CAPE COD COMMISSION

Appendix 4A: Nutrient Mitigation Technologies and Policies

Table of Contents

Table of Figures and Tables

This appendix contains detailed summaries on nutrient management technologies and tools. Much of the content of the first draft of the chapter on nutrient mitigation technologies and policies (issued with the draft Section 208 Plan Update in August, 2014) is contained in this appendix, as well as additional information on traditional techniques for wastewater processing, treatment and disposal. The technology descriptions found in these pages are a supplement to the more comprehensive compilation of data presented in the Water Quality Technologies Matrix (Technologies Matrix) found in ***Appendix 4B***.

NITROGEN REDUCTION

Nitrogen is plentiful in the environment and extremely important to life. Humans, plants, and animals require nitrogen to survive and thrive. In its most plentiful form, nitrogen is a gas which makes up about 78%of our atmosphere. Nitrogen is also abundant in soils as organic material. Nitrogen cannot be absorbed directly by the plants and animals until it is converted into compounds they can use. This process is called the Nitrogen Cycle.

The nitrogen gas in our atmosphere is not generally a concern to either freshwater or salt water quality. The form in which nitrogen is most often a concern is when it is converted to nitrate (NO3). As nitrate, nitrogen is a food (energy) source for plants and animals. Nitrate is soluble and mobile in both groundwater and surface waters, and is therefore easily transported to streams, rivers, ponds and estuaries. If nitrate remains in balance, plants and animals can uptake it, store it, consume it and ultimately converted it back to nitrogen gas with little noticeable impact to the environment.

However, if there is an overabundance, the excess nitrate becomes available for plants and algae leading to eutrophication, a condition in which excessive plant and algal growth occurs and results in depletion of dissolved oxygen. In salt water estuaries, nitrate is the nutrient that results in an overabundance of algae; in fresh water bodies, phosphorus is the nutrient that results in an overabundance of algae. In freshwater streams, rivers, and ponds, nitrate is less of a concern than phosphorus. When there is a relatively small increase in the nitrate load in salt water bodies or in the phosphorus load in fresh water bodies, eutrophication can occur. This is the case with many ponds and coastal estuaries.

Water Quality Technologies Matrix

The Matrix was developed by the Cape Cod Commission, AECOM Technical Services, Inc., Scott Horsley, consultant to the Cape Cod Commission, and Offshoots, Inc., as well as through the contributions of many state, federal and private stakeholders and experts. The Technologies Matrix presents information on various technologies that are currently available, including collection, treatment, disposal and solids processing, and should be considered a flexible and dynamic source of information that is updated as additional information becomes available through both national and international research, as well as through direct application of these technologies in pilot projects on Cape Cod. The Technologies Matrix was developed as a series of Excel spreadsheets easily converted to a SQL database for ease in coordinating data with the Section 208 Plan Update.

The technologies and approaches included in the Technologies Matrix address nutrients by means of reduction, remediation, and restoration and are implementable in scales ranging from on-site, neighborhood, watershed, and Cape-wide.

The Technologies Matrix has been developed to bring together in one place a summary of information that can serve as a starting point to help Cape Cod communities evaluate various alternatives through adaptive management to address their water quality issues. The Technologies Matrix should be used as an educational tool to understand the benefits, design requirements, and regulatory considerations of the various technologies, along with their order of magnitude costs, which must be adjusted based on local/site specific conditions.

GUIDELINES FOR THE READER

It is anticipated that readers of Chapter 4 will also wish to reference the Technologies Matrix directly for more detailed information. The Technologies Matrix is provided in its entirety in ***Appendix 4B***. The user of the Technologies Matrix should be aware of the following assumptions made during the development of the Matrix:

- Watershed site specific conditions will define and/or limit technologies that may be evaluated for that watershed. As an example, the unit costs for decentralized options that involve on-site or local disposal must be combined with an estimate of the additional nitrogen removal required by in-watershed disposal. Similarly, disposal in non-nitrogen sensitive watersheds will generally reduce costs.
- Redundancy and reliability standards are typically incorporated into traditional technology reviews by regulators. Redundancy and reliability of non-traditional options will be based upon technology specific considerations and, therefore, must be reviewed with the regulatory agencies to fully understand the technology requirements and associated project and operation and maintenance (O&M) costs.
- Although cost and performance are important, the factors of "permit-ability" and "implement-ability" are important and are site specific.

Although the Technologies Matrix has a contingency incorporated into the project costs, the user should consider adjusting the contingency when developing options, incorporating site specific information, and identifying the risks for the options.

The Technologies Matrix presents information on specific technologies and approaches which may or may not be useable as a single solution and, therefore, may or may not be able to be compared directly to one another. For example, the user must assemble various cost elements (collection, treatment and disposal, for example) to be able to make a fair comparison between approaches that require collection and off-site disposal versus those that involve on-site treatment and disposal. The Technologies Matrix presents a summary of infrastructure to consider when designing and pricing various technologies and approaches.

GENERAL NOTES

The following notes summarize some of the information that is presented in the Technologies Matrix:

1. Various references, notes, and assumptions utilized in the development of the information presented for each technology.
2. The pollutant treated by the technology (nitrogen or phosphorus, etc.) or the reason to use the technology (avoiding discharging wastewater from wastewater treatment facilities (WWTF) effluent to groundwater).
3. The general requirements that need to be considered when siting the technology. The user must understand that the siting requirements will be site specific with additional engineering necessary to determine if a technology is applicable to a specific location.
4. The annual average household wastewater flow on the Cape of 160 gallons/household/day which is based on water use records.
5. Assumptions about various nitrogen input concentrations, based on influent source flow. The nitrogen input concentration will vary based on water collected at its source and wastewater effluent which has been released into the environment. The effluent nitrogen from the technology is dependent on the technology applied. The total nitrogen reduction for the technology is: specified input concentration minus the effluent nitrogen concentration.
6. Nutrient (nitrogen and phosphorous) percent removal is the estimated low to high range considering actual operating facilities/technologies, pilot testing performed on the technology and research performed on the technology. In general, the closer the range of percent removals equals a higher predictability of the technology to reduce nutrients.
7. The nitrogen reduction percent is used to estimate the cost per pound or kilogram of nitrogen reduction. In other words, the cost per pound or kilogram of nitrogen removed is: the influent load specified minus the effluent nitrogen load. The net reduction from a specific technology would be the specified influent nitrogen load minus the effluent nitrogen load resulting from installing and operating a selected technology. The Watershed Calculator has been designed for estimating the net nitrogen load reduction from the watershed.
8. The Watershed Calculator assumes a baseline input of 26.25 milligrams per liter (mg/L). The input is based on the Massachusetts Estuaries Project (MEP) assumption that existing nitrogen load from existing septic systems to the groundwater is 26.25 mg/L.

This 26.25 mg/L assumes nitrogen reduction from the existing septic systems, as well as treatment in the subsurface soils between the septic system discharge and the water table. In other words, the existing nitrogen load to the watershed is 26.25 mg/L from the existing septic systems. Information developed at the DEP Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems has shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa et al. 2001). The net reduction from a specific technology would be the decreased nitrogen load achieved by installing and operating the selected technology.

9. Quantities/unit costs have been based on the following: (a) Pricing as of March 2014 (no escalation was included); (b) Construction costs include contractor's overhead, profit, general condition costs, etc. (estimated at 20 percent); (c) Project cost equals the construction cost plus 40 percent for engineering (design and construction engineering), municipal administrative, legal costs and contingency; (d) Pricing does not include considerations for site specific conditions or items such as hazardous materials; (e) Accuracy is assumed to be plus or minus 15 percent; and (f) In providing these estimated costs, it is understood that the developers of the Technologies Matrix have no control over costs of labor, materials, equipment or services furnished by others or over market conditions or contractors' methods of determining prices, and that any evaluation of alternatives to be constructed or work to be performed is speculative. Accordingly, there is no guarantee that proposals, bids or actual costs will not vary from cost information provided herein.
10. Land cost is based on the Barnstable County Cost Report (BCCR) Update 2014 (***Appendix 4C***) estimate of $250,000 per acre.
11. The construction cost and O&M cost for Cluster Treatment System - Two-Stage, Advanced Treatment, and Satellite Treatment - Enhanced Facilities are based on the cost curve in the BCCR Update (2014)plus a 20 percent factor for the higher level of treatment. The construction cost and O&M cost for Cluster Treatment System - Single-Stage, Conventional Treatment, and Satellite Treatment Facilities are not based on the cost curve in the BCCR Update because the flows they treat – less than 10,000 gpd – fall outside the range of the cost curve.
12. The construction cost and O&M cost for Constructed Wetlands (Surface Flow and Horizontal Subsurface Flow) are based on the cost curve in Appendix E of the BCCR Update (2014).
13. The construction cost and O&M cost for permeable reactive barriers (PRBs) (both trench and injection well methods) are based on the cost curve in Appendix F of the BCCR Update (2014).

14. Adjustment factors are included for some technologies to anticipate pilot testing that can be used for refinement to performance and cost data presented. Each adjustment factor increases or decreases project and O&M costs by 10 percent in order to account for the relative complexity of the technology, local oversight, and regulatory compliance such as pilot testing, short and long term monitoring, etc.
15. There are many potential impacts of climate change. The primary impacts examined in this plan, characterized as "System Resilience," consist of the impact on the technology during sea level rise and flooding conditions (i.e. nitrogen release, pathogen release, timely ability to replace/begin operation). Other potential impacts considered include increased air and ocean temperatures, but these will have little effect on system resiliency of the technologies considered. It is possible that over time increased air and ocean temperatures will improve performance of biological communities through lengthened growing seasons.
16. Eco Services are considered ecological and social co-benefits of a technology. A cost offset of a benefit is not included in the technology cost analysis, but the environmental and social eco-services that a technology provides should be considered when selecting a technology. Elements of Eco Services include, but are not limited to, total nitrogen and phosphorus, carbon sequestration, sediment accretion, water filtration, bioturbation, bioremediation, and biodiversity.
17. Monitoring of a technology will generally occur over the life of the system. Monitoring of most of the traditional and non-traditional technologies will be required to confirm nitrogen removal capacities of each technology. The length of this monitoring period is estimated. Annual monitoring costs are included in the annual O&M cost estimates.
18. The O&M costs for non-traditional technologies include both pilot testing monitoring and compliance monitoring. Pilot test monitoring generally represents a period of two to three years of site specific monitoring. This may involve frequent monitoring and/or monitoring in multiple locations, depending on the technology. Pilot test monitoring is used to help establish nitrogen load reduction as well as the efficiency with which the non-traditional technology works. Compliance monitoring is generally used to establish progress in meeting water quality goals in the receiving water body. Compliance monitoring, with respect to specific technologies, is used to monitor the long-term effects of the technology. Based on the results of this compliance monitoring (if technology performance drops or increases over time), adjustments can be made to the technology or, reliance on a new technology can be established if necessary.

Technology Descriptions

The following section provides a brief description of each technology included in the matrix, based on the information available at the time of this Section 208 Plan Update submission. These descriptions are intended as a narrative overview for the reader of a few elemental characteristics of each technology. Each section discusses conceptually how the technology works; how the technology performs, expressed as a range of nitrogen removal percentages; potential performance challenges, which includes some discussion of siting constraints; examples of existing applications of the technology, including where they may have been implemented on Cape Cod; and a discussion of the costs of implementation, operations and maintenance. Where a technology provides some meaningful co-benefits, not otherwise quantified, the description discusses these briefly. Additional information, including more specific siting characteristics, regulatory considerations, and references, can be found in the Technologies Matrix. In time, the data in the Matrix will be migrated to a web-based user interface to allow easy access for anyone, at any time. Updates will be made to the database supporting the web-interface, making the Matrix the best source of current data, removal rates, and references. The technology descriptions that follow are a starting point for a community's consideration of nitrogen management strategies for a given watershed.

REDUCTION

The technologies presented in this section are those which reduce nitrogen concentrations in effluent before it enters the groundwater. These technologies are typically traditional, but also include several varieties of eco-toilets, hydroponic systems, fertilizer management, and various planning tools.

There are four categories or scales of traditional infrastructure wastewater systems. These include:

- Individual on-site Systems with and without nitrogen removal.
- Cluster Systems serving up to approximately 30 homes with aggregate wastewater flows less than 10,000 gallons per day (gpd).
- Satellite Systems serving from 30 to 1,000 homes (wastewater flows between 10,000 gpd and 300,000 gpd), intended to treat and dispose of wastewater from one area of a town or towns.
- Centralized Systems which can provide for most or all of a town's wastewater management needs, and that might be suitable for serving portions of neighboring towns.

INDIVIDUAL ON-SITE SYSTEMS

The most common traditional infrastructure on the Cape is individual on-site systems. These systems include cesspools, non-Title 5 compliant septic systems, Title 5 compliant septic systems, I/A septic systems, and enhanced I/A septic systems. All of these systems work similarly. Wastewater from households and businesses are collected and treated to varying degrees by microbes. Once treated, the liquid wastewater is then discharged leaving behind a small amount of solid waste. The degree to which these systems treat the wastewater varies.

Cesspools are usually a dug pit. The sidewalls are generally made up of cement blocks or a poured concrete cylinder with holes. This design provides the least nutrient treatment, especially if there is no septic tank before the cesspool or if the bottom of the cesspool extends into the water table. Cesspools, standard septic systems (Title 5 and non-compliant systems) are not designed to remove nutrients.

Grandfathered septic systems that do not comply with Title 5 have a tank (septic tank) that removes solids and provide a chamber for some microbial digestion to take place prior to discharge. As wastewater enters the septic tank, an equivalent amount of treated wastewater discharges to a soil absorption system (SAS), or the leaching component of the system. The treated wastewater flows through the SAS and discharges to the underlying soils to infiltrate into the groundwater.

A standard Title 5 septic system has the same general design as the non-Title 5 septic system, but the design meets MassDEP standards outlined in their Title 5 Regulations. The SAS from a standard Title 5 system is located a minimum of 4 feet above the high water table under the discharge. The separation between the SAS and the water table allows aerobic microbes to remove additional nitrogen. The amount of nitrogen reduction is somewhat dependent on the soil type and the distance between the discharge and groundwater. Very sandy soils with little organic material, soils common on the Cape, allow the discharge to drain to the water table with less treatment than other soil types.

Innovative/Alternative (I/A) systems are designed to remove more nitrogen than standard Title 5 septic systems. Enhanced I/A systems have provisions for chemical addition (pH adjustment and carbon source) increasing microbial denitrification in the unsaturated soils. I/A systems require a higher level of maintenance and are often more expensive to construct, operate and maintain than standard Title 5 septic systems. I/A systems commonly have pumps, aerators, fans and other parts which increase the installation and maintenance costs. The MassDEP standards for operation and maintenance of I/A systems can be found at: www.mass.gov/eea/agencies/massdep/water/wastewater/maintaining-and-repairing-innovative-alternative-system.html.

There are numerous I/A system designs. However, there are only a few approved by MassDEP for the removal of nitrogen. When considering I/A systems for installation, MassDEP approved systems should be used. If a town considers allowing the use of an I/A system not approved for nitrogen reduction, the system must go through an approval process. Details of the I/A approval process, I/A system designs, and approved I/A systems are provided at the following MassDEP website: http://www.mass.gov/eea/agencies/massdep/water/wastewater/septic-systems-title-5.html#1 . The link also provides updates on MassDEP approved systems.

When estimating nitrogen concentrations being discharged to groundwater, Title 5 systems are assumed to have a discharge concentration of 26.25 mg/L. This concentration includes all denitrification that occurs in the wastewater within the septic system. MassDEP approves I/A septic systems for 19 mg/L. This value is typically used when estimating nitrogen reduction for nutrient management plans. Higher removal rates that exceed the permitted levels may be achieved by some enhanced I/A systems (13 mg/L) and would also involve monitoring and compliance.

TREATMENT PROCESSES

Traditional wastewater management technologies typically consist of a collection system, a WWTF and an effluent discharge. Wastewater generated from homes and businesses is collected and conveyed to the WWTF through the collection system, such as gravity sewers, low pressure sewers, vacuum sewers and/or septic tank effluent pumping. From there, the wastewater is treated through a variety of treatment processes.

The removal of nutrients can be part of this process. The amount of nutrients removed is based on the type of design and operation of the WWTF. A WWTF designed to remove nitrates and/or phosphorus can reduce the concentrations significantly prior to discharge to the ground and/or a surface water body. The bulk of the treatment at WWTFs occurs from microbes breaking down organic compounds including nitrate. The microbes found in WWTFs are generally the same as those found in groundwater and surface waters.

The key reason that the microbes in a WWTF are more efficient at removing waste is that WWTFs can create more optimal environmental conditions than is often found in nature. This is primarily done through the addition of chemicals and necessary food sources. Providing the proper aeration, detention time, and chemical addition to wastewater throughout the treatment process allows microbes to efficiently break down these compounds. In short, WWTFs are designed to create a more optimal environmental condition for microbes to break down human waste.

CLUSTER, SATELLITE AND CENTRALIZED SYSTEMS

Cluster, satellite and centralized systems all have a system of pipes and sometimes pumps that collect wastewater from multiple households conveying it to a centralized facility for the treatment and disposal of treated wastewater (effluent) and solids. The primary difference in the facilities is the amount of wastewater each treats. In general, cluster systems treat less than 10,000 gpd, satellite systems may treat up to 300,000 gpd, while centralized systems are used to treat flows greater than 100,000 gpd.

Each of these systems collects the wastewater, removes the solids, and through a series of treatment technologies treats the wastewater by partially removing the undesirable constituents in the wastewater, including nitrogen and phosphorus, prior to discharge to the groundwater, surface water, or an ocean outfall. The degree of removal is dependent on the treatment type and degree of treatment designed into the facility. In general, the greater the treatment, the greater the costs to design and build the facility and collection system, operate and maintain the facility, and treat and discharge the wastewater.

The denitrification that takes place in the traditional methods and non-traditional methods discussed above are very similar. Most traditional and non-traditional technologies provide a food source that allows microbes to remove nutrients.

Performance

The effectiveness of the traditional infrastructure can vary and is site-specific. Many of the wastewater pollutants can be managed with traditional systems, including nitrogen, phosphorus, total suspended solids, bio-chemical oxygen demand, pH, suspended metals, total petroleum hydrocarbon, and pathogens.

The following table (Table 4A-1) summarizes the percentage of nutrients that can be removed from wastewater using traditional infrastructures. Additional detail on each system's performance can be found at the following link: http://www.mass.gov/eea/agencies/massdep/water/wastewater/septic-systems-title-5.html#1.

TRADITIONAL INFRASTRUCTURE - NUTRIENT REDUCTION		
	Percent Nitrogen Removal (Low to High)	**Percent Phosphorus Removal (Low to High)**
Cesspool	No Data	No Data
Non-Title 5 Septic System	34 or less	20 or less
Title 5 Septic System	34	10 – 20
I/A Septic System	45 – 60	10 – 20
Enhanced I/A Septic System	60 – 75	26 – 40
Cluster System (range for single stage and 2-stage systems)	55 – 90	26 – 60
Satellite System	72 – 78	60 - 72
Centralized WWTF	80 – 90	60 – 72

TABLE 4A-1 TRADITIONAL INFRASTRUCTURE NITROGEN REDUCTION (SOURCE: TECHNOLOGIES MATRIX)

Traditional infrastructure requires proper siting, installation, operation and maintenance for proper performance. All individual on-lot systems require periodic pumping of the septic tank for solids. I/A systems require periodic inspection and removal of solids. When considering traditional infrastructure for nutrient management planning or when selecting locations for installation, an engineering firm with traditional infrastructure experience should be consulted.

Potential Performance Challenges

Traditional infrastructure generally performs well when operated properly. However, there is the potential for these systems to operate below their nutrient reduction potential if not operated properly. Decreases in performance can occur if the design flow is exceeded, the influent contains too much fats, oils or grease, or if the influent contains a compound that compromises the health of the microbes in the septic tank or soil absorption system.

Existing Applications

It is likely that all traditional infrastructure methods are in use on the Cape. Existing MassDEP regulations do not require the replacement of cesspools and non-Title 5 compliant septic systems with Title 5 compliant systems unless there is a system failure. Due to the poor treatment capabilities of cesspools, these systems should be replaced with Title 5 compliant systems to remove pathogens and viruses at the very least; replacement with other technologies may be required if nutrient reduction is required.

Most I/A and enhanced I/A septic systems operating on the Cape are tracked by the Barnstable County Health and Environment Department. Information on the I/A systems including location is available at the following link: https://septic.barnstablecountyhealth.org/posts/data-and-statistics .

Costs

The Barnstable County Wastewater Cost Task Force was established to compile and analyze current local information on the costs to build and operate traditional wastewater systems on Cape Cod. The BCCR was prepared in 2010, and based on the information collected, the Task Force developed cost estimates for a wide range of wastewater system sizes and types to help Cape Cod towns compare available options. These costs were updated by AECOM Technologies Services, Inc. in 2014. The application of the results allow communities to identify which options are best for their circumstances and thus streamline their watershed and wastewater planning.

Data were compiled and cost estimates prepared for four types of wastewater systems:

- Individual on-site Systems with and without nitrogen removal.
- Cluster Systems serving up to approximately 30 homes with aggregate wastewater flows less than 10,000 gallons per day (gpd).
- Satellite Systems serving from 30 to 1,000 homes (wastewater flows between 10,000 gpd and 300,000 gpd), intended to treat and dispose of wastewater from one area of a town.
- Centralized Systems which can provide for most or all of a town's wastewater management needs, and that might be suitable for serving portions of neighboring towns.

Cost estimates were prepared to be inclusive of all aspects of wastewater management: collection, treatment, and disposal. Costs were also included for conveyance between the collection system and the treatment site, and between the treatment and disposal sites if they cannot be co-located. Four measures of cost were considered:

- Capital Cost - The cost to design, permit and build the facilities, including land costs.

- Operation and Maintenance (O&M) Costs - The ongoing expenses for labor, power, chemicals, monitoring, sludge disposal, etc.
- Equivalent Annual Costs (EAC) - A mathematical combination of O&M expenses and amortized capital costs.
- Costs per Pound of Nitrogen Removed - The equivalent annual cost divided by the annual nitrogen load removed from the watershed of a nitrogen-sensitive embayment.

Actual cost information was obtained from over 30 existing wastewater treatment facilities, located largely in southeastern Massachusetts. The data were carefully reviewed to be sure they included all pertinent cost items. "Unit costs" were computed by dividing construction costs and O&M costs by the associated wastewater flows. Graphs of these unit costs show clear trends and demonstrate significant economies of scale, which are summarized below in Table 4A-2.

UNIT CONSTRUCTION AND O&M COSTS BY CAPACITY FOR WASTEWATER TREATMENT FACILITIES		
Capacity	**Unit Construction Cost**	**Unit O&M Cost**
10,000 gpd	$108 per gpd of design flow	$13 per gpd of average flow
100,000 gpd	$46 per gpd of design flow	$5 per gpd of average flow
1,000,000 gpd	$19 per gpd of design flow	$2 per gpd of average flow

TABLE 4A-2 UNIT CONSTRUCTION AND O&M COSTS BY CAPACITY FOR WASTEWATER TREATMENT FACILITIES (SOURCE: COMPARISON OF COSTS FOR WASTEWATER MANAGEMENT SYSTEMS APPLICABLE TO CAPE COD, 2014)

Compared to a satellite facility of 100,000-gpd capacity, a central facility of 1.0-mgd (million gallons per day) capacity costs about 40% less to build and 40% less to operate on a per-gallon basis.

Twelve scenarios were developed to combine capital and O&M costs for wastewater collection, transport, treatment and disposal and to compare those costs with the nitrogen removal that can be expected. Costs and performance were estimated both for Base Cases (with a uniform set of assumptions for all scenarios) and as part of a sensitivity analysis to determine how costs might change with assumptions that are either more or less favorable for each system size. Samples of the results are as follows (Table 4A-3), expressed as equivalent annual cost per pound of nitrogen removed.

RANGE OF COSTS FOR NITROGEN REMOVAL TECHNOLOGIES (BC COST REPORT)			
Description	**Low**	**Base Case**	**High**
Individual N-removing systems	$540	$860	$920
Cluster systems, 8,800 gpd	$710	$1,020	$1,080
Satellite systems, 50,000 gpd	$410	$580	$590
Satellite systems, 200,000 gpd	$270	$390	$390
Centralized systems, 1.5 mgd	$210	$260	$280
Centralized systems, 3.0 mgd	$200	$250	$260

TABLE 4A-3 RANGE OF COSTS FOR NITROGEN REMOVAL TECHNOLOGIES (SOURCE: COMPARISON OF COSTS FOR WASTEWATER MANAGEMENT SYSTEMS APPLICABLE TO CAPE COD, 2014)

The sensitivity analysis allows the identification of the most important cost factors, which are:

- Economies of Scale. Large systems may be significantly less expensive per gallon treated because many of the cost components do not increase directly with the flow.
- Density of Development. Wastewater collection costs are the largest component of a complete system and they increase in direct proportion to the lot size served.
- Location of Disposal Facilities. An effluent disposal site within a nitrogen-sensitive watershed returns some of the collected nitrogen to the watershed because there is residual nitrogen in the effluent. Compared to a disposal site that is outside of a sensitive watershed, the in-watershed disposal option must have a collection and treatment system which is more widespread to eliminate more septic systems and to remove enough additional nitrogen to offset that returned in the effluent.
- Land Costs. Land suitable for wastewater management functions is scarce and expensive on Cape Cod. Using town-owned parcels is cost-advantageous for any scenario, but particularly if multiple small systems are to be built, each with its own need for set-backs and buffer zones. Land has been estimated at $250,000 per acre.

From this sensitivity analysis, conclusions can be drawn about the circumstances that favor one size of system over another.

