FLORIDA DEPARTMENT OF HEALTH

Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task A.7, A.8 and A.9

Classification, Ranking and Prioritization of Technologies

Final Report

September 2009

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Environmental Engineers & Scientists

In association with

SCHOOL OF MINES 1874 COLORADO

AET
Applied Environmental Technology

OTIS ENVIRONMENTAL CONSULTANTS, LLC

Florida Onsite Sewage Nitrogen Reduction Strategies Study

TASK A.7, A.8 AND A.9
FINAL REPORT

Classification, Ranking and Prioritization Of Technologies

Prepared for:

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Section 1.0
Introduction

The Florida Department of Health has contracted with Hazen and Sawyer, P.C. to conduct the Florida Onsite Sewage Nitrogen Reduction Strategies (FOSNRS) Study to evaluate technologies and develop strategies to reduce nitrogen loading from onsite wastewater treatment systems in Florida. This multi-year, multi-disciplinary study consists of four main areas of work, as summarized below.

Task A: Technology Evaluation for Field Testing: Review, Prioritization and Development

Task B: Field Testing of Technologies and Cost Documentation

Task C: Evaluation of Nitrogen Reduction Provided by Soils and Shallow Groundwater

Task D: Nitrogen Fate and Transport Modeling

This report covers preliminary work under FOSNRS Task A. This effort includes a multistep process to identify and evaluate available nitrogen reduction technologies for subsequent field testing in Task B. Task A includes an expansion and update to the literature review of nitrogen reduction technologies that was conducted under a previously completed FDOH project, the Passive Nitrogen Reduction Study (PNRS I). The literature review is presented as a separate report and was used as the basis for identifying and classifying available onsite sewage nitrogen reducing technologies in this report.

This report summarizes the results from the Technology Classification, Ranking and Prioritization Workshop (Task A) conducted with the FDOH Research Review and Advisory Committee (RRAC) on May 28, 2009. The following summarizes the contents of this report.

- ***Classification of Technologies (Task A.7)*** includes a classification system for nitrogen reduction technologies that includes major categories of source separation, physical/chemical treatment technologies, biological treatment technologies, and natural systems. The classification scheme was based on the literature review and consideration of fundamental principles of wastewater treatment unit processes.

- ***Technology Ranking Criteria (Task A.8)*** presents important criteria for onsite nitrogen reduction technologies, defines the criteria attributes, and delineates numerical scores for each criterion. The criterion scores are combined with criteria weighing factors which can then be used to generate an overall score for each technology in Task A.9 technology prioritization for testing.

- ***Prioritization of Nitrogen Reduction Technologies (Task A.9)*** this portion of the report outlines the overall methodology by which technologies will be classified, ranked and evaluated in order to prioritize technologies for testing.

The Technology Classification, Ranking and Prioritization Workshop presented the nitrogen reduction technology classifications, ranking criteria, and weighting factors recommended by the project team in the draft report, and sought input from the stakeholders on the RRAC. The objectives of the workshop were to gain consensus on the methods that will be used to rank and prioritize technologies for subsequent field testing. Based on input from the workshop and review comments, this is the final Technology Classification, Ranking and Prioritization Report.

Section 2.0
Classification of Nitrogen Reduction Technologies (Task A.7)

The results of the literature review (Task A.2) led to development of a scheme for classifying nitrogen reduction technologies to allow comparisons between the many options that are available for use by onsite sewage treatment systems. This scheme consists of four categories for classification; source separation, biological treatment via nitrification/denitrification, physical/chemical treatment, and natural systems (Figure 2-1). In most available onsite nitrogen reduction technologies, it is typical that more than one of these processes are operative in any given treatment system.

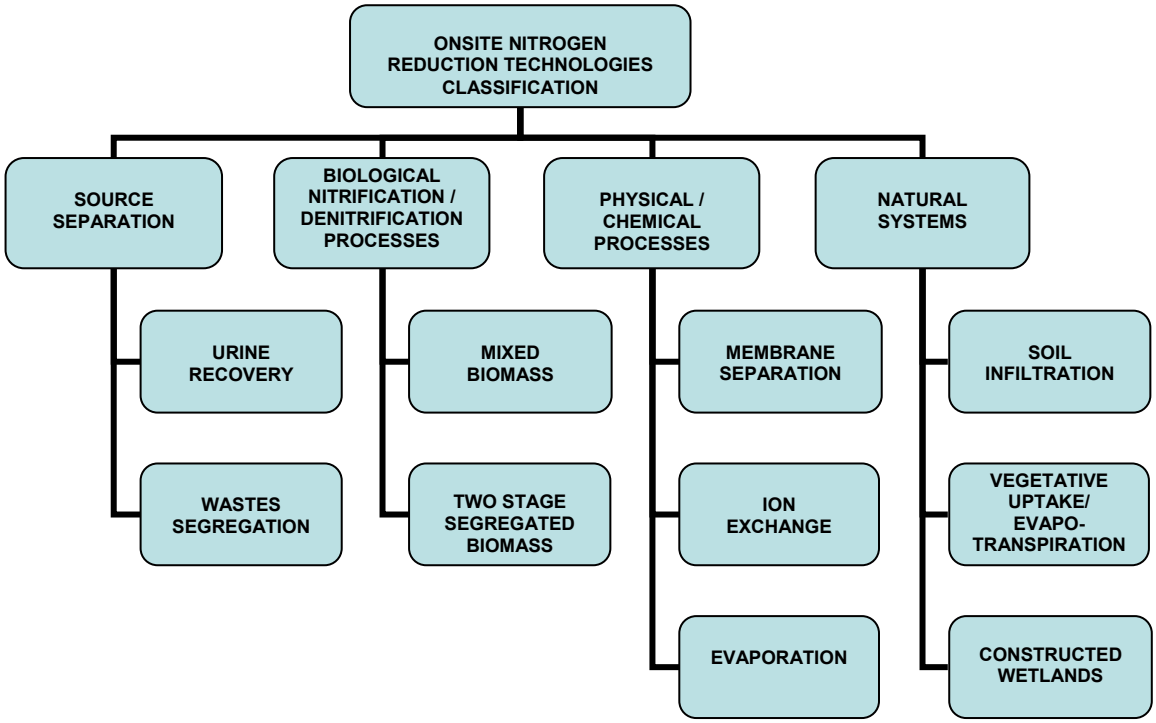

Figure 2-1: Options for Reducing Nitrogen in Household Sewage

2.1 Source Separation

Source separation options are shown in Figure 2-2. The primary source separation options include: 1) urine recovery and 2) separation of domestic wastewater into greywater and black water waste streams. Toilets are the source of approximately 80% of all nitrogen discharged in household waste streams making urine recovery or wastes segregation significant nitrogen reduction options. Segregation of waste streams also would allow for treatment of the more concentrated, nitrogen-laden waste streams separately via nitrification/denitrification and would result in less waste volume for treatment.

