FLORIDA DEPARTMENT OF HEALTH

Florida Onsite Sewage Nitrogen Reduction Strategies Study

Classification, Ranking and Prioritization of Technologies

DRAFT REPORT

May 2009

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HAZEN AND SAWYER
Environmental Engineers & Scientists

In association with

SCHOOL OF MINES COLORADO 1874

AET Applied Environmental Technology

OTIS ENVIRONMENTAL CONSULTANTS, LLC

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DRAFT REPORT
Classification, Ranking and Prioritization of Technologies

Prepared for:

Florida Department of Health
Division of Environmental Health
Bureau of Onsite Sewage Programs
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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.1 is to expand and update the literature review of nitrogen reduction technologies that was conducted under a previously completed FDOH project, the Passive Nitrogen Reduction Study (PNRS I). The draft 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 includes preliminary results of FOSNRS Study Tasks A.3 and A.4 and an outline of Task A.5, and is presented to provide information for a Technology Classification, Ranking and Prioritization Workshop (Task A) to be held with the FDOH Research Review and Advisory Committee (RRAC). The following summarizes the contents of this report.

- ***Classification of Technologies (Task A.3)*** 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 (Task A.1) and consideration of fundamental principles of wastewater treatment unit processes.

- ***Technology Ranking Criteria (Task A.4)*** 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.5.

- ***Priority List for Testing (Task A.5)*** this portion of the report outlines the overall methodology by which individual technologies will be classified, ranked and evaluated in order to prioritize technologies for testing. This section contains an outline only, and will be completed after the Technology Classification, Ranking and Prioritization Workshop.

The Technology Classification, Ranking and Prioritization Workshop will present the nitrogen reduction technology classifications, ranking criteria, and weighting factors recommended by the project team in this report, and seek input from the stakeholders on the RRAC. The objectives of the workshop are to gain consensus on the methods that will be used to rank and prioritize technologies for subsequent field testing. After the workshop and receipt of written comments from RRAC and FDOH, the Hazen and Sawyer Team will apply the final ranking criteria and weighting factors to data collected during the literature review and develop a priority list for field testing. Based on input from the workshop and review comments, a final Technology Classification, Ranking, and Prioritization Report will be submitted to FDOH.

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Section 2.0
Classification of Nitrogen Reduction Technologies

Task A.3

The results of the literature review from task A.1 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 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.

