COMPARISON OF COSTS

FOR

WASTEWATER MANAGEMENT SYSTEMS

APPLICABLE TO CAPE COD

Guidance to Cape Cod Towns Undertaking Comprehensive Wastewater Management Planning

Prepared for:

Association to Preserve Cape Cod

Cape Cod Business Roundtable

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Updated by:

AECOM

April 2010

(Updated April 2014 v2)

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PREAMBLE

As part of the 208 Water Quality Management Plan Update, the Cape Cod Commission performed an update to the "Comparison of Cost for Wastewater Management Systems Applicable to Cape Cod" dated April 2010. The April 2010 document was used as basis for the development of the April 2014 document. In general the April 2014 document adjusted the costs previously presented based on the current Engineering News Record (ENR) Index, provided additional projects as part of the Wastewater Treatment Facilities Project and Operation and Maintenance Costs, and created a section which presents generalized information on a broad range of various Non-Traditional Technologies being considered as part of the 208 Water Quality Management Plan Update. These non-traditional technologies cover individual on-lot systems, neighborhood systems, watershed wide systems, and Cape wide system, as well as traditional effluent disposal technologies and biosolids management options. Format changes were made to highlight these variations for the reviewer. This update retains information from the April 2010 document which is still valid. Updated information is show in italics.

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EXECUTIVE SUMMARY

The Barnstable County Wastewater Cost Task Force was established to compile and analyze current local information on the costs to build and operate wastewater systems in use on Cape Cod. Based on that information, the Task Force has developed cost estimates for a wide range of wastewater system sizes and types to help Cape Cod towns fairly compare available options. The application of the results will allow towns to identify which options are best for their circumstances and thus streamline their comprehensive wastewater management planning.

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

- **Individual on-lot 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 here:

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

Compared to a satellite facility of 100,000-gpd capacity, a central facility of 1.0-mgd (million gallons per day) capacity costs about *60%* less to build and 60*%* 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, expressed as equivalent annual cost per pound of nitrogen removed:

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*

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. Use of these systems would be targeted to areas and sub-watersheds where lower levels of nitrogen reducing performance of 25% to 50% (in comparison to larger scaled treatment facilities), may be appropriate to protect coastal waters in watersheds that require less than 50% nitrogen removal. I/A systems have the advantage of treating household effluent at its source, which eliminates the collection costs of sewered systems. They may be preferable in areas of new development at lower density to prevent nitrogen contamination generated by traditional Title 5 systems.*

  The greatest benefit of individual denitrifying systems is the avoidance of a collection system, since they provide for treatment and disposal on the same parcel where the wastewater is generated. In neighborhoods where the average length of collection pipe per property served would exceed 200 feet, the substantial cost of wastewater collection may make other systems more expensive as compared to I/A systems. In these circumstances, individual systems should be evaluated, considering all costs as well as the administrative issues related to property access and TMDL compliance.

- **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 the existing sewer system or other areas or need), with vacant publically-owned land nearby. These systems are also applicable in the case of an existing or proposed private facility that can be taken over by the town and expanded to provide wastewater service to existing nearby properties currently on septic systems, particularly if the town-wide system may be not be available for many years and the 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 the cost estimates presented in this report *for traditional technologies (individual nitrogen removing systems, cluster systems, satellite systems, and centralized systems)* are conceptual and based on a uniform set of assumptions, they are supported by a review of actual data from 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.

Cost estimates presented in this report for non-traditional technologies are conceptual and based on a various assumptions supported by a review of actual data from example projects, if available, and data from on-going pilot studies, various research projects and manufacturers.

It should be noted that direct cost comparisons between traditional and non-traditional technologies, as well as among the technologies, are not warranted without the development of a conceptual design for a specific set of local conditions and regulatory requirements, by experienced professionals.

One of the goals of this study is to help Cape Cod towns streamline their Comprehensive Wastewater Management Plans by identifying the circumstances that are most favorable for each type of system. For example, if a town owns a site *which is not within a sensitive watershed, which is* suitable for both treatment and disposal, and is located near the most densely developed areas needing nitrogen control, then economies of scale will make a centralized system the least expensive by a considerable margin. Nonetheless, this report is intended as general guidance, and specific local conditions must be evaluated to be sure that the most cost-effective solution is determined. The sensitivity analysis conducted in this study should help towns target the most appropriate cost factors.

