Recommendations of the On-Site Wastewater Treatment Systems Nitrogen Reduction Technology Expert Review Panel

FINAL REPORT

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Acronyms

ALR	area loading rate
ATU	aerobic treatment unit
BAT	best available technology
BMP	best management practice
BNR	biological nitrogen removal
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
CBPO	Chesapeake Bay Program Office
CSM	Colorado School of Mines
DO	dissolved oxygen
ES	effective size
FOG	fats, oils and greases
FWS	free water surface
gpcd	gallons per capita per day
gpd	gallons per day
HLR	hydraulic loading rate
HRT	hydraulic retention time
IFAS	integrated fixed-film activated sludge
IMF	intermittent media filter
ISF	intermittent sand filter
LHD	local health department
LPD	low pressure distribution (or dispersal)
LPP	low pressure pipe
MDE	Maryland Department of the Environment
mpi	minutes per inch
NAHB	National Association of Homebuilders
NEHA	National Environmental Health Association
NO_3/NO_2	nitrate/nitrite
NPDES	National Pollutant Discharge Elimination System
NSF	NSF International (formerly National Sanitation Foundation)
O&M	operation and maintenance
OLR	organic loading rate
OWM	USEPA Office of Wastewater Management
OWTS Expert Panel	On-Site Wastewater Treatment Systems Nitrogen Reduction Technology Expert Review Panel
PE	population equivalents
PRB	permeable reactive barrier

RME	responsible management entity
RMF	recirculating media filter
RR	recirculation ratio
SA	surface area
sf	square feet
SORA	State Onsite Regulators Alliance
STE	septic tank effluent
TMDL	total maximum daily load
TN	total nitrogen
TKN	total Kjeldahl nitrogen
TP	total phosphorus
TSS	total suspended solids
UC	uniformity coefficient
USEPA	U.S. Environmental Protection Agency
VSB	vegetated submerged bed
WIP	watershed implementation plan
WWTWG	Wastewater Treatment Workgroup

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Summary of Recommendations

The On-Site Wastewater Treatment Systems Nitrogen Reduction Technology Expert Review Panel (OWTS Expert Panel) was tasked with identifying and recommending on-site wastewater treatment technologies or modifications to existing wastewater treatment systems that would reduce total nitrogen (TN) loads to the Chesapeake Bay watershed. The OWTS Expert Panel was instructed not to address the issue of nitrogen attenuation in the native soils between the edge of the treatment system (drainfield) and the edge of the stream, since the Chesapeake Bay Program Office (CBPO) and a future Expert Panel will review and address this issue. The OWTS Expert Panel also reviewed the existing scientific research and provided recommendations for TN reduction credits that can be assigned for specific OWTS technologies and system modifications. To the extent possible, the associated TN reduction credits were linked to the planning, design, installation, and operational elements of OWTS. Recommendations were also made regarding verification of best management practice (BMP) performance.

As a starting point, the OWTS Expert Panel used existing CBPO guidance and reviewed recent literature to develop baseline TN load estimates for use in modeling and BMP performance comparisons. This exercise required the OWTS Expert Panel to determine how much TN was discharged per capita as a baseline necessary to model system performance. The OWTS Expert Panel concluded that 5 kg TN/person/year or a 60 mg/L concentration of TN at a flow rate of 60 gallons per capita per day (gpcd) could be reasonably estimated as the TN loading associated with the septic tank effluent (STE) applied to the drainfield from a conventional septic tank system. The OWTS Expert Panel agreed that the current CBPO assumption that a 20 percent TN reduction occurs within a conventional gravity flow drainfield was reasonable. Based on these assumptions, the OWTS Expert Panel also concluded that the TN load discharged at the edge-of-drainfield can be estimated to be 4 kg TN/person/year, as currently defined in the Chesapeake Bay Model.

The OWTS Expert Panel divided appropriate BMPs into two main categories: *ex situ* BMPs that occur prior to the drainfield, and *in situ* BMPs that are implemented as enhancements to the soil treatment unit, including the drainfield. Reduction credits for *ex situ* systems were compared to the baseline of 5 kg TN/person/year associated with STE. Reduction credits for *in situ* and combined BMPs were compared with the baseline edge-of-drainfield performance of 4 kg TN/person/year that was used to model the performance of a conventional septic tank coupled with a gravity-flow drainfield. Tables ES-1, ES-2, and ES-3 summarize the OWTS Expert Panel recommendations for *ex situ* BMPs, *in situ* BMPs, and combined BMPs, respectively.

Table ES-1. Summary of BMP Recommendations for *Ex Situ* Unit Processes.

Best Management Practice	Qualifying Conditions	*Ex Situ* Reduction Credit[1]
Septic tank (baseline practice)	N/A	0
NSF 40 Class I Equivalent Secondary Systems	• Certified as Class I under NSF International Standard 40 or equivalent (e.g., CAN/BNQ 3680-600, CEN Standard 12566-3) • Design, installation, and operation in accordance with manufacturer recommendations and state or local regulation	20%
Intermittent media filters	• Timer-based flow equalization with 12–24 doses/day • 2' depth (sand) media ES = 0.5–1.0 mm; UC ≤ 4.0; < 0.5% passing #200 sieve • HLR ≤ 2 gpd/sf • OLR ≤ 5 lb BOD/1,000 sf • Uniform, pressurized distribution ≤ 6 sf/orifice	20%
Constructed wetlands	• 2' depth media ES = 40–80 mm inlet/outlet; ES = 20–30 mm treatment zone • OLR ≤ 1.2 lb BOD_5/1,000 sf-day; SA ≥ 54 sf/PE • Length ≥ 50 ft • Outlet structure for variable flooding depth • 6" top layer of planting media	20%
Recirculating media filters	• Timer-based flow equalization with 24–48 doses/day • 2' depth media • Sand media: ES = 1.0–5.0 mm; UC ≤ 2.5; < 0.5% passing #200 sieve; HLR ≤ 5 gpd/sf; OLR ≤ 5 lb BOD/1,000 sf • Gravel media: ES = 5.0–20 mm; UC ≤ 2.5; < 0.5% passing #200 sieve; HLR ≤ 15 gpd/sf; OLR ≤ 15 lb BOD/1000 sf • Uniform, pressurized distribution ≤ 6 sf/orifice • Device capable of recirculating 3–5 times forward flow back to anoxic zone	50%
Anne Arundel County IFAS	• 2-day HRT anoxic chamber • 1-day HRT aerobic chamber with ≥ 600 sf surface area fixed-film media • Aeration device capable of maintaining 3.0 mg/L DO • Device capable of recirculating 3–5 times forward flow back to anoxic zone • Alarm for aeration device fault	50%
Proprietary treatment systems	• NSF 245 certification • Technology-specific • Percent removal based on qualifying third-party field testing	≥ 50%

[1] TN reduction beyond STE baseline of 5 kg/person/year. Additional TN reductions will take place in the *in situ* (soil) treatment unit.
BOD = biochemical oxygen demand; ES = effective size; HLR = hydraulic loading rate; IFAS = integrated fixed-film activated sludge; OLR = organic loading rate; UC = uniformity coefficient; HRT = hydraulic retention time; NSF = NSF

International; SA = surface area; PE = population equivalent (typically 2 PE/bedroom); gpd = gallons per day; sf = square feet.

Table ES-2. Summary of BMP Recommendations for *In Situ* Soil Treatment Unit Processes.

Best Management Practice	Qualifying Conditions	*In Situ* Reduction Credit[1]
Conventional system (baseline practice)	N/A	20%
Shallow-placed, pressure-dosed dispersal	• Drip or LPD within 12" of grade in A or A/B horizon • Credit not provided for sand or loamy sand soils • Lines placed on contour • Drip requires prefiltration system, automatic flush cycle, flow equalization, air release valves • LPD requires: working pressure head of 2–5', dosing volume of 7–10 times distribution system piping, lateral flushing provisions, max flow variation of 10% for each lateral	50%
Elevated sand mounds	• Installation within intact A or A/B horizon • Scarify surface of soil under mound • Uniform, pressurized distribution ≤ 6 sf/orifice • 1–2' layer of sand: ASTM C33; ≤ 20% by weight > 2 mm; D10 = 0.15 to 0.3 mm; UC = 4 to 6 • Max. top of sand ALR = 1 gpd/sf for STE, 2 gpd/sf for secondary • 6–12" loamy cover layer • Credit not given for sand or loamy sand textures in surface soil immediately under mound	50%
Permeable reactive barriers	• Site-specific	Case-by-case

[1] TN reduction applied to *ex situ* system effluent load (from Table ES-1.
LPD = low pressure distribution; UC= uniformity coefficient; ALR = aerial loading rate; STE = septic tank effluent; D10 = 10% cumulative undersize particle size distribution; gpd = gallons per day.

Table ES-3. Summary of Net TN Load Reductions for Combined *In Situ* and *Ex Situ* Systems.

In Situ Practice / *Ex Situ* Practice	Conventional Baseline	Shallow, Pressure Dosed	Elevated Mound
Septic Tank Baseline	4.0 kg/p/yr (0%)	2.5 kg/p/yr (38%)	2.5 kg/p/yr (38%)
NSF 40 Class I Secondary Systems	3.2 kg/p/yr (20%)	2.0 kg/p/yr (50%)	2.0 kg/p/yr (50%)
Intermittent Media Filter	3.2 kg/p/yr (20%)	2.0 kg/p/yr (50%)	2.0 kg/p/yr (50%)
Vegetated Submerged Bed	3.2 kg/p/yr (20%)	2.0 kg/p/yr (50%)	2.0 kg/p/yr (50%)
Anne Arundel Co. IFAS	2.0 kg/p/yr (50%)	1.25 kg/p/yr (69%)	1.25 kg/p/yr (69%)
Recirculating Media Filter	2.0 kg/p/yr (50%)	1.25 kg/p/yr (69%)	1.25 kg/p/yr (69%)

Note: Percent reductions in table entries represent net reduction from baseline of 4 kg/person/year.
IFAS=integrated fixed-film activated sludge; kg/p/yr = kilograms per person per year; NSF = NSF International.

In addition to the distinction between *in situ* and *ex situ* BMPs, the OWTS Expert Panel recognized fundamental differences between proprietary and nonproprietary BMPs. Proprietary systems are those developed, marketed, and constructed by a manufacturer. Nonproprietary systems are those designed on a case-by-case basis for each site. Tables ES-1, ES-2, and ES-3 address nonproprietary BMPs. A two-tiered approval protocol is recommended for proprietary BMPs since the manufacturer typically has standardized design and operating protocols, which increase the likelihood that the system will perform consistently if the manufacturer's recommendations are followed. The proprietary BMP protocol consists of an initial provisional approval on the basis of a recognized third-party testing protocol. A final approval, based on the results of the field testing, is also recommended. Nonproprietary BMPs, however, need to be evaluated on an individual basis unless the state or local government validates the performance of nonproprietary systems that are constructed with standardized system designs and materials and operated under recognized and specified operation and maintenance (O&M) protocols.

At a minimum, all of the *in situ* and *ex situ* BMPs described should have a system operator (typically a contract operator) consistent with the U.S. Environmental Protection Agency's (USEPA's) Level 2 management program model (USEPA 2003). The operator performs specified O&M activities, verifies proper system function, and reports back to the local health department (LHD) or state. An operating or construction permit should also be required. State-issued and renewable permits consistent with the USEPA's Level 3 management program model are encouraged but not deemed mandatory for reduction credit. Responsible management entities (RMEs) are also encouraged and, for permeable reactive barriers (PRBs), required.

During the course of their work, the OWTS Expert Panel considered a number of additional BMPs and related issues. Where applicable, the OWTS Expert Panel provided information and recommendations to help the CBPO and future Expert Panels refine the representation of on-site systems in the CBPO model and better understand factors associated with TN load reductions from this sector. The OWTS Expert Panel's broad recommendations include:

- **Ensuring sufficient alkalinity** is critical for nitrification and thus TN reduction. Although it is frequently monitored, little effort has been made to control alkalinity in on-site TN reduction systems. Additional research and development of alkalinity control methods would help optimize the TN removal associated with biological nitrogen removal systems and, if widely implemented, could allow for higher TN reduction credits to be justified for OWTS BMPs. The critical concern is that alkalinity control be relatively easy to manage and ideally, not be reliant on the system owner (e.g., homeowner) for effectiveness.
- **BMP sampling** is encouraged by the OWTS Expert Panel, but not recommended to be mandatory for verification or used to disqualify credit at individual sites. Monitoring plans should be left to the discretion of the states. Nevertheless, installation of BMPs throughout the watershed offers a good opportunity to collect additional data that could be useful in refining TN reduction performance and also suggest design or operational enhancements. Numerous protocols for and examples of statistically robust sampling and assessment exist and can be used by interested parties as models to design their own programs.

- **Data sharing and interstate reciprocity** should be the focus of data management efforts to support Chesapeake Bay watershed total maximum daily load (TMDL) implementation. States and local jurisdictions generally lack the resources to ensure BMP performance at a high level of confidence, either through sampling or field inspection. Additionally, duplicative protocols for technology approval can present logistical and financial obstacles for technology developers. These obstacles can preclude the display of promising TN reduction technologies, potentially at the expense of Chesapeake Bay Watershed water quality. Therefore, Chesapeake Bay Watershed states and other jurisdictions should share information to the greatest extent possible. USEPA's Office of Wastewater Management (OWM) has offered to help facilitate data sharing.
- **Soil type** should be considered as a potential predictor of TN reduction performance in future watershed models. The OWTS Expert Panel recognizes that the characteristics of the soil within the drainfield highly influence both baseline and BMP on-site system performance. Soil texture, in particular, is a relatively easy characteristic to represent in a model that is known to influence treatment. The existing model only allows the assignment of a single soil texture per county. Although the OWTS Expert Panel's analysis suggests that it is feasible to assign a predominant soil texture for each county, it is recommended that the future Attenuation Expert Panel explore this issue in more detail, since it relates to the interaction between natural soil conditions and system performance.

1 Expert Panel Charge and Membership

The OWTS Expert Panel was initially convened in January 2012 under the *Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model*. Table 1-1 lists the members of the OWTS Expert Panel.

Table 1-1. List of OWTS Panelists.

Panelist	Organization
Jim Anderson	University of Minnesota
Eric Aschenbach	Virginia Department of Health
Jason Baumgartner	Delaware Department of Natural Resources and Environmental Control
Derrick Caruthers	Delaware Department of Natural Resources and Environmental Control
Marcia Degen	Virginia Department of Health
Kitt Farrell-Poe	University of Arizona
Joshua Flatley	Maryland Department of the Environment
Robert Goo	U.S. Environmental Protection Agency
Rick Hertges	West Virginia Health and Human Services
Mike Hoover	North Carolina State University
Joyce Hudson	U.S. Environmental Protection Agency
Randy Miles	University of Missouri
Jeff Moeller	Water Environment Research Foundation
Dave Montali	West Virginia Department of Environmental Protection
Sushama Pradhan	North Carolina State University
Jay Prager	Maryland Department of the Environment

The main charge for the panel was to review available science on the pollutant removal performance of treatment practices to derive nutrient removal rates for individual on-site wastewater practices. The practices must currently be in use or have the potential of use in the Chesapeake Bay watershed. The primary objective of the OWTS Expert Panel was to review documentation and provide concise definitions and percent reductions for nitrogen load reduction practices. The OWTS Expert Panel could propose changes to the method of modeling to the CBPO.

The OWTS Expert Panel was specifically requested to provide a definition for each treatment practice and the qualifying conditions under which credits can be received. Beyond this specific charge, the panel was asked to:

- Recommend whether to establish interim removal treatment rates prior to the conclusion of the panel for watershed implementation plan (WIP) planning purposes.
- Recommend procedures for reporting, tracking, and verifying the recommended retrofit credits.

- Critically analyze any unintended consequences associated with the credits and any potential for double- or over-counting the credits.

The treatment practices initially suggested by the states to the Wastewater Treatment Workgroup (WWTWG) include:

- Shallow-placed dispersal systems using gravity flow
- Secondary treatment to shallow-placed, pressure-dosed dispersal systems
- Denitrification unit coupled with shallow-placed, pressure-dosed distribution systems

The treatment practices suggested by panel members include:

- Sand mounds
- Shallow-placed drip irrigation

OWTS Expert Panel members were surveyed for their perspectives on issues of importance to the OWTS Expert Panel's charge. Appendix A provides a summary of the survey results. Based on the survey and ensuing discussions among the OWTS Expert Panel, the list of practices was refined to include:

Ex situ (or pretreatment) system components

- NSF Standard 40 Class I secondary systems
- Intermittent (single-pass) media filters
- Constructed wetlands (vegetated submerged beds)
- Recirculating media filters (RMFs)
- Anne Arundel County Integrated Fixed-Film Activated Sludge (IFAS)
- Proprietary *ex situ* treatment systems

In situ (soil treatment) system components

- Shallow-placed, pressure-dosed dispersal
- Elevated sand mounds
- Permeable reactive barriers

The charge of the OWTS Expert Panel was to only address treatment technologies. In the future, the CBPO and another Expert Panel will review nitrogen attenuation in the soil between the edge of the treatment system (drainfield) and the edge of the receiving water. This Attenuation Expert Panel will not look at BMPs or other system modifications.

2 Baseline Loadings from On-Site Systems

2.1 Introduction

The OWTS Expert Panel was charged with developing and reviewing proposed BMPs for the on-site sector. The BMPs must be assessed against the baseline nutrient removal performance defined for conventional septic systems (septic tank and gravity-distributed drainfield) in the Chesapeake Bay Model. This section provides a summary of the OWTS Expert Panel's understanding of current model assumptions and recommends baseline figures based on those assumptions.

BMPs for the on-site sector will normally fall into one of three categories: (1) treatment to reduce TN loading to the soil; (2) soil dispersal configurations other than gravity trenches, which reduce TN from the on-site system; or (3) a combination of the two.

In order to assess proposed BMPs, a baseline TN reduction must be identified for (1) the applied TN to the soil from a conventional system, and (2) the resulting TN at the edge-of-drainfield for a conventional system.

Ideally, the reduction of TN by a BMP is based on actual influent concentration, if known. However, representative influent samples can be difficult to collect in on-site systems, owing to highly variable wastewater generation characteristics and system designs without appropriate locations for influent sampling. Therefore, the OWTS Expert Panel recommends the utilization of standard baseline TN loads based on published data.

During the period of applicability of the Chesapeake Bay Model 5.3.2, baseline edge-of-drainfield load estimates are presented consistent with the representation of conventional systems in the existing model. Future model revisions could include a variable baseline loading based on soil characteristics (e.g., texture); however, due to a lack of information, the OWTS Expert Panel could not justify a recommendation at this time.

2.2 Existing Model Synopsis

Documentation for the Chesapeake Bay Model 4.3 (Palace et al. 1998) discusses the basis for the loadings used in the model. To the OWTS Expert Panel's knowledge, subsequent versions of the model remain unchanged with regard to the on-site sector. Therefore, the OWTS Expert Panel assumes that this documentation is current and accurate. Sections H.2.2.1.3 and H.2.2.1.4 discuss the on-site sector. The following items are noted in the document:

1. The model is designed to include only three BMPs: hookup to central sewer (100 percent TN reduction credit for on-site sector); a 50 percent TN removal denitrification treatment system (50 percent reduction credit); and routine pump-out of the septic tank (5 percent reduction credit).
2. An assumed flow of 75 gpcd is used for the model (Salvato 1982a).

3. The model documentation reports a TN concentration of 39 mg/L at the edge of the septic field. In the documentation, this is noted to compare favorably with Salvato (1982a), who calculated on-site wastewater management system TN concentrations of 36 mg/L.
4. At 39 mg/L and 75 gpcd, the loading at the edge of the drainfield (defined herein as the effluent from the soil treatment system at the point where it rejoins the receiving environment) is 4 kg N/person/year or 8.82 lb N/person/year. There is insufficient information in the model documentation to directly determine the TN load applied to the soil or the influent TN to the septic tank. The model documentation provides only the edge-of-drainfield value, 4 kg/person/year.
5. The model documentation provides attenuation assumptions for the on-site sector. The documentation defines attenuation in the Chesapeake Bay Model as the reduction in TN loading that occurs between the edge-of-drainfield and the edge of the stream. The current model assumes a 60 percent attenuation rate.

The OWTS Expert Panel was instructed to not consider attenuation in the receiving environment that might occur after the effluent is discharged from the soil treatment system, because it represents nitrogen reductions not directly associated with verifiable management practices. To evaluate this issue, the CBPO will convene a separate Expert Panel or reassign the OWTS Expert Panel.

2.3 Baseline Septic Tank Effluent TN Recommendation

The applied TN loading to the soil treatment unit is equivalent to the product of the STE concentration and flow under average conditions.

Studies have attempted to quantify the raw TN inputs to a septic tank. Recent studies used whole-house raw wastewater sampling to determine the baseline measurement of pollutants. Over the last 10 years, the Colorado School of Mines (CSM) has published the most comprehensive studies. The comprehensive literature review that has served as the basis for numerous presentations and reports by the CSM research team suggests that these data support an increase in TN mass loadings from 11.2 to 13.3 g/person/day (4.09 to 4.85 kg TN/person/year).

In a 1979 study on mounds, Harkin et al. (1979) reported a TN loading of 13.7 g/person/day (5 kg N/person/year) from the septic tank. They noted that an assumed protein intake of 100 g/person/day would result in a raw wastewater load of 16.0 g/person/day (5.84 kg N/person/year).

Tchobanoglous et al. (2003) report the typical raw loading of total Kjeldahl nitrogen (TKN) from individual residences as 13.3 g/person/day (4.85 kg /person/year), with a range of 9.0 to 21.7 gpcd (3.29 to 7.9 kg/person/year) depending on the use of garbage grinders. The 13.3 g/person/day figure assumes that 25 percent of the homes have garbage grinders.

USEPA (2002) reports a range of TN mass loadings of 6 to 17 g/person/day (2.19 to 6.2 kg/person/year), with an average of 11.2 g/person/day (4.09 kg/person/year).

The Chesapeake Bay Model documentation (USEPA 2010) also recognizes that the influent load can vary and states that the TN loading rate is typically between 11 and 13 lb/person/year (5 to 6 kg/person/year).

Large studies in California (Leverenz et al. 2002; Ventura Regional Sanitation District 2001) demonstrated that septic tanks do little to reduce TN. Removal rates were not only negligible in those studies, but they were also negligible in a large field assessment and demonstration project in LaPine, Oregon (Rich et al. 2003a, 2003b).

Based on this summary of the relevant literature, the reported range of raw TN loading is from 2.19 to 7.9 kg/person/year (5 kg/person/year average of range). Accordingly, the OWTS Expert Panel assumed that the average generated TN load of 5 kg TN/person/year is delivered to the soil in the STE.

Using the existing model flow rate of 75 gpcd and the estimated load of 5kg TN/person/year, the calculated STE concentration is 48 mg TN/l. However, recent studies do not support this flow figure and resulting concentration. Studies have generally shown a decreasing trend in average daily household flows and an increase in concentration over recent years.

The model flow figure of 75 gpcd is found in several state regulations, but is thought to represent a peak day design flow from a residence, not an average flow. Therefore, this higher figure includes a hydraulic safety factor to allow for high-flow wash days, water leakage, etc. Mayer et al. (1999) conducted the largest known residential water study. The reported average demand of 69.3 gpcd includes 16 gpcd of leaks and other uses (e.g., outdoor irrigation) that might not reach the wastewater stream from the house. If this 16 gpcd were subtracted, the average daily flow would be 53.5 gpcd.

A more recent study (Rockaway et al. 2011) verifies the decline in water demand by single-family homes in North America. In this study, the researchers noted that the majority of the decline is due to reduced numbers of residents per household and the wider use of low-flow appliances and fixtures. Rockaway et al. (2011) used various models to analyze the large data set, which generally showed a 10 to 15 percent reduction in water use over the past decade. A CSM study (Tucholke et al. 2007) exhibited approximately a 30 percent reduction from the Mayer et al. (1999) figure of 69.3 gpcd to 45 gpcd based on data from monitored on-site systems in three different states.

USEPA (2002) references Anderson et al. (1994) and indicates a mean STE TKN concentration of 44.2 mg/L, with a range of 19 to 53 reported based on 11 samples. (Nitrate-N was negligible in the study with a maximum concentration of 0.16 mg/L.) However, as water use declines, the resulting concentration of constituents in wastewater tends to increase, assuming that there is little change in human-generated TN load. Studies within the last 10 years indicate higher concentrations of TN. Rich et al. (2003a, 2003b), Tucholke et al. (2007), and Harden et al. (2010) imply that STE will contain between 62 and 67 mg TN/L, and that the nitrogen is almost completely made up of organic and ammonium species.

The Maryland Department of the Environment (MDE) uses a treatment unit influent TN of 60 mg/L as the baseline concentration for comparison to the treated effluent as part of their testing protocol for denitrification treatment units. Influent to a treatment unit is typically from a septic tank or another settling tank with at least a 24-hour detention time.

Based on this summary of the relevant literature, the expected STE TN concentration in the model documentation of 48 mg/L is low compared to recent study data. The lower value is partially due to the higher flow figure used in the model. If it is assumed that the TN loads have remained the same and that the concentration varies due to flow, then comparing the concentrations based on various flow assumptions results in the TN concentrations shown in Table 2-1.

Table 2-1. TN concentration for various design flow assumptions.

Average Daily Flow (gpcd)	TN from Septic Tank (mg/L)
50	72.44
60	60.36
75	48.29

Note: Assumptions based on a constant per capita load of 5 kg/person/year.
gpcd = gallons per capita per day.

Based on this review, the OWTS Expert Panel recommends the adoption of a baseline STE TN concentration of 60 mg/L for the purposes of comparing treatment BMPs where site-specific influent concentration data is lacking. This value recognizes that using a lower daily flow figure of 60 gpcd is more representative of average flows than the model’s current 75 gpcd value, and the resulting TN concentration compares well with available data on STE concentration.

The OWTS Expert Panel recommends that the baseline load applied to the soil treatment system from a conventional septic tank be 5 kg TN/person/year, which is the loading associated with a 60 mg/L TN concentration at an assumed flow of 60 gpcd.

2.4 Baseline Edge-of-Drainfield TN Recommendation

As previously indicated, the current model documentation uses an edge-of-drainfield load of 4kg TN/person/year. Therefore, assuming that the STE load is 5 kg TN/person/year, the model assumes a baseline reduction across the drainfield of 20 percent ([(5.0-4.0)/5.0] × 100).

Conventional gravity-fed soil treatment systems can account for significant TN removal, typically in inverse proportion to soil grain size. Relatively permeable loamy soils, which might be expected at various locations in the Chesapeake Bay watershed, should provide 20 to 25 percent TN removal (Jenssen and Siegrist 1990; Long 1995). The OWTS Expert Panel believes that the current bay model baseline assumption of 20 percent TN removal by conventional systems represents a good average TN removal estimate for Chesapeake Bay watershed soils. Although some soils in the watershed will be coarser sands, which are not expected to provide as much TN removal, some are tighter clays that should provide better than 20 percent TN removal.