- Individual Nitrogen Removing Systems. These systems are also referred to as "Innovative/Alternative" or "I/A" systems. Their most efficient applicability is within areas of low density and in watersheds that require less than 50% wastewater nitrogen reduction. Their location on the parcel where the wastewater is generated eliminates collection costs.
- Cluster Systems. These systems should be considered for existing neighborhoods with small lots that are remote from sewered areas and have publically-owned land nearby. They also are good options for new cluster developments where infrastructure can be installed by the developer and later turned over to the town, or for shore-front areas that may not be connected to larger-scale systems until later phases of a project.
- Satellite Systems. Satellite facilities make the most economic sense in remote watersheds (more than 5 miles from existing sewer systems or other areas of need), with vacant publically-owned land nearby. These systems are also applicable when existing or proposed private facilities can be converted to public operations and expanded to provide wastewater services to existing nearby properties on septic systems. This is particularly appropriate if a town-wide system may be not be available for many years and a developer is prepared to proceed in the near future.
- Centralized Systems. This option is likely to be the most viable when:

    - Dense development exists in nitrogen-sensitive watersheds;
    - Suitable treatment and disposal sites (outside sensitive watersheds and Zone IIs) are available at no or low cost;
    - A high degree of nitrogen control is required;
    - Areas of dense development in sensitive watersheds are within 3 miles of desirable effluent treatment and disposal sites; and
    - Opportunities are available for cost reductions through regionalization.

While cost estimates presented in this report are conceptual and based on a uniform set of assumptions, they are supported by a review of actual data for nine example projects. Those examples indicate costs ranging from about $300 per pound of nitrogen removed for centralized systems up to $700 or more for smaller systems.

Estimated costs are based on a common set of assumptions about the density of development served by the various systems. Communities with less dense development face higher collection costs than shown here. Collection systems can be very expensive and towns should investigate alternatives to traditional gravity systems. Cost savings associated with the use of those alternative collection systems may apply to any of the scenarios reviewed in this study and should not be attributed to one option over another.

For more information please see the Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod (the BCCR, updated in 2014) in ***Appendix 4C***.

WASTE REDUCTION TOILETS

How It Works

Approximately 80% of the controllable nitrogen sources on Cape Cod are attributed to wastewater, most of which is discharged to groundwater via septic systems. The majority of the nitrogen in wastewater is derived from human excreta (urine and feces) via toilets. Urine contains approximately 90% of the nitrogen found in excreta. This section summarizes various technologies that reduce the nitrogen at the source by reducing or eliminating the amount of nitrogen discharged to septic systems. They also provide a potentially valuable by-product – fertilizer.

A variety of source reduction toilets (sometimes referred to as ecotoilets) accomplish this goal, using different methods. Urine diversion (UD) toilets separate urine and capture it in a dedicated tank for later removal and processing. Composting toilets capture all waste in an enclosed chamber beneath the fixture, where biological processes convert waste to compost. No water is used, and no human excreta enters the wastewater leaving the building, although a septic system still may be utilized to handle graywater from other household sources (such as showers, sinks and laundries). Urine diversion may also be used in conjunction with composting toilets. Packaging toilets utilize a biodegradable plastic bag to contain human waste that are then collected and processed at a central facility. Finally incinerating toilets use an internal heater to reduce human waste to an ash.

All waste reduction toilets require some form of residuals management. Urine diversion toilets require the removal of urine from a holding tank for processing. This is generally performed by a contractor and is similar to having a septic tank pumped. The compost from composting toilets will also require periodic removal. Incinerating toilets have an ash residual requiring removal. The human waste from packaging toilets will also require frequent removal, often performed by a contractor.

Performance

Properly designed and used, source reduction toilets can remove 70-80% of the nitrogen and phosphorus from the domestic wastewater stream at relatively low costs. Optimal performance is dependent on design and operation. This will require education for residential architects, engineering design professionals, and homeowners and operators.

The Town of Falmouth is conducting a study of both UD and composting toilets where they are measuring the residual nitrogen content in the remaining graywater. This will provide more detailed guidance on actual performance.

Potential Performance Challenges

Homeowners may feel some reluctance about adopting an alternative source reduction toilet in their homes. Studies were conducted in Switzerland and Australia to assess public perceptions of urine diversion toilets. Overall, users have been receptive to the idea of these toilets, with acceptance levels higher among those who had more information about proper use and benefits. For example, of 480 respondents to a survey at the Swiss Federal Institute of Aquatic Science and Technology and at a vocational school where the same technology had been implemented, 87% of those who had read the informational material responded that they would be willing to move into an apartment with urine diversion toilets, whereas only 67% of those who had not read the informational material said that they would (Berndtsson, 2007).

Source reduction toilets require fundamentally different maintenance considerations than conventional flush toilets. The following are key considerations:

- It is important to keep the urine-collecting basin clear of solids, including paper, which can cause pipe blockages.
- As with conventional septic tanks, urine-holding tanks must be emptied periodically by a licensed hauler, unless an on-site nutrient recycling system or other approved system for neutralizing the urine is installed.
- Composting toilets require annual removal of compost that can be utilized on-site as a soil conditioner.
- Packaging toilets require daily collection and storage (for disposal) for packaged waste.
- Incinerating toilets require periodic collection and disposal of ash.
- Requires a significant number of citizens to participate for waste reduction toilets to become an effective strategy.

The Town of Falmouth implemented an eco-toilet program in 2014 to encourage private use of eco-toilets within homes, with little success. The cost to retrofit homes was one of the significant barriers to wider interest in, and installation of these toilets.

Existing Applications

Composting toilets have been utilized for over 30 years with diverse applications including lake shorefront homes (to reduce phosphorus loading) and visitor centers and parks (in close proximity to pristine environmental resources). Urine-diversion toilet technology is more recent and has been formally studied in several pilot projects since the 1990s. UD toilets have been installed in urban and rural settings, in private homes and public facilities, and in areas with or without existing sanitation infrastructure.

Applications in Switzerland and Australia have assessed the feasibility and public perceptions of UD toilets in developed nations with existing sanitation infrastructure. These are most similar to applications on Cape Cod, where residents are accustomed to conventional flush toilets.

Eawag, the Swiss Federal Institute of Aquatic Science and Technology, is headquartered in a building that uses a variety of water-saving technologies, including urine diversion toilets. Users include both employees and visitors to the site, as the building itself is used as a public showcase for these technologies. A survey of users in 2011 reported that more than 70% of those who responded to the surveys considered the urine diversion toilets either better or the same as conventional toilets with regard to design, hygiene and odor (Muench and Winker, 2011). Significant water savings were realized and the nitrogen captured by the urine diversion system was converted to agricultural fertilizer (Leinert & Larson 2007).

Kinglake West is located on the outskirts of Melbourne, Australia. Like Cape Cod, it is an environmentally sensitive region where wastewater was primarily treated using septic systems. Yarra Valley Water, the regional entity responsible for handling wastewater, implemented the Kinglake West Sewerage Project to improve environmental outcomes. As part of the project, 30 urine diverting toilets were installed in private homes. Reports in 2013 show that the project achieved a 56% reduction in nitrogen load, with user acceptance generally high (Paminger, et al., 2013). Unfortunately, manufacturing and installation problems resulted in some odors and blockages. Several design modifications were recommended to avoid these problems in future applications.

US EPA Region 1 recommends piloting waste reduction toilets to determine their social acceptability on Cape Cod.

Cost

Cost estimates vary based on site specifications, types of fixtures, and types of treatment. They also vary for retrofits of existing buildings versus new construction (new construction being significantly less). Cost estimates for the four technologies are as follows in Table 4A-4:

COST ESTIMATES FOR WASTE REDUCTION TOILETS		
Project Type	**Project Cost**	**Annual O&M Costs**
Composting	$14,000	$413
Urine Diversion	$11,200	$396
Packaging	$6,720	$825
Incinerating	$12,900	$963

TABLE 4A-4 COST ESTIMATES FOR WASTE REDUCTION TOILETS (SOURCE: TECHNOLOGIES MATRIX)

Co-benefits

Urine collected from UD toilets can be converted to safe, effective fertilizers, turning a waste product into a valuable resource for landscapers, golf courses and farmers in many cases replacing the need and cost associated with commercial fertilizers. Similarly, compost can be used locally as a fertilizer. In Vermont, the Rich Earth Institute is currently conducting research and pilot programs applying collected urine as a fertilizer to hayfields. Additionally, the use of eco-toilets can result in substantial water savings.

HYDROPONIC TREATMENT

- Achieves 58-98% nitrogen removal rate
- Doesn’t typically require chemicals that are harmful to the environment
- Can provide an aesthetically pleasing form of treatment for community settings

How It Works

Hydroponic treatment (commercially known as Living- or Eco-Machines) is a plant-based system that treats septic tank effluent or primary-treated wastewater. With hydroponic treatment, aeration and clarification chambers are combined with constructed wetlands to treat the influent. The wetlands are a series of chambers allowing for microbial communities to engage with and treat the wastewater. Plants are often suspended on racks with their root systems doing the work. Solids removal is generally onsite, after which water is pumped through the gravel filled cells (similar to subsurface wetlands). This process transfers more oxygen to the wastewater increasing the treatment capabilities of the system. For greater denitrification a sand or gravel filter with carbon source in addition is added prior to discharge. The wetland effluent can be discharged into a water body or used for open space irrigation after treatment. The wetland effluent can also be discharged into a leach field or similar system for discharge to the groundwater.

This technology can be used for wastewater treatment with primary, secondary, or advanced effluent generally for flows less than 500,000 gallons per day (gpd).

Performance

Several federally-funded Eco Machine demonstration systems have been constructed, the largest of which handled design flows of up to 80,000 gpd. As configured for these demonstrations, these systems treated municipal wastewater at various strengths, and reliably produced effluents with five-day biochemical oxygen demand (BOD5), total suspended solids (TSS), and total nitrogen ≤ 10 milligrams per liter (mg/L), nitrate ≤ 5 mg/L, and ammonia ≤1 mg/L (US EPA 2002). These systems can have higher treatment efficiencies than individual on-site systems, ranging from 58 – 95% nitrogen removal rates. These systems are capable of tertiary treatment (here defined as effluents with <10mg/L nitrogen).

Vegetated treatment systems hold promise for removal of some contaminants of emerging concern (CECs). Plant uptake, microbial action, nitrification and denitrification have been cited as effective biochemical mechanisms for the breakdown of a wide range of CECs within constructed wetland systems and to the extent that these mechanisms and pathways are present in a vegetated system similar results can be expected.

Potential Performance Challenges

Hydroponic systems are typically designed for institutional, neighborhood-scale or community applications, and require collection systems. Preliminary and/or polishing treatment units in addition to the plants may be necessary to meet permit standards. In addition, the biomass resulting from the system must be managed, like any crop, and those hydroponic systems providing primary treatment of wastewater will also require solids management. The potential nutrient management rates cited are based on projects and studies outside of the Cape Cod region; local pilot projects are needed to confirm nitrogen removal rates for Cape Cod. A greenhouse is likely needed to ensure year-round performance on the Cape, adding to project costs.

Existing Applications

The City of South Burlington, VT has had a system in place since 1995, funded by US EPA as one of several pilot projects of this technology.

Living Machine® has a portfolio of projects at schools and universities, military installations, private developments and resorts, as well as municipal sites. More information can be found at http://www.livingmachines.com/Portfolio.aspx.

John Todd Ecological Design has a client & case study list including businesses, cities, resorts, and schools. More information can be found at http://www.toddecological.com/clients/list.php.

US EPA Region 1 recommends piloting Hydroponic systems to determine their potential effectiveness for removing nitrogen loadings on Cape Cod.

Costs

The costs for these machines will vary widely depending on size and many other factors. The South Burlington Living Machine®, which processes 80,000 gpd, had a capital cost of $1.7 million, with O&M costs of $70,625 annually to run the 0.14 acre site. Other facilities may have higher annual O&M costs.

FERTILIZER MANAGEMENT

Fertilizer leaching contributes up to 26% of controllable nitrogen in Cape Cod estuaries
Best Management Practices (BMPs) can significantly reduce fertilizer leaching
Low cost of implementation

In this context, fertilizer management refers to a variety of practices aimed at reducing the amount of nitrogen leaching into groundwater from fertilizer application. Massachusetts

Estuaries Project (MEP) Technical Reports estimate fertilizer nitrogen contributions ranging from 1% to 26% of controllable nitrogen for estuaries on Cape Cod. Managing fertilizer use, through education, BMPs, and enforceable regulations, will achieve cost-effective and efficient nitrogen reduction.

How It Works

Effective fertilizer management, through education, BMPs, and enforceable regulations, reduces the amount of nitrogen leaching into groundwater from fertilizer application.

Education and Best Management Practices (BMPs)

Education and BMPs are aimed at ensuring proper timing, location, and manner of application of fertilizers. Properly applied fertilizers will maximize nutrient absorption by plants and soils and minimize leaching into the groundwater. Below are some of the key BMPs that are detailed in the Best Management Practices for Lawn and Landscape Turf prepared by the UMass Extension Center for Agriculture (UMass 2013)

Timing: application period corresponding with active turfgrass growth, avoiding dormant months and before or during heavy rain events
Location: avoid application in environmentally sensitive areas and on non-pervious surfaces; and/or establish no fertilizer zones; and
Manner: application rate and frequency should be determined based on soil conditions and turf type; use of slow-release fertilizer and water-insoluble fertilizer is preferable in most situations

Enforceable Regulations

Local regulations can be an important tool in ensuring responsible fertilizer application practices and avoiding application practices that result in high leaching rates, such as over-application and application in environmentally sensitive area. Where regulations establish a process to certify fertilizer applicators, these certified applicators should be required to adhere to UMass Extension BMPs. Regulations establishing a process for others applying fertilizer (ie. most homeowners) must be simple to follow and generally more restrictive than UMass Extension BMPs. The Towns of Falmouth and Orleans have already adopted local codes that manage fertilizers, and several additional towns are considering the adoption of town codes (see below).

Performance

A recent report prepared for the Cape Cod Commission, entitled "Cape Cod Pesticide and Fertilizer-Use Inventory" (Appendix 7C) found that the total amount of fertilizer use on Cape Cod is nearly 5.2 million pounds per year, with the greatest amount coming from residential fertilizer use (Horsley Witten Group Inc. 2013). Effectiveness of fertilizer management practices hinges on the ability to reduce the nitrogen in fertilizer from leaching into the groundwater. It should be noted that the majority of fertilizers applied by most users is absorbed by plants and soils, such that only a portion of the applied fertilizers leaches into the groundwater. The MEP model assumes approximately 20% leaching of fertilizers applied to turf. A review of existing scientific literature and available data conducted on behalf of the Massachusetts Department of Environmental Protection concluded that 20% leaching was a reasonable rate for Cape Cod soil conditions (Horsley Witten Group Inc. 2009). According to studies conducted by the golf course industry, leaching rates can be reduced to 10% or less using well-planned fertilization programs. This could result in a reduction of fertilizer-based nitrogen loading of 25-75%.

Nitrogen reduction expected from fertilizer management varies based on the extent to which fertilizer management practices are effectively implemented. The greatest gains would be from avoiding unnecessary fertilizer application practices. For example, a very high percentage of nitrogen from fertilizers applied when grass is dormant, on impervious surfaces (such as inadvertent application on driveways), before heavy rain events, and when the quantity of fertilizer applied exceeds the nutrient needs of the turf, leaches into the groundwater. Where these practices are eliminated virtually all nitrogen leaching into the groundwater from fertilizer application could be eliminated.

Other fertilizer management practices, and more broadly vegetation management practices, would further reduce fertilizer-related nitrogen contributions to estuaries. For example, a transition from fast-release to slow-release fertilizers would also reduce the overall nitrogen leaching into the groundwater. Other vegetation management practices such as appropriate watering and aerating can increase the health of turf and reduce the need for fertilizer application.

The overall extent to which fertilizer management practices will reduce the amount of nitrogen entering into groundwater is dependent on the extent to which fertilizer management practices are effectively implemented.

Potential Performance Challenges

While education and outreach are important tools for informing professional applicators and homeowners, there remains a reliance on the individual to make responsible decisions when it comes to fertilizer application. Regulations that require these responsible behaviors can be effective, but can be difficult to enforce.

Existing Applications

Fertilizer management efforts have been successfully implemented in a variety of ways on Cape Cod.

In 2013, the Cape Cod Commission created a cape-wide Fertilizer Management District of Critical Planning Concern (DCPC) that allows towns to adopt fertilizer management regulations at the local level provided that they are consistent with the DCPC guidelines for implementing regulations. These guidelines include consistency with the DCPC model regulation and the UMass Extension nutrient management BMPs. At present, Orleans and Falmouth have fertilizer control bylaws grandfathered from Mass. Department of Agricultural Resources' exclusive jurisdiction by way of a legislated exception. Several Cape Cod communities have adopted fertilizer bylaws, including Barnstable, Brewster, Chatham, Eastham, Mashpee, and Provincetown. All but Mashpee regulate both nitrogen and phosphorus application, with some agricultural exemptions and time of year restrictions. Barnstable and Chatham require certification for applicators. Orleans recently adopted phosphorus regulations in addition to its previously adopted nitrogen bylaw.

Outside of residential turf, existing fertilizer management efforts have been successfully implemented in agricultural, golf course, and municipal applications. An example of successful fertilizer management implementation is at Captain's Golf Course where a total reduction of 2,050 lbs of nitrogen a year was seen. This equates to eliminating the nitrogen contribution of 315 household septic systems (Horsley Witten Inc. 2013).

Costs

The costs for fertilizer management are related to education, outreach, and enforcement of any regulations that are adopted. To varying degrees, local officials and boards, Barnstable County Cooperative Extension, and local and regional advocacy groups are currently involved in education and outreach. To the extent that these existing efforts need to be expanded the associated costs would be relatively small. Where new programs need to be established or where regulations need to be established and enforced, the costs would be higher. Such actions will likely require additional staff time or additional staff positions at the local or regional level for proper implementation.

In terms of implementing the fertilizer management BMPs, most have little or no associated costs. An exception is the selection of fertilizers containing primarily slow-release over those containing primarily fast-release nitrogen which tend to be less expensive, but generally need to be applied more frequently.

NUTRIENT REDUCING DEVELOPMENT

How It Works

The concept is that as property is developed, or redeveloped, and property owners are required to address wastewater treatment, that they will consider not only their needs but the needs of surrounding development. Ultimately, this would lead to a solution that removes both the new nitrogen generated by the new development and the existing nitrogen generated by existing proximate development. Thus, a net nitrogen reduction would be realized in the area. This could also be done between existing developments, where one existing development has excess capacity and allows another existing development to connect to their underutilized wastewater treatment infrastructure.

Performance and Potential Performance Challenges

The performance and potential challenges of this approach will depend on the technology employed by the development; it is generally assumed that it will be traditional infrastructure options that will have excess capacity to cover other new or existing development, but could potentially apply to non-traditional technologies and approaches moving forward. Agreements between the parties served should assist with maintenance and monitoring issues.

The greatest challenge is that this approach would, under current regulations, be entirely voluntary and would be more complicated than simply addressing the on-site nitrogen generated by the new development.

In order for this approach to be widely used, incentives within the regulations would need to be developed. These could include density bonuses or reductions in other mitigation costs for non-nitrogen impacts. Current potential permitting agencies include: MassDEP, local departments of public works, boards of health, and building departments, and the Cape Cod Commission.

Existing Applications

Two example projects that have been permitted on Cape Cod are Willowbend (Mashpee) and Red Brook Harborview (Bourne). The Willowbend project entailed the construction of a nine-hole golf course expansion on Shoestring Bay. In addition to using an Integrated Pest Management Plan to minimize the use of fertilizers and chemicals, the project provided a nitrogen loading offset by connecting the neighboring Cotuit Bay Condominiums to the Willowbend Wastewater Treatment Plant. Willowbend paid for and constructed the sewer connection at no cost to the Cotuit Bay Condominiums resulting in a net reduction of 1,274 pounds of nitrogen/year to Shoestring Bay.

The Red Brook Harborview project is a mixed use (residential and commercial) project that provides a village-scale wastewater treatment plant located on Red Brook Harbor in Bourne and was enabled by the Marine Commercial Overlay District zoning amendment. The bylaw allowed an increase in density (from 4 to 15 residential units) in exchange for an advanced wastewater treatment plant. The plant was oversized to treat wastewater from the adjacent Kingman Yacht Center, the 15 townhomes and up to 52 existing single family homes in the Cedar Point neighborhood. Upon buildout the project will result in a net reduction of 2,468 pounds of nitrogen/year to Red Brook Harbor. The wastewater treatment plant will be constructed and paid for by the private developer and made available to the neighborhood residents.

Costs

The costs of this solution will be variable according to the technology employed. The cost will likely be reduced in settings where higher densities of wastewater generators (e.g. residential or high-volume commercial) are located in close proximity to the development site, thereby reducing infrastructure connection costs.

COMPACT AND OPEN SPACE DEVELOPMENT

- Smart Growth strategy
- Reduced infrastructure costs
- Co-benefits of improving quality and quantity of open space for recreation and habitat

How It Works

Compact and Open Space Developments are forms of residential subdivision development that aim to maximize the preservation of natural open areas by designing subdivision layouts with smaller lots than typically allowed under conventional zoning, and clustering the lots together. Depending on the zoning requirements adopted, developments can be required to set-aside half to two-thirds of a property for open space. The more condensed development footprint minimizes road lengths and paved areas, reducing stormwater generation, and reducing infrastructure requirements and costs overall. Smaller lots may also contribute to smaller lawn and fertilized areas. (RI DEM 2011).

In Massachusetts, these development forms require that towns have adopted local zoning bylaws that specifically allow for smaller minimum lot sizes, dimensional requirements, and requirements for the layout and design of the open space.

Performance

Compact forms of development provide opportunities to reduce infrastructure costs, especially for shared wastewater management systems. These open space areas can provide co-benefits in the form of wildlife habitat, recreational opportunities, nutrient recovery (through the uptake of atmospheric nutrients by wooded and naturally vegetated areas), and in some settings, flood water storage. The open space set aside through these projects is often more meaningful than the open land remaining from conventional suburban subdivisions because the land is in a form that is more useable as common or shared space, for wildlife and plant habitat, or for recreation purposes.

Potential Performance Challenges

It is very difficult to quantify the potential nitrogen management benefits from Compact or Open Space Development. Nitrogen removal efficiencies will depend on many factors, including the size of the development, the size of the lots, paved and lawn areas, size of the homes (number of bedrooms), etc. However, as a smart growth strategy for reducing impacts to the environment, these forms of development can have lower overall impacts. (RI DEM 2011).

Allowing for Compact or Open Space Residential Development requires towns to adopt the appropriate zoning into their town codes. Changing zoning requires a 2/3 vote at town meeting and can be difficult if the proposed change is controversial, changes property values, or is misunderstood.

Existing Applications

Natural Resource Protection Zoning (NRPZ) is a relatively new form of zoning that has been adopted in several towns in Massachusetts since 2009. It is a variation of a clustered subdivision, but with several enhancements. NRPZ preserves large areas of open space, concentrating all development in a small area. The number of allowed dwelling units is determined by a calculation that first eliminates the amount of important natural resource lands from the determination of the number of allowed units. The net acreage is then divided by the base density to determine the number of units. The base density is less than typically found in Massachusetts towns, but the number of units can be increased if the development includes public benefits such as affordable housing, wastewater treatment for the development itself as well as for other units, preservation of farmland, and other benefits to the larger community. See further discussion in the Growth Management section of Chapter 6.

The Brewster Natural Resource Protection Design (NRPD) bylaw was adopted in 2009 to foster compact development patterns within a defined district using flexible regulations for density and lot dimensions and to promote and encourage creativity in neighborhood design. The goal of the bylaw is to protect water resources and the preservation of contiguous open space and important environmental resources while allowing design flexibility. NRPD is allowed by right in Brewster, subject only to the requirements of subdivision regulations (Town of Brewster 2013).

Costs

Costs are associated with the scale of development, and are not quantifiable.

TRANSFER OF DEVELOPMENT RIGHTS

How It Works

Transfer of Development Rights (TDR) is a method of directing growth to "receiving areas," such as a town center, and away from "sending areas," such as natural resource areas. A TDR program works by providing a mechanism and a formula that offers incentives for development in receiving areas that are upzoned and a disincentive in sending areas that have been downzoned. Such a tool could be an effective way to help manage the growth effects from sewers. TDR could be used at either the watershed or regional scale to direct growth and associated nutrient loading away from sensitive receiving watersheds or water bodies.

Because Massachusetts law does not require the adoption of local zoning consistent with either a state or regional vision, development on Cape Cod has proceeded according to market forces and local zoning. The result is a sprawling development pattern across the Cape that makes the provision of centralized infrastructure such as wastewater treatment expensive. Whereas zoning changes create development winners and losers, TDR can provide a market based system to more equitably redistribute development potential to areas with infrastructure to accommodate the efficient provision of public utilities, and away from sensitive resource areas. On Cape Cod, such a system could redirect new development and re-development into town centers or other designated areas for growth that have the wastewater and other infrastructure to accommodate increased density.

Existing Applications

Implementation of TDR requires the identification of sending and receiving areas. Several regional land use agencies across the country utilize "land use vision" maps, often called "land capability" maps, to define desired land uses within their jurisdictions. The New Jersey Pinelands, Adirondack Park Agency, and the Long Island Central Pine Barrens all have adopted maps that function as landscape-scale zoning, defining appropriate land use depending on the capability of the resources to accommodate development. These maps all share common themes of identifying villages, hamlets, or growth centers, and resource protection areas such as agricultural districts, forest zones, or preservation areas. A component of the 2009 Regional Policy Plan includes the Land Use Vision Maps (LUVM) for Cape Cod, identifying these growth and preservation zones. With some modification, a regional LUVM could become the basis for TDR sending and receiving zones.