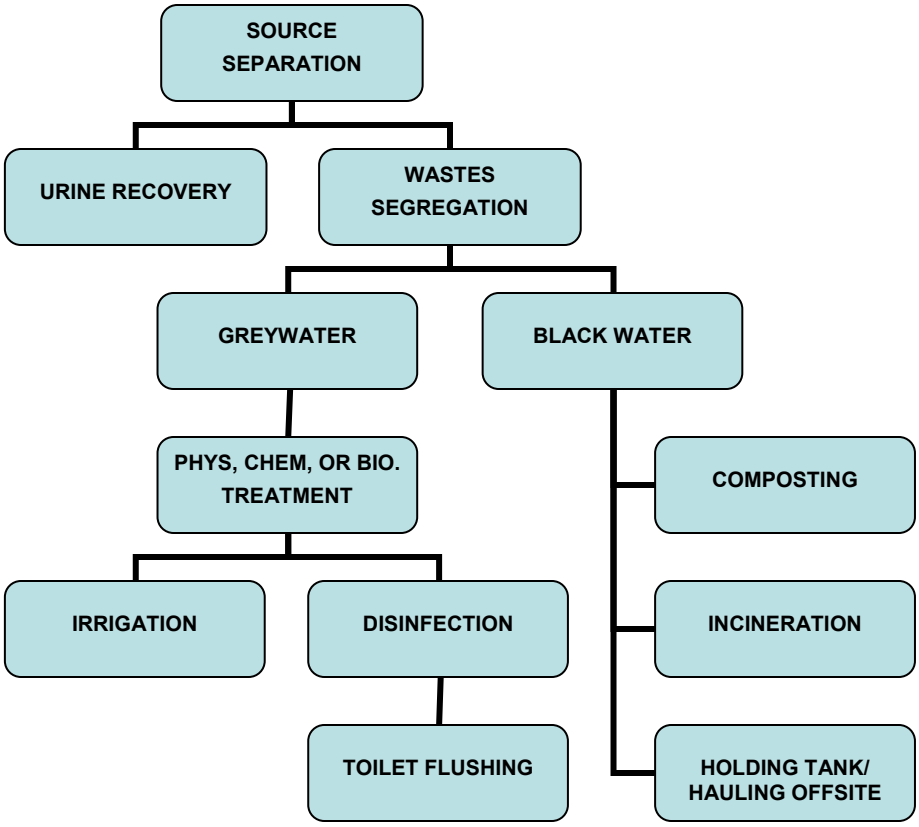

Figure 2-2: Source Separation Options

2.2 Physical / Chemical Treatment

Physical / chemical treatment processes do not rely on biological processes and therefore are typically more stable and consistent in their performance. However, as a consequence their operation and maintenance can be more intensive. Figure 2-3 illustrates the classification of these processes for nitrogen removal.

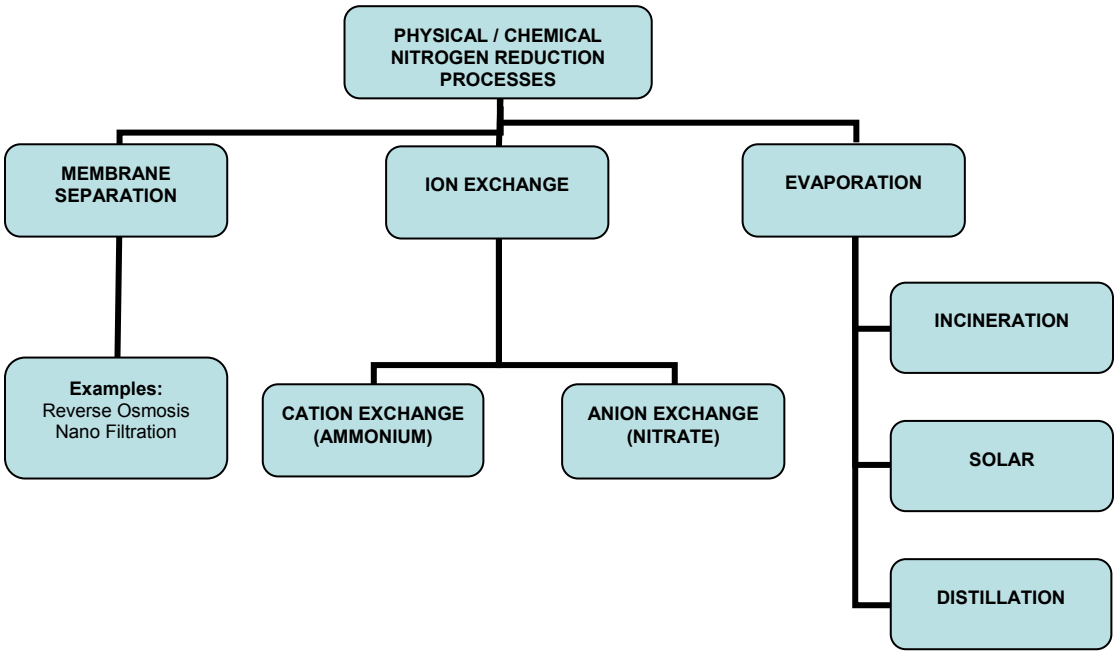

Figure 2-3: Physical / Chemical Nitrogen Reduction Categories

2.3 Biological Nitrification / Denitrification

Biological nitrification / denitrification processes are the most commonly used methods for reduction of nitrogen in wastewater. The two that are the most practical for onsite sewage treatment are mixed biomass and segregated biomass processes. The mixed biomass process includes suspended growth, fixed film, and integrated fixed film activated sludge technologies as shown in Figure 2-4. The segregated biomass technologies use various external organic carbon sources or elemental chemicals in place of the mixed biomass process' complete reliance on wastewater organic carbon as the electron donors necessary for microbial metabolism to reduce nitrate nitrogen. The segregated biomass systems require a highly nitrified influent to achieve nitrogen reduction goals.

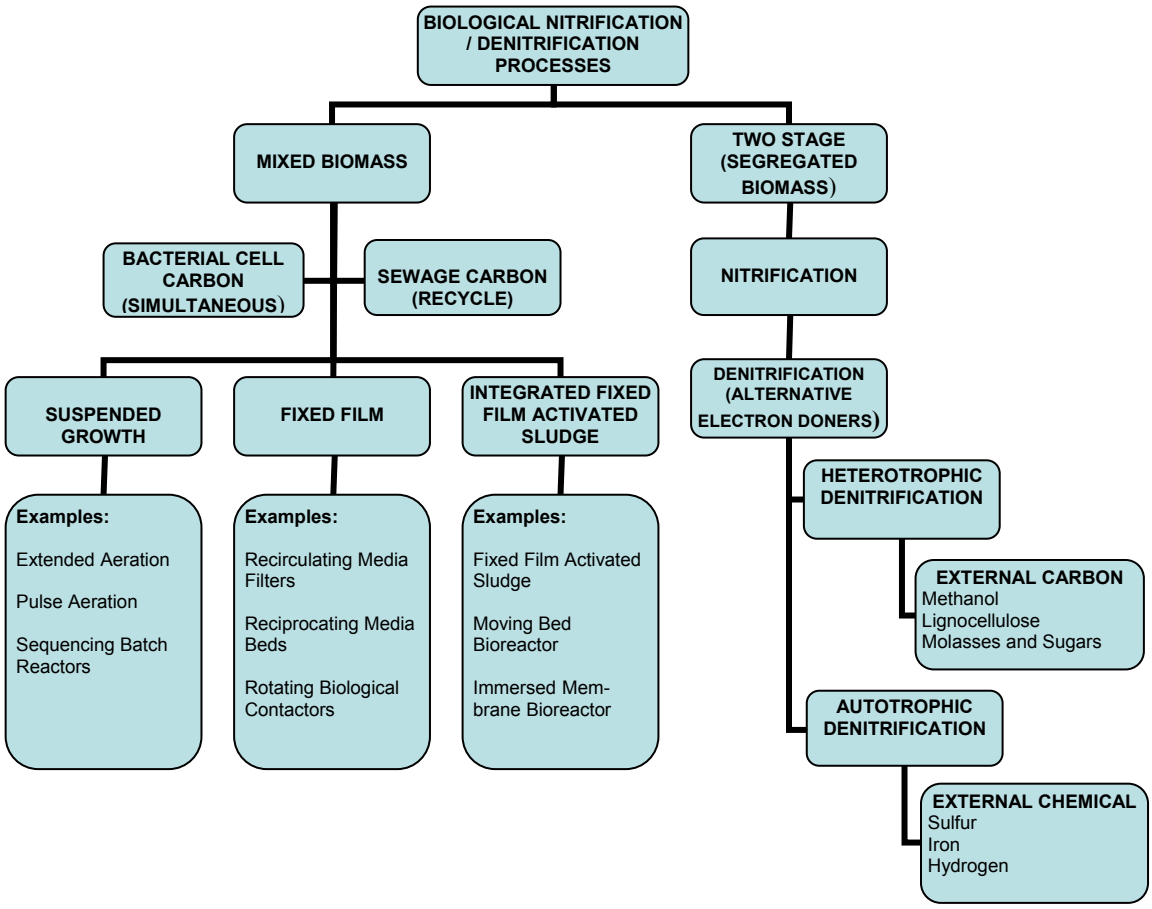

Figure 2-4: Biological Nitrification / Denitrification Technology Classifications

Table 2.1 provides a summary of the various biological denitrification processes and their typical treatment limits for onsite wastewater systems. These denitrification processes can be linked to any source of nitrified wastewater to provide nitrogen reduction by converting nitrate nitrogen to gaseous nitrogen. Figure 2-5 illustrates the relative system complexity for biological nitrogen reduction systems in relation to the process used.