The OWTS Expert Panel recommends accepting the edge-of-drainfield baseline value as 4kg/TN/person/year for the purposes of comparing BMPs to conventional systems, as represented in the existing model.

2.5 Overall Recommendations for Assessing BMP Efficiencies

The overarching objective is to determine the reduction in TN loading to the Chesapeake Bay watershed for a given BMP as compared to a conventional system baseline.

BMPs for the on-site sector will normally fall into one of three categories: (1) *ex situ* treatment to reduce TN loading to the soil; (2) *in situ* soil treatment unit designs (other than baseline gravity trenches), which reduce TN from the on-site system; or (3) a combination of the two.

In order to assess proposed BMPs under (1) above, a baseline must be identified for the applied TN to the soil from a conventional system and for (2), the baseline reduction from the point of soil application to the edge-of-drainfield. The above analysis sets the baseline for (1) as 5 kg TN/person/year or 60 mg/L at 60 gpcd and for (2) as 4 kg TN/person/year, as Figure 2-1 illustrates.
Source: Joubert et al. (2005)
Figure 2-2 depicts a conventional (baseline) septic system.

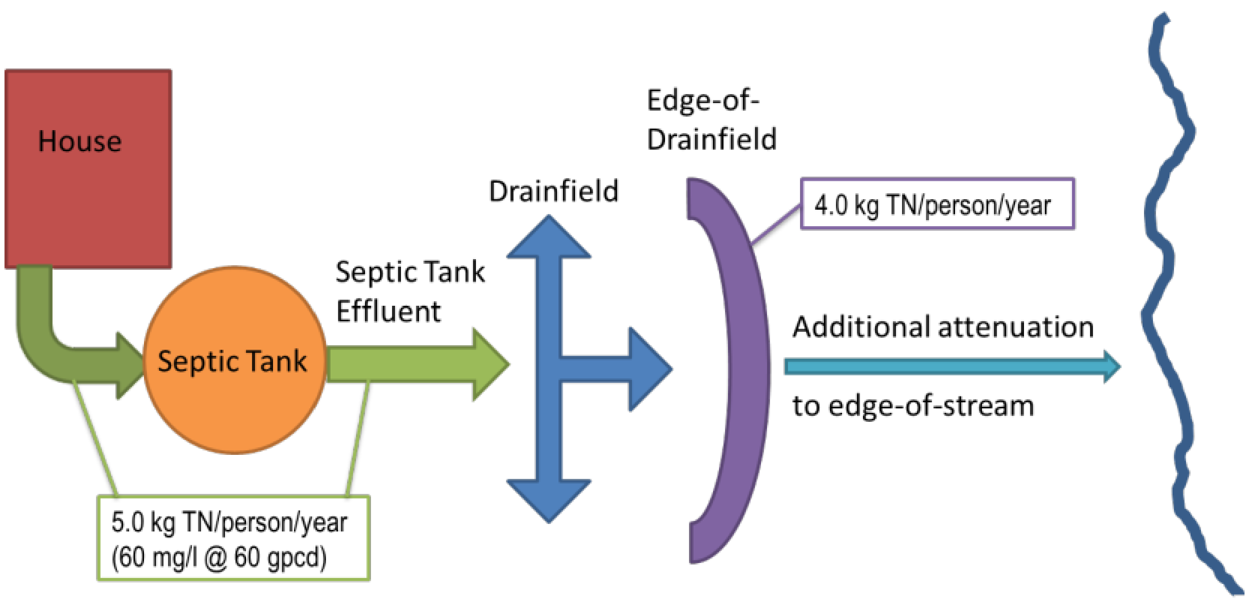
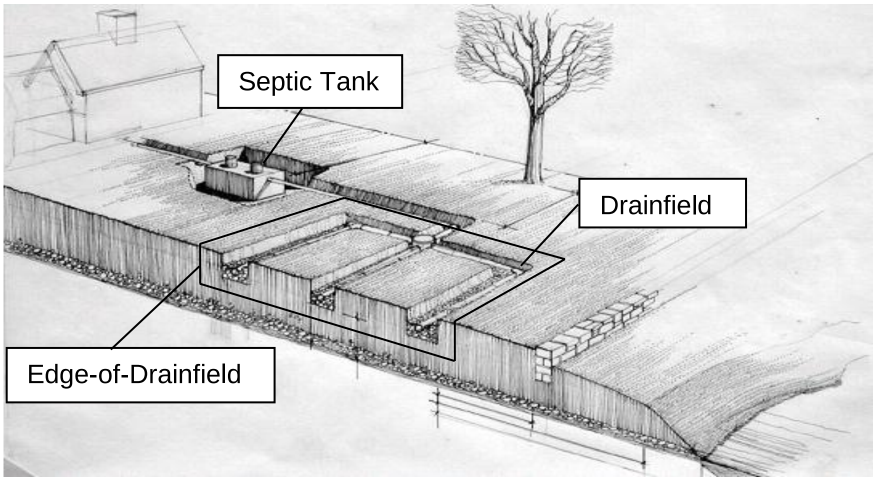


Figure 2-1. Summary of Baseline Recommendations.



Source: Joubert et al. (2005)
Figure 2-2. Drawing of Baseline Conventional Septic System.

As indicated, the CBPO will compare TN reduction systems (depicted in

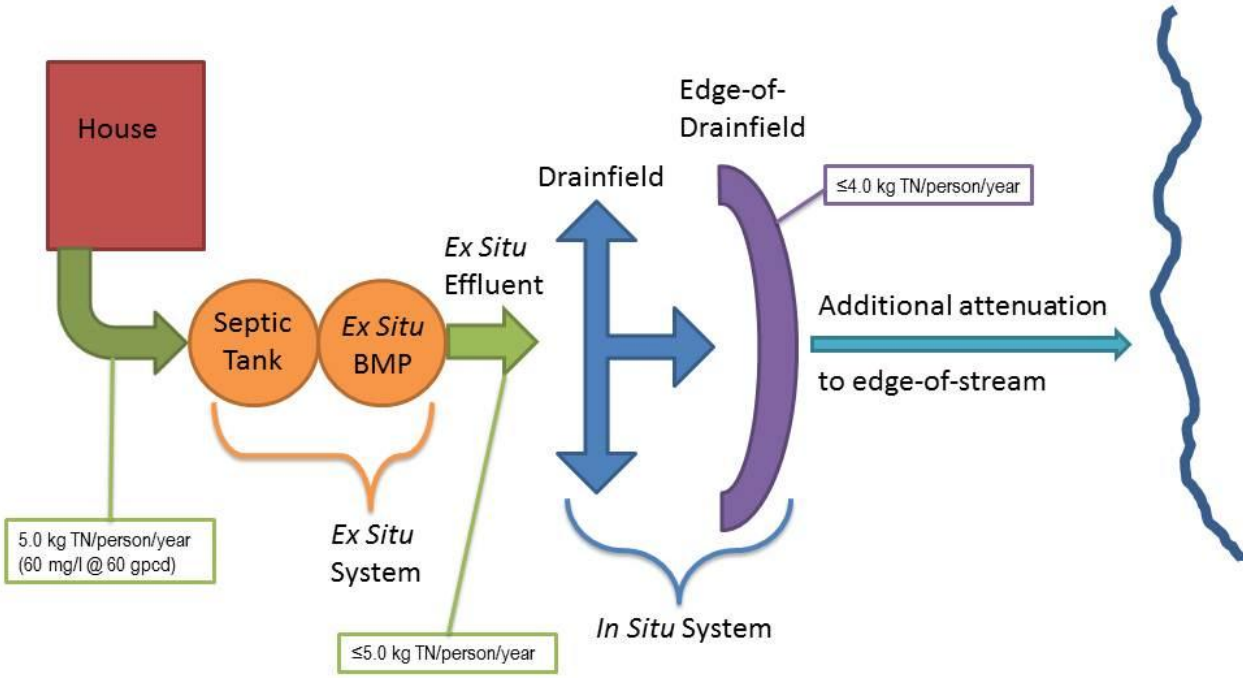


Figure **2-3** and
Source: Joubert et al. (2005)
Figure 2-4) against the baseline conventional system.

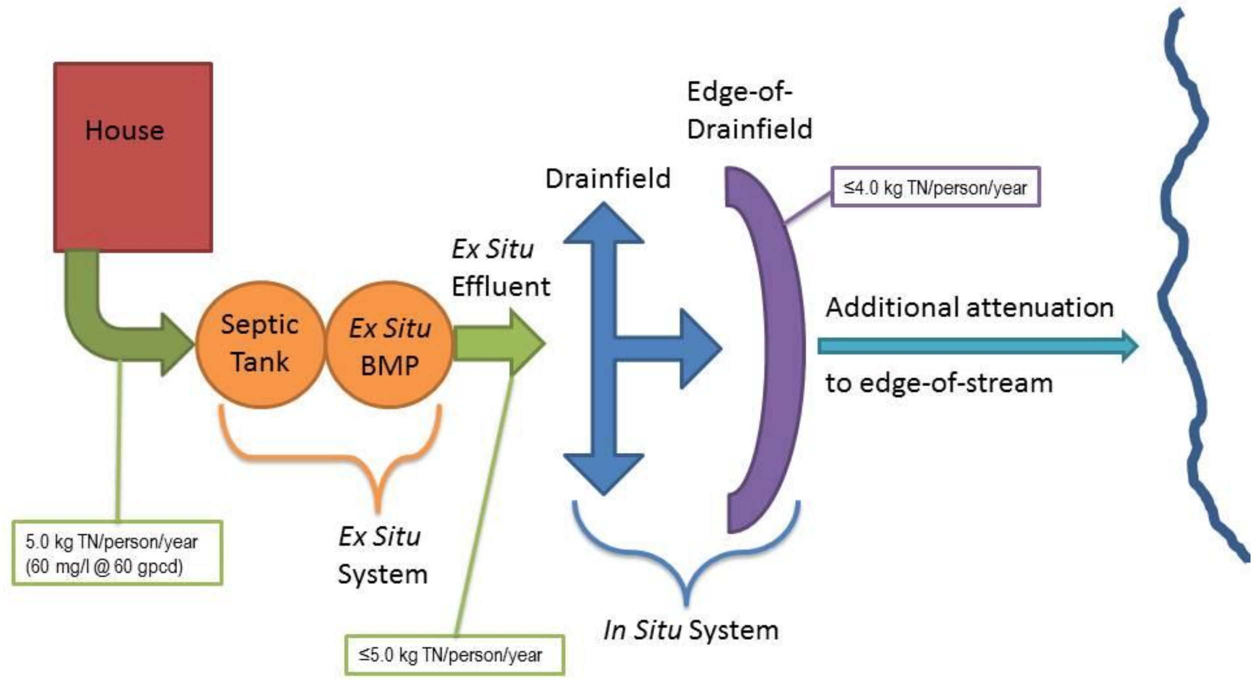
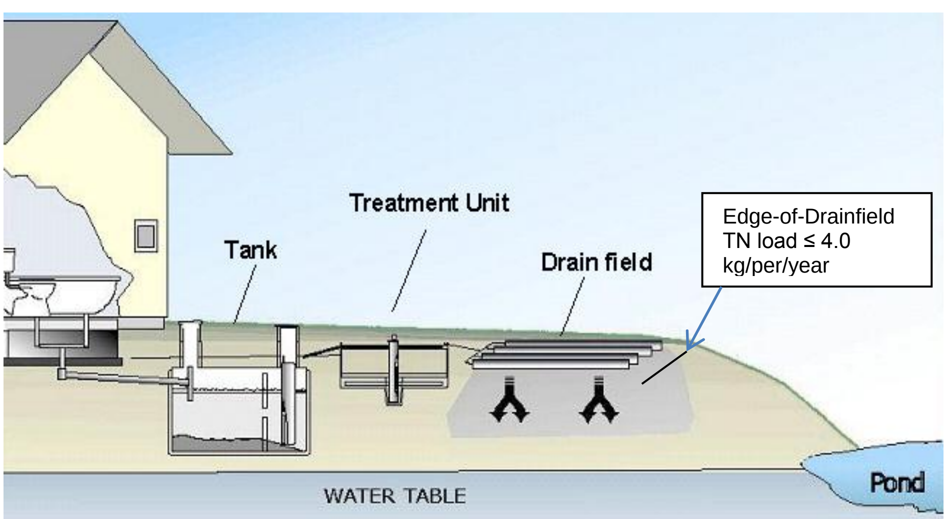


Figure 2-3. Schematic of System with BMPs.



Source: Joubert et al. (2005)

Figure 2-4. Drawing of System with *Ex Situ* BMP.

For illustration purposes, the edge-of-drainfield includes the vertical and bottom planar faces of the drainfield, which represent the transition of the drainfield's infiltrative soils through which

effluent passes to more natural soils beneath and alongside the drainfield (see
Source: Joubert et al. (2005)
Figure 2-2 and Figure 2-5). No specific dimensions are associated with the edge-of-drainfield, as they vary with site features, soil characteristics, system characteristics and other factors. Edge-of-drainfield is used conceptually in this document simply to distinguish BMPs that improve TN reduction within the system versus TN reductions that occur naturally in the receiving environment.

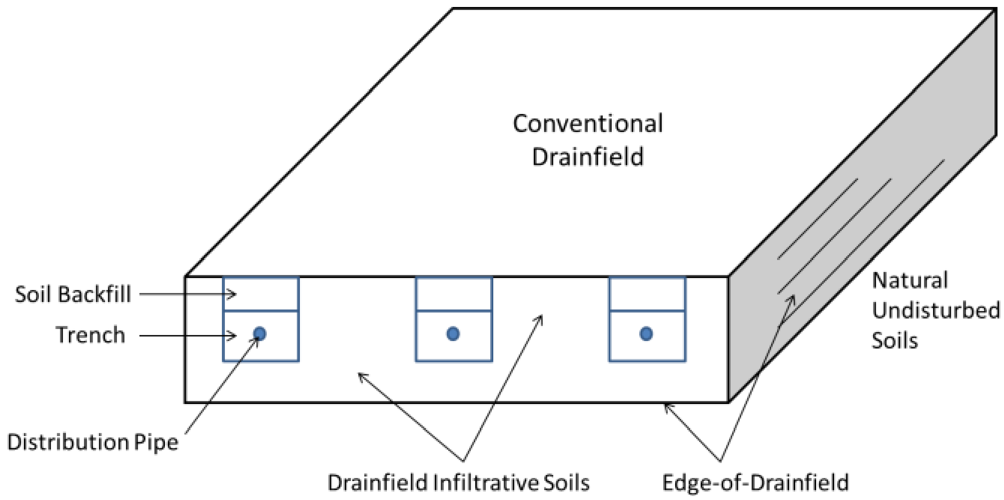


Figure 2-5. Edge-of-Drainfield Schematic Illustration.

2.5.1 Assessing *Ex Situ* Treatment to Reduce TN Prior to Soil Treatment

Ex situ treatment (often called "pretreatment") units will typically use a septic tank or other primary treatment device (e.g., trash/settling tank) followed by an advanced treatment unit. The primary treatment unit might also be used as an anoxic reactor for denitrifying recirculated nitrified secondary effluent. The point of assessment for the BMP efficiency is at the end of the treatment process prior to application to the soil. The TN load reduction is based on a reduction in the load of TN in the effluent, as compared to the influent, TN load (5 kg/person/day or 60 mg/L).

In controlled testing facilities, influent and effluent flow and TN concentrations can be monitored so that the load reduction through the treatment unit can be calculated. However, in more representative field testing, it is difficult to measure flow from an individual household because most systems are not equipped with a flow monitoring device. It is exceptionally difficult to collect a representative sample of raw wastewater from a home, given widely varying flows and usage types throughout the day. Sampling from the septic tank is an accepted way to collect representative composite samples from households, but the design of some treatment units (e.g., ones that recirculate back to the septic or anoxic tank) makes it difficult to measure the influent into a treatment unit.

Based on a review of the available information, the OWTS Expert Panel recommends that for *ex situ* treatment units, the TN reduction across the drainfield be the same as for STE (e.g., 20 percent for a baseline conventional system). However, the assumption of consistent TN reduction across the soil treatment system, regardless of pretreatment effluent characteristics, is the subject of much debate. As researchers learn more about the relationship between nitrogen removal in pretreatment stages versus nitrogen removal in the soil treatment unit, more specific recommendations might be possible.

2.5.2 Assessing *In Situ* Treatment to Reduce TN within Soil Unit

According to the model, the baseline removal across a conventional gravity-fed drainfield is 20 percent or 1 kg TN/person/year, because it reduces the load from 5 to 4 kg TN/person/year at the edge of the drainfield. Any soil-based BMP, such as a modified dispersal method, must demonstrate a reduction in applied TN in excess of 20 percent or demonstrate an edge-of-drainfield load of less than 4 kg TN/person/year. The TN reduction credit would be for the additional removal beyond the baseline.

Soil-based BMP efficiency should recognize these baselines during the period of applicability of the existing model. Although the existing model was designed to reflect a 20 percent N reduction for the drainfield, the use of varying baselines in future models (i.e., adjusted for soil texture) could improve the accuracy of future model runs.

2.5.3 Assessing Combined *Ex Situ*/*In Situ* BMPs

Combined *ex situ/in situ* BMP designs must be assessed based on performance of the overall system rather than on the individual components. In other words, the combined BMP must ultimately reduce TN below the edge-of-drainfield value of 4 kg TN/person/year in the model baseline (i.e., more than the 20 percent from the raw loadings of 5 kg TN/person/year).

Section 3 addresses credits for combined BMPs, along with credits for stand-alone *ex situ* and *in situ* BMPs.

3 BMP Definitions and Qualifying Conditions

In this section, nitrogen reduction credits associated with treatment and dispersal technologies recognized as BMPs are assumed to provide average nitrogen reduction performance across the population of installed systems, provided that the system is verified to be maintained and functioning as designed. The OWTS Expert Panel does not recommend sampling each system on an ongoing basis to confirm the TN reduction due to the expense to system owners. Accordingly, the OWTS Expert Panel only recommends as BMPs those (nonproprietary) treatment units whose performance is well-supported by science and verifiable data.

As previously described, the OWTS Expert Panel considered two main categories of BMP types: *ex situ* BMPs (precede the soil treatment unit) and *in situ* BMPs (implemented within or down-gradient of the soil treatment unit).

The subsections that follow provide BMP recommendations to complement existing state regulations and policies, not to supplant them. Although states should apply the recommended nutrient reduction credits equally, recommendations regarding design criteria and management (e.g., O&M, verification) provisions should be customized to ensure consistency with existing state practices.

Likewise, the OWTS Expert Panel acknowledges that most states have certain criteria (e.g., design flow rates above a set number, typically 2,000 to 5,000 gallons per day [gpd]), that trigger additional restrictions (e.g., design and certification by Professional Engineer, state approval, additional permits, additional management provisions, etc.). Accordingly, these recommendations are intended to apply to only those systems that do not exceed these state-specific thresholds. For proprietary systems and the smaller set of high-risk (e.g., larger) systems that do trigger additional state requirements, states should be encouraged to provide more robust, case-by-case verification of TN reduction than the minimum standards identified herein.

The OWTS Expert Panel recommends following the Wastewater Treatment Workgroup (WWTWG) BMP Verification Protocol Narrative for on-site system BMPs. On-site TN removal systems are highly dependent on proper oversight to ensure sustained performance. The OWTS Expert Panel provides recommendations for O&M frequency and activities in the recommendations for individual BMPs below.

Nitrification is the most critical step in the overall nitrogen removal process because nitrifying bacteria are slow-growing and their growth is easily inhibited. Some of the factors that can inhibit nitrification are: low temperature, non-neutral pH, inadequate alkalinity, low dissolved oxygen (DO), high biochemical oxygen demand (BOD), and inhibitory chemicals. Due to these factors, and flow rates and wastewater characteristics that can vary greatly from household to household (and even from individual homes over time), achieving optimum levels of nitrogen reduction from individual homes is not always possible. However, performance will greatly improve if trained practitioners provide responsible operation and maintenance.

At a minimum, all of the *in situ* and *ex situ* BMPs described should have a system operator (typically a contract operator) consistent with USEPA's Level 2 management program model

(USEPA 2003). The operator performs specified O&M activities, verifies proper system function, and reports back to the LHD or state. An operating or construction permit should also be required. State-issued and renewable permits consistent with the USEPA's Level 3 management program model are encouraged but not deemed mandatory for reduction credit. RMEs are also encouraged and, for PRBs, required. The RME role can be fulfilled by LHDs, public or private wastewater utilities, and some system manufacturers.

Given the variability between states on how they regulate and evaluate on-site systems, each state and their local LHDs must determine BMP verification provisions. It is anticipated that BMP system installations need to be documented when approved and reported to the state by the LHD.

In Delaware, a management contract is required for at least 2 years. Any interruption of that contract will likely be reported to the LHD, which will in turn notify the state as a further check on the status of the system. For innovative/alternative technologies, the contract must last the life of the system.

MDE tracks best available technology (BAT) for TN removal. The state requires servicing by certified service providers trained by the product manufacturers (for proprietary systems). Annual reporting is necessary.

In Virginia, all alternative system designs less than or equal to 1,000 gpd are regulated under the Regulations for Alternative On-Site Sewage Systems which require an O&M manual, a minimum of one O&M visit per year by a licensed operator, and BOD_5 (and possibly residual chlorine and fecal coliforms) measurement within 180 days of startup and every 5 years thereafter for all third-party tested systems. If a third party does not test the system, the frequency increases to every 6 months for 2 years, with an assessment made of performance after a total of 5 samples are collected. For systems greater than 1,000 gpd, the requirements for O&M and monitoring increase as the flows increase.

3.1.1 Overarching Management Activities

Reducing the TN in systems at individual homes requires proper operation and maintenance of the systems. The BMP recommendations in this document provide specific verification and O&M requirements.

Certain operational factors and considerations are common to the recommended BMPs that rely on biological nitrogen removal (BNR; nitrification followed by denitrification). In certain applications, nitrification and denitrification processes can be tested during maintenance visits by methods that give immediate results, to allow for immediate operational adjustments if necessary. Commercially available test kits provide a quick and inexpensive method of field testing the effluent of BNR systems. While not recommended for use to disqualify credit, this type of monitoring and subsequent mitigating action might allow improved performance at an individual site. Important factors for BNR include the following:

- Optimum pH range for nitrification is 6.5 to 8.0. Therefore, in areas with acidic (low alkalinity) well waters, nitrification could be inhibited. If nitrification is restricted, then so is denitrification. To ensure adequate buffering for nitrification, maintain alkalinity levels of no less than 50 mg/L as $CaCO_3$ in the final effluent. Where the influent alkalinity is less than 200 mg/L as $CaCO_3$, alkalinity feed should be included in the design. Supplemental alkalinity can be provided through the drinking water supply or be added to the wastewater system through a dosing system, calcite filter, etc.

- Nitrifying bacteria are susceptible to a wide range of organic and inorganic inhibitors**.** The type of cleaning products and practices used at households can greatly affect nitrification. Not only can the overuse of antibacterial and disinfecting chemicals inhibit nitrification, but so can certain concentrations of surfactants from the major brands of laundry detergents.
- Additionally, it should be noted that optimum nitrification occurs around 30 °C (86 °F); at 10 °C (50 °F), nitrification is only 20 percent as fast. This is mainly for information, although there are some things that an operator can do to a suspended growth system to compensate for depressed reaction rates during colder conditions (e.g., increasing sludge age by wasting less).

3.2 Proprietary and Nonproprietary BMPs

On-site systems use both proprietary and nonproprietary treatment technologies. Proprietary systems are those developed, marketed, and constructed by a manufacturer. The manufacturer typically also has some responsibility for system design, installation, and ongoing management (a required responsibility in many states). Because of these factors, and because these systems are typically standardized in their design and construction and there is little variability between the same model delivered to different job sites, states typically grant manufacturers model-specific approvals.

Nonproprietary systems are those designed on a case-by-case basis for each site. These are typically constructed using nonspecific and readily available materials and mechanical equipment. Although design standards for these nonproprietary systems exist, design variations based on locally available materials and designer preferences are common. In contrast to proprietary systems, LHDs or states typically approve these on a case-by-case basis.

In general, the OWTS Expert Panel does not favor assigning TN reduction credits and BMP specifications to general categories of proprietary treatment units, due to the wide range of results for designs within the same general categories. An exception was made for NSF Standard 40 certified systems as described in section 3.4. Additionally, there are several nonproprietary BMPs that have been well-documented to achieve consistent TN reductions when following specific design criteria. This report addresses some selected nonproprietary systems, and additional systems can be added in the future as needed. It is anticipated that other nonproprietary engineered designs will eventually be added to this list when sufficient data are generated to support the given design and associated TN reduction credit.

3.2.1 Proprietary System Protocol

A proprietary system should undergo third-party testing before it is recognized as a system that can achieve a given effluent quality. Many states have a protocol for recognizing proprietary systems as meeting a defined effluent quality. These protocols vary from acceptance of third-party testing according to a standard protocol such as NSF International (formerly the National Sanitation Foundation), to a combination of a third-party and in-state field testing. This discussion outlines a recommended protocol for accepting proprietary products as a recognized BMP with a defined TN reduction credit. This recommended protocol is not meant to supplant existing protocols, but rather to encourage states to pool resources and data for TN-reducing BMPs in the Chesapeake Bay watershed.

The OWTS Expert Panel recommends two-tiered protocol that consists of an initial provisional approval on the basis of NSF Standard 245 certification, a recognized third-party testing protocol. The OWTS Expert Panel also recommends that final BMP approval be based on the results of field testing. The provisional approval would allow a system to initially be used in a state, but would require field testing to verify the TN reduction credit. Once a treatment design passes the field testing component, the proprietary treatment technology would be accepted as a full BMP. MDE's Bay Restoration Fund provides a good example of such a two-tiered protocol adopted by a Chesapeake Bay watershed state (MDE 2013).

Provisional Testing: A third party must conduct provisional testing at or near the unit's design flow and loading for BOD_5, total suspended solids (TSS), and TN. There is currently only one recognized protocol that evaluates TN reduction in treatment units. NSF Standard 245 evaluates the percent TN reduction through the treatment unit. Certification under NSF Standard 245 requires a TN reduction of at least 50 percent. The CBPO and Chesapeake Bay Watershed states can consider other protocols as they are developed and proposed for use. Appropriate protocols must minimally include loading at or near the design flow; stress test mode; documentation of influent conditions including alkalinity; and seasonal variation.

Field Testing: The OWTS Expert Panel strongly recommends field testing because of the potential for high variability in field performance versus performance in controlled testing. The field testing should incorporate the following elements:

1. A third party should conduct the field testing.
2. A minimum of 12 field sites should be sampled.
3. There should be a minimum of four sampling events per site over four seasons.
4. All sampling and analyses must follow 40 CFR 136 for sample collection, sample preservation, holding times, and analytical procedures. 24-hour composite samples should be collected for all parameters except pH and alkalinity.
5. Paired influent and effluent sampling is necessary to verify the TN reduction capability, unless the state accepts an assumed influent (e.g., 60 mg/L).
6. Influent parameters to be tested include BOD_5, TSS, flow, pH, TKN, and alkalinity.
7. Effluent parameters to be tested include BOD_5, TSS, pH, TKN, nitrite-N, nitrate-N, and alkalinity.

