WRF 4973 Fact Sheet: ID 2120

Strategy: Small Systems Nutrient Removal Optimization

Mechanical Treatment Plants for Small Systems

Package Plant.
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Package Plant: TITAN MBR™.
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This fact sheet is one in a series of fact sheets addressing nutrient optimization for small systems. It acts as an extension of Fact Sheet 2101 and a companion to Fact Sheet 2110 while focusing on mechanical treatment facilities serving small systems. While many small treatment systems may use only non-mechanical equipment, others use mechanical-based plants that are smaller versions of large treatment systems. These facilities use mechanical equipment such as pumps, mixers, blowers, and diffusers.

Many mechanical systems serve small communities in the flow range from 100,000 gallons per day (gpd) to 1 million gallons per day (mgd), but smaller systems may be served by mechanical plants in some cases. These treatment systems typically use a surface water discharge under a National Pollutant Discharge Elimination System (NPDES) permit. Like non-mechanical systems, these treatment processes are often designed to provide a low-cost system with simple operations. Mechanical plants serving small communities are designed to be robust so they can handle high peaking factors and a wide range of conditions.

Nutrient removal in mechanical treatment plants for small communities follows many of the same fundamental concepts of nutrient removal optimization for medium and large communities. The unique challenges of nutrient removal optimization within small systems are related to the unique characteristics of small systems, such as high peak flow ratios, limited staffing, and reduced funding. Here are some examples:

Nitrogen removal. Incorporation of nitrogen (N) removal within a mechanical small system plant may be accomplished with an appropriate solids retention time and dissolved oxygen (DO) concentration for nitrification and anoxic conditions with 5-day carbonaceous biochemical oxygen demand ($cBOD_5$) for denitrification.

Phosphorus removal. Phosphorus (P) removal in a mechanical small system plant may be possible with the introduction of an anaerobic zone for biological P removal or the addition of metal salts for chemical P removal.

Nutrient diversion. One opportunity for nutrient removal optimization that small systems may consider is source control. Collaborating with the community and/or industry may identify a significant source of nutrients when considering small community loading.

Fact Sheet Application Checklist

R = key concepts relevant to this fact sheet
PR = key concepts potentially relevant to this fact sheet depending on application, existing conditions, etc.

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

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

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

See tables at the end of this fact sheet for review of small systems technologies summary evaluation.

Footprint	1–3	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	4–5	Technology ranking based (LIFT) see below*
Energy efficiency	2–4	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M impact	2–4	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
Material/consumables	2–3	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1–3	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	Small system nutrient removal optimization
Description	This fact sheet presents nutrient removal optimization approaches applicable to mechanical small systems. The nutrient removal optimization schemes for mechanical small systems are often similar to strategies used for medium and large systems. Mechanical small system plants may require unique equipment options that require special consideration, e.g., airlift pumps entraining DO in an anaerobic zone.

Application	Small system technologies using mechanical processes may be modified to achieve the following goals:
	• Create conditions supportive of nitrification with increased biomass retention and aeration
	• Improve nitrification in existing nitrifying treatment process
	• Improve total nitrogen (TN) removal by the process (this may use capacity and needs to be evaluated carefully)
	  ▪ Reduce aeration need
	  ▪ Reduce alkalinity demand
	• Incorporate total phosphorus (TP) removal capabilities with biological P removal
	See summary tables at the end of this fact sheet for a summary of possible nutrient removal optimization options for mechanical processes.