Table 2.1
Biological Denitrification Processes and Typical Nitrogen Reduction Limits of OSTDS

Process	Mixed Biomass (Simultaneous)	Mixed Biomass (with Recycle)	Segregated Biomass (Two Stage)
Electron Donor	Organic carbon from bacterial cells and influent wastewater	Organic carbon from influent wastewater and bacterial cells	External electron donor (Organic carbon; Ligno-cellulose; Sulfur; Iron, Other)
Typical N Reductions	40 to 65%	45 to 75%	70 – 96%
Typical Technologies	• Extended aeration[1] • Pulse aeration[2] • Recirculating media filters[3] • Sequencing batch reactors[4] • Reciprocating media beds[5] • Membrane bioreactor[6]	• Extended aeration with recycle back to septic tank • Recirculating media beds with recycle back to septic tank[7] • Moving bed bioreactor	• Heterotrophic suspended growth[8] • Heterotrophic packed bed fixed film • Autotrophic packed bed fixed film[9]

[1] *Leverenz, et al., (2002); USEPA (2002)*
[2] *California State Water Resources Control Board (2002)*
[3] *USEPA (2002)*
[4] *Ayres Associates (1998)*
[5] *Behrends, et al. (2007)*
[6] *Abbeggen, et al., (2008); Sarioglu, et al. (2009)*
[7] *Ronayne, et al. (1982); Gold, et al. (1992); Piluk and Peters (1994); Roy and Dube (1994) California Regional Water Quality Control Board (1997); Ayres Associates (1998); Louden et al. (2005)*
[8] *USEPA, (1993)*
[9] *Rich (2007); Heufelder et al. (2008)*

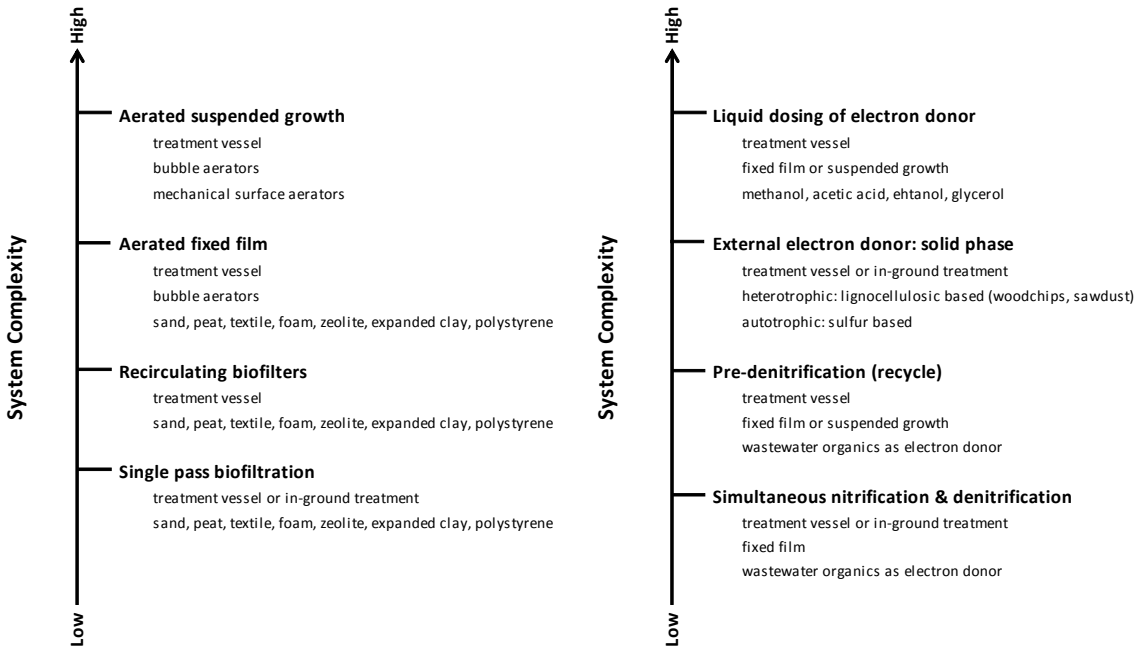

Figure 2-5: Generic System Complexity for Biological Nitrogen Reduction Systems

2.4 Natural Systems

Natural systems include soil infiltration, vegetative uptake, evapotranspiration and constructed wetlands as shown in Figure 2-6. These technologies use a variety of physical, chemical and biological processes to effect treatment. The reason they are listed in a separate category is that they are typically passive systems that depend more on natural, ecological processes within the receiving environment where process control is severely limited.

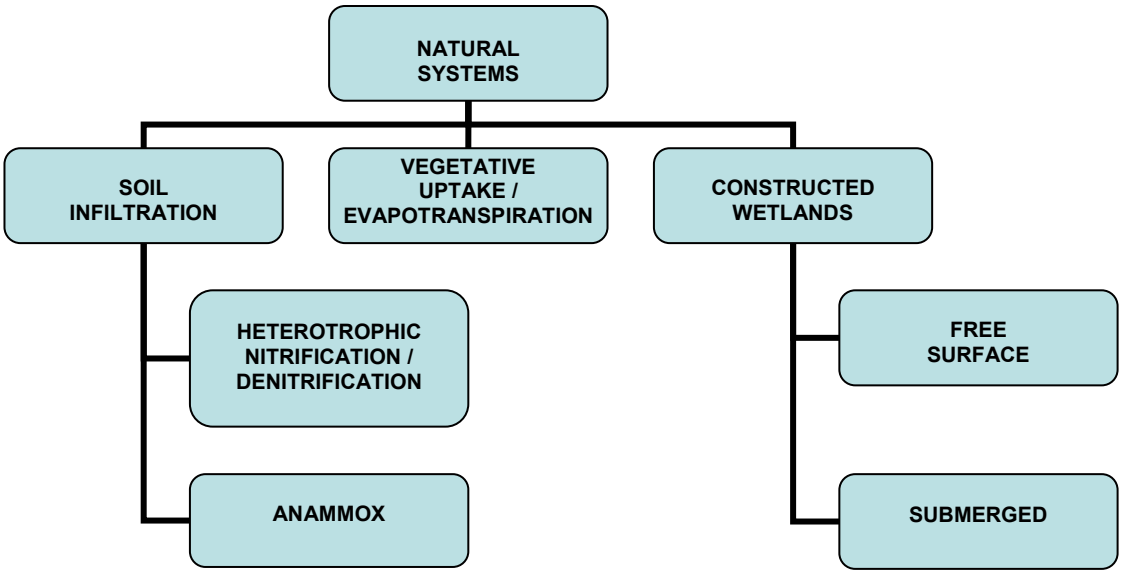

Figure 2-6: Natural Systems Categories

2.5 Treatment Technologies for Wastestream Components

As developed in the Task A literature review report, the domestic sewage from individual households can be divided into 4 individual waste streams:

A – Greywater
B – Kitchen waste
C – Fecal waste
D – Urine

Separation of these waste streams at the source can be utilized to reduce the nitrogen content of the remaining wastewater. Since toilet wastes contribute approximately 80% of the nitrogen to household sewage, with urine the principal contributor, separation of

toilet wastes or urine from the waste stream could significantly reduce the nitrogen content of household wastewater. However, the separated waste streams must still be treated and reused or discharged for soil infiltration.

Nitrogen reduction technology selection would be guided by the flow and constituent concentrations in the waste stream, the intended application of the final liquid effluent, and the degree of nitrogen reduction required in the final effluent. Greywater separation removes over half of the water volume and concentrates the constituent mass, while urine separation removes substantial nitrogen content while having little effect on total volume. Effluent from in-vessel nitrogen reduction systems may be applied to natural systems for irrigation use or for soil dispersal or subjected to disinfection treatment for indoor reuse.

Greywater may be made suitable for irrigation or indoor use with appropriate treatment. Aerobic biological treatment stabilizes biodegradable organics in the greywater stream and maintains oxidizing conditions; these enable storage for on demand reuse of the water and nutrient values while reducing possible odors. Treated greywater may be directly applied for irrigation, or recycled for indoor toilet flushing after disinfection. Ultraviolet disinfection is one candidate onsite technology.