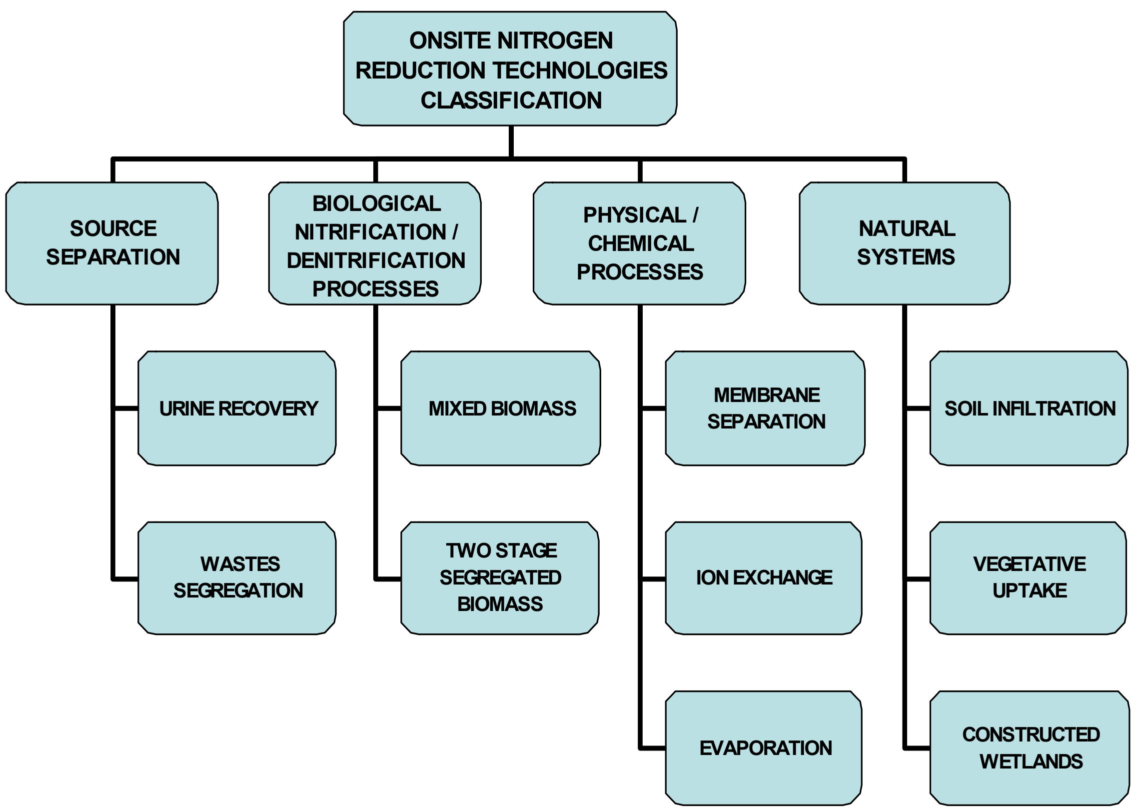

Figure 1. Options for Reducing Nitrogen in Household Sewage

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Source Separation

Source separation options are shown in Figure 2. The primary source separation options include urine recovery and separation of toilet wastes (black water) from the other domestic wastestreams. Toilets are the source of approximately 80% of all nitrogen discharged in household waste streams making urine recovery or black water segregation significant nitrogen reduction options.

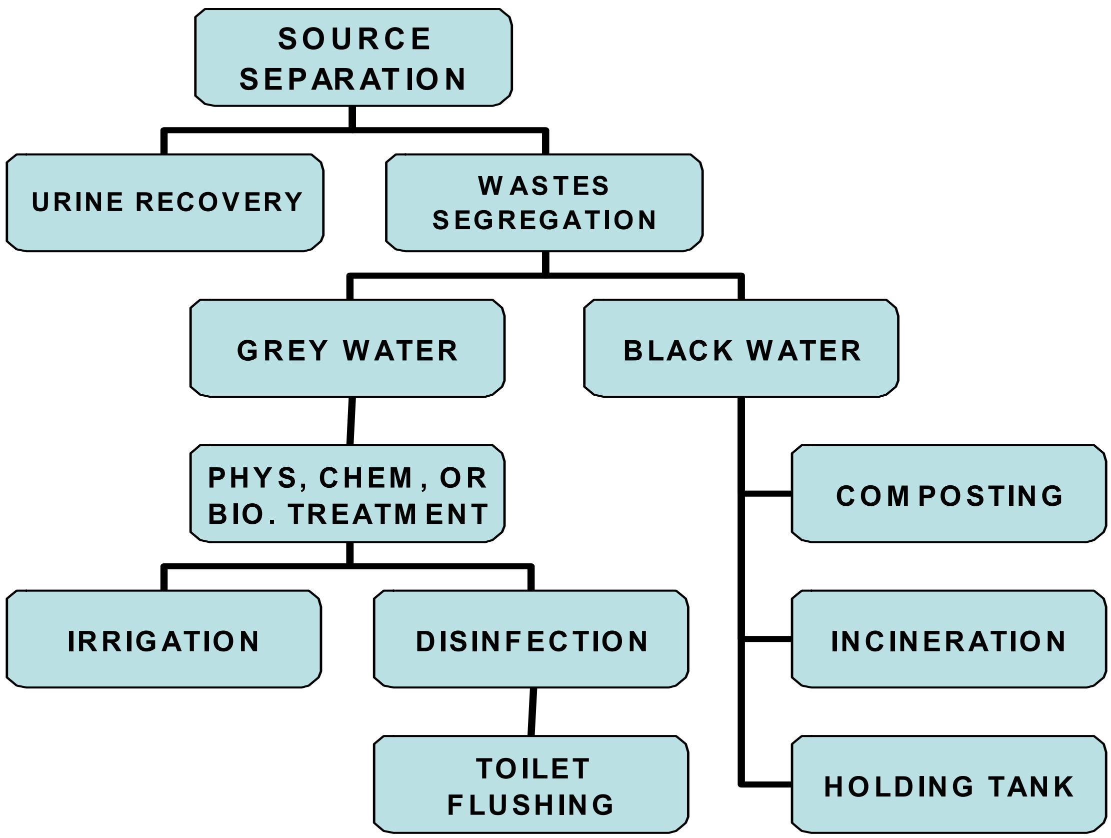

Figure 2. Source Separation Options

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 3 illustrates the classification of these processes for nitrogen removal.