Influent sampling can be difficult depending on the design of the treatment unit. For those systems that receive influent from a primary unit (settling tank or septic tank), the OWTS Expert Panel recommends that the effluent from that primary unit be sampled as the influent to the treatment unit. Some states have opted to not include influent sampling due to the difficulty in obtaining a representative sample. Therefore, these states rely on an assumed influent TN concentration of 60 mg/L. The OWTS Expert Panel recommends that where paired influent/effluent data are not available, an influent of 60 mg/L TN to an *ex situ* treatment unit be assumed (e.g., an effluent TN of 30 mg/L would reflect a 50 percent TN reduction).

Field testing does not necessarily have to be unique to a particular state. States should consider utilizing field data collected in other states if the climate is similar and the data collection methodology is adequate. The OWTS Expert Panel recommends that USEPA serve as a repository for data collected from various states. The data could be used in accordance with each state's protocol for data analysis and acceptance or rejection of a treatment unit.

Under the recommended protocol, technologies exhibiting a TN reduction of greater than 50 percent will be assigned a TN reduction credit of 50 percent. If, however, the technology will be managed according to USEPA's Level 3 management program model (or higher), the actual field-verified TN reduction can be used as the credit. USEPA's Level 3 management program model includes state-issued and renewable permits, in addition to service contracts and other requirements of lower level management program models (USEPA 2003).

Data Analysis: Long-term averages are most relevant to determine compliance with TMDLs. Therefore, the data from each unit in the field test should be averaged, and then the means from all treatment units averaged. The mean of the aggregated data establishes the TN reduction credit for the BMP.

3.2.2 Nonproprietary System Protocol

The OWTS Expert Panel recommends a two-step approach for engineered nonproprietary systems that are not currently assigned nitrogen reduction credits in this document. The first step would be the submittal of engineering design justification that follows standard engineering practice for nitrogen removal. The system should then undergo accelerated testing to verify the design and estimated TN removal. Testing should be at least 1 to 2 years in duration, seasonal, and otherwise in accordance with the field testing protocol for proprietary systems.

Those seeking watershed-wide approval for nonproprietary systems will need to contact the WWTWG, which can then assign the BMP review to the OWTS Expert Panel. The BMP recommendations and supporting information reported below provide good examples of the type of information and level of detail required for justifying new BMPs.

3.3 BMP Summary Recommendations

The OWTS Expert Panel has defined BMPs for both *ex situ* and *in situ* treatment. *Ex situ* processes are those occurring prior to dispersing effluent into the soil treatment unit (described in section 3.2.1). The baseline *ex situ* technology is the septic tank, for which the OWTS Expert

Panel recommends no TN reduction credit (i.e., STE TN will be the same as the TN for raw wastewater, 5 kg/person/year). *Ex situ* BMPs include various suspended growth, attached growth, and hybrid biological treatment processes for secondary treatment. The OWTS Expert Panel recommends an additional overarching BMP category to account for the many proprietary technologies available (described in section 3.2.1).

There are *ex situ* pretreatment devices available that are generally expected to provide 20 to 25 percent nitrogen reduction, including properly loaded aerobic treatment unit (ATU) systems, sand and peat filters, and vegetated submerged beds (subsurface wetlands). Higher TN removals of around 50 percent are achievable using recirculating media filters. The best removals of about 90 percent can be achieved using denitrification systems that use additional labile carbon materials (e.g., wood chips) to drive the reaction to near completion. For all BMPs, the OWTS Expert Panel assumed standard residential-strength STE with a TN of approximately 60 mg/L; 150 to 250 mg/L BOD_5; TSS of 50 to 100 mg/L; and fats, oils and greases (FOG) below 15 mg/L. Large, non-residential systems and systems treating higher-strength wastewaters (e.g., restaurants) should be handled by CBPO and the states on a case-by-case basis.

Table 3-1. Summary of BMP Recommendations for *Ex Situ* Unit Processes.

Best Management Practice	Qualifying Conditions	*Ex Situ* Reduction Credit[1]
Septic tank (baseline practice)	N/A	0
NSF 40 Class I Equivalent Secondary Systems	• Certified as Class I under NSF International Standard 40 or equivalent (e.g., CAN/BNQ 3680-600, CEN Standard 12566-3) • Design, installation, and operation in accordance with manufacturer recommendations and state or local regulation	20%
Intermittent media filters	• Timer-based flow equalization with 12–24 doses/day • 2' depth media ES = 0.5-1.0 mm; UC ≤ 4.0; < 0.5% passing #200 sieve • HLR ≤ 2 gpd/sf • OLR ≤ 5 lb BOD/1000 sf • Uniform, pressurized distribution ≤ 6 sf/orifice	20%
Constructed wetlands	• 2' depth media ES = 40–80 mm inlet/outlet; ES = 20–30 mm treatment zone • OLR ≤ 1.2 lb BOD_5/1000 sf-day; SA ≥ 54 sf/PE • Length ≥ 50 ft • Outlet structure for variable flooding depth • 6" top layer of planting media	20%
RMF	• Timer-based flow equalization with 24–48 doses/d • 2' depth media • Sand media: ES = 1.0–5.0 mm; UC ≤ 2.5; < 0.5% passing #200 sieve; HLR ≤ 5 gpd/sf; OLR ≤ 5 lb BOD/1000 sf • Gravel media: ES = 5.0–20 mm; UC ≤ 2.5; < 0.5% passing	50%

Best Management Practice	**Qualifying Conditions**	***Ex Situ* Reduction Credit[1]**
	#200 sieve; HLR ≤ 15 gpd/sf; OLR ≤ 15 lb BOD/1000 sf • Uniform, pressurized distribution ≤ 6 sf/orifice • Device capable of recirculating 3–5 times forward flow back to anoxic zone	
Anne Arundel County IFAS	• 2-day HRT anoxic chamber • 1-day HRT aerobic chamber with ≥ 600 sf surface area fixed-film media • Aeration device capable of maintaining 3.0 mg/L DO • Device capable of recirculating ≥ 3 times forward flow back to anoxic zone • Alarm for aeration device fault	50%
Proprietary treatment systems	• NSF Standard 245 certification • Technology-specific • Percent removal based on qualifying third-party testing	≥ 50%

[1] TN reduction beyond STE baseline of 5 kg/person/year. Additional TN reductions will take place in the *in situ* (soil) treatment unit.
BOD = biochemical oxygen demand; ES = effective size; HLR = hydraulic loading rate; OLR = organic loading rate; RMF = recirculating media filters; UC = uniformity coefficient; IFAS = integrated fixed-film activated sludge; SA = surface area; PE = population equivalent (typically 2 PE/bedroom); gpd = gallons per day; sf = square feet.

In situ processes are those occurring after *ex situ* treatment, within the soil treatment unit (**Error! Reference source not found.**). The baseline *in situ* technology is a conventional gravity flow, gravel trench drainfield, for which the OWTS Expert Panel recommends a baseline 20 percent reduction in TN is recommended (i.e., STE TN will be reduced by 20 percent to 4 kg/per/year).

Table 3-2. Summary of BMP Recommendations for *In Situ* Soil Treatment Unit Processes.

Best Management Practice	Qualifying Conditions	*In Situ* Reduction Credit[1]
Conventional system (baseline practice)	N/A	20%
Shallow-placed, pressure-dosed dispersal	• Drip or LPD within 12” of grade in A or A/B horizon • Credit not provided for sand or loamy sand soils • Lines placed on contour • Drip requires: prefiltration system, automatic flush cycle, flow equalization, air release valves • LPD requires: working pressure head of 2–5’, dosing volume of 7–10 times distribution system piping, lateral flushing provisions, max flow variation of 10% for each lateral	50%
Elevated sand mounds	• Installation within intact A or A/B horizon • Credit not provided for sand or loamy sand surface soils under mound • Scarify surface of soil under mound • Uniform, pressurized distribution ≤ 6 sf/orifice • 1–2’ layer of sand: ASTM C33; ≤ 20% by weight > 2 mm; D10 = 0.15 to 0.3 mm; UC = 4 to 6 • Max. top of sand ALR = 1 gpd/sf for STE, 2 gpd/sf for secondary • 6–12” loamy surface layer	50%
Permeable reactive barriers	• Site-specific	Case-by-case

[1] TN reduction applied to *ex situ* system effluent load (from Table 3-1).
LPD= low pressure dispersal; UC= uniformity coefficient; ALR = aerial loading rate; STE= septic tank effluent.

Table 3.3 summarizes recommended TN reduction credits for combinations of *in situ* and *ex situ* systems.

Table 3-3. Summary of Net TN Load Reductions for Combined *In Situ* and *Ex Situ* Systems.

In Situ Practice / *Ex Situ* Practice	Conventional Baseline	Shallow, Pressure Dosed	Elevated Mound
Septic tank baseline	4.0 kg/p/yr (0%)	2.5 kg/p/yr (38%)	2.5 kg/p/yr (38%)
NSF 40 Class I Secondary Systems	3.2 kg/p/yr (20%)	2.0 kg/p/yr (50%)	2.0 kg/p/yr (50%)
Intermittent Media Filter	3.2 kg/p/yr (20%)	2.0 kg/p/yr (50%)	2.0 kg/p/yr (50%)
Vegetated Submerged Bed	3.2 kg/p/yr (20%)	2.0 kg/p/yr (50%)	2.0 kg/p/yr (50%)
Anne Arundel Co. IFAS	2.0 kg/p/yr (50%)	1.25 kg/p/yr (69%)	1.25 kg/p/yr (69%)
Recirculating Media Filter	2.0 kg/p/yr (50%)	1.25 kg/p/yr (69%)	1.25 kg/p/yr (69%)

Note: Percent reductions in table entries represent net reduction from baseline of 4 kg/person/year at edge-of-drainfield.
IFAS = integrated fixed-film activated sludge; kg/p/yr = kilograms per person per year.

The subsections below provide detailed recommendations for each BMP.

3.4 SECONDARY TREATMENT SYSTEMS CERTIFIED UNDER NSF STANDARD 40 CLASS I OR EQUIVALENT

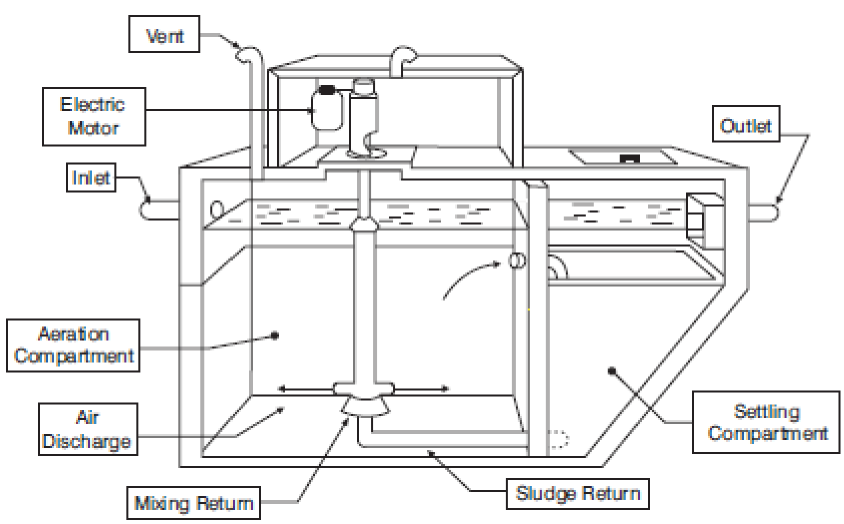
3.4.1 Detailed Definition of Practice

The NSF Standard 40 Class I protocol (and related protocols, including CAN/BNQ 3680-600 and CEN Standard 12566-3) evaluates a variety of treatment units for compliance with the construction and effluent standards of the protocol. These units are certified to produce effluent that is less than or equal to 30 mg/L BOD_5 and TSS. The treatment processes fall into three broad categories: activated sludge, fixed film, and a combination of the two.

USEPA (2002) defines the activated sludge process as an “aerobic suspended-growth process that maintains a relatively high population of micro-organisms (biomass) by recycling settled biomass back to the treatment process.” For on-site wastewater treatment systems, this process typically consists of a primary settling zone, an aeration zone, and a clarification zone. In the primary settling zone, heavier solids and floatables are removed. The settled effluent travels to the aeration zone where air is injected into the liquid for mixing and to increase the DO concentration, which facilitates breakdown of the waste by the micro-organisms. In the clarification zone, the biomass is separated from the treated effluent by gravity settling. The biomass is returned to the aeration zone for additional treatment. The clarified effluent is distributed to the drainfield.

The configuration of the system varies by manufacturer. Source: USEPA (2002)

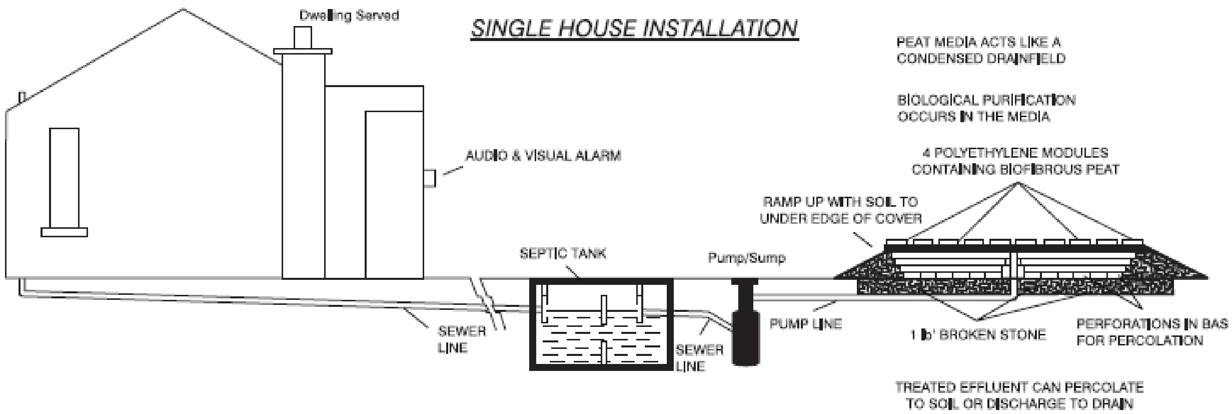
Figure 3-1 shows a common configuration.



Source: USEPA (2002)
Figure 3-1. Typical continuous flow, suspended growth aerobic treatment unit.

Fixed-film treatment units apply settled wastewater to a media in an unsaturated environment. The media used include sand, gravel, plastic, textile, and peat. The units may or may not have a

recycle component. Source: USEPA (2002)
Figure 3-2 shows a common system layout.



Source: USEPA (2002)
Figure 3-2. Fixed-film system using peat moss as a treatment medium.

A variation of the treatment process involves the addition of a fixed-film media to the suspended growth process so that the process uses both fixed and suspended growth. This combined treatment process is referred to as an integrated fixed-film activated sludge (IFAS) system.

Nitrogen is not actively removed by such treatment units, but there are incidental losses that occur through the settling in the primary zone, uptake by the micro-organisms in the activated sludge, and denitrification in the clarifier.

This BMP applies to treatment units that are certified to Class I under NSF Standard 40 or its equivalent.

3.4.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that NSF Standard 40 Class I Equivalent units designed, installed, operated, and maintained in accordance with this section be assigned a 20-percent TN reduction, for an *ex situ* effluent concentration of 48 mg/L TN or an effluent TN load of 4 kg/person/year going into the drainfield. Table 3-3 summarizes net TN reductions for various combinations of *ex situ* and *in situ* BMPs.

The removal of N in these systems is limited and occurs to some degree by several pathways.

- N associated with solids is removed in primary settling.
- N (in the form of the relatively volatile ammonia ion) is stripped from solution during aeration.
- N is incorporated into the cell mass and typically represents about 10 percent of the cell mass. When the activated sludge is removed from the system, the N present in the cell mass is removed.
- Anoxic conditions and denitrification can occur in the clarifier and in the aeration chamber due to slow removal rates of the settled sludge or aeration dead zones. USEPA (2002) notes that average TN concentrations in older residential extended aeration unit

effluents ranged from 17 to 40 mg/l. USEPA (2002) goes on to note that most aerobic units, including IFAS, remove 15 to 25 percent TN.

For fixed-film systems, USEPA (2002) notes that removal rates range from 0 to 35 percent.

For the National Pollution Discharge Elimination System (NPDES)-permitted treatment facilities, Virginia conducted a study of the reported TN in the effluent from secondary treatment systems. Approximately 25 treatment plants contributed data. None of the plants were operating in other than a secondary treatment mode. The reported average TN was 18.7 mg/l with an assumed influent of 30 mg/l (37 percent TN reduction) (John Kennedy, VA Department of Environmental Quality, personal communication). The Virginia Department of Environmental Quality later used this average TN concentration as a default TN loading in the TMDL for the existing discharging systems. The reduction is noted to have been credited to some nitrification and then unintended denitrification in dead zones in aeration tanks and clarifiers. The 37 percent removal rate compares well with reported TN removal rates in engineering texts of less than 40 percent for conventional primary and secondary treatment plants (Hammer 1975).

While the OWTS secondary treatment units use the same basic processes as the larger discharging secondary treatment plants, the OWTS systems are not actively managed. As a result, the OWTS Expert Panel does not expect them to achieve the same levels of removals as the discharging secondary plants. For example, the N that is captured in solids or biomass can be released back into the water column of the treatment unit if the solids are not removed on a routine basis. The amount of nitrification that occurs is also limited by alkalinity and aeration, so the amount of N available for denitrification is limited. As a result, the OWTS Expert Panel has set the BMP removal rate at 20 percent to reflect the limited O&M occurring, and also to recognize the benefit of using secondary treatment in reducing N applied to the soil.

The BMP is limited to proprietary treatment units certified under the NSF 40 Class I standard or equivalent, including CAN/BNQ 3680-600 used in Canada and CEN Standard 12566-3 used in the European Union. No field testing is required for the BMP because the units do not actively remove N. The BMP recognizes the incidental N removal that occurs in all secondary treatment units. The limitation of the BMP to NSF Standard 40 Class I Equivalent units will ensure that only third-party tested units are used, which will provide assurance that (1) the units will function as secondary treatment systems with the incidental TN removal; (2) the units have been proven to meet the construction and function standards of the NSF protocol; and that (3) the units will function as designed.

3.4.3 Ancillary Issues and Interactions with Other Practices

Several of the bay states have used secondary treatment units to offset site limitations such as depth to restrictions and drainfield area. These units reduce BOD_5 and TSS to 30 mg/L or less, and also reduce the level of pathogens. The reduced organic and solids load extends the life of the drainfield and the reduced level of pathogens reduces the public health risk. Therefore, there is benefit to public health and the environment from using secondary treatment systems even though they do not actively remove TN.

As with any of the *ex situ* BMPs, this BMP will interact with *in situ* BMPs to further reduce the TN released to the environment.

3.4.4 Design and Installation Criteria

Minimum design and installation criteria for NSF Standard 40 Class I Equivalent proprietary treatment units include:

- Certified under NSF Standard 40 Class I or equivalent (e.g., CAN/BNQ 3680-600, CEN Standard 12566-3)
- Sized in accordance with local regulations for flow and loading
- Selection of the proper size unit in accordance with manufacturer's information with regard to design flow and load
- An appropriately sized primary settling tank if not integral to the treatment unit
- Siting of the unit in accordance with local regulations
- Installation of the unit in accordance with the manufacturer's instructions.
- Startup of the unit in accordance with the manufacturer's instructions.

3.4.5 Temporal Performance

As with most biological systems, secondary treatment units will take several weeks to be fully functional. The time frame is dependent on the temperature and the loading. Warmer temperatures will speed up the time to full function. Low loading will reduce the time to full function.

3.4.6 Recommended Management Requirements

In general the system should follow the manufacturer's recommended O&M requirements. Additional O&M visits may be needed for proper operation. Ancillary equipment (e.g., separate septic tank, effluent filter, pump tanks, and drainfield) will require additional O&M.

Annual Inspection Checklist

- Check all mechanical systems such as pumps and blowers for proper operation. Perform any maintenance required such as cleaning filters, lubrication, etc.
- Check the sludge depth in the aeration zone and clarifier, and pump out if needed.
- Follow the manufacturer's instructions for O&M for additional detail. More frequent O&M visits may be needed to ensure proper operation.
- Conduct other generic O&M procedures as needed depending on the other components of the system (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).

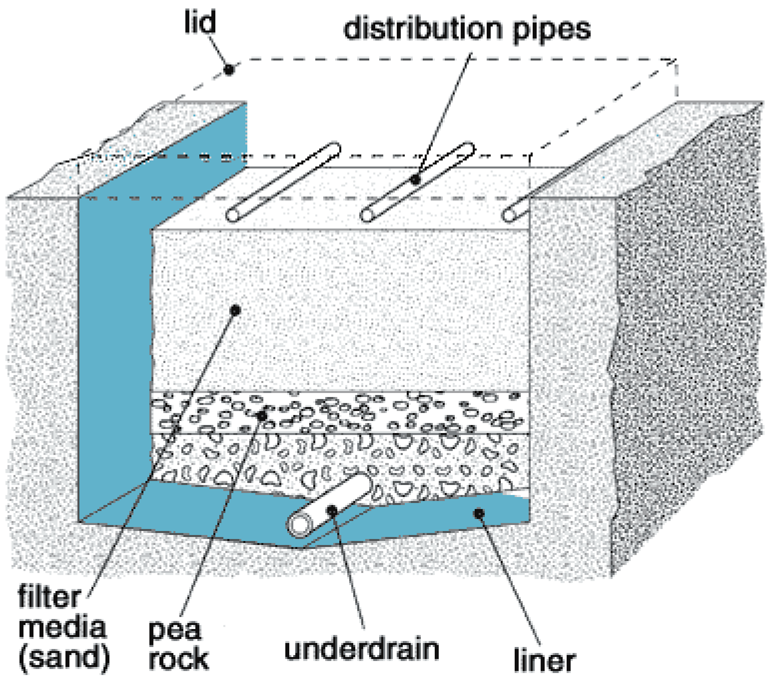
3.4.7 Review Timeline and Recommendations

The secondary treatment units certified through the NSF Standard 40 protocol are generally fairly robust, but are not designed to actively reduce TN. The 20 percent TN reduction assigned to these units is very conservative, but considered appropriate given the range of the units and the lack of data specifically from these small systems. Additional research could be done to determine if a higher reduction is actually occurring. The OWTS Expert Panel recommends a review period of 5 years to follow such developments.

3.5 INTERMITTENT (SINGLE PASS) MEDIA FILTERS

3.5.1 Detailed Definition of Practice

An intermittent or single-pass media filter is a filter packed with sand or other granular media. They support aerobic biological mechanisms and physical processes such as sedimentation, filtration, and chemical adsorption. The basic components of an intermittent media filter (IMF) system include a septic tank, a dosing tank, a pump with controller (or a siphon), a distribution network, the filter bed, and an underdrain (
Source: Gustafson et al. (2002a)
Figure 3-3). The wastewater is periodically dosed to the filter via the distribution system, where it percolates through the media to the underdrain that carries the treated effluent from the unit process.



Source: Gustafson et al. (2002a)
Figure 3-3. Intermittent Sand Filter Cross-Section.

Intermittent sand filters (ISF) have been used for decades to purify wastewater. Major cities even used them in the late 1800s; however, the space required for ISFs treating large flows eventually limited their use. The primary historical use of ISFs was based on their ability to effectively remove organics (BOD) and suspended solids (TSS). As on-site treatment systems, there are some common design variations. Distribution via low pressure dispersal (LPD) is most common, but use of drip dispersal is on the rise. Spray irrigation is also sometimes used. In addition to sand, media types commonly used today include peat, gravel, crushed glass, bottom ash from coal burning, foam chips, and coarse-fiber synthetics. One additional media variation is high-iron sands and gravels, which enhance the duration and capacity of phosphorus removal by ISF systems. However, for the purposes of this BMP, the OWTS Expert Panel only considered sand IMFs.

As a TN removal process, reported performance is variable, but with hard media effective sizes (ES) near 1 mm, the IMF usually removes 20 to 25 percent TN. Manipulation of hydraulic and organic loading rates, media size (smaller ES improves treatment), and the distribution and dosing regimen can enhance TN removal. Recent recommendations suggest the use of organic loading as a design criterion instead of only using hydraulic loading.

3.5.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that IMFs designed, installed, operated, and maintained in accordance with this section be assigned a 20 percent TN reduction, for an *ex situ* effluent concentration of 48 mg/L TN or an effluent TN load of 4 kg/person/year going into the drainfield. Table 3-3 summarizes net TN reductions for various combinations of *ex situ* and *in situ* BMPs.

Since most BOD and TSS are removed in the top 6 inches of the filter bed, the media can quickly nitrify influent TN to nitrate (NO_3-N). Depending on the filter media, IMFs have variable ability to denitrify the nitrate. However, that ability is limited due to the lack of labile carbon to drive that reaction, especially in hard media like most sands, gravel, plastic, etc. Thus, TN removal is limited to an average of 20 percent. Peat media could enhance denitrification by providing a supply of labile carbon. Peat-based systems are typically proprietary in nature, so they are addressed under the protocol in section 3.2.1.

The primary reference used to develop this recommendation was the USEPA *On-Site Wastewater Treatment Systems Manual* (2002a), which considered a broad set of references, and was authored by researchers involved in the seminal studies on IMFs from the University of Wisconsin in the 1970s. Other important references include:

Otis, R.J. 2007. *Estimates of Nitrogen Loadings to Groundwater from On-Site Wastewater Treatment Systems in the Wakiva Study Area*. Task 2 Report for the Wekiva On-Site Nitrogen Contribution Study.

Pincince, A.B., and J.E. McKee. 1968. Oxygen relationships in intermittent sand filtration. *Journal of the Proceedings of the American Society of Civil Engineers, Sanitary Engineering Division* 94(SA6):1093-1119.

Pell, M., F. Nyberg, and H. Ljundggren. 1990. Microbial numbers and activity during infiltration of septic tank effluent in a subsurface sand filter. *Water Research* 24(11).

Darby, J., G. Tchobanoglous, M. Asri Nor, and D. Maciolek. 1996. Shallow intermittent sand filtration. *The Small Flows Journal* (2):1.

USEPA (U.S. Environmental Protection Agency). 1978. *Management of Small Waste Flows*. Small Scale Waste Management Project of the University of Wisconsin. EPA-600/2-78-173. US Environmental Protection Agency, Cincinnati, OH.

McLellan, J.K., and C.A. Rock. 1986. The application of peat in environmental pollution control. *International Peat Journal* (1).

Johnson, C.G., and J.C. Converse. 2001. Single-Pass Sand Filter and Soil Dispersal Unit Performance in Reducing Pathogens and Nitrogen from Domestic Wastewater. In *Proceedings of 10th NOWRA Conference and Exhibit*, Virginia Beach, VA.