Tahoe Regional Planning Agency Case Study

The Tahoe Regional Planning Agency (TRPA), an interstate land use planning agency between California and Nevada established to protect the water quality of Lake Tahoe, has adopted a development right transfer system with growth management concepts that may have application to redirect growth patterns on Cape Cod. The foundation of the TDR system is the designation of Stream Environment Zones (SEZ), defined by the wetlands and stream corridors flowing to Lake Tahoe. The TDR system aims to redirect growth from the SEZs and other sensitive lands to "non-sensitive lands," growth centers and transit routes; part of the goal is to retire and restore previously developed areas. The system works through a "commodities" market that assigns greater development potential to properties located in sensitive resource areas if their development rights are transferred to receiving parcels in town centers. Additional development potential may be realized depending on the distance of the sending parcel from the town center. Even greater incentives are provided for removing existing development located in SEZs and transferring those development rights to parcels in town centers. TRPA has set up an online TDR Exchange; persons willing to buy or sell development rights can post the particulars of the property to the exchange website. Anyone can review the postings; registered users can review contact information: http://www.trpa.org/permitting/transfer-development-rights/tdr-marketplace.

The TDR program works in concert with TRPA's Regional Plan and Section 208 Water Quality Management Plan (updated June 2013) to redirect new and existing development into designated town centers and sewer districts. On the California side of Lake Tahoe these Public Utilities Districts (PUDs) serve defined areas with a variety of services, and are managed by local boards. In Nevada, wastewater is managed in districts known as General Improvement Districts.

Costs

A TDR program has the potential to lower capital and operations and maintenance costs for infrastructure, as housing density is encouraged in village centers, economic centers, or other compact development areas and discouraged in areas with less compact development. This allows more wastewater flow to be addressed from a smaller area, decreasing the size and extent of the infrastructure needed.

REMEDIATION

Technologies in this section help remove nitrogen from nutrient rich water as it moves through the ground and before it discharges to the affected water body. They include constructed wetlands, phytotechnologies, fertigation wells, permeable reactive barriers, and "green" stormwater systems.

CONSTRUCTED WETLANDS

How It Works

Sometimes referred to as "the earth's kidneys", natural wetlands are well known for their function in water quality treatment. Through proper design and siting, constructed wetlands can effectively integrate and mimic the physical, chemical, and biological processes of natural systems (US EPA 2000).

Constructed wetlands are commonly divided into two main forms: free surface water (FSW) wetlands and vegetated submerged bed (VSB) wetlands. FSW wetlands are commonly known as surface flow wetlands and are characterized by open, standing water with various stages of treatment – the forebay allows sedimentation, while different cells within the wetland system perform different processes that in sum reduce nitrogen and other pollutant loads. Generally, these types of systems are used to either treat tertiary-treated wastewater effluent or can intercept groundwater and/or surface water flows that contain elevated nitrogen concentrations within a watershed.

Subsurface flow wetlands (or vegetated submerged beds) process water though saturated soils, beneath the land surface. In some cases, a liner may be required beneath the constructed wetland. This is dependent on the source of water being treated and the permeability of the underlying soils. In general, treated wastewater entering a constructed wetland will need a liner to prevent contact with the groundwater. Wetlands constructed to intercept and polish groundwater flow may not need a liner. Very coarse soils can also necessitate the use of a liner to prevent infiltration prior to treatment. Because these systems are designed to keep water well beneath the ground, odors, wildlife attraction, and potential disease vectors are minimized or eliminated.

Performance

Constructed wetlands provide several treatment mechanisms including settling, physical filtration, biological uptake, nitrification/ denitrification and other biochemical processes. They draw upon the performance of bacteria that thrive in aerobic and anaerobic zones in order to complete the processes of nitrification and denitrification. Constructed wetlands can be designed to accommodate both aerobic and anaerobic zones and associated treatment mechanisms. The aerobic zones in constructed wetlands are located either in the standing water (free surface wetlands) and/or around the root zone of plants (subsurface flow wetlands). As oxygen is circulated down from the above-water aspects of plants to their roots, the process of nitrification occurs. The denitrification process in the adjacent anaerobic zones then transforms the nitrates into nitrogen gas and organic nitrogen (Campbell and Odgen 1999). Subsurface flow wetlands contain more anaerobic treatment which allows greater removal of nitrogen and a lower nitrogen concentration in the effluent.

The treatment performance of wetlands for nitrogen removal ranges from 50 – 95% (Kadlec et al. 2000, US EPA 2000). Several factors affect this performance including temperature, biological productivity, and residence time (flow rate). Generally speaking at least 3 days retention time is required to accomplish significant nitrification-denitrification (Hammer 1989, US EPA 2000).

Constructed wetlands have also been shown to provide significant treatment for some contaminants of emerging concern (CECs). One study examined the removal efficiencies of 13 pharmaceuticals and personal care products in a subsurface flow constructed wetland. Removal efficiencies of greater than 95% were accomplished for caffeine, salicyclic acid, methyl dihydrojasmonate, caroxy-ibuprofen, hydroxy-ibuprofen, hydrocinnamic acid, oxybenzone, and ibuprofen. More moderate removal efficiencies of 70 – 90% were achieved for naproxen, diclofenac, galaxolide, and tonalide. Only one of the tested compounds (carbmazepine) was poorly removed, i.e. less than 30% (Matamoros, 2007)

Potential Performance Challenges

Constructed wetlands are generally limited to areas where the depth to water is shallow (generally less than 12 inches). They can be constructed in higher upland areas with the application of a liner, adding significant expense. They are also somewhat limited seasonally, with peak performance during the summer growing season. However, subsurface flow wetlands are somewhat insulated from this seasonal effect and demonstrate better year-round performance. Disinfection may be required, and vegetation harvesting may need to be performed periodically. Siting may require fencing and security measures, depending on the location. Successful wetlands could attract water fowl, which could result in increased nitrogen in the waterbody.

Applications

Cranberry Bog Conversions - Former cranberry bog sites show a great deal of potential for constructed or restored wetland sites. Cranberry bog conversion has multiple advantages of reducing fertilizer inputs, strengthening the nitrogen removal capacity and providing/restoring habitat. Tidmarsh Farms, in Plymouth, provides a good example of this type of project where approximately 190 acres of bogs are in the process of being restored to their natural wetlands condition. The project is receiving financial and technical support from United States Department of Agriculture's Natural Resource Conservation Service (NRCS), the U.S. Fish & Wildlife Service and the Massachusetts Division of Ecological Restoration.

Tertiary Treatment at Wastewater Treatment Facilities – Constructed wetlands can be added to conventional wastewater treatment plants to provide additional "polishing" of the effluent. These can be seasonal facilities that target peak summer flows or can be operated year-round.

Secondary and Tertiary Treatment at Wastewater Treatment Facilities – Constructed wetlands can be used as conventional wastewater treatment plants to provide both secondary and tertiary treatment of the effluent. A small primary treatment facility would be necessary to screen the influent and remove solids prior to discharging to the wetlands. These wetlands would require liners. These can be seasonal facilities that target peak summer flows or can be operated year-round.

Watershed Wetlands – Additional wetlands can be constructed at upland sites within a watershed either by excavating downward in relatively low-lying areas (that are currently less than approximately 5 feet to the water table) to within 12 inches of the water table thereby establishing wetland hydrologic conditions, or by pumping the water to be treated to a lined constructed wetland. Numerous constructed wetlands of these types have been constructed throughout Massachusetts in compliance with the Massachusetts Stormwater Standards.

EPA Region 1 recommends piloting constructed wetlands for groundwater treatment to determine their potential effectiveness for removing nitrogen loadings on Cape Cod.

Cost

Like many other construction projects, the costs of developing wetlands can be remarkably variable depending on type (FSW, VSB), location, materials, climate and contractor choice. However, some estimates can be made based on current materials and labor costs - outlined in the table below. The US EPA published an in-depth wetlands construction guide in 1997, from which this table was adapted. These figures have been adjusted to 2014 dollars. Note that 2 of the more significant costs (liners and gravel) can be reduced (by as much as 30 – 60%) on Cape Cod due to the shallow depths to groundwater at many locations and the wide availability of sand and gravel. Table 4A-5 summarizes cost comparisons for a 50,000 square foot wetland.

COST COMPARISONS FOR 50,000 SQ FT WETLAND			**Free Water Surface Wetland**		**Vegetated Submerged Bed Wetland**	
Item	**Units**	**Unit Price**	**Total Cost ($)**	**% of Total**	**Total Cost ($)**	**% of Total**
Excavation/ Compaction	m3	$3.36	19,000	17.7	19,000	10.06
Soil (45 cm)	m3	$1.90	4,100	3.8	Na	-
Gravel (60cm)	m3	$30.65	Na	-	75,930	40.2
Liner (35 mil PVC)	m2	$7.00	35,900	33.4	35,900	19
Plants	Each	$1.00	12,500	11.6	22,217	11.8
Plumbing	Lump Sum		11,000	10.2	11,000	5.8
Control Structures	Lump Sum		10,240	9.5	10,240	5.4
Other	Lump Sum		14,600	13.6	14,600	7.7
		Totals	$107,340	100	$188,887	100

TABLE 4A-5 COST COMPARISONS FOR 50,000 SQUARE FOOT WETLAND (SOURCE: TECHNOLOGIES MATRIX)

Operations and maintenance costs of constructed wetlands are generally both simple and minimal. These costs include periodic inspections, sediment removal and plant replacement. These costs are estimated at $5,000 – 10,000/acre/year.

Co-Benefits

Constructed wetlands have multiple co-benefits. They include aesthetic, ecological (habitat), microclimate, climate change resiliency, and flood control benefits. Constructed wetlands are also believed to be able to treat a broad range of pollutants including nutrients, metals, total suspended solids, pathogens, hydrocarbons and may have the capacity to treat emerging contaminants. There is no contact with the water being treated with the VSB wetland allowing partial use of the site as open space.

PHYTOTECHNOLOGIES

Achieves 50 - 75% nitrogen removal rate
Potentially effective strategy for areas with higher seasonal effluent
Agricultural bio-produce could be sold
Lower capital and O&M costs

Phytotechnologies use plants to extract, degrade, contain, or immobilize pollutants in soil, groundwater, surface water, and other contaminated media. Some phytotechnology applications can be primary methods of cleaning up or stabilizing contamination while others can supplement primary remedies. Phytotechnologies may potentially (1) clean up moderate to low levels of select elemental and organic contaminants over large areas, (2) maintain sites by treating residual contamination after completion of a cleanup, (3) act as a buffer against potential waste releases, (4) aid voluntary cleanup efforts, (5) facilitate nonpoint source pollution control, and (6) offer an enhancement of natural attenuation (McCutcheon and Schnoor 2003, US EPA 2010).

The most likely application of phytotechnologies on Cape Cod would be planting *phytobuffers* to intercept and uptake stormwater and groundwater through leaves and roots to control infiltration and cleanse runoff entering surface water lakes and ponds, or *phytoirrigation*, where after secondary treatment, wastewater effluent is irrigated onto plants to remove nutrients and other contaminants.

How It Works

Phytotechologies work through the natural processes of trees, shrubs, or other plant materials that intercept groundwater or surface water flow and extract contaminated water through the process of evaporation and transpiration. Dense plantings in rows or clusters are installed in various soil media perpendicular to groundwater or surface water flow in order to capture and treat horizontally flowing water. In general, the deep-rooted, high-transpiring trees must be actively tapping into the groundwater to create the barrier.

Furthermore, a relatively large number of trees (and associated area) are generally required to extract the volumes necessary to achieve containment.

Many species of plants have been used in phytotechnology projects including "salix species (hybrid poplars, cottonwoods, and willow), grasses (rye, Bermuda grass, sorghum, fescue, bullrush), legumes (clover, alfalfa, and cowpeas), aquatic plants (parrot feather, duckweed, arrowroot, cattail, pondweed), and hyperaccumulators for metals (sunflowers, Indian mustard, and Thlaspi spp.)" (Shnoor, 1997). Poplars and willows are by far the most popular plants used because of their deep and prolific roots, ability to process large amounts of water, and rapid growth. "Poplars and willows have been used extensively in Europe as a vegetative filter for cleaning polluted drainage water from agricultural land and for wastewater treatment and soil remediation combined with biomass production for energy use" (Westphal and Isebrands 2001) (see Table 4A-6).

SUMMARY OF PHYTOTECHNOLOGY MECHANISMS		
Mechanism	**Description**	**Cleanup Goal**
1. Phytosequestration	The ability of plants to sequester certain contaminants in the rhizosphere through exudation of phytochemicals and on the root through transport proteins and cellular processes	Containment
2. Rhizodegradation	Exuded phytochemicals can enhance microbial biodegradation of contaminants in the rhizosphere	Remediation by destruction
3. Phytohydraulics	The ability of plants to capture and evaporate water off the plant and take up and transpire water through the plant	Containment by controlling hydrology
4. Phytoextraction	The ability of plants to take up contaminants into the plant with the transpiration stream	Remediation by removal of plants
5. Phytodegradation	The ability of plants to take up and break down contaminants in the transpiration stream through internal enzymatic activity and photosynthetic oxidation/reduction	Remediation by destruction
6. Phytovolatilization	The ability of plants to take up, translocate, and subsequently transpire volatile contaminants in the transpiration stream	Remediation by removal through plants

TABLE 4A-6 SUMMARY OF PHYTOTECHNOLOGY MECHANISMS (SOURCE: INTERSTATE REGULATORY TECHNOLOGY COUNCIL 2009)

Performance

Based on previous studies and applications, *phytoirrigation* has resulted in a reduction of 50-70% of nitrogen and phosphorus, while *phytobuffers* have resulted in a reduction of 25-40% of nitrogen and phosphorus. Nitrogen removal rates have been as high as 90-100% depending on application at an agronomic rate and efficient evapotranspiration. Phytobuffers can be particularly effective in improving surface water quality. Phytotechnologies can be effective in the first year of installation. The useful life of phytotechnologies is approximately 20 years with periodic plant replacements and other operation and maintenance. The depth that groundwater can be treated is based on the type of vegetation grown. The roots of some trees can penetrate 20 feet or more, some having roots that extend below the water table treating to a greater depth in the groundwater. Many factors influence phytotechnologies, such as soil conditions, climate, suitable plant species, and associated rhizosphere microbes. Therefore, every project is unique and must be custom designed, installed, and operated (IRTC 2009).

Vegetated treatment systems hold promise for removal of some contaminants of emerging concern (CEC). Plant uptake, microbial action, nitrification and denitrification have been cited as effective biochemical mechanisms for the breakdown of a wide range of CECs within constructed wetland systems and to the extent that these mechanisms and pathways are present in a vegetated system similar results can be expected.

Potential Performance Challenges

Where phytotechnologies are used to treat groundwater one must consider the local hydrology and surrounding aquifer properties. In order to ensure groundwater interception, the vertical thickness of the groundwater lens must be considered. Plants can only be irrigated during the growing season (about 3 months). For tree systems, it takes several years before plants are mature enough to uptake the maximum number of gallons per day, requiring the effluent to be held in holding ponds until the irrigation season. Phyto installations will likely require compliance with stringent water reuse regulations. The use of phytotechnologies, however, are potentially a good strategy for areas where more effluent is generated during the summer season.

Existing Applications

Phytotechnology has been implemented on varying scales by bioengineering firms throughout the globe for in situ treatment of contaminated soil. The use of phytotechnology for wastewater treatment is in an early stage, and there is little North American research about its use in coastal communities such as Cape Cod. In order to learn more about the potential effectiveness of phytotechnology for wastewater treatment, in the Summer – Fall 2012 the Cape Cod Commission conducted a pilot phytotechnology demonstration project to assess the viability of utilizing a phytotechnology approach to wastewater treatment on Cape Cod. The project, consisting of nine test cells filled with indigenous substrate and planted with poplar and willow cuttings (see Figure 4A-1 Schematic of phytotechnology Test Cells), was constructed in partnership with the Town of Barnstable and the University of Massachusetts Dartmouth School for Marine Sciences and Technology (SMAST) laboratory.

US EPA Region 1 recommends piloting Phytoirrigation to determine its potential effectiveness for removing nitrogen loadings on Cape Cod.

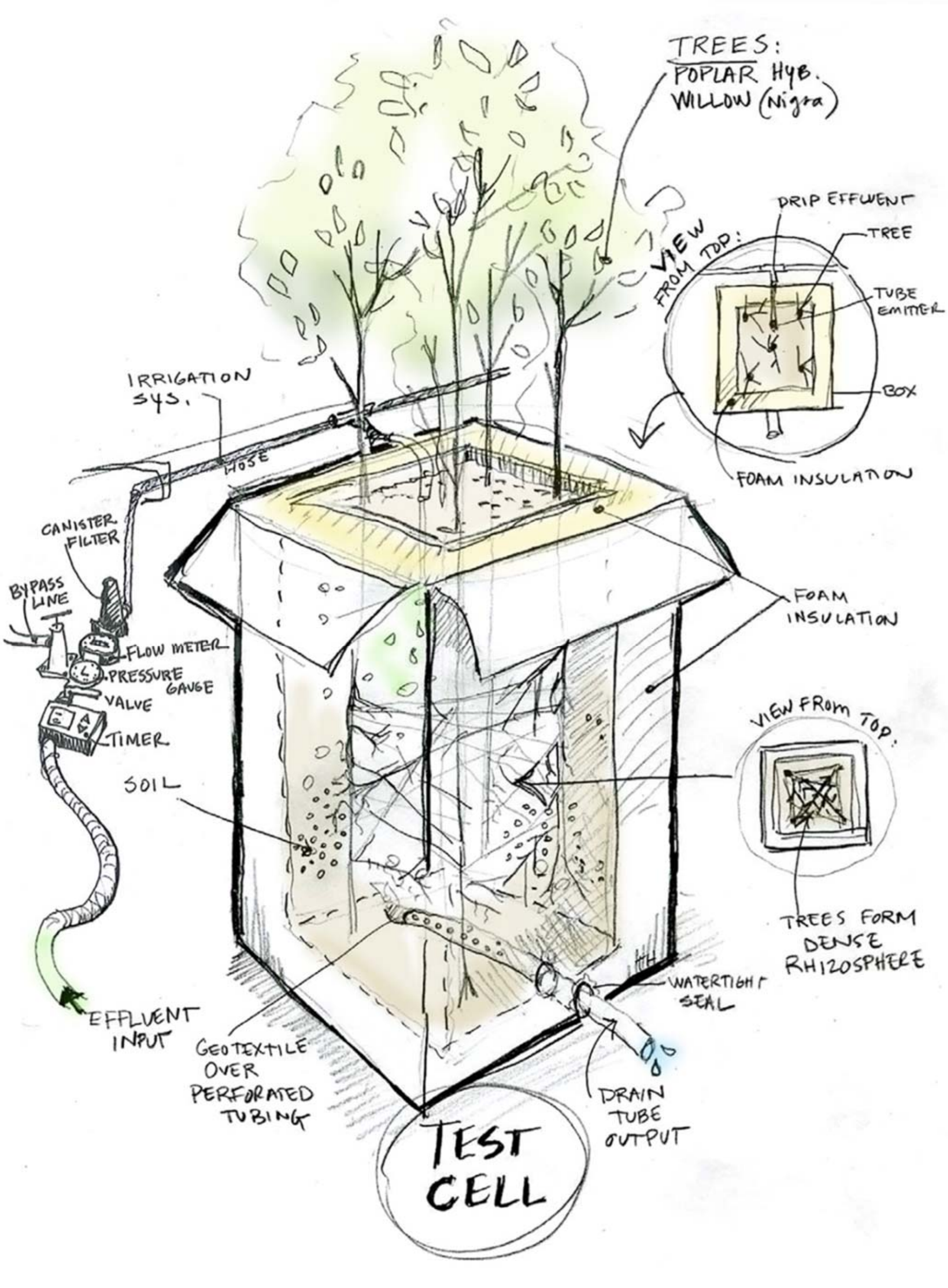

FIGURE 4A-1 SCHEMATIC OF PHYTOTECHNOLOGY TEST CELLS (SOURCE: CCC, ADAPTED FROM ECOLOTREE)

The project was sited at the Hyannis Water Pollution Control Facility (WPCF), provided as an in-kind service by the Town of Barnstable Department of Public Works. The facility houses primary and secondary wastewater treatment tanks, laboratory facilities, and disposal beds. The project cells were situated on the grated decking suspended above the secondary effluent tanks where a feeder hose was connected to the irrigation system dosing the tree plantings with nitrogen rich effluent at an average of 5-7 milligrams per liter (mg/L). This setup also allowed for excess effluent from the cell's drain tubes to flow directly back into the tanks below. Following initial installation and plant establishment in June 2012, the project began sampling via collection canisters in August 2012, and completed in December 2012.

Approximately 45 tree cuttings were dosed with secondarily-treated effluent and were monitored over a six-month period. An average of 82% nitrogen removal and 65% total phosphorus removal was reported. Extrapolating from the data collected, the study found that at the rate of dosing and with the planting scheme dictated, approximately 631 tree cuttings of this type could treat one pound of nitrogen annually.

In addition to individual on-site pilot testing and monitoring, larger-scale pilot projects at a certified test center, such as the Massachusetts Alternative Septic Systems Test Center, would be useful to evaluate costs and nitrogen removal capabilities on the Cape. A large-scale pilot study utilizing a control planting group, or varying type, dosed with effluent, all in native sand, could be considered, along with different application rates, soil types, species and density of plantings. Long-term monitoring could demonstrate effectiveness, perhaps with pan lysimeters. In particular, there could be some release of residual nitrogen, particularly organic nitrogen, stored in the soil during the non-growing season. This should be evaluated.

Costs

Construction costs can range from a low of $25,000/acre to a high of $100,000/acre with 60% of the cost being labor to install the cuttings/plantings. Total project costs range from a low of $285,000/acre to $390,000/acre, based on an average land cost of $250,000/acre. If existing public lands are available, this could lower the total project costs. As an unproven wastewater treatment technology in the New England region, use of phytoirrigation will likely require meeting water reuse regulations and may include increased treatment and monitoring requirements. The costs to monitor phytobuffers are substantially less and limited to periodic inspection of vegetation. The estimated annual evaluation monitoring costs for phytoirrigation could be range from $15,000 - $25,000/year for 2-4 years, while phytobuffer operations and maintenance (O&M) costs may be considerably lower – $4,000 - $6,000/year. Annual O&M costs could be as low as $5,000/acre when small cuttings are used and there is no irrigation.

STORMWATER: BIORETENTION/SOIL MEDIA FILTERS

How It Works

Bioretention is a technique that uses soils, plants, and microbes to treat stormwater. Smaller residential applications are shallow depressions filled with sandy soil topped with a thick layer of mulch and planted with dense native vegetation. Stormwater runoff is directed into the cell via piped or sheet flow. The runoff percolates through the soil media that acts as a filter. Microorganisms in the root zone provide a broad range of biochemical processes (including nitrification-denitrification) that break down a broad range of pollutants.

According to the MassDEP Stormwater Handbook there are two types of bioretention cells: those that are designed solely as an organic filter, filtering bioretention areas and those configured to recharge groundwater in addition to acting as a filter, exfiltrating bioretention areas (MassDEP 2008). A filtering bioretention area includes an impermeable liner and underdrain that intercepts the runoff before it reaches the water table so that it may be conveyed to a discharge outlet, other best management practices, or the municipal storm drain system. An exfiltrating bioretention area has an underdrain that is designed to enhance exfiltration of runoff into the groundwater.

Due to the highly permeable soils on Cape Cod, the simpler version of this system (that is considerably less expensive to construct) can be utilized. Such a system does not need a liner or collection system but rather can infiltrate directly to underlying sandy soils.

Performance

According to the MassDEP Handbook nitrogen removal rates of 25-45% can be expected using this technology (MassDEP 2008). The University of New Hampshire Stormwater Center identifies an average removal rate of 42% nitrogen for bioretentions systems (UNH Stormwater Center 2012). These systems are also effective at attenuating phosphorus, metals, total suspended solids and other pollutants. MassDEP reports removal rates of 90% for total suspended solids, 20 – 30% for total phosphorus, and 40 – 90% metals.

Bioretention treatment systems hold promise for removal of some contaminants of emerging concern (CECs). Plant uptake, microbial action, nitrification and denitrification have been cited as effective biochemical mechanisms for the breakdown of a wide range of CECs within constructed wetland systems and to the extent that these mechanisms and pathways are present in a vegetated system similar results can be expected.

Potential Performance Challenges

Siting bioretention systems requires land area that is approximately 5-7% of the impervious drainage area. This should be considered as a requirement as part of local subdivision bylaw updates. Seasonal variation in water quality treatment can be expected. Nitrification – denitrification rates will be lower during the colder winter months. The reported removal rates take this into account and are average annual figures. Annual removal of dead vegetation is recommended to remove the accumulated biomass which contains nitrogen (MassDEP, 2008).

Applications

Bioretention systems can be designed in a wide variety of sizes and shapes ranging from small residential rain gardens as small as one hundred square feet up to several acres in size. Hundreds of bioretention systems have been successfully constructed throughout Massachusetts. The Town of Barnstable has constructed several systems that intercept stormwater runoff upgradient of coastal waters.

Costs

According to the University of New Hampshire Stormwater Center the capital/construction costs for bioretention systems are estimated at $14,000 – $24,000 per acre of impervious treated (UNH 2012). Operation and maintenance costs are estimated at $2,250/year for a system that treats one acre of impervious surface (Houle et al. 2008).

Co-benefits

Bioretention systems provide multiple benefits including aesthetics, habitat, groundwater recharge, flood control and treatment for a broad range of pollutants. They can provide windbreaks, shade and absorb noise. Maintenance is relatively minimal and can provide landscaping jobs.