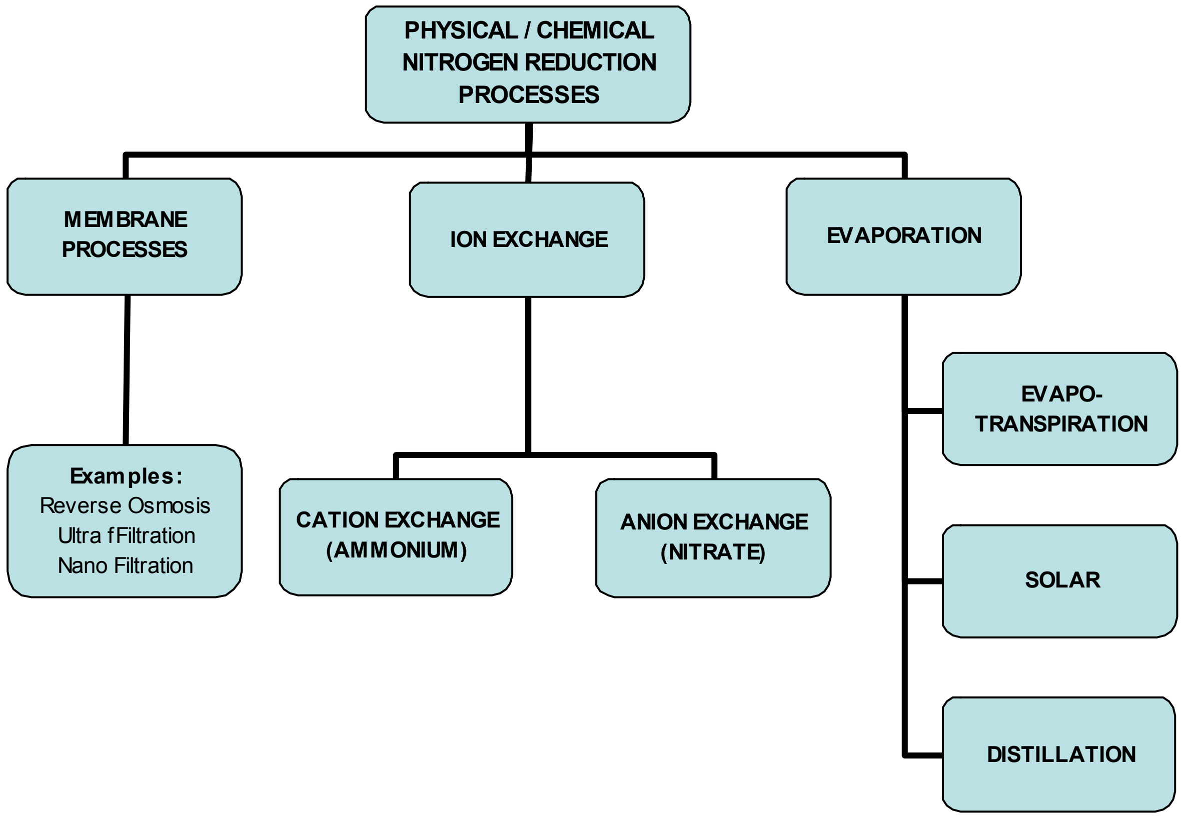

Figure 3. Physical / Chemical Nitrogen Reduction Categories

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 (Figure 4). The segregated biomass technologies use various external organic carbon sources or elemental chemicals in place of 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.

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Table 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 5 illustrates the relative system complexity for biological nitrogen reduction systems in relation to the process used and the level of total nitrogen reduction.