3.5.3 Ancillary Issues and Interactions with Other Practices

By having excellent BOD and TSS removal and nitrification capability, ISFs have been a popular means of basic pretreatment of STE in on-site systems prior to soil dispersal.

IMF systems are occasionally subject to odors in hot climates (although covering, venting, and other design modifications generally prevent these) and to distribution system freezing in colder climates (again, various design provisions prevent freezing).

3.5.4 Design and Installation Criteria

Minimum design and installation criteria for IMFs include:

- Preceded by properly sized/designed septic tank (minimum 48-hour hydraulic retention time [HRT] in most states)
- Properly sized pump tank (≥ 1.5 x HRT) with timer-based flow equalization controls to dose 12 to 24 times/day
- Media (sand) size and specifications
  - ES = 0.5 – 1 mm
  - Media uniformity coefficient (UC) ≤ 4.0
  - ≤ 0.5 percent fines passing #200 sieve
- Media depth = 2’
- Hydraulic loading rate (HLR) ≤ 2 gpd/sf
- Organic loading rate (OLR) ≤ 5 lb BOD/1000 sf-day
- Uniform, pressurized distribution with a spacing that provides 4 to 6 sf per orifice (i.e., 2’ × 2’ or 2’ × 3’ grid)
- Installation within watertight tank or in the ground with 30 mil liner

3.5.5 Temporal Performance

In warmer periods, full functioning is expected less than 2 weeks from startup. There can be a delay in severe cold periods, but that delay is mostly related to the sensitivity of nitrification bacteria to cold climates. All other biological functions should be complete in less than 2 weeks, while physical and chemical functions are immediate.

Depending on the structural status of the housing units, sand media should experience a service life of 20 to 30 years.

3.5.6 Recommended Management Requirements

O&M requirements for IMFs are quite simple and include an annual check of the pump, controls, and surface condition. The distribution system should also be flushed at least once per year and the pressure head reset if needed. IMFs with bare sand surfaces (versus cover layer of gravel or other media) and those with surface distribution of effluent require periodic (at least annual) raking of the surface to unearth vegetation, clear surface biofilms, and maintain permeability. Properly sized media rarely requires replacement. If clogging becomes an issue, replacing the top 6 to 12 inches of media typically is sufficient to re-establish permeability. Pumps need periodic replacement (roughly every 5 to 10 years for planning purposes), but they are readily available, relatively inexpensive, and easy to replace.

Annual Inspection Checklist

- Check pump and control operation.
- Check and/or rake surface if needed.
- Check operating pressure for distribution system. Flush system and reset head as needed.
- Conduct other generic O&M procedures (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).

3.5.7 Review Timeline and Recommendations

IMFs are a fully developed technology. Future development efforts could include research into the use of filter media with special properties as well as design enhancements that can enhance TN removal.

The OWTS Expert Panel recommends a review timeline of 5 years to follow such developments.

3.6 Subsurface-Constructed Wetlands/Vegetated Submerged Beds

3.6.1 Detailed Definition of Practice

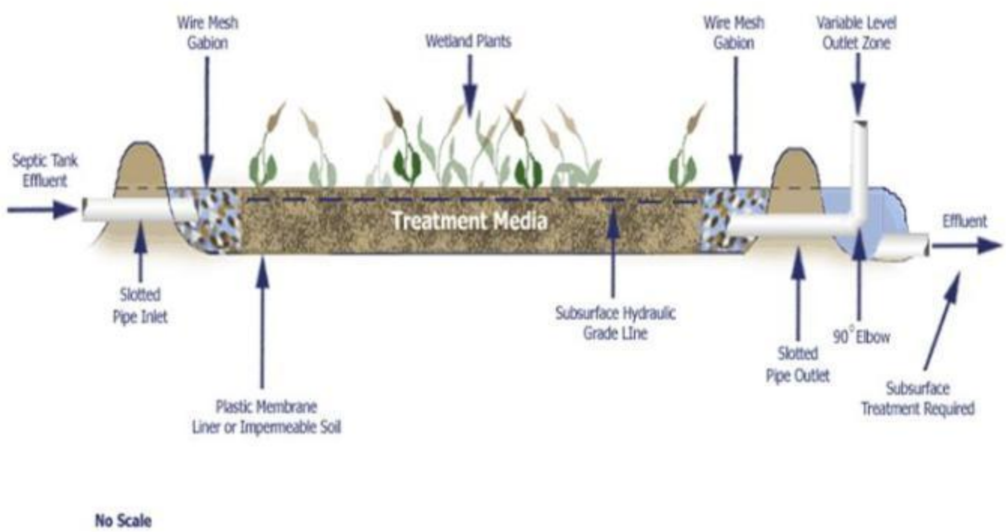
Constructed wetlands are wastewater treatment systems consisting of shallow ponds or channels that are usually less than a meter deep; have been planted with aquatic plants; and rely upon natural microbial, biological, physical, and chemical processes to treat wastewater. They typically have impervious clay or synthetic liners, as well as engineered structures to control the flow direction, liquid detention time, and water level. Depending on the type of system, they sometimes contain an inert porous media such as rock, gravel, or sand.

For some applications, they are an excellent option because they are relatively inexpensive to construct and maintain, offer stable performance, provide a natural appearance, and potentially have some ecological benefits. Constructed wetlands following septic tanks are suitable for wastewater treatment from individual homes and for small communities where inexpensive land is available and skilled operators are hard to find.

The literature and practitioners classify constructed wetlands into two main types. Free water surface (FWS) wetlands, which are also known as surface flow wetlands, closely resemble natural wetlands in appearance because they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland. Water flows through the leaves and stems of plants. FWS systems are typically used as a tertiary process in large wastewater treatment installations, and are mainly used for polishing secondary effluent. Vegetated submerged bed (VSB) systems, which are also known as subsurface flow wetlands, are the focus of this report because they have no visible standing water and are most common in small systems. OWTS Expert Panel recommendations exclude FWS systems from the BMP due to the potential for vector attraction and public health concerns with the FWS.

The VSB is essentially a horizontal gravel filter with attractive vegetation growing upon its surface

Source: University of Georgia Department of Chemistry (2003)
Figure 3-4). Without any harvesting of the vegetation, pollutant removal is comparable to that produced by horizontal gravel filters. Researchers have not undertaken any precise studies of VSBs to determine the lower limit of particulate retained by the system. However, one can assume that it will be in the range of 0.1 to 1.0 micron, which will remove a significant proportion of bacteria and algae. This is somewhat validated by the commonly expressed removal of two logs of fecal coliform organisms, which is comparable to the performance of a typical secondary biological treatment system without tertiary filtration or a disinfection unit, or a single-pass coarse media (gravel) filter.



Source: University of Georgia Department of Chemistry (2003)
Figure 3-4. Vegetated Submerged Bed Schematic

Europe and North America have employed VSBs for passive treatment of wastewaters and stormwater for over 25 years. VSBs provide filtration in a horizontal mode with a more attractive appearance than a simple gravel filter.

Normally, the VSB receives effluent from the septic tank and delivers its effluent to the soil. However, the reduction of BOD and TSS approaches secondary treatment requirements, and thus serves to protect the soil from clogging and assists in accomplishing overall required removals of other constituents.

VSBs have occasionally been used to provide denitrification of previously nitrified effluents. In this application, an aerobic process is employed before the VSB. Although there are very few studies of this application of VSBs, studies show that denitrification and nitrogen removal is limited on a year-round basis by the lack of labile carbon available in the VSB during non-growing seasons. However, a recent field study of a septic tank, RMF, and VSB where 5 to 25 percent of the STE was bypassed to the VSB to provide necessary labile carbon showed that an effluent TN of about 10 mg/L was achievable (Leverenz et al. 2010). They noted that the addition of organic woodchip media in VSBs can enhance the naturally low TN removal in laboratory studies. A laboratory study (Duncan et al. 1994) showed an 18 percent increase in TN removal by the septic tank, VSB, and pressure-dosed soil column over the septic tank alone prior to pressure dispersal. USEPA (2000) notes that a VSB following a nitrification system, such as an intermittent sand filter, can remove 55 to 75 percent of TN.

Some recent design approaches that artificially and mechanically provide DO to the VSB in order to improve pollutant removals and effluent DO levels have been studied, but there is little experience to support these design variations. Since one of the primary reasons for using VSBs is their simplicity of operation, use of these variations is not common.

3.6.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that VSBs designed, installed, operated and maintained in accordance with this section be assigned a 20 percent TN reduction, for an *ex situ* effluent concentration of 48 mg/L TN or an effluent TN load of 4 kg/person/year going into the drainfield. Table 3-3 summarizes net TN reductions for various combinations of *ex situ* and *in situ* BMPs.

Removal of TN is not in itself a major issue in design of a VSB. VSBs are most likely to remove the pollutants associated with influent particulates and coarser colloids since physical sedimentation, sorption, and filtration followed by biological transformation are its primary treatment mechanisms. Contact time and media characteristics will influence TN removal efficiencies.

For typical systems and treatment applications (i.e., STE before soil dispersal) under typical hydraulic and organic loading rates, the OWTS Expert Panel expects modest TN removals. Using lower loading rates can enhance TN removal.

The most complete and accurate publications on constructed wetlands for small residential applications include:

USEPA (U.S. Environmental Protection Agency). 2000. *Constructed Wetlands Treatment of Municipal Wastewaters*. EPA 625/R-99/010. U.S. Environmental Protection Agency, Cincinnati, OH.

WERF (Water Environment Research Foundation). 2006. *Small-Scale Constructed Wetland Treatment Systems*. WERF report 01-CTS-5, Alexandria, VA.

With limited additional input from other sources, these two references constitute the most comprehensive discussion of the use of these treatment systems for individual households and small neighborhoods producing domestic wastewaters. Some other references that provided relevant information include:

Duncan, C., R.B. Reneau, Jr, and C. Hagedorn. 1994. Impact of Effluent Quality and Soil Depth on Renovation of Domestic Wastewater. In *Proceedings of Seventh ASAE International Symposium on Individual and Small Community Sewage Systems*, Atlanta, GA.

Whitehill, T.J., B. Tercha, and J.F. Davis. 2003. Evaluation of a Recirculating Sand Filter Followed by a Subsurface Flow Constructed Wetland to Achieve Denitrification. *Small Flows Quarterly* (4) 4.

Leverenz, H.L., K. Haunschild, G. Hopes, G. Tchobanoglous, and J.L. Darby. 2010. Anoxic treatment wetlands for denitrification. *Ecological Engineering* 36(11):1544-1551.

VSBs are not typically the technology of choice where effluent requirements call for significant TN removal. In their normal application, they generally remove between 20 to 30 percent of the TN, with a high degree of variability owing to the makeup of the STE colloidal and particulate fractions.

At this time, there is not enough reliable data on the performance of VSBs following nitrification units to make a recommendation for this application.

3.6.3 Ancillary Issues and Interactions with Other Practices

VSBs are normally used to treat STE prior to soil dispersal. They also help reduce soil dispersal system clogging because they can be used to further reduce TSS and BOD concentrations, which can slow the rate of soil clogging. Another primary reason for VSB use is their simplicity: they generally lack electro-mechanical components, which simplifies associated operation and maintenance demands. VSBs are also popular because of the aesthetic value of their appearance during the growing season.

In order to extend the service life of the system, systems need some means of reducing large suspended solids and debris from the raw wastewater prior to the VSB. The septic tank fulfills this role. Almost always, a soil treatment and dispersal system follows owing to the anaerobic nature of the VSB effluent. Thus, the system fits into the conventional septic system, protects the soil system, and allows system installation on marginal lots without the need for electro-mechanical equipment. There are few limitations on the siting of a VSB system provided there is sufficient area for installation and for siting the soil absorption system.

3.6.4 Design and Installation Criteria

Minimum design and installation criteria for VSBs follow recommendations in USEPA (2000) and include:

- Preceded by properly sized/designed septic tank
- Media size and specifications
  - o 40 to 80 mm ES gravel in inlet distribution and outlet collection zones. All gravel media should have a hardness of 3 or more and be washed clean of fines and debris.
  - o 20 to 30 mm ES in treatment zone
  - o 6" top layer of planting media (e.g., peat, soil, expanded slate) for planting natural, attractive species (Chicken wire can be installed underneath this layer and in the berms to deter burrowing animals.)
- Media depth ≤ 2' of stone at least 0.1 m above the water level
- Length ≥ 50'
- Surface area ≥ 54 sf/person (assume two persons per bedroom)
- OLR ≤ 1.2 lb BOD_5/1000 sf-day
- Ability to vary flooding depth using outlet structure (Outlets are generally simple rotating 90-degree elbows that can be adjusted as needed.)
- Installation within watertight tank or in the ground with 30 mil liner
- The bed surface should be level, and the bottom should slope slightly to enable drainage.

USEPA (2000) describes more detailed design criteria.

3.6.5 Temporal Performance

VSBs can be employed immediately and functioning in less than a week since the treatment is primarily physical in nature. There are temporary removals that occur during the life of these systems. For a period after startup, the system can remove total phosphorus (TP) rather efficiently until the media becomes exhausted in its ability to uptake the phosphorus. During the growing season is some apparent enhancement of nitrogen and phosphorus removal by the vegetation. However, since the vegetation is not typically harvested, most of the N and P follow the natural cycle of uptake in the growing season and return to the soil toward the beginning of senescence.

An on-site septic tank, VSB, and gravity soil dispersal and treatment system should have a service life of 30 or more years with the appropriate (minimal) monitoring and maintenance. The unknown factor is the rate of VSB media clogging, which has never been well-defined. If one follows the conservative USEPA design criteria and performs the installation properly, one should anticipate a service life of at least 10 years before mitigating media clogging.

3.6.6 Recommended Management Requirements

VSB operation and management is relatively straightforward, consisting of mostly visual inspections of the inlet and outlet structures, media, plantings, and structural elements of the system. Media clogging is generally the most significant potential problem. If clogging occurs it usually results in a slow or "soft" failure that is obvious to any operator. Removal of clogged stones and replacement with fresh washed ones is a large undertaking, which generally requires heavy equipment. For household systems, it might be easier to build a new system adjacent to the old one or perform high-pressure media cleaning.

Annual Inspection Checklist

- Conduct other generic O&M procedures (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).
- Conduct monthly visual inspections of the VSB media, screens, berms, etc. to assess damage from muskrats or similar animals.
- Remove dead vegetation and replant as needed.
- Check any other mechanical (inlet or outlet) components that are part of the VSB annually.
- If a treatment unit is used before the VSB, complete O&M in accordance with the recommendations for that unit.

3.6.7 Review Timeline and Recommendations

New information on the TN reduction associated with VSBs is generated slowly given the lack of research funding, especially considering that traditional VSBs are rarely used in situations where nutrient reduction is a treatment objective. More data is necessary on media life before clogging, media replacement, and the expected service life.

Additionally, more data is necessary to establish the expected performance of different VSB designs, especially those that follow nitrification systems. If such reviews develop a solid case for use of VSBs for denitrification, the TN reduction recommendation can be revised accordingly.

The OWTS Expert Panel recommends a review timeline of 2 years to follow such developments.

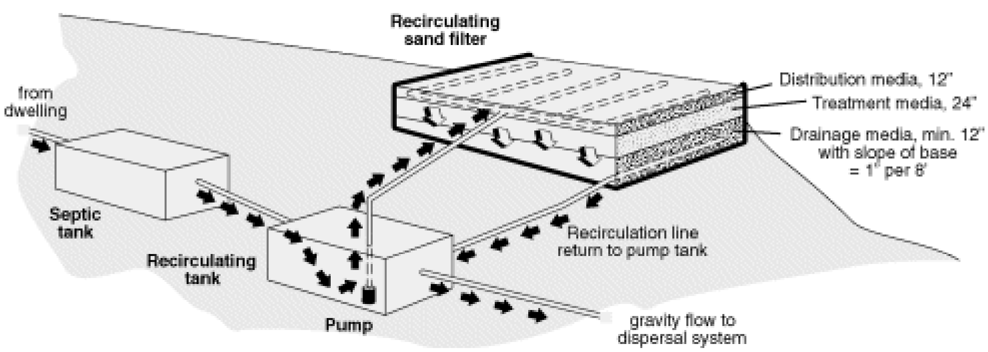
3.7 Recirculating Media Filters

3.7.1 Detailed Definition of Practice

The system performance of RMFs differs from single-pass filters (e.g., IMFs) in that RMFs can remove an average of about 50 percent of the TN. Media with a larger ES allows for higher HLRs and smaller filter sizes (surface area). This footprint advantage is somewhat offset by the need for a recirculation tank that mixes STE with filter effluent to allow significant denitrification. The engineered systems covered in this section generally use gravel or coarse natural media (e.g., sand) specifically designed for recirculating filters and readily available to the construction site. Commercially marketed RMFs (covered under the proprietary BMP protocol) generally use lightweight media that minimize shipping costs and facilitate installation.

For effective nitrogen removal, the influent must first be nitrified by periodically dosing it from a recirculation tank under pressure to the surface of the filter where percolation of wastewater through the filter draws in air that promotes aerobic treatment. Denitrification is facilitated by recirculating a majority of the nitrified effluent back to a septic tank (where it mixes with influent) or separate recirculation tank (where it mixes with STE). Septic tanks or recirculation tanks generally feature conditions that promote denitrification, including a lack of DO (anoxic conditions) and a sufficient quantity of labile carbon.

RMFs are dosed with a mixture of STE and (nitrified) recirculated sand filter effluent. Mixing is typically done in a separate recirculation tank that follows a conventional septic tank, although sometimes effluent is recirculated back to an oversized septic tank to take advantage of the slightly higher organic loads in the raw STE that drive denitrification. The disadvantage of this design is that the relatively large recirculation flow rate, which is typically at least three times that of the forward flow, can disrupt primary treatment in the septic tank. The effluent from the recirculation tank is typically pressure dosed onto the surface (or just below the surface) of the filter. Effluent from the filter is split to return nitrified effluent to the recirculation tank for further denitrification and return to the filter while allowing the discharge of forward flow (in most cases to a soil treatment unit). Figure 3-5 provides a schematic drawing of a typical RMF.



Source: Gustafson et al. (2002b)

Figure 3-5. Recirculating Media Filter Schematic.

3.7.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that RMFs designed, installed, operated and maintained in accordance with this section be assigned a 50 percent TN reduction, for an *ex situ* effluent concentration of 30 mg/L TN or an effluent load of 2.5 kg/person/year going into the drainfield. Table 3-3 summarizes net TN reductions for various combinations of ex situ and in situ BMPs.

Some studies show better than 50 percent TN reductions achieved through different means of recirculation. For example, if the septic tank is used as the recirculation unit, a greater organic carbon-to-nitrate ratio might permit more complete denitrification. Some studies show slightly poorer performance for other design changes that reduce the denitrification potential. The best references for these issues are:

Piluk, R.J., and B.R. Byers. 2001. Small recirculating filters for nitrogen reduction. *Journal of Environmental Health* 64(2): 15-19.

Rich, B., D. Haldeman, T. Cleveland, J. Johnson, and R. Weick. 2003. Denitrifying Systems Using Packed Bed Filters in the LaPine National Demonstration Project. In *Proceedings of 2003 National Onsite Wastewater Recycling Association*, Seattle, WA.

USEPA (U.S. Environmental Protection Agency). 2002a. *On-Site Wastewater Treatment Systems Manual*. USEPA/625/R-00/008. U.S. Environmental Protection Agency, Cincinnati, OH.

Converse, J.C. 2004. Field Evaluation of ATU and Packed Bed Filters. In *Proceedings of 2004 NOWRA Conference*, Albuquerque, NM.

Sandy, A.T., W.A. Sack, and S.P. Dix. 1987. Enhanced Nitrogen Removal Using a Modified Recirculating Sand Filter (RSF). In *Proceeding of 5th ASAE National Symposium on Individual and Small Community Sewage Systems*, Chicago, IL.

3.7.3 Ancillary Issues and Interactions with Other Practices

RMFs normally follow septic tanks in the treatment train. There is no reason to add other intermediate (pretreatment) systems.

3.7.4 Design and Installation Criteria

Minimum design and installation criteria for RMFs include:

- Preceded by properly sized/designed septic tank (minimum 48-hour HRT in most states)
- Properly sized recirculation pump tank (≥ 1.5 x HRT) with timer-based flow equalization controls to dose 24 to 48 times/day
- Media size and specifications
  - For sand media:
    - ES = 1-5mm
    - UC ≤ 2.5
    - HLR ≤ 5 gpd/sf
    - OLR ≤ 5 lb BOD/1000 sf-day
    - ≤ 0.5 percent fines passing #200 sieve
  - For gravel media:
    - ES = 5 to 20 mm
    - UC ≤ 2.5
    - HLR ≤ 15 gpd/sf
    - OLR ≤ 15 lb BOD/1000 sf-day
    - ≤ 0.5 percent fines passing #200 sieve
- Media depth = 2’
- Uniform, pressurized distribution with a spacing that provides 4 to 6 sf per orifice (i.e., 2’ × 2’ or 2’ × 3’ grid)
- Recirculation device capable of recirculating 3 to 5 times the forward flow back to separate anoxic recirculation tank or second compartment of septic tank
- Installation within watertight tank

As noted above, TN removal is generally in the range of 50 percent. The recirculation rate is between 3 and 5 times the forward design flow to optimize denitrification. Periodic saturation and draining of the filter media is important for drawing air into the system for effective nitrification. Accordingly, filters are generally dosed under pressure every 30 minutes to an hour.

USEPA (2002) provides other relevant design criteria.

Although many RMFs are engineered and built to local specifications, there are numerous commercial (i.e., proprietary) systems available. These systems are generally easier to install because of their lightweight media and ease of hookup with other system components. Some might also have space-saving features that make limited lot areas sufficient. The approval protocol described in section 3.2.1 covers these proprietary systems.

3.7.5 Temporal Performance

RMFs are extremely reliable treatment systems rarely upset by variations in local conditions (e.g., wastewater flow or load changes). They are far less sensitive than typical on-site suspended growth systems. Like any biological system, however, there is a startup period during which the microbial population develops and stabilizes. For RMFs, this period is typically no more than a couple months, during which TN removals can be lower than they will be during stable performance. Nitrification capacity typically takes time to develop during this startup period. Because nitrifier growth is temperature dependent, the startup period can be somewhat longer during cooler seasons. Once nitrification capacity has been established, however, it should remain consistent regardless of temperature, assuming that the design provides for appropriate aerobic conditions.

3.7.6 Recommended Management Requirements

O&M requirements for RMFs are similar to those for IMFs; however, the OWTS Expert Panel recommends an increased frequency, since RMFs require additional mechanical components (e.g., recirculating tank, pumps and controls, recirculation device). Properly sized media rarely requires replacement. If clogging becomes an issue, replacing the top 6 to 12 inches of media typically is sufficient to re-establish permeability. Pumps need periodic replacement (roughly every 5 to 10 years for planning purposes), but they are readily available, relatively inexpensive, and easy to replace.

Semiannual Inspection Checklist (2 times/year)

- Inspect the recirculation tank and pump out excess solids.
- Inspect and service the filter dosing pumps and controls.
- Inspect and calibrate the dosing frequency, volume, and recirculation ratio (RR).
- Maintain the filter surface. (Finer media units can require extra maintenance to keep media surfaces clean.)
- Check operating pressure for distribution system and flush system. Reset head as needed. Complete other generic O&M procedures (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).

3.7.7 Review Timeline and Recommendations

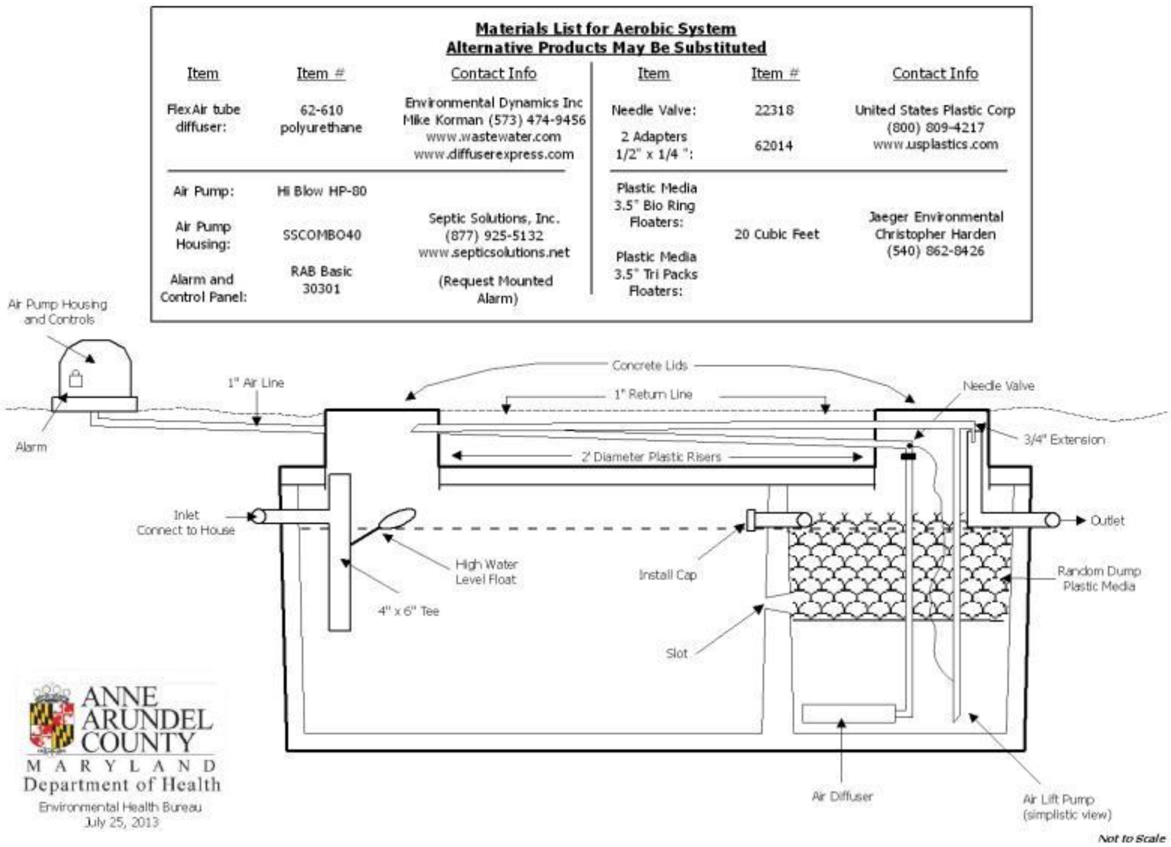
This is an established technology, and little would be gained from further research reviews. However, additional performance data is always valuable if it can be obtained with minimal effort. The OWTS Expert Panel recommends a review timeline of 5 years.