The estimated costs presented in this report *for traditional technologies* are based on a common set of assumptions about the density of development served by the various systems. Towns with less dense development will be faced with higher collection costs than shown here. Costs for 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 and not another.

While the information described above focuses on the four most common methods of addressing wastewater treatment and nutrient removal (Individual on-lot Systems, Cluster Systems, Satellite Systems, and Centralized Systems), there are many alternatives to those systems which may be relevant to the unique needs of some Cape Cod Communities. The final section of this report provides a description of these "nontraditional" technologies, as well as estimated associated costs and sources of assumptions.

COMPARISON OF COSTS

FOR

WASTEWATER MANAGEMENT SYSTEMS

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PURPOSE

The first part of this report summarizes the methodology and results of an investigation of the costs *of the four primary types of wastewater management systems* that can be expected at public wastewater facilities on Cape Cod. *The second part discusses some of the many alternatives to those systems which may be relevant to the unique needs of some Cape Cod Communities, including a description of these "nontraditional" technologies, as well as estimated associated costs and sources of assumptions.*

Wastewater management can be accomplished with relatively small-scale systems (serving single homes or neighborhoods of up to 30 homes), at moderate-sized facilities that might serve up to 1,000 properties, and/or in a central facility serving an entire town alone *and/*or *all or portions of* one or two neighboring towns.

This investigation addresses the costs to build and operate wastewater systems of various sizes and types and identifies those circumstances where each type of system may be most applicable. The choice of wastewater management approach is an essential element of a town's Comprehensive Wastewater Management Plan (CWMP), and this report was prepared to provide general guidance to the towns who are preparing CWMPs.

DEFINITIONS *FOR CONVENTIONAL SYSTEMS*

Wastewater systems have been considered in four categories as follows:

- **Individual System.** Serving one property and located on the parcel where the wastewater is generated.

- **Cluster System.** Serving nearby properties with an aggregate flow less than 10,000 gallons per day (gpd), roughly equivalent to 30 three-bedroom homes.

- **Satellite System.** Serving an area of a town with an aggregate flow greater than 10,000 gpd (and thus requiring a MassDEP groundwater discharge permit), and as much as 300,000 gpd.

- **Centralized System.** A larger system that provides for most or all of a town's wastewater management needs, and could be regional.

Figure 1 illustrates these four types of wastewater systems.

FIGURE 1
TYPES OF WASTEWATER SYSTEMS

Estimates have been prepared for two types of costs:

- **Capital Costs.** The costs to plan, design, permit and build wastewater facilities, including the purchase of land; and

- **Operations and Maintenance (O&M) Costs.** The annual expenses to run the facilities, *including monitoring costs*.

Wastewater management systems are typically comprised of the following elements, not all of which are needed in every instance:

- **Collection**, including sewers (of several types) and pumping stations needed to bring the collected wastewater to one point;

- **Transport from the collection area to the treatment site**, including pumping facilities and pipelines;

- **Treatment** to achieve effluent quality requirements as dictated by Title 5, by a MassDEP groundwater discharge permit, or by a nitrogen-based *Total Maximum Daily Load* (TMDL);

