WRF 4973 Fact Sheet: ID 1501

Strategy: Instrumentation and Controls

Overview of Instrumentation and Control Strategies

Wastewater treatment process automation has advanced in recent years because of increased sophistication in instrumentation to monitor nutrient concentrations and other constituents reliably on a continuous basis. Coupled with increased computing and process model understanding, instrumentation and controls (I&C) advancements have opened new opportunities to control biological and chemical processes to achieve optimal performance, reduce operating costs, and maximize treatment capacity.

Figure 1 and Table 1 include some application points and nutrient reduction opportunities relying on instrumentation for automated process control. Automated process control can improve process stability and reduce effluent nutrient levels as well as reduce energy use (e.g., blower control) or chemical dose.

This fact sheet has an overview of automation and I&C optimization opportunities. Process automation and control requires three essential parts (Figure 2):

- Reliable sensors to measure the components of interest (nutrients, dissolved oxygen [DO], flow, actuator performance, etc.) (see Fact Sheet 1560)
- Actuators and final control elements with sufficiently wide working ranges to counteract process disturbances (e.g., airflow valve and positioner, pump with variable-frequency drive [VFD], etc.)
- Controllers to adjust the manipulated variable (in the end the final control element) so that the variable of interest (controlled variable) is maintained around a set point (see Fact Sheet 1510)

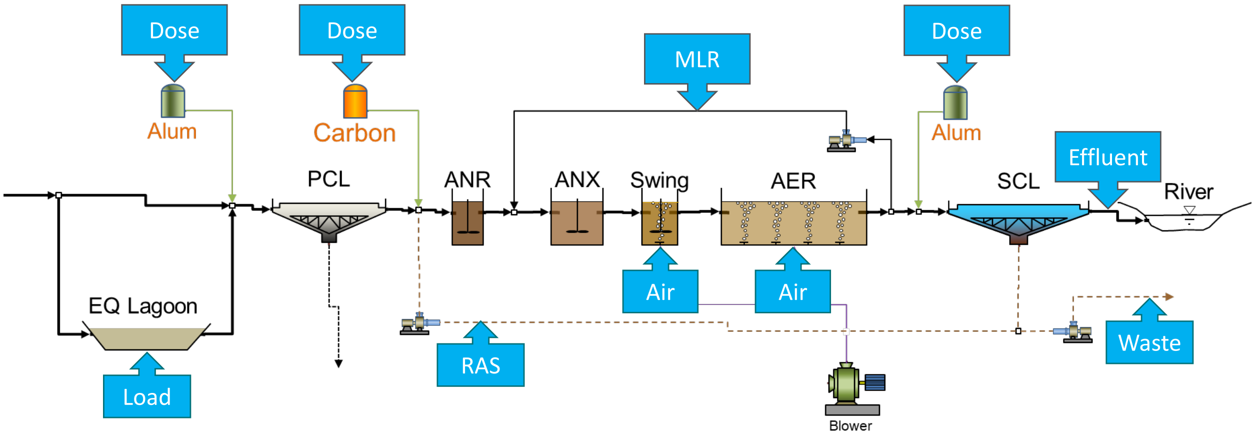

Figure 1. Typical Application Points for Process Automation and Control.
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Table 1. Examples of Process Nutrient and Process Control Opportunities.
Source: Rieger et al. 2014. Reprinted with permission from inCTRL, Inc.

		Ex-situ					In-situ					
	Objective	**Ammonia** Colorimetric, IC, GS Electrode	**Nitrate, nitrite** Colorimetric, IC, UV	**Ortho-Phosphate** Colorimetric, IC	**P-total** Thermal chemical oxidation + colorimetric	**TOC, DOC, COD, BOD**	**Dissolved oxygen**	**Turbidity, TSS, Sludge blanket level in sec. clarifier**	**pH, redox, conductivity**	**Ammonia** Ion sensitive electrode (ISE)	**Nitrate, nitrite** UV, Ion sensitive electrode (ISE)	**Organic compounds** UV/VIS
Influent	Load monitoring Equalization of load					X		X	X	X		X
Primary Effluent	Load monitoring Aeration control					X		X	X	X		X
Activated Sludge	Aeration control	X	X				X			X	X	
	RAS, internal recycle		X								X	
	WAS control/monitoring							X				
	P precipitation			X								
	Dosage of carbon source		X								X	X
Effluent	Monitoring	X	X	X	X	X	X	X	X	X	X	X
	Control of P precipitation			X	X							