3.8 ANNE ARUNDEL COUNTY IFAS

3.8.1 Detailed Definition of Practice

Aerobic treatment units (ATUs) refer to a broad category of wastewater treatment devices for residential and commercial use. Most commercial ATUs use compressors or other types of aerators to oxygenate and mix the wastewater. The historical dependence of ATUs using suspended growth (activated sludge) processes is diminishing with the development of more reliable fixed-film systems. More recently, hybrid systems have been developed that use high specific surface area plastic media submerged in an aerobic unit to promote attached or fixed bacterial growth. These units are known as integrated fixed-film activated sludge (IFAS) systems. These processes are very effective at oxidizing organics and oxidizing ammonium to nitrates. Nitrates can be converted into nitrogen gas by incorporating an anoxic denitrification step in the treatment train.

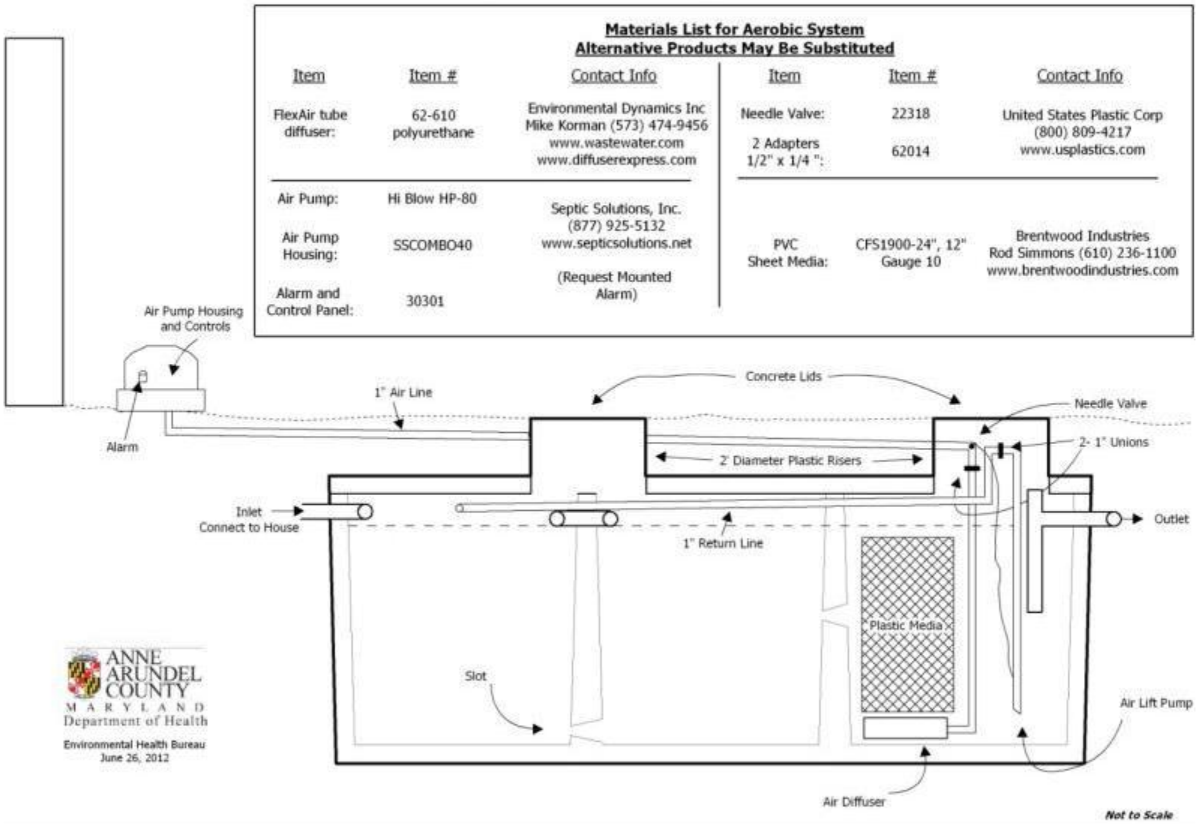
Examples of plans for IFAS designs approved by Anne Arundel County, Maryland, for various situations are summarized below. Source: Anne Arundel County Health Department
Figure 3-6 provides an example of a plan developed by the Anne Arundel County Health Department showing how to convert an existing two-compartment septic tank into a nitrogen-reducing tank. The type of plastic media shown can be installed through the typical access openings of both new and existing tanks. Note that in this design, the air lift pump not only returns flow to the first compartment, but also lifts forward flow into an outlet standpipe. The standpipe does not allow backflow into the tank, and the air lift slowly feeds the final disposal system.



Source: Anne Arundel County Health Department

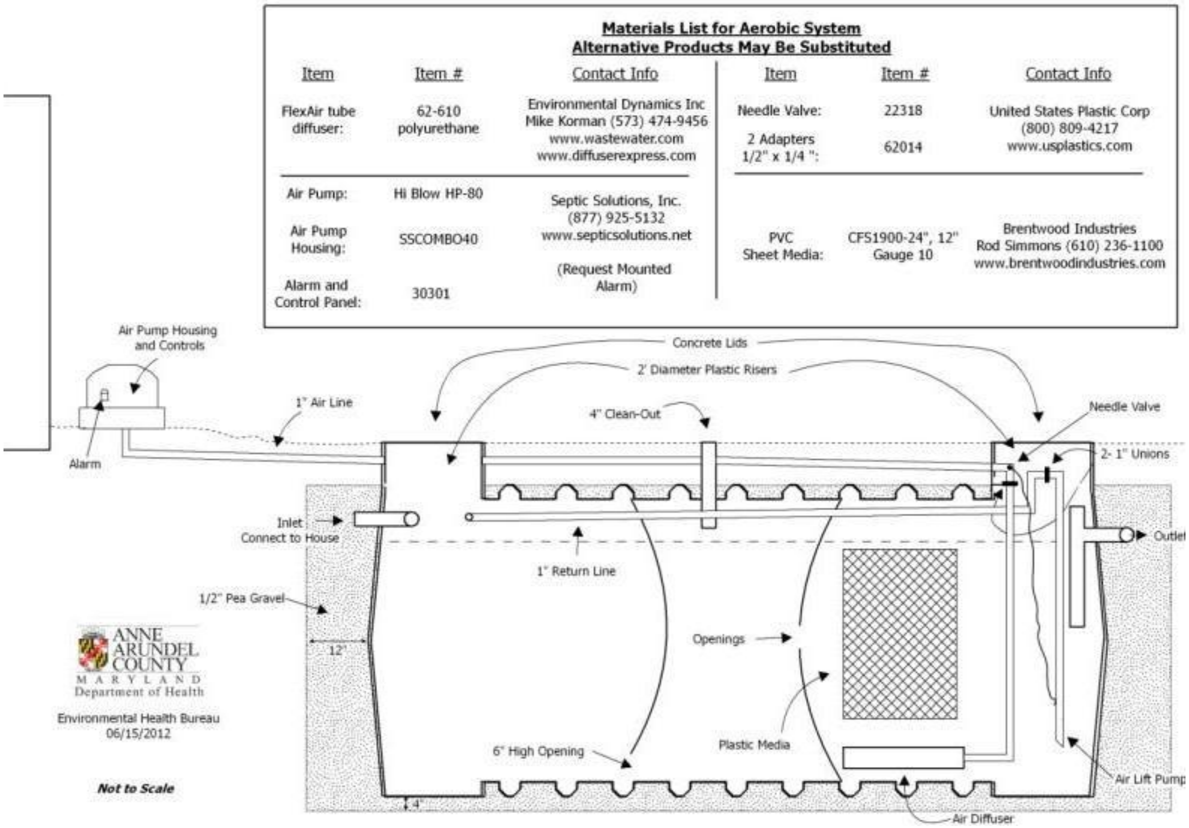
Figure 3-6. Example Two-Compartment Tank Conversion Profile.

The type of plastic media used in the three-compartment tank plan in Source: Anne Arundel County Health Department
Figure 3-7 can only be installed with the top of the tank off. Although the specifications require only two compartments, if there are three compartments, flow between the first and second anoxic compartments should be through a submerged slot to improve mixing and contact with settled sludge, provided that minimum design standards for the aerated tank can be met by the remaining compartment.



Source: Anne Arundel County Health Department
Figure 3-7. Example Three-Compartment Tank Conversion Profile.

Fiberglass and plastic tanks can be used for sites where access is restricted and installing a concrete tank is difficult. The round shape of the fiberglass tank shown in Source: Anne Arundel County Health Department
Figure 3-8 and
Source: Anne Arundel County Health Department
Figure 3-9 should promote better air and water circulation.



Source: Anne Arundel County Health Department
Figure 3-8. Example Plastic Tank Conversion Profile.

Source: Anne Arundel County Health Department
Figure 3-9. Plastic Tank Cutaway Photographs.

3.8.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that IFAS systems designed, installed, operated and maintained in accordance with this section be assigned a 50 percent TN reduction, for an *ex situ* effluent concentration of 30 mg/L TN or an effluent load of 2.5 kg/person/year going into the drainfield. Table 3-3 summarizes net TN reductions for various combinations of *ex situ* and *in situ* BMPs.

The National Association of Home Builders (NAHB) Research Center (2004) and West Virginia University (Vandivort and Solomon 2010) performed third-party research and found that the IFAS systems used in Anne Arundel County reduce nitrogen levels by 76 percent and 68 percent, respectively.

These IFAS systems have an anoxic zone that uses influent carbon for denitrification and an aerobic zone for nitrification. Some of the nitrified effluent from the aerobic zone is returned to the anoxic zone to promote TN reduction. The proportion of the flow returned to a location closer to the beginning of the system for denitrification compared to the quantity of flow that leaves the system is called the recirculation ratio (RR). For example, if a system recirculates 200 gpd and discharges 100 gpd, it would have a 2:1 RR.

Knowing the RR allows the user to estimate the percentage of TN removal that a system can achieve based on the following assumed conditions:

- All of the nitrogen in the nitrification zone has been converted to nitrates.
- All of the nitrates that are recirculated back to the denitrification zone are converted to nitrogen gas and leave the system.
- The carbon and energy sources required for denitrification are present in the wastewater in the denitrification zone.

A simplistic equation to describe the estimated optimum percent reduction in TN based on the RR is: % reduction of Total Nitrogen = RR / (1 + RR).

1:1 → 1/2, or 50%	4:1 → 4/5, or 80%
2:1 → 2/3, or 66%	5:1 → 5/6, or 83%
3:1 → 3/4, or 75%	20:1 → 20/21, or 95%

As illustrated, increasing the RR might increase the percent removal of nitrogen, but with diminishing returns. Additionally, increasing the RR has the negative effect of increasing the flow of oxygenated effluent into the denitrification zone and reducing the HRT in the system. High RRs can destroy the anoxic environment needed for denitrification and reduce the reduction of TN removal. For this reason, the OWTS Expert Panel does not recommend a RR above 5:1.

In the NAHB Research Center (2004) study, researchers took wastewater samples every 2 weeks for a year. Initial sampling after installation of the system showed positive results. Nitrification occurred in the aerobic tank as intended, and denitrification was evident from the effluent sample test results. Based on 12 months of sampling data, Site 2 showed an average 76 percent reduction in TN compared to samples taken from the septic tank prior to the installation of the IFAS system. Other parameters—alkalinity, BOD, TSS, ammonia, phosphorous, and TKN—also showed significant reductions. Fecal coliform testing showed little or no reduction between the septic and aerobic tank effluents. There was also a high level of homeowners' acceptance for the system at Site 2. The air blower made very little noise and odors were not an issue. The only system component installed above grade was the blower.

Vandivort and Solomon (2010) studied nutrient-reducing on-site or decentralized wastewater treatment systems. Researchers identified and monitored four residential on-site wastewater treatment systems in Anne Arundel County, Maryland, for their ability to reduce nutrients. Three systems were monitored for nitrogen reduction and one for phosphorus reduction. Older, single-compartment septic tanks at sites experiencing malfunctions were replaced with multicompartment (either two or three compartments) concrete or fiberglass septic tanks. Plastic media for secondary treatment was added to each system with blowers to oxygenate the compartment. Air lift pumps recirculated effluent from the aerated compartment back into the first compartment.

The researchers monitored all four systems weekly for a year. They collected 24-hour composite samples for 52 weeks. The samples collected to assess nitrogen reduction were analyzed for nitrate/nitrite (NO_3/NO_2) and TKN. TN was calculated as the sum of these fractions. Results showed that when the IFAS systems operated properly with recirculation, average TN reductions of approximately 68 percent were obtained, with effluent TN concentrations less than 14.0 mg/L.

Based on these findings, researchers concluded that replacing existing residential on-site wastewater treatment systems in the Chesapeake Bay with the engineered design monitored in this study could, depending on a number of variables, result in acceptable end-of-pipe levels of nitrogen.

Even though data on the Anne Arundel County IFAS systems resulted in TN reductions of 68 to 76 percent in STE, there are factors that can inhibit TN reduction at individual residences, including low temperatures, low pH, low alkalinity, high BOD, DO problems, and inhibitory chemicals. Because of these factors, the OWTS Expert Panel recommends that nonproprietary IFAS systems be credited with a 50 percent reduction.

3.8.3 Ancillary Issues and Interactions with Other Practices

Anne Arundel County IFAS systems are typically useful for retrofits of malfunctioning systems and well-suited for this application, since they can be adapted to a variety of existing septic tank configurations. As with any of the *ex situ* BMPs, this practice may interact with an *in situ* soil BMP to qualify for additional TN reductions for the system.

3.8.4 Design and Installation Criteria

The most common method of reducing TN in wastewater is through the sequential biological processes of nitrification and denitrification. These biological processes have different environmental requirements. Nitrification requires an aerobic environment with low levels of BOD, whereas DO inhibits denitrification and requires BOD as a carbon source. Furthermore, nitrification consumes alkalinity which buffers pH within a favorable range, while denitrification recovers a portion of the alkalinity lost during nitrification. Therefore, sufficient influent alkalinity is necessary to affect a high level of nitrification as needed for TN reduction.

The typical septic tank in Maryland has two compartments, a 1,000-gallon first compartment and a 500-gallon second compartment. Other states and jurisdictions use similar designs. To convert a two-compartment septic tank into a nitrogen-reducing unit, the second compartment is converted to an aerobic chamber with an aerator and plastic or other media, and some of its effluent is recirculated back to the first anoxic compartment for denitrification. The second compartment of the septic tank becomes an IFAS. The IFAS process is used with two compartment tanks because it has the advantage of not requiring an additional compartment for final sedimentation as typically required for suspended growth systems.

Anne Arundel County uses the following specifications for the approval of IFAS systems for single-family residential homes. The Anne Arundel County Health Department developed these specifications based on experience with their use in Anne Arundel County and from research conducted by Brentwood Industries and the NAHB Research Center. Systems that meet these minimum specifications are generic, not individually engineered. These minimum specifications set the basis for the development of enhancements of the systems. Other states and jurisdictions that opt to use these systems should modify the specifications to meet their needs.

Septic (Denitrification/Anoxic) Tank

- A separate septic tank or a compartment preceding the aerobic section should be used as a zone for denitrification.
- Use of an existing multicompartment septic tank will be considered if it has a volume of at least 1,000 gallons (minimum HRT of 2 days for systems with design flows greater than 500 gpd based on 60 gpcd). The tank and all piping and connections to the tank must be watertight.
- New septic tanks must meet the design requirements of the state or local jurisdiction.
- The denitrification compartment must be at least 1,000 gallons with two, 500-gallon compartments preferred. For systems with design flows greater than 500 gpd based on 60 gpcd, the denitrification unit must have a minimum HRT of 2 days.
- Tanks must be accessible for pumping. Lightweight access lids are not allowed unless some means of providing long-term securing of the lids can be demonstrated.

Aerobic Chamber

- The liquid capacity of the aerobic chamber must be at least 500 gallons (or a minimum 1-day HRT for systems with design flows greater than 500 gpd based on 60 gpcd).
- The minimum surface area of the fixed-film media is approximately 600 square feet based on a 150 mg/sf/day nitrification capacity at 20° C.
- The openings within the fixed-film media must be large enough to avoid clogging.
- With a proper outlet tee or effluent filter (in accordance with state or local requirements), a clarifying chamber is not necessary.
- Tanks must be accessible for pumping. Lightweight access lids are not allowed unless some means of providing long-term securing of the lids can be demonstrated.
- An easily accessible sampling port for the final effluent from the aerobic chamber must be provided.

Aeration Device

- The aeration device (typically a blower) must be sized to maintain DO levels above 3 mg/L in the aerobic chamber. For most single-family homes (up to four bedrooms or approximately 500 gpd), 80 liters of air per minute is adequate. For larger facilities, an engineer should determine the appropriate aeration capacity.
- Fine bubble tube diffusers such as those with polyurethane membranes are the preferred air injection method.
- The aeration device motor must be located above the 100-year flood elevation.
- The aeration device must be equipped with a pressure sensor and connected to a control panel that has an alarm to alert home occupants or service providers of inappropriate pressures.
- The aeration device must be on a separate circuit. It must be protected from circuits such as those for outdoor electrical outlets because ground fault interceptor circuits can easily trip.

Recirculation Device

- The system must provide recirculation of nitrified effluent back to the denitrification chamber. This is normally achieved with the use of an airlift pump or effluent pump.
- The RR must be between 3:1 and 5:1.
- The RR rate must have a means for control such as adjustable weirs, splitter box with outlets that can be capped, etc.

Other Design Considerations

- Designs should seek to minimize electric power consumption.
- The backwash from water conditioners (e.g., softeners) should not be discharged into the units.

3.8.5 Temporal Performance

IFAS systems use micro-organisms to facilitate the nitrogen removal process and usually establish biological populations within 3 to 4 weeks, although it can take longer at lower temperatures. As long as the systems are properly operated, maintained, and monitored and the occupants do not use excessive products that inhibit nitrification, the practice will have a useful life of 20 to 30 years. However, some parts (e.g., pumps, blowers, diffusers) might require replacement in the interim.

3.8.6 Recommended Management Requirements

O&M requirements for IFAS systems are similar to those for RMFs and limited mainly to checking electrical and mechanical components and ensuring that operation (e.g., RR) is consistent with the original design. IFAS media rarely requires replacement, but it should be inspected at each visit to check for signs of degradation or damage. Pumps need periodic replacement (roughly every 5 to 10 years for planning purposes), but they are readily available, relatively inexpensive, and easy to replace.

Semiannual Inspection Checklist (2 times/year)

- Inspect the aerobic and anoxic zones for sludge accumulation, as well as proper function of the aeration device and the return device.
- Service the blower in accordance with the manufacturer's recommendation
- Inspect and service the pumps and controls.
- Inspect and calibrate the RR.
- Inspect the aeration device.
- Conduct other generic O&M procedures (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).

3.8.7 Review Timeline and Recommendations

Given the somewhat unique nature and currently limited geographic use of these systems, it is expected that any additional research will be well-known in states and areas that use the systems. The OWTS Expert Panel recommends a review timeline of 5 years.

3.9 SHALLOW-PLACED, PRESSURE-DOSED DISPERSAL

3.9.1 Detailed Definition of Practice

Pressure-dosed dispersal is an *in situ*, or soil treatment, process that allows for uniform distribution of effluent across the entire dispersal field. Dosing allows for the creation of fluctuating aerobic/anoxic environments, which sets up the conditions for nitrification and denitrification to occur. Numerous research studies indicate that denitrification occurs in pressure-dosed systems and that the highest rates are achieved when the dispersal is into surficial soil horizons. Dosing also promotes wetting/drying cycles, which improves soil structure, improves soil permeability, and enhances long-term wastewater disposal at the site.

The OWTS Expert Panel recommends shallow-placed, pressure-dosed dispersal systems as a BMP under the Chesapeake Bay Program's model for nitrogen reduction capabilities for the on-site sector. For the purposes of this BMP, *shallow* is defined as no more than 12 inches deep as measured from the ground surface. However, this technology will not achieve full nitrogen removal potential in areas with sand or loamy sand soils where there is little soil organic content to fuel the denitrification process; accordingly, although shallow pressure-dosing can and should be used in these areas, the practice will not be eligible for TN reduction credits.

There are two main pressure-dosed dispersal methods in use: drip dispersal and low pressure pipe (LPP), which is sometimes called low pressure distribution (LPD) or low pressure dispersal. These dispersal technologies can be used with STE or higher quality effluents. Both of these technologies allow for the uniform application of wastewater at shallow depths where the most biologically active zones exist, where oxygen penetration is definite, and where the underlying soil horizons will permit dispersal of effluent and conveyance off-site. Drip dispersal delivers small doses of effluent uniformly to a soil treatment system under pressure. The U.S. has used this technology since the early 1990s. Drip dispersal has been used with both STE and higher quality effluent. Manufacturers and practitioners recommend prefiltration of the effluent so that the drip emitters do not clog.

Drip tubing is typically 0.5 inches in diameter and has emitters embedded along the length of the tubing, generally spaced 2 feet apart. The emitters come in both pressure-compensating and non-pressure-compensating designs. Pressure-compensating emitters provide a steady flow per emitter once a minimum pressure is reached, and allow for differences in tubing elevation and pressure head without affecting the delivery rate from individual emitters, avoiding localized overloading of the soil treatment system. Non-compensating emitters provide a steady flow at a given pressure and require a pressure regulator to adapt to different elevations. No bedding is required and the tubing can be placed in direct contact with the soil. However, with no bedding (e.g., gravel) to provide storage, small doses are critical to ensure the soil is not hydraulically overloaded.

Drip tubing is generally laid with a chisel or vibratory plow at a shallow depth and in direct contact with the soil. Drip tubing delivers effluent to the soil at low application rates in multiple doses per day, which facilitates oxygen transfer while promoting the formation of anaerobic/anoxic microsites. This alternating aerobic/anoxic environment promotes nitrification and denitrification. The shallow placement allows for greater contact with organic material along with the root zone of plants, which promotes N uptake. N uptake can temporarily enhance nitrogen removal during the active growing season. However, if the plants are not harvested, most of the nitrogen taken up is reintroduced to the environment during plant senescence.

LPP (also known as LPD) uses rigid pipe to provide uniform distribution over the dispersal field. The effluent is dispersed under relatively low pressure head (generally less than 5 feet of head of water) through specially sized and spaced orifices drilled in the pipe. The system must be fully pressurized before even distribution occurs. The dose is larger and less frequent than with drip tubing. The piping is installed in a trench using either gravel or a gravel-less technology that provides effluent storage.

3.9.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that shallow-placed, pressure-dosed dispersal systems designed, installed, operated and maintained in accordance with this section be assigned a 50 percent TN reduction, for an *in situ* edge-of-drainfield concentration of 30 mg/L TN or TN load of 2.5 kg/person/year (for STE). This results in a *net* TN reduction of 38 percent after accounting for the baseline BMP of 4 kg TN/person/year ((4-2.5)/4 = 0.38). Table 3-3 summarizes net TN reductions for various combinations of *ex situ* and *in situ* BMPs.

TN reduction via denitrification can occur when nitrified effluent is in contact with a sufficient carbon source in an anoxic environment. Studies show that STE nitrifies in close proximity to the orifice or emitter (Parzen et al. 2007; Hepner et al. 2005; Beggs, et al. 2011; Long 1995). Studies have reported denitrification rates for shallow-placed drip systems in organic soil horizons ranging from 38 to 96 percent for STE, but the performance with nitrified effluents is less clear. The bulk of the data comes from Delaware Valley College (Hepner et al. 2005), which reported reductions of 79 to 96 percent TN based on leachate data from lysimeters at 2 and 4 feet below the emitters. Degen (1992) applied effluent to columns to simulate daily dosing similar to an LPD or LPP system. In the experiment, the author applied both nitrified and non-nitrified effluent to surface soils and average total N losses were 54 and 52 percent, respectively, based on a mass balance on 6-inch-deep soil cores. The laboratory column studies did not consider plant uptake.

Shallow dispersal of wastewater also allows for greater opportunity for plant uptake during the growing season. Uptake by various grasses and other vegetation is fully discussed in USEPA's *Process Design Manual for Land Application of Municipal Wastewater* (1981). Long (1995) reports that up to 46 percent of the TN could be removed by plant uptake during the active growing season when the effluent is in close proximity with plant roots. However, when evaluated on a year-round basis, the uptake is usually less than 10 percent. Grasses provide higher uptake rates than woody plants or wetlands. All plant enhancements are essentially negated unless harvesting is employed during the growing season. Appendix A provides a more complete discussion of the research as it pertains to vegetative uptake and evapotranspiration.

Additional relevant literature is summarized below.

Anderson, D., R.J. Otis, J. McNeillie, and R. Apfel. 1994. In-Situ Lysimeter Investigation of Pollutant Attenuation in the Vadose Zone of a Fine Sand. *On-Site Wastewater Treatment: Proceedings of the Seventh International Symposium on Individual and Small Community Sewage Systems*. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

- The authors applied STE loading rates of 0.75 and 1.5 gpd/sf to constructed infiltration cells in fine sands with a controlled water table elevation at 2 and 4 feet below the trench bottom. They collected leachate samples at 2 feet and 4 feet below the application point. TKN was reduced by over 97 percent, which is most likely due to nitrification. Nitrate N was reduced to 20 mg/L (mean influent TN of 44.24 mg/L), but the authors suggest that dilution could have been a factor. However, the nitrate-Cl ratio was also decreasing. This suggests that dilution alone was not reducing the TN levels. Percent reduction ranged from 49 to 69 percent depending on loading rate and depth of sampling, with the lowest reduction at 2 feet below the application point at the lower loading rate.

Beggs, R.A., G. Tchobanoglous, D. Hills, and R. Crites. 2004. Modeling Subsurface Drip Application of On-Site Wastewater Treatment System Effluent. ASABE Publication Number 701P0104.

- The authors found that the vertical extent of nitrate nitrogen percolation was greatest with higher loading rates, which support the concept that small doses will reduce the nitrate percolation potential.

Beggs, R.A., D. Hills, G. Tchobanoglous, and J. Hopmans. 2011. Fate of nitrogen from subsurface drip dispersal of effluent from small wastewater systems. *Journal of Contaminant Hydrology* 126: 19-28.

- The authors constructed container tests with a total depth of 115 centimeters (approximately 45 inches) of sandy loam, loamy sand, and silt loam soils. They installed drip lines at 15 centimeters (6 inches) with suction lysimeters 30 and 45 inches below the drip lines. They applied STE at the rates summarized in Table 3-4.

Table 3-4. Loading Rates for Container Tests.

Container	Texture	Organic Matter (%)	Phase 1 Loading Rate (cm/day)	Phase 2 Loading Rate (cm/day)
South	Sandy Loam	0.52	0.315	0.239
Middle	Loamy sand	0.28	0.529	0.343
North	Silt loam	1.33	0.237	0.170

Source: Beggs et al. (2011)

The authors reported N removal rates from 63 to 95 percent. They used the data to calibrate a HYDRUS model to predict denitrification rates in these soils.

The study concluded that “nitrogen removal is especially effective in medium to fine soils and soils with shallow restrictive or capillary break layers. In these soils, a 50 percent nitrogen removal rate is reasonable to expect” (Beggs et al. 2011). The authors provided recommended design rates of denitrification based on the model runs of 10 percent for loamy sand, 30 percent for sandy loam, and 50 percent for loam or clay loam.

