EPA 625/R-00/008

Onsite Wastewater Treatment Systems Technology Fact Sheet 9

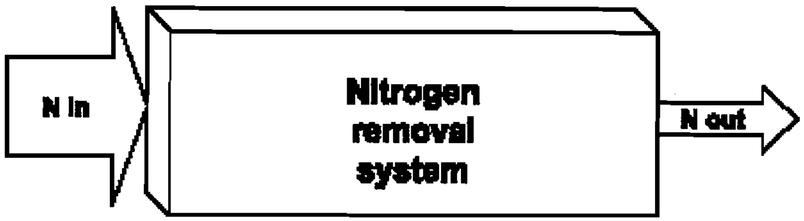
Enhanced Nutrient Removal--Nitrogen

Description

Nitrogen is a pollutant of concern for a number of reasons. Nitrogen in the ammonia form is toxic to certain aquatic organisms. In the environment, ammonia is oxidized rapidly to nitrate, creating an oxygen demand and low dissolved oxygen in surface waters. Organic and inorganic forms of nitrogen may cause eutrophication (i.e., high productivity of algae) problems in nitrogen-limited freshwater lakes and in estuarine and coastal waters. Finally, high concentrations of nitrate can harm young children when ingested.

Ammonia oxidation (nitrification) occurs in some of the processes described in previous fact sheets, and is dependent upon oxygen availability, organic biochemical oxygen demand (BOD), and hydraulic loading rates. Nitrogen removal by means of volatilization, sedimentation, and denitrification may also occur in some of the systems and system components. The amount of nitrogen removed (figure 1) is dependent upon process design and operation. Processes that remove 25 to 50 percent of the total nitrogen include aerobic biological systems and media filters, especially recirculating filters (Technology Fact Sheet 11). Enhanced nitrogen removal systems can be categorized by their mode of removal. Wastewater separation systems, which remove toilet wastes and garbage grinding, are capable of 80 to 90 percent nitrogen removal. Physical-chemical systems such as ion exchange, volatilization, and membrane processes, are capable of similar removal rates. Ion exchange resins remove NH_4-N or NO_3- N. Membrane processes employ a variety of membranes and pressures that all have a significant reject flow rate. Volatilization is generally significant only in facultative lagoon systems where ammonia volatilization can be significant. The vast majority of practical nitrogen-removal systems employ nitrification and denitrification biological reactions. Most notable of these are recirculating sand filters (RSFs) with enhanced anoxic modifications, sequencing batch reactors (SBR), and an array of aerobic nitrification processes combined with an anoxic/anaerobic process to perform denitrification. Some of the combinations are proprietary. Any fixed-film or suspended-growth aerobic reactor can perform the aerobic nitrification when properly loaded and oxygenated. A variety of upflow (AUF), downflow, and horizontal-flow anaerobic reactors can perform denitrification if oxygen is absent, a degradable carbon source (heterotrophic) is provided, and other conditions (e.g., temperature, pH, etc.) are acceptable.

Figure 1. Nitrogen removal systems

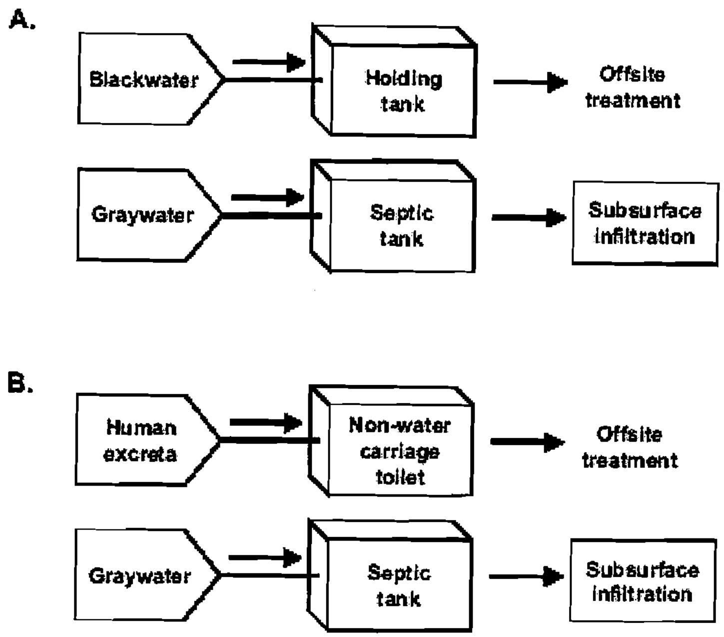


The most commonly applied and effective nitrogen-removal systems are biological toilets or segregated plumbing options and/or nitrification-denitrification process combinations. A more complete list is described below, along with accompanying schematic diagrams.