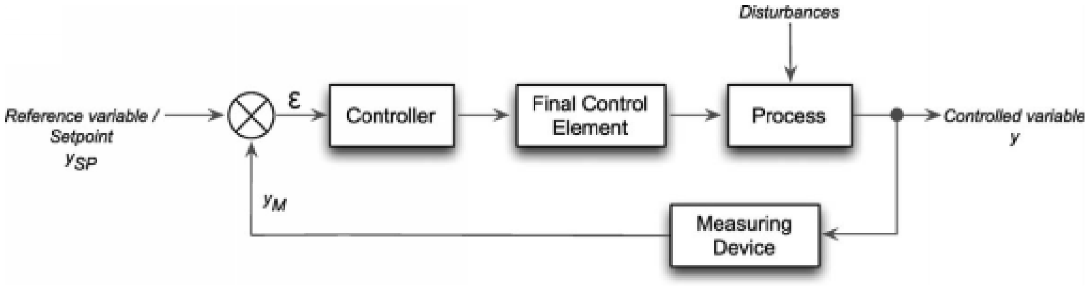

Figure 2. Feedback Control.
Source: Rieger et al. 2014. Reprinted with permission from inCTRL, Inc.

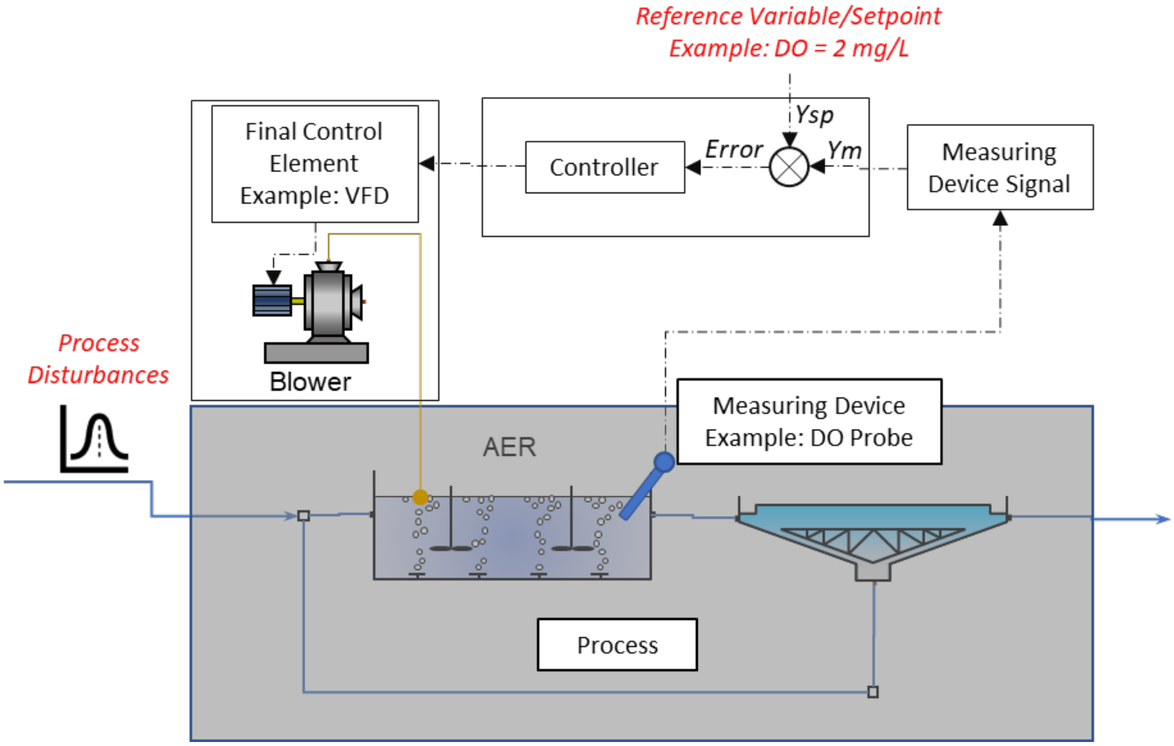

Figure 3. Feedback Control Implementation Example.