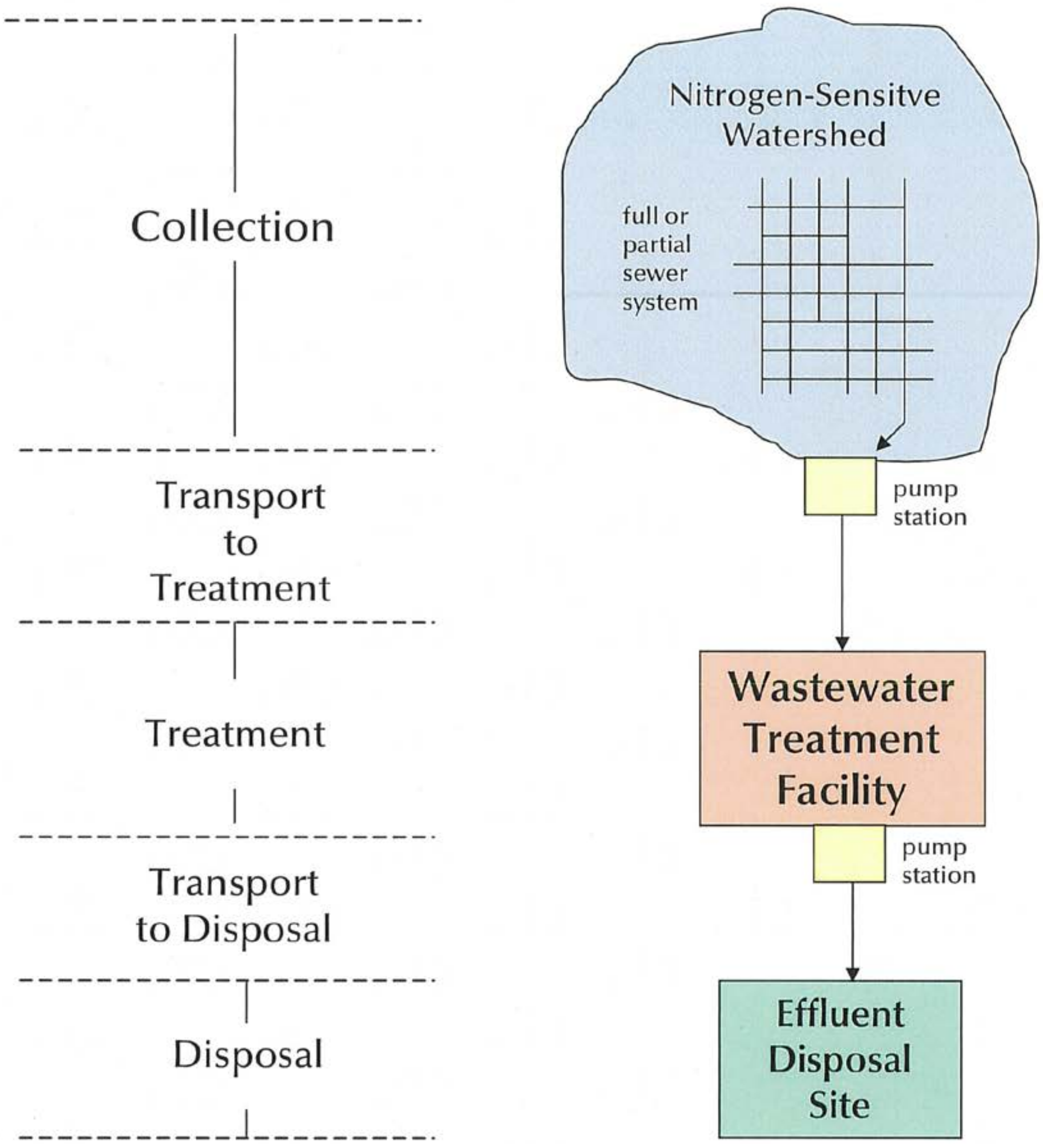
- **Transport from the treatment site to the effluent disposal site**, if the treatment and disposal functions cannot be co-located; and

- **Disposal**, which typically involves subsurface leaching or rapid infiltration, as well as monitoring wells, and may include effluent reuse.

These typical elements of a municipal wastewater system are shown conceptually in Figure 2.

While wastewater collection systems on Cape Cod are needed to eliminate Title 5 systems in the watersheds of nitrogen-sensitive embayments, it should be noted that the associated treatment and disposal facilities may be located either within or outside those watersheds.

Wastewater facilities on Cape Cod are governed by three regulatory programs. The first is the state sanitary code, Title 5. A traditional on-site system consisting of a septic tank and leaching field is called a "Title 5 system". Title 5 systems may be appropriate for on-site wastewater management for many reasons, but their effluent contains significant amounts of nitrogen, the contaminant that is causing widespread water quality problems in Cape Cod's coastal waters. The second regulatory program is the MassDEP groundwater discharge permitting program that requires a permit (and significant nitrogen removal) for projects with wastewater flows exceeding 10,000 gpd. Most coastal embayments on Cape Cod are impacted by excess nitrogen loads resulting in ecological impairment. The Federal Clean Water Act, the third regulatory program, has established TMDLs for these impaired embayments and has identified on-site wastewater disposal as the main contributor of nitrogen.



Notes: 1. Treatment and disposal may occur at a single site.
2. Treatment or disposal or both may occur within a nitrogen-sensitive watershed.