Source separation systems

Source separation relies on isolating toilet wastes or blackwater from wastewater. This requires separate interior collection systems. Two source separation systems were identified: blackwater holding tank with low-volume-discharge toilets and graywater septic tank system, and non-water-carriage toilets and graywater septic tank system (figure 2). These types of toilets are discussed in chapter 3.

Figure 2. Source separation systems: A. blackwater holding tank with tank with low-volume discharge toilets and graywater septic tank system B. non-water-carriage toilet and graywater septic tank system



Blackwater holding tank with low-volume-discharge toilets and graywater septic tank system

Blackwater discharged directly to a holding tank requires periodic removal for offsite treatment. Graywater wastes can be discharged to a conventional septic tank or subsurface infiltration system.

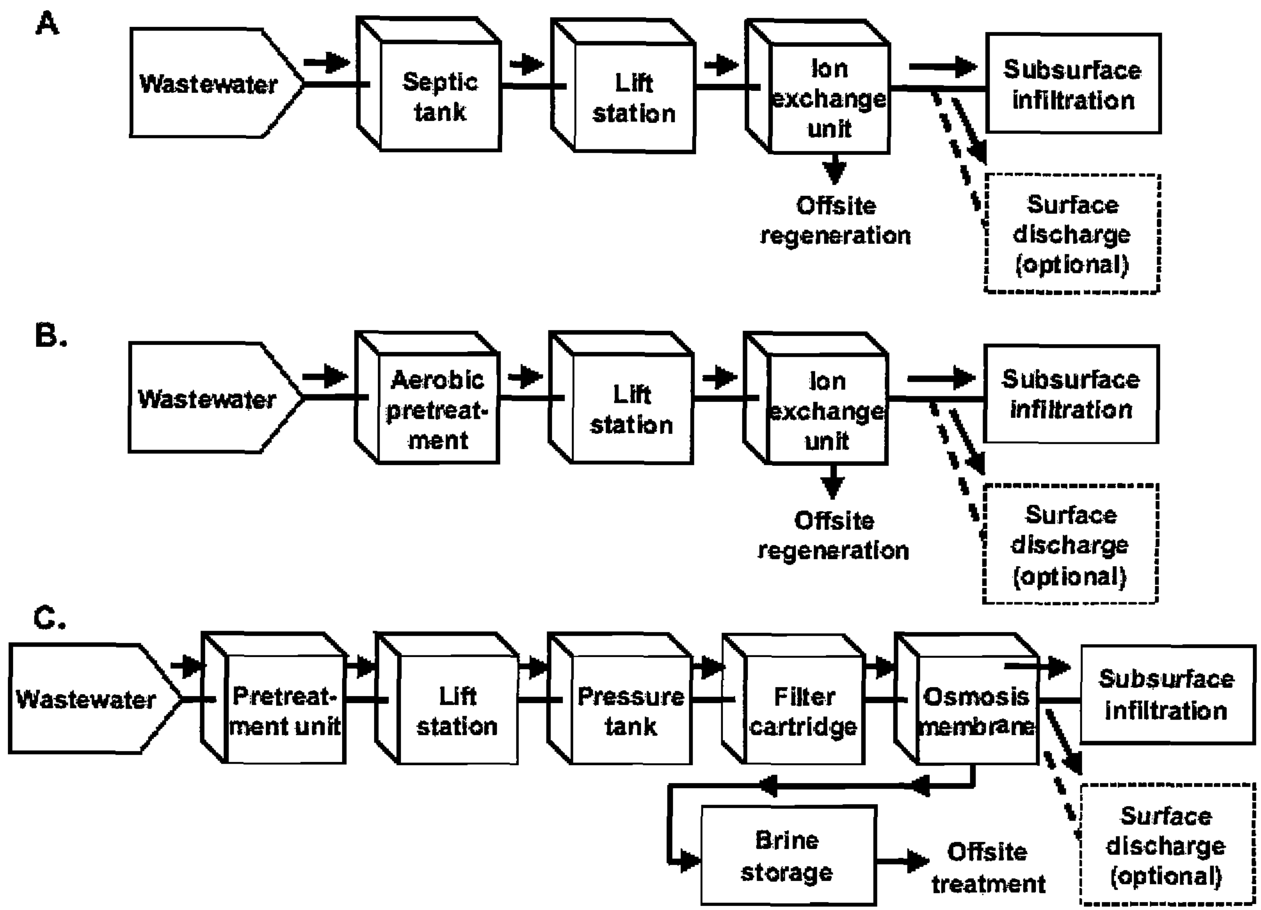
Non-water-carriage toilets and graywater septic tank system