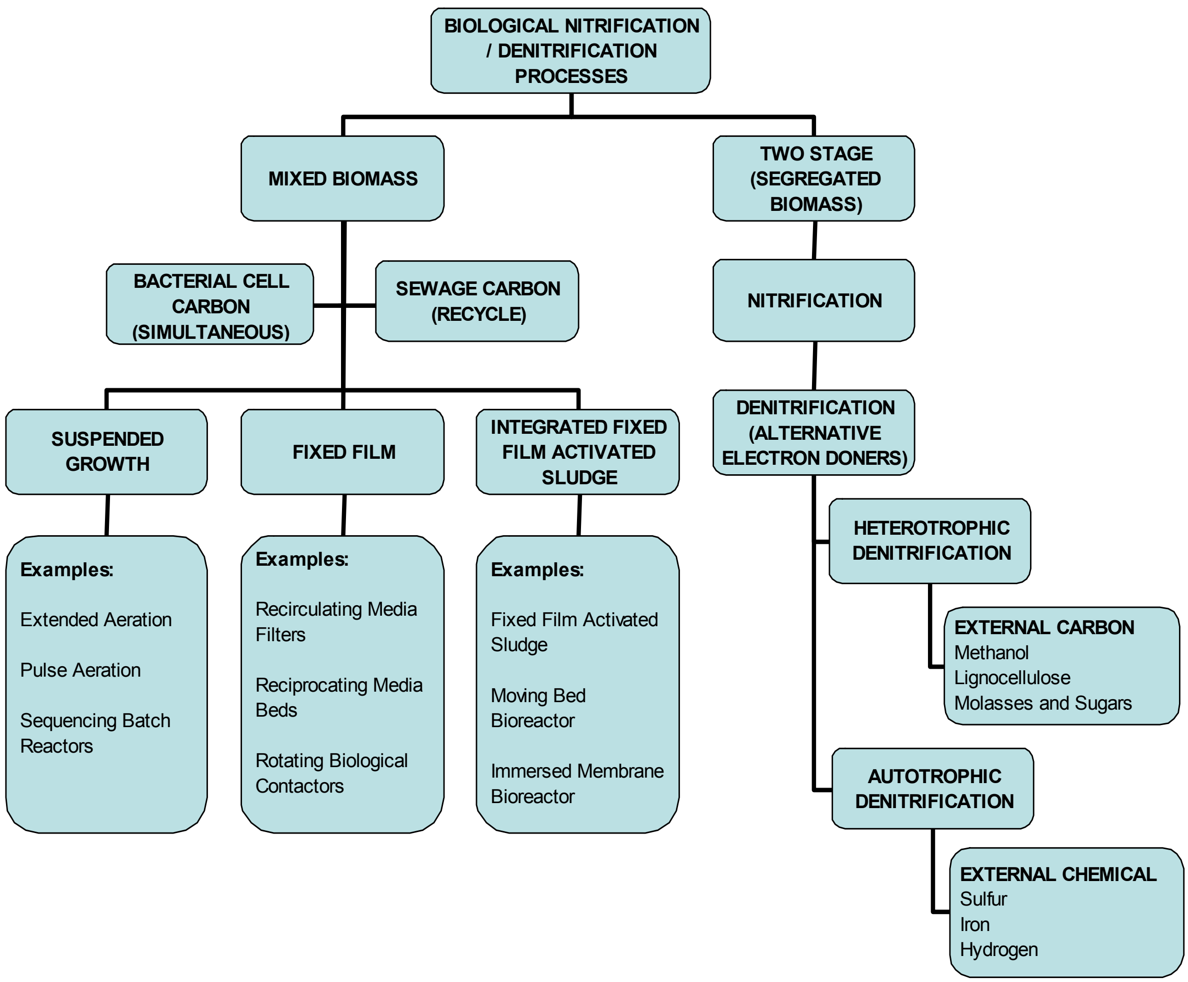

Figure 4. Biological Nitrification / Denitrification Technology Classifications

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Table 1:
Biological Denitrification Processes and Typical Treatment Limits

Process	Simultaneous (Mixed Biomass)	Recycle Mixed Biomass	External Donor Two Stage
Electron Donor	Organic carbon from bacterial cells	Organic carbon from influent wastewater	Cellulose, Sulfur, Iron, Other
Typical Removal	40 - 60%	60 - 80%	70 – 96%
Technologies	• Recirculating media filters w/o recycle[1] • Reciprocating media beds[2] • Extended aeration[3] • Pulse aeration[4] • Moving bed bioreactor[5] • Sequencing batch reactors[6] • Membrane bioreactor[7]	• Recirculating media filters with recycle[8] • Extended aeration with recycle[9] • Moving bed bioreactor[9]	• Heterotrophic suspended growth[10] • Heterotrophic packed bed reactive media[11] • Autotrophic packed bed reactive media[12]