FIGURE 2

ELEMENTS OF TYPICAL
WASTEWATER SYSTEM

METHODOLOGY

Data Sources for Individual and Cluster Systems

Although many individual wastewater systems have been constructed on Cape Cod, both simple Title 5 systems and those with nitrogen-removal components, the purchasers of those systems are individual property owners and there is no readily accessible database on the costs to build and maintain these systems. Accordingly, data were obtained from the following sources for this study:

- Interviews with suppliers of treatment systems;
- Discussions with construction contractors and developers;
- Data available from the Massachusetts Alternative Septic System Test Center; and
- Reports from the New Jersey Pinelands Commission.

The information from the Pinelands Commission is of interest because that organization has undertaken a formal program of tracking the cost and performance of nitrogen-removing systems installed within its jurisdiction, and data are available for four common technologies and approximately 180 individual systems. Although this database is not local to Cape Cod, there are many similarities in the soil types and groundwater regimes that allow its extrapolation to Cape Cod.

Data Sources for Satellite and Centralized Systems

There is considerable experience with satellite and centralized wastewater facilities on Cape Cod and in southeastern Massachusetts. Cost information from existing facilities throughout Massachusetts including Cape Cod, was viewed as an important definitive database for this evaluation. Assembling an appropriate database was undertaken in the following steps:

1. Determine the actual costs to construct numerous wastewater facilities in southeastern Massachusetts in recent years;
2. Canvas existing wastewater facilities to determine actual O&M costs;
3. Adjust the capital and O&M costs to a common basis, both in time and in terms of included items; and
4. Compute "unit costs" for construction (cost per daily gallon of capacity) and for O&M (cost per gallon treated) and develop graphical summaries *(curves)* to depict how those unit costs vary with facility size.

Cost Estimating Methodology

The costs to build and operate wastewater facilities were estimated for several wastewater management approaches, ranging from a single centralized facility down to multiple small facilities. For each approach, the cost estimates were prepared using a common set of assumptions to enable the results to be fairly compared.

The costs to design, permit and construct facilities (the capital costs) were estimated in the following steps:

1. Basic construction costs were estimated from data compiled from the surveys noted above. Costs were estimated for each of the elements shown in Figure 2;

2. An allowance was included for engineering planning and design costs, permitting costs, legal expenses and a contingency for unexpected construction items;

3. Land costs were estimated based on the nature and extent of the wastewater facilities; and

4. Capital costs were computed as the sum of the three items above.

The costs to operate and maintain smaller wastewater facilities were prepared by estimating typical expenses for labor, power, chemicals, etc. For satellite and centralized facilities, the cost curves described above were applied based on the average flow treated.

As a final step, the assumptions for each scenario were systematically varied to estimate likely cost ranges for each management approach and to determine the circumstance where each type of system may be most favorable.

SURVEY RESULTS--INDIVIDUAL AND CLUSTER SYSTEMS

Construction Costs

From all of the sources available, it was determined that the costs to design, permit and build most conventional Title 5 septic systems fall in the range of *$9,000* to *$17,000*. The low end of this range applies to new homes where the septic system is installed during home construction, sandy soils are available, and there is sufficient depth to groundwater. Higher costs pertain when the soils and groundwater conditions are less favorable, or when the system is built as a replacement and costs are incurred to restore site features that are disturbed. There are documented cases of properties spending more than $30,000 for mounded systems that require influent pumping, significant site grading and restoration of landscaping. For the purposes of this study, an average cost of $13,000 was used for a simple Title 5 system. Both lower and higher costs were considered as part of the sensitivity analysis.

Data from the Barnstable County Septic Loan Program were reviewed and found supportive of this estimate. For over 1,100 properties, owners borrowed an average of $11,000 (median of $8,500) to replace individual septic systems. These costs include some partial replacements (leaching field only) and some full replacements.

Nitrogen-removing *(I/A)* systems add to the cost of the basic septic tank and leaching field system, resulting in total costs *ranging from $12,000 to $34,000*. The average cost for 180 homes in the Pinelands of New Jersey was $24,000, including $11,000 for the basic septic-tank-and-leaching-field components and $13,000 for the nitrogen-removing elements. This study has used *$22,400* as the base case for new systems with nitrogen removal. The sensitivity analysis considered both lower and higher costs. *In addition, the installation of nitrogen removing systems can offer a reduction in the leach field size which can offset a potion of the increased cost over a conventional Title 5 system.*