Separation of urine is a candidate technology with potential benefit for both onsite nitrogen reduction and beneficial use of nitrogen contained in the urine stream. One year's urine production from a typical household could be captured in a single 500 gallon tank, removed annually and processed for recovery using struvite precipitation or other nitrogen and phosphorus recovery techniques. However, onsite urine recovery systems are not likely to become widespread in the near future. The service and recovery infrastructure is not currently in place in the U.S., and may take considerable time to be developed.

Section 3.0
Technology Ranking Criteria (Task A.8)

3.1 General Description of the Ranking System

A simple numerical ranking system was developed to prioritize available nitrogen reduction systems based on thirteen selected criteria. Each criterion is scored against its particular attribute using a scale ranging from 1 to 5. To account for relative differences in significance of each of the criteria, the criteria are assigned weighting factors indicating relative importance, compared to the other criteria. The priority ranking for a technology is determined by its total score, which is the sum of the products of the individual criterion scores times the weighting factors for each criterion. The highest score represents the highest priority ranking.

3.2 Criteria Selection and Relative Significance Comparison

Thirteen ranking criteria were selected based on priority concerns regarding their influence on the performance, costs, and acceptance of the available nitrogen reduction technologies. The selected criteria are listed in Table 3.1, which also provides how the relative significance of each criterion was weighted.

Table 3.1
Ranking Criteria and Weighting Factors

Criterion Description	Maximum Score (S)	Weighting Factor (W)	Total Possible Score (S x W)
Effluent Total Nitrogen Concentration	5	11	55
Performance Reliability	5	10	50
Performance Consistency	5	9	45
Construction Cost	5	7.5	37.5
Operation and Maintenance Cost	5	7	35
Energy Requirements	5	7	35
Construction Complexity	5	5	25
Operation Complexity	5	5	25
Land Area Requirements	5	4.5	22.5
BOD/TSS Effluent Concentration	5	3.5	17.5
Restoration of Performance	5	3.5	17.5
System Aesthetics	5	2	10
Stage of Technology Development	5	0.5	2.5
			377.5

The relative weights of the criteria were determined via a two stage process. First, each criterion was compared to every other criterion by the project team prior to the Technology Classification, Ranking and Prioritization Workshop and then by the RRAC at the workshop. If the criterion in a given column was considered to be more important than the criterion in a given row, then a “0” was entered into the box at the intersection of the column and row. If the criterion in the row was considered more important, then a “1” was entered into the box. The totals for each row established the relative rankings of each criterion with the highest score receiving the highest rank. Second, in order to reconcile the differences between the project team and RRAC weights, the weights for each criterion were averaged. Two criteria, construction and operational complexity, were added during the RRAC workshop. During subsequent discussions, RRAC concluded that the weight for energy requirements should be the same as for Operation and Maintenance Cost. Table 3.2 lists the weighting factor assigned to each criterion based on this process.

The scoring systems were created with the full knowledge that data would not be universally available. Scores were made using the given criteria and good engineering judgment, based on the experience of the team where data was not available. Generally, nitrogen concentration, performance reliability, construction costs, energy requirements, BOD/TSS concentration and stage of technology development data were generally easy

to find for most systems. Performance consistency, O&M cost, land area, system aesthetics, and restoration of performance data were harder to come by and more frequently required judgment.

Table 3.2
Selected Ranking Criteria and Weighting Factor Determination

	Effluent Nitrogen Concentration	Performance Consistency	Performance Reliability	Construction Cost	Operation and Maintenance Cost	Land Area Required	Energy Requirement	System Aesthetics	BOD/TSS Effluent Concentration	Restoration of Performance	Stage of Technology Development	Construction Complexity	Operation Complexity	RRAC Relative Rank Score	H&S Relative Rank Score	Average
Effluent Nitrogen Concentration		1	1	1	1	1	1	1	1	1	1	1	1	12	10	11
Performance Consistency	0		0	1	1	1	1	1	1	1	1	1	1	10	8	9
Performance Reliability	0	1		1	1	1	1	1	1	1	1	1	1	11	9	10
Construction Cost	0	0	0		1	1	1	1	1	1	1	1	1	9	6	7.5
Operation and Maintenance Cost	0	0	0	0		1	1	1	1	1	1	1	1	8	6	7
Land Area Required	0	0	0	0	0		1	1	0	0	1	0	0	3	6	4.5
Energy Requirement	0	0	0	0	0	0		1	0	0	1	0	0	2	4	7
System Aesthetics	0	0	0	0	0	0	0		0	0	1	0	0	1	3	2
BOD/TSS Effluent Concentration	0	0	0	0	0	1	1	1		1	1	0	1	6	1	3.5
Restoration of Performance	0	0	0	0	0	1	1	1	0		1	1	1	6	1	3.5
Stage of Technology Development	0	0	0	0	0	0	0	0	0	0		0	0	0	1	0.5
Construction Complexity	0	0	0	0	0	1	1	1	1	0	1		0	5		5
Operation Complexity	0	0	0	0	0	1	1	1	0	0	1	1		5		5

3.3 Criteria Descriptions and Values

A description of each criterion is presented below together with the attributes for the criterion and the value scores that are the basis for scoring of individual technologies.

3.3.1 Effluent Total Nitrogen Concentration

The attribute of this criterion is the concentration of total nitrogen in the final effluent that is achieved under suitable conditions with proper and adequate operation and maintenance. Effluent total nitrogen concentration is assigned a weighting factor of 11. The criterion values for total nitrogen effluent concentration are listed in Table 3.3. Total nitrogen values used to score a given technology were based on an average of values from various sources, ranging from peer reviewed publications with systems data to manufacturers' websites. The scores in the prioritization report represent what the project team determined to be accurate reflections of the system potentials.

Table 3.3
Criterion Values for
Total Nitrogen in Effluent

Effluent TN (mg/L)	Score
< 3	5
3 – 10	4
11 – 15	3
16 – 30	2
> 30	1

3.3.2 Performance Reliability

The attributes of the reliability criterion is expressed as the "mean time between unscheduled service calls". The frequency of routine service and unscheduled call-outs provides a measure of the reliability of a technology. Unscheduled service calls exclude inspections required by the FDOH rule. Factors that can increase the need for service include a high number of mechanical components (pumps, aerators, mechanical mixers), complexity of electrical systems, complexity of design, components prone to failure, and complex equipment that requires specialized parts and training of personnel. The reliability of onsite nitrogen reduction is assigned a weighting factor of 10. The categories for performance reliability are listed in Table 3.4.

Table 3.4
Criterion Values for
Performance Reliability

Mean Time Between Unscheduled Service Calls	Score
Annually	5
Semi-annually	4
Quarterly	3
Monthly	1

3.3.3 Performance Consistency

The consistency of performance is defined here as the sensitivity of the treatment system to upset. The sensitivity of a system is heavily influenced by the treatment process used. Therefore the attribute of the performance consistency criterion is the type of treatment process used, based on a review of wastewater treatment design guidelines and onsite wastewater treatment performance. Performance consistency is assigned a weighting factor of 9. The categories for performance consistency are listed in Table 3.5.

Table 3.5
Criterion Values for
Performance Consistency

System Type	Score
Physical/Chemical & Source Separation	5
Fixed Film	4
MBR / IMB*	3
IFAS**	2
Activated Sludge Nite/Denite	1

**MBR/IMB: Membrane Bioreactor / Immersed Membrane Bioreactor*

***IFAS: Integrated Fixed-Film Activated Sludge*

3.3.4 Construction Cost

The attribute of this criterion is the total capital cost of system installation, including septic tank and drain field where necessary. Available data on construction costs can be found in the technology database that accompanies this report. However, available data was not always complete, and therefore engineering judgment and cross-study comparisons were used to attempt to compare costs between technologies. Construction cost is assigned a weighting factor of 7.5. The categories for construction costs are listed in Table 3.6.