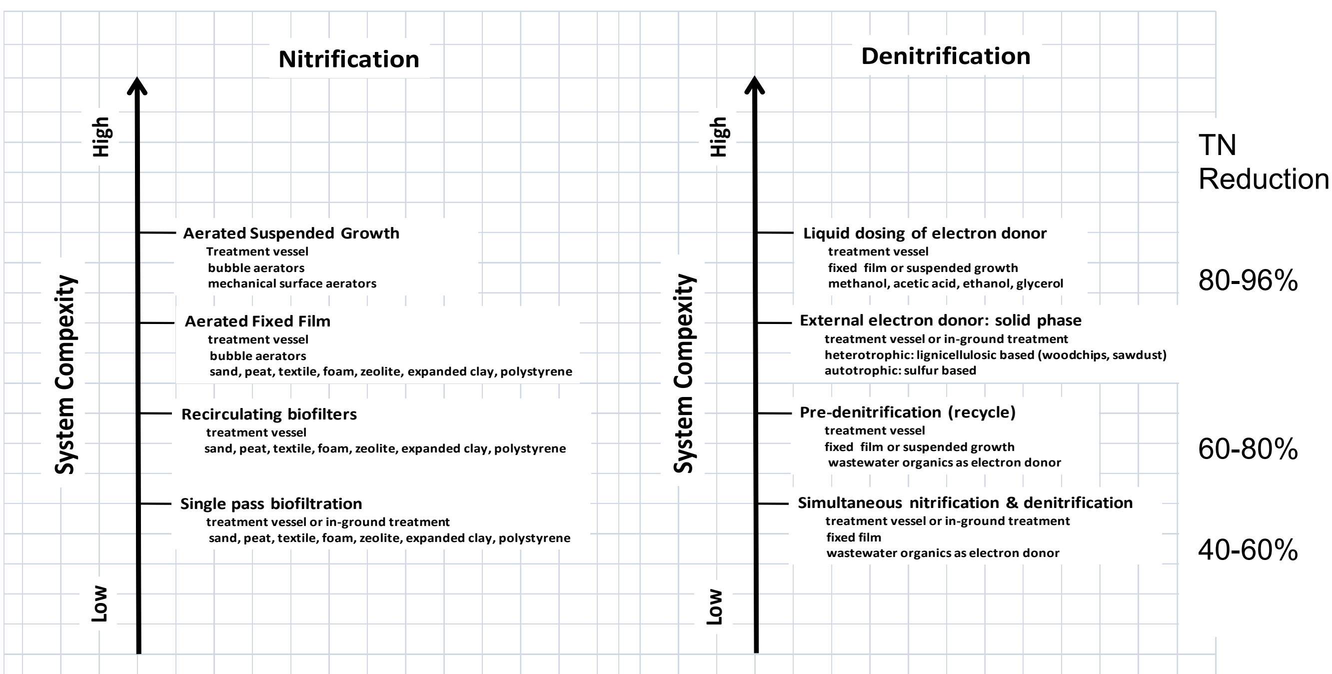

Figure 5. Generic System Complexity for Biological Nitrogen Reduction Systems

Natural Systems

Natural systems include soil infiltration, vegetative uptake and constructed wetlands as shown in Figure 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 processes within the receiving environment where process control is severely limited.

