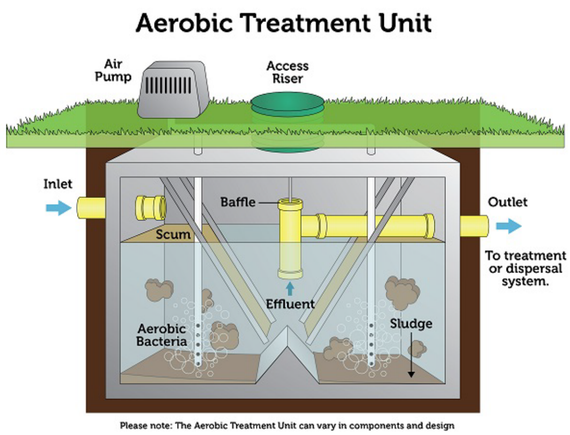
WRF 4973 Fact Sheet: ID 2110

Strategy: Small Systems Nutrient Removal Optimization

Non-Mechanical Treatment Plants for Small Systems



Aerated Septic Tank.
https://www.epa.gov/septic/types-septic-systems
(accessed January 7, 2022)

Lagoon.
https://www.iowadnr.gov/environmental-protection/water-quality/npdes-wastewater-permitting/npdes-operator-information
(accessed February 19, 2022)

This fact sheet is one in a series of fact sheets addressing nutrient removal optimization for small systems. It acts as an extension to Fact Sheet 2101 and a companion to Fact Sheet 2120. This fact sheet focuses on non-mechanical treatment facilities for small systems. While some treatment systems may not use any mechanical equipment (some septic tanks), most of the treatment systems require some mechanical equipment, such as small pumps, mixers, flow measurement devices, screens, and grit for larger, lagoon-based systems. Some lagoons may use mechanical aerators, which makes them a hybrid between non-mechanical and mechanical systems. These systems generally fit in the non-mechanical category, because they require little operator input, little control adjustments, and no ongoing solids management requirements. Solids are dredged from lagoons and disposed of occasionally as needed.

Many non-mechanical systems serve a significant number of small communities. These treatment systems may use two disposal options: groundwater discharge (including leachfields and injection) and surface water discharge under a National Pollutant Discharge Elimination System (NPDES) permit. These treatment processes are characterized by low operating cost, low maintenance cost, and reduced operational needs. The plants are robust to meet treatment objectives reliably with little attention under a wide range of treatment and environmental conditions.

Non-mechanical treatment plants typically are not designed to remove nutrients within the base process, because nutrient removal has not been a requirement. Some non-mechanical systems have previously been upgraded because of effluent ammonia requirements for surface discharge. When needed, tertiary treatment is sometimes added to produce reuse water, which is typically used for irrigation or land application.

Achieving nutrient removal in non-mechanical treatment plants requires modifications to the process and additional facilities with new operational requirements. Simple nature-based and non-mechanical solutions can be added by constructing additional treatment facilities. Here are some examples:

- **Nitrogen removal:** Convert a septic tank to an aerobic treatment unit with media and aeration, add a submerged attached growth reactor (SAGR), zeolite/anammox or zeolite/nitrification, or other polishing process for a lagoon system to nitrify and denitrify.
- **Phosphorus removal:** Use a tertiary filter containing media with phosphorus (P) sorption capacity. Add chemicals to the influent and settle solids in lagoon.
- **Nutrient diversion:** Reclaim water and direct to irrigation maintaining agronomic loading rate for nutrients.

See Additional Information section below for more information.