Table 3.6
Criterion Values for
Construction Cost

Construction Cost ($1000)	Score
< 5	5
5 - 10	4
10 – 15	3
15 – 20	2
> 20	1

3.3.5 Operation and Maintenance Cost

The attribute of this criterion is the cost of routine or recommended operation and maintenance, excluding power costs, that is needed to ensure that the treatment system meets its performance objectives. Operation and maintenance cost data obtained during this study is summarized in the technology database that accompanies this report. While the number of service calls would likely be a key factor in the operation and maintenance cost, data typically only included a total cost or estimate, and did not specify details of the various cost components. Operation and maintenance cost is assigned a

weighting factor of 7. The categories for operation and maintenance are listed in Table 3.7. Operation and maintenance costs typically included the costs of equipment servicing and consumable materials (reactive filter media, chemicals, etc.) but not the replacement cost of primary treatment components such as tanks. Notably, this criterion does not include energy costs, which are accounted for separately. The operation and maintenance costs are calculated as the present value of these costs over the useful life of the system.

Table 3.7
Criterion Values for Required Operation and Maintenance Costs

O&M Annual Cost ($/year)	Score
<200	5
200 - 300	4
301 - 400	3
401 - 500	2
> 500	1

3.3.6 Energy Requirements

The attribute of this criterion is the annual energy usage of the entire treatment system, including pumps, aerators, and mixing devices. The annual energy requirement is the sum of all energy requiring components or the rate of energy usage in operating the component multiplied by the component operating time. Energy requirement is assigned a weighting factor of 7. Criterion values for energy requirements are listed in Table 3.8. Greater energy use is associated with more “active” technologies that employ greater numbers of liquid pumps, aeration pumps, and mechanical mixing, whereas unsaturated granular media filters that employ passive aeration would consume less energy.

Table 3.8
Criterion Values for Energy Requirements

Energy Req. (kW-hr/year)	Score
< 500	5
500 – 1,000	4
1,001 – 1,500	3
1,501 – 2,500	2
> 2,500	1

3.3.7 Construction Complexity

The attribute of this criterion is the degree of difficulty necessary to install the system in question. High scoring systems will be simple to install even by an untrained contractor or installer – put it in the ground, plug it in, and it works. Low scoring systems will require substantial training and require an extensive installation process. Construction complexity is assigned a weighting factor of 5. Criterion values for construction complexity are qualitative, and are listed in Table 3.9. Data for this criterion was generally unavailable, and engineering judgment was therefore used to score the various technologies based on knowledge of system components and the perceived difficulty of installation.

Table 3.9
Criterion Values for
Construction Complexity

Description	Score
Simple to install by any contractor	5
Some specialized knowledge and training required	3
Complex installation, specialized training, sophisticated electrical and controls knowledge req., master septic tank contractor	1

3.3.8 Operation Complexity

The attribute of this criterion is the degree of complexity required to operate the system in question. High scoring systems will allow operation by the homeowner with little or no effort or training, while low scoring systems will not. Operation complexity is assigned a weighting factor of 5. Criterion values for operation complexity are qualitative, and are listed in Table 3.10. Data for this criterion was generally unavailable, and engineering judgment was therefore used to score the various technologies based on the knowledge of the process utilized and perceived difficulty in maintaining treatment performance.

Table 3.10
Criterion Values for
Operation Complexity

Description	Score
Simple operation with limiter operator requirements annual scheduled visit	5
Some specialized operator training required; Scheduled visits by manufacturer's representative required twice per year	3
Complex operation with operator training required; Scheduled visits by manufacturer's representative required > quarterly	1

3.3.9 Land Area Requirements

The attribute of this criterion is the plan area or the size of the footprint required for the treatment system, including the drain field, nitrogen reducing component, and septic tank where required. Available data for this criterion can be found in the technology database accompanying this report. However, data was limited and significant judgment was required to compare relative land area requirements between technologies. Land area required is assigned a weighting factor of 4.5. Criterion values for land area required are the footprint area in square feet, and are listed in Table 3.11.

Table 3.11
Criterion Values for
Land Area Requirements

Land Area Req. (ft^2)	Score
< 250	5
250-500	4
501-1000	3
1001-2000	2
> 2000	1

3.3.10 Effluent cBOD/TSS Concentrations

The attribute of this criterion are the final effluent concentrations of five day carbonaceous biochemical oxygen demand ($cBOD_5$) and total suspended solids (TSS) under suitable conditions with proper and adequate operation and maintenance. BOD and TSS effluent concentration is assigned a weighting factor of 3.5. Categories for BOD and TSS effluent concentration are listed in Table 3.12.

Table 3.12
Criterion Values for
cBOD/TSS Effluent Concentrations

Effluent cBOD/TSS (mg/L)	Score
10 / 10	5
20 / 20	4
30 / 30	2
> 50	1

3.3.11 Performance Restoration

Treatment technologies occasionally will fail to achieve their performance expectations. Such upsets may be due to electrical or mechanical problems or a process upset. The time needed to restore treatment is an important criterion in preventing harm to the environment. The consequences of an operational failure are much less significant if treatment efficacy is restored rapidly. Data was generally unavailable for this criterion, so scoring was based on engineering judgment related to the treatment process utilized by a given technology, as noted in Table 3.13. Performance restoration is assigned a weighting factor of 3.5. The categories for performance restoration are listed in Table 3.13.

Table 3.13
Criterion Values for
Performance Restoration

System Type	Score
Physical/Chemical & Source Separation	5
Fixed Film	4
MBR/IMB*	3
IFAS**	2
Activated Sludge Nite/Denite	1

**MBR/IMB: Membrane Bioreactor / Immersed Membrane Bioreactor*

***IFAS: Integrated Fixed-Film Activated Sludge*

3.3.12 System Aesthetics

The attribute of this criterion is a general judgment of the aesthetic perception of the system when it is properly and adequately operated and maintained. System Aesthetics is assigned a weighting factor of 2. Categories for system aesthetics are listed in Table 3.14.

Table 3.14
Criterion Values for System Aesthetics

System Aesthetics	Score
Acceptable	5
Perceived nuisance/displeasing	3
Not acceptable	1

3.3.13 Stage of Technology Development

The attribute of this criterion is the stage in development of the nitrogen reduction technology. Stage of technology development is assigned a weighting factor of 0.5. Criterion values for stage of technology development are listed in Table 3.15. Systems used nationwide, or thoroughly tested by NSF or MASSTC will be assigned the highest ranking, while the lower rankings allow room for consideration of meritorious ideas that have not yet been tested. This would include "experimental" systems, such as those tested in PNRS I, or "conceptual" system ideas based on processes, components, or operational strategies that have yet to be tested.

Table 3.15
Criterion Values for Stage of Technology Development

Stage of Development	Score
National use	5
State use	4
Demonstration	3
Experimental	2
Conceptual	1

Section 4.0
Prioritization of Nitrogen Reduction Technologies (Task A.9)

Prioritization of nitrogen reduction technologies was based on systematic application of the ranking criteria to the technologies identified in the literature review. Technologies were grouped according to the classification scheme developed in Task A.7. Each technology classification received individual scores for the separate evaluation criterion, and the weighting criteria were used to generate the total score for the technology classification. The technologies within each classification were prioritized according to their total score.

4.1 List of Technologies

The literature review and survey of manufacturers indicated that many processes and commercial systems are available for onsite wastewater treatment. The technology database is comprised of available onsite nitrogen reduction technologies from manufacturers and the literature review. The identified technologies were sorted according to the major classifications developed in Task A.7: source separation, biological treatment, physical/chemical treatment and natural systems. The basis for assignment of classification was the principal nitrogen reduction process of the technology. The systems within the major groupings were then further grouped into the process variations within each major classification.

4.2 Technology Evaluation Criteria

The technology evaluation criteria were individually discussed and edited, and a final consensus list of criteria was agreed to and adopted during the Technology Classification, Ranking and Prioritization Workshop held with the Research Review and Advisory Committee on May 28, 2009. Also agreed to and adopted at that meeting were the weighting factors for each individual criterion. The finalized criteria and weighting factors are listed in Table 4.1.