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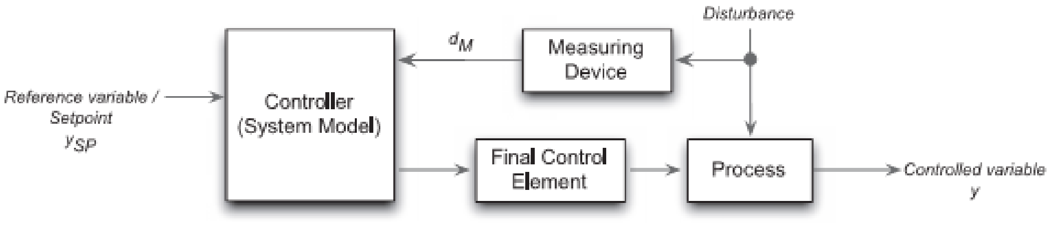

Figure 4. Feed-Forward Control.
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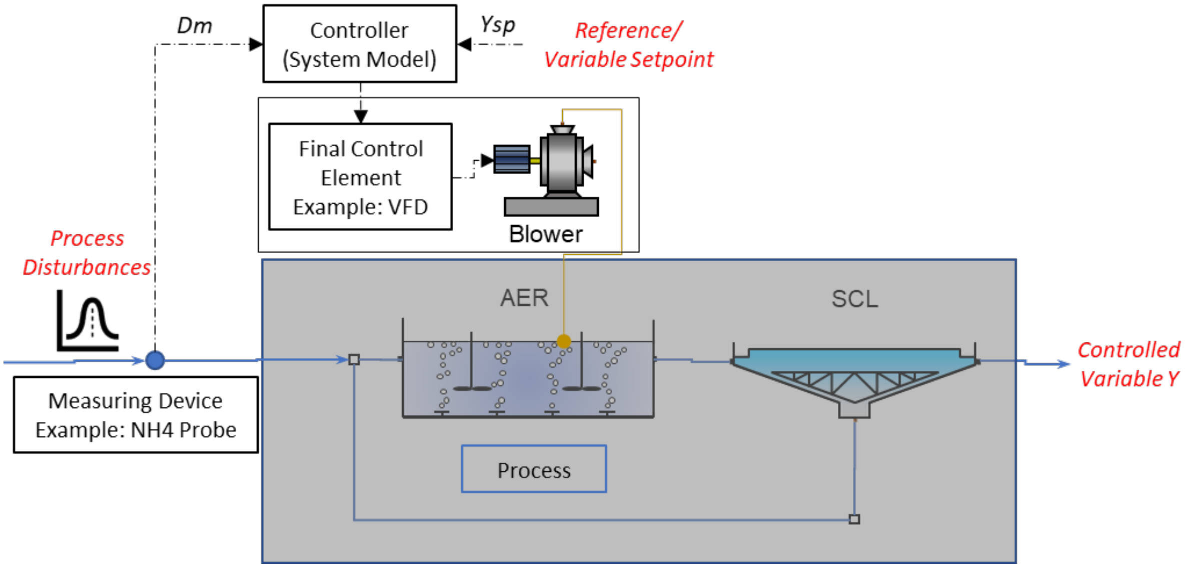