The *$22,400* figure was used to characterize the current use of individual denitrifying systems on Cape Cod, where inexpensive construction and lack of oversight have resulted in less than optimum performance. *Therefore, it is critical that I/A systems only be used when there is effective management and responsible management entities. Refer to EPA's National Voluntary Guidelines and consider appropriate oversight under Model 2, Model 3 and Model 4 management programs and entities. Use of these systems would be targeted to areas and sub-watersheds where lower levels of nitrogen reducing performance of 25% to 50% (in comparison to larger scaled treatment facilities), may be appropriate to protect coastal waters in watersheds that require less than 50% nitrogen removal. I/A systems have the advantage of treating household effluent at its source, which eliminates the collection costs of sewered systems. They may be preferable in areas of new development at lower density to prevent nitrogen contamination generated by traditional Title 5 systems.*

In the current MassDEP program under Title 5, systems are required to achieve effluent nitrogen of 19 mg/l and many do not perform that well. It was assumed that a somewhat higher cost ($26,000) would best characterize a more rigorous design and better construction oversight as would be needed to achieve a lower effluent nitrogen concentration (13 mg/l), as demonstrated in the Pinelands program. If these systems are to be used for long-term, documented TMDL compliance, additional costs would be needed for a more robust and longer-lasting design and for more frequent testing of the effluent. A capital cost of $28,000 was assumed in this instance.

For cluster systems, data from several Cape Cod facilities were compiled and adjusted to a common basis. For the example 8,800-gpd systems, capital costs were estimated to be *$405,000* for systems *constructed* under Title 5 (achieving 15 mg/l) and *$481,000* for systems *constructed* under the *Mass*DEP groundwater discharge permit program (achieving 8 mg/l). The higher cost reflects a separate denitrification process, chemical feed facilities, a small control building, monitoring wells and a smaller effluent disposal area. The *$405,000* and *$481,000* figures do not include effluent disposal, land or a collection system. *These costs scale up to $460,000 and $548,000 for 10,000-gpd systems.*

Operation and Maintenance Costs

Using data from all sources, a baseline *annual* O&M cost of *$1,375* was computed for the typical individual denitrifying systems installed under current *Mass*DEP program, and *a higher cost, approximately* $2,000, *was computed* for systems receiving more oversight and testing. The average O&M cost for 180 systems in the Pinelands of New Jersey is $1,800, where somewhat lower labor costs prevail and where effluent testing is less rigorous than would be needed on Cape Cod. This figure was derived from discussions with participating vendors who charge approximately $9,000 for a 5-year contract for operation and maintenance. Where TMDL compliance is to be documented, monitoring costs increase the annual total O&M expenses to *$3,850*. By comparison, it is estimated that the typical Title 5 system would have an average *annual* O&M cost of *$165*, largely for once-in-four-year septage pumping.

SURVEY RESULTS--SATELLITE AND CENTRALIZED SYSTEMS

Construction Costs

To form a sound basis for predicting the construction costs of small-scale wastewater systems, contacts were established with the owners or builders of existing New England wastewater facilities to determine what was actually spent to construct them. To date, data have been obtained from *35* facilities, *19* of which are located in southeastern Massachusetts. Their design flows range from 15,000 gpd to *4.1* million gallons per day (mgd), and they were built over the last *17* years. The surveyed facilities are largely satellite and centralized treatment plants that remove nitrogen and have groundwater discharge permits. About half are private facilities. A wide range of technologies is represented, including *Sequencing Batch Reactors* (SBRs), *Rotating Biological Contactors* (RBCs), *Trickling Fixed Film Biological Treatment Processes* (BioClere™), *Membrane Bioreactors* (MBR)s, and conventional activated sludge.

This segment of the survey has specifically focused on the costs of treatment, and not collection, transport or disposal. Many of the cost quotations required some analysis. Often the quoted construction cost includes both treatment and disposal; in those cases discussions were held with the developer or engineer to separately estimate the cost of the disposal system and subtract it from the quoted number. When the data received have included land, permitting or engineering costs, those items have been subtracted out to arrive at a pure construction cost. The cost estimating procedure later adds a consistent allowance for non-construction aspects of the capital cost such as design, permitting, construction phase engineering services, legal expenses and land.