FERTIGATION WELLS

How It Works

Fertigation is the process of integrating fertilization and irrigation practices. Properly-designed and located, irrigation wells can capture nutrient-enriched groundwater, for example downgradient from high-density septic systems (that currently discharges to embayments and ponds) and recycle it back to irrigated and fertilized turf grass areas (including golf courses, athletic fields and lawns). In this manner, nitrogen is recycled as a resource/fertilizer. This can significantly reduce nutrient loads to downgradient surface waters and reduce fertilizer costs. These wells should be installed to target groundwater high in nitrates such as sewage disposal areas, golf courses and areas of dense development with septic systems.

Performance

The mass of nutrients removed from the watershed and downgradient embayments using this technology is the product of the pumping rate and the concentration of nitrogen in the groundwater that is pumped. For example, groundwater downgradient from a high-density residential area (average 0.25 acre lots) that utilizes septic systems can be expected to have nitrate-nitrogen concentrations of approximately 5 mg/liter. Similar concentrations might be found in groundwater downgradient from a wastewater treatment plant discharge. The amount of water that can be effectively utilized by areas that receive fertilizers depends upon the area to be fertilized and irrigated. For example a typical 18-hole golf course (with approximately 100 acres of managed turf) utilizes approximately 20 million gallons of irrigation water per growing season. At an average concentration of 5 mg/liter this represents an annual load of 378.5 kg/year (or 3.8 kg/acre/year). Assuming that this will replace commercial fertilizer applications by this amount it represents a net reduction of 378.5 kg/year for each golf course application. Nitrogen load reductions for other turfgrass areas (such as athletic fields or lawns) can be estimated using a rate 3.8 kg/acre-year).

Potential Performance Challenges

The efficiency of this technology depends upon finding locations with relatively high nitrogen concentrations (donor areas) and vegetated areas that can receive fertilization and irrigation (receiving areas) that are in relatively close proximity. Unless a greenhouse is utilized, the technology is limited in application to the growing season. Annualized load reductions must be accounted for during this seasonal period. To potentially overcome the seasonality of fertigation, it may possible to install a constructed wetland near the irrigation source allowing for year-round pumping and treatment of the high nitrate groundwater.

Applications

The Pinehills golf course in Plymouth installed a series of fertigation wells downgradient from their wastewater treatment plant (which discharges the treated water to the ground). A nitrogen leaching rate of 20% was assumed, but because fertilizer application rates were reduced commensurate with the amount of nitrogen in the pumped groundwater, the level of leaching was assumed constant. The pumped water was distributed to their golf course resulting in a reduction of the amount of commercial fertilizers applied. During a two-year monitoring period (2008 – 2009) they recovered and recycled 289 and 580 kg/year, averaging 434 kg/year (Horsley Witten Group, Inc. 2009).
US EPA Region 1 recommends piloting fertigation wells to determine this technology's potential effectiveness for removing nitrogen loadings on Cape Cod.

Costs

The cost of developing a fertigation well system typically includes a well and the transmission line. According to the Technologies Matrix these costs are estimated at approximately $3,000 for the well installation and $200 for annual operation and maintenance (primarily power to pump the well). Several wells, pumps and a small collection may be necessary to collect the groundwater and pump it to the golf courses irrigation system.

PERMEABLE REACTIVE BARRIERS – TRENCH METHOD, INJECTION WELL METHOD

- Achieves 75-95% nitrogen removal rate
- Provides passive treatment with minimal O&M (Trench Method)
- Can utilize/recycle local waste wood resources (Trench Method)

A permeable reactive barrier (PRB) is a subsurface zone of reactive material designed to intercept and remediate contaminated groundwater. Utilizing different reactive media, PRBs have historically been used to treat groundwater contaminated by a broad range of contaminants including chlorinated solvents, arsenic, chromium, nitrate and other organic and inorganic compounds (US EPA 2012). There are two main types of PRB installations: trench and injection wells.

How It Works

PRBs provide a carbon source to microbes that exist in groundwater. The carbon source provides energy to allow the microbes to breakdown nitrogen to nitrogen gas. There are two means of providing the carbon source to the microbes in the groundwater: the trench and the injection well methods. The two methods are installed differently and provide a different carbon source; however the nitrogen reduction process works similarly.

Trench PRBs

Trench PRBs are comprised of a coarse grained soil mixed with a reactive media (such as wood chips or sawdust) that provides a carbon source for microorganisms that remove contaminants from groundwater. Generally, trenches are constructed vertically, perpendicular to groundwater flow, in order to capture and treat horizontally flowing groundwater. A trench-style PRB is typically excavated to a certain thickness and depth, then filled with some type of reactive media.

Injection Well PRBs

An injection well PRB is a network of wells where a reactive media is injected in to the subsurface where it reacts with contaminated groundwater. The wells are constructed by first drilling a series of boreholes and then injecting the reactive media under pressure in to the subsurface, often using a carrier fluid (e.g., high-pressure gas, water, or other solution). The injection wells are spaced to provide overlapping radii of influence (ROI) to create a continuous reactive zone. Borings are typically installed 20-25 feet apart, having a radius of influence of 12-15 feet from each injection point.

Performance

From numerous studies conducted over the past few decades, PRBs have proven to remove 75-95% of nitrate in the groundwater that flows through them.

PRBs have operated for extended periods of time. A widely-recognized study conducted in Ontario, Canada showed that only 3% of the wood chip-based carbon source had been metabolized over a seven-year test period, suggesting that the longevity of this system could extend for decades (Robertson 2000). To determine the mass or load of nitrogen that will be treated by a PRB installation the groundwater capture zone must be determined. There are multiple methods to estimate/model these areas using water table/groundwater flow direction maps.

Potential Performance Challenges

The optimal design of a PRB that intercepts the groundwater plume must consider the local hydrology and surrounding aquifer properties. In order to ensure groundwater interception, the vertical thickness of the groundwater lens relative to the depth of the PRB must be considered. The practical maximum depth that can be achieved with trench designs is 40 – 45 feet. Injection wells installation methods have the potential for a much deeper design. PRBs should also be designed to match the hydraulic conductivity and permeability of the surrounding groundwater matrix. With regard to downgradient impacts of PRBs, anaerobic byproducts such as methane, manganese, sulfide, and ferrous iron may be generated, but are anticipated to return to background levels at short distances downgradient (less than 100 feet) of the PRB.

Existing Applications

In 2005, pilot-scale NITREX™ PRBs, whose medium consists of woodchips and lime covered with local sand, were installed along Waquoit Bay and Childs River in Falmouth. A 50' PRB was installed on a beach, and a shorter barrier was installed on a private lot bordering the estuary.

Both the Waquoit Bay and Childs River PRBs achieved 99% nitrate removal. Longer term installations have been tested with favorable results for removal of nitrogen associated with septic systems at the University of Waterloo in Canada (Robertson 2000) and elsewhere throughout the United States (ITRC 2011, US EPA 2013).

US EPA Region 1 recommends piloting injection well and trench PRBs to determine their potential effectiveness for removing nitrogen loadings on Cape Cod.

Costs

The costs for PRBs include design, permitting, construction, and operation and maintenance. Design includes site characterization (including hydrogeologic study), identification of existing subsurface infrastructure and engineering plans. Permitting is variable depending upon site locations and scale. Construction costs vary depending upon installation method (trench versus injection wells). Operation and maintenance includes monitoring and potentially rejuvenation of reactive media. CDM Smith recently completed a cost analysis for a proposed pilot project to test PRB technology in the Town of Falmouth. Table 4A-7 summarizes the estimated costs of this pilot project using two alternative installation methods.

ESTIMATED COST OF GREAT HARBORS PILOT PROJECT IN FALMOUTH, MA	One-Pass Trench
Design/Permitting	$100,000
Construction – One Pass Trench Construction – Injection Wells	$1,386,000 $673,120
Monitoring Well Installation	$75,000
Sampling & Analysis	$80,000/yr
Interpretation of Results	$25,000
Rejuvenation (Injection Wells)	$234,000

TABLE 4A-7 ESTIMATED COST OF GREAT HARBORS PILOT PROJECT IN FALMOUTH, MA (SOURCE: CDM SMITH)

The Technologies Matrix has integrated these CDM Smith costs into a calculator that allows the user to estimate the costs of a specific PRB application by inputting the length of the PRB and the estimated nitrogen capture.

STORMWATER BMPS - PHYTOBUFFERS, VEGETATED SWALES, & CONSTRUCTED WETLANDS

How It Works

There are several stormwater treatment systems that can provide significant nutrient removal capabilities. Generally, they are the vegetated systems: phytobuffers, constructed wetlands, vegetated swales, and bioretention systems. As bioretention is described in another section of this report, this section is focused on the first three practices. A broad range of treatment mechanisms exist within these systems and include physical filtration, uptake within plant tissue, nitrification-denitrification, and other microbial biochemical processes. These processes are effective in treating a broad range of pollutants including nutrients, metals, hydrocarbons and pathogens.

These stormwater treatment systems can be designed as a "treatment train" in concert with each other or with other practices. For example the phytobuffer or vegetated swale can serve as pretreatment for a constructed wetland. In these cases the overall treatment capacity is significantly increased and is cumulative.

Phytobuffers, also known as vegetated filter strips are uniformly graded vegetated surfaces that receive runoff from adjacent impervious areas. Vegetated filter strips typically treat sheet flow or small concentrated flows that can be distributed along the width of the strip using a level spreader. Vegetated filter strips are designed to slow runoff velocities, trap sediment, and promote infiltration, and biochemically metabolize the pollutants.

Water quality swales are vegetated open channels designed to treat water quality and to convey runoff from the 10-year storm without causing erosion. They can be substituted for subsurface piping or open (unvegetated) channels to provide enhanced water quality treatment when constructed in association with other stormwater BMPs.

Constructed stormwater wetlands can be designed as surface flow (with standing water) or gravel wetlands (with subsurface flow). Both systems provide effective treatment of stormwater. The surface wetlands provide significant habitat enhancement and can provide aesthetic benefits. The gravel wetlands have been shown to have higher nitrogen removal rates and eliminate the possibility of mosquito breeding habitat with no standing water.

Performance

Due to the multiple treatment mechanisms associated with these vegetated stormwater treatment systems, a broad range of pollutants can be treated including nutrients, hydrocarbons, metals and pathogens. Phosphorus is removed via precipitation in the soils and uptake within the plant tissue. Nitrogen removal is primarily related to microbial nitrification and denitrification biochemical processes. Table 4A-8 below, lists the nitrogen removal rates that have been observed:

NITROGEN REMOVAL RATES FOR VEGETATED STORMWATER TREATMENT SYSTEMS		
	Nitrogen Removal Rates	**References**
Phytobuffer	25 – 40%	MassDEP 2008
Vegetated Swales	25 – 40%	Houle et al. 2013
Wetland (Surface)	50 – 75%	Houle et al. 2013
Gravel Wetland	75%	Houle et al. 2013

TABLE 4A-8 NITROGEN REMOVAL RATES FOR VEGETATED STORMWATER TREATMENT SYSTEMS (SOURCE: TECHNOLOGIES MATRIX)

Vegetated treatment systems hold promise for removal of some CECs. Plant uptake, microbial action, nitrification and denitrification have been cited as effective biochemical mechanisms for the breakdown of a wide range of CECs within constructed wetland systems and to the extent that these mechanisms and pathways are present in a vegetated system similar results can be expected.

Potential Performance Challenges

Seasonal variation in water quality treatment can be expected. Nitrification – denitrification rates will be lower during the colder winter months. The reported removal rates take this into account and are average annual figures. Annual removal of decayed vegetation (and its nitrogen biomass) is also an important component of the maintenance requirements. Requires the creation and enforcement of stormwater regulations and policies. Tree systems take several years before the plants are mature enough to uptake the maximum number of gallons per day requiring the effluent to be held in holding ponds until the irrigation season.

Applications

Vegetated stormwater treatment systems can be designed to fit into almost any configuration and space. They can be retrofit into existing drainage systems by intercepting existing drainage pipes or surface drainage and redirecting the stormwater into a vegetated practice. They can also be easily integrated into new development projects. There are numerous installations of these systems throughout Cape Cod and Massachusetts.

EPA Region 1 recommends piloting phytobuffer stormwater BMPs to determine their potential effectiveness for removing nitrogen loadings on Cape Cod.

Costs

According to publications from the University of New Hampshire Stormwater Center and compiled in the Technologies Matrix, the costs for construction (per acre) and operation and maintenance (on an annual basis) are as follows
(see Table 4A-9):

VEGETATED STORMWATER TREATMENT SYSTEMS COSTS (PER ACRE)			
	Construction	**O&M**	**Reference**
Phytobuffer	$405,000	$5500	Houle et al. 2008
Vegetated Swales	$28,370	$1100	Houle et al. 2008
Wetland (Surface)	$382,800	$5500	Houle et al. 2008
Gravel Wetland	$321,200	$2640	Houle et al. 2008

TABLE 4A-9 VEGETATED STORMWATER TREATMENT SYSTEMS COSTS (SOURCE: TECHNOLOGIES MATRIX)

Co-Benefits

Bioretention systems can provide multiple benefits including aesthetics, habitat, groundwater recharge, flood control and treatment for a broad range of pollutants. They can provide windbreaks, shade and absorb noise. Maintenance is relatively minimal and can provide landscaping jobs.

RESTORATION

The technologies classified here as Restoration are those which address the removal of nitrogen from nutrient rich water within the affected water body. They include aquaculture and shellfish restoration, inlet and culvert widening, coastal habitat restoration, floating constructed wetlands, surface water remediation wetlands, and pond and estuary dredging.

AQUACULTURE AND SHELLFISH RESTORATION

How It Works

Because oysters have been shown to positively impact water quality by filtering particulate organic matter, interest in using them to manage anthropogenic sources of nitrogen has recently surged. Additional co-benefits of oyster reefs may include habitat provision for juveniles and adults of commercially important fisheries (Coen et al. 2007), shoreline stabilization through reduced wave energy (Newell 2004), and increased removal of particulate matter, light penetration, and submerged aquatic vegetation growth due to improvements in water clarity (Golden 2011). Some of these studies suggest variable results in terms of water quality benefits including light penetration with the best results occurring during the summer growing season (Golden, 2011).

Oysters remove nitrogen via two primary pathways: filtration and bio-deposition. The majority of organic matter filtered by oysters is used for growth and maintenance. Bio-deposition is the process by which excess filtrate is packaged into waste products and deposited in the sediment below. It then becomes a food source for a diverse community of bacteria, bio-turbators and other macrofauna. Performance rates vary by several unique contextual factors that include salinity, temperature, season, pH, dissolved oxygen, turbidity, and seston (organisms and non-living matter in a water body) concentration.

The associated communities that come up with oyster reefs often include various other denitrifying organisms that provide for a third pathway for nitrogen removal, albeit one that is not as well understood or studied as the primary pathways. Increased biodiversity at oyster reefs also helps protect against disease and positively impacts the ecosystem resilience of near shore systems.

Performance

Performance estimates for nitrogen removal associated with aquaculture and reef restoration vary considerably by location, target metric and methodology. A study conducted by the Cape Cod Cooperative Extension, along with Woods Hole Sea Grant, attempted to summarize these data with a focus on native Cape Cod studies. They found that local oysters contain on average

0.28 grams of nitrogen per individual, with quahogs showing a slightly lower content at 0.22 grams of nitrogen per individual. Oyster density is reported at 2,000,000 oysters/acre of reef in the Wellfleet restoration project and at approximately 1,250,000 oysters/acre for the Falmouth oyster propagation project in Little Pond (Woods Hole Group 2013). Using the more conservative density of 1,000,000 animals/acre this represents a potential nitrogen mitigation of approximately 250 kg/acre/year (accounting for only nitrogen in the flesh and shell of the oyster). Additional nitrogen removal benefits associated with biodeposition and subsequent denitrification are likely where oyster reefs are formed.

Potential Performance Challenges

There are a few challenges that should be considered with oyster reef restoration and aquaculture expansion. These challenges include climate change and rising water temperatures, oyster diseases, ocean acidification, and potential public concerns about the visibility of aquaculture equipment. In addition, removal rates may depend on water circulation within the water body, resulting in localized nitrogen removal effects.

It is important to anticipate the public response to the impact of aquaculture on shoreline aesthetics. Oyster aquaculture expansion will increase floats, trucks or workers in designated areas of the coast. Some residents may not want to see this activity on the shoreline.

Ocean acidification has the potential to decrease survival rates of oysters in both aquaculture and reef restoration. This is a global phenomenon that results from oceans taking in large amounts of carbon dioxide and leads to a change in water chemistry, making the water more acidic. Oyster larvae and young oysters are particularly vulnerable to this increase in acidity. In waters with a low pH oyster shells become thinner, growth slows and mortality rates increase.

Diseases and bacteria present on Cape Cod could affect oyster survival rates and regulations for oyster harvest. There are two diseases that have been known to affect oyster populations on Cape Cod and will be a challenge to projects focused on increasing oyster populations. These diseases are MSX (haplosporidium nelsoni) and dermo (perkinsus marinus.) Vibrio (vibrio parahaemolyticus) is a naturally occurring bacteria that can rapidly multiply at elevated temperatures and can subsequently pose a health risk to consumers of raw shellfish, though it has no effect on the shellfish themselves.

Climate change and rising water temperatures may not only increase the prevalence of oyster disease but could also have an impact on oyster spawning patterns and survival rates of oysters in the period following spawning. Spawning is a natural phenomenon but has the potential to lead to premature oyster deaths if it occurs when the oysters are exposed to high temperatures (Yan 2009). Spawning requires significant energy, leaving oysters more vulnerable to temperature stress and compromising their ability to defend against disease. It can also affect the desirability of oysters for consumption. Oysters are in peak condition for harvest just prior to spawning. Although spawning is known to be seasonal, it is triggered by high temperatures and the marketable quality of oysters significantly drops for at least a month following spawning.

Existing Applications

The Chesapeake Bay watershed is the most relevant existing application of using oyster reefs and aquaculture to address water quality concerns. Oyster restoration in the Chesapeake uses the same species (Crassotrea virginica) and has a short but successful history of cooperation between Federal agencies, universities and nonprofit organizations. There are successful precedents on both the West Coast (California, Washington) and in Europe, but key differences in both cases (species, cost estimates, institutional capacity, regulatory considerations) reduce the applicability to the Cape Cod region. In terms of the Chesapeake Bay, President Obama issued Executive Order 13508 in May of 2009 that mandated a comprehensive environmental restoration plan for the region, including the restoration of oyster populations in 20 tributaries by 2025. This represents an unprecedented level of activity in both the breadth and depth of the Federal commitment and will not only ensure the continued relevance of the Chesapeake region as an existing application, but also provide a wealth of new data and scalability lessons that can be transferred to Cape Cod.

US EPA Region 1 recommends piloting aquaculture and shellfish restoration to determine this approach's potential effectiveness for removing nitrogen loadings on Cape Cod.

Costs

For restored oyster reefs, key cost variables include survival rate, reef definitions, natural spat set rates and substrate availability. The Maryland Interagency Oyster Restoration Workgroup (MIORW 2013) has several estimates that have been used to form a conservative baseline:

Seed costs: $7,500 per million (based on Oyster Restoration Project experience)
Substrate costs: $44.63 per cubic yard of either oyster shell, clam shell, crushed concrete, crushed gravel, or reef balls (based on US Army Corps of Engineers experience)

Co-benefits

There are many significant co-benefits to the use of oysters as a mechanism for nitrogen filtration. Oysters from both aquaculture and restored reefs filter nitrogen in the water column by consuming phytoplankton and inorganic particles. In doing so, they clarify the water column and reduce turbidity. Once this matter is filtered out of the water, sunlight is able to penetrate to greater depths and promote the growth of native seagrass (Newell 2004). These benefits can be realized within short time frames, as the oysters grow and mature within the target water bodies.

The expansion of oyster aquaculture could offer economic benefits from job growth and return revenues. The continuing efforts in shellfish cultivation in parts of Asia and Europe suggest that there is great potential for growth in the oyster aquaculture industry (Newell 2004). The expansion of the industry could offer employment opportunities for residents of Cape Cod, increase revenues from oyster sales and possibly generate revenues from nutrient trading.

Promoting the growth of natural oyster reefs has significant environmental benefits that go far beyond nutrient filtration. The structure of the oyster reef provides an important habitat for a variety of organisms including recreational and commercial fish, crustaceans and eelgrass and can help to restore natural ecosystems that have been severely degraded on Cape Cod. Some of these reef associated organisms have shown the potential to increase nitrogen filtration, although there are no current estimates that quantify this effect. Oyster reefs also help slow wave action, reducing shoreline erosion.

INLET/CULVERT WIDENING

- Achieves 75-95% nitrogen removal rate
- Provides passive treatment with minimal to no O&M
- Has numerous ecosystem benefits
- Nitrogen removal rate is dependent on many factors, including scope of restoration up to full tidal exchange

How It Works

Inlet/culvert widening involves the re-engineering and reconstruction of a bridge or culvert, dredging, or widening of an estuary inlet to increase tidal flow in and out of an estuary or tidally restricted salt marsh. Increasing the tidal flux will generally decrease the nitrogen residence time within the embayment or salt marsh, thereby lowering the nutrient concentration in the estuary/salt marsh (MEP 2003). With the return of natural salinities, nutrient balance, and improved tidal exchange, and with opportunities for sediment to move more naturally through a coastal system, native plant and animal species may return and thrive. With more naturally functioning coastal systems at work, Cape Cod benefits from the numerous ecosystem services provided by healthy aquatic and salt marsh habitats upstream of the restricted culvert or inlet.

Performance

The opportunity for significant nitrogen attenuation improvements within an estuary or tidally restricted salt marsh is greatest in locations where a redesigned culvert or bridge can facilitate significantly increased tidal exchange within the impacted water body or wetland. In suitable locations, the inlet widening can result in a more natural hydrologic regime, reduced flow velocity due to a larger opening, less scour around the culvert/bridge structure, increased capacity for flood flows (reducing road overtopping), and possibly fewer snags and reduced maintenance.

The time frame from construction to measurable results within the water body or salt marsh can be relatively quick, ranging from 0.5 to 3 years. Since this is a restoration type of project the results can be self-sustaining and have multiple co-benefits: improving water quality results in improved fisheries habitat, improving opportunities for recreational and commercial fishing, and having cascading positive effects on other ecosystem flora and fauna. Increased salinity from inlet widening is also known to stress and reduce the presence of phragmites australis (a state listed invasive species) over time.

Potential Performance Challenges

The design of an inlet widening must be carefully studied in order to ensure success. Inadequate modeling of the system hydraulics and coastal processes at the mouth of the inlet can result in disruption of sediment transport, later undermining the success of the project. Also, the widening must allow for a significant increase in tidal exchange, or little nitrogen attenuation benefits will result. At the same time, project engineers need to model the extent of the new high tide line to understand flooding potential of shoreline properties upstream of the structure to be widened. Some restoration projects cannot fully open an inlet or culvert due to development encroachment on the floodplain and the potential to flood existing structures (NPS 2012). On Cape Cod, the MEP reports provide some initial analysis of opportunities for inlet widening where some nitrogen management may be attained, or conversely, settings where an inlet widening will result in little nitrogen attenuation improvement. Communities should review the relevant MEP report for guidance on opportunities for a given embayment.

Existing Applications

Several towns on Cape Cod have successfully opened inlets or widened culverts in road stream crossings. The effects of restorations may be observed in Brewster, Barnstable, and Dennis, among many sites. Stony Brook Salt marsh restoration in Brewster was completed in 2013, and was designed to improve salt marsh, shellfish habitat, a fish run, and reduce invasive species over 41 acres (NOAA 2011).

Two culverts in West Barnstable, one under Route 6A and the other under the railroad bed, were replaced in 2003 and 2005, resulting in the restoration of 42 acres of salt marsh, fish run, shellfish habitat, and reduction of invasive species.

The Town of Dennis replaced the bridge over Sesuit Creek in 2008, improving salt marsh, shellfish habitat, a fish run, and reducing invasive species. Evidence of the impacts of restored salt water flushing within the wetland system can be observed from 6A, where the dead trunks of trees and fresh water shrubs are visible.

The Towns of Harwich and Chatham have partnered to replace the Route 28 Bridge over Muddy Creek, the shallow river defining the boundary between these two communities. The MEP Technical Report for Chatham watersheds (2003) identified the opportunity to improve tidal flushing and nitrogen attenuation within Muddy Creek by opening the culvert at this location. Harwich incorporated this restoration project into their CWMP as a means for reducing nitrogen loading, and Chatham and Harwich, together, have engineered the project and secured grant funding to assist with construction. The project is currently in the permitting phase.

The Cape Cod National Seashore, together with the towns of Wellfleet and Truro and other federal and state partners, has been studying alternatives for restoring the approximately 1,000 acre Herring River system in Wellfleet. This long term restoration planning project is currently in the midst of the MEPA and NEPA permitting processes (NPS, 2012). More information can be found at http://www.apcc.org/documents/pdfs/2-Herring_River_EIS-EIR_Chapters_1-5.pdf.

Costs

Costs for these types of projects will be highly variable, depending on the complexity of the project, land use issues, and construction costs. However, many projects have already been completed on Cape Cod, with others undergoing feasibility analysis, engineering or permitting. There are significant federal, state, and private dollars available to move these projects forward.

COASTAL HABITAT RESTORATION

- Achieves 5-12% nitrogen removal rate
- Provides passive treatment with minimal to no O&M
- Has numerous ecosystem benefits
- Nitrogen removal is typically a by-product of a restoration project pursued for other environmental benefits

How It Works

Coastal Habitat Restoration is a whole systems approach for managing coastal resources in locations where numerous benefits may be realized depending on the nature of the project. Coastal Habitat Restoration may result in improved water quality, restore a more natural hydrologic regime, increase quality and quantity of habitat, buffer estuarine pH levels through carbon sequestration, and improve natural sediment transport processes (NPS 2012 & NRCS 2011). Coastal Habitat Restoration may be achieved through natural resource management techniques including sediment management (beach or dune restoration), native plantings (upland, intertidal, and/or subtidal), removal of structures or dredging to restore tidal flow, and offshore reef creation or restoration (The Nature Conservancy). The goals of Coastal Habitat Restoration are to return coastal resources to a more natural balance: with the return of natural salinities and improved tidal exchange and with opportunities for sediment to move more naturally through a coastal system, native plant and animal species may return and thrive. With more naturally functioning coastal systems at work, Cape Cod benefits from the numerous ecosystem services provided by healthy aquatic, salt marsh, and beach and dune systems (NPS 2012).