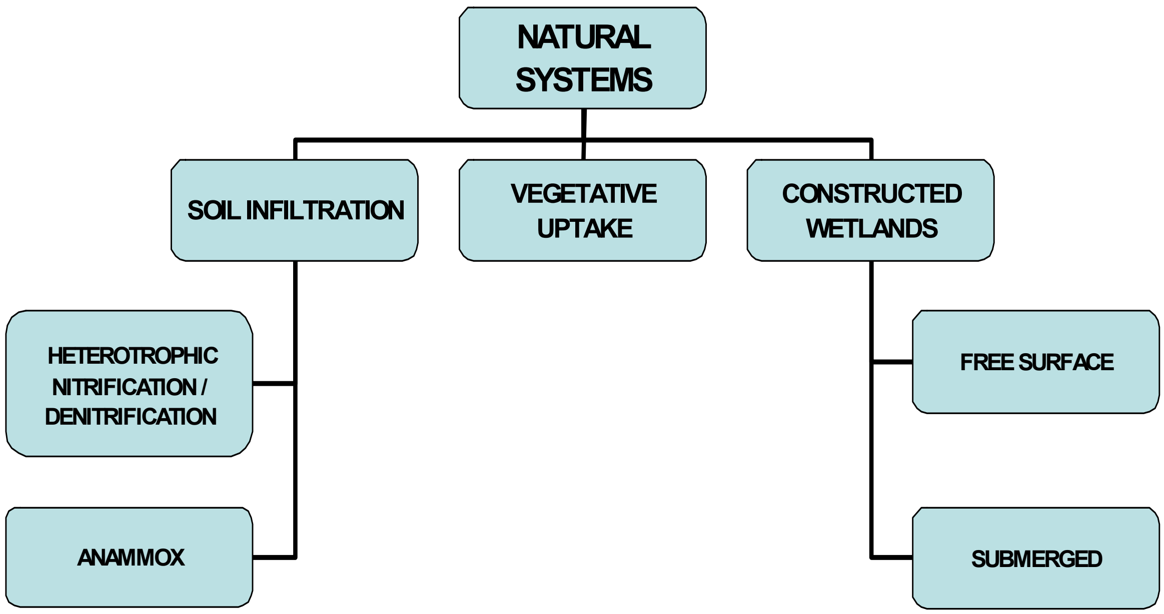

Figure 6. Natural Systems Categories

Wastestream Component and Treatment Technology Matrix

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

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

Separation of these wastestreams 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 wastestream could significantly reduce the nitrogen content of household wastewater. However, the separated wastestreams must still be treated and reused or disposed of. A matrix of wastestream components and potential treatment technologies is shown in Fig. 7. Three wastestream component groupings are illustrated based on applicable technology combinations for nitrogen removal. The entire domestic household wastestream (A+B+C+D) is grouped with three scenarios of source separation: greywater, urine or both. All four wastestreams contain substantial suspended solids and biochemical oxygen demand; primary treatment would be used as the first treatment step prior to nitrogen reduction technologies. Nitrogen reduction options for primary effluent (i.e. septic tank effluent) include mixed biomass nitrification/denitrification, mixed biomass nitrification/denitrification followed by a second stage denitrification filter for greater nitrogen reduction, two-stage nitrification/denitrification, and application to natural systems. Nitrogen reduction technology selection would be guided by the flow and constituent concentrations in the wastestream, 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. Aerobically 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 years 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 technique. 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.

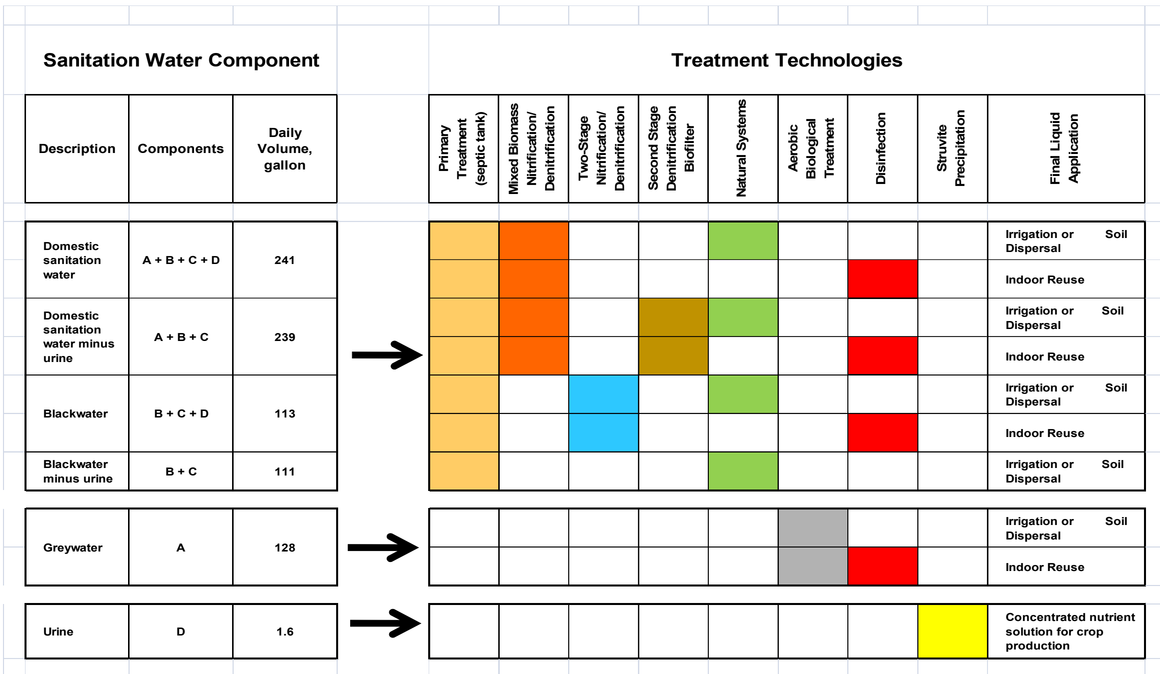

Figure 7. Matrix of wastestream components and nitrogen reduction technologies

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Section 3.0
Technology Ranking Criteria

Task A.4

General Description of the Ranking System

A simple numerical ranking system was developed to prioritize available nitrogen reduction systems based on eleven 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 ranging from 1 to 10. 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.