Table 4.1
Technology Criteria and Weighting Factor

Criteria	Weighting Factor
Effluent Nitrogen Concentration	11
Performance Reliability	10
Performance Consistency	9
Construction Cost	7.5
Operation and Maintenance Cost	7
Energy Requirement	7
Construction Complexity	5
Operation Complexity	5
Land Area Required	4.5
BOD/TSS Effluent Concentration	3.5
Restoration of Performance	3.5
System Aesthetics	2
Stage of Technology Development	0.5

For each of the individual technologies identified within the literature review, data were acquired from a wide variety of sources focusing on the ranking criteria. Manufacturer's information and third party test results such as the NSF International (NSF) Standard 40 Protocol, EPA Environmental Technology Verification Program (ETV), or field and/or laboratory evaluations reported in the technical literature were utilized to develop the technology database. Some performance data were available only as manufacturer's claims, other data as a range of removal percentages from field installations, and some data included detailed analytical results with statistical ranges. Results were averaged because sufficient data was generally not available to distinguish between differences in scale, number of experiments and control of influent variability. Nitrogen effluent data were generally available while nitrogen influent data were not. The attributes of the performance consistency and performance reliability criteria were based on the type of treatment process used. Construction cost was estimated for a newly installed, complete treatment system for a three-bedroom home in Florida, and included primary treatment (i.e. septic tank) and a conventional drainfield. Performance reliability data were available for a few systems for which frequency of maintenance visits recorded were available, and estimated for the remainder. Energy use data (kW-h/day or kW-h/year) were available for a few systems that detailed a cost per month or cost per year, and estimated for the others. For energy use, a conversion to uniform data values was obtained by using an assumption of $0.10 per kW-h. Operation and maintenance cost estimates, land area required, constructional complexity, operational complexity, and system aesthetics data

were very limited, so professional judgment was used to assign scores for individual criteria to the technology classifications. Data which was available was referenced and summarized in the technology database provided with this report. Assumptions used in the scoring process are footnoted below the criteria scoring tables that follow.

4.3 Criteria Scores

For each of the thirteen criteria, scores were established based on cost and/or non-cost attributes. Table 4.2 presents a summary of score assignments for each criterion. The criterion assignments were the basis for scoring and ranking of the technology classifications.

Table 4.2
Criteria Scores

Criteria Number	Criteria	Score				
		1	2	3	4	5
1	Effluent Nitrogen Concentration (mg-N/L)	> 30	16 – 30	11 – 15	3 – 10	< 3
2	Performance Reliability	Monthly		Quarterly	Semi-Annually	Annually
3	Performance Consistency[1]	Activated Sludge Nite/Denite	IFAS[2]	MBR/IMB[3]	Fixed Film	Physical/ Chemical & Source Separation
4	Construction Cost[4] ($1,000's)	>20	16-20	11-15	5-10	<5
5	Operation and Maintenance Cost[5] ($/year)	>500	401-500	301-400	200-300	<200
6	Energy Requirement (kW-h/year)	>2500	1501-2500	1001-1500	500-1000	<500
7	Construction Complexity	Complex installation, specialized training, sophisticated electrical and controls knowledge req., master septic tank contractor		Some specialized knowledge and training required		Simple to install by any Contractor

Table 4.2 (continued)
Criteria Scores

Criteria Number	Criteria	Score				
		1	2	3	4	5
8	Operation Complexity	Complex operation with operator training required; Scheduled visits by manufacturer's representative required > quarterly		Some specialized operator training required; Scheduled visits by manufactur-er's repre-sentative re-quired twice per year		Simple operation with limited operator require-ments; annual scheduled visit
9	Land Area Required[6] (ft^2)	>2000	1001-2000	501-1000	250-500	<250
10	BOD/TSS Effluent Concentration (mg/L)	>50	30/30		20/20	10/10
11	Restoration of Performance[7]	Activated Sludge Nite/Denite	IFAS[2]	MBR/IMB[3]	Fixed Film	Physical/ Chemical & Source Separation
12	System Aesthetics	Not Acceptable		Perceived Nuisance/ Displeasing		Acceptable
13	Stage of Tech. Development	Conceptual	Experimental	Demonstra-tion	State Use	National Use

1. *Since most of the natural systems include fixed film, the natural systems received a score of "4".*
2. *Integrated Fixed-Film Activated Sludge*
3. *Membrane Bioreactor / Immersed Membrane Bioreactor*
4. *Construction cost assumes a standard septic tank cost of $2000 and drainfield cost of $4500 installed.*
5. *Operation and maintenance cost includes inspections, annual operating permit fee ($100), and maintenance entity, but it does not include power costs.*
6. *Land area is for a new entire system, and assumed standard septic tank 50 SF and drainfield 400 SF.*
7. *Since soil infiltration is fixed film, a score of "4" was used for the natural soil infiltration classifications. The constructed wetlands subsurface flow is not quite comparable; therefore it received a score of "3".*

The criteria were developed with the full knowledge that data for many of the criteria would be sparse and difficult to attain. Good engineering judgment and experience with various types of systems were used to develop technology ranking scores when data were not available.

4.3.1 Criteria Scores for Physical/Chemical and Biological Technology Classifications

A summary of the individual criterion scores for physical/chemical and biological technology classifications is presented in Table 4.3. While the table encompasses the full range of possible systems contained in our classification, technology classifications that lacked sufficient data to make a criteria ranking determination were left blank. Natural and source separation systems need to be considered separately and are therefore summarized in Table 4.5.

Table 4.3
Criteria Scores for Physical/Chemical and Biological Technology Classifications

Technology Classification	Criteria													Total Score
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Effluent TN Conc. (mg/L)	Performance Reliability	Performance Consistency	Construction Costs ($1000)	O&M Cost	Energy Req. (kW-h/yr)	Construction Complexity	Operation Complexity	Land Area Req. (ft^2)	BOD/TSS Effluent Conc (mg/L)	Restoration of Performance	System Aesthetics	Stage of Technology Development	
Weighting Factor[1]	11.0	10.0	9.0	7.5	7.0	7.0	5.0	5.0	4.5	3.5	3.5	2.0	0.5	
Physical/Chemical														
Membrane Separation	Not Enough Available Data to Score													
Ion Exchange	Not Enough Available Data to Score													
Evaporation	Not Enough Available Data to Score													
Biological														
Mixed Biomass														
Suspended Growth	3	3	1	2	2	2	3	3	3	4	1	5	5	188.5
Fixed Film														
Fixed Film with recycle	2	4	4	2	3	2	3	3	3	5	4	5	5	235.5
Fixed Film without recycle	1	4	4	2	4	3	3	3	3	4	4	5	5	235
Integrated Fixed Film Activated Sludge	2	3	2	2	2	1	3	3	3	4	2	5	5	183
Two Stage (Segregated Biomass)														
Heterotrophic Denitrification	4	5	4	2	3	2	3	5	3	4	4	5	3	273[2]
Autotrophic Denitrification	4	5	4	2	3	2	3	5	3	5	4	5	3	276.5[2]

1. *See Section 3.0 for how weighting factors were developed.*
2. *Criteria score pertains to a fixed film (Stage 2) denitrification biofilter and fixed film aerobic (Stage 1) process. For other types of Stage 1 systems, the criteria score for the two stage system would be the criteria score for the Stage 1 system (e.g. activated sludge, IFAS).*

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For each technology classification, the criterion scores (Table 4.3) were multiplied by the weighting factor (Table 4.1) and summed to generate a total score. The total score was used to rank technology classifications. Total scores for biological technology classifications are listed in Table 4.4 and plotted in Figure 4-1.