Performance

Natural resource restoration provides nitrogen removal rates that are at the low end of the spectrum for the non-traditional approaches considered in the Section 208 Plan Update. It should be noted that much of the coastal restoration projects completed or currently underway on Cape Cod were initiated not for nitrogen removal goals, but for the numerous other benefits of habitat restoration. Consequently, Coastal Habitat Restoration should be considered as an approach in suitable locations where restoration will provide other benefits, as well as nitrogen management. Some benefits that may be realized from suitable restoration projects include water quality improvements, improved habitat, which may result in improved fisheries and economic benefits, and wave attenuation during coastal storm events, resulting in reduced flooding and coastal erosion.

Nitrogen removal rates will vary depending on pre-existing conditions and the scope and type of restoration implemented. The literature cites removal rates of between 5 and 15% (Carmichael et al. 2012).

Potential Performance Challenges

Coastal Habitat Restoration projects are very location-specific. For example, land managers seeking to restore tidal flow to an estuary where an undersized culvert or bridge has restricted flow for decades may find ecological, physical, and/or social acceptance challenges. The scope or geographic extent of a restoration project may be limited by development that has encroached on the former floodplain. In some locations full restoration of tidal flow cannot be implemented without flooding private properties or infrastructure. Similarly, ecological changes that have occurred over long periods of time may resist a quick return to a former vegetative community (e.g. freshwater wetlands to salt marsh) because the substrate is no longer present. Trees and shrubs that thrived in the freshwater environment will die from exposure to increased salinity from increased tidal exchange, and the resulting dead roots, trunks and branches may interfere with a smooth transition to salt marsh. In addition, members of the public may have difficulty accepting the transition of a fresh-water shrub swamp habitat supporting woodland fauna to open salt marsh, driving out the woodland flora and fauna in the process (and looking messy in the interim) (NPS 2012).

Similarly, managers seeking to establish or restore aquatic reef habitats may experience difficulties associated with establishing oyster reefs, managing disease, public health impacts from unauthorized consumption of shellfish from restoration sites, community acceptance of reef aesthetics, and conflicts with existing uses (such as boating or swimming).

Coastal managers that seek to restore beaches or dunes may experience management challenges if coastal sediment transport processes are not adequately understood. Improperly designed dredging or beach nourishment projects may fail to have the intended effect, may have only a temporary effect, and/or may have impacts on downdrift beaches, habitats, and properties.

Existing Applications

Experimental Restoration of an Intertidal Oyster Reef at Wellfleet Audubon in Wellfleet, MA: this project evaluated three methods of oyster reef restoration using cultch, reef balls, and oyster castles. More information can be found http://www.scseagrant.org/icsr10/faherty.poster.pdf.

An Oyster Propagation Project in Wellfleet Harbor, a partnership of Green Harbors Project, Town of Wellfleet, and Environmental Partners Group, is investigating a habitat restoration project near the outlet of Duck Creek in Wellfleet Harbor. The two acre project aims to establish 2.5 million oysters, improve commercial shellfish value, filter 140 million gallons of water daily, and attenuate 3,500 lbs of nitrogen per year. More information can be found at http://www.umb.edu/ghp/green_harbors/wellfleet_harbor.

Stony Brook Salt marsh and Fish passage Restoration project: With federal, state, local, and non-profit partners, the Town of Brewster replaced culverts under Route 6A at Stony Brook and near Freeman's Pond with the goal of restoring 41 acres of upstream salt marsh and herring run (NOAA, 2011). The project will also restore a failing dam to allow for fish passage. The project will improve the coastal ecosystem by improving water quality, salt marsh, and river herring and eel habitat.

The Herring River Restoration Project in Wellfleet, MA is a very large ecosystem restoration project currently under study and permitting. The Cape Cod National Seashore, the Towns of Wellfleet and Truro, and other partners, are pursuing restoration of approximately 1,000 acres of wetland and river system to salt water marsh and habitats. The project involves replacement of the dike and bridge at Chequessett Neck Road, as well as upstream dikes and culverts (NPS 2012). The project has undergone considerable study and public review.

Costs

These costs are highly variable, site-specific, and depend on the kind of restoration. The Natural Resources Conservation Service (NRCS), Cape Cod Office, prepared a Final Watershed Plan and Areawide Environmental Impact Statement in 2011 of 76 salt marsh and fish run restoration projects on Cape Cod. The program later received ~$30 million in American Recovery and Reinvestment Act (ARRA) funds to implement these projects. Some of these projects were completed; others have been put on hold following withdrawal of the federal funding.

FLOATING CONSTRUCTED WETLANDS

- Achieves nitrogen and phosphorus removal in estuaries and ponds.
- Provides passive treatment with minimal O&M.
- Utilizes recycled plastics for the base from which the wetlands grow.
- Can be used in conjunction with other non-traditional technologies for enhanced benefits.

Floating constructed wetlands are manmade structures that function like a natural wetland by removing nutrients from surface waters. The floating wetlands are made of porous, non-toxic recycled plastic mats. Vegetation is planted on the mats with the leaves growing above the mats and the roots hanging below the water surface. The floating islands provide an environment where nutrients and other compounds are removed from the underlying water body.

Potential applications include estuaries, lakes, ponds, and waterways that have been impacted by septic systems, stormwater, agricultural runoff and wastewater from WWTF discharges.

How It Works

Floating wetlands work like a hydroponic treatment system where nutrients and other compounds are removed from the water by plants. Floating wetlands are designed to work in fresh, and brackish waterways. Many of the nutrients removed from the waterways are converted to plant foliage and root material. However, the plant uptake only accounts for a portion of the nutrient removal. Within the plants root systems and the porous mats, a biofilm harboring beneficial bacteria and microbes removes a majority of the nutrients. The microbes consume nutrients that would otherwise be available to algae, reducing the likelihood of algal blooms.

The floating wetlands can be installed in lakes, streams, rivers, estuaries and marine environments and function well in almost any water depth and under a wide range of water quality; including WWTF lagoons. They can be installed along existing docks, or along the banks of water bodies, as anchored "islands", or as a dock where they can be accessed from land.

Performance

Studies of floating wetlands in WWTF lagoons show that nitrogen removal ranges from 8 to 15%. Phosphorus removal under similar conditions ranged from 0.5 to 1% of phosphorus in the surface water that flows through them. The amount of nitrogen removal can also be equated to the size of the floating wetland. For nitrogen, removal rates range from 0.1 to 2.5 pounds per year per cubic foot (lb/yr/ft3). Phosphorus removal rates range from 0.05 to 0.52 lb/yr/ft3 (Floating Islands International 2011).

Independent laboratory tests showed removal rates far in excess of previously published data: 20 times more nitrate, 10 times more phosphate and 11 times more ammonia, using unplanted islands.

The studies referenced were performed in WWTF lagoons at several facilities. Pilot testing and subsequent studies would need to be performed to establish the nitrogen load removal per cubic foot for floating wetlands in Cape Cod estuaries and ponds.

Potential Performance Challenges

The efficiency of the floating wetlands increases with water and air temperatures. For this reason, a majority of the nitrogen removal takes place during the spring, summer and fall months. Although the floating islands are relatively durable, damage during very high wind events or storm surges are possible. Icing conditions generally do not damage the floating wetland structures. Periodic maintenance of the plants is required. Shading of the lake or estuary bottom by the floating constructed wetlands should be assessed. In addition, removal rates may depend on water circulation within the water body, resulting in localized nitrogen removal effects.

Existing Applications

There are no known applications on Cape Cod. However, it is expected that the floating wetlands would function well on Cape Cod as installations in other areas of the country function well. Site selection should consider navigation and shading from bank vegetation.

EPA Region 1 recommends piloting floating constructed wetlands to determine their potential effectiveness for removing nitrogen loadings on Cape Cod.

Co-Benefits and Potential Use with other Non-Traditional Technologies

The biological activity of the floating wetlands not only uptakes nitrogen, but can also remove ammonia, phosphorus, biological oxygen demand (BOD), total suspended solids (TSS), and certain metals. They are also effective at reducing total suspended solids and dissolved organic carbon in waterways. As some microbes are capable of reducing the concentration of certain contaminants of emerging concern (CECs), there is the potential for CECs removal, although few papers were noted confirming and/or quantifying CEC removal. Floating constructed wetlands can be installed with water circulator or aeration systems, increasing flow in the water body. These systems increase flow through the plant's root zone which increases the efficiency of the nutrient uptake.

If water is circulated from deeper low oxygen zones, the increased circulation can increase oxygen levels in these layers while removing nitrogen. The increased water quality can improve habitat for aquaculture and coastal habitat restoration.

The root matrix underlying the floating wetlands also supplies beneficial food for fish and other organisms. By selecting specific plant species, floating islands can potentially provide habitat for birds, fish or other wildlife such as waterfowl, turtles, frogs, and otters. Plant selection can also include flowering species as well as fruiting plants and vegetables (Floating Islands International 2011).

Costs

The costs for floating wetlands include design, permitting, construction, monitoring and operation and maintenance. Design includes site characterization and baseline water quality sampling and analysis. Permitting is variable depending upon site location and scale. Construction costs also vary depending on size and where the floating wetland is installed (e.g. existing dock, an anchored "island" or along the bank of a water body). Operation and maintenance includes water quality monitoring and plant maintenance.

The following table (Table 4A-10) summarizes the estimated costs for two alternatives, a small and large floating wetland. A life cycle cost analysis was performed assuming annual testing, and monitoring with a 5 percent discount rate. The results of this cost analysis suggest that installations could achieve cost efficiencies of $40 to $70 per kilogram removed.

FLOATING CONSTRUCTED WETLAND COST COMPARISON		
	Scenario 1: Small	**Scenario 2: Large**
Size (cubic feet)	250	2,000
Estimated Nitrogen Removal (kg/yr)	100	800
Estimated Design and Permitting Costs	$20,000	$45,000
Estimated Construction Costs	$4,000	$50,000
Operation and Maintenance (cost/yr)	$2,000	$5,000
Sampling & Laboratory Analysis (cost/yr)	$10,000	$10,000
Reporting of Monitoring Results (cost/yr)	$15,000	$15,000

TABLE 4A-10 FLOATING CONSTRUCTED WETLAND COST COMPARISON (SOURCE: TECHNOLOGIES MATRIX)

SURFACE WATER REMEDIATION WETLANDS

- Achieves 70-95% nitrogen removal rate
- Sustainable technology, creating wetland habitats and improving biodiversity

How It Works

Surface Water Remediation Wetlands are constructed to aid in water quality improvements to surface water bodies, usually streams or rivers. Water is pumped or allowed to flow naturally through treatment cells containing wetlands. Surface water remediation wetlands are often used in combination with groundwater recharge or water reuse systems. Surface water remediation wetlands are generally used with Free Water Surface Wetlands due to their larger size, and lower capital and O&M costs. Siting these wetlands typically requires 5 or more acres, and sites which are topographically situated to facilitate natural water movement through the system. The design of these systems can incorporate public recreation amenities (US EPA June 1999; USEPA September 1999).

Performance

These systems are suitable for polishing water quality in impaired water bodies, providing water filtration and reduced turbidity while supporting the growth of native plant species and increasing habitat and biodiversity. The diversion of water flow through the treatment wetlands can help reduce scour and deposition, and can return an estuary to a more natural hydrologic regime. The creation of wetlands can also help mitigate coastal flooding in appropriate locations.

Many pollutants can be managed with these systems, including nitrogen and phosphorus, total suspended solids, biological oxygen demand, pH, suspended metals, total petroleum hydrocarbon, and pathogens (US EPA June 1999).

Potential Performance Challenges

These systems can require large land area adjacent to the river or estuary, and consequently are less efficient than other treatment types in removing nitrogen per unit land consumed. In addition, they are best employed in riverine systems where there is an existing large nutrient load; they will not capture groundwater inputs. Regulatory concerns include safeguarding the movement of aquatic organisms through these systems. In addition, removal rates may depend on water circulation within the water body, resulting in localized nitrogen removal effects.

Existing Applications

DesPlaines River Wetland Demonstration Project involved alterations to the river width, depth, sinuosity, and substrate to slow the movement of the water and direct it through emergent native plants. Water quality is enhanced by evapotranspiration, infiltration and recharge, and the greater detention time of the water in the system enhances sediment settling and nutrient uptake. More information can be found on the US Geological Survey website: http://www.npwrc.usgs.gov/resource/habitat/ripareco/desplain.htm or the Illinois Department of Natural Resources Website: http://www.dnr.illinois.gov/oi/documents/june08trialbywater.pdf.

The City of Arcata, California constructed a surface water treatment system in 1986 to remediate municipal primary treated discharge to Arcata Bay. Seven and a half acres of treatment wetlands process 2.9 million gallons per day (mgd). 31 acres of enhancement marshes provide further polishing, as well as habitat and recreational benefits for the community. A detailed case study of this project, as well as projects in West Jackson County, Mississippi, and Gustine, California, can be found in the US EPA Manual of Constructed Wetlands Treatment of Municipal Wastewaters.

Costs

Adjusted project costs are based on costs cited in a 1999 US EPA Manual on Constructed Wetlands Treatment of Municipal Wastewaters and can range from $426,000 - $510,000 per acre. Adjusted annual O&M costs can range from $3,000 - $8,000 an acre. The useful life of these projects is approximately 20 years.

POND AND ESTUARY DREDGING

- 80-95% nitrogen and phosphorus removal rates from the sediments removed
- Can return relatively quick water quality improvements (0.5 – 1 year)

How It Works

Lakes, ponds, streams and estuaries store nutrients within their sediments. These sediments tend to accumulate over time. Later, these nutrients can be released into the overlying water column and can become a major source of nitrogen and phosphorus. Removing these nutrient-laden sediments through dredging removes the nutrients from the water body, and potentially the watershed.

Performance

The effectiveness of this nutrient management approach can vary and is site-specific. The type and concentration of nutrients to be managed will depend on inputs to the water body, the length of time that nutrients have accumulated, ecology of the water body, and other factors.

Potential Performance Challenges

While this technology may have application in particular situations, a number of factors should be considered. Dredging can be highly disruptive to biological communities, so the nature of the plant and wildlife species (including state-listed rare species) present in the water body should be carefully evaluated. Also, in nutrient-rich waters not subject to tidal flushing, excavation (creation of a larger "holding tank") can actually increase residence time, and consequently not result in water-quality improvements. Dredging projects should be carefully modeled to understand potential improvements; in some settings, the small changes in volume will not provide significant improvements (MEP 2006). In addition, sediments should be tested and appropriate disposal areas identified. Depending on contaminants present within the bottom sediments, disposal of sediments may be costly.

Permitting for these projects can be involved, lengthy, and costly. State permitting agencies will be looking at disruption of fish habitat, the consequences of conversion of fresh water habitats to saline, impacts to rare species, as well as anticipated water quality improvements. Consequently, extensive biological, hydrological, hydraulic, and water quality assessments will be required. Most dredging projects will require Massachusetts Environmental Policy Act review, an Order of Conditions, Section 401 Water Quality Certificate, Chapter 91 Waterways Permit, and possibly a permit under the Massachusetts Endangered Species Act.

Existing Applications

This nutrient management approach is approved for use in Massachusetts, though a pilot project(s) is needed to evaluate its effectiveness for nitrogen removal.

The Town of Wellesley, MA recently dredged a portion of Morses Pond for the purposes of restoring the pond's detention capacity, allowing sediment entering the pond to settle, and improving pond clarity and health. More information can be found at http://www.wellesleyma.gov/pages/wellesleyma_nrc/Morses%20Pond%20Dredging%20Project.

A 2008 study of Long Pond in Tewksbury, MA assessed opportunities for improving the water quality of the pond in the interest of improving access and aesthetics. Many factors were evaluated, and among the recommendations was adoption of a town bylaw that would track commercial application of fertilizers. More information can be found at http://www.tewksbury.info/Pages/TewksburyMA_BComm/CPC/long.pdf.

Costs

Adjusted project costs range from $210 - $252 per cubic yard removed. Adjusted annual O&M costs range from $6 - $11 per cubic yard. The useful life of a dredging project is 25 years, though this will vary depending on the specifics of the project.

Conventional Wastewater Treatment Methods

INTRODUCTION

There are many conventional methods for treating wastewater, which are reviewed in the following section. Technologies or approaches discussed include primary and secondary treatment, conventional activated sludge, pure oxygen activated sludge, trickling filters, rotating biological filters, aerated lagoons, physical-chemical treatment, land application, reverse osmosis, granular activated carbon, several methods of disinfection, several methods of phosphorous reduction, and intermittent sand filters.

Basically, there are three degrees of sewage treatment available: primary, secondary, and advanced treatment. The type of treatment to be used depends upon the amount of pollutants to be removed from the wastewater. Pollutants in sewage are present in the form of both solid material and dissolved material. Primary treatment is intended to remove approximately 50 percent of the pollutants in sewage, primarily solid material that can be easily screened or settled out of the wastewater. Secondary treatment removes 85 to 95 percent of the pollutants in sewage, including almost all of the solid material and a major portion of the dissolved material. Advanced treatment, sometimes called tertiary treatment, is a polishing step added to secondary treatment. Advanced treatment results in the removal of between 95-98 percent of the pollutants in sewage.

PRIMARY TREATMENT

Primary treatment is strictly a physical process that removes about 50 percent of the solid material in domestic wastewater. The process involves the use of bar racks (screens) and other simple equipment to remove materials such as stones, sticks, sand, etc., which if not removed could damage downstream mechanical equipment, such as pumps. This is followed by a clarification or settling step, which allows the wastewater to remain in a clarifier tank for several hours without disturbance. This sedimentation process allows solid material such as paper, garbage, human waste, etc. to settle to the bottom of the tank to be collected and disposed of. This settled material is commonly called sludge. Following clarification, the wastewater is treated with a disinfectant, typically chlorine, to kill the harmful bacteria before being discharged into the ground or a surface water body.

SECONDARY TREATMENT

Secondary treatment, which is the minimum treatment level required by the Federal Government, generally consists of adding a biological process onto primary treatment. Some explanation of the term "biological process" may be helpful at this point. Sewage contains countless numbers of living organisms, mostly bacteria, and the success or failure of the biological method of treatment is dependent upon the activity of the bacteria. The bacteria, called microorganisms, utilize the organic matter (pollutants) in sewage as food and thus are able to generate additional microorganisms, through reproduction. The conversion of the food to microorganisms is the initial phase in biological treatment, but as the available food becomes limited the bacteria population declines.

As this process continues the food becomes scarce and microorganisms eventually die off. Ideally, this process could continue until all of the pollutants and microorganisms were gone; however, this process is very slow. In order to utilize this process as an acceptable treatment method, it must operate continuously and sufficient numbers of microorganisms must be available to rapidly remove the pollutants from the sewage. Thus, it is necessary to add more microorganisms and to distribute them throughout the sewage. This is accomplished through the use of activated sludge. The bacteria that remove the pollutants from sewage require oxygen to live. With the large numbers of bacteria required to purify sewage, it is necessary to add oxygen or air to the wastewater. This is done by containing the sewage in tanks and aerating via mechanical mixers (aerators), diffuse aeration, etc.. The sludge which is settled out after aeration is a food source which microorganisms can use to multiply to maintain a large enough "population" to continue to remove pollutants from the sewage.

This sludge which is present in the aeration tanks is known as activated sludge. It is returned to the aeration tank in several types of activated sludge processes to increase the number of organisms and the efficiency of this process. The only ingredients that the typical biological process requires is oxygen, food and sufficient microorganisms to effectively operate the system. Another method of secondary treatment, which differs from the biological process, is a physical-chemical system. This type of treatment process depends upon chemical addition followed by sedimentation and some type of filter, for example a sand filter. The following discussion presents a brief description of several types of secondary treatment processes commonly used. These processes are called:

- Conventional Activated Sludge
- Pure Oxygen Activated Sludge
- Trickling Filters
- Rotating Biological Filters
- Aerated Lagoons
- Physical-Chemical Treatment
- Land Application

CONVENTIONAL ACTIVATED SLUDGE

With conventional activated sludge, wastewater entering an aeration tank is mixed with a concentrated mixture of microorganisms and treated wastewater. This provides a colony of microorganisms that consume the pollutants (food) in the sewage and reproduce new microorganisms, gases and water. Oxygen which is needed by the microorganisms to live is supplied to this mixture from a grid of submerged air diffusers or by means of a mechanical mixer at the surface of the water. The air supply also provides for the mixing of the contents of the tank to keep the microorganism mass suspended in the tank. After passing through the aeration tank, the flow goes to the secondary settling tanks (clarifiers) where the suspended material is allowed to settle out of suspens1on and then is collected for return to the aeration tank. A portion of this suspended material is withdrawn from the system in order to maintain a microorganism balance in the aeration tank. This excess material, which is called sludge, is pumped to the sludge handling area where it is processed and disposed of. The wastewater leaving the secondary clarifiers goes on to the disinfection phase of treatment. After disinfection (destruction of bacteria and some viruses) the effluent is discharged to a receiving stream, or other appropriate site.

PURE OXYGEN ACTIVATED SLUDGE

This system is very similar to the conventional activated sludge process with the major difference being the. use of pure oxygen rather than air for bacterial activity. This allows for a more concentrated suspended growth of bacteria as oxygen is more readily available in the system. Normal waste loadings for the aeration tank are four to six times those of conventional systems. These higher waste loadings in conjunction with more concentrated suspended bacterial population result in smaller aeration tank volumes and a reduction in waste sludge production due to the higher rate of treatment by the microorganisms. The reduction in tankage volume results in a more compact system that typically requires less land than the conventional process, however the costs are typically greater for the pure oxygen system, due to the type and complexity of the necessary equipment. This type of system is not generally economical for small treatment facilities.

TRICKLING FILTERS

A trickling filter consists of a circular tank, approximately six (6) to ten (10) feet in depth filled with a natural or synthetic material. The bottom of the tank is covered with perforated drainage tiles that allow wastewater to pass through while retaining the filter material in the tank. The filter material normally consists of small diameter crushed stone or a manufactured plastic honey- comb type of material which provides the ability to increase the depth of the tank, increases surface area and enhances treatment levels and efficiency. The wastewater is applied to the filter by a rotating distributor arm that applies the wastewater evenly over the filter material in a coarse spray. As the wastewater flows over the filter material in a thin film, a bacterial slime growing on the material utilizes the organic matter and oxygen in the wastewater to produce more bacteria that purify the sewage. Treated wastewater flows to the bottom of the tank where it is collected and flows to the secondary clarifiers. Any excess bacterial growth that is washed off of the filter materials flows to the secondary clarifiers with the treated wastewater. This excess bacterial slime is collected in the clarifiers and returned to the filters or disposed of as excess sludge. Depending on the degree of treatment required, the treated wastewater can be recycled to the filter for additional treatment or allowed to continue to the disinfection phase. The overall advantage of trickling filters is the lower operation and maintenance costs in comparison to activated sludge or physical/chemical systems, but the drawbacks of reliability, flexibility and land requirements often out- weigh the systems advantages.

ROTATING BIOLOGICAL FILTERS

A rotating biological filter, often referred to as a Bio-Disc, is a series of thin plastic discs mounted on a horizontal shaft at a very narrow spacing interval. The shaft is mounted above a rectangular tank that wastewater flows through. The discs on the shaft are approximately 40 percent submerged, area wise, at any one time as the shaft is rotated. Each disc is alternatively exposed to the wastewater stream and then the atmosphere. Biological growths establish themselves on the discs and convert the wastewater to new growth, which removes pollutants from the sewage, as occurs in a trickling filter. The size of the tank, the number of discs per shaft and the number of shafts per tank depends on the wastewater strength, degree of treatment required, and design flow. The flow passes from this reac-tion tank to the clarifier, where solids separation occurs. All or part of the flow can be recycled for further treat-ment or disinfected and discharged. The Bio-Disc is a modern adaption of the trickling filter. The concept of operation is the same in both pro-cesses, with the disadvantages of the trickling filter being eliminated to a degree by the advanced design of the Bio-Disc system. Unfortunately, the primary advantages of trickling filters, low power consumption and ease of oper-ation, were also designed out of the system. While power consumption is still less than the activated sludge processes it is not substantially different and the Bio-Disc system is a labor intensive system due to the numerous small motors and shaft units. In addition, the problem of adverse weather and industrial wastewater, which can upset the treatment process, still exists though not in the degree that is pre- sent with conventional trickling filters.

AERATED LAGOONS

An aerated lagoon is a simplified adaptation of an activated sludge system. Rather than utilizing concrete aeration tanks, lagoons consist of earth dikes and may or may not have a lining. Waste flow and treatment in the lagoon is similar to a conventional activated sludge system. The wastewater must be treated for a much longer time in a lagoon system which is less efficient than the conventional activated sludge system. Air is transferred to the wastewater by means of either fixed or floating mechanical aerators. As the lagoons are much larger than aeration tanks, mixing of the wastewater is not as complete as in the conventional system. The degree of treatment and reliability of the system is not comparable to the conventional activated sludge system and the flexibility of a lagoon system is lowThis is due to the lack of treatment process control inherent in the system. Lagoons are primarily used for strictly domestic or industrial wastes where volumes of wastewater are not excessive and land is readily available. As the degree of treatment is dependent on the length of time the sewage is retained in the lagoon, stricter treatment requirements would mean increased land area. Power costs are lower than other acti-vated sludge systems but not as low as might be expected for a relatively simple system.