Criteria Selection and Relative Significance Comparison

Eleven 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 1, which also provides the significance ranking of each criterion and how the relative significance of each criterion was weighted.

Table 2:
Ranking Criteria, Level of Significance and Weighting Factors

Criterion Description	Maximum Score (S)	Level of Significance	Weighting Factor (W)	Total Possible Score (S x W)
Effluent total nitrogen concentration	5	Very High	10	50
Performance consistency	5	Very high	10	50
Performance reliability	5	Very high	10	50
Construction costs	5	High	7	35
Operation and maintenance cost	5	High	7	35
Land area requirements	5	High	7	35
Energy requirements	5	Medium	4	20
Homeowner acceptance	5	Medium	4	20
BOD/TSS effluent concentration	5	Low	2	10
Restoration of performance	5	Low	2	10
Stage of technology development	5	Low	2	10
				325

The relative weights of the criteria were determined by comparing each criterion against each of the other individual criteria (Table 2). 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. Table 2 lists the level of significance and weighting factor assigned to each criterion based on this process.

Table 3:
Selected Ranking Criteria and Relative Significance Determination

	Effluent Total Nitrogen Concentration	Performance Consistancy	Performance Reliability	Restoration of Performance	Construction Costs	Operation and Maintenance Costs	cBOD/TSS Effluent Concentrations	Homeowner Acceptance	Energy Requirements	Land Area Requirements	Stage of Technology Development	Relative Rank Score	Criterion Rank
Effluent Total Nitrogen Concentration		1	1	1	1	1	1	1	1	1	1	10	Very High
Performannce Consistancy	0		0	1	1	1	1	1	1	1	1	8	Very High
Performance Reliability	0	1		1	1	1	1	1	1	1	1	9	Very High
Restoration of Performance	0	0	0		0	0	0	0	0	0	1	1	Low
Construction Costs	0	0	0	1		1	1	1	1	0	1	6	High
Operation and Maintenance Costs	0	0	0	1	0		1	1	1	1	1	6	High
cBOD/TSS Effluent Concentrations	0	0	0	1	0	0		0	0	0	0	1	Low
Homeowner Acceptance	0	0	0	1	0	0	1		0	0	1	3	Med
Energy Requirements	0	0	0	1	0	0	1	1		0	1	4	Med
Land Area Requirements	0	0	0	1	1	0	1	1	1		1	6	High
Stage of Technology Development	0	0	0	0	0	0	1	0	0	0		1	Low
	0	2	1	9	4	4	9	7	6	4	9		

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.

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 very high level of significance with a weighing factor of 10. The criterion values for nitrogen effluent concentration are listed in Table 4.

Table 4:
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

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 very high level of significance and a weighing factor of 10. The categories for performance consistency are listed in Table 5.

Table 5:
Criterion Values for Performance Consistency

Variation in Onsite Nitrogen Removal Efficiency	Score
Physical/Chemical & Source Separation	5
MBR / IMB*	4
Fixed Film	3
IFAS**	2
Activated Sludge Nite/Denite	1

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

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

Performance Reliability: The attributes of the reliability criterion is expressed as the "mean time between service calls. The frequency of routine service and unscheduled call-outs provides a measure of the reliability of a technology. 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 very high level of significance and a weighting factor of 10. The categories for performance reliability are listed in Table 6.

Table 6:
Criterion Values for
Performance Reliability

Mean Time Between Service Calls	Score
annually	5
semi-annually	4
quarterly	3
monthly	1

Construction cost: The attribute of this criterion is the total capital cost of system installation. Construction cost is assigned a high level of significance and a weighing factor of 7. The categories for construction costs are listed in Table 7.

Table 7:
Criterion Values for
Construction Cost

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

Operation and Maintenance Costs: The attribute of this criterion is the cost of routine or recommended operation and maintenance, excluding power costs, that is needed to insure that the treatment system meets its performance objectives. Operation and maintenance cost is assigned a high level of significance and a weighing factor of 7. The categories for operation and maintenance are listed in Table 8. Operation and maintenance costs include the costs of equipment servicing and consumable materials (reactive filter media, chemicals, etc.). The operation and maintenance costs are calculated as the present value of these costs over the useful life of the system.