The approximate bid date was obtained for all projects, and then the cost information was projected forward to *March 2014* at an ENR cost index of *9702*. *Engineering News Record* is a construction industry publication that reports a monthly cost index that is a widely used to benchmark costs. For each facility, the date-adjusted construction cost was compared with the system's design flow *(ADF)*. When the construction cost is divided by the design flow, the result is a metric expressed as "dollars per gpd of design flow". Those unit costs have been plotted using a logarithmic scale for the flow, and the results are shown in Figure 3.

As noted, flows to a satellite or centralized facility will vary over the course of a year. Generally, Cape Cod communities see an influx of tourists and residents in the summer months. Hence, wastewater flows in summer months can be two times higher than winter months. The design flow for a satellite or centralized facility are typically based on peak summer flows in consideration of non-peak and non-summer variations including the observed average daily flow of the summer months as compared to the average daily flow of the year. This should be kept in mind when using the cost curve in Figure 3 which uses the summer average flows to make construction cost estimates.

Although there is significant scatter in the data, a trend line is evident. Some scatter would be expected given the site-to-site variability among projects, the different treatment processes, varying degrees of conservatism in design, and the competitiveness of the bidding process. A mathematical curve-fitting approach was used to establish a line of central tendency. That line-of-best-fit yields the following points:

Capacity	Unit Construction Cost
10,000 gpd	*$108* per gpd of design flow
100,000 gpd	*$46* per gpd of design flow
1,000,000 gpd	*$19* per gpd of design flow

Figure 3 is a good example of the concept of "economies-of-scale"; the larger the facility, the lower the cost to provide treatment for a daily gallon of capacity. These data indicate that, on a per-gallon basis, a 1.0-mgd plant can be built at *40%* of the *unit* cost of a 100,000-gpd plant, and only *18%* of the *unit* cost of a 10,000-gpd facility. A tabulation of the assembled survey data is contained in Appendix A.