Excreta is discharged to non-water-carriage toilets to promote bulk reduction and decomposition. Biological and incineration toilets are the most common methods of accomplishing this. Non-water-carriage toilets that use these processes are commercially available. The remaining graywater wastes can be discharged to a conventional septic tank subsurface infiltration system.

Physical/chemical treatment systems

Two types of physical/chemical treatment systems, ion exchange and reverse osmosis, appear to have some promise for single home use, although neither is in use at present (figure 9-3).

Figure 3. Physical chemical systems: A. cation (NH_4^+) exchange; B. anion (NO_3^-) exchange; C. reverse osmosis



Ion exchange

Two types of systems may be employed: cationic or anionic exchange systems. In the cationic system, the ammonium in septic tank effluent is removed. Clinoptilolite, a naturally occurring zeolite that has excellent selectivity for ammonium over most other cations in wastewater, can be used as an exchange medium. In the anionic system, septic tank effluent must be nitrified prior to passage through the exchange unit. Strong-base anion resins can be employed as an exchange medium for nitrate. Both systems require resin regeneration offsite.

Reverse osmosis

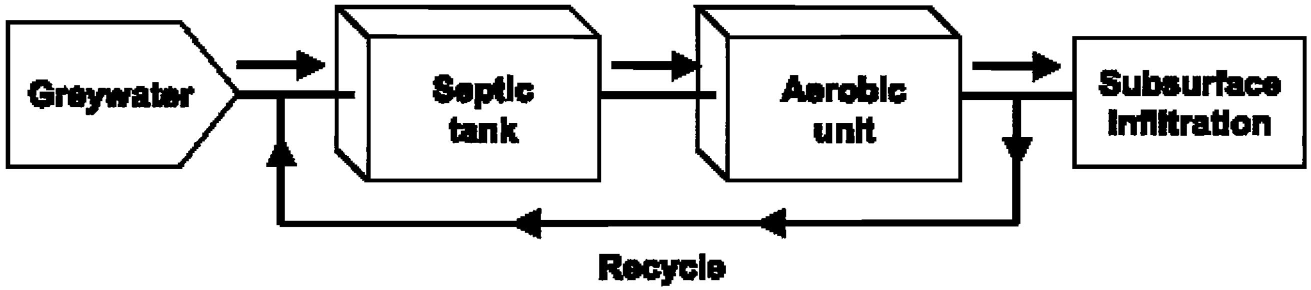
This system requires pretreatment to remove much of the organic and inorganic suspended solids in wastewater. Pretreated wastewater stored under pressure is fed to a chamber containing a semipermeable membrane that allows separation of ions and molecules before disposal. Large volumes of waste brine are generated and must be periodically removed for offsite treatment.