Figure 5. Feed-Forward Control Implementation Example.
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Figure 2 and Figure 4 depict a high-level overview of how two fundamental control schemes work, and Figure 3 and Figure 5 provide an example of implementation. Feedback control is shown in Figure 2 and Figure 3. The baseline process (e.g., activated sludge) is shown for both control types. External disturbances on the process (flow changes, load changes, temperature shift, etc.) create dynamic conditions or changes in the process itself (DO change, change in ammonia concentration, etc.). With no controller, the amplitude of the process changes can be highly variable. With no real-time control strategy, process dynamics go unnoticed until analytical data are available at a later date (often well after the original disturbance), which makes it difficult or impossible to make operational adjustments to the changes. Real-time control provides a way to respond much faster to the original disturbance. The two fundamental real-time control schemes are feedback and feed-forward control.

With feedback control (Figure 2 and Figure 3), a controlled or target variable is measured and differences between the observed or measured value and a set point, because of the external impacts or disturbances on the process, are calculated. Based on the differences between the measured value and set point, the controller makes changes to the final control element, adjusting the process to address the disturbance. In this case, the controller is responding to the way the process acts or changes in response to the disturbance. For example, a controller responding to an increase in aeration basin ammonia concentration measurement responds by increasing a DO set point and consequently airflow to the process is a type of feedback control approach. Note, the increased basin effluent ammonia concentration could have been due to increased ammonia load, lower temperature, or insufficient aeration intensity. A control system should be designed to handle all standard disturbances within defined ranges.

Figure 4 and Figure 5 show a representation of feed-forward control strategy. With feed-forward control, the external impact or disturbance on the process is measured instead of the process response to the disturbance. The impact of the disturbance is anticipated by the controller based on a control model (can be as simple as a pre-defined ratio or a complex mechanistic or data-driven model). The controller then adjusts the final control element to counteract the disturbance and maintain the controlled variable around the set point. In this case, the controller predicts how the process reacts to the external disturbance and calculates the setting for the final control element. For example, a controller responding to an influent ammonia load measurement by changing the process using increased airflow is a feed-forward control approach. Note, the increased ammonia load could have resulted in an increased aeration basin ammonia concentration, but that was not measured in the example.

A feedback control approach is a direct response to how the process acts, and a feed-forward control approach anticipates how the process acts. Therefore, feed-forward control must be complemented by a feedback controller, or a feedback signal should be integrated into the feed-forward control concept.

Fact Sheet Application Checklist

R = fact sheet relevant to item
PR = fact sheet is potentially relevant to item depending on application, existing conditions, etc.

Category	PR	Intensification
	PR	Chemical addition
	PR	Carbon management
	R	I&C strategies
	PR	Sidestream mgmt.
	PR	Energy savings
	PR	Chemical savings
	PR	Operational savings
		By other means
Nutrient	R	Ammonia
	R	NOx
	PR	TN
	R	Ortho-P
	PR	TP
Scale (design flow)	R	Small (<1 mgd)
	R	Medium (1–10 mgd)
	R	Large (>10 mgd)

Goal	R	Improve reliability
	R	Reduce nutrient
	R	Reduce O&M cost
Group	R	Optimize existing CNR
	R	Optimize existing TNR
	PR	NutRem in secondary plant
Process		Small
		Pond
		Fixed film (secondary)
		Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
	R	Tertiary NutRem (TNR)
		Other

CAS = conventional activated sludge (BOD only)
NAS = nitrifying activated sludge (without denitrification)
CNR = conventional nutrient removal no chemical/no filter, etc.
TNR = tertiary nutrient removal with chemical, filter, etc.