Constituents removed	Ammonium (NH_4), N, and/or P Small system nutrient removal optimization is used to achieve N and/or P removal and improve reliability, but nutrient removal optimization in small systems may come at the cost of treatment capacity. Baseline or existing treatment processes are often associated with different optimization approaches. See the summary tables at the end of this fact sheet for more information.
Development status*	Varies depending on the small system nutrient removal optimization scheme. For many mechanical small systems, the development status tends to be consistent with medium and large system applications.
O&M considerations	Increased aeration requires increased maintenance of the aeration system. Chemical addition and sorption processes increase maintenance cost to replenish the chemical or media. See the tables at the end of this fact sheet for more information.
Benefits	The primary benefit is nutrient removal, but process stability or reliability may be a secondary benefit.
Limitations	Some small system baseline or existing processes are more amenable to nutrient removal optimization strategies than others. See the tables at the end of this fact sheet for more information.
Design considerations	Varies with the nutrient removal optimization approach. • **Package system:** Coordinate with supplier on possible implications for implementing nutrient removal. • **Oxidation ditch:** Small system oxidation ditch plants are typically designed without primary clarification with long solids retention time (SRT) to simplify operation. The oxidation ditch lends itself to simultaneous nitrification and denitrification (SND) operation. Include aeration controls and lay out basin to create in-basin anoxic areas or add dedicated anoxic basins. • **Rotating biological contactor (RBC):** Increased aeration is often considered to support nitrification and N removal. • **Trickling filters:** Reduced $cBOD_5$ loading, such as in a second-stage trickling filter, allows for nitrification in trickling filters. Recirculation of nitrate into a first-stage trickling filter may support nitrification based on anecdotes from utilities. Additional follow-up may be needed to better understand.

	• **Algae treatment:** Coordinate with supplier.
Potential fatal flaws	Challenges include: • Increased process sensitivity to conditions, e.g., aeration, $cBOD_5$ loading rates • Increased operations and maintenance (O&M) requirements • Possible reduction in treatment capacity (coordinate with engineer or treatment process supplier)
Footprint requirements	Varies based on the nutrient removal optimization scheme applied. See the summary tables at the end of this fact sheet for more information.
Residuals	Biosolids residuals may decrease when transitioning from a non-nitrifying to nitrifying process. Residuals will increase with the addition of chemical P removal and sorption processes.
Cost considerations	Cost varies based on the specific optimization scheme or technology being applied. See the tables below for more information.
Past experience	Varies with the specific optimization scheme or technology being applied. See the tables below for more information on development levels.
Publications	BACWA. 2019. "Nature-Based Solutions for Nutrient Load Reduction from Wastewater: Scoping and Evaluation Plan." Bay Area Clean Water Agencies, Oakland, California. Boelee, N.C., H. Temmink, M. Janssen, C.J.N. Buisman, and R.H. Wijffels. 2012. "Scenario Analysis of Nutrient Removal from Municipal Wastewater by MicroAlgal Biofilms." Water. 4:460–473. Crites, R., E.J. Middlebrooks, R. Bastian, and S. Reed. 2014. "Natural Wastewater Treatment Systems, 2nd ed." CRC Press: Boca Raton, Florida. Gross, M., W. Henry, C. Michael, and Z. Wen. 2013. "Development of a Rotating Algal Biofilm Growth System for Attached Microalgae Growth with In Situ Biomass Harvest." Bioresource Technology. 150:195–201. Hassard, F., J. Biddle, E. Cartmell, B. Jefferson, S. Tyrrel, and T. Stephenson. 2015. "Rotating biological contactors for wastewater treatment - A review." Process Safety and Environmental Protection. 94:285–306. Hu, Z. and G.G. Gagnon. 2005. "Re-examining recirculating filters." Water Environment Technology. 17(1):64–68. Kadlek, R. and S. Wallace. 2008. "Treatment Wetlands, 2nd ed." CRC Press: Boca Raton, Florida. http://dx.doi.org/10.1201/9781420012514 Mattson, R.R., M. Wildman, and C. Just. 2018. "Submerged attached-growth reactors as lagoon retrofits for cold-weather ammonia removal: performance and sizing." Water Sci Technol. 78 (8): 1625–1632. Nesshöver, C., T. Assmuth, K.N. Irvine, G.M. Rusch, K.A. Waylen, B. Delbaere, D. Haase, L. Jones-Walters, H. Keune, E. Kovacs, K. Krauze, M. Külvik, F. Rey, J. van Dijk, O.I. Vistad, M.E. Wilkinson, and H. Wittmer. 2017. "The science, policy and practice of nature-based solutions: An interdisciplinary perspective." Science of the Total Environment. 579:1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106 U.S. EPA. 2011. "Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers." EPA/600/R-11/088; U.S. EPA Office of Research and Development National Risk Management.
Related fact sheets	1110: Increase Biomass 1120: Nutrient Removal in Existing Secondary Process 1301: Overview of Chemical Addition 1310: External Carbon Sources 1320: Chemical Phosphorus Removal 1501: Overview of Instrumentation and Control Strategies 2101: Overview of Nutrient Removal for Small Systems

