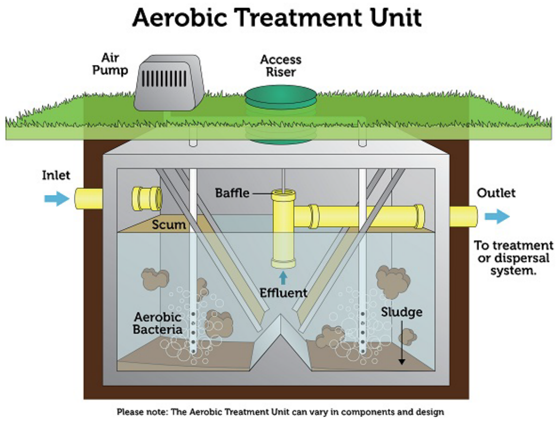
WRF 4973 Fact Sheet: ID 2101

Strategy: Small Systems Nutrient Removal Optimization

Overview of Nutrient Removal for Small Systems



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

Rock Media Trickling Filter.
Reprinted with permission from HDR Engineering, Inc.

Small community systems are a unique group of wastewater treatment systems with several unique nutrient removal optimization challenges. As a result, small systems are the focus of this fact sheet, 2101, along with Fact Sheets 2110 and 2120. This fact sheet provides an overview of small systems including a definition of small systems, size categories for small systems, a discussion of baseline treatment categories for small systems, and an introduction to fundamental needs for nutrient removal in small systems. Fact Sheet 2110 represents an extension of this fact sheet and focuses more specifically on nutrient removal optimization strategies for non-mechanical processes used in small systems (as defined in this fact sheet). Similarly, Fact Sheet 2120 focuses on nutrient removal optimization strategies for the mechanical processes used in small systems (as defined in this fact sheet).

Small systems are defined by several characteristics, such as the size of the process, population served, discharge type, and treatment method. They generally support communities discharging less than 1 million gallons per day (mgd) of wastewater on average. These systems are used in a wide range of locations, from suburbs of large communities to remote areas or small towns. When installed to support small towns, land is often available for small community treatment systems, making large treatment system footprints possible, but funding for these treatment systems may also be more limited in these communities. Simplicity and ease of operation are key trademarks of small community systems, wherever they are used.

Small community systems can be subdivided based on their size, discharge/disposal requirements, treatment technology, local conditions, and many other parameters. When considering size, small community systems are defined or categorized in terms of population served or the average wastewater flow rate treated by the system. A treatment system with an average flow between 100 gallons per day (gpd) and 1 mgd could be defined as a small system. On a population (equivalent) basis, a small system could serve up to 10,000 total people within single-family dwellings. This represents a significant (4 orders of magnitude) range of flows, which means that different small systems require a variety of wastewater treatment and disposal options.

When considering discharge types, small systems use two key categories of disposal: groundwater disposal and surface water disposal. Groundwater disposal relies on flow directed to ground infiltration by leachfields, subsurface injection, or land application. Surface water disposal directs water to receiving streams like most medium and large systems. Treatment technologies for small systems can be categorized as mechanical and non-mechanical systems. These classifications are not black and white, but rather shades of gray.

Table 1 contains the general characterization for the three types of small systems, the treatment technologies commonly used for each type, and the typical range of population sizes served by each type. However, there is variability in the type of treatment system used, and the population range categories are only a general representation. For example, lagoons may be a typical baseline technology for system sizes between 500 and 100,000 gpd, but lagoons may also be found serving flow rates of several mgd. As a result, Fact Sheets 2110 and 2120 discuss nutrient removal based on baseline treatment system type rather than population served or average flow.

In some cases, septic tank effluent from on-site systems servicing single homes or clustered communities are collected and conveyed to a central location for follow-up or further treatment. This provides a mechanism to centralize and provide cost efficiency for improved treatment levels. Two common conveyance types are septic tank effluent gravity (STEG) and septic tank effluent pump (STEP) systems (U.S. EPA 2002). Once combined, add-on treatment may be applied to the septic tank effluent. Several treatment alternatives have been applied resulting in successful nutrient treatment; including but not limited to recirculating sand filters, constructed wetland systems, and reactive filtration systems (providing nitrogen [N] and/or phosphorus [P] removal).

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
		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 Table 1 below for a 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)
Material/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 an introduction to nutrient removal optimization approaches applicable to small systems. The nutrient removal optimization schemes presented are based on the fundamental concepts common to medium and large systems, but the schemes are customized to small systems' unique treatment goals and configurations. Several proprietary technologies are identified, and some investment may be required. The efficacy of proprietary technologies should be validated. Ideally, commercial processes should be pre-approved through the National Sanitation Foundation (NSF) or by the regulator. Examples of small system nutrient removal optimization solutions include: • Recirculating media filters • Media addition to suspended growth (mechanical and non-mechanical) systems • Add-on processes

Application	Small system technologies and modifications are used 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
	Small system nutrient removal goals vary with the baseline or existing treatment process, which varies based on the system size and regulatory requirements. Please see Table 1 at the end of this fact sheet for a breakdown of the categories and corresponding nutrient optimization approaches.