Biological treatment systems

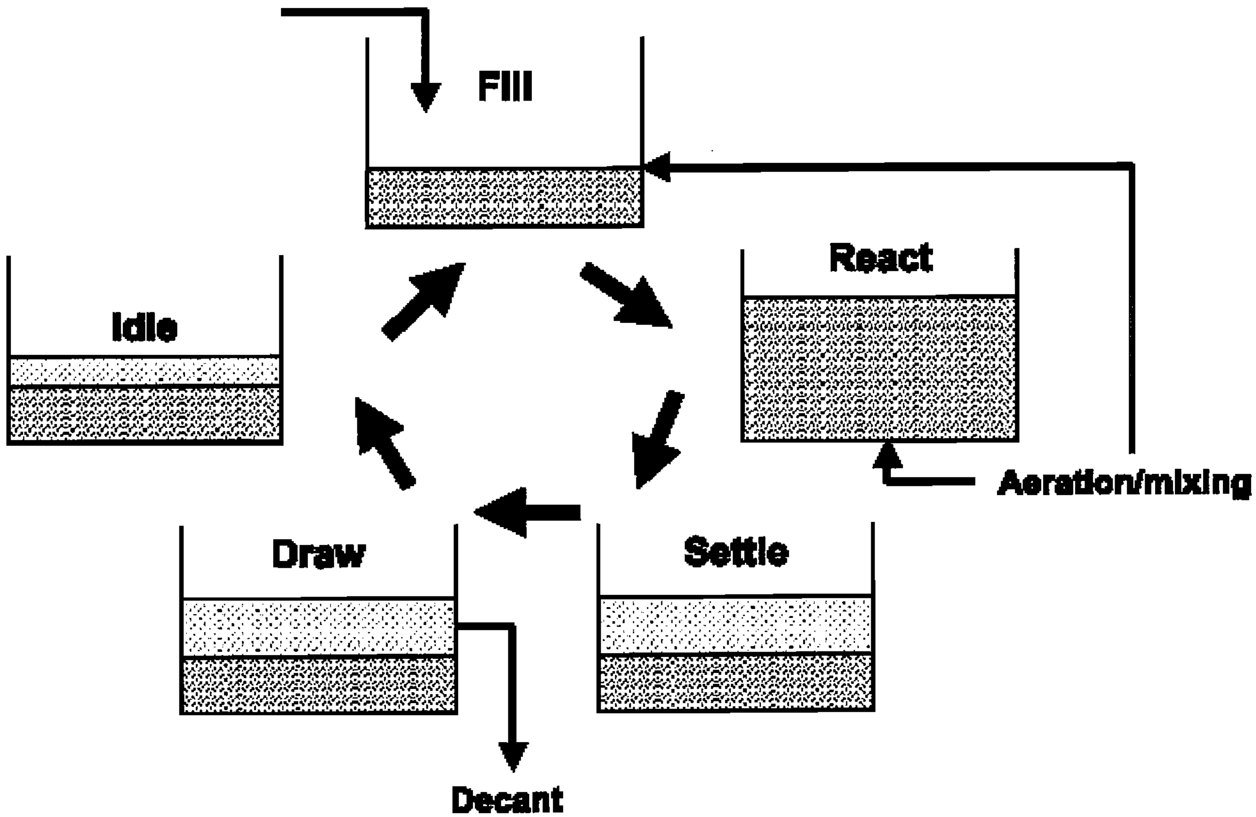
A number of onsite treatment systems use biological denitrification for removal of nitrogen from wastewater. These systems have received the most scrutiny with respect to development and performance monitoring. However, more development and performance monitoring will be necessary to refine the performance consistency and improve understanding of operation processes and mechanisms (see figure 4).

Figure 4. Biological systems: A. anaerobic/anaerobic trickling filter package plant, B. sequencing batch reactor (SBR) design principle; C. ISF with AUF; D. source separation, treatment, recombination; E. recirculating sand filter with septic tank options; F. recirculating sand filter with anaerobic filter and carbon source

A.