Table 8:
Criterion Values for Required Operation and Maintenance Costs

Operation and maintenance annual cost, $year	Score
100 - 200	5
200 - 300	4
300 - 400	3
400 - 500	2
> 500	1

Land Area Requirements: The attribute of this criterion is the plan area or the size of the footprint required for the treatment system. Land area required is assigned a high level of significance and a weighing factor of 7. Criterion values for land area required are the footprint area in square feet, and are listed in Table 9.

Table 9:
Criterion Values for Land Area Requirements

Land Area Required (ft^2)	Score
< 250	5
251-500	4
501-1000	3
1001-2000	2
> 2000	1

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 medium level of significance and a weighing factor of 4. Criterion values for energy requirements are listed in Table 10. 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 10:
Criterion Values for Energy Requirements**

kW-hour/year	Score
< 500	5
500 – 1,000	4
1,000 – 1,500	3
1,500 – 2,500	2
> 2,500	1

Homeowner Acceptance: The attribute of this criterion is acceptance of the system by the homeowner when the system is properly and adequately operated and maintained. Homeowner acceptance is assigned a medium level of significance and a weighing factor of 4. Categories for homeowner acceptance are listed in Table 11.

**Table 11:
Criterion Values for Homeowner Acceptance**

Homeowner Acceptance	Score
Acceptable	5
Perceived nuisance	3
Aesthetically displeasing	1

Effluent BOD/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 low level of significance and a weighing factor of 2. Categories for BOD and TSS effluent concentration are listed in Table 12.

Table 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

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. Performance restoration is assigned a low level of significance and a weighting factor of 2. The categories for performance restoration are listed in Table 13.

Table 13:
Criterion Values for Performance Restoration

90% Performance Restoration Time (days)	Score
< 1	5
1 - 3	4
3 – 7	3
7 – 14	2
> 14	1

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 low level of significance and a weighing factor of 2. Criterion values for stage of technology development are listed in Table 14.

**Table 14:
Criterion Values for Stage
of Technology Development**

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

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Section 4.0
Prioritization of Nitrogen Reduction Technologies

Task A.5

TO BE COMPLETED AFTER WORKSHOP INPUT

Prioritization of nitrogen reduction technologies will be based on systematic application of the ranking criteria to individual technologies identified in the literature review conducted in Task A.1. Technologies will be grouped according to the classification scheme developed in Task A.3. Each technology will receive individual scores for the separate evaluation criteria and the weighing criteria will be used to generate a total score. For each classification, the technologies will be ranked according to their total score.

List of Technologies

The compiled list of onsite nitrogen reduction technologies will be listed in Tables 15 through 18. Technologies will be grouped according to the classification scheme. The entries for each technology classification are listed in order of their overall ranking.

Table 15. Source Separation Technologies

Table 16. Physical / Chemical Treatment Technologies

Table 17. Biological Treatment Technologies

Table 18. Natural Systems Technologies

Table 15:
Source Separation Technology Summary *(Example)*

Urine Recovery			
Rank	Name	Vendor	Grade
1			
2			
3			
Greywater Separation			
Rank	Name	Vendor	Grade
1			
2			
3			
Toilet Waste Segregation			
Rank	Name	Vendor	Grade
1			
2			
3			
Kitchen Waste Segregation			
Rank	Name	Vendor	Grade
1			
2			
3			

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Table 16:
Example Summary Table for Biological Treatment Technologies

Technology	Criteria 1: Nitrogen effluent concentration	2: Performance consistency	3: Reliability	4: Construction costs	5: Operation and maintenance cost	6: BOD/TSS effluent concentration	7: Homeowner acceptance	8: Energy requirement	9: Land area required	10: Stage of technology development	Total Score (out of 330)
	mg/L, Table 2,3,4	Table 5	Table 6,7	$, Table 8	$/year, Table 9	mg/L, Table 10	Table 11	kw-hr/ year, Table 12	1000 ft^2, Table 13	Table 14	
Two stage biofiltration: expanded clay single pass/sulfur denitrification	<3	5	5	7,187	1	5	5	1,209	200	3	285
One stage biofiltration: expanded clay single pass unsaturated biofilter	<1	5	5	3,770	5	5	5	1,209	120	4	315
One stage biofiltration: elemental sulfur single pass saturated biofilter	<1	5	5	3,417	1	5	5	1,209	80	2	278
MicroFAST								3,273			
Waterloo Biofilter								886			
Amphidrome								823			
Geoflow								565			
Recirculating sand filters	20	5	5	2,800	5	5	5	909	120	5	

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