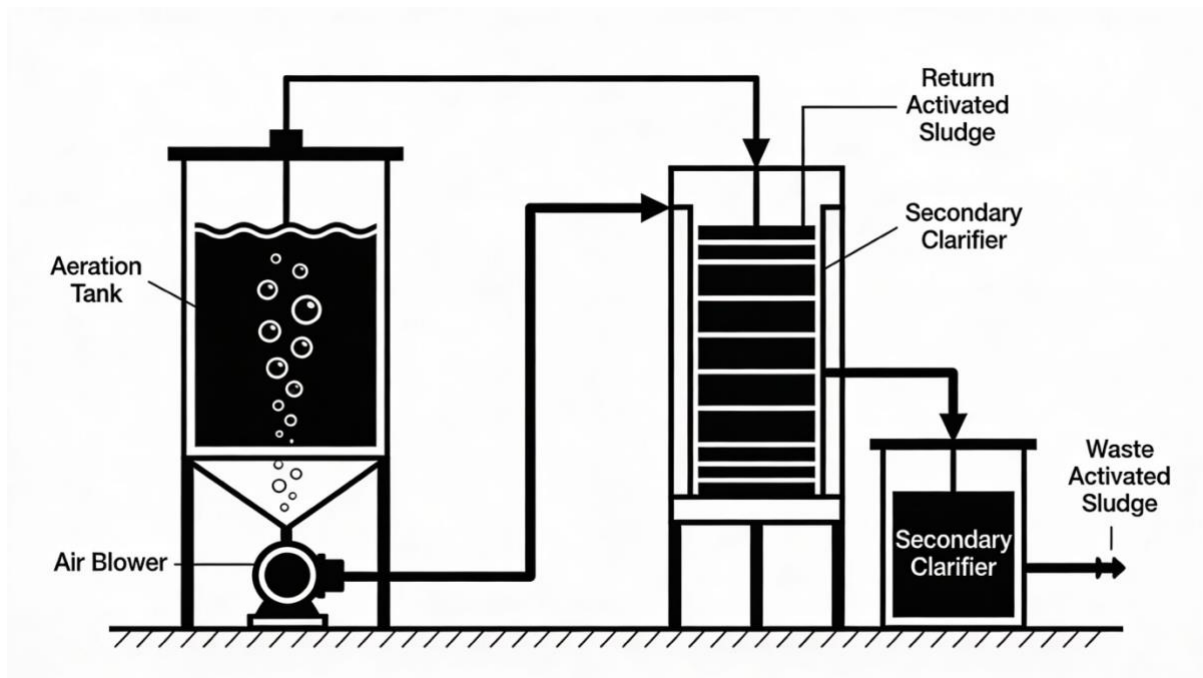


Figure 2: Figure 2. Activated sludge process diagram. Generated by Perplexity AI, 2026

4.2 Controllers and Local Control Strategies

Controllers use measurement data to decide whether the process needs correcting. In simple terms, they compare the measured value against a target and then adjust plant equipment to bring the process back towards the desired condition. In wastewater treatment, this is done to maintain stable operation, protect assets, reduce energy use and keep final effluent within consent limits (Olsson et al., 2005).

The simplest control method is on–off control. This is often used where only a basic response is needed, such as starting a pump when a sump reaches a high level and stopping it again when the level falls. This type of control is easy to implement, but it is not suitable where process conditions need fine adjustment. For that, the most common method is PID control. PID controllers are widely used for flow, level, pH and dissolved oxygen because they can respond continuously rather than simply switching equipment fully on or off. In a typical dissolved oxygen loop, the DO sensor measures oxygen concentration in the aeration tank, the controller compares it with the setpoint, and the output signal then adjusts blower speed or air valve position. This helps the plant maintain suitable oxygen levels without using more energy than necessary (Henze et al., 2008; Olsson et al., 2014).

The same principle is used in chemical dosing. pH correction, phosphorus removal and disinfection all rely on dosing systems that respond to measured conditions. Sludge process control also depends on this approach. Return activated sludge and waste sludge flows can

be adjusted to support a stable biomass concentration and sludge age, which are important for keeping the biological stage healthy and consistent (Metcalf and Eddy et al., 2014).

4.3 Actuators and Final Control Elements

Actuators are the part of the system that physically changes the process. They receive commands from controllers or PLCs and turn those commands into action. In a wastewater treatment works, the main actuators include pumps, blowers, mixers, valves, penstocks and scraping equipment (Olsson et al., 2005).