PHYSICAL-CHEMICAL TREATMENT

Physical-Chemical treatment is entirely different from the previous forms of treatment in that biological activity is not a factor in the removal of pollutants. Wastewater 1s treated with chemicals, principally lime, and then subjected to both rapid and slow mixing to form a solid material consisting of the added chemical and the solids in the wastewater. This material is called floc. The wastewater, containing the floc, passes to the clarifiers where the floc settles out and can be withdrawn as a sludge. This process is repeated to remove all of the settleable material possible. The effluent from the secondary clarifier is applied to either a sand or other type of filter to remove the finer particles which were not removed by settling. The resultant effluent is very low in solid pollutants. Disinfection prior to discharge is usually practiced. A physical-chemical system will produce a high quality effluent from a plant that requires m1n1mum land use. This type of system requires a high degree of skill to operate and overall operation and maintenance costs are also high.

LAND APPLICATION

Land application of wastewater is just what it implies. Wastewater is applied to the ground in one of three ways: spraying, flowing over the ground, or filtering into the ground via sand beds. Each process has its advantages, but the discussion will be limited to the spraying of wastewater on the ground or sprav irrigation, which 1s the most popular method presently in use. Wastewater can be sprayed after primary settling, but most regulatory agencies require some form of secondary treatment prior to application. The most common form of secondary treatment prior to application is aerated lagoons due to their moderate costs. A typical spray irrigation system consists of storage lagoons, an irrigation pump ng system and the actual spray nozzles and pipe grid. The system is usually constructed at a location where some sort of agricultural activity occurs, or at a wooded site. These sites enable the treated sewage to be re-absorbed from the ground by the plants providing for a system of nutrient removal. If the irrigation system is constructed in conjunction with an agricultural activity, crop harvesting must be part of the system to assure nutrient removal. Spray irrigation of treated wastewater is a combination of advanced treatment and wastewater reuse and is really a higher degree of treatment than would be required for most situations. Also, its application in a moderate to severe climate, such as in northern New England, requires storage lagoons for treated wastewater for a minimum of several months during the winter, when it would not be possible to spray the wastewater without major freezing problems. Environmentally, land application is the ideal form of sewage treatment, as there is no effluent discharge to a stream but rather natural filtration and groundwater recharge. Realistically, it could result in degradation of the groundwater if nutrient uptake was not accomplished. In addition it is not a flexible system, as the pretreatment by lagoons is not necessarily sufficient for a stream discharge in the event of a failure in the land application system, and no storage lagoon space available.

The following chart compares the secondary treatment processes described (Table 4A-11). This comparison is a general one and realistic comparisons can only be made on a case-by-case basis depending on the particular type of wastewater treatment problem involved.

COMPARISON OF SECONDARY TREATMENT PROCESSES							
	Conventional Activated Sludge	**Pure Oxygen Activated Sludge**	**Trickling Filters**	**Aerated Lagoons**	**Rotating Biological Filters**	**Physical-Chemical Treatment**	**Land Application**
Compatibility with Industrial Wastes	Good	Good	Poor	Good	Fair	Good	Poor
System Flexibility	Good	Good	Fair	Poor	Fair	Fair	Poor
Operation	Good	Good	Fair	Good	Fair	Good	Good

and Maintenance Reliability							
Process By-Products	Sludge	Sludge	Sludge	Sludge	Sludge	Sludge	Sludge
Operation under Adverse Weather Conditions	Good	Excellent	Poor	Poor	Poor	Good	Fair
Ability to meet future increase in effluent quality restrictions	Good	Good	Fair	Poor	Fair	Good	Good

TABLE 4A-11 COMPARISON OF SECONDARY TREATMENT PROCESSES

REVERSE OSMOSIS

Reverse osmosis (RO) uses a semipermeable membrane to remove larger particles and many types of molecules and ions from solutions, including bacteria, from a raw water supply used for drinking water or wastewater effluent prior to discharge to a surface water or groundwater or for effluent reuse. In reverse osmosis, an applied pressure is used to overcome osmotic pressure, a colligative property that is driven by chemical potential, a thermodynamic parameter. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side.

GRANULAR ACTIVATED CARBON

Granular activated carbon (GAC) is used to adsorb the relatively small quantities of soluble organics and inorganic compounds such as nitrogen, sulfides, and heavy metals remaining in the wastewater following biological or physical-chemical treatment. This adsorption process has been used successfully for the advanced (tertiary) treatment of municipal and industrial wastewater. The molecules of the organics and inorganic compounds adhere to the internal walls of pores in carbon particles. A fixed bed down-flow column vessel is often used to contact wastewater with the carbon. Wastewater is applied at the top of the column, flows downward through the carbon bed, and is withdrawn at the bottom of the column. The carbon is held in place with an underdrain located at the bottom of the vessel.

DISINFECTION

Disinfection is considered a primary mechanism for inactivating/destroying pathogenic organisms and preventing the spread of waterborne diseases to downstream users and the environment. Typical disinfection standards for secondary and tertiary wastewater, such as 200 Fecal Coliforms per 100 mL on a 30 day geometric mean, can be achieved with a properly designed and operated disinfection system. Wastewater must be adequately treated prior to disinfection in order for any disinfectant to be effective. Two if the most commonly used processes for disinfection include: (1) chlorine; and (2) ultraviolet (UV) radiation.

Chlorine

Chlorine is a widely used disinfection for wastewater because it destroys target organism by oxidizing cellular material as wells as controlling nuisance organisms such as iron-reducing bacteria, slime, and sulfate-reducing bacteria (see Table 4A-12). Chlorine can be supplied in many forms including chlorine gas, hypochlorite solutions and chlorine compounds in both solid and liquid form. Chlorine is a disinfectant that has certain environmental, health and safety limitations but has a long history of being and effective disinfectant .

CHLORINATION	
Advantages	**Disadvantages**
Reliable and Effective Method	Highly Corrosive and Toxic
Dosing Rates are Flexible and Can be Controlled Easily	High Operator Safety Hazards
Cost-Effective as Compared to Other Methods	Typically Requires Dechlorination
Chlorine Residual Allows for Prolonged Disinfection	Wastewater with High BOD May Require Higher Doses for Adequate Disinfection
	Can Creating Hazardous Compounds

TABLE 4A-12 CHLORINATION ADVANTEGES AND DISADVANTAGES

Ultraviolet Radiation

The effectiveness of a Ultraviolet (UV) Radiation disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration (see Table 4A-13). The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV radiation is either the low-pressure or medium-pressure mercury arc lamp with low or high intensities.

The most common UV system used is a low-pressure, low-intensity system which signifies the pressure of the mercury in the lamp, which is typically 13.8 Pa (0.002 lbs/in^2). The term intensity refers to the lamp power. Standard low-pressure, low-intensity lamps typically have a power of 65 watts. These lamps are generally efficient in producing germicidal wavelengths necessary for damaging DNA in bacteria. The low-pressure, low-intensity lamp typically has 40 percent of its output at 253.7 nm, which is within the ideal range for inactivating bacteria. This type of system can be configured vertically or horizontally.

UV is an ideal disinfectant for wastewater since it does not alter the water quality except for inactivating microorganisms. UV is a chemical-free process that can inactivate chlorine-resistant microorganisms like Cryptosporidium and Giardia. Unlike other chemical disinfectants, UV does not produce any carcinogenic disinfection by-products that could adversely affect the water quality.

UV RADIATION	
Advantages	**Disadvantages**
Physical process rather than a chemical disinfectant	High/Inconsistent Turbidity and TSS Impacts Effectiveness
No Residual Effects	High Energy Usage
Less Space Required as Compared to Other Disinfection Methods	Low Dosages may not effectively inactivate some viruses, spores, and cysts
Effective Inactivation of Most Viruses, Bacteria, and Spores	Potential for Photo Reactivation
Short Contact Time	Potential Release of Mercury from Lamp Bulbs, if Damaged
	Requires Protection from UV Light

TABLE 4A-13 UV RADIATION ADVANTEGES AND DISADVANTAGES

PHOSPHOROUS REDUCTION

In general, wastewater entering a municipal wastewater treatment facility contains 5 to 20 mg/L of total phosphorous, consisting of about 1 to 5 mg/L of organic phosphorous and the remainder being inorganic phosphorous. The usual forms of phosphorous found in aqueous solutions include orthophosphates and polyphosphates. Normally conventional secondary treatment results in effluent total phosphorous concentrations of about 1 to 2 mg/L. These levels still result in causing eutrophication in the surface waters bodies.

Various treatment technologies exist to remove phosphorous to low levels in the wastewater. The removal of phosphorous from wastewater involves the incorporation of the phosphate into the waste solids and the subsequent removal of these solids. Phosphorous can be incorporated into either chemical precipitates or biological solids (e.g. microorganisms). Treatment technologies are grouped into the following three categories: (1) chemical precipitation; (2) biological; and (3) physical.

CHEMICAL PRECIPITATION

Chemical precipitation removes the inorganic forms of phosphate by the addition of a coagulant (chemical) and mixing the chemical with the wastewater. Chemical precipitation can reduce effluent total phosphorous concentrations to about 0.5 mg/L but is expensive and increases sludge volumes by up to 40 percent (see table 4A-14). Chemical precipitation has been a very common method for the reduction of phosphorous in wastewater. Dosages are generally established on the basis of bench-scale tests and occasionally by full-scale tests, especially if polymers are used. Chemical addition can adversely affect the microbial population in activated sludge, especially protozoa and rotifers, especially at higher dosages. However this does not affect much either BOD or TSS removal, as the clarification function of protozoa and rotifers is largely compensated by the enhanced removal of suspended solids by chemical precipitation.

Reduction of phosphorous can occur by addition of chemicals at various locations of the liquid stream of a wastewater treatment facility including during the treatment of raw wastewater or the biological process (co-precipitation). However, cost effective reduction of phosphorous typically occurs when multi-point chemical addition is utilized.

A significant amount of phosphorous can be removed with 90 percent efficiency resulting in a relatively low phosphorous concentration. Typically the chemical dosage for phosphorous removal is about the same as the dosage needed for BOD and SS removal, which uses the main part of these chemicals. However, while utilizing high dosages of chemicals at this stage results in increased solids removal, it also reduces the amount of food required for the biological process of the facility. Refer to Figure 4A-2.

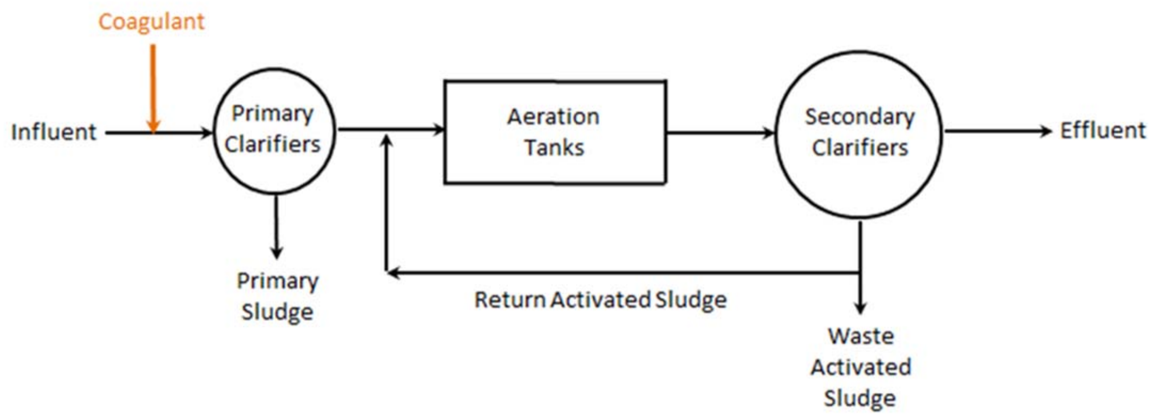

FIGURE 4A-2 TREATMENT OF RAW WASTEWATER SCHEMATIC

Biological Process

The biological or co-precipitation process, is particularly suitable for active sludge plants, where the chemicals are fed directly into the aeration tank or just before it. The continuous sludge recirculation, together with the coagulation-flocculation and adsorption process due to active sludge, allows a reduction in chemical consumption. In this process the chemical added typically consists of are only iron and aluminum with lime only being added for pH correction. The phosphorous concentration in the final effluent is about 1 mg/L. Additional chemical addition into the effluent can result in phosphorous concentrations from the secondary clarifier effluent of about 0.5 mg/L. Refer to Figure 4A-3.

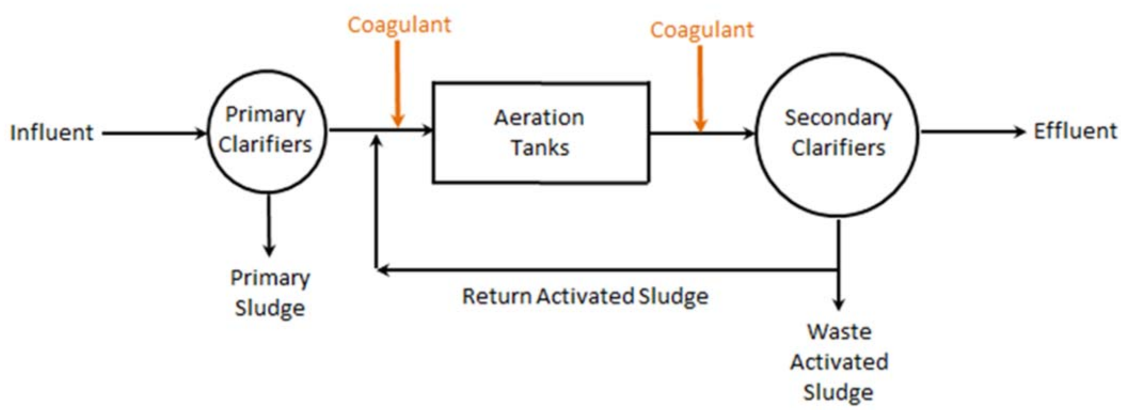

FIGURE 4A-3 BIOLOGICAL PROCESS SCHEMATIC

The most commonly used chemicals are metal ions including calcium, aluminum and iron.

Calcium

Calcium addition to the wastewater using lime is typically a cost effective method. Lime reacts with the natural alkalinity in the wastewater to produce calcium carbonate, which is primarily responsible for improving suspended solids removal. Once the pH increases beyond 10, excess calcium ions reacts with the phosphate. Since the reaction is occurring between the lime and the alkalinity of the wastewater, the quantity of lime required is typically independent of the amount of phosphate present. Therefore, the quantity of lime required will depend primarily on the alkalinity of the wastewater.

Two major disadvantages exist with the use of lime. The first disadvantage is that since the pH has been increased above typical effluent pH requirements (6.5 to 8.0), neutralization of the wastewater is required resulting in additional chemical operation and maintenance. The second disadvantage is the operation and maintenance of the lime storage and feed system which can be very labor intensive. Although sodium hydroxide can be utilized as a substitute for lime addition, its purchase cost has typically cost prohibitive.

Aluminum

Aluminum or hydrated aluminum sulfate is a chemical compound with the formula $Al_2(SO_4)_3$. It is sometimes referred to as Alum. Aluminum sulfate causes impurities to coagulate which are removed as the particulate settles to the bottom of the clarifiers or removed via effluent filters. This process is called coagulation or flocculation. The basic reaction is: $Al^{3+} + H_nPO_4^{3-n} \leftrightarrow AlPO_4 + nH^+$.

This reaction is deceptively simple and must be considered in light of the many competing reactions and their associated equilibrium constants and the effects of alkalinity, pH, trace elements found in wastewater. The dosage rate required is a function of the phosphorous removal required. The efficiency of coagulation falls as the concentration of phosphorous decreases. In practice, an 80 to 90 percent removal rate is achieved at coagulant dosage rates between 50 and 200 mg/L.

Iron

Ferric chloride or sulphate and ferrous sulphate also known as copperas, are all widely used for phosphorous removal, although the actual reactions are not fully understood. Ferric ions combine to form ferric phosphate which is removed via settlement. The basic reaction is: $Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4 + nH^+$.

They react slowly with the natural alkalinity and so a coagulant aid, such as lime, is normally add to raise the pH in order to enhance the coagulation process.

CHEMICAL PRECIPITATION	
Target - Reduce Phosphorous levels to less than 1.0 mg/L	
Advantages	**Disadvantages**
Simple	Impacted by Commodities Market
Not Impacted by Process Upsets	Increased Safety Issues
Allows Multiple Injection Locations	Increased Solids Handling

TABLE 4A-14 CHEMICAL PRECIPITATION ADVANTEGES AND DISADVANTAGES

BIOLOGICAL

Biological phosphorous removal can be achieved by the use of various biological suspended growth process configurations. The major advantages of biological phosphorous removal are a reduction in chemical costs and sludge production as compared to chemical precipitation. The major disadvantage biological phosphorous removal is the potential loss of phosphorus removal due to a biological system upset. Biological phosphorous removal involves the incorporation of the phosphorous which exists in the influent wastewater into the cell biomass. This is accomplished by adding an anaerobic tank sometimes called a "selector basin". The retention time in the selector basin is typically 1-½ to 2 hours of the average daily flow.

The selector basin is typically divided into three compartments. The first compartment receives return activated sludge from the secondary clarifiers, the second compartment receives influent wastewater or, if utilized, primary clarifier effluent, and the third compartment provides additional retention time. This configuration provides the phosphorous accumulating organisms with a competitive advantage over other bacteria. Upon reaching the aeration tanks, the phosphorous accumulating organisms are encouraged to grow and consume phosphorous and are subsequently removed from the process as a result of sludge wasting in the secondary clarifiers. Refer to Figure 4A-4.

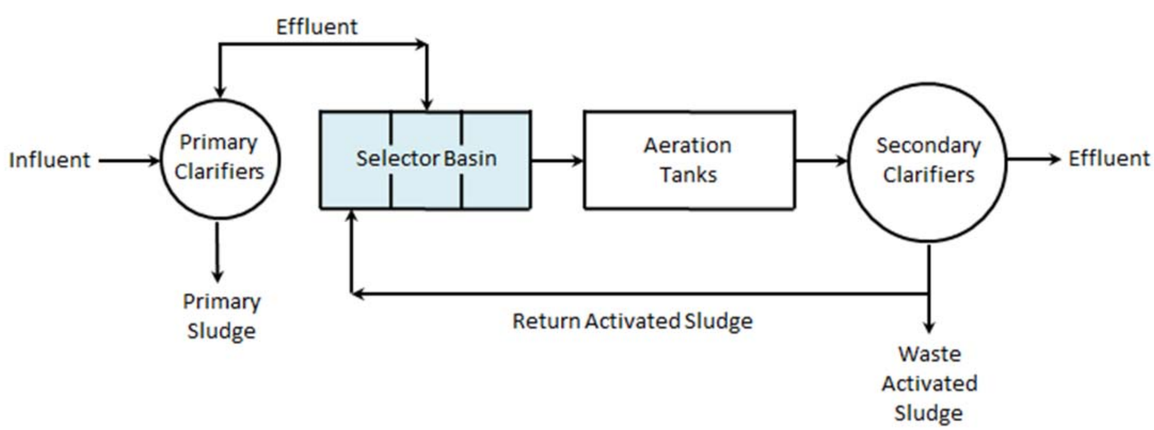

FIGURE 4A-4 BIOLOGICAL PHOSPHOROUS SCHEMATIC

The amount of phosphorous removed by a biological basin can be estimated from the amount of COD that is available in the wastewater influent. Better performance of biological phosphorous removal systems is achieved when COD acetate is available at a steady rate (Table 4A-15).

BIOLOGICAL	
Target - Reduce Phosphorous levels to less than 1.0 mg/L.	
Advantages	**Disadvantages**
Low O&M Cost	Prone to Process Upsets
Simple Operation	Dependent on Influent Characteristics
Improves Biological Process	Dependent on WWTF Process Performance

TABLE 4A-15 BIOLOGICAL ADVANTEGES AND DISADVANTAGES

PHYSICAL

Filtration

Filtration is a mechanical or physical operation which is used to separate solids from liquids by interposing a medium through which only the liquid can pass. The liquid that pass through is called a filtrate while oversize solids in the liquid are retained. It does not result in a complete separation of the liquid and solids as the solids will contain some liquid and the liquids will contain some solids both of which depends on the pore size and filter thickness (Table 4A-16).

FILTRATION	
Target - Reduce Phosphorous levels to less than 0.2 mg/L.	
Advantages	**Disadvantages**
Reliable Operation	May Be Impacted by Process Upsets
Simple and Operator Friendly Technology	High Headloss
Enhances Disinfection Performance	May Require Pumping

TABLE 4A-16 FILTRATION ADVANTEGES AND DISADVANTAGES

Ballasted Flocculation

US EPA's Wastewater Technology Fact Sheet defines ballasted flocculation or high rate clarification as a physical-chemical treatment process that uses continuously recycled media and a variety of additives to improve the settling properties of suspended solids through improved floc bridging. The objective is to form micro-floc particles with a specific gravity of greater than two. Faster floc formation and decreased particle settling time allow clarification to occur up to ten times faster than with conventional clarification, allowing treatment of flows at a significantly higher rate than allowed by traditional unit processes (Table 4A-17). Four common processes are: (a) BluePRO™; (b) Siemens - CoMag™; (c) AquaDAF™; and (d) ACTIFLO®.

- **Blue Water – Blue PRO™**
  The BluePRO™ process is a physical and chemical treatment process, which combines co-precipitation and adsorption. The technology uses an automatically regenerating up-

flow filter for solids removal. The filter has continuous flow, which allows constant operation without having to shut down for backwashing. The Blue PRO™ process uses ferric oxide coated sand through two continuously operating up-flow filters to remove phosphorus through adsorption and filtration of precipitated particles. This process requires a steady dosing of ferric chloride to continuously regenerate the sand for proper operation. This process can produced phosphorus concentrations below 0.1 mg/L but upstream process upsets can result in problematic operation resulting in phosphorus concentrations of over 1.0 mg/L in the effluent of the first filter. Using a second filter, directly following the first filter, is required to achieve low levels of phosphorus (<0.05 mg/L).

- **Siemens - CoMag™**
  The Siemens - CoMag™ process uses magnetite (Fe_3O_4) as a ballast to assist in settling of flocculated particles. Siemens - CoMag™ uses ballasted flocculation, solids contact and high gradient magnetic separation to enhance phosphorus and suspended solids removal. Metal salt is added to the wastewater and the pH is adjusted. The wastewater is mixed with fine magnetic ballast to increase floc density and permit floc removal using a magnetic separator. The tiny magnetic particles, with a specific gravity of approximately 5.2, are enmeshed into the floc and function as magnetic handles and weighting agents. Polymer addition enhances flocculation. The ballasted flocs settle rapidly in a small clarifier. Most of the solids are recirculated to the reaction tanks and the rest are removed as sludge. The clarified effluent passes through a magnetic separator in a final polishing stage to remove flocs that escaped the clarifier. The ballast is recovered from the sludge in a recovery drum separator and recycled to the reaction tanks. The phosphorus-containing sludge is removed from the system at the recovery drum. This process can operate with ferric chloride, aluminum sulfate, and poly-aluminum chloride to consistently achieve concentrations of phosphorus below 0.1 mg/L. The process uses higher concentrations of polymer (3.0 mg/L) and coagulant to reach the low concentrations of phosphorus without the assistance of a polishing magnet. Using a polishing magnet typically produces low phosphorus concentrations (<0.05 mg/L).

- **IDI - AquaDAF™**
  The AquaDAF™ process used air injection to float flocculated particles to the surface, as opposed to settling Dissolved air flotation (DAF) is a clarification process in which destabilized particles are removed by attachment to air bubbles and are floated to the water surface and removed. DAF has been shown to be effective in the removal of low-density particles such as iron- and aluminum hydroxide flocs and algae. In the DAF process, chemically treated water is flocculated in mechanical flocculation basins where particles are created for subsequent removal in the DAF clarifier. After the flocculation state (typically 10 to 15 minutes), water enters the DAF clarifier where a supersaturated air-water stream is injected resulting in the release of micro-bubbles. The formed bubbles attach to particles floating them to the surface where they are removed. Typical DAF loading rates are limited to less than 10 gpm/sf because the down-flow velocity of the water is greater than the rise rate of the bubbles. However, the high-rate AquaDAF process utilizes a false-floor as a bubble collector enabling loading rates exceeding 10 gpm/sf. The sludge "blanket" created by the rising air bubbles, will be removed through hydraulic flooding. This process operates with ferric chloride to achieve consistent concentrations of phosphorus below 0.1 mg/L. Alternative coagulants such as aluminum sulfate and poly-aluminum chloride can be used be typically results in slightly higher phosphorus concentrations. This process requires filtration to consistently achieve low

concentrations of phosphorus (<0.05 mg/L).

- **Kruger - ACTIFLO®**
  The ACTIFLO® process is a ballasted flocculation system with microsand injection for additional sedimentation. used microsand as a ballast to assist in settling of flocculated particles. The high rate flocculation system contains basins for coagulation, microsand and polymer injection and maturation of the ballasted floc particles. A settling basin with tube settlers is also included for the removal of settleable particulate material. The microsand is removed using hydrocyclone pumps, which separates the microsand from the sludge with centrifugal forces. This process can operate with ferric chloride, aluminum sulfate, and poly-aluminum chloride to achieve consistent concentrations of phosphorus below 0.1 mg/L. This process requires filtration to consistently achieve low concentrations of phosphorus (<0.05 mg/L).