- This paper supports the exclusion of sands from the BMP, but not the exclusion of loamy sands. However, the consensus of the OWTS Expert Panel is that there is an insufficient amount of directly measured evidence to support the inclusion of sand and loamy sand soils in this BMP at this time.

Bohrer, R., and J. Converse. 2001. Soil Treatment Performance and Cold Weather Operations of Drip Distribution Systems. University of Wisconsin-Madison.

- The study included both STE and treated effluent with areal loading rates of 0.08 to 0.6 gpd/sf. This study was generally inconclusive with respect to TN reduction due to abnormally high TN values in the background samples. However, the authors did conclude that drip systems are functional during cold weather and, based on bacteria reduction, provide adequate treatment.

Degen, M. 1992. Denitrification in Low Pressure Distribution On-Site Wastewater Disposal Systems. Ph.D. diss., Virginia Polytechnic Institute and State University, Blacksburg.

- The authors conducted laboratory column studies utilizing a Groseclose silt loam. They collected soil cores (6 inches deep and 2 inches in diameter) from the surface Ap horizon. They collected a second set of 6-inch-deep, 2-inch-diameter cores from 45 to 60 centimeters in the Bt horizon. Seventy-two cores received treatment and six cores were used as controls. The author applied nitrified (27.6 mg/L TN) and non-nitrified wastewater (30.7 mg/L TN) to the soil cores at loading rates of 0.5, 1, and 1.5 times the Virginia regulatory rates for the two soil horizons. The surface horizon received loading rates of 0.31 gpd/sf, 0.61 gpd/sf, and 0.92 gpd/sf. The subsurface horizon received loading rates of 0.11, 0.22, and 0.33 gpd/sf. The authors designed the study to simulate LPD systems. The study was run at 10° C and 20° C for 4 weeks. A mass balance was done by measuring all applied nitrogen, all TN removed in the leachate, and all TN remaining in the soil. Any TN unaccounted for was assumed to have been lost via denitrification. Table 3-5 provides a summary of the results, noting the average TN removals. Also note that the columns were each 6 inches deep with effluent application at the surface of each column.

Table 3-5. TN Reduction for Column Studies.

Soil Horizon	Wastewater	Percent N Lost
Surface	Nitrified	54%
Surface	Non-nitrified	52%
Subsurface	Nitrified	69%
Subsurface	Non-nitrified	40%

Source: Degen (1992)

Duncan, C., R.B. Reneau, Jr, and C. Hagedorn. 1994. Impact of Effluent Quality and Soil Depth on Renovation of Domestic Wastewater. In *Proceedings of Seventh ASAE International Symposium on Individual and Small Community Sewage Systems,* Atlanta, GA.

- The authors obtained soil cores from a fine loamy, mixed, mesic Typic Hapludult from a depth of 18 inches. They applied three effluent types to the soil six times a day: STE, RMF effluent, and constructed wetland effluent. They also collected leachate samples at 6, 12, and 18 inches below the application point over a period of one year. The table below summarizes the results.

Table 3-6. TN Reduction by Effluent Type.

Effluent Type	Effluent TN (mg/L)	TN, mg/L @ 6-Inch Depth	TN, mg/L @ 12-Inch Depth	TN, mg/L @ 18-Inch Depth
STE	38.34	19.19 (50%)	19.74 (50%)	21.83 (43%)
RMF	21.82	14.4 (34%)	14.21 (35%)	15.64 (28%)
Constructed wetlands	28.01	8.38 (70%)	13.43 (52%)	11.37 (59%)

Source: Duncan et al. (1994)

- This study supports the belief that denitrification can occur in the subsurface soil horizons, but not to the extent that the surface soil horizons can. This supports restricting the BMP to the surface horizons.

USEPA (U.S. Environmental Protection Agency). 2010. *Guidance for Federal Land Management in the Chesapeake Bay Watershed.* EPA841-R-10-002. U.S. Environmental Protection Agency, Cincinnati, OH.

- USEPA referenced Long (1995) and recognized that time-dosed, pressurized drip dispersal in the top 12 inches of soil has been credited with 50 percent reduction.

Hayes, J.G, and A. Moore. 2007. Long Term Impacts of Micro-Irrigation "Drip" Treatment and Disposal Systems on Delaware's Marginal Soils. In *Proceedings of Eleventh Individual and Small Community Sewage Systems Conference*, Warwick, RI.

- The authors installed shallow drip systems (15 to 20 centimeters deep) in coarse-loamy soils (see table below) that are somewhat poorly drained, but relatively permeable. They also installed shallow wells at each site to obtain groundwater samples. Well depths were 1.5 meters, with screening at 30 centimeters. The table below summarizes the characteristics of each site and system.

Table 3-7. Site and System Characteristics.

Site	Soil Class[1]	Permeability	SHWT	System Type
1	Aquic Hapludult	30 mpi	50 cm	Drip
2	Typic Endoaquult	30 mpi	28 cm	Drip
3	Aquic Hapludult	60 mpi	50 cm	Drip
4	Typic Umbraquult	60 mpi	0 cm	Drip with ATU

Source: Hayes and Moore (2007)
[1]Coarse-loamy
mpi = minutes per inch

- The sites receiving STE averaged 54 mg/L TN applied to the soil. The highest TN reported from the wells was 11.4 mg/L, which suggests a 78 percent reduction of TN. The site receiving the treated effluent had an applied TN of 20.8 mg/L, with the highest reported TN in the wells being 7.72 mg/L or a 62 percent reduction in TN.

Hepner, L., D. Linde, C. Weber, and D. Smith. 2005. Alternative On–Lot Technology Research-Soil-Based Treatment Systems. Delaware Valley College, New Britain, PA.

- The authors ran multiple studies to evaluate different technologies. The authors reviewed studies utilizing drip or LPD in surface soils. All of these studies used leachate samples collected below the effluent application point.
- The authors applied nitrified secondary effluent (42.5 mg/L TN) at a rate of 0.056 gpd/sf to a surface drip system in a poorly drained Chalfont series soil with a restriction at 13 inches and estimated percolation rate of 70 to 200 minutes per inch (mpi). They collected leachate samples from 2 and 4 feet below the drip lines over a period of 2 years. Over 88 samples of nitrate-N and ammonia-N were collected. The authors noted a 94 percent reduction at the 2-foot depth and a 96 percent reduction at the 4-foot depth. However, the samples might have been impacted by dilution due to the distance between the collection point and the application point.

- The authors installed drip irrigation at an 8-inch depth in a wooded site with a Readington series soil that contained a fragipan horizon at 25 inches and a reported 20 to 60 mpi percolation rate. The application rate was not specified. The authors applied STE with a TN concentration of 42.5 mg/L and collected leachate samples at 1, 2, 3, and 4 feet below the drip lines. Over 55 samples were collected at each depth for ammonia-N and nitrate-N, with more samples collected at the 1-foot depth (89 samples minimum). Data from the 1- and 2-foot depths was evaluated for this BMP. At a foot, the leachate had an 84.5 percent reduction from the STE. At the 2-foot depth, the reduction was calculated as 80 percent. This is a large, robust data set that spans multiple seasons. The lower reduction at the 2-foot depth is likely due to accumulation of effluent at the fragipan layer.
- The authors installed LPD in a surface gravel bed/mound and dispersed STE to a Lansdale soil characterized as deep and well-drained, with a percolation rate of 11 to 18 mpi. The loading rate was calculated as 0.5 gpd/sf to the mound base. Researchers collected leachate samples at 1, 2, 3, and 4 feet below the soil surface. At a foot the TN reduction was 28 percent (n = 49). At 2 feet the reduction was 45 percent. The fact that this was a highly permeable soil could account for the lower reductions of TN reported.
- The authors installed drip irrigation using a chisel plow at 9 to 11 inches in a Chalfont series soil, with redox at 11 inches and rock fragments at 25 inches. They applied STE (42.5 mg/L TN) at a rate of 0.08 gpd/sf May through November and at 0.04 gpd/sf December through April and took leachate samples for ammonia-N and nitrate-N at 2 and 4 feet below the drip tubing. They reported 91 percent TN removal at the 2-foot depth and 93 percent removal at the 4-foot depth (n = 83). Note that the results for both loading rates are combined.
- The authors installed drip irrigation with a chisel plow at 9 to 11 inches, with redox at 11 inches and rock fragments at 25 inches. They applied STE (42.5 mg/L TN) at a rate of 0.08 gpd/sf from May through November and at a rate of 0.04 gpd/sf from December through April. They injected air through the drip system after the effluent had been applied. The addition of the air chase differentiates this design from the one used in the study summary above. Researchers took leachate samples at 2 and 4 feet below the drip tubing and analyzed them for ammonia-N (n = 123 at 2 feet and 66 at 4 feet) and nitrate-N (n = 118 at 2 feet and n = 64 at 4 feet). At 2 feet, the samples indicated a 93 percent reduction. At 4 feet the samples supported a reduction of 89 percent. Again the data from the two loading rates is combined.
- The authors installed drip irrigation with a chisel plow at 9 to 11 inches, with redox at 11 inches and rock fragments at 25 inches. They applied STE (42.5 mg/L TN) at a rate of 0.08 gpd/sf from May through November and at a rate of 0.04 gpd/sf from December through April. The site was covered with no-till corn. Researchers took leachate samples at 2 and 4 feet below the drip tubing and analyzed them for ammonia-N (n = 128 at 2 feet and 90 at 4 feet) and nitrate-N (n = 127 at 2 feet and 92 at 4 feet). The samples indicated a 79 percent TN reduction at 2 feet. At 4 feet, the samples supported a reduction of 72 percent. Again, the data from the two loading rates is combined.
- The authors installed drip irrigation with a chisel plow at 9 to 11 inches, with redox at 11 inches and fragments at 25 inches. They applied STE (42.5 mg/L TN) at a rate of 0.08 gpd/sf from May through November and at a rate of 0.04 gpd/sf from December through April. The site was maintained as pasture. Researchers took leachate samples at 2 and 4

feet below the drip tubing and analyzed them for ammonia-N (n = 98 at 2 feet and 87 at 4 feet) and nitrate-N (n = 100 at 2 feet and 88 at 4 feet). The samples indicated a 96 percent reduction at 2 feet. At 4 feet, the samples supported a reduction of 96 percent. Again, the data from the two loading rates is combined.

Hepner L., D. Linde, C. Weber, and D. Smith. 2007. Reduction of Bacteriologic and Chemical Constituents of Septic Tank Effluent with Depth Using a Drip Dispersal System, *In Proceedings of Eleventh Individual and Small Community Sewage Systems Conference*. Warwick, RI

- The authors evaluated drip dispersal of STE installed 8 to 10 inches deep in a Reading series soil (fine-loamy, mixed, active, mesic Oxyaquic Fragiudalf), with a fragipan and redox indicators at 25 inches. The applied effluent had a TN concentration of 49.4 mg/L and was applied at a rate of 0.17 gpd/sf. The authors collected samples at 1 foot below the drip lines, and observed an 85 percent reduction of TN based on leachate samples.

Long, T. 1995. Methodology to Predict Nitrogen Loading from On-Site Sewage Treatment Systems. Presented at 8th Northwest On-Site Wastewater Treatment Short Course, Seattle, WA, September 18-19, 1995.

The author provides an extensive review of literature relating to nitrogen in on-site systems. Relevant statements are provided below.

- Denitrification can occur at microsites in aerated soils.
- “Finer grained soils achieve greater denitrification due to substrate exposure to larger biofilm surfface area per unit volume and restricted drainage through smaller pore spaces that saturate readily” (Long 1995).
- Denitrification is limited in deep, very coarse-grained soils.
- Plant uptake can occur if nitrification occurs high enough within the soil columns for plant roots to reach them. Up to 46 percent of the applied N was removed by uptake from on-site systems in a slowly permeable soil with a Bermuda grass cover. Nutrient uptake and storage in hardwoods, on the other hand, did not occur to significant amounts.

Parzen, R.E., J. Tomaras, and R.L. Siegrist. 2007. Controlled Field Performance Evaluation of a Drip Dispersal System Used for Wastewater Reclamation in Colorado. In *Proceedings of Eleventh ASAE Individual and Small Community Sewage Systems Conference*, Warwick, RI.

- The authors installed a pilot scale drip system with two zones dispersing 0.5 cm/day (0.122 gpd/sf) or 1.0 cm/day (0.244 gpd/sf) of STE. They installed the systems in a sandy loam soil at 0.2 to 0.3 meters below the surface (7 to 12 inches). They took soil cores through the system after 6 months. The authors drew no conclusions, but the data indicate nitrification occurring near the emitter and TN concentrations decreasing with distance from the emitter.

3.9.3 Ancillary Issues and Interactions with Other Practices

In situ treatment BMPs interact with *ex situ* treatments. In the case of this BMP, the OWTS Expert Panel recommends a 50 percent TN reduction or a *net* TN reduction of 38 percent, regardless of the quality of effluent being treated in the *in situ* BMP.

3.9.4 Design and Installation Criteria

Although the amount of TN removal that occurs with various soil types is not well-defined, the ability of surface soils to remove TN is established. For this BMP, minimum design and installation criteria include the following:

- The drip tubing or LPD piping must be installed in a natural surface (i.e., A or B) horizon no deeper than 12 inches from the original soil surface. Loading rates must be appropriate for the soil hydraulic properties and the effluent properties.
- BMP credits are not provided for installation in sand or loamy sand textured soils.
- Loading rates must be appropriate (e.g., per state regulation, peer reviewed articles, or manufacturer guidance) for the soil hydraulic properties and effluent quality.
- The site must have a stable vegetative cover.
- For sloping sites, the drip or LPD piping must be placed on contour, and the linear loading rate across the slope must be minimized.
- The minimum vertical separation from a restriction will vary by state, and nothing in this document is intended to call into question state requirements. Sufficient unsaturated soil must exist below the drip tubing or LPD piping to allow for movement of the applied wastewater from the site.
- Landscape position is also a necessary consideration. Systems should not be sited within a closed depression, or where water tends to pond during heavy rainfall events.
- All drip system designs shall incorporate the following:
    - A vibratory plow, static plow, or trencher is most typically used to install the tubing, and soil moisture must be dry enough so that soil compaction does not occur.
    - A filtration system shall be provided to protect the emitters from clogging.
    - An automatic flush cycle shall provide a minimum flushing velocity at the rate the tubing manufacturer recommends.
    - The effluent is to be equalized and timed-dosed over a 24-hour period to maximize the fluctuation between aerated and non-aerated periods. Minimum dose volume shall be 3.5 times the volume of the drip network or zone as applicable.
    - The system shall be designed to minimize draindown effects on the lowest line in a zone.
    - Air vacuum release valves shall be provided at the high points of the feed and return lines to prevent entry of soil particles into emitters.
- All LPD or LPP systems shall incorporate the following elements:
    - The working pressure head is less than 5 feet.
    - The dosing volume is 7 to 10 times the volume of the distribution piping.
    - The piping shall be properly bedded in accordance with state regulations.
    - LPP/LPD lines should be sleeved in perforated pipe or chambers to minimize orifice shielding by gravel.
    - The system shall be equipped to allow system flushing as needed for maintenance.
    - The hole size and spacing shall be designed to produce a maximum flow variation of no greater than 10 percent along the length of each pipe.

Shallow drip and LPP/LPD systems should be effective at reducing TN when properly sited, designed, and managed. Important considerations include the shallow placement of the distribution system in an organic-rich mineral soil horizon; appropriate loading rates; use of small, frequent doses of wastewater; and use of low linear loading rates on sloping sites.

3.9.5 Temporal Performance

Drip and LPP/LPD systems use ubiquitous micro-organisms to facilitate the nitrogen removal process. There should be little lag time and established biological populations should occur within 3 to 4 weeks.

The duration of denitrification capability is difficult to determine since the soil organic matter is continuously depleted owing to the denitrification demand. Decaying vegetative matter such as roots may provide more continuous fuel for the reaction. Robertson and Cherry (1995) suggested that even a low-efficiency contactor with 2 percent organic carbon should last at least 20 years.

Annual Inspection Checklist

- Inspect the pump chamber and filtration system for proper function. Confirm that the dosing volume and dosing frequency comply with the original design parameters.
- Check the pump chamber for solids carryover and remove the solids if needed.
- Verify the LPP/LPD dosing volumes and flush the LPP/LPD lines and reset the pressure head if needed.
- Verify the drip dosing and flushing volumes and reset if needed.
- Examine the dispersal field for leakage or any indications of uneven distribution.
- Conduct maintenance in accordance with the manufacturer's or designer's requirements if a treatment unit is used prior to the dispersal field. More frequent visits might be necessary to maintain proper function.
- Conduct other generic O&M procedures (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).

3.9.6 Recommended Management Requirements

Additional O&M visits might be necessary depending on the complexity of the system.

3.9.7 Review Timeline and Recommendations

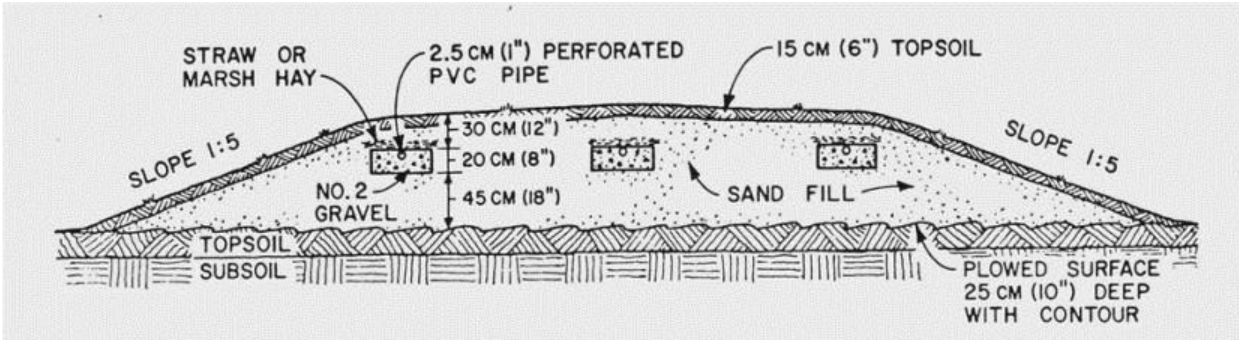
The OWTS Expert Panel recommends a review timeline of 2 years to determine if there is any additional information that would require a modification of the assigned TN reductions.

3.10 ELEVATED SAND MOUNDS

3.10.1 Detailed Definition of Practice

Elevated sand mounds have been in use as a combination wastewater treatment and dispersal system since the 1970s. The technology was developed to address sites with shallow depth to restrictions such as seasonal water tables and bedrock. Mounds originated in Wisconsin and the bulk of the nitrogen removal research is on the effectiveness of mounds designed in accordance with the Wisconsin design manuals released in the 1970s and 1990s. The mound system consists of a septic tank and bottomless intermittent sand filter installed above an organic–rich soil (Source: http://www.engr.wisc.edu/alumni/perspective/02.4/mound.html

Figure 3-10).



Source: http://www.engr.wisc.edu/alumni/perspective/02.4/mound.html

Figure 3-10. Elevated Sand Mound Diagram.

The traditional elevated sand mound is comprised of a raised sand bed, 1 to 2 feet in depth, which is overlain by a gravel layer that has pressure distribution piping imbedded in the gravel. The gravel is covered with a minimum of 1 foot of soil to protect the system from freezing. Grass or other vegetation is established on the soil to stabilize the surface of the mound. The original system designs applied STE, but later design documents (Converse and Tyler 2000) describe applying secondary effluent (i.e., meeting effluent concentrations of 30 mg/L BOD_5 and 30 mg/L TSS) to a mound as well. The wastewater is applied to the sand and nitrified as it passes through the sand. The sand layer essentially acts as a single-pass sand filter. When the nitrified effluent reaches the soil layer, the effluent tends to pond due to the discontinuity between the sand and the soil layer creating an anoxic zone. If the soil layer has sufficient organic matter available, denitrification occurs in the upper horizon.

3.10.2 Nitrogen Load Reduction and Recommended Credit

The OWTS Expert Panel recommends that elevated sand mounds designed, installed, operated and maintained in accordance with this section be assigned a 50 percent TN reduction (for all soils except sands and loamy sands), for an *in situ* edge-of-drainfield concentration of 30 mg/L TN or TN load of 2.5 kg/person/year (for STE). This results in a *net* TN reduction of 38 percent after accounting for the baseline BMP of 4 kg TN/person/year. ((4-2.5)/4 = 0.38) Table 3 3 summarizes net TN reductions for various combinations of *ex situ* and *in situ* BMPs.

Proper siting, design, and construction are critical to the nitrogen removal effectiveness of elevated sand mounds. The OWTS Expert Panel expects variations in TN reduction with changes to loading rates, dosing frequency, and receiving soil environment. The sand loading rate and depth of sand is critical to maximizing nitrification of the STE so that denitrification can occur at the sand/soil interface and below.

The bulk of the data available comes from several extensive studies conducted in Wisconsin. The earliest studies indicated that 44 percent of nitrate formed through the mound is denitrified. The percentage of nitrate formed through the sand layer of the mound in the early studies was only about 50 percent. These studies had issues with the sand fill material, the loading rate, and dosing volume. As the design for mounds was refined, several changes were made that improved the nitrification rate through the mound. These modifications included: reduction of loading rates to the sand media to 1 gpd/sf or less; refinement of the specification of the sand media to eliminate fines and reduce the UC; and an increase in the number of doses per day to the sand with a resulting decrease in volume per dose.

The relevant literature is summarized below.

Charles, K. J., J. F. Schijven, D. Baker, D.J. Roser, and D.A. Deere, and N.J. Ashbolt. 2004. Transport and Fate of Nutrients and Pathogens During Sewage Treatment in a Mound System. In *Proceedings of Tenth National Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, Sacramento, CA.

> The authors constructed two sand mounds receiving STE from four households and two public toilet blocks. They designed the mounds to alternate once every 6 months. They modified the mounds by adding an industrial by-product to the media mix to facilitate P removal (no discussion of the composition of the material). The mounds were underlain with a plastic liner and the leachate was collected and then distributed to a gravel trench.
>
> The design flow was 5 m^3 (1,320 gallons) per day, but the actual flows were 1.6 m^3/day (422 gpd). The mounds had a 138 m^2 surface area (1,485 sf) (assume each). There is no discussion of loading rates or method of loading, but if one assumes 5 m^3 applied to two 138 m^2 mounds, then the design loading is 0.018 m^3/m^2 or 0.44 gpd/sf.
>
> The authors collected samples from the drainage trench in the bottom of the mound that discharged to a pump station, or from a well in the mound. The TN applied to the filters was 83.1 mg/L TN (38 samples total) and the mean effluent concentration was 39.6 mg/L TN.
>
> The study only tracked the quality of effluent through the sand layer and not after interaction with soil where most denitrification occurs. The abstract states that TN removal averaged 19 percent, but data suggest higher removals of 52 percent based on average influent of 83 mg/L and average effluent of 39.6 mg/L. There does not appear to be a rationale for the TN removal in the mound. It is assumed that the lining produced a saturated zone near the base of the filter and allowed for denitrification occur.

Converse, J.C., N. Kean, E. Tyler, and J. Petersen. 1991. Bacterial and Nutrient Removal in Wisconsin At-Grade On-Site Systems. In *Proceedings of Sixth National Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, Chicago, IL

> The authors selected 31 mound systems for the study. The mound systems were of the Wisconsin design and in accordance with the 1983 Wisconsin State Code. All sites applied STE to the mound surface except one, which had an ATU for pretreatment. The design loading rate was 0.6 gpd/sf. Five of the sites had bedrock as a limiting condition at 36 or more inches. The remaining sites had high seasonal water table based on redox indicators at 28 or more inches. The sites had silt loam or loam surface horizons, with one site having a sandy loam surface horizon. For sites that used pressure distribution, the authors collected soil samples near an orifice in the distribution manifold to a depth of

105 centimeters. For gravity distributed systems, they collected samples beneath a ponded surface. If a ponded surface was not found, then no samples were collected.

The average TN concentration of the STE was 59 mg/L based on 30 samples. The site using an ATU had an average TN concentration of 54 mg/L based on 21 samples. It should be noted that the ATU produced primarily nitrate-N, while the septic effluent had no reported nitrate-N.

For the pressure-dosed systems, the soil samples collected beneath the mounds indicated very high levels of TKN, from 2,136 mg/kg at the soil surface to 400 mg/kg at 105 centimeters below the soil surface. The background TKN values were just as high adjacent to the mounds, averaging 2,048 mg/kg at the soil surface and 348 mg/kg at the 90- to 105-centimeter depth. Ammonia-N ranged from 29 mg/kg at the soil surface beneath the mound to 15 mg/kg at the 90- to 105-centimeter depth. Nitrate-N ranged from 21 mg/kg at the soil surface to 9 mg/kg at the 90- to 105-centimeter depth. If one assumes that the ammonia-N and nitrate-N can be added to estimate total N and neglect the organic N component, then the reduction in TN from the soil surface to the 90- to 105-centimeter depth is ((29+21)-(15+9)/(29+21)) × 100 = 52 percent. However, nitrate-N is mobile in soil and therefore use of nitrate associated with the soil fraction is unlikely to be completely accurate; ignoring organic nitrogen further denigrates these findings.

An alternate mechanism is to use nitrate/chloride ratios in the solution fraction. Both nitrate and chloride move with the soil solution and are subject to the same dilution effects. The authors considered reductions in the nitrate/chloride to be indications of removal of nitrate and not just dilution. They calculated the solution concentration for both nitrate-N and chloride based on the soil moisture and the soil fraction concentration of both constituents. At the soil surface beneath the mound, the average nitrate-N concentration was 66 mg/L and the average chloride concentration was 287 mg/L. That results in a nitrate-N/chloride ratio of 0.229. The nitrate-N concentration at the 90- to 105-centimeter depth was 35 mg/L and the chloride concentration was 287 mg/L. The ratio for that depth is 0.122. The calculated reduction in nitrate-N is therefore 46.7 percent ((0.229-0.122)/.229) × 100). The authors cautioned that the higher chloride concentrations adjacent to the mounds (148 to 164 mg/L) bring this method into question.

For the two gravity-fed systems, the nitrate concentration in the soil solution at the 90- to 105-centimeter depth averaged 65 mg/L. In general the gravity-fed systems had higher ammonia levels at the soil surface and the nitrate formation occurred deeper into the soil profile with little apparent denitrification occurring.

The one system that had an ATU for pretreatment showed little ammonia-N below the mound (4 mg/kg at the soil surface and 1 mg/kg at the 90- to 105-centimeter soil depth). Nitrate-N was highest at the soil surface at 23 mg/kg and slowly reduced to 5 mg/kg at the 90- to 105-centimeter depth.

Harkin, J.M. and C. Chen. *1995. Long-Term Transformation and Fate of Nitrogen in Mound-type Soil Absorption Systems for Septic Tank Effluent*. Prepared for the state of Wisconsin Department of Natural Resources.

The authors studied 12 systems of varying designs receiving STE. These included existing (at least 18 years old) conventional gravity-fed trench systems, pressure-dosed trench systems, and elevated sand mounds. Five of the sites were mounds. The influent TKN was extremely high at each of these sites at 164.48, 65.43, 105.58, 110.21, and 134.2 mg/L.