	2110: Non-Mechanical Treatment Plants for Small Systems
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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)

Additional Information

This section provides additional information about nutrient reduction strategies for mechanical small systems. The strategies for nutrient removal optimization in these systems depend on the baseline technology, such as RBCs, trickling filters, oxidation ditches, and packaged activated sludge plants. Strategies are outlined in this section.

Nutrient Reduction Strategies for Mechanical Small Systems

Nutrient reduction strategies for small systems based on mechanical processes are summarized in the tables below:

- Table 1. Small Systems Optimization or Upgrade/Add-on Schemes for NH4 Removal.
- Table 2. Small Systems Optimization or Upgrade/Add-on Schemes for TN Removal.
- Table 3. Small Systems Optimization or Upgrade/Add-on Schemes for TP Removal.

Key Considerations for Nutrient Removal Optimization of Mechanical Small Systems

Nutrient removal optimization must consider several key factors when supporting mechanical, small community systems. Some of these factors or considerations have been presented in Fact Sheets 2101 and 2110. Small systems' challenges are listed with their applicable optimization considerations as follows:

- **Delayed growth:** Use excess capacity for nutrient removal optimization but plan for expansion when growth occurs.
- **High peaking factors:** Consider equalization where site footprints allow for low-cost earthen basins and use appropriate high-flow strategies when needed (e.g., step feed).
- **A wide range of environmental conditions:** Plan and design with an appropriate safety factor that considers swings in pH and temperature.
- **Reduced staffing:** Use simple and low-maintenance equipment where possible (e.g., mechanical aerators) and integrate support with third-party contractors or circuit-riders as discussed with non-mechanical systems. Stay away from optimization strategies that may require more staffing than is available.

- **Lower available funding for capital and O&M budgets:** Look for strategies that optimize both nutrients and cost; e.g., N removal strategies that reduce aeration cost.
- **Unique regulatory requirements:** Work with regulators to determine specific requirements and verify rationale behind the requirements; e.g., discharge requirements meant to protect drinking water supply.

Table 1. Small Systems Optimization or Upgrade/Add-on Schemes for NH_4 Removal.

Baseline Technology	Example(s)	Optimization Schemes	Capital Improvements Project
Mechanical: activated sludge	Package plants: several suppliers may provide systems (e.g., AeroMod, Smith & Loveless, Inc. [S&L]) Oxidation Ditch	Increase SRT[b] Add media Increase aeration capacity	Integrated fixed-film activated sludge (IFAS) media addition Blower capacity increase
Mechanical: RBC	Envirex[a] (by Evoqua)	Lower process loading rate Increase rotational speed Incorporate or increase aeration Split treatment with nitrifying process Increase suspended growth concentration in RBC tanks	Tertiary nitrifying process
Mechanical: trickling filters	Rock media, low-rate trickling filter Plastic media, medium- and high-rate trickling filter	Increase airflow through trickling filter by mechanical aeration Add or increase recirculation Add more media or surface area	Tertiary nitrifying process Upgrade from rock media filter (low-rate) to plastic media filter (high-rate) Algae (GWT Revolving Algal Biofilm [RAB]) Convert to submerged fixed film, incorporate suspended growth (S&L FAST or Modular FAST®)
Mechanical: sequencing batch reactor (SBR)	Aqua Aerobics[a] Davco/ADI[a] (by Evoqua)	Increase SRT[b] Increase aeration[b]	N/A

a. Example of proprietary technology; other alternatives may be available.
b. Refer to Fact Sheets 1110, 1120, and 1130 for more information.