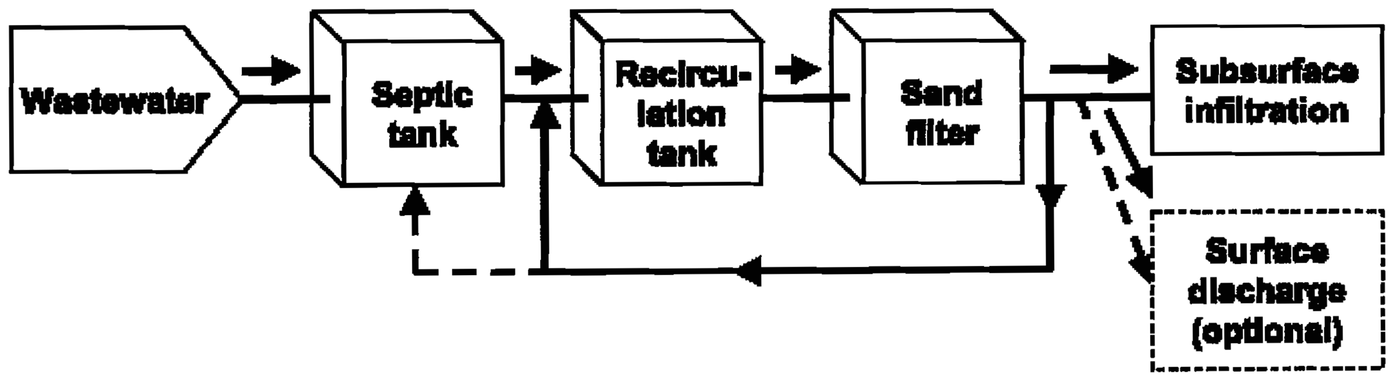

Greywater
Septic tank
Aerobic unit
Subsurface infiltration
Recycle

B.