Pumps are used throughout the plant for influent lifting, sludge transfer, recirculation and chemical dosing. Many are now fitted with variable speed drives (VSDs) so that their output can be adjusted smoothly instead of switching between fully on and fully off. This can reduce wear, improve process stability and save energy. Blowers in aeration systems are another good example, as their speed can be linked directly to dissolved oxygen demand. Control valves and penstocks are also important because they regulate flows between process units and can be positioned accurately using electric or pneumatic actuators. These devices are not operated in isolation; they are built into wider control loops and linked back to PLC or SCADA systems through status signals, fault alarms and position feedback. They are also protected by interlocks such as overload trips, low-level protection and dry-run prevention, which help avoid damage and keep the process safe (Metcalf and Eddy et al., 2014).

5 Supervisory Control, Regulations and Advanced Technologies

5.1 Supervisory Control and Data Systems

Although local control loops manage individual pieces of equipment, a treatment works still needs a higher level of control to bring the whole process together. This is the role of supervisory systems. In most modern WWTWs, field instruments and actuators are connected to PLCs or RTUs, and these in turn are linked to a SCADA system. This allows plant data to be viewed from a central point and gives operators a much clearer understanding of what is happening across the works as a whole (Olsson et al., 2005).

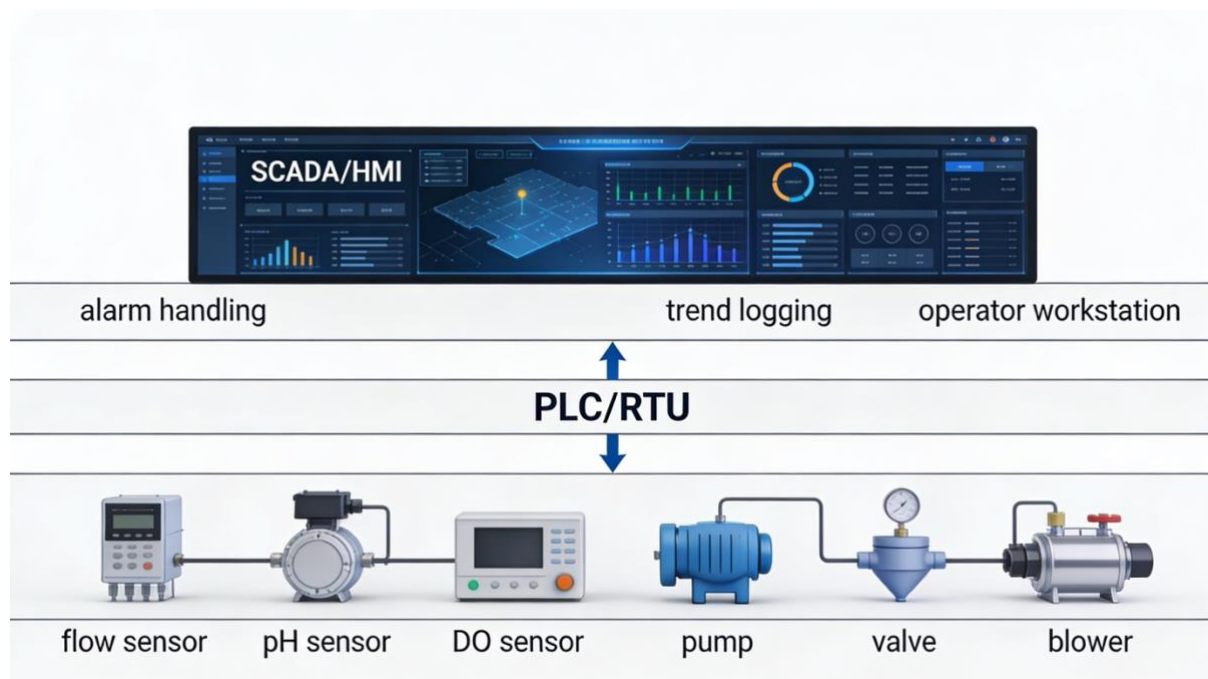


Figure 3: Figure 3. SCADA architecture diagram. Generated by Perplexity AI, 2026

SCADA screens usually show process diagrams, live instrument values, alarm lists, setpoints and equipment status. They also store historical data, which is valuable because many process issues only become obvious when looked at over time. Trends can reveal gradual sensor drift, recurring overloads, seasonal changes in loading or poor control tuning. This helps not only with fault-finding, but also with longer-term performance improvement. SCADA also makes remote supervision possible, which is especially useful for pumping stations and small unmanned sites. Even so, automation does not remove the need for human oversight. Operators still play an important part in checking whether sensor readings are believable, deciding how to respond to unusual conditions and judging when manual intervention is necessary (Olsson, 2012).

5.2 Regulations, Standards and the Role of ICA in Compliance

Wastewater treatment works are required to meet environmental discharge standards, often covering BOD, ammonia, suspended solids, phosphorus and other pollutants depending on the receiving water and permit conditions. In practice, ICA helps plants meet these obligations in two ways. First, it improves the control of the treatment process itself. Second, it provides the measurement records, alarms and operational history needed to demonstrate that the site is being managed correctly (Olsson et al., 2014).