The authors sampled groundwater monthly in the vicinity of the systems for 13 months and analyzed the groundwater for TN, as summarized in Table 3-8. Wells were located downslope, with the closest well 0.3 meters horizontally from the gravel bed in the mound. The second well was 3 meters farther down gradient (approximately toe of mound) and the third well was 3 meters farther down gradient.

Table 3-8. Nitrogen Species Concentrations versus Horizontal Distance from Mound

Well	Nitrate-N (mg/L)	Ammonia-N (mg/L)	TKN (mg/L)
1 (0.3 m)	18	1.55	21
2 (3.3 m)	10	1.5	12
3 (6.3 m)	2	1.4	6

Source: Harkin and Chen (1995)

This study did not measure chloride, so the effect of dilution on the values of nitrate-N is not considered. The low ammonia values in the groundwater suggest that the bulk of the effluent was nitrified going through the mound. The reduction in nitrate from Well 1 to Well 2 (not accounting for dilution) was 43 percent. The reduction in nitrate from Well 1 to Well 3 indicates a 70 percent loss, again with dilution unaccounted for.

Smith, D. P, and R. Otis. 2007. Florida Passive Nitrogen Removal Study: Literature Review and Database. Prepared for Florida Department of Health.

The authors reviewed numerous papers on available technologies that fit within the study's definition of "passive" treatment. A technology could use no more than one pump and use no active aeration units, such as blowers.

The authors reviewed achievable N removal in soil-based treatment systems (STS) as summarized in Table 3-9.

Table 3-9. TN Removal for Soil-Based Treatment Systems

STS Type	N Removals	
	Typical	Range
Traditional In-Ground	20%	10%–40%
Mound/Fill	25%	15%–60%
Systems with Cyclic Loading	50%	30%–80%

Source: Smith and Otis (2007)

This study stressed the need for adequate alkalinity to fuel the nitrification process and recognized that denitrification potential is limited to the amount of available nitrate-N. Alkalinity is required at a rate of 7.14 mg per mg of ammonia-N.

Harkin, J.M., C. J. Fitzgerald, C. P. Duffy, and D.G. Kroll. 1979. *Evaluation of Mound Systems for Purification of Septic Tank Effluent*. Technical report WIS WRC 79-05. Water Resources Center, University of Wisconsin, Madison, WI.

The authors studied a total of 33 elevated sand mounds over a 2-year period. All of the mounds were designed, installed, and operated in accordance with state guidelines. Three designs were used. Package 1 was used for sites with slowly permeable soils (60 to 120 mpi) with or without high groundwater (within 1 foot of sand fill in mound). This design used a trench configuration for the pressurized distribution lines in gravel and not a bed configuration as used in the other designs. One foot of sand fill was used. Package 2 was used for permeable soils (3 to 60 mpi) overlying pervious bedrock (within 2 feet of base of mound). The sand fill depth was 2 feet with a gravel bed construction on top of the sand for the pressurized dispersal system. Package 3 was used on sites with permeable soils (3 to 60 mpi) with high water table (within 1 foot of sand fill in mound). The sand fill depth was 1 foot with a gravel bed construction on top of the sand for the pressurized dispersal system.

The authors dosed STE to the mounds four to six times a day using a pressurized distribution system. They used a medium sand fill and constructed the distribution network on top of the sand in a gravel layer. They based the designs on a 150 gpd/bedroom and a sand loading rate of 1.2 gpd/sf. The authors do not discuss the soil loading rate (basal area).

Of the 33 mounds included in the study, 3 were of the Package 1 design, 6 were of the Package 2 design, and 24 were of the Package 3 design. The authors sampled systems bimonthly for a period of 16 months. They sampled at least 6 times for a total of 347 sampling events. Monitoring included the STE concentration, soil samples within and directly downslope of the mounds, and groundwater wells downslope from the toe of the mound. Nitrogen was one of the parameters studied as TKN, ammonia-N, and nitrate-N analyses were conducted. The authors conducted additional groundwater monitoring at four Package 3 sites with high groundwater.

The applied STE averaged 82.5 mg/L TN (165 samples). In general, the mound systems allow nitrification within the sand fill, denitrification at the natural soil surface, and either nitrification or continued denitrification in the natural soil depending upon the moisture level and texture of the soil. Overall, the study found that the effluent nitrifies as it passes through the mound with denitrification occurring 5 to 25 centimeters below the mound. 44 percent of the nitrified effluent is denitrified on average. The average TN removal was 72 percent at the 25–centimeter depth. The authors stated that assuming no further N transformations occurred below 55 centimeters, the average TN flux to groundwater is 19.5 mg/L. which represents a 76 percent reduction in TN.

The Package 1 design with 1 foot of sand and trench construction did a better job nitrifying the effluent and achieved almost total nitrification through the mound. It was speculated that the sidewall the trench created provided additional treatment zones for nitrification to occur. The Package 2 design showed nitrification occurring to a deeper depth (15 centimeters) into the soil before denitrification occurred. The designs were installed in more permeable soil and thus maintained a deeper unsaturated zone.

The study also evaluated the systems on combinations of dosing rate and fill uniformity. The authors identified four groups of systems (1) high dosing rate and fill with high UC; (2) low dosing rate and fill with high UC; (3) high dosing rate and low UC; and (4) low dosing rate and low UC. A high dosing rate was greater than 0.8 gpd/sf/dose and a high UC was >5. Of these, the Group 4 (low dosing and low UC) systems allowed the maximum amount of nitrification in the sand fill. Denitrification begins at the soil surface and continues with depth to 15 centimeters, with total removals ranging from 17 to 54 percent.

The authors recommended that to maximize denitrification, the system must cycle from aerobic to anaerobic every 6 to 12 hours. Systems should be dosed 2 to 4 times daily to minimize the hydraulic flux pushing the nitrate into the groundwater and also to maximize nitrification within the mound. The fill material quality is also of prime concern and the authors suggest a medium sand, neither too coarse nor too fine. An adequate soil cap is necessary to avoid freezing of the system.

Magdoff, F. R., D. R. Keeney, J. Bouma, and W. A. Ziebell. 1974. Columns representing mound-type disposal systems for septic tank effluent II nutrient transformations and bacterial populations. *Journal of Environmental Quality* 3:228-234.

The authors concluded from column studies that about one-third of the nitrate formed in a mound system was denitrified. (Referenced in Harkin et al. 1979)

3.10.3 Ancillary Issues and Interactions with Other Practices

In situ treatment BMPs interact with *ex situ* treatments. In the case of this BMP, the OWTS Expert Panel recommends a 50 percent TN reduction (*net* 38 percent reduction) regardless of the quality of effluent being treated in the *in situ* BMP.

3.10.4 Design and Installation Criteria

- Minimum design and installation criteria for this BMP are based on Converse and Tyler (2000).The mound must be installed over a natural surface A or B horizon.
- No credit is given to mounds installed over sand or loamy sand soils.
- Small, frequent timed doses of effluent must be dosed to the sand media through a pressurized distribution system (i.e., LPP/LPD or drip) with a spacing that provides 4 to 6 sf per orifice (i.e., 2' × 2' or 2' × 3' grid).
- The surface of the soil under the mound must be tilled or scarified to allow movement of the wastewater into the soil.
- The sand layer should be coarse sand with ≤ 0.5 percent fines passing #200 sieve. Additional descriptors include: ASTM C33 sand; ≤ 20 percent by weight material that is greater than 2 in diameter; D10 = 0.15 to 0.3 millimeters; UC = 4 to 6.
- The sand depth should be 1 to 2 feet, depending on the depth to a restricting feature underneath and the level of effluent quality applied to the mound. For STE, the sand should be at least 2 feet deep. A lesser depth of sand (no less than 12 inches) may be used for pretreated effluent.
- The allowable depth to a restriction from the natural ground surface will vary by state, and nothing in this document is intended to infringe on those separation distances. Sufficient unsaturated soil must exist below the mound to allow for movement of the applied wastewater from the site without surfacing. Converse and Tyler (2000) recommend a minimum of 10 inches of vertical separation from the ground surface to a restriction to avoid leakage at the toe of the mound.
- The sand media loading rate for STE should be no greater than 1 gpd/sf. If the effluent is pretreated to secondary standards, the loading rate may be increased to 2 gpd/sf.
- Converse and Tyler (2000) provide basal area loading rates that may be used if a state does not have appropriate basal area loading rates.
- The linear loading rate should be limited to 3 to 4 gpd/lf on sites with restrictions that rely on horizontal movement of the wastewater away from the mound.
- Mounds should be covered with a 6- to 12-inch layer of sandy loam, loam, or silt loam. Clay loam, silty clay loam, and clay soils are not acceptable because they retard the diffusion of oxygen to the sand layer.
- The site must have a stable vegetative cover.

Under the above design conditions, the sand mound should nitrify the wastewater adequately prior to the wastewater reaching the sand/soil interface where the potential formation of an anoxic zone will allow for denitrification. The amount of denitrification will vary depending on the conditions underneath the mound. Maximum denitrification will occur where there is sufficient organic matter in the soil to complete the denitrification process.

Mounds are likely to be viable for TN removal in most areas where there is an organic surface horizon. However, the mound height is unsightly and expensive, and homeowners do not generally choose a mound when an in-ground system will work. Mounds are most often used when there is a reduced vertical separation to a limiting feature which restricts the options for in-ground systems.

3.10.5 Temporal Performance

Mounds use micro-organisms to facilitate the nitrogen removal process. However, most media filters have established biological populations within 3 to 4 weeks, so there is little lag time.

The duration of denitrification capability is difficult to determine since the soil organic matter is continuously depleted owing to the denitrification demand. Robertson and Cherry (1995) suggested that even a low-efficiency contactor with 2 percent organic carbon should last at least 20 years.

3.10.6 Recommended Management Requirements

Additional O&M visits might be necessary depending on the complexity of the system.

3.10.7 Review Timeline and Recommendations

The OWTS Expert Panel recommends a review timeline of 5 years to determine if there is any additional information that would require a modification of the assigned TN reductions. Additional research needs are summarized as follows:

- The criteria for optimizing the nitrification process through the sand mound should be better developed.
- Impacts of various soil types and site limitations should be better defined.
- Augmentation of the mound with additional carbon sources, engineered treatment media, etc., can help to expand the effectiveness and longevity of the mounds.

Annual Inspection Checklist

- Inspect the pump for proper function. Confirm that the dosing volume and frequency comply with the original design parameters.
- Check the pump chamber for solids carryover and remove the solids if needed.
- Flush the LPP/LPD lines and reset the pressure head.
- Verify the dosing volume and reset if needed. For drip, verify that the flush cycle operates properly and reset if needed.
- Visually inspect the mound to ensure that there are no breakouts of wastewater around the perimeter of the mound. Examine the mound for leakage or any indications of uneven distribution.
- Operate and maintain in accordance with the manufacturer's or designer's requirements if a pretreatment unit is used prior to the mound. Additional visits might be necessary to maintain proper function.
- Conduct other generic O&M procedures (measure sludge/scum levels in septic tank, pump septic tank as needed, clean effluent screen/filter, walk drainfield, etc.).

3.11 Permeable Reactive Barriers

3.11.1 Detailed Definition of Practice

PRBs or denitrification walls are a remedial process for treating shallow groundwater impacted with nitrogen-rich effluent from on-site wastewater systems and other sources where the extent of the groundwater plume and its flow direction are well-defined.

PRBs have historically been used for remediating groundwater impacted from mostly industrial uses. The basic process involves digging a trench of suitable depth and width to intercept the flow of impacted groundwater. Ideally, the trench should be dug perpendicular to the predominant groundwater flow vector. Multiple trenches are required in certain areas to fully intercept plumes. Reactive materials are placed in the trench to treat the groundwater as it flows through the PRB. In the groundwater remediation field, various electron donor materials are used as reactive media depending on the contaminant that is being treated. In these applications, contaminants of concern are often chlorinated hydrocarbons. Therefore, the concept of using PRBs to denitrify nitrate-impacted groundwater plumes is established both in concept and in practice.

More recently, water quality managers have used PRB technology to target nitrate-impacted, shallow groundwater plumes, such as those associated with agricultural and on-site wastewater practices. PRBs are usually relatively easy to implement where known groundwater plumes are directly impacting nearby surface waters by siting the PRB between the on-site wastewater system(s) and the receiving water.

PRBs for remediating groundwater impacted from septic systems are denitrification systems. Denitrification can be accomplished at each individual site or with a PRB that intercepts existing nitrate plumes from multiple sites prior to their transition to local surface waters. Individual on-site denitrification systems can be constructed as separate modules by adding carbon or sulfur reaction driver sources in the base of the dispersal field with the appropriate reactive material. If nitrate is present in the absence of DO, this reactive material intercepts and denitrifies the effluent.

3.11.2 Nitrogen Load Reduction and Recommended Credit

PRBs are unique among the recommended practices for on-site wastewater systems because most are applied outside of the property footprint of the on-site systems themselves. Since PRBs generally treat effluent plumes from multiple on-site systems, there is no direct way to relate performance back to individual system baseline loads. Given the site specificity of PRBs, CBPO and the states will have to document this practice for each individual site and jurisdictions will need to use design and monitoring documentation to provide confident estimates on the flows and populations being treated and accordingly, TN load reductions. The consultant/designer or other responsible party must justify proposed reductions to the satisfaction of the state regulatory entity and the USEPA CBPO.

Given the lack of comprehensive information on the logistical challenges associated with siting PRBs and the lack of stringent regulatory effluent requirements that would justify its application, the OWTS Expert Panel does not anticipate installation of a large number of PRBs in the immediate future, although the need for Chesapeake Bay TMDL compliance and increasing familiarity with the approach could drive accelerated use of PRBs.

Studies have demonstrated PRBs to be almost 100 percent effective in remediating nitrate in groundwater plumes provided that they are properly designed, installed, and maintained. One of the most important factors for success is ensuring that the entire groundwater plume is intersected and that sufficient contact time is provided in the PRB to affect complete denitrification. Before construction can begin on a PRB, groundwater flows, tidal impact, and soil studies must be completed to show that the PRB will be able to not only encompass the horizontal width but also the vertical depth of the plume. The concentration and loading of the nitrogen entering the water body must be understood for comparison studies to understand whether the PRB can meet design performance goals.

A summary of the relevant literature is provided below.

Vallino, J., and K. Foreman. 2008. *Effectiveness of Reactive Barriers for Reducing N-Loading to the Coastal Zone.* Prepared for NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology.

- The authors studied PRB technology in field-based, pilot scale. They constructed NITREX™ PRB in the Childs River and Waquoit Bay areas near Falmouth, Massachusetts. The study found that groundwater nitrate plume concentrations were nearly depleted after percolating through the PRB. It appears only a handful of systems have been studied.

USEPA (U.S. Environmental Protection Agency). 1998. *Permeable Reactive Barrier Technologies for Contaminant Remediation*. USEPA/600/R-98/125. U.S. Environmental Protection Agency, Washington, DC.

- This is USEPA's detailed process and design guidance document on PRBs. The document provides the most recent information on PRB technology (as of 1998).

McCray, J and K. Heatwole. 2009. An Analytical Model for Prediction of Groundwater Plumes Originating from On-Site Wastewater Treatment Systems. In *Proceedings of NOWRA 18th Annual Technical Conference and Expo*. Milwaukee, WI.

- The authors provide a model to predict and determine the flow paths and density of groundwater plumes in an analytical sense with factors of homogenous, isotropic aquifer medium.

Cardona, M.E. No Date. Nutrient and Pathogen Contributions to Surface and Subsurface Waters from On-Site Wastewater Systems – A Review. Department of Environment and Natural Resources, Raleigh, NC.

- The author presents a review of studies conducted in past decades on nutrient and pathogen contributions to surface and subsurface waters.

Lombardo, P., N. Brown, J. Barnes, K. Foreman, and W. Robertson. No Date. *Holistic Approach for Coastal Watershed Nitrogen Management*.

- The authors provide an overview of the Falmouth, Massachusetts, PRB study from the private entity perspective.

Robertson, W.D., and J.A. Cherry. 1995. In situ Denitrification of Septic-System Nitrate Using Reactive Porous Media Barriers: Field Trials. *Groundwater* 33: 99–111.

- The authors discuss four field trials demonstrating two barrier configurations: as a horizontal layer positioned in the vadose zone below a conventional septic system infiltration bed and as a vertical wall intercepting horizontally flowing down-gradient plumes.

Tucholke, M.B., J.E. McCray, G.D. Thyne, and R.M. Waskom. 2007. Variability in Denitrification Rates: Literature Review and Analysis. In *Proceedings of the 2006 NOWRA Conference*, Denver, CO.

- The authors performed a rigorous literature review, summarizing denitrification rates from past research. They illustrated the range in denitrification rates based on measuring methods. They also showed the variations in rates due to variables including water-filled porosity and carbon content.

Interstate Technology Regulatory Cooperation (ITRC) Work Group. 1999. *Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Chlorinated Solvents*. 2nd ed. ITRC Permeable Barriers Team.

- The publication provides regulatory guidance for implementation of PRB technology.

Guvaskar, A., N. Gupta, B. Sass, T. Fox, R. Janosy, K. Cantrell, and R. Offenbuttel. 1997. *Design Guidance Application of Permeable Reactive Barriers to Remediate Dissolved Chlorinated Solvents*. Report AL/EQ-TR-1997-0014. Prepared for the United States Air Force, Environics Directorate, Armstrong Laboratory.

- The publication provides regulatory guidance for implementation of PRB technology through the U.S. Air Force.

Robertson, W.D., G.I. Ford, and P.S. Lombardo. 2005. Wood-Based Filter for Nitrate Removal in Septic Systems. *Transactions of the ASAE* 48(1): 121-128.

- The authors present long-term (3- to 5-year) monitoring results for four full-scale, on-site wastewater treatment systems using a novel porous media filter (Nitrex filter) for enhanced nitrogen removal.

Long, L.M. 2011. Long-term nitrate removal in a denitrification wall. *Agriculture, Ecosystems & Environment* 140 (3-4): 514-520.

- This New Zealand study demonstrated nitrate reduction from 2.6 mg/L to 0.2 mg/L of TN and calculated service life of the PRB to be 14 years.

3.11.3 Ancillary Issues and Interactions with Other Practices

PRBs are unique among the recommended practices for on-site wastewater systems because most are applied outside of the property footprint of the on-site systems themselves. Therefore, there should be virtually no potential interactions with other on-site practices. They will, however, impact the attenuation, fate, and transport of nitrates in on-site wastewater effluents as they move from treatment sites toward receiving surface waters and through the PRB trench.

In some cases, changing the oxidation state of the subsurface soils and groundwater can have unintended effects associated with liberating materials that have previously been bound to the soils. This can cause groundwater discoloration, odors, and in some cases, introduce new dissolved contaminants (e.g., arsenic) from the media into the groundwater and nearby surface waters.

Depleting the contaminant to the water body could disrupt certain ecological species' dependency on the contaminant-rich effluent. Disrupting the natural barriers and firmness of the shoreline soils can impact the erosion contribution to the water body and its tributaries immediately adjacent to the PRB and the water body.

3.11.4 Design and Installation Criteria

Minimum siting, design, and installation requirements for PRBs include the following:

- A well-established connection between on-site systems, a groundwater plume, and a receiving water impact must be established and understood.
- The hydrogeology of the site should be relatively simple and understood, and the groundwater plume should be shallow enough to make intercepting it by digging a trench feasible and cost-effective.
- There exists available property with ownership or easements on which to site and perpetually maintain a PRB.
- The groundwater plume boundaries determine the length of the trench. The depth relates to the local hydrology and plume depths. The width of the trench is typically 0.6 to 1.5 meters.
- The media can be sawdust, woodchips, or other available organic materials. Researchers have conducted most research using woodchips and sawdust mixed with other porous materials to regulate flow flux and other site reaction needs (e.g., alkalinity).

PRBs will be a less viable alternative in areas where:

- Nitrate plumes are not confined or are too deep, or there is a high probability of salt water intrusion.
- Impacted groundwater flows are deep or highly dispersed across a broad area.
- Impacted groundwater flow direction is difficult to determine.
- Connection between the impacted groundwater plume and surface water is unclear.
- Saltwater from tidal waters may negatively impact PRB performance.
- Access for maintaining and monitoring PRBs would be difficult (e.g., low, marshy, swampy areas along coastline).

PRBs are likely most viable in coastal areas and adjacent to tributaries where hydrogeological conditions are suitable and there is little saltwater intrusion. PRBs are best used to intercept comingled groundwater flows which have high nitrogen loadings from multiple systems or systems with extremely high N loadings near and between well-established groundwater intrusion sites to tributary streams, lakes, and rivers. PRBs are especially valuable in such places when nitrogen impacts are significant and must be minimized without the lengthy delays involved with nitrogen removal at each source. The simplified management requirements of a single PRB can be superior and cost-effective compared to those related to multiple individual on-site nitrogen removal systems.

3.11.5 Temporal Performance

PRBs can be almost immediately effective at remediating groundwater flowing through them. The lag time in terms of nitrogen loadings to adjacent surface waters is based on the travel time for the groundwater, which is a function of hydraulic gradient and soil conditions. However, because the PRB would be between the on-site systems and the water body, the time frame for surface water loading improvements will be significantly shorter (possibly by years) than that associated with the alternative of retrofitting multiple on-site systems with denitrification, which would have longer groundwater transport times.

Depending on the media chosen, the release of excess carbon during the startup period can increase the BOD of the PRB effluent, but this is generally a short-lived phenomenon.

Media replenishment and integrity, as well as the long-term upper limit on system lifespan are not well-established. Operating systems that are still functional are approaching 20 years of service life with the original trench materials, although 15 years is a more conservative media life for planning purposes.

Annual Inspection Checklist

- Monitor nitrogen concentrations in groundwater up- and down-gradient of the PRB.
- Conduct a visual inspection of the system for physical damage to the wall, maintenance of access, etc.
- Replace media when it has been exhausted (roughly every 15 years).
- Conduct annual inspection of the reactive media and replenish any damaged or depleted media sections.
- Conduct annual inspection for structural damage to structure of PRB.
- Re-evaluate the monitoring of plume and groundwater flows periodically to ensure flow paths have not been affected through the disturbance of the natural hydrology of the soils.

3.11.6 Recommended Management Requirements

The requirements for a PRB system are primarily having ownership or access easements along or in proximity to the impacted shorelines and a RME that conducts required inspections and monitoring. Since there are no external additive requirements, no mechanical components, and PRB media lives are estimated to exceed 15 years, there is not a great operational demand on the management entity.

3.11.7 Review Timeline and Recommendations

New information on this particular application of PRBs is being generated regularly. The OWTS Expert Panel recommends a review timeline of 2 years. Research needs include the following:

- Additional research on the nitrogen reduction capabilities of the PRB and different media mixtures on performance
- Research on the economic factors involved in the design and implementation of the planning stage, the installation stage, and the operation and maintenance stage of a PRB

4 Examples

The following examples are meant to illustrate how TN reduction credits are calculated for various types of system installations.

Example 1. Intermittent sand filter preceding a conventional drainfield.

Intermittent media filters are credited with a 20 percent TN reduction prior to the drainfield. Conventional drainfields are credited with an additional TN reduction of 20 percent (baseline). Therefore, the associated credits are:

Ex situ: 5 kg/person/year – (20%)(5 kg/person/year) = 4 kg/person/year in effluent
In situ: 4 kg/person/year – (20%)(4 kg/person/year) = 3.2 kg/person/year at edge-of-drainfield
Total percent TN reduction improvement by BMP: (4 kg/person/year – 3.2 kg/person/year) / 4 kg/person/year = 20% (or use Table 3-3)

Example 2. Standard septic tank preceding a shallow low pressure pipe system.

Septic tanks receive no TN reduction credit prior to the drainfield. Shallow, pressured-dosed drainfields are credited with a TN reduction of 50 percent. Therefore, the associated credits are:

Ex situ: 5 kg/person/year (baseline) in effluent
In situ: 5 kg/person/year – (50%)(5 kg/person/year) = 2.5 kg/person/year at edge-of-drainfield
Total percent TN reduction improvement by BMP: (4 kg/person/year –2.5 kg/person/year) / 4 kg/person/year = 38% (or use Table 3-3)

Example 3. Recirculating media filter preceding a drip irrigation system.

RMFs are credited with a 50 percent TN reduction prior to the drainfield. Shallow, pressured-dosed drainfields are credited with a TN reduction of 50 percent. Therefore, the associated credits are:

Ex situ: 5 kg/person/year – (50%)(5 kg/person/year) = 2.5 kg/person/year in effluent
In situ: 2.5 kg/person/year – (50%)(2.5 kg/person/year) = 1.25 kg/person/year at edge-of-drainfield
Total percent TN reduction improvement by BMP: (4 kg/person/year – 1.25 kg/person/year) / 4 kg/person/year = 69% (or use Table 3-3)

5 Future Research and Management Recommendations

5.1 Alkalinity Control

Ensuring sufficient alkalinity is critical for nitrification and thus TN reduction. Although it is frequently monitored, practitioners have made little effort to control alkalinity in on-site TN reduction systems. Additional research and development of inexpensive and simple alkalinity control methods would help optimize the TN removal associated with biological nitrogen removal systems and, if widely implemented, could allow for higher TN reduction credits to be justified for BMPs. The critical concern is that alkalinity control be relatively easy to manage and ideally, not be reliant on the system owner (e.g., homeowner) to be effective.

To ensure adequate buffering for nitrification, alkalinity levels of no less than 50 mg/L as $CaCO_3$ should be maintained in the final effluent. This could be problematic with water supplies lacking adequate alkalinity. Where the influent alkalinity is less than 200 mg/L as $CaCO_3$, alkalinity feed should be included in the design or nitrification will be restricted. If nitrification is restricted, then denitrification is restricted. Supplemental alkalinity can be provided through the drinking water supply or be added to the wastewater system through a dosing system, calcite filter, etc.

5.2 BMP Sampling

The OWTS Expert Panel encourages BMP sampling, but does not recommend that it be mandatory for verification or used to disqualify credit at individual sites. The OWTS Expert Panel believes that monitoring plans should be left to the discretion of the states. The proposed TN reduction credits are conservative and assume that, of the population of BMPs in operation, there is an equal level of under-performance (i.e., TN reduction less than credited) and over-performance (i.e., TN reduction greater than credited), which balances out on a watershed-wide basis to the TN reductions recommended herein. Nevertheless, installation of BMPs throughout the watershed offers a good opportunity to collect additional data that could be used to refine TN reduction performance and suggest design or operational enhancements. Numerous protocols for and examples of statistically robust sampling and assessment exist (e.g., Cape Cod, MDE), and interested parties can use them as models to design their own programs.