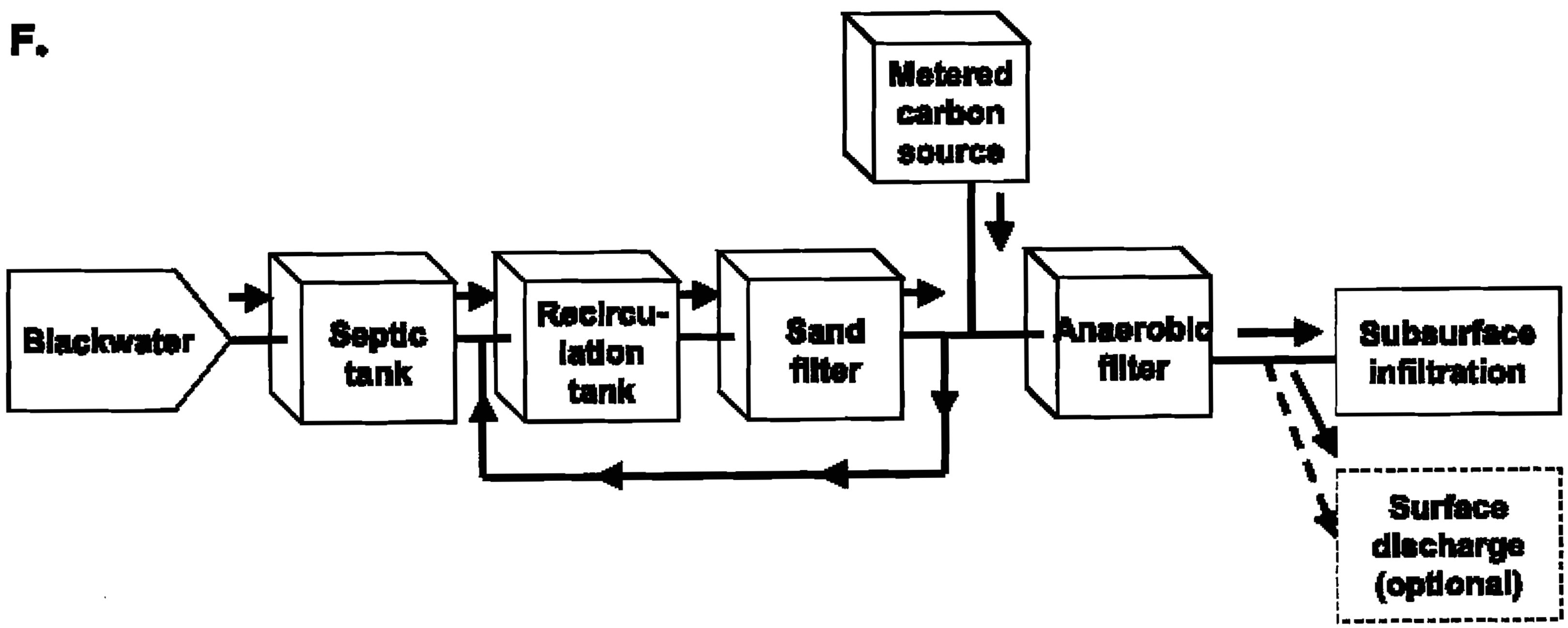

Fill
React
Aeration/mixing
Settle
Draw
Decant
Idle

C.

E.



F.



Aerobic/anaerobic trickling filter package plant

These commercial systems use synthetic media trickling filters that receive wastewater from overlying sprayheads for aerobic treatment and nitrification. Filtrate returns to the anaerobic zone to mix with either septic tank contents or incoming septic tank effluent and undergoes denitrification. A portion of the filtered effluent (equal to the influent flow) is discharged for disposal or further treatment.

Sequencing batch reactor (SBR)

If sufficient hydraulic retention time (HRT) is provided to permit nitrification during the "react" phase of the SBR cycle and if the fill stage is anoxic for a sufficient HRT, the system can remove significant amounts of nitrogen and phosphorus. The SBR design is essentially the same as is described in the SBR fact sheet, while operationally the conditions noted above must be maintained.

Intermittent sand filters with anaerobic filters

Nitrification is provided in the ISF, while denitrification is provided in either the preceding septic tank with recirculation or a separate anaerobic filter. A vegetated submerged bed (VSB) ("subsurface flow wetland") may be substituted for the anaerobic filter.

Source separation, treatment, and recombination

One commercial system employs this sequence where blackwater (toilet wastewater), after settling in a separate tank, is aerobically treated with an ISF to nitrify the majority of the nitrogen before it is recombined with settled greywater in an anaerobic upflow filter (AUF) for denitrification.

Recirculating sand filters combined with anaerobic/anoxic filters

RSF systems normally remove 40 to 50 percent of influent nitrogen. To enhance this capability, they can be combined with a greater supply of carbon, time, and mixing than is normally available from the conventional recirculation tank. The anaerobic/anoxic options include recycling to the septic tank, better mixing, and longer HRT in a separate UF or VSB, or adding supplemental carbon (e.g., methanol, ethanol) to enhance the potential of the denitrification step.

Typical applications

Nitrogen removal is increasingly being required when onsite systems are on or near coastal waters or over sensitive, unconfined aquifers used for drinking water. Nitrogen removal systems generally are located last in the treatment train prior to SWIS disposal and may be followed by disinfection when the system must discharge to surface waters. Usually, the minimum total nitrogen standard that can be regularly met is about 10 mg/L. Aerobic biological systems should not be employed at seasonal facilities.

Design assumptions

A myriad of potential systems exist for enhanced nitrogen removal, and all of the major unit processes of such systems are described elsewhere. Also, since waste stream modification is covered in chapter 3, only the most promising, developed options are discussed in this fact sheet. Of the options discussed, granular media filters or aerobic biological systems (usually combined with an anaerobic upflow filter or the original septic tank process) are discussed in more detail.

Some salient design considerations that are not covered in other fact sheets or text include the following:

- Autotrophic denitrification in packed-bed sulfur reactors (variation on AUF) has been successfully demonstrated, but the need for additional alkalinity and the production of a high sulfate effluent have thus far limited the process.
- Denitrification improves with increased HRT in the recirculation tank, better mixing, and a pH between 7 and 8.
- Use of greywater as the degradable carbon source for denitrification limits the degree of denitrification attainable owing to reduced nitrogen content and low carbon-to-nitrogen ratio. The latter should exceed 5:1 for good denitrification.
- Use of synthetic anionic exchange resins appears impractical at this time. Cationic exchange of NH4-N with clinoptilolite is feasible but very expensive because of the regeneration management costs. Both may be subject to fouling and clogging problems.
- Membranes present a major problem given the volume of the reject stream, which must be collected and frequently trucked to a site that will accept it for disposal.
- The use of beds of carbon-rich materials below SWIS leach lines could be a promising concept if the hydraulic matching problems are solved and the bed service life can be extended for 10 years or more.
- Accessibility, size of the holding tank, and availability of residual management facilities are significant design considerations in blackwater separation systems.
- Recycling to the septic tank may affect solids and grease removal in the tank and cause poor mixing of the nitrified stream with the septic tank contents. This could raise the oxidation-reduction potential (ORP) of the mixture above the normal range for an anoxic zone that accomplishes denitrification. Recycling to the second compartment of a multicompartment tank is suggested at a ratio of less than 2.5 to 1 with a contact time of greater than 2 days.
- An AUF used for enhanced denitrification should be loaded with between 0.06 and 0.3 1b COD/ft^3 per day and have an HRT of at least 24 hours (preferably 36 or more hours). It can be filled with large (> 2 inches) rocks or synthetic media. A vegetated submerged bed (VSB) can be substituted for an AUF and may contribute some labile carbon to aid the process.
- SBR design for nitrogen and phosphorus removal is essentially similar, but the amount of labile carbon required is greater (6 to 8 mg/LCOD/ mg/L of TKN to be denitrified).

- Modern microprocessor controls make very complex process combinations possible to remove nitrogen, but overall simplicity is still desirable and requires less O/M sophistication.
- To attain full (>85 percent) nitrification, fixed-film systems cannot be loaded above 3 to 6 g BOD/m^3 per day or 6 to 12 g BOD/m^3 per day for rock and plastic media, respectively.

Performance

Some expected sustainable performance ranges for the most likely combinations of nitrogen removal processes are given in table 1. Some of the nitrogen-removal systems could be combined with source separation and product substitution (low-phosphate detergents) for a maximum reduction in nitrogen where extreme measures might be required. However, the removals would not be additive owing to the changes in wastewater characteristics.

Table 1. Typical N-removal ranges for managed systems

Process	Percent TN removal
RSF	40 - 50
RSF (with recycle to ST or AUF)	70 - 80
ST - FFS (with recycle to ST or AUF)[a]	65 - 75
SBR[a]	50 - 80
SS and removal	60 - 80
(SS - TT R)[a]	40 - 60
ISF - AUF	55 - 75

a Commercially available systems.
Note: RSF = recirculating sand filters; AUF = anaerobic upflow filter; ST = septic tank; FFS = fixed-film system; SBR = sequencing batch reactor; SS = source separation; TT = treatment applied to both systems; R = recombined; ISF = intermittent sand filter.

Management needs

Management needs for most unit processes are covered in other fact sheets. Source separation is feasible only for new homes, as it would be prohibitively expensive for existing homes. AUF systems are different from the fact sheet in that they must have HRTs greater than 2 days to enable anaerobic biological denitrification to be effective. This will add to O/ M tasks by requiring regular flushing of excess biological growth. Some separation and removal would require regular inspection and maintenance of non-water-carriage toilets and periodic removal and proper disposal of excess solids from these units and from holding tanks.

Risk management issues

Of the most likely systems shown in the table, few are extremely susceptible to upset by hydraulic loading variations. However, soluble toxic shocks could affect any AUF, SBR, or fixed-film nitrification system. Extreme cold will also have an impact on these systems. However, the ISF, RSF, and AUF systems have been the most resilient unit processes (excluding source separation) when properly housed and insulated. Power outages will affect all of the treatment systems. Reliability would be greatest for those that incorporate filters and less for the SBR and fixed-film systems.

Costs

The capital and total costs of most of the nitrogen removal systems are very site specific, but non-water-carriage toilet source separation (assuming new homes) is the least expensive (low-water-use fixtures and holding tanks would add about $4,000 to $6,000). The biological combinations would be more expensive, and the physical/chemical systems would likely be the most expensive. Multiple units will generally increase costs, while the use of gravity transfer between processes will reduce them.

The additional O/M associated with an AUF involves flushing and disposal of excess flushed solids. If methanol is employed to enhance denitrification, additional O/M is required for the feeding system.

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