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	Varies	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	Varies	Technology ranking based (LIFT) see below*
Energy use	Varies	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M impact	Varies	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
Materials/consumables	Varies	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	Varies	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 non-mechanical small systems. Non-mechanical optimization may include incorporation of increased mechanization, but the baseline technology is assumed as the main treatment process. Examples of non-mechanical small system nutrient removal optimization solutions include: • Recirculating media filters • Media addition to suspended growth (mechanical and non-mechanical) systems • Add-on processes such as ion exchange (zeolite)
Application	Optimization strategies to reduce nutrient discharged from small systems are highly dependent on the specific treatment technology used in the small system. See the Additional Information section below for more information.
Constituents removed	Ammonium (NH_4), nitrogen (N), and/or phosphorus (P) Baseline or existing treatment processes are often associated with different optimization approaches. See the summary tables in the Additional Information section below for more information.
Development status*	Varies depending on the small system nutrient removal optimization scheme. See Table 5 for a summary of development statuses.
O&M considerations	Varies depending on strategy. Potential operations and maintenance (O&M) requirements could include mechanical equipment (energy, maintenance), chemical addition, residual management, and others. See the tables in the Additional Information section below for more information.
Benefits	Strategies for nutrient removal could improve effluent quality and make it more attractive for reuse.
Limitations	Varies depending on the strategy being used. See the tables in the Additional Information section below for more information.
Design considerations	Varies based on the nutrient removal optimization approach
Potential fatal flaws	Challenges include: • Increased mechanization and process complexity • Increased operations and maintenance requirement
Footprint requirements	Varies with the nutrient removal optimization strategy. See the summary tables below for more information.
Residuals	Residual management for small non-mechanical systems is challenging. In many instances solids accumulate in (septic) holding tanks and lagoons. Sometimes residuals are land-applied. Options for beneficial reuse are composting, land application, and others. Many states have published guidance (e.g., https://dec.vermont.gov/waste-management/residuals-management/guidance-documents [accessed 9/10/2022]). Key factors for residual management are to have a planned schedule to dispose of residuals and to reduce/prevent return flows with high nutrient concentrations to return to the treatment system and escape with the effluent stream.
Cost considerations	Cost varies based on the specific optimization scheme or technology being applied. Expect an increase in operating cost. See the tables below for more information.
Past experience	Varies based on the specific optimization strategy. See the tables below for more information.
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 Micro Algal 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 Controls Strategies 2101: Overview of Nutrient Removal for Small Systems 2120: 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 non-mechanical small systems.

Key Considerations for Nutrient Removal Optimization of Small Systems

The appropriate nutrient removal optimization strategy depends on the existing treatment process and past performance experience with the baseline process. Non-mechanical small systems for this fact sheet are focused on four baseline technologies:

- Septic tank
- Facultative lagoons
- Aerated lagoon
- Constructed wetlands

Septic tanks usually direct effluent to leachfields and infiltration beds. Effluent from these single-dwelling and other on-site treatment systems can be combined into a cluster system that optimizes for nutrient removal. A cluster system may be set up or optimized for taking raw wastewater, or in the case where individual septic systems are already in place, the cluster system may be designed to manage septic system effluent. This is known as a septic tank effluent pump (STEP) system.

Table 1 provides a summary of process mechanisms, their general performance, and other characteristics of these four baseline non-mechanical treatment technologies.

Some optimization strategies that are holistic approaches to consider for small systems may be independent of the baseline technology. For example, one approach for diverting nutrients from receiving waters is land application or irrigation. While land application of effluent from medium and large systems may not be practical, it may be more realistic for small systems. Land application consists of conveying the effluent and proper distribution. The final fate of nutrients should be evaluated carefully with land application systems. In some cases, nutrient removal may be required by a regulatory authority prior to land application. In other cases, land application may be limited to the agronomic demand for nutrients.

Table 1. Characteristics of Non-Mechanical Small Treatment Systems.

Parameter	Septic Tank	Facultative Lagoons	Aerated Lagoons	Constructed Wetlands
Operational features	Static, unaerated treatment	Static, rely on natural processes, solids settle, surface aeration, algae-bacterial synergy	Performance depends on aeration input, mixing and hydraulic characteristics	Wetland configurations vary. Use active root zone activity for treatment in subsurface flow configuration.
Technology variants	Multistage septic system, variations of leachfields depending on native soils	High-rate lagoons: shallow with low intensity mixing (example, floating paddle mixer) promote biological growth and oxygen supply	Series operation with variable aeration-mixing can provide different levels of treatment Nitrification possible	Free water surface wetlands Subsurface flow wetlands Vertical/horizontal flow
Operational flexibility	Limited	Dependent on natural processes and loading rates	Depends on design Change mixing and aeration characteristics	Limited, may be able to isolate cells
Effluent quality	NH_4: high NO_x: very low TN: high TP: high	NH_4: high NO_x: low TN: high TP: high	NH_4: low–high NO_x: low–high TN: varies TP: varies	NH_4: Varies NO_x: Varies TN: varies TP: varies
N removal potential	Medium: mixed results demonstrated, see below	Algal growth Stripping ammonia Upgrade to aerated lagoon	Varies: Lagoons in series may offer some potential to nitrify. Some aerated lagoons are sized for nitrification.	Subsurface flow configuration is noted to offer potential. Hydraulic retention time (HRT) and biomass harvesting may be factors to control.
P removal potential	Limited	Baseline may be limited. Chem-P option a consideration.	Baseline may be limited. Chem-P option a consideration.	Varies like N removal potential.