BALLASTED FLOCCULATION	
Target - Reduce Phosphorous levels to less than 0.1 mg/L	
Advantages	**Disadvantages**
High Removal Capabilities	High Capital and O&M Costs
Well-Suited for Lower P Limits	Increased Sludge Handling
Flexible and Ability to Phase Operation	May Require Pumping

TABLE 4A-17 BALLASTED ADVANTEGES AND DISADVANTAGES

Membrane

Membrane bioreactor (MBR) is the combination of a membrane process like microfiltration or ultrafiltration with a suspended growth bioreactor, and is now widely used for municipal and industrial wastewater treatment facilities. Municipal wastewater treatment facilities continue to MBR technology due to two advantages over conventional biological wastewater treatment-improved effluent quality and a smaller footprint. When coupled with membranes, biological and chemical phosphorous removal methods can be employed to meet total phosphorous effluent limits of less than 0.1 mg/L. Phosphorus precipitation, combined with the positive barrier the membrane provides, reduces the amount of phosphorus and suspended solids in the wastewater effluent (Table 4A-18).

It is possible to operate MBR processes at higher mixed liquor suspended solids (MLSS) concentrations compared to conventional settlement separation systems, thus reducing the reactor volume to achieve the same loading rate. Two MBR configurations exist: (a) internal/submerged, where the membranes are immersed in and integral to the biological reactor; and (b) external/sidestream, where membranes are a separate unit process requiring an intermediate pumping step.

MEMBRANE	
Target - Reduce Phosphorous levels to less than 0.05 mg/L	
Advantages	**Disadvantages**
High Removal Capabilities	High Capital Cost

Exceptional Solids Removal	Effluent Pumping Required
Flexible Operation	High O&M Cost

TABLE 4A-18 MEMBRANE ADVANTEGES AND DISADVANTAGES

INTERMITTENT SAND FILTERS

An Intermittent Sand Filter (ISF) removes contaminants in wastewater through a combination of physical, chemical, and biological treatment processes. Although all three play an important role in effective treatment, the biological processes play the most important role. A ISF is typically built below grade with a 24-inch bed of graded media, lined with an impermeable membrane. A well graded sand is the most common media, but anthracite, mineral tailings, bottom ash, etc., have also been used. The surface of the ISF is intermittently dosed with effluent that percolates in a single pass through the media. After being collected in the underdrain, the treated effluent is transported to a line for further treatment or disposal. Three common IFS systems are: (a) gravity discharge; (b) pumped discharge; and (c) bottomless.

Gravity Discharge

A gravity discharge ISF is usually located on sloping topography with the long axis perpendicular to the slope to minimize the excavation required. The bottom of the gravity discharge ISF is typically constructed several feet higher than the leaching field area and may require that the filter to be constructed partially above ground.

Pumped Discharge

A pumped discharge ISF is usually sited on level ground and its location in relation to the leaching field is not critical since a pump located within the sand filter bed allows effluent to be pumped to a leaching field at any location or elevation. Discharge piping goes over and not thru the sand filter liner, so the integrity of the liner is protected.

Bottomless

A bottomless ISF has no impermeable liner and does not discharge to a leaching field, but rather directly to the soil below the sand.

INTERMITTENT SAND FILTERS	
Advantages	**Disadvantages**
High Quality Effluent	Large Land Area Required
Low Energy Usage	Odor Problems with Open Filter Configurations
Flexible Operation	Sensitive to Extremely Cold Temperatures
No Chemicals Required	Filter Media Clogging
Expandable	
Moderate Construction Costs	

WASTEWATER REUSE

Over 97 percent of water on earth is salty and nearly 2 percent is locked up in snow and ice. That leaves less than 1 percent of water for human uses such as drinking, growing crops, household uses, and commercial/industrial processes. This limited resource has driven the need for wastewater reuse.

The term "recycling" is generally associated with aluminum cans, glass bottles, and paper products. When applied to water, the term "reuse" is used. Water reuse of treated wastewater is used for beneficial purposes such as agricultural and landscape irrigation, industrial processes (such as cooling), toilet flushing, and replenishing a ground water basin (known as ground water recharge). The quality of wastewater effluent to be reused is treated to standards, criteria, and regulations considering the planned reuse. Reuse of treated wastewater has typically been associated with onsite process uses (ie. plant water supply, wash water, etc.) and groundwater recharge.

"Gray water" is a term that consists of the reuse of wastewater that originates from bathroom sinks, bath/shower drains and clothes washing equipment drains. Gray water is typically reused onsite as a source of landscape irrigation. The National Science Foundation (NSF) International developed a guide entitled *NSF 350 – Onsite Residential and Commercial Reuse Treatment Systems*. This guide is to onsite residential and commercial gray water treatment systems. Refer to the NSF website for more information http://www.nsf.org/services/by-industry/water-wastewater/onsite-wastewater/.

Recycled water can satisfy most water demands, as long as it is adequately treated to ensure water quality appropriate for the use. As for any water source that is not properly treated, health problems could arise from drinking or being exposed to recycled water if it contains disease-causing organisms or other contaminants. A majority of the states along with the federal government have established rules, regulations, standards, criteria, and regulations to ensure that the water quality is appropriate for the end use. For example, the US EPA has developed a guide entitled *Guidelines for Water Reuse* (http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf) which contains a summary of state requirements, and guidelines for the treatment and uses of recycled water.

The most common form of wastewater reuse is for non-potable purposes or water which is not used for direct human consumption. The following are some typical and most common uses of recycled water:

- Golf Course Irrigation
- Process Water for Industrial Facilities
- Agriculture Irrigation
- Cooling Water for Power Plants
- Landscape Irrigation
- Toilet Flushing

The following are the benefits of using recycled water:

Type of Benefits	Remarks
Environmental Benefits	Provides an additional source of water Decreases the diversion of water from sensitive ecosystems Decreases wastewater discharges thus reducing and preventing pollution Creates or enhances wetlands and riparian habitats
Energy Savings	Significant amounts of energy is required to extract, treat, and transport water Water reuse reduces this energy

EFFLUENT DISPOSAL

Once wastewater is collected and treated at a Wastewater Treatment Facility (WWTF), the treated wastewater (effluent) is generally discharged to surface water or groundwater. Both discharge methods are summarized below.

SURFACE WATER

Federal and state laws prohibit the dumping of waste into waters of the United States or the Commonwealth. The Massachusetts Ocean Sanctuaries Act of 1990, as amended, (Chapter 132A, §12A-16E, and §18) regulates discharge of wastes, including municipal wastewater, into the Commonwealth's ocean sanctuaries, rivers and estuaries (see discussion below). Variances that might be granted under the Ocean Sanctuaries Act are administered by MassDEP. As authorized by the federal Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Under these regulations, no new NPDES permits can be issued for new WWTF's on the Cape that would discharge WWTF effluent to a freshwater body or stream. According to the US EPA, there are seven facilities on the Cape that have NPDES Permits.

GROUNDWATER

The vast majority of WWTFs on Cape Cod are permitted with effluent recharged to the groundwater through a bed, field or well designed for specific site locations and hydrogeologic site conditions. These site conditions include soil characteristics, offset distance between the effluent point of discharge and the groundwater layer that the effluent will flow to, and the environmental limitations imposed by natural and/or regulatory requirements. According to the MassDEP, there are 59 facilities on the Cape which have Groundwater Discharge Permits (GWDP).

When thinking about siting new wastewater treatment alternatives, effluent disposal can occur at the site of treatment or remotely, depending on the availability of appropriate site conditions.

The location of disposal sites may be inside or outside the watershed being served by the WWTF. Effluent transport out of the watershed is an option where the nitrogen load of the current watershed imposes severe limitations or prohibits disposal of the wastewater effluent.

The following is a summary of various disposal alternatives, including a general description, site requirements, and a summary of the advantages and disadvantages for each:

- Infiltration basin
- Soil absorption system – less than 10,000 gpd
- Soil absorption system – greater than 10,000 gpd
- Injection well
- Wick well
- Ocean outfall
- Effluent transport out of watershed

Infiltration Basin

An infiltration basin is an unlined basin or bed located at the ground surface. The effluent is discharged to the bed where it percolates through a bed of soil/sand, until it recharges the groundwater. A large amount of wastewater can be treated on a relatively small plot of land. The system is not climate dependent, allowing the system to function year-round. Multiple basins are normally installed to allow resting between applications, especially during wet seasons.

The site selection for an infiltration basin is largely dependent upon the type of soils and the depth to groundwater. The best soil type consist of small particle grains of sand as compared to a coarse sand or large gravel that allows discharged wastewater to move too fast through the soil and prevents the natural biological and chemical breakdown of nutrients and pathogens from taking place. Typically the depth to groundwater from the bottom of the basin during loading conditions should be at least four feet. This allows for the proper filtering of the discharged effluent and avoids flooding of the infiltration basins.

It is critical that proper field investigations of proposed infiltration basin sites occur during the planning and design phases to ensure that the most effective system WWTF and discharge system is identified. Field investigations typically consist of a combination of the following: (a) test pit excavation; (b) soil boring drilling; (c) collecting soils for grain-size analyses; (d) monitoring well installation; (e) conducting infiltrometer tests to measure the soils vertical permeability; and (f) potentially conducting a full scale hydraulic loading test. The data collected during the field investigations are summarized, analyzed and used as inputs into a hydraulic model such as the USGS MODFLOW (McDonald and Harbaugh 1988), to simulate the predicted groundwater mounding under various wastewater effluent loading conditions.

Following site selection, design and construction of the infiltration basins, the wastewater effluent is discharged into the basins so that it can percolate and receive treatment. Similar to the process taking place in a sand filtration system, sand and soil at the surface facilitate physical filtering while ion exchange, chemical precipitation, and adsorption take place as the water filters downward. Biological treatment also occurs as wastewater mixes with air in the top 2 to 3 feet of soil. Rapid infiltration's highest removal rates are in suspended solids, fecal coliform, and biochemical oxygen demand, with limited success in nutrient and heavy metal removal. Various methods of increasing the nutrient removal rate can be implemented, including varying the wetting and drying periods, adding a pre-treatment process, adding vegetation to the top soil or lengthening the soil depth through which treatment occurs.

While having one of the smaller discharge footprints and typically being the most cost effective to construct, the top 2 to 3 feet of soil in rapid infiltration basins can become laden with pollutants, particularly solids), reducing the treatment efficiency of the system. It is therefore recommended that multiple basins be installed to allow resting between dosing the basins. This is particularly important during wet seasons. Infiltration basins require periodic maintenance with occasional removal and replacement of the top few feet of soils.

Major factors in siting a rapid infiltration system include soil type, depth to watertable, and percolation rates. Sands and gravel below the basins are the most desirable soil types as they best facilitate percolation.

Siting Requirements

- Massachusetts Regulations 314 CMR 5.00: Groundwater Discharge Permits cites the specific technical and permitting requirements for the design and construction of all on-site disposal sites for treated wastewater effluent

Advantages

- Lower construction costs than soil absorption systems (SAS)
- Easy access to soils underlying the discharge
- Relatively easy operation and maintenance.
- Smaller footprint than subsurface disposal bed

Disadvantages

- Requires periodic maintenance of the basins
- Requires large area of open land
- Potential safety concerns with exposure
- Soil clogging may generate odors and/or visual impact

Soil Absorption System (SAS) – less than 10,000 gpd

A soil absorption system (SAS) is a means of providing subsurface treatment and hydraulic disposal of septic tank effluent from septic systems permitted under Title 5. An SAS can take the form of leaching trenches, leaching fields, leaching chambers and leaching pits. For larger systems, an SAS can be installed below ball fields, parks, and open space areas. Title 5 requires that systems over 2,000 gpd but less than 10,000 gpd be designed with pressure distribution to maintain consistent loading throughout the SAS. Dosing provides intervals between field loading to 'rest' the SAS and is preferred in most applications because of its consistent distribution and long-term treatment reliability. In general discharges less than 10,000 gpd do not require a groundwater discharge permit.

For individual on-site use, a soil absorption system is preceded by a septic tank and distribution structure. A septic tank is an underground, watertight tank which receives the wastewater from the home. It is designed to allow the solids and scum to separate from the liquid. The liquid is discharged to the SAS while the solids and scum are pumped out for treatment and disposal.

The site selection for a soil absorption system is largely dependent upon the type of soils and the depth to groundwater. The best soil type consists of loamy sand as compared to a coarse sand or large gravel that allows discharged septic tank effluent to move too fast through the soil limiting the natural biological and chemical breakdown of nutrients and pathogens from taking place. For Title 5 systems, the depth to groundwater from the bottom of the SAS to maximum high groundwater must be at least five (5) feet in rapidly percolating soils (i.e., two minutes per inch or less) and at least four (4) feet for all other soils. This provides an adequate unsaturated zone for inactivation of pathogens. Additionally, in order to ensure overall effectiveness, it is better that the infiltration basins are constructed at near level topography.

Septic tank effluent is released under pressure from orifice openings in the lateral located at intervals not to exceed 5-feet. Orifice shields are one method used in a pressurized distribution system to prevent surrounding media from blocking orifices, protect the orifice, and allow the discharge to spray and encourage even distribution throughout the leaching field. Constructed of PVC, orifice shields snap-fit onto laterals and can be installed facing up or down (cold weather applications).

Soil Absorption System (SAS) - Greater than 10,000 gpd

For discharges greater than 10,000 gpd, a more detailed field investigation of proposed effluent disposal sites occurs during the planning and design phases to ensure that a most effective system be identified. Field investigations, although more detailed, are similar to those described above for infiltration basins. Also required for discharges greater than 10,000 gpd, a WWTF must be constructed to treat the effluent.

The design hydraulic loading rates for SAS systems must be in accordance with 314 CMR 5.00 based on site conditions including; soil texture, groundwater elevation, the percolation rate measured in the field and the mounding analysis. The loading rate is adjusted to account for the long term acceptance rate of the leaching field, which is limited in part by the texture of the soil layers under the field and the strength of effluent applied to the soil. In general, the loading rate per square foot of discharge area is greater than systems that discharge less than 10,000 gpd. The increased loading rate accounts for a more highly treated effluent being discharged from WWTF than a septic tank.

Siting Requirements

- Massachusetts Regulations 314 CMR 5.00: Groundwater Discharge Permits cites the specific technical and permitting requirements for the design and construction of all on-site disposal sites for treated wastewater effluent

Advantages

- Low maintenance and long- life cycle systems.
- Virtually no above ground utilities with limited at-grade access requirements
- Can be installed under public areas (golf course fairways, parks, etc.) with use of land above disposal

Disadvantages

- Requires the most land area of discharge options
- Generally most expensive (land and construction costs) of the land discharge options

Injection Well

An injection well is a vertical pipe installed in the ground generally below a confining layer with a discharge screen section at the bottom for discharge of various fluids. These fluids may be water, wastewater, brine (salt water), or water mixed with chemicals. Injection wells began in the 1930s to dispose of brine generated during oil production.

For the disposal of wastewater effluent, the effluent is pumped through the casing pipe to maintain positive pressure to force flow through the screen. If geologic conditions are right, an injection well can discharge the effluent deep in the aquifer where it may not resurface and is effectively distributed into porous material, such as sand, sand and gravel, sandstone or limestone, or into or below the shallow soil layer. Injection wells require a highly treated effluent for injection, but have the advantage of using only a fraction of the land area required for an equivalent discharge through infiltration basins or subsurface absorption systems.

Siting Requirements

- Massachusetts Regulations 314 CMR 5.00: Groundwater Discharge Permits cites the specific technical and permitting requirements for the design and construction of all on-site disposal sites for treated wastewater effluent
- Installation requires access by drilling equipment
- Location and size of pump station to maintain effluent discharge conditions

Advantages

- Requires only a fraction of the land area needed for infiltration basins or soil absorption systems
- Can be installed on very small parcels or within easements
- Injection wells can be installed through shallow fine layers that may limit or prohibit the installation of infiltration basins or soil absorption systems.
- Discharge generally occurs deeper in the aquifer, where the effluent can travel below surface waters and some water supplies
- Minimal above ground utilities

Disadvantages

- High level of treatment required
- Capital, operation and maintenance costs are high due to pumping and depth of well
- Effluent discharge is under anaerobic conditions

- Microbe growth requires periodic disinfection (chlorine) and maintenance of the injection well screen
- Requires higher level of hydrogeologic investigation than infiltration basin and soil absorption systems (SAS)
- MassDEP has not yet permitted an injection well for a new wastewater discharge

US EPA Region 1 recommends piloting effluent disposal by injection well to determine its potential effectiveness for removing nitrogen loadings on Cape Cod.

Wick Well

Wick wells (or Wicks) are large diameter conduits of stone that allow for the rapid infiltration of effluent to the underlying groundwater. The wick column (two to six feet in diameter) acts as a conduit to infiltrate the treated effluent by gravity into the underlying aquifer. This arrangement allows for an aerobic condition which does not support the growth of pathogenic microbes that can be problematic with injection wells.

The site selection for a wick is largely dependent upon the type of soils and the depth to groundwater. It is critical that proper field investigations of proposed wick sites occur during the planning and design phases to ensure that a most effective system be installed. Field investigations typically consist of a combination of the following: (a) test pit excavation; (b) soil boring drilling; (c) collecting soils for grain-size analyses; (d) monitoring well installation; (e) conducting infiltrometer tests to measure the soils vertical permeability; and (f) conducting a full scale hydraulic loading test. The data collected during the field investigation are summarized, analyzed and used as inputs into a hydraulic model such as the USGS MODFLOW (McDonald and Harbaugh, 1988), to simulate the predicted groundwater mounding under various wastewater effluent loading conditions.

Wicks do not require a highly treated effluent like injection wells, but they still have the advantage of using only a fraction of the land area required for an equivalent discharge through infiltration basins and SAS systems. The effluent must have low levels of solids and nutrients, and is generally disinfected before discharge to the wicks. In general, a minimum of three wicks are required to allow for the rotation of discharge and resting of the wicks. Note that the WWTF effluent discharge to the wick column is contained within a concrete enclosure at grade that allows access for inspection and servicing.

Siting Requirements

- Requires significantly less land than conventional bed disposal methods
- Below ground placement of the wick column and minimal surface infrastructure
- Flexibility in placement of the installation
- Detailed hydrogeologic investigation is required including groundwater flow modeling and a loading test

Advantages

- Approved by MassDEP for new wastewater discharges as well as replacement discharge for a failing discharge bed

- Requires only a fraction (approximately 5 %) of the land area needed for infiltration basins or soil absorption systems
- Can be installed on very small parcels or within easement areas – thus increasing siting potential
- Can be installed in areas where conventional disposal beds are not feasible due to low permeability soil layers near the surface or at depth
- Low capital, operation, and maintenance costs compared to the other discharge options
- Minimal above ground infrastructure
- Easy access to wicks for inspection and monitoring
- Allows indirect reuse for site irrigation

Disadvantages

- Higher level of treatment than infiltration basins and soil absorption systems discharges may be required
- May require a higher level of hydrogeologic investigation than infiltration basin and soil absorption systems
- Higher level of permitting may be required than infiltration basins or soil absorption systems
- Require a reserve discharge area of sufficient size to allow for a conventional (SAS or infiltration basin) discharge
- Require periodic disinfection (chlorine)

US EPA Region 1 recommends piloting wick wells to determine this technology's potential effectiveness for removing nitrogen loading on Cape Cod.

Ocean Outfall

Ocean outfalls are a method of treated effluent disposal that remove the source of nitrogen from the impacted watershed entirely. Collected sewage is treated at a central treatment facility where primary treatment removes solids and secondary treatment removes significant levels of BOD and TSS as wells as some toxic contaminants. The resulting effluent is disinfected before discharge via pipes at the ocean floor. Diffusers at the end of the pipe facilitate dilution of the effluent into the surrounding seawater. Because the fresh water is lighter than seawater, the effluent rises through the water column, mixing with seawater as it rises. Depending on the depth of the pipe end and diffusers, the effluent may not reach the ocean surface before it is sufficiently diluted into the ambient salt water environment.

Ocean outfalls have the advantage of removing the nitrogen load from the watershed. An ocean outfall would allow the effluent to bypass already-impacted watersheds, estuaries, and coastal ponds where the addition of more nutrients would have a significant environmental impact.

Performance

- The Massachusetts Water Resources Authority (MWRA) plant at Deer Island in Boston Harbor was not designed to remove nutrients in any significant quantity. Nutrients in the treated effluent are diluted and dispersed into the surrounding seawater. Since most phytoplankton growth occurs at the ocean surface, and most nutrients will be dispersed before reaching the surface, algae growth and eutrophication are minimized.

- The MWRA outfall into Massachusetts Bay discharges 11,000 metric tons of nitrogen per year, or 190 pounds nitrogen for every million gallons of effluent discharged. In the 14 years since the outfall began operation, monitoring has not detected impacts to Cape Cod Bay ecology. Other ocean outfalls in Massachusetts are employed in Fall River and New Bedford (Falmouth CWMP Final EIR 2013).
- More recent and local discussions exploring the viability of ocean outfalls have suggested that consideration of outfalls from Cape Cod and the South Shore should include tertiary treatment to reduce nutrient concentrations in outfall effluent.

Potential Performance Challenges

- Ocean outfalls rely on dilution near the ocean floor, before nutrients reach the ocean surface, and have the potential to disrupt ocean ecology. Poorly designed projects could have significant effects on local populations of ocean wildlife.
- The public has varying perspectives on ocean outfalls. The Buzzards Bay Coalition has been an advocate of ocean outfall, provided that effluent receives tertiary treatment and other resource-based impacts are adequately studied and mitigated. The Massachusetts Chapter of the Sierra Club has cited their policy that dilution is not the solution to pollution in opposition to ocean outfall as a disposal alternative (Falmouth CWMP Final EIR 2013).
- A recent amendment filed as Massachusetts Senate Bill #2021, and approved in the 2014 legislative session, modifies the Oceans Act. The legislative changes stipulate conditions under which ocean outfalls of treated municipal wastewater into the marine sanctuaries around Cape Cod might be permitted. The amendment requires, among other standards: the discharge must meet the water quality standards of the receiving water body, including any TMDLs in place; implementation of plans to minimize inflow and infiltration; programs to conserve water; consistency with the policies and plans of Coastal Zone Management (which includes the policies and standards of the Massachusetts Ocean Management Plan); that the discharge shall not affect the quality or quantity of existing or proposed water supplies by reducing ground water recharge; and that the proposed discharge will not adversely impact marine fisheries. The amendment also requires study of the environmental impacts of a discharge through the state MEPA process, including ecological, hydrologic, hydraulic, and water quality evaluations.

Siting Requirements

- Feasible distance from WWTF considering pumping and piping requirements
- Acceptable pipe or force main alignments to the outfall location
- Geotechnical site suitability for outfall installation
- Dilution and dispersion characteristics of the outfall pipe discharge point
- Consideration of fisheries impacts; SA classification (oil and gas infrastructure, toxicity, pathogens, etc.)

Advantages

- High levels (100%) of reduction as nutrients are removed from the watershed
- Reliable, proven technology
- Long life-cycle systems
- Suitable for larger facilities in densely developed areas

Disadvantages

- Extensive permitting requirements (MEPA, Ocean Management Plan, wetlands, etc.)
- High level of treatment required
- Eliminates groundwater recharge back to the watershed
- High capital, operation and maintenance costs
- Siting and abutter issues
- Modeling of ocean outfall and potential impacts required

Costs

- Permitting costs could be extensive. Under a recent amendment to the Massachusetts Ocean Sanctuaries Act, proposed ocean outfalls into the ocean sanctuaries around Cape Cod will require extensive analysis and environmental review to establish the need, identify potential impacts, and define appropriate mitigating actions.

Effluent Transport Out of Watershed

Effluent transport out of the watershed has the advantage of removing the nitrogen load to another watershed that is not stressed. Transport to another watershed requires gravity or force main conveyance of treated effluent from the WWTF site to groundwater recharge, reuse or disposal sites. The receiving watershed must be able to accommodate the additional nitrogen load.

Siting Requirements

- Feasible distance from WWTF considering pumping and piping requirements
- Acceptable pipe or force main alignments
- Suitable site for pumping station (0.25-0.5 acre)
- Available suitable land for groundwater recharge or disposal site (2-4 gpd/sf) with necessary redundant area
- Per 314 CMR 5.00
- Issues are: in-basin recharge areas limiting nitrogen credit, distance from WWTF, geotechnical site suitability, Zone IIs, abutter concerns, and disease vectors

Advantages

- High levels (100%) of nutrient reduction as nutrients are removed from the watershed
- Site selection based on favorable conditions for selected proven technology
- Long life-cycle systems
- Suitable for larger facilities in densely developed areas

Disadvantages

- Relatively high capital, operation, and maintenance costs
- Extensive permitting issues (Possible Interbasin Transfer, etc.)
- Siting and abutter issues with disposal sites
- Lack of groundwater recharge within wastewater generating basin
- Discharge sub watershed and watershed must be able to handle the additional nutrient load

SOLIDS COLLECTION, TREATMENT AND DISPOSAL TECHNOLOGIES

Solids, or sewage sludge, removed from septic systems or wastewater treatment facilities (WWTF) are managed through means of disposal or recycling after treatment and/or dewatering. Disposal of solids involves either landfilling, with other municipal solid waste or separately, or incineration. Wastewater solids that are treated more extensively and processed for safe land application are called biosolids (an organic residual generated during the treatment of sewage sludge) and they are managed in several forms including liquid, cake, compost, and heat-dried granules. Recycling, or beneficial use of biosolids, includes land application on farm land, general use as gardening or landscaping fertilizer, and soil amendment after composting, heat-drying, or other advanced treatment. The following technologies or management strategies are utilized in solids processing and are summarized in this section: Septage Processing, Commercial Disposal, Dewater and Haul to Landfill, Composting, Incineration, Lime Stabilization, Digestion, Thermal Drying, and Drying and Gasification. Communities may find economies of scale in seeking regional solutions for solids management and treatment.