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 Table 1 at the end of this fact sheet for more information.
Development status*	Varies depending on the small system nutrient removal optimization scheme
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 tables 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 optimization strategies than others. See Table 1 for more information.
Design considerations	Varies with nutrient removal optimization approach. • Implementation of nitrification requires increased air requirement • Recirculating media filter—requires flow control structure(s) • Package system—coordinate with supplier on possible implications for implementing nutrient removal • Algae treatment—coordinate with supplier
Potential fatal flaws	Challenges include: • Increased process complexity • Increased operations and maintenance (O&M) requirement

	• Possible reduction in treatment capacity (coordinate with engineer or treatment process supplier)
Footprint requirements	Varies with nutrient removal optimization scheme applied. See Table 1 for more information.
Residuals	Biosolids residuals may decrease when transitioning from 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 Table 1 below for more information.
Past experience	Varies with the specific optimization scheme or technology being applied. See Table 1 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 Nurdogan, Y. and W.J. Oswald. 1995. Enhanced nutrient removal in high-rate ponds." Wat. Sci. Technol. 31(12) 33-43,1995. doi: https://doi.org/10.2166/wst.1995.0453. U.S. EPA. 2002. "Sewers, Pressure." Wastewater Technology Fact Sheet. EPA 832-F-02-006; Office of Water, September 2002. https://www.epa.gov/sites/default/files/2015-06/documents/presewer.pdf (accessed 4/26/2023). 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. U.S. EPA. 2022. "Onsite Wastewater Treatment Systems Manual." EPA/600/R-00/008; U.S. EPA Office of Water, Office of Research and Development.
Related fact sheets	1110: Increase Biomass 1120: Nutrient Removal in Existing Secondary Process 1130: Improve Nutrient Removal in an Existing BNR Process 1301: Overview of Chemical Addition 1310: External Carbon Sources 1320: Chemical Phosphorus Removal

	1501: Overview of Instrumentation and Controls Strategies 2110: Non-Mechanical Treatment Plants for Small Systems 2120: Mechanical Treatment Plants for Small Systems
Date updated	9/10/2022
Contributors	John Buchanan, Raj Chavan, Eric Evans, Max Gangestad, Mike Hines, Murthy Kasi, Anand Patel, JB Neethling, Andy Shaw

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 small systems, and the categories/types of systems addressed in this guidance document.

Small Systems Classification

Small systems refer to a wide group of wastewater treatment and management options with one thing in common: they serve a small community with vastly different needs in terms of wastewater quantity, treatment, and disposal. Each community is different—size, location, environment, seasonal population, transient population, etc. Table 1 contains some descriptions that provide a common understanding of the system size and the typical technologies and disposal options associated within the size classification.

As illustrated in Table 1 there is an overlap in the disposal and treatment options for the three community sizes. Nano communities are essentially single families of small clusters of single-family units that could have individual treatment technologies/systems (such as septic tanks) with a combined disposal system (such as a leachfield). As the community served by the system grows, the ability to dispose of treated water into the ground becomes more challenging until it eventually may reach a point when the community is now considered a micro or small community and must dispose of the treated wastewater via surface discharge.

Small communities may rely on a formal treatment system that is mechanical or non-mechanical to meet National Pollutant Discharge Elimination System (NPDES) or other discharge permit requirements. The treatment technologies used for non-mechanical systems include septic systems, lagoons, and constructed wetlands. The treatment technologies used for mechanical systems are typically smaller versions of conventional secondary or even conventional nutrient removal (CNR) treatment systems. The technologies need to be robust but simple; often these are provided by equipment manufacturers as a single-source provider of a package plant. Some may be as sophisticated as large water resource recovery facilities (WRRFs).

Table 1. Small Systems Classifications, Baseline Technologies, and Disposal Options.