Technology Summary Evaluation

Footprint	1	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	4–5	Technology ranking based (LIFT) see below*
Energy efficiency	2	Scale 1–5: 1 = use much less; 3 = use similar to conventional; 5 = use much more
O&M impact	2	Scale 1–5: 1 = cost much less; 3 = cost similar to conventional; 5 = cost much more
Material/consumables	2	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1	Scale 1–3: minimal/none = 1; some = 2; significant = 3 (e.g., chemical process)

* Technology ranking based on Leaders Innovation Forum for Technology (LIFT) Water Research Foundation (WRF) Technology Development Level (TDL) definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional

Descriptions/Evaluation

Strategy	Instrumentation and controls (I&C) summary
Description	I&C are key parts of nutrient removal process control. Many different technologies can provide continuous monitoring of nutrient species. The measurement signal can be used to automatically control the treatment process or to provide a visual trend that reflects the process variations and allow troubleshooting for excursions in performance.
Application	I&C strategies can be used in many applications including the following: • Blower control strategies to provide sufficient air to the basins (typical concepts are pressure control, average DO control, and total airflow control). • Airflow most-open valve (MOV) concepts, which coordinate between air distribution control and air supply control. MOV makes sure that blowers are not being operated against closed valves. • Air distribution control strategies: ▪ DO control to guarantee sufficient oxygen for all aerobic processes. It helps to prevent over- or under-aeration. ▪ Ammonia-based aeration control (ABAC) focuses on maintaining ammonia around a set point by limiting nitrification via aeration. This is possible because nitrification is the rate-limiting process and therefore other aerobic processes such as BOD removal are not impacted. • Total inorganic nitrogen (TIN) control such as ammonia versus NO$_x$ (AvN) control and others measure ammonia and nitrate and minimize TIN by balancing nitrification and denitrification. • Chemical dose control, such as carbon addition for denitrification, metal salt addition for phosphorus (P) removal. • Oxidized nitrogen (nitrate + nitrite) (NO$_x$) control for nitrified mixed liquor recycle (NMLR) is aiming at matching the incoming carbon with the recycled NO$_x$, leading to denitrification efficiency improvement. • Process monitoring to track process performance, excursions, variability to troubleshoot process performance, identify and correct conditions that impact reliability, etc.
Constituents removed	Ammonia, NO$_x$, total nitrogen (TN), Ortho-P, total phosphorus (TP)—all are potentially reduced by I&C improvements
Development status*	LIFT TDLs 4–5. Most strategies are well developed. New approaches and probes continue to emerge.
O&M considerations	Probes should be calibrated and validated to maintain accurate readings. Probes require cleaning periodically. Online wet chemistry uses sampling and typically requires a filtration unit. Chemical reagents required for online sensors using wet chemistry.
Benefits	Provide accurate and continuous monitoring of process streams to verify performance and maintain stable operation. Allow for fine tuning and early warning of process performance. Optimize chemical and energy use. Reduce operator effort (offset by increased maintenance).
Limitations	Instrument and probe maintenance (offset by decreased operator time).
Design considerations	Probe locations must be carefully evaluated to collect representative samples.
Potential fatal flaws	I&C cannot overcome equipment limitations—for example, blower control may be limited by equipment capacity (high end) and ability to turn down to low demands (low end). A badly sized air valve can limit control authority and increase energy consumption of the aeration system.

Footprint requirements	Small
Residuals	None
Cost considerations	Depends on probe type and function. Determine specific cost based on life-cycle analysis (LCA) and include both capital and operations and maintenance (O&M) cost.
Past experience	Hampton Roads Sanitation District, Raleigh, North Carolina San Antonio Water System (SAWS) Lincoln, Nebraska Denver, Colorado, Metro Wastewater Reclamation District (MWRD) Robert Hite Facility
Publications	Miller, M., P. Regmi, and J. Jimenez. 2019. "Sensors Versus Analyzers: The Case for Ammonia-based Aeration Control." Proceedings of the 92nd Water Environment Federation's Technical Exhibition Conference (WEFTEC), Chicago, Illinois. Regmi, P., B. Holgate, D. Fredericks, M.W. Miller, B. Wett, S. Murthy, and C.B. Bott. 2015. "Optimization of a mainstream nitritation-denitritation process and anammox polishing." Water Science Technology. 72(4), 632–642. Rieger, L., R.M. Jones, P.L. Dold, and C.B. Bott. 2014. "Ammonia-based feedforward and feedback aeration control in activated sludge processes." Water Environ Res., 86(1), 63–73. Schraa, O., L. Rieger, J. Alex, and I. Miletic, I. 2019. "Ammonia-based aeration control with optimal SRT control: improved performance and lower energy consumption." Wat. Sci. Tech. 79(1).
Related fact sheets	1150: Use of Chemicals to Improve Nutrient Removal 1401: Optimize Carbon Use for Nutrient Removal 1410: Fermentation 1450: DO Control to Increase Denitrification 1510: Improve Control, Stability, and Efficiency 1560: Sensors and Instrumentation 1701: Reduce Energy Consumption Overview 1740: Reduce Process Power Demand 1820: Chemical Testing and Selection 1901: Optimize Operation and Maintenance
Date updated	9/10/2022
Contributors	Eric Evans, Leiv Rieger, Anand Patel, JB Neethling