5.3 Data Sharing and Reciprocity

The OWTS Expert Panel believes that data sharing and interstate reciprocity should be the focus of data management efforts to support Chesapeake Bay watershed TMDL implementation. States and local jurisdictions lack the resources to ensure BMP performance at a high level of confidence, either through sampling or field inspection. Additionally, duplicative protocols for technology approval can present logistical and financial obstacles for technology developers. These obstacles can preclude the deployment of promising TN reduction technologies, potentially at the expense of Chesapeake Bay watershed water quality. Therefore, Chesapeake Bay watershed states and other jurisdictions should share information to the greatest extent possible. USEPA's Office of Wastewater Management (OWM) has offered to help facilitate data sharing.

At the State Onsite Regulators Alliance (SORA) and National Environmental Health Association (NEHA) conference in July 2013, state on-site system regulators, environmental health agents, USEPA, and others had significant discussion on nutrient contamination from on-site system wastewater. The key theme was the need to widely approve and apply current and new advanced technologies (and their management) to address nutrient contamination. Conference attendees discussed the NEHA/SORA panel on nutrients and technologies, as well as the SORA business plan for next year, and four technology themes emerged (innovative technologies, state reciprocity, evaluation, and centralized data availability). Appendix C provides a more complete summary of these discussions.

5.4 Variable Baseline and BMP Performance by Soil Type

The OWTS Expert Panel suggests that soil type be considered as a potential predictor of TN reduction performance in future watershed models. The OWTS Expert Panel recognizes that both baseline and BMP on-site system performance is highly influenced by the characteristics of the soil within the drainfield. Soil texture, in particular, is known to influence treatment while being a relatively easy characteristic to measure. The existing model only allows a single soil texture to be assigned per county. Although the OWTS Expert Panel's analysis suggests that it would be feasible to assign a predominant soil texture for each county (Appendix D), they recommend that the future Attenuation Expert Panel explore this issue further.

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Appendix A

Summary of Interviews with OWTS Expert Panel Members

Questions 1 and 2 – References

On the basis of the attached literature reference list for review by the Expert Panel, do you feel there is enough literature available to determine an appropriate nitrogen reduction credit (e.g., percent nitrogen reduction) for the proposed treatment systems? Or do you feel that a certain treatment system might require revision at a later date, when more research is available?

Please identify any literature or other significant information sources on each treatment system that you believe the Expert Panel should review.

Most panelists thought that although the reference list provided was a good start, additions might be required as reviews progress. A few panelists offered additions to the basic list that they felt were important enough to include. One panelist suggested looking at IWA's *Journal of Water Science and Technology* for additional documentation. Some panelists had difficulties correlating Jim Kreissl's (Tetra Tech) analyses or relevant documents with number identifiers. One comment made was that *proven* material on the list was insufficient to achieve all goals. Some panelists expressed surprise that some literature was simply not available.

A panelist observed that treatment trains, rather than specific technologies, should be identified for their nitrogen removal capabilities since few if any specific stand-alone technologies can exceed stringent (>50 percent) removal goals. In addition, the recommendation was to broaden the scope of *ex situ* technologies. Several panelists felt that the *ex situ* subpanel by itself cannot provide useful removal efficiencies for the bay model without taking into account the role of the landscape, soils, and proper O&M. Another panelist thought that the panel might have to combine research results and sound engineering judgment to come up with removal numbers. Also, the subpanels will have to determine how to deal with pre-manufactured systems versus site-built systems (like RSFs, etc.). Rather than review every pre-manufactured technology, subpanels might want to review test protocols/treatment standards. Maybe the subpanel can leverage the Maryland/USEPA reciprocity effort to come up with something that works throughout the watershed or even more broadly.

Question 3 – Additional Contacts

Please identify other individuals whom we should contact for additional information on each treatment system. Please provide contact information, if available.

The panel members identified several other information sources that could offer meaningful assistance to the effort. Among them were: Mike Vespraskis (NCSU), Jack Hayes (DNREC), Pio Lombardo (Lombardo Associates), Bob Freeman (USEPA), Eberhard Roeder (Florida DOH), Bob Mayer (American Manufacturing), Ray Reneau (Virginia Tech), Rich Piluk (Anne Arundel County, Maryland), USEPA-ORD, and Jay Conta (Virginia Tech), Active Mid-Atlantic Soil Science groups.

Question 4 – Most Important Factors for an Effective Nitrogen Removal Program

Please identify the three most important factors that you believe affect the nitrogen removal effectiveness of treatment systems in your state/area of most familiarity.

(1) Good O&M, (2) good pretreatment (removal of as much nitrogen as possible before entering soils), and (3) good soil evaluation were the most important factors. Other responses mentioned at least twice include:

- good siting (e.g. groundwater separation, distance to water bodies)

- good overall design
- good enforcement
- effective management, and
- trained practitioners

Responses mentioned only once include good monitoring, good installation, good owner education, high initial nitrogen, and source water quality, as well as season temperature fluctuations, system density, soil attenuation, supportive regulations, and lack of management plans.

A panelist felt that the entire treatment train and the quality of management would be the primary determinants of potential nitrogen removal performance. This would factor in how a treatment train performs under less than optimum management. Passive systems would be far less impacted than complex electro-mechanical systems.

Questions 5 and 6 – State Requirements

Please give an indication about the level of operation, maintenance, monitoring, and management that occurs on treatment systems in your state/area. How does your state track information about the operation of these systems and is there means for ensuring compliance?

Does your state or counties in your state have a tracking system in place to track the types of on-site systems that are being installed? If so, who tracks the data? If counties track the data, is it reported to the state? What information does it track? How is this information tracked (e.g., paper, electronic, GIS-friendly)? If your state does not track treatment systems, does your state have the capacity to do the tracking?

- In West Virginia, smaller mechanical (alternative) systems need continual maintenance, but there is no monitoring or enforcement to ensure compliance. Minimal compliance monitoring is done with the exception of responses to occasional complaints. West Virginia had hoped to have a web-based tracking system for operators to enter information regularly, but the state's new data management system allows counties only to log permits, installation, etc. There is no provision for tracking maintenance. The new data management system currently being tested provides a method for tracking different types of systems, both new and old.

- Maryland requires installers and service providers of technologies approved as a best available technology (BAT) for nitrogen removal to be state certified. In addition, installers of sand mounds must also be state certified. Commercial units require manufacturer training and certification of operators. For all technologies approved as a BAT for nitrogen removal, O&M for 5 years after installation is included in the upfront cost of the system. Technologies approved as a BAT for nitrogen removal are required for new on-site disposal systems installed to serve new construction in the Chesapeake Bay watershed and also for all repairs within 1,000 feet of tidal water. O&M is required for the life of the systems. Commercial units requirea USEPA model 2 management program, while engineered (noncommercial systems) require a model 3 program. Maryland has conducted field tests of nitrogen removal systems and has approved Retrofast, Orenco Advantex, Norweco, and Septi-Tech. They did not approve the field tests for four technologies that can no longer be marketed in Maryland as a BAT for nitrogen removal. Maryland has a good tracking program for alternative systems. O&M is tracked separately. Maryland does not monitor the performance of on-site systems.

- Delaware trains and licenses O&M practitioners and has a database for identifying advanced nitrogen removal systems and locations of permitted systems. The state has separate databases for innovative/alternative systems and small septic systems. They are attempting to incorporate O&M and monitoring into the database. Delaware monitors older (>5 years old) on-site systems and relies on licensed operator monitoring of newer systems (since 2007) on 3-year cycles. System operators are required to submit an annual compliance report. Additionally, the state performs an annual compliance inspection accompanied by the system operator. All permitted advanced systems are to have one or two O&M visits per year by certified operators for the life of the system.
- Virginia's rules require annual inspections of single-family residences with alternate systems by licensed operators, who report to the local health department. The larger the system, the more frequent the inspection. The state has a database (VENIS) which has permit information for on-site systems built since 2005 and is presently in the process of entering older units. The VENIS database includes operator-entered O&M and monitoring reports. Pump-outs are required every 5 years per the bay compact. Virginia trains and licenses operators.
- Pennsylvania does not typically track the O&M or the type of system. Local municipal enforcement of any existing BMP requirements is not uniformly applied and might be leading to uncertain assurance of needed O&M for treatment systems to reduce nitrogen. Pennsylvania Department of Environmental Protection (PA DEP) does not specifically track the installation of on-site (soil-based) systems, but it does track the installation of PA DEP-permitted small flow treatment (SFT) facilities (small volume surface discharge systems). Given that on-site systems are permitted via municipally contracted sewage enforcement officers in approximately 1,500 municipal local agencies, obtaining the capacity to track on-site system installations would be difficult and is not being considered.

Non-bay state panelists report that two counties in North Carolina use GIS tracking of systems (including location and system type) and that Missouri and Iowa have excellent databases. Minnesota and Arizona do not have tracking databases. New systems in Arizona are required to have one year of maintenance, unless they are NSF approved, in which case 2 years are required. The Iowa database system can capture all of the above information and be readily used by practitioners and regulators.

Question 7 – Most Popular Alternative Systems

What are the most popular types of treatment systems in your area? Should these or other treatment systems be added to the list or treatment systems to review?

- Maryland reports that the rate of new and repaired systems has halved under the present economy. The nitrogen removal systems are projected to constitute 20 percent of new and repaired systems in the future. The state has approved the nitrogen removal systems (identified in questions 5 and 6), which can meet 20 mg/L of TN effluent, but failed several others through field testing. Sixty percent of the *flush tax* revenues go toward nitrogen removal upgrades. A number of alternative systems are in place, headed by sand filters, mounds, and drip systems.

- West Virginia notes that drip and pressure (LPP) distribution systems and recirculating media filters are most commonly installed, along with mounds.
- Delaware reports that peat systems, pressurized distribution, mounds, and commercial ATUs by FAST, Norweco, and Presby are popular. Larger systems tend to be SBRs/MBRs to drip or RIBs.
- Virginia reports that suspended growth, IFAS, peat systems, drip and LPP distribution systems, textile filters (RMFs), constructed wetlands, and mounds are all in use throughout the state.
- In Pennsylvania, conventional on-site sewage systems are the most typical type of treatment system. The only on-site nitrogen reduction system currently approved by PA DEP is the Orenco AdvanTex AX Series system.
- Non-bay state panelists noted that the above mentioned technologies are most popular in their states also. However, they noted the need to expand the systems for nitrogen removal, include impacts of proper versus improper O&M, and possibly include cluster/neighborhood systems. This observation is pertinent because the trend in almost all the bay states is to consider or implement cluster systems in lieu of large numbers of complicated on-site systems in order to gain better management and more reliable nitrogen removal.

Question 8 – Trends

What kind of trends for treatment systems do you see? For example, is there a trend toward surface rather than subsurface dispersal or are there new technology trends? Is there a trend toward certain types of attached growth (biofiltration) systems over other types of attached or suspended growth pretreatment systems?

West Virginia is showing increased interest in cluster systems in lieu of large numbers of more sophisticated on-site systems. This is also true of Virginia, Delaware, and Maryland. West Virginia is concerned that on-site practitioners need to be educated to remove their reluctance to providing better technologies. They note that peat systems have gotten a foothold in the market and RSFs are popular.

Virginia credits their new rules on vertical separation versus pretreatment as being a major incentive toward using more advanced technologies, while the low capital cost of suspended growth treatment systems might be moving the field in that direction. Currently advanced treatment systems are less than 1 percent of the total on-site systems in the state. They are seeing more shallow-placed systems and a lot of drip systems. Virginia is not seeing a preference for attached over suspended growth, but the low cost of some suspended growth systems is resulting in a resurgence of the suspended growth systems.

Delaware is seeing private utilities competing for management of cluster and larger systems. However, sequencing batch reactors and membrane bioreactors are the most popular and dependable units for nitrogen removal down to 5 mg/L. About 1 percent of replacement systems in Delaware are advanced. Other popular technologies being installed are commercial systems (like peat), commercial ATUs, and drip systems, instead of natural constructed systems.

Maryland's nitrogen removal systems are RMFs, combined suspended and attached systems, and suspended growth ATUs. Pennsylvania sees the trend towards systems like the AdvanTex AX

Series system (fixed-film biofiltration system). Other panelists found similar trends in mostly the same technologies in their states. Some other technologies were noted, like ozone and UV disinfection.

Question 9 – Patterns

Do you see a pattern as to what areas or regions (e.g., Critical Areas) treatment systems are being installed in your state/area?

Except for Chesapeake Bay Preservation Act (CBPA)-defined zones, the bay states have few special zones where local codes impose specific requirements.

- West Virginia does see commercial suppliers battling for market control. West Virginia does not feel that the present bay model offers much incentive for additional special zones. They feel that their karst regions might become an incubator for new technologies if better treatment requirements become necessary.
- Maryland expects to see an increase in nitrogen removal systems in the bay area. Effective January 1, 2013, all OSDS installed to serve new construction in the Chesapeake Bay watershed must include the BAT for removing nitrogen. In the CBPA area, nitrogen removal is required, but no monitoring is required to assure compliance.
- Delaware has special requirements for inland bays that have driven the installation of advanced treatment systems. Systems within 1,000 feet of Chesapeake Bay waters are proposed to have loading restrictions for nutrients if they exceed 2,500 gpd, but those rules are not yet in effect.
- Virginia does not define critical areas. Soils and other site restrictions are driving patterns in system types. CBPA requirements place stringent demands in critical areas where reserve areas and STE filters are required in addition to 5-year pump-outs. N reduction systems will be required for alternative systems in the Chesapeake Bay watershed beginning December 2013.
- In Pennsylvania, nitrogen reduction treatment systems are generally limited to areas of elevated background nitrates often associated with agriculture. Such systems are increasingly being considered for use in special protection waters (exceptional value and high-quality watersheds) to reduce or mitigate the impact of nitrates from soil-based systems.
- In North Carolina coastal zones, reuse of effluents is becoming popular because groundwater is not suitable for irrigation.

Question 10 – State Guidelines for Specific Zones

Does your state have any guidelines or requirements for certain specific treatment systems under certain conditions? (For example, are systems required near streams?) If so, please summarize or provide supporting information describing the guidelines/requirements.

Technologies approved as a BAT for nitrogen removal are required for new OSDS installed to serve new construction in the Chesapeake Bay watershed and also for all repairs within 1,000 feet of tidal water. O&M for the life of the systems are required.

In West Virginia, horizontal setback requirements are currently driving better systems. The next revision to system rules is coming soon and might include footprint reductions for pretreatment and nutrient management for individual systems.

Delaware has vertical separation rules that vary on the basis of treatment/dispersal technology.

In Virginia, licensed design engineers, installers, soil evaluators, and operators are required for all alternative treatment systems, and 50 percent nitrogen removal is required in the Chesapeake Bay watershed. For systems with direct (no vertical separation) groundwater discharge, nitrogen must be reduced to 3 mg/L before release to the groundwater. Virginia is looking to shift larger developments to clusters to avoid compliance with such stringent rules. Single-family residences (<1,000 gpd) can either have a 50 percent reduction (if they have an adequate soil/separation distance) or, for direct groundwater dispersal, meet TN of 3 mg/L. Systems between 1,000 and 10,000 gpd must comply with 20 mg/L TN either applied to the soil or as measured *in situ*. Systems with design flow rates greater than 10,000 gpd, must meet standard BNR limits of 8 mg/L TN or demonstrate that they are meeting 5 mg/L at 24 inches below the point of effluent application.

In Pennsylvania, treatment systems installed in high-nitrate areas must achieve 10 mg/L TN at the property line. New nitrogen reduction technologies would be required to complete their *Experimental Onlot Wastewater Verification Program* before being classified for permitting in the state to achieve nitrogen reduction. Consideration is being given to adopting NSF Standard 245 and, thereby, to treatment system technologies that meet this Standard.

Question 11 – Tracking and Reporting Chesapeake Bay Model Inputs

How do you see new treatment options being tracked and reported to your state and eventually to USEPA for inclusion in the Chesapeake Bay Model?

Virginia, Delaware, and Maryland are upgrading their databases on nitrogen removal systems, but presently they only track systems and their location. O&M and monitoring will be added soon. As BMPs are identified, Virginia will modify their database to extract existing systems that fall within the BMP. West Virginia is moving that same direction and hopes to add expert design reviews for new systems. Delaware already submits their large system database to USEPA. Pennsylvania does not see this information being tracked in the future.

Appendix B

Evaluation of Nitrogen Removal and Evapotranspiration Associated with Vegetative Cover Present on On-Site Sewage System Dispersal Areas

Summary:

The panel reviewed various references in an attempt to identify the nitrogen removal and evapotranspiration benefits associated with vegetative cover present on on-site sewage system dispersal areas. While some limited benefit is expected from the presence of a vegetative cover, the panel found the available literature lacking.

Many Cooperative Extension references that discuss vegetative cover on dispersal fields address topics such as erosion prevention, oxygen exchange, and moisture removal benefits. Most indicate turf grasses are best, with some recommendation of alternative herbaceous plants, but strongly cautioning against the use of plants with woody, deep roots due to the threat posed to the long-term functionality of the drainfield. None of the references discuss nitrogen reduction benefits of turf grasses or alternative vegetation types (Day 2009, Dickert 2010, Donaldson 2007, Meyer 2008, Stanton 2008).

Modest nitrogen reduction can be expected via plant uptake processes, but only during the growing season. Permanent nitrogen removal requires harvesting and off-site management during the growing season. Such practices are not common and it would be difficult to verify the practice at the majority of on-site treatment sites. In addition, this mechanism can be limited in conventional installations, which typically place the dispersal field below the root zone of plants.

Biological uptake of nitrogen by vegetation can be significant in dispersal field configurations using pressurized, uniform distribution of pretreated effluent where the receiving interface of the soil is very high in the soil profile near root structures and higher organic-content soils. Low-pressure and drip systems can provide shallow placement that takes advantage of these natural phenomena, but references do not distinguish the plant uptake benefit from that associated with denitrification in anaerobic soil conditions created by such systems. Shallow placement of subsurface dispersal lines does promote evapotranspiration through direct evaporation and the transpiration from shallow rooted vegetation (Beggs 2011, Hepner 2007).

Vegetative uptake and storage of nutrients in forested settings depends upon the species, stand density structure, age, length of season, and temperature. Large trees, understory trees, and herbaceous vegetation all take up and store nutrients, and return a **portion** of those nutrients back to the soil in the form of leaf-fall and other debris. There was some discussion of the nutrient reduction benefits from silviculture and estimates for the annual nitrogen uptake rates in various forest ecosystems were developed. However, the estimates are conditioned by whole tree harvesting (with leaves on for deciduous trees), with nitrogen removal less than 30 percent of biomass storage if only merchantable stems are removed from the system (USEPA 2006). No information was available to quantify nitrogen reduction benefits in no-harvest scenarios.

There are a number of references discussing nitrogen loss in spray irrigation systems, but these appear to be of limited benefit, because evaporative losses from spray irrigation are different than those expected from typical on-site systems. Much of the spray irrigation research also involves agricultural crops which are harvested.

Recommendation:

Although there are likely limited benefits associated with unharvested vegetation, the effect of vegetation is confounded with other factors (soil type, dispersal type). Additionally, the presence of a vegetative cover over a soil dispersal system is generally considered a standard practice. To be considered a BMP, we would need to understand the specific vegetation management practices (e.g., species, dispersal system interactions, maintenance measures) that enhance nitrogen removal and we would need to be able to verify those factors. We do know that harvesting nitrogen sequestered in vegetation during the growing season could result in permanent nitrogen removal, provided that effluent is applied to the root zone. However, vegetation harvesting and off-site disposal is not currently practiced in (subsurface) on-site systems. Additionally, current verification procedures would be insufficient for verifying this practice if it were to be implemented.

Accordingly, we recommend that this topic not be included as a BMP for the on-site wastewater sector in the Chesapeake Bay TMDL at this time. We recommend that this topic be revisited in 5 years, when any additional research that becomes available and updated on-site system implementation and verification practices can be reviewed.

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Appendix C

Summary of SORA/NEHA Conference Discussion on Interstate Cooperation on Nutrient Reduction Technology, July 2013

From the 2013 State Onsite Regulators Alliance (SORA) and National Environmental Health Association (NEHA) conference in July 2013, state on-site regulators, environmental health agents, USEPA, and others had significant discussion on nutrient contamination from on-site system wastewater. The key theme was the need to widely approve and apply current and new advanced technologies (and their management) to address nutrient contamination.

Conference attendees discussed the NEHA/SORA panel on nutrients and technologies and the SORA business plan for next year, and four technology themes emerged (innovative technologies, state reciprocity, evaluation, and centralized data availability). The State Regulators/ SORA approved items 1, 2, and 3 for business plan action (item 4 could apply to all). Brief explanations of these items (technology themes) are presented below.

1. Evaluate and promote a new generation of innovative technologies being introduced into testing phases by university environmental / engineering programs, water technology clusters, international aide competitions, and others. It calls for providing a competent unified means of testing, or a test facility, whose results would be widely accepted by most states. This would improve bringing new systems to market by reducing the bottleneck of 50 individual state approval processes.
2. To further examine and evaluate the opportunities for and hold direct dialog among state on-site wastewater and health agencies to improve reciprocity among state agencies to aid and speed state approval of new technologies. It would include the exchange of information on technology approval processes, adoption of other state-approved technologies, exchange of data on proprietary and nonproprietary test data, collaboration of interstate commissions and organizations, sharing of third-party data, etc.
3. To examine the current state-by-state approach for evaluating and approving new technologies. The current approach is costly to agency budgets and technology developers, is stifling new innovations coming to market, and is confusing to developers. Methods may also be redundant, unnecessary, etc. State regulators and industry representatives should examine evaluation requirements, suggest efficiencies, and propose alternative approaches such as a unified testing process or test facility, potential regionalization, etc.
4. To conduct further dialog to evaluate and create a central means of collecting on-site system data, as a repository, for state program approval processes to access on-site system technology performance data and experience. Examine the type of information that would be useful to states' approval processes, the feasibility of the method for collecting data and providing access to such information, the potential role of a third-party organization (commission, public agency, other) to be central administrator for the information system.

Appendix D

Assessing the Practicality of Generating and Assigning a Single Soil Texture for Each County in the Chesapeake Bay Watershed

The OWTS Expert Panel had discussions concerning whether soil texture should be considered a "baseline" feature, or whether it should be a BMP. CPBO informed the OWTS Expert Panel that the existing model would allow only a single soil texture to be assigned per county. This summary is an attempt to address the feasibility of assigning a single soil texture to each county in the Chesapeake Bay watershed.

Virginia Department of Health (VDH) randomly selected Chesapeake Bay counties in Virginia. The only criteria were:

- The county must be completely within the Chesapeake Bay watershed.
- Soils information must be available, either in a paper soil survey report or online from the Web Soil Survey.
- A summary table of the acreage of each soil mapping unit must be available.
- Preferably, there is a Soil Taxonomic Classification table for the soil series in the county.

METHODOLOGY

Using the soil taxonomic classification table, VDH assigned a soil texture to each soil mapping unit found in the county. The USDA Soil Texture particle-size class family designation was used for this.

Following earlier discussions by our work group, the soil texture groupings were: sandy (sand and loamy sand soil textures); clayey (sandy clay, clay, silty clay); and loamy (all other textures). Since it was established that the soil texture-N reduction benefit would be one value assigned countywide, it did not seem necessary to attempt to fine tune, so coarse- and fine-loamy, and coarse- and fine-silty soils were lumped together as "loamy".

Once all soil mapping units were assigned a soil textural group, the percentage of the county area that was sandy textured was determined. This process was repeated for the loamy and clayey textured mapping units. If there were miscellaneous map units, those were tallied as well (e.g., pits and dumps, water, etc.).

SAMPLING RESULTS

Table D-1 shows the results of the analysis of soil textures per county. The location code is: CP = a Coastal Plain county; P = a Piedmont county; R + V = a Ridge and Valley county.

Table D-1. Analysis of Soil Texture by County

County	Location	Texture Groupings (as % of county area)			
		Sandy	Loamy	Clayey	Miscellaneous
Essex Co, VA	CP	1.7%	86.9%	2.3%	9.1%
Middlesex Co, VA	CP	1.7%	91.2%	4.9%	2.2%
Northumberland & Lancaster Co, VA	CP	21.4%	49.8%	1.1%	27.7%
Louisa Co, VA	P	0%	19.1%	80.2%	0.7%
Shenandoah Co, VA	R + V	4.1%	59%	35.6%	1.3%

RESULTS AND DISCUSSION

Based on the Virginia sampling, it appears that there will be, in most cases, a single soil texture that clearly represents the vast majority of the soils in any given county. In all probability, most Coastal Plain counties will be predominantly loamy textured.

Most Piedmont counties will likely be predominantly clayey textured, given how old the soils are and how long-term weathering has produced clayey subsoils in many cases.

For Ridge and Valley counties, the soil texture could be dependent upon the size and location of the county (because a larger county might encompass more areas of shale derived soils, and so be predominantly clayey textured; while a smaller county might be predominantly over sandstone and siltstone geology, and so have loamy textured soils).

However, the predominant soil texture should be determined for each locality to ensure the accuracy of the designation.

There is a question about how to handle counties that have significantly contrasting geologies or soils. An example might be a Fall Line county (partly in the Coastal Plain and partly in the Piedmont) or a Piedmont county that includes a portion of a Triassic Basin. Under these examples, while it might be that a county has 51 percent of its soils in a certain texture group, that 51 percent might not be widely distributed or representative of the entire county. A Virginia illustration of this would be Henrico County, where the western half of the county is in the Piedmont (clayey soils dominate) and where the eastern half is in the Coastal Plain (loamy soils dominate). Because a county can have only one soil texture, the texture assigned to these types of localities might not be as reasonable or representative of the county as a whole.

In some places the majority of the acreage in the county might be in the mountains and have clayey textures, yet most homes—and on-site drainfields—are in valleys on soils with a different texture. How this should be handled and who should make that determination needs to be established. In addition to the soil texture analysis on a countywide basis, VDH conducted some random spot-sampling. Several spots interior to Essex County, Virginia, along a creek or stream were chosen for analysis. One spot along Church Swamp was 57 acres, and 100 percent of the soils in a 800-foot-wide strip along the creek were loamy textured. A second location in central Essex County was an 800-foot-wide strip along a creek, and was also 100 percent loamy soils. This random spot-sampling seems in agreement with the countywide analysis that the soils of Essex County, Virginia, are predominantly loamy textured.

An additional spot-sampling was performed in Lancaster County, Virginia. The site was along a peninsula extending into the Chesapeake Bay. An 800-foot-wide strip along the shoreline was sampled, or approximately 230 acres of land. For this test location, 17 percent of the land area was sandy textured, 79 percent was loamy, and 4 percent was marsh. These results are in agreement with those seen in other Coastal Plain localities in which the soils are predominantly loamy textured. An additional point of interest was that while this site had an obviously sandy shoreline and associated dunes, and was much sandier than any other location tested, it still had only 17 percent of the land area as sandy textured. This seems to indicate that there might not be whole counties of predominantly sandy soil textures, and that the process of assigning a soil texture to a locality could be as simple as choosing either loamy or clayey.

It is recommended that other states perform countywide testing to assess the validity of using soil mapping units on a countywide basis to assign soil textures. It is anticipated that there could be significant differences in some localities due to differences in climate and geology (i.e., glaciated versus unglaciated portions of the same county).