Size Classification	Flow Range	Population	Example	Baseline Technology Types	Disposal Options	Nutrient Control Requirements
Nano community	< 1,000 gpd	1–20 people	Single-family dwelling	Septic tanks with advanced treatment systems (single-home package plants)	Drainfields/leachfields, land application/absorption fields.	Usually minimal; required for sensitive areas.
Micro community	500–100,000 gpd	10–2,000 people	Subdivisions, cluster systems, camp systems	Facultative lagoons, constructed wetlands, septic tanks with advanced treatment systems	Drainfields/leachfields, land application/absorption fields, irrigation. NPDES discharge to surface water.	Range from no limits to N limits to protect groundwater or ammonia limits to protect surface water.
Small community	50,001–>1,000,000 gpd	500–>10,000 people	Larger subdivision, small town, unincorporated community, work camp	Facultative lagoons, aerated lagoons, package plants, constructed wetlands, aerated lagoons, trickling filters, conventional activated sludge, sequencing batch reactors (SBRs), rotating biological contactors (RBCs), membrane bioreactor (MBR).	NPDES permit discharge to surface water, land application/adsorption fields, irrigation, reuse.	NPDES permits require secondary treatment for discharge to waters of the state. Groundwater infiltration typically includes N limits.

Special Requirements and Challenges

Small systems face special challenges, because they may be in remote areas, have limited funding, and have unique regulatory requirements.

Challenges

Some of the challenges include regulatory, funding, and staffing. These unique challenges make nutrient removal optimization especially cumbersome. This section identifies some of these challenges.

Regulatory Requirements

Regulatory requirements are determined by the local regulatory authority. In some cases, the county health department may be the responsible authority; in particular, with septic systems and leachfields. In other cases, a state agency is the regulatory authority; in particular, with surface water discharge permits. Less frequently, the U.S. Environmental Protection Agency (EPA) is the regulatory authority; this may be the case with some tribes and national parks.

Flow Variation

Small community systems typically experience a high degree of flow and load variability because of the small population and collection system that often include intermediate pumping stations and on/off operation. This is of greater concern for small community systems that service a seasonal, vacation, or weekend population shifts (for example, ski resorts).

Funding

Small systems often serve communities with limited funding. This is partly due to small communities consisting of a smaller base service area for rates. It may also be due to the fact that the community's population is decreasing, the community is made up of a retired population on a fixed income, and/or the community is made up of an underrepresented population with limited resources (e.g., tribes).

Staffing

O&M personnel for small communities may be limited. These communities may not have the resources to hire staff dedicated specifically to operating and maintaining the water resource recovery system, but rather, the staff have a wider range of responsibilities including maintenance of other infrastructure; e.g., streets, parks, etc. As a result, staff may not be as specialized and/or have enough time to operate and understand more advanced treatment processes.

Opportunities

This section identifies some opportunities to help overcome the unique challenges of small systems.

Land Application

Land application of small systems discharge represents an opportunity to divert nutrients from surface water discharge. Ultimately, land application results in groundwater infiltration/discharge, but nutrients are often captured or treated on or near the surface prior to infiltrating into the groundwater. Nutrient removal by groundwater discharge is variable because of factors such as soil type, discharge type and design, environmental factors, etc. Despite the variability, this reduction in nutrients should be considered as part of the overall treatment process. Quantification of nutrient capture and/or treatment by groundwater discharge systems may be evaluated to better understand the level of removal.

Funding Opportunities
Limited funding is often a key challenge for small systems when it comes to maintenance and upgrades. Some funding sources that could be considered to support nutrient removal optimization projects include the following:

- Clean Water State Revolving Fund
- Section 319 Grants
- United States Department of Agriculture (USDA) Rural Development Grants
- U.S. Department of Housing and Urban Development (HUD)

State and tribal funding may also be available.

Staffing
Small communities may consider hiring external staff to supplement their staff. This may include third-party operations contractors or journeyman (funded by external agencies specifically to support small systems). For example, the USDA offers a circuit rider program to help small communities with technical challenges (https://www.rd.usda.gov/programs-services/water-environmental-programs/circuit-rider-program-technical-assistance-rural-water-systems).

Underloaded Systems
Like all wastewater treatment processes, small systems are installed with capacity for future growth and a design safety factor. Small systems, however, often see delayed growth and have higher design safety factors. As a result, the excess capacity (volume) available may be redirected to nutrient removal. Cluster systems for subdivisions that undergo phased development in particular may have significant excess capacity with which to support nutrient removal optimization. Growth may be delayed, and use of excess capacity can be a very cost-effective method to provide nutrient removal within a small system. If excess capacity is used for nitrification and/or nutrient removal, the facility must be derated to account for the modification(s). As a result, it is important to plan for expansion when growth does occur.

Abbreviations

BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
EPA	U.S. Environmental Protection Agency
gpd	Gallon(s) per day
HUD	U.S. Department of Housing and Urban Development
I&C	Instrumentation and controls
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
MBR	Membrane bioreactor
mgd	Million gallons per day
N	Nitrogen
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
RBC	Rotating biological contactor
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SBR	Sequencing batch reactor
STEG	Septic tank effluent gravity
STEP	Septic tank effluent pump
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
USDA	United States Department of Agriculture
UV	Ultraviolet
WRF	The Water Research Foundation
WRRF	Water resource recovery facility