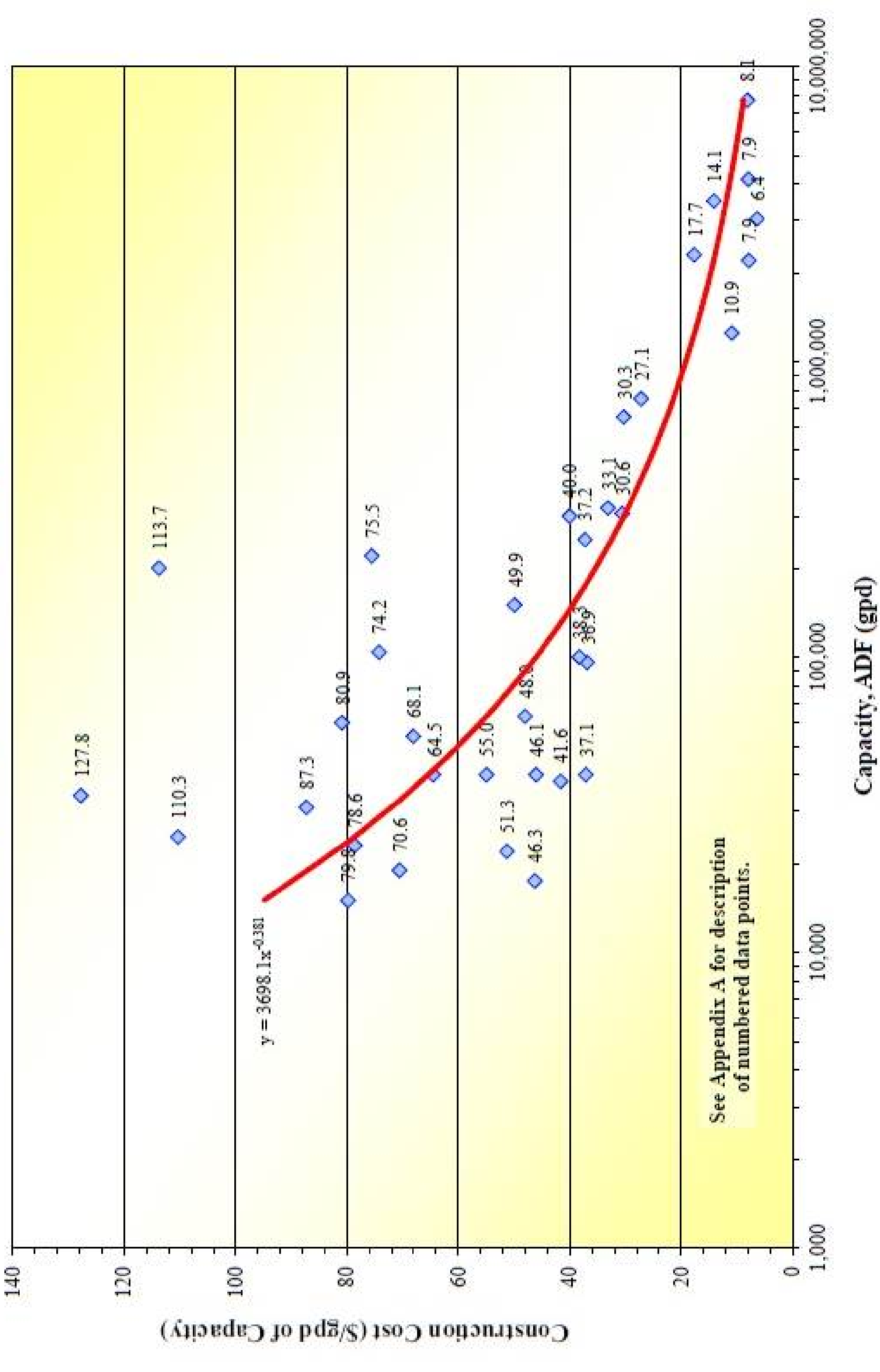
Operation and Maintenance Costs

A similar survey was conducted of existing New England wastewater facilities to determine actual O&M expenditures for collection, treatment and disposal. To date, *34* facilities have been contacted, *22* of which are in southeastern Massachusetts. Their design flows range from 17,000 gpd to *7.7* mgd. The surveyed facilities are largely satellite and centralized facilities that remove nitrogen and have groundwater discharge permits. A wide range of technologies is represented, including SBRs, RBCs, BioCleres, MBRs, and conventional activated sludge.

Care was taken to document what is included in the cost quotations that were received, to be sure that at least the following items are included:

- Labor
- Electricity and Chemicals
- Laboratory analysis
- Repairs and equipment replacement
- Administrative costs including insurance
- Sludge disposal

FIGURE 3
RESULTS OF PROJECT COST SURVEY



When the data received did not include all of these cost items, discussions were undertaken with the owner, operator or DPW staff person to make the estimate more complete. In all cases, it was determined that no debt service costs or depreciation are included. The private satellite system costs include only a small amount for operating and maintaining the collection system, because the facility is often located on the same property where the wastewater is generated. Public systems include significant collection system O&M costs. Therefore the private plant costs may understate what the O&M cost would be for a similarly-sized public satellite system. Partially offsetting that factor is the MassDEP annual compliance fee that is paid by private plants but waived for public plants. That fee is $7,000 or $12,500 depending on whether the facility is smaller or larger than 40,000 gpd.

As stated in the previous section regarding construction costs, flows to a satellite or centralized facility will vary over the course of a year. Generally, Cape Cod communities see an influx of tourists and residents in the summer months. Hence, wastewater flows in summer months can be two times higher than winter months. The design flow for a satellite or centralized facility will be based on the observed average daily flow of the summer months, not the average daily flow of the year. This should be kept in mind when using the cost curve in Figure 4 to make estimates.

For each facility, the annual O&M cost was compared with the estimated annual average flow. *As stated above, flows vary seasonally, but the average annual flow may be used for annual budgeting purposes because it accounts for the seasonal highs and lows.* When the cost is divided by the flow, the result is a cost measure expressed as "dollars per year per gpd of actual flow". That unit cost was plotted on a graph with a logarithmic scale for the flow; see Figure 4. There is some scatter in the data, but less than with construction costs. A line of central tendency through all the data yields the following points:

Capacity	Unit O&M Cost
10,000 gpd	$13 per year per gpd of actual flow
100,000 gpd	$5 per year per gpd of actual flow
1,000,000 gpd	$2 per year per gpd of actual flow