Optimization Strategies for Non-Mechanical Small Systems

Strategies for nutrient optimization often depend on the baseline technology, as shown in the tables below. These tables provide examples of optimization and include example technologies that can be implemented to achieve nutrient removal for ammonia, total nitrogen (TN), and total phosphorus (TP). While outside the scope of a strict "optimization project," some potential capital improvements are identified.

- Table 2. Small Systems Optimization or Upgrade/Add-on Schemes for NH4 Removal
- Table 3. Small Systems Optimization or Upgrade/Add-on Schemes for TN Removal
- Table 4. Small Systems Optimization or Upgrade/Add-on Schemes for TP Removal
- Table 5. Evaluation Summary of Small System Technologies.

Table 2. Small Systems Optimization or Upgrade/Add-on Schemes for NH_4 Removal.

Baseline Technology	Example(s)	Optimization Schemes	Capital Improvements Project
Non-mechanical: septic tank with drain field	On-site treatment for single-family dwelling or multiple-dwelling development	Add aeration (aerobic treatment unit by EPA) and media (e.g., ClearPod: Biocolumn[a], BAT® Media Septic System[a])	NSF-approved advanced treatment unit (ATU) (e.g., Smith & Loveless, Inc. [S&L] ADDIGEST, Orenco: Advantex On-site Treatment[a]) Recirculating sand/media Filter system Constructed wetland system Zeolite treatment
Non-mechanical: facultative lagoon	Shallow pond system relying on high surface area and algae to provide dissolved oxygen (DO) for $cBOD_5$ and TSS removal	Incorporate aeration: surface aerators, diffused aeration (e.g. Parkson-Biolac[a], LemTec Aeration[a]). Increase SRT; e.g. add media (multiple vendors) and/or incorporate solids separation and recycle.	Media-based post-nitrification removal process (Nexom SAGR with TN removal, TriplePoint: NitrOx[a]). Algae (GWT RAB)
Non-mechanical: aerated lagoon	Pond system using aeration (typically surface aerators) for $cBOD_5$ and TSS removal	Increase/change aeration: add surface aerators, replace surface aerators with diffused aeration (see facultative lagoon), add SolarBee™ aerator Increase solids retention time (SRT) with fixed film (LemTec or EDI moving-bed biofilm reactor [MBBR])	Media-based post-nitrification removal process (Nexom SAGR with TN removal, TriplePoint: NitrOx[a]) Algae (GWT Revolving Algal Biofilm [RAB])
Non-mechanical: constructed wetland	Surface flow and subsurface flow wetland systems	Increase HRT Create or optimize subsurface flow condition to support nitrification plant root zone Harvest plants to remove nutrients removed by uptake Modify vegetation	Recirculating media system on the front end of the wetland

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

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

Baseline Technology	Example(s)	Optimization Schemes	Upgrade/Add-on Schemes
Non-mechanical: septic tank with drainfield	On-site treatment for single-family dwelling or multiple-dwelling development	Add aeration (ATU by EPA) and media (e.g., ClearPod: Biocolumn[a], BAT® Media Septic System[a])	Recirculating sand/media filter system Constructed wetland system Zeolite
Non-mechanical: facultative lagoon	Shallow pond system relying on high surface area and algae to provide DO for $cBOD_5$ and TSS removal	Incorporate aeration: surface aerators, diffused aeration (e.g., Parkson-Biolac[a], LemTec Aeration[a]). Increase SRT; e.g., add media (multiple vendors) and/or incorporate solids separation and recycle Lagoon incorporation of settling (e.g., Parkson-Biolac WaveOx™ Plus)	Media-based post-nitrogen removal process (Nexom SAGR with TN removal[a]) Algae (GWT RAB)
Non-mechanical: aerated lagoon	Pond system using aeration (typically surface aerators) for $cBOD_5$ and TSS removal	Increase/change aeration: add surface aerators, replace surface aerators with diffused aeration (see facultative lagoon) Increase SRT with media (LemTec or EDI MBBR) Lagoon incorporation of settling (e.g., Parkson-Biolac WaveOx™ Plus)	Media-based post-nitrogen removal process (Nexom SAGR with TN removal[a]) Media-based post nitrification with recirculation (TriplePoint: NitrOx) Algae (GWT RAB)
Non-mechanical: constructed wetland	Surface flow and subsurface flow wetland systems	Increase HRT Create or optimize subsurface flow condition to support nitrification plant root zone Harvest plants to remove nutrients removed by uptake[b] Modify vegetation with plants that have higher N requirements[b]	Recirculating media system on the front end of the wetland receiving nitrified wetland effluent