Table 2. Small Systems Optimization or Upgrade/Add-on Schemes for TN Removal.

Baseline Technology	Example(s)	Optimization Schemes	Upgrade/Add-on Schemes
Mechanical: activated sludge (including MBR)	Package plants: several suppliers may provide systems (e.g. AeroMod, S&L) Oxidation ditch	Incorporate anoxic zone[c] Incorporate intermittent aeration[b] Throttle DO concentration down to optimize TN removal[b] Adjust aerators in oxidation ditch; e.g., raise brush, operate in low DO, operate aeration in ON/OFF (maintain mixing), etc.	Denitrifying media filter Aeration controls; variable-frequency drive (VFD) for blower or throttling valves Add timer for intermittent aeration Add VFD to oxidation ditch aerator; e.g., brush motor speed control.
Mechanical: RBC	Envirex[a] (by Evoqua)	Lower process loading rate Increase rotational speed Incorporate or increase aeration Recirculate to anoxic zone Intermittent aeration	Denitrifying media filter Algae (e.g., GWT RAB[a])
Mechanical: trickling filters	Rock media, low-Rate trickling filter Plastic media, medium- and high-rate trickling filter	Recirculate from nitrifying trickling filter to headworks	Denitrifying media filter Algae (GWT RAB) Convert to submerged fixed film, incorporate suspended growth for increased SRT (S&L FAST or Modular FAST)
Mechanical: SBR	Aqua Aerobics[a] Davco/ADI[a] (by Evoqua)	Incorporate anoxic reaction phase	Denitrifying media filter

a. Example of proprietary technology; other alternatives may be available.

b. Refer to Fact Sheets 1110, 1120, and 1130 for more information.

Table 3. Small Systems Optimization or Upgrade/Add-on Schemes for TP Removal.

Baseline Technology	Example(s)	Optimization Schemes	Upgrade/Add-on Schemes
Mechanical: activated sludge	Package plants: several suppliers may provide systems (e.g., AeroMod, S&L) Oxidation ditch	Incorporate biological P removal[b]	Chemical P removal Sorption filter (Nexom BluePro reactive filtration[a])
Mechanical: RBC	Envirex (by Evoqua)	Incorporate biological P removal[c]	Algae (GWT RAB[a]) Chemical P removal Sorption filter (Nexom BluePro Reactive Filtration[a])
Mechanical: trickling filters	Rock media, low-rate trickling filter Plastic media, medium- and high-rate trickling filter	N/A	Algae (GWT RAB[a]) Chemical P removal Sorption filter (Nexom BluePro reactive filtration[a])
Mechanical: SBR	Aqua Aerobics Davco/ADI (by Evoqua)	Incorporate biological P removal (anaerobic fill)	Chemical P removal Sorption filter (Nexom BluePro reactive filtration[a])

a. Example of proprietary technology; other alternatives may be available.

b. Refer to Fact Sheets 1110, 1120, and 1130 for more information.

c. Indicated to have limited success (Hassard et al. 2015). Additional study and demonstration suggested.

Abbreviations

BOD	Biochemical oxygen demand
BNR	Biological nutrient removal
CAS	Conventional activated sludge: BOD removal only
$cBOD_5$	5-day carbonaceous biochemical oxygen demand
CNR	Conventional nutrient removal
DO	Dissolved oxygen
gpd	Gallon(s) per day
I&C	Instrumentation and controls
IFAS	Integrated fixed-film activated sludge
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
N	Nitrogen
N/A	Not applicable
NAS	Nitrifying activated sludge
NH_4	Ammonium
NO_x	Oxidized nitrogen (nitrate + nitrite)
NPDES	National Pollutant Discharge Elimination System
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
RAB	Revolving Algal Biofilm
RBC	Rotating biological contactor
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SBR	Sequencing batch reactor
S&L	Smith & Loveless, Inc.
SND	Simultaneous nitrification and denitrification
SRT	Solids retention time
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
UV	Ultraviolet
VFD	Variable-frequency drive
WRF	The Water Research Foundation