Table 4.4
Biological Technology Classification Overall Ranking

Technology Classification	Total Score	Overall Ranking
Two Stage (Segregated Biomass) – Autotrophic Denitrification	276.5[1]	1
Two Stage (Segregated Biomass) – Heterotrophic Denitrification	273.0[1]	2
Mixed Biomass – Fixed Film with Recycle	235.5	3
Mixed Biomass – Fixed Film without Recycle	235.0	4
Mixed Biomass – Suspended Growth	188.5	5
Mixed Biomass – Integrated Fixed Film Activated Sludge	183.0	6

1. *Criteria score pertains to a fixed film (Stage 2) denitrification biofilter and fixed film aerobic (Stage 1) process. For other types of Stage 1 systems, the criteria score for the two stage system would be the criteria score for the Stage 1 system (e.g. activated sludge, IFAS).*

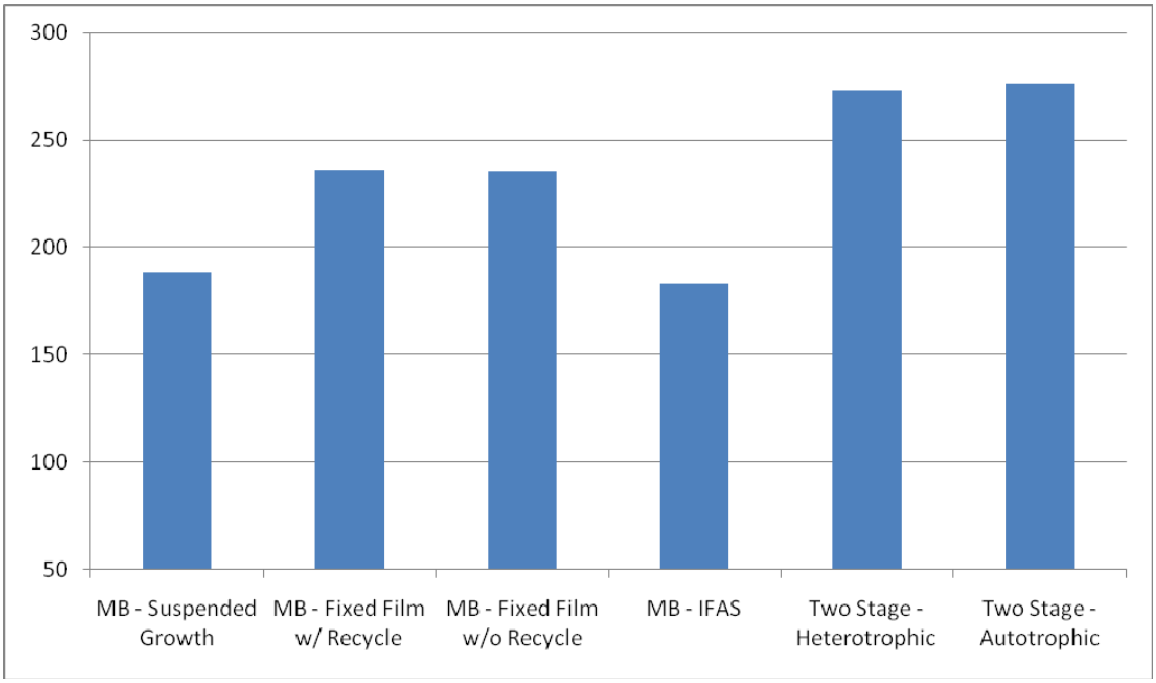

Figure 4-1: Overall Ranking of Biological Technology Classifications

The top ranked technology classifications (1 & 2) were biological systems with two stage segregated biomass employing autotrophic and heterotrophic denitrification. These systems are passive, require little operator attention, and provide high reliability. The total scores for autotrophic and heterotrophic denitrification technologies in two stage segregated biomass systems were sufficiently close that they were considered essentially equal.

The third and fourth ranked technology classifications were mixed biomass fixed film biological systems with recycle and without recycle, respectively. The total scores for these systems were sufficiently close that they were considered essentially equal. These technology classifications have the stability advantages that are inherent in fixed film processes.

Mixed biomass suspended growth systems were the fifth ranked technology classification and mixed biomass integrated fixed film systems were the sixth. These systems employ suspended growth basins and exhibit higher effluent nitrogen concentrations and lower performance consistency and reliability.

4.3.2 Criteria Scores for Natural and Source Separation Technology Classifications

Table 4.5
Criteria Scores for Natural and Source Separation System Technology Classifications

Technology Classification	Criteria													Total Score
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Effluent of TN Conc. (mg/L)	Performance Reliability	Performance Consistency	Construction Costs ($1000)	O&M Cost	Energy Req. (kW-h/yr)	Construction Complexity	Operation Complexity	Land Area Req. (ft^2)	BOD/TSS Effluent Conc (mg/L)	Restoration of Performance	System Aesthetics	Stage of Technology Development	
Weighting Factor[1]	11.0	10.0	9.0	7.5	7.0	7.0	5.0	5.0	4.5	3.5	3.5	2.0	0.5	
Natural Systems														
Soil Infiltration														
With dosing	1	5	4	5	4	5	5	5	3	5	4	5	5	305
With reactive barriers	5	5	4	3	3	5	3	4	5	5	4	5	3	320
With drip dispersal	2	4	4	4	3	5	3	3	3	5	4	5	5	271.5
Annamox	Not Enough Available Data to Score													
Constructed Wetlands														
Subsurface flow with pre-nitrification	3	5	4	2	4	5	3	3	3	3	3	5	5	274
Source Separation Systems														
Urine Recovery	Not Enough Available Data to Score													
Wastes Segregation	Not Enough Available Data to Score													

1. *See Section 3.0 for how weighting factors were developed.*

Table 4.6
Natural System Technology Classification Overall Ranking

Technology Classification	Total Score	Overall Ranking
Soil Infiltration with reactive barriers	320.0	1
Soil Infiltration with dosing	305.0	2
Constructed Wetlands subsurface flow with pre-nitrification	274.0	3
Soil Infiltration with drip dispersal	271.5	4

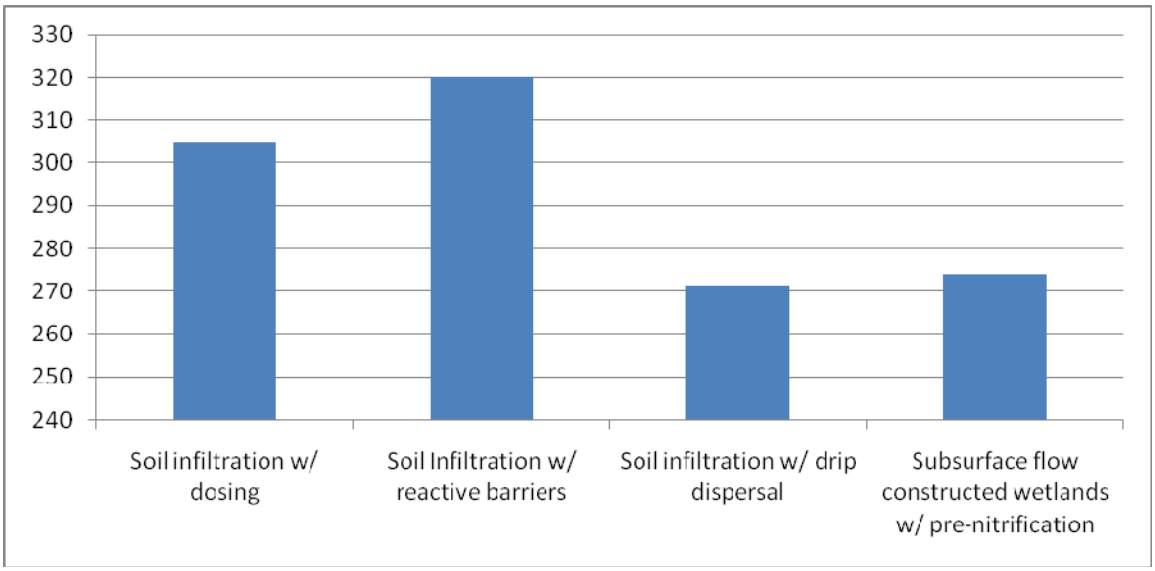

Figure 4-2: Overall Ranking of Natural System Technology Classifications

The top ranked natural system was soil infiltration with reactive barriers. The second ranked natural system is traditional trench drainfield with timed dosing of septic tank effluent. However, this system received the lowest treatment score. Application of our ranking system to certain kinds of natural systems can be misleading from a purely quantitative perspective: in this instance, the score is high because of its passive characteristics and low operating costs, but does not address the difficulty of performance monitoring and the costs associated with correcting poor performance.

Subsurface-flow constructed wetlands with pre-nitrification and drip dispersal of septic tank effluent to soil infiltration technologies ranked within 1% of each other. The constructed wetlands can achieve more complete nitrification and denitrification than soil infiltration with drip dispersal, but drip dispersal offers much greater control of perfor-

mance and repairs of malfunctions are less costly and easier to perform. Aesthetically, the systems scored the same, but the acceptance could be quite different among property owners.