Alongside environmental requirements, instrumentation and control equipment must also meet technical standards for safe operation, accurate measurement and dependable electrical performance. This matters because poor-quality instrumentation can lead to poor decisions, unreliable reporting and higher risk of non-compliance. As systems become more connected, cybersecurity and data integrity are becoming more important as well. Access to control systems must be managed properly, and operational records must be secure and traceable. In that sense, good ICA design is not only about control performance; it is also about making the plant easier to regulate, audit and defend when problems occur (Parsa, Dhib and Mehrvar, 2024).

5.3 Recent and Emerging Advanced ICA Technologies

Recent work in wastewater automation has moved beyond standard feedback control towards more predictive and data-driven methods. Advanced online sensors can now estimate nutrient levels and organic load much more quickly than traditional lab testing, which means the plant can react sooner to changing influent conditions. On top of this, model-based control and soft sensing are being used to improve the way aeration, nutrient removal and chemical dosing are managed (Parsa, Dhib and Mehrvar, 2024).

There is also growing interest in IoT-based monitoring, predictive maintenance and machine-learning tools. These can help identify hidden trends in plant behaviour, flag likely equipment failures and support better setpoint selection. The idea of a digital twin has also gained attention. In this approach, a virtual model of the plant is linked to real operational data and used to test scenarios or support decision-making. These tools are still developing, but they suggest that wastewater treatment is moving towards greater autonomy, provided the underlying instrumentation remains reliable and skilled engineering judgement is still applied (Olsson et al., 2014; Qadir et al., 2024).

6 Conclusions

6.1 Summary of Key Points

Instrumentation, control and automation has changed wastewater treatment from a mainly manual activity into a closely monitored and increasingly self-regulating process. Sensors provide the data, controllers decide how the system should respond, actuators carry out those actions, and supervisory systems bring everything together into a plant-wide operating framework. This has improved process stability, helped plants meet tighter discharge standards and supported better use of energy and chemicals (Olsson et al., 2014; Parsa, Dhib and Mehrvar, 2024).

6.2 Overall Significance and Future Outlook

As treatment requirements continue to tighten, ICA will remain central to wastewater engineering. The next stage is likely to involve better online sensing, wider use of predictive control and stronger digital integration, but these developments will still depend on careful engineering judgement, good maintenance and sound plant operation rather than automation alone (Olsson, 2012; Qadir et al., 2024).

7 References

Henze, M., van Loosdrecht, M.C.M., Ekama, G.A. and Brdjanovic, D. (eds.) (2008) Biological Wastewater Treatment: Principles, Modelling and Design. London: IWA Publishing. Available at: <https://iwaponline.com/ebooks/book/96/Biological-Wastewater-Treatment>

Metcalf and Eddy, Inc., Tchobanoglous, G., Stensel, H.D., Tsuchihashi, R. and Burton, F. (2014) Wastewater Engineering: Treatment and Resource Recovery. 5th edn. New York: McGraw-Hill.

Olsson, G. (2012) 'ICA and me – A subjective review', Water Research, 46(6), pp. 1585–1624. Available at: <https://doi.org/10.1016/j.watres.2011.12.054>

Olsson, G., Carlsson, B., Comas, J., Copp, J., Gernaey, K.V., Ingildsen, P., Jeppsson, U., Kim, C., Rieger, L., Rodríguez-Roda, I., Steyer, J.-P., Takács, I., Vanrolleghem, P.A., Vargas, A., Yuan, Z. and Åmand, L. (2014) 'Instrumentation, control and automation in wastewater – from London 1973 to Narbonne 2013', Water Science & Technology, 69(7), pp. 1373–1385. Available at: <https://doi.org/10.2166/wst.2014.057>

Olsson, G., Nielsen, M.K., Yuan, Z., Lynggaard-Jensen, A. and Steyer, J.-P. (2005) Instrumentation, Control and Automation in Wastewater Systems. London: IWA Publishing. Available at: <https://iwaponline.com/ebooks/book/28/Instrumentation-Control-and-Automation-in>

Parsa, Z., Dhib, R. and Mehrvar, M. (2024) 'Dynamic modelling, process control, and monitoring of selected biological and advanced oxidation processes for wastewater treatment: A review of recent developments', Bioengineering, 11(2), 189. Available at: <https://doi.org/10.3390/bioengineering11020189>

Qadir, M., Zarei, A., Heidrich, O., Mahjoub, O., Al-Bastaki, N. and Al-Ansari, T. (2024) 'Revolutionizing wastewater treatment toward circular economy and carbon neutrality goals: Pioneering sustainable and efficient solutions for automation and advanced process control

with smart and cutting-edge technologies', Journal of Water Process Engineering, 63, 105486. Available at: <https://doi.org/10.1016/j.jwpe.2024.105486>

OpenAI / Perplexity-generated figure. Wastewater treatment process diagram [generated image]. 2026.

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