SEPTAGE PROCESSING

Septage solids management is typically all that is necessary for Title 5 or other individual on-site wastewater systems. It is handled by a service company to pick-up, haul, and dispose of septic tank solids. Disposal is typically at a WWTF or regional septage receiving facility. The service company is responsible for providing tank trucks and equipment for pump-out, and hauling. Pump-outs are scheduled at appropriate intervals (typically every 2 to 3 years) for residential properties by the owner and for commercial properties either by owner request or contract schedule. The hauler is responsible for making arrangements for the sludge to be further processed for beneficial use or disposal at a suitable facility and for presenting records to the local Board of Health.

Siting Requirements

- Septic tank should be located within 200 to 300 feet from the street or driveway for convenient pump-out
- Tanker truck is equipped with vacuum pump-out; no equipment is needed at the property

Advantages

- Low capital cost
- Uncomplicated and easily implemented
- Potential savings using liquid disposal
- Guaranteed disposal
- Minimal maintenance – all tank contents are removed

Disadvantages

- Not a sludge reuse option
- Uncertain long-term costs

- System performance not typically monitored except during pump-outs
- Risk of system issues if pump-outs not completed when necessary

COMMERCIAL DISPOSAL

The owner or facility manager is responsible to contract with a service company to pick-up, haul, and dispose of septic tank solids at regular intervals. The service company is responsible for providing tank trucks to pump-out and haul the sludge at appropriate intervals and making arrangements for the sludge to be further processed for beneficial use or disposal at a suitable facility.

Siting Requirements

- Septic tank should be located within 200 to 300 feet from the street or driveway for convenient pump-out
- Tanker truck is equipped with vacuum pump-out; no equipment is needed at the property

Advantages

- Low capital cost
- Uncomplicated and easily implemented
- Potential savings using liquid disposal
- Guaranteed disposal
- Minimal maintenance – all tank contents are removed
- Periodic access to septic tank allows visual inspection

Disadvantages

- Not a sludge reuse option
- Uncertain long-term costs
- System performance not typically monitored except during pump-outs
- Risk of system issues if pump-outs not completed on schedule

COMPOSTING

Composting is an aerobic process in which biodegradable material is decomposed by aerobic microorganisms in a controlled environment. The heat generated in composting pasteurizes the product, significantly reducing pathogens. The heat generated also drives off water vapor, further dewatering the product and reducing reuse volume. Composting that is performed properly produces nuisance-free humus like material.

All composting processes generally include common basic steps. First, the dewatered sludge is mixed with an amendment and/or bulking agent to increase porosity of the mixture and provide a carbon source to improve the degradability of the compost. A rule of thumb for composting is to have a 30 to 1 ratio of carbon to nitrogen (mass basis). The resulting mixture is piled or placed in a vessel where microbial activity causes the temperature to rise starting the "active composting" period. The desired temperature required for optimal operation and end quality vary based on the method of composting and desired use of the end product. After the "active composting" period is complete, the material is cured and distributed.

In general, three types of composting are practiced: aerated static pile, windrow, and in-vessel as described below. All are practiced throughout New England.

Aerated Static Pile Composting

In aerated static pile composting, the sludge and bulking agent is mixed and distributed in a long pile over a grid of air piping. The air for reaction is provided through the air piping to achieve the "active composting" period. The pile is typically covered with finished compost to provide insulation. After the "active composting" period is complete, the compost is moved to a separate curing pile for cooling. The bulking agent is typically screened and recycled in this method (US EPA 2002).

Windrow Composting

The compost mixture for windrow composting is prepared in a similar manner as it is for aerated static pile composting. The mixture, however, is spread into windrows and a mechanical turner device, as opposed to air grid piping, is used to periodically agitate the pile and provide a source of air to the compost material. Once the "active composting" period is complete, the material is moved to a separate curing pile. The bulking agent is typically screened out and recycled. Windrow composting has a high potential to create odors (US EPA 2002).

In-Vessel Composting

Unlike aerated static pile and windrow methods, in-vessel composting occurs inside an enclosed vessel or container. In-vessel composting systems are also typically more sophisticated then aerated static pile or windrow methods and contain a higher degree of control. The mechanical systems allow for control of the airflow, temperature, and oxygen concentration while also offering better containment of odors. Due to the higher degree of process control, in-vessel systems typically can achieve composting at a faster rate yielding a smaller footprint. In vessel composting can be plug flow or complete mix type systems (US EPA 2002).

Siting Requirements

- Requires a dewatering device and truck loading
- The area required depends on type of composting (windrow, aerated static pile or in vessel)
- Design and selection of an applicable composting site will depend on land area available, distance from neighbors and availability and source of amendment materials. If close to neighbors the system will likely need to be enclosed with odor control

Advantages

- Beneficial use
- Can produce a Class A product that is more marketable than other types of biosolids (US EPA 1994)

- Generally simple process that is relatively easy to operate and maintain
- Well proven technology
- Potential Income Source
- Minor Regulatory Requirements

Disadvantages

- Relatively high operation and maintenance cost
- Many systems are labor intensive
- Reliance on demand for end product
- Market study needed
- Sludge type assessment required
- Winter months impact distribution and marketing and wintertime storage is typically required
- Potential for odors and typically not well suited for raw primary sludges

INCINERATION

Incineration or advanced thermal oxidation is a combustion reaction that occurs in the presence of excess oxygen. Incineration is the most commonly used thermal conversion process practiced for sewage sludge today. Historically multiple hearth incineration has been the most common incineration technology employed for sewage sludge. However, due to the improved operation and reduced O&M costs associated with fluidized bed incineration, very few new multiple hearth incineration systems are being constructed, however several are still in operation in New England.

Incineration of sludge converts the waste into ash, flue gas, and heat. Flue gas treatment is required and the US EPA has recently implemented strict air permitting regulations and control limits for new sewage sludge incinerators. In some cases, the heat generated by incineration can be recovered for electrical generation or other waste heat purposes. There are several facilities that accept sewage sludge throughout New England, including the following sites:

- Fall River, Massachusetts
- Brockton, Massachusetts
- Cranston, Rhode Island

Multiple Hearth Incineration

Multiple hearth incineration systems consist of a refractory-lined, circular steel shell with several hearths. The center of the shell contains a rotating hollow cast iron shaft with rake (or rabble) arms mounted to it. Dewatered sludge fed onto the top hearth is raked slowly on alternating hearths to the outside circumference or to the center of the hearth in a series of spiral pattern paths. The solids are burned on the middle hearth, at temperatures over 900 degrees F. The remaining ash is cooled on the bottom zone prior to being discharged.

The solids burning on the middle hearths release heat which generates a flow of hot gases that rise countercurrent to the incoming sludge. This helps dry the sludge and improve combustion efficiency. Non-contact cooling air used to keep the rotating center shaft and rabble arms cool is introduced in the bottom of the hollow center shaft and is discharged through the hollow central shaft at the top of the unit. This pre-heated air can then be directed either to the lowest hearth or exhausted via either a dedicated stack or the downstream ductwork. The flue gases typically exit the upper hearths and are directed to the air pollution control equipment. The flue gas must be treated to meet air permitting requirements.

The rabble arms on the bottom hearth push the hot ash out of the system through a drop out port where it is transported to a containment area for further storage and processing.

The ancillary equipment associated with the multiple hearth incineration process include the biosolids feed system, air blowers, a number of burners (typically 12 to 20 per unit) located around the unit at various hearth levels, air pollution control system, induced draft fan, stack, ash conveyance and disposal system, and the general building services. Optional items would include any additional heat recovery and energy generation devices.

Fluidized Bed Incineration

Fluidized bed incinerators consist of a vertically oriented outer shell constructed of steel and lined with refractory. Partially dewatered sludge is fed into the lower portion of the furnace on top of a bed of sand. Air at 3 to 5 pounds per square inch (psig) is injected through nozzles, known as tuyeres, simultaneously fluidizing the bed of hot sand and the incoming sludge. The fluidizing action creates turbulence and mixing to allow for optimal combustion conditions while using less excess air than multiple hearth incinerators.

Combustion temperatures of 1,400 to 1,700 degrees F are maintained in the bed with residence times of approximately 2 to 5 seconds. The combustion reaction is separated into two zones, one within the bed and one in the freeboard area above the bed. In the fluidized bed, the water in the sludge evaporates simultaneously along with pyrolysis of the sludge. The combustible gas produced during the pyrolysis reaction is burned in the freeboard area just above the bed. The residual ash particles remaining after combustion along with some sand are carried out the top of the furnace thus requiring downstream removal. The resulting flue gas must be treated in accordance with the air permitting requirements. The fluidizing combustion air is typically preheated utilizing a large air to air heat exchanger (or air preheater) before being injected into the furnace which is known as a "hot windbox" design. If ambient air is used, it is known as a "cold windbox" design.

The ancillary equipment associated with the fluidized bed incinerator process include the biosolids feed system, high pressure fluidizing air blower, air preheater, air pollution control system, stack, ash conveyance and disposal system, sand makeup system, and the general building services. Optional items would include any additional heat recovery and energy generation devices.

Siting Requirements

- Requires a dewatering device and building to house the incineration equipment
- Incineration takes up a fairly small footprint when compared to other technologies. This will likely not be feasible in a non-attainment area

Advantages

- Eliminates pathogens and toxic compounds
- Potential for energy recovery and electrical generation
- Significant volume reduction
- Byproduct is an inert sterile ash
- Small footprint
- Many vendors available

Disadvantages

- High capital cost and operation and maintenance costs
- Significant emission and regulatory requirements especially with newer SSI rules
- Requires highly skilled personnel to operate
- May require supplemental fossil fuel consumption
- May not be feasible in a non-attainment area
- Complex process with lots of instrumentation for air emissions control
- Potential for public opposition
- Requires ash disposal or beneficial use location

LIME STABILIZATION

Lime stabilization involves addition of lime to biosolids in order to raise the pH to levels unfavorable for pathogen growth. The heat produced by the reaction of the lime with the water in the biosolids raises the pH and temperature of the biosolids sufficiently to comply with US EPA's 40CFR Part 503 regulations for pathogen destruction for either Class A or Class B biosolids (US EPA 1994). The process converts sewage sludge into a stable product, improves the density and physical handling characteristics of the biosolids and offers a cost-effective, flexible, and environmentally protective alternative that promotes beneficial reuse. The lime stabilized biosolids provide a rich source of essential fertilizer to farmland, improve acidic soils, and are excellent for land reclamation and as soil substitute for landfill cover or as soil conditioner.

Siting Requirements

- Requires dewatering device
- Typically use additional mixing device such as a pug mill unless lime added prior to dewatering
- Requires building for processing and/or storage and loading facilities for reuse hauling

Advantages

- Simple to operate
- Can be designed to meet Class A or Class B requirements for pathogen and vector attraction reduction (US EPA 1994)
- Simple technology requiring few special skills for reliable operation
- Easy to construct of readily available parts
- Small land area required
- Flexible operation easily started and stopped

Disadvantages

- The resulting product is not suitable for use on all soils
- Volume of final material is increased which increases transportation costs.
- Odor and dust potential
- Potential for pathogen regrowth if the pH drops below 9.5 while the material is stored prior to use
- Plant available nitrogen and phosphorous content is reduced

DIGESTION

Anaerobic Digestion

Conventional high rate anaerobic digestion involves the decomposition of organic matter and inorganic matter in the absence of oxygen. The decomposition process produces a digester gas that consists of mostly methane (approximately 65%) and carbon dioxide (approximately 35%). Anaerobic digestion of municipal wastewater solids can, in many cases, produce sufficient digester gas to meet the energy requirements of digestion and other plant operations. Therefore, due to the emphasis on energy conservation and recovery, the process continues to be advantageous for stabilizing solids. In principle, the conversion of organic matter to carbon dioxide and methane reduces biological solids leaving the digestion process. Digestion can reduce the total volume of solids to be dewatered and the polymer cost for dewatering. The process is typically operated at mesophilic conditions (approximately 35 degrees C) but some plants also operate at thermophilic conditions (approximately 55 degrees C) to increase reaction rate and provide a greater degree of pathogen reduction.

Anaerobic digestion also reduces attraction to vectors during land application. There are a number of digestion designs which can produce Class A and Class B biosolids by meeting the requirements of US EPA's Part 503 Rule (US EPA 1994).

Siting Requirements

- Consumes a relatively large footprint for digester tanks and they are typically sized for greater than 15 day hydraulic retention time (HRT) at peak month or peak 15 day conditions to meet US EPA Class B requirement (US EPA 1994)
- Dewatering and other further processes may be desired after digestion to reduce volume and hauling requirements

Advantages

- Well proven process
- Potential for electrical energy and heat recovery from biogas
- Low net energy requirements
- Good pathogen inactivation
- Operationally quite stable once started
- Odor potential is low with proper operation
- Stabilized product and reduces the volume of residual solids for disposition.
- Significant reuse potential

- Biogas produced can be captured and treated for energy recovery uses including heat and electrical power

Disadvantages

- Relatively large footprint when compared to alternative stabilization technologies
- High capital cost
- Recovers slowly from upset
- Cleaning is difficult (scum and grit)
- Potential for struvite (magnesium ammonium phosphate) scale formation on lines and clogs in system pipes
- If reuse options for solids residuals are not available, significant landfill disposal can be required

Aerobic Digestion

Aerobic digestion is most commonly practiced at WWTFs rated for less than 5 million gallons per day (MGD). It is a well-proven process and is similar to activated sludge processes used in secondary treatment. Under aerobic conditions, microbes rapidly consume organic matter and convert it into carbon dioxide. Once there is a lack of organic matter, bacteria die and are used as food by other bacteria and this stage of the process is known as endogenous respiration. Aerobic digestion typically yields high volatile solids destruction, has a low biological oxygen demand concentration in the side streams from dewatering, produces a relatively odorless stable end product, maintains a high nutrient value in the biosolids, is simple to operate, and involves relatively low capital costs. The aerobic process, however, requires a lot of air input which causes the process to have a high electrical consumption. The resulting liquid biosolids are typically difficult to dewater. The process is also very dependent on operating conditions and does not produce a useful energy producing byproduct (methane) like anaerobic digestion. Conventional aerobic digestion produces Class B biosolids (US EPA 1994).

Siting Requirements

- Consumes a relatively large footprint for digester tanks and they are typically sized for greater than 60 day hydraulic retention time (HRT) at peak month or peak 15 day conditions to meet US EPA Class B requirements for wastewater that is at 10 degrees C. Shorter HRTs can be used but then site specific pathogen testing is required to ensure Class B (US EPA 1994)
- Dewatering and other further processes may be desired after digestion to reduce volume and hauling requirements

Advantages

- Well proven process
- Simple to operate
- Good pathogen inactivation
- Operationally quite stable once started
- Odor potential is low with proper operation
- Stabilized and reduces the volume of residual solids for disposition or reuse

Disadvantages

- Relatively large footprint when compared to alternative stabilization technologies
- High capital cost
- High electrical cost for aeration
- May experience foaming
- More difficult to dewater
- High ammonia concentration following dewatering
- If reuse options for solids residuals are not available, significant landfill disposal can be required
- Potential for struvite (magnesium ammonium phosphate) scale formation on lines and clogs system pipes

THERMAL DRYING

Biosolids dryers come in several types, all of which operate with the goal of decreasing water content in wastewater sludge. Drying is typically used in the last stage of solids processing and is done in combination with a dewatering process. Dryers are typically fed with dewatered sludge at approximately 10 -35% dry solids (DS) and dry the biosolids to 90-96% DS. Sludge fed to dryers can be either undigested or digested dewatered sludge, although some vendors have restrictions with handling undigested primary sludge. As a general rule upstream digestion is typically recommended for primary sludge due to potential for odors in the final product. Dryers are able to produce Class A biosolids which can be beneficially used for land applications such as soil conditioning, fertilizing, or fertilizing supplement (US EPA 1994). Even if beneficial use is not the desired option, the drying process greatly reduces the storage, transportation and disposal cost since it significantly lowers the water content and reduces the weight. The dried biosolids can also be used as a renewable energy source.

Dryers are generally classified into three categories: (a) direct (convective) dryers, (b) indirect (conductive) dryers, and (c) combination direct/indirect dryers. Direct dryers use a drying medium such as hot air, which comes in direct contact with the sludge to increase the sludge temperature through convective heat transfer and evaporate the water in the sludge. Types of direct dryers include; belt, rotary drum, and fluidized bed type. Indirect dryers use a medium such as hot oil or steam that heats the sludge through a conducting surface, so that the heating medium does not come in direct contact with the sludge. Indirect dryers include paddle (most common), vertical tray and horizontal thin film type.

Siting Requirements

- Requires dewatered sludge but generally consumes a relatively small footprint
- Desirable to couple thermal dryers with anaerobic digestion to utilize digester gas or combined heat and power waste heat to reduce operating costs
- Digestion improves the quality of the sludge and reduces odors in final product, especially if the WWTF generates primary sludge

Advantages

- Requires a relatively small footprint compared to other stabilization technologies

- Reduces volume for disposition
- Does not require chemical additives
- Generates a potentially marketable product
- Proven process with several established vendors

Disadvantages

- Relatively high capital cost
- Large fuel requirements
- Payback from sale of Class A product may not offset high operating costs (US EPA 1994)
- Potential to create dust and odors
- Fire and explosion risks
- Relatively complex system; requires highly trained operating staff

DRYING AND GASIFICATION

Gasification is a process used to convert organic waste to a fuel gas called syngas, and has been practiced since the 1800s to generate fuel gas from coal and other biomass. Syngas is composed mainly of CO, CO_2, H_2 and CH_4 and has a low heating value of 120 to 150 British Thermal Units (BTUs)/cubic foot, which is approximately 25% of the heat value of biogas generated from anaerobic digestion. The heat value of the syngas can be increased if steam or enriched air (mostly oxygen) is used as the gasification medium. The final product is an inert ash, slag, or biochar that will either be beneficially used or disposed of in the landfill.

Currently, there are several biosolids gasification installations worldwide. One of the larger differences between traditional organic materials used as the fuel source in gasification and biosolids is the higher ash content of biosolids.

Pyrolysis is also an established technology used in the chemical industry to produce charcoal, activated carbon and methanol. Similar to gasification, pyrolysis at high temperatures generates a combustible gas, pyrolysis gas, with a low heating value but also can be used to generate char and oil. Pyrolysis is the first step that occurs in both gasification and combustion reactions.

There are several types of gasification and pyrolysis systems available with different flow patterns and configurations. The flow patterns, configuration, and auxiliary components are generally vendor specific. Gasification and pyrolysis can also occur in rotary kilns.

Energy Recovery from Gasification

There are two forms of recovering energy from gasification: closed-couple gasification and two stage gasification. Energy generation from biosolids through pyrolysis also allows for similar energy recovery methods. To increase the energy generation, other forms of biomass can be used as additional fuel to the gasification or pyrolysis process; such as treated fats, oils and grease and/or wood waste. WWTF screenings can also be used as a fuel since screenings contain plastic and paper material with high BTU fuel value compared to sludge.

Close coupled gasification is when the syngas from the gasification or pyrolysis system is directly oxidized without a syngas cleaning step. Syngas oxidation generates a high temperature flue gas, approximately 1,800 degree F, which can be used for thermal heat recovery. The energy recovered from the flue gas can be used as the energy source to dry to the biosolids to the desired dryness and thus minimize or eliminate the need for fossil fuels (e.g., natural gas or fuel oil). The hot flue gas can also be used an energy source for generating electricity through the use of steam turbines or an organic Rankin cycle.

The close coupled method of electrical production is commonly practiced on other types of biomass gasification; however, this system is not common for biosolids since it is generally more economical to use the energy to offset the drying energy requirement. The closed coupled mode of energy recovery is considered commercially developed and is currently practiced in the U.S. (Fed. Reg. 2011)

Siting Requirements

- Requires upstream dewatering and drying to at least 75% solids content in granular form
- Generally consumes a relatively small footprint

Advantages

- Potential for lower emissions than incineration technologies.
- Energy and electrical production potential
- Stabilization (digestion) of biosolids is not required - raw dewatered sludge has higher thermal content than digested biosolids
- Complete destruction of pathogens and organic portion of the feed
- Minimize hauling and disposition of biosolids
- Potential to generate "green energy"

Disadvantages

- Limited commercial scale experience for biosolids
- High capital costs
- Air permits likely required and may be difficult to differentiate from incineration
- Potential for ash and slag to fuse and generate Clinkers. Some systems may not be suitable with some sludge's depending on ash softening and melting point temperatures
- Chemical consumption for flue gas and or syngas polishing

Sea Level Rise and Storm Surge Risks to Technology Options

Massachusetts' climate will continue to change over the course of the century and many such changes have already been observed in our region. Winter temperatures are increasing and extreme summer heat events are becoming more frequent (Massachusetts Climate Change Adaptation Report, Massachusetts Executive Office of Energy and Environmental Affairs and the Adaptation Advisory Committee, 2011). The high emission scenario of the Intergovernmental Panel on Climate Change (IPCC), predicts that Massachusetts will experience a 5-10°F increase in average ambient temperature by the end of the century. The report cites further predictions that there will be 28 days each year that reach above 100°F, compared to only two days annually today. Climate change will also affect water resources and coastal processes in Massachusetts. Sea level is rising approximately 10 inches per century which will increase the height of storm surge and associated coastal flooding frequency, inundate low-lying coastal areas, and amplify shore-line erosion. Even with successful mitigation strategies, these climate trends will continue for generations and new trends, such as increased intensity of hurricanes, are expected to emerge.

Cape Cod is vulnerable to climate change. With 586 miles of tidal shoreline and only 10 miles of land at its widest point, the entire peninsula is vulnerable to the forces of storm activity, sea-level rise and catastrophic forces of hurricanes and nor'easters. A risk assessment for the Town of Barnstable predicts as much as 2.8 additional inches of annual precipitation and 5-6 feet of sea level rise by the end of the century (New England Climate Adaptation Project; Summary Climate Change Risk Assessment 2014). The National Climate Assessment has documented an increase in heavy downpours, or extreme precipitation events, since 1958 in the Northeast region of the United States. Sea level rise will increase the region's risk to coastal flooding especially when coupled with extreme precipitation events and increases in hurricane intensity. Also, as a result of sea level rise, water levels will rise and damage infrastructure and property along the Cape Cod coastline.

While the effects of climate change are projected to occur in the distant future, it will take years to develop and implement adaptation strategies for the region. The Section 208 Plan Update provides an opportunity to determine how to adapt the region's water infrastructure to changes in climate. This section summarizes potential risks that climate change-induced sea level rise and storm surge may present to the technologies considered in the Section 208 Plan Update. In addition to the likely risks, high level solutions have also been identified for each technology.

Note that the impacts associated with increased air and water temperatures were not assessed for each technology since they are anticipated to have little effect on system resiliency of the technologies. It is possible that over time increased air and ocean temperatures may improve performance, through lengthened growing seasons, of the approaches that rely on biological communities. Similarly, the effects of heavier downpours were not evaluated since overall precipitation is not expected to increase significantly, though precipitation may come in fewer, more intense, rain events (National Climate Assessment, 2014). One important exception to this conclusion is that stormwater systems should be designed to accommodate higher runoff volumes.

The general climate vulnerability, risk assessment and adaptation planning process is outlined in Table 4A-19. The table also indicates how each step of the general process has been applied to this assessment. The following assumptions have been made:

GENERAL CLIMATE VULNERABILITY, RISK ASSESSMENT AND ADAPTATION PLANNING PROCESS

Process	How it was applied to this assessment
Confirm the climate stressors to be considered	Sea level rise and storm surge were considered.
Identify the assets to be assessed	34 nitrogen removal technology options were assessed.
Identify the sensitivity of assets to the climate stressors	Risks to each technology option were identified.
Identify the exposure of assets to climate stressors (e.g. the nature and degree to which a system is exposed to significant climatic variations)	This was not completed as it would be dependent on the specific location and design (i.e. material selection, elevation etc.) of the technologies.
Determine the vulnerability (e.g. the combination of sensitivity and exposure)	Not assessed.
Undertake a detailed risk assessment of most vulnerable assets. This may include a more detailed analysis of the likely hazard areas and how they may change overtime	Not assessed.
Identify and prioritize adaptation options	High level solutions were identified for each technology.

TABLE 4A-19 GENERAL CLIMATE VULNERABILITY, RISK ASSESSMENT AND ADAPTATION PLANNING PROCESS

The risks identified relate only to sea level rise and storm surge. Risks related to other climate variables such as changes in temperature, precipitation, ocean temperature and acidification are not discussed.

The information presented focuses exclusively on the generic sensitivity of a technology to sea level rise or storm hazards. It does not consider the specific risks related to the location of a technology in a given area.

For the purposes of this assessment, several technologies are grouped together because they are made up of similar components and therefore face similar risks from sea level rise and storm surge. For example, technologies that contain underground infrastructure, soil absorption, and removal of waste material utilize different processes, but they were grouped together because they share similar risks.

SUMMARY OF ASSESSMENT FINDINGS

In assessing the technology options, the following general risks were identified:

- Damage to, or increased degradation of, structures and materials.
- Mobilization of contaminants as a result of the failure of storage systems.
- Backflow of saline water into systems causing overflows, increased degradation of materials and change in biological processes.
- Reduced effectiveness of biological processes as a result of more frequent inundation or exposure to saline water.
- Destabilization of assets as a result of change in groundwater levels or erosion.
- Restricted ability to access systems to collect outputs or re-use outputs due to salinity.

The following solutions were identified to help minimize the impact of the identified risks:

- Design systems to avoid hazard areas, or allow migration of vegetation as hazard areas change.
- Select materials, coatings and species that are able to cope with an increasingly saline environment.
- Install backflow valves on systems
- Anchor buried assets
- Ensure frequent maintenance inspections to monitor asset condition (e.g. rate of corrosion) and performance of technology (i.e. achieving nutrient removal targets).
- Use protective structures to reduce wave or wind impacts to systems.

Appendix 4D, Summary of the Risks and Solutions Relevant to Each Technology Option, presents a summary of the risks and solutions that are relevant to each technology option that was assessed.