Note

* Technology ranking based on LIFT WRF TDL definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional (https://www.waterrf.org/sites/default/files/file/2019-07/LIFT%20Scan%20Application-LIFT%20Link%2BHub_0.pdf : accessed September 2020)

Instrumentation and Controls Applications

Table 2 includes some commonly used I&C strategies used to improve nutrient removal in water resource recovery facilities (WRRFs) or to improve reliability of operation.

Table 2. Strategies that Rely on Instrumentation and Controls.

Control Strategy	Brief Description	Nutrient	Control Measurements
DO control	Control biological process to maintain set DO concentrations. DO set point can be operator-input or adjusted based on secondary control. Typical in form of a controller cascade DO → airflow → valve position.	Ammonia nitrate (Ortho-P)	DO Underlying control loops: airflow, valve position
Ammonia-based aeration control (ABAC)	Manipulates DO set point to achieve a certain target ammonia concentration. Typically feeds into a DO control system.	Ammonia TN	Ammonia
AvN	Ammonium versus NO_x used for TIN control. AvN can be implemented as continuous control feeding into a DO control system or intermittently.	Ammonia NO_x	Ammonia NO_x
Denitrification: NMLR	Control NMLR flow rate based on target NO_x measurement.	NO_x	NO_x
Flow-paced chemical feed (dose concentration)	Adjust chemical dose to maintain a set dosage concentration at the measured flow at dose point.	NO_x Ortho-P	Flow at dose point
Nutrient concentration control	Control chemical dose to maintain nutrient (example NH_4, NO_x, Ortho-P) at target concentration. Feedback solutions are based on concentration measurements, feedforward solutions require concentration and flow measurements.	Ammonia NO_x Ortho-P	Ortho-P, NO_x (feedback) Feed concentration for feed-forward
Solids retention time (SRT)	Maintain SRT to operator-set value by measuring mixed liquor suspended solids (MLSS) and waste activated sludge (WAS) concentrations, and then mathematically determine the WAS flow required to match the target SRT. Secondary effluent total suspended solids (TSS) can also be measured or estimated and included in the control algorithm.	All but specifically for slow processes such as nitrification and Bio-P	TSS in MLSS, WAS, and possibly secondary effluent
ABAC-SRT	Calculates the optimal SRT for ABAC.	Ammonia NO_x	NH_x, TSS in MLSS, flow in influent, RAS, WAS, NMLR

Abbreviations

ABAC	Ammonia-based aeration control
ABAC-SRT	ABAC combined with sludge retention time control
AvN	Ammonia versus NO_x (aeration control)
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
DO	Dissolved oxygen
I&C	Instrumentation and controls
LCA	Life-cycle analysis
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
MLSS	Mixed liquor suspended solids
MOV	Most-open valve
MWRD	Metro Wastewater Reclamation District
N	Nitrogen
NAS	Nitrifying activated sludge
NH_4	Ammonium
NMLR	Nitrified mixed liquor recycle
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SRT	Solids retention time
TDL	Technology Development Level
TIN	Total inorganic nitrogen
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UV	Ultraviolet
WAS	Waste activated sludge
WRF	The Water Research Foundation
WRRF	Water resource recovery facility