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

b. Indicated to have variable results (Crites et al. 2014).

Table 4. Small Systems Optimization or Upgrade/Add-on Schemes for TP Removal.

Baseline Technology	Example(s)	Optimization Schemes	Upgrade/Add-on Schemes
Non-mechanical: septic tank with drainfield	On-site treatment for single-family dwelling or multiple-dwelling development	N/A	Chemical P removal Constructed wetland system Nexom BluePro Reactive Filtration[a]
Non-mechanical: facultative lagoon	Shallow pond system relying on high surface area and algae to provide DO for $cBOD_5$ and TSS removal	N/A	Chemical P removal Algae; e.g., GWT RAB[a] Nexom BluePro Reactive Filtration[a] Biolac® Wave-Ox[a]
Non-mechanical: aerated lagoon	Pond system using aeration (typically surface aerators) for $cBOD_5$ and TSS removal	N/A	Chemical P removal Algae; e.g., GWT RAB[a] Nexom BluePro Reactive Filtration[a] Biolac® Wave-Ox[a]
Non-mechanical: constructed wetland	Surface flow and subsurface flow wetland systems	Harvest plants to remove nutrients ammonia removed by uptake[b] Modify vegetation with plants that have higher P requirements[b]	N/A

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

b. Indicated to have limited success (Crites et al. 2014). Additional study and demonstration suggested.

Table 5. Evaluation Summary of Small System Technologies.

Technologies	Nutrient Removed	Footprint	Develop-ment Status	Energy Efficiency	O&M Impact	Materials Consum-ables	Chemical Use
Septic tank: aerated or ATU (e.g., ClearPod: Biocolumn[a])	NH_4, TN	Small	TDL 3	Low	Medium	Low	None
ATU (S&L: ADDIGEST or Titan MBR, BAT® Media Septic System, Orenco: Advantex [a])	NH_4, TN	Small	TDL 3	Low	Medium	Low	None
Lagoon aeration + settling (e.g., BioLac WaveOx™ Plus)	NH_4, TN	Medium	TDL 4	Low	Medium	Low	None
Lagoon media addition (LemTec or EDI)	NH_4, TN	Medium	TDL 4	Low	Medium	Low	None
Post-lagoon, fixed-film process (S&L: FAST or Modular FAST, TriplePoint: NitrOx, Nexom SAGR)	NH_4	Small	TDL 4	Low	Medium	Low	None
Recirculating media filter	NH_4, TN	Small–medium	TDL 5	Medium	Medium	Medium–high	Carbon
Algae (e.g., GWT-RAB)	NH_4, TN, TP	Medium–high	TDL 4	High	Medium	Low	None
Zeolite	NH_4	Medium–large	TDL 5	High	Low–medium	Medium–high	Medium
Chemical P removal	TP	Small	TDL 5	Medium	Medium	High	High
P sorption (e.g., Nexom BluePro)	TP	Small	TDL 5	Medium	Medium	Medium–high	Medium

Abbreviations

ATU	Advanced treatment unit
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
$cBOD_5$	5-day carbonaceous biochemical oxygen demand
CNR	Conventional nutrient removal
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
HRT	Hydraulic retention time
I&C	Instrumentation and controls
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
MBBR	Moving-bed biofilm reactor
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
NSF	National Sanitation Foundation
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
RAB	Revolving Algal Biofilm
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SAGR	Submerged attached growth reactor
S&L	Smith & Loveless, Inc.
SRT	Solids retention time
STEP	Septic tank effluent pump
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
TSS	Total suspended solids
UV	Ultraviolet