It is important to note that the natural systems should not be quantitatively compared, using these ranking criteria, to the groups of proprietary and non-proprietary biological systems detailed in Tables 4.3 and 4.4, and Figure 4-1. Primary among considerations supporting this division of technologies is the need to consider separately the elements, of each system, that perform treatment. The soil infiltration units utilize the soil's ecology and physical characteristics to perform treatment and all relevant data measures the treatment capacity within the soil pedon to reduce nitrogen. However, it must be kept in mind that the vast majority of proprietary systems also discharge to the soil. In order to be able to rank each technology fairly, only the nitrogen reduction components were considered. Moreover, management of non-soil based technologies, though more expensive, is simplified because the units can be operated effectively to adjust to varying conditions and serviced easily, which may not be the case with soil-based nitrogen reduction technologies. When malfunctions occur with soil-based technologies, repairs may be necessary and could lead to expensive reconstruction. When the latter is necessary, available land area can become a severe constraint. Finally, while soils provide good treatment over a broad range of conditions, variability of characteristics among soil units can be large creating significant uncertainty in predicting a soil's nitrogen reduction capacity.

4.4 Recommendations for Testing

The technology classification ranking provides the basis from which to formulate recommendations for the field testing to be conducted in Task B of the Florida Onsite Sewage Nitrogen Reduction Strategies Study. The criteria used to consider in establishing priorities for testing include representation of several technology classifications, nitrogen effluent performance data, similarity of technologies, and maturity level of technologies. The purpose of prioritization is to select the more promising technologies that may not have sufficient prior testing or may be differently configured to improve performance, and to avoid duplicate testing where substantial experience already exists. The priority list for Task B testing is listed in Table 4.7. The recommended technologies include mixed biomass, two stage segregated biomass biofiltration systems, natural systems with and without external sources of electron donors for denitrification, fixed film and integrated fixed film activated sludge processes, denitrification filters with reactive media as post-treatment to commercial aerobic treatment processes, onsite elimination of urine effluent, and urine separation and recovery.

Table 4.7
Technologies Recommended for Testing in Task B

System	Technology	Comment
1	Two stage (segregated biomass) system: Stage 1: Biofiltration with recycle (nitrification) Stage 2: Autotrophic denitrification with reactive media biofilter	• Top ranked system capable of meeting the lowest TN concentration standard Suitable for new systems or retrofit
2	Two stage (segregated biomass) system: Stage 1: Biofiltration with recycle (nitrification) Stage 2: Heterotrophic denitrification with reactive media biofilter	• Top ranked system capable of meeting the lowest TN concentration standard • Suitable for new systems or retrofit
3	Natural system: Septic tank/Mound with in-situ reactive media layer	• Lower cost natural system that is untested but appears capable of achieving 75-78% TN removal before reaching groundwater • Suitable for new systems or replacing existing systems at end of useful life
4	Natural system: Settled or secondary effluent with drip dispersal	• Suitable for reducing TN impacts on groundwater through enhanced TN removal and reduced TN loading on soil • Suitable for new systems or retrofit
5	Mixed biomass fixed film system with recycle followed by a heterotrophic denitrification with reactive media biofilter	• High performance aerobic treatment with anoxia for enhanced TN removal followed by second stage heterotrophic denitrification for high nitrogen removal • Suitable for new systems or nitrogen reduction upgrades
6	Mixed biomass fixed film system with recycle followed by an autotrophic denitrification with reactive media biofilter	• High performance aerobic treatment with anoxia for enhanced TN removal followed by second stage autotrophic denitrification for meeting low TN concentration standard • Suitable for new systems or nitrogen reduction upgrades
7	Mixed biomass integrated fixed film activated sludge system: Suspended growth with recycle	• High performance aerobic treatment • Suitable for new systems or nitrogen reduction upgrades

Table 4.7 (continued)
Technologies Recommended for Testing in Task B

System	Technology	Comment
8	Mixed biomass integrated fixed film activated sludge system: Moving bed bioreactor	• High performance aerobic treatment with simultaneous denitrification • Suitable for new systems or nitrogen reduction upgrades
9	Mixed biomass suspended growth system: Suspended growth sequencing batch reactor	• Aerobic treatment • Suitable for new systems or nitrogen reduction upgrades
10	Membrane process system: Membrane bioreactor (MBR)	• Suitable for new systems or nitrogen reduction upgrades
11	Source separation system: Dry toilet (evaporative or composting)	• Eliminates liquid disposal of wastes
12	Source separation system: Urine separating (recovery) toilet	• Innovative system that is capable of removing 70-80% of the household TN at little capital cost • Provides potential for sustainable recovery of nutrients

The first two technologies listed in Table 1.7 are hybrid mixed biomass/segregated biomass systems. The first stage of each is a mixed biomass recirculating biofilter through which nitrification occurs. Significant denitrification also occurs due to the recirculation. The biofilters can employ a variety of fixed film media, many of which are in current use and are described in the literature review. PNRS II testing will provide additional data for biofiltration with recycle using clinoptilolite, expanded clay, and polystyrene. The best performing media from PNRS II testing will be recommended for Task B testing. Stage 2 of these hybrid systems will employ autotrophic denitrification (System 1) and heterotrophic denitrification (System 2). The hybrid mixed biomass/separate biomass Systems 1 & 2 can be employed for new installations or inserted between primary treatment (i.e. septic tank) and soil dispersal in existing systems.

System 3 is a natural system that uses drip dispersal into the soil of settled or secondary effluent. The design of this system will be based on the results of PNRS II, in which variants of this basic system will be evaluated to determine the design that results in the best nitrogen reduction performance. To enhance denitrification, an in-situ reactive media barrier will be constructed below the drip dispersal tubing. Effluent is dispersed within the root zone and percolates downward through the reactive media barrier containing high water retention materials such as expanded clay and lignocellulosic or elemental sulfur electron donors to support heterotrophic or autotrophic denitrification. This system

would meet the FDOH definition of passive technology and has the potential to be a low cost in-situ system that can be applied for new installations or retrofits.

System 4 is a natural system using drip dispersal of settled or secondary effluent into the soil. By dosing septic tank effluent into the soil on timed cycles alternating aerobic and anoxic conditions are created in the soil near each emitter, which creates the necessary conditions for nitrification/denitrification to occur. This intermittent dosing of septic tank effluent has been shown by several studies to reduce the total nitrogen that migrates downward from the point of application.

Systems 5 and 6 are similar to Systems 1 and 2, in that they are hybrid mixed/segregated biomass systems with a first stage fixed film bioreactor with or without recycle, followed by a heterotrophic (System 5) or autotrophic (System 6) denitrification filter. While Systems 1 and 2 utilize various widely available media, System 5 and 6 will use a combination of different proprietary and non-proprietary media systems. Systems 5 will include recycling around the first stage aerobic biofilter to enhance pre-denitrification and lessen the nitrate loading to the Stage 2 denitrification filter. Systems 5 and 6 expand the evaluation of the hybrid mixed/segregated biomass systems over that provided by Systems 1 and 2 alone.

Systems 7 and 8 are IFAS (Integrated Fixed-Film Activated Sludge) systems. They combine elements of both fixed film and suspended growth microbial communities, resulting in relatively stable treatment processes that achieve more reliable and consistent performance than other mixed biomass processes.

System 9 is a suspended growth system, specifically Sequencing Batch Reactors (SBR). Theoretically, SBR's should be able to control the loss of carbon better than other mixed biomass systems.

System 10 is a membrane bioreactor (MBR) which combines suspended growth with a membrane filtration unit. MBR has been applied for onsite treatment of multifamily residential wastewater and is an emerging treatment option for single family home systems.

Systems 11 and 12 are source separation systems. Source separation is an emerging onsite wastewater management option, and may become increasingly prevalent in the future in keeping with needs for sustainability and resource recovery. With regard to nitrogen removal, source separation has the potential to be a particularly efficient option since 50 to 75% of household waste nitrogen is from urine. Accordingly, separating the waste streams allows for more efficient, dedicated treatment options for individual components of the wastewater stream.

Section 5
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