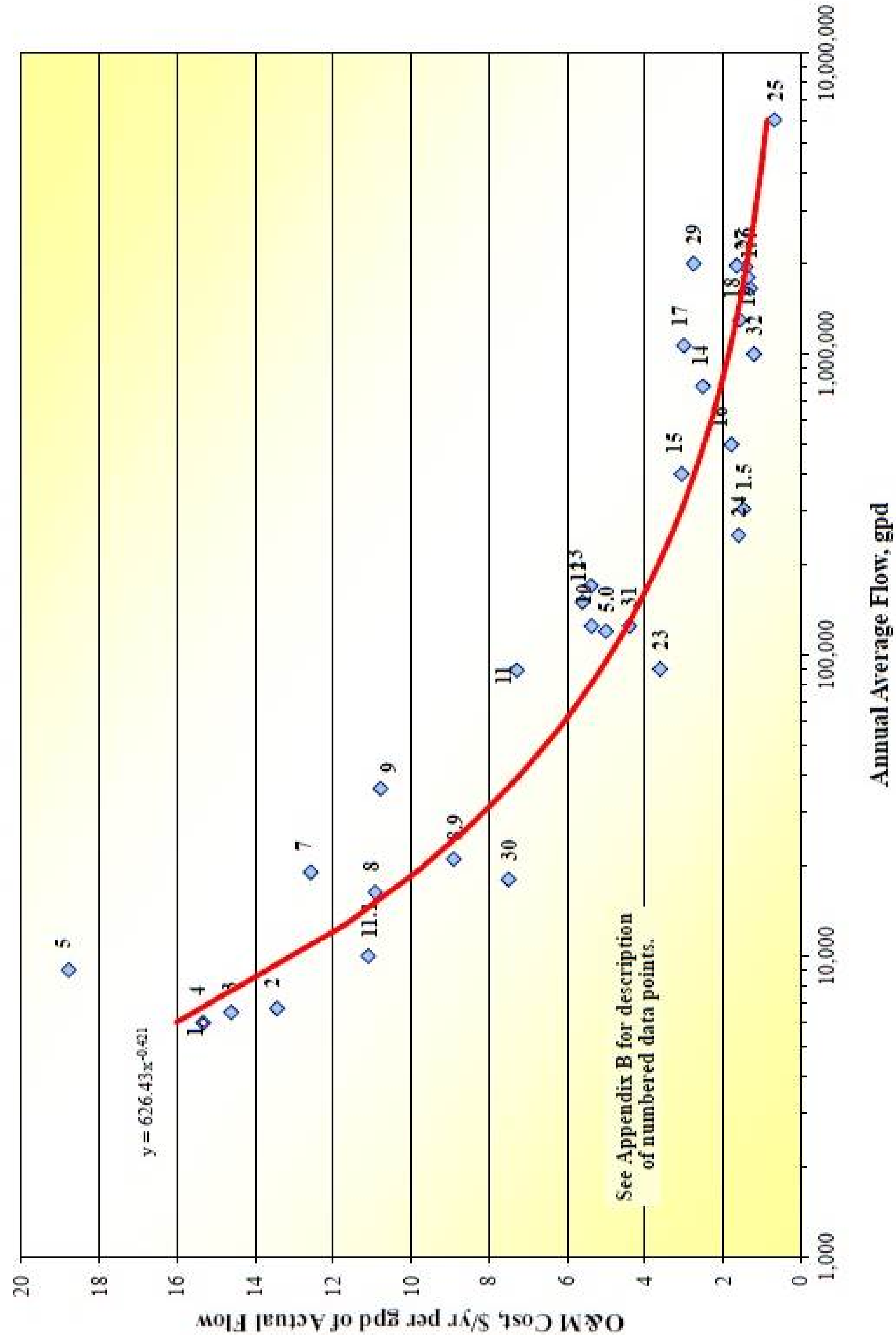
The apparent economies-of-scale are significant, perhaps stronger than with construction costs. These data indicate that a 1.0-mgd plant can treat one gallon of wastewater at 40% of the *unit* cost of a 100,000-gpd plant, and only 15% of the *unit* cost of a 10,000-gpd facility.

Appendix B contains a tabular summary of the data from this survey.

COSTS FOR COLLECTION SYSTEMS

Construction costs for wastewater collection systems were estimated by compiling typical unit costs for gravity pipe, pressure pipe, grinder pumps, and pumping stations of various sizes. It was assumed that 5% of the properties would require grinder pumps to access the sewer, and that one pumping station would be needed on average for every one hundred properties. Figure 5 illustrates the results of that analysis, and shows how construction costs for collection systems are significantly affected by the distance between individual connections. The construction costs vary directly with the average length of pipe needed to serve one connection.

FIGURE 4
RESULTS OF O&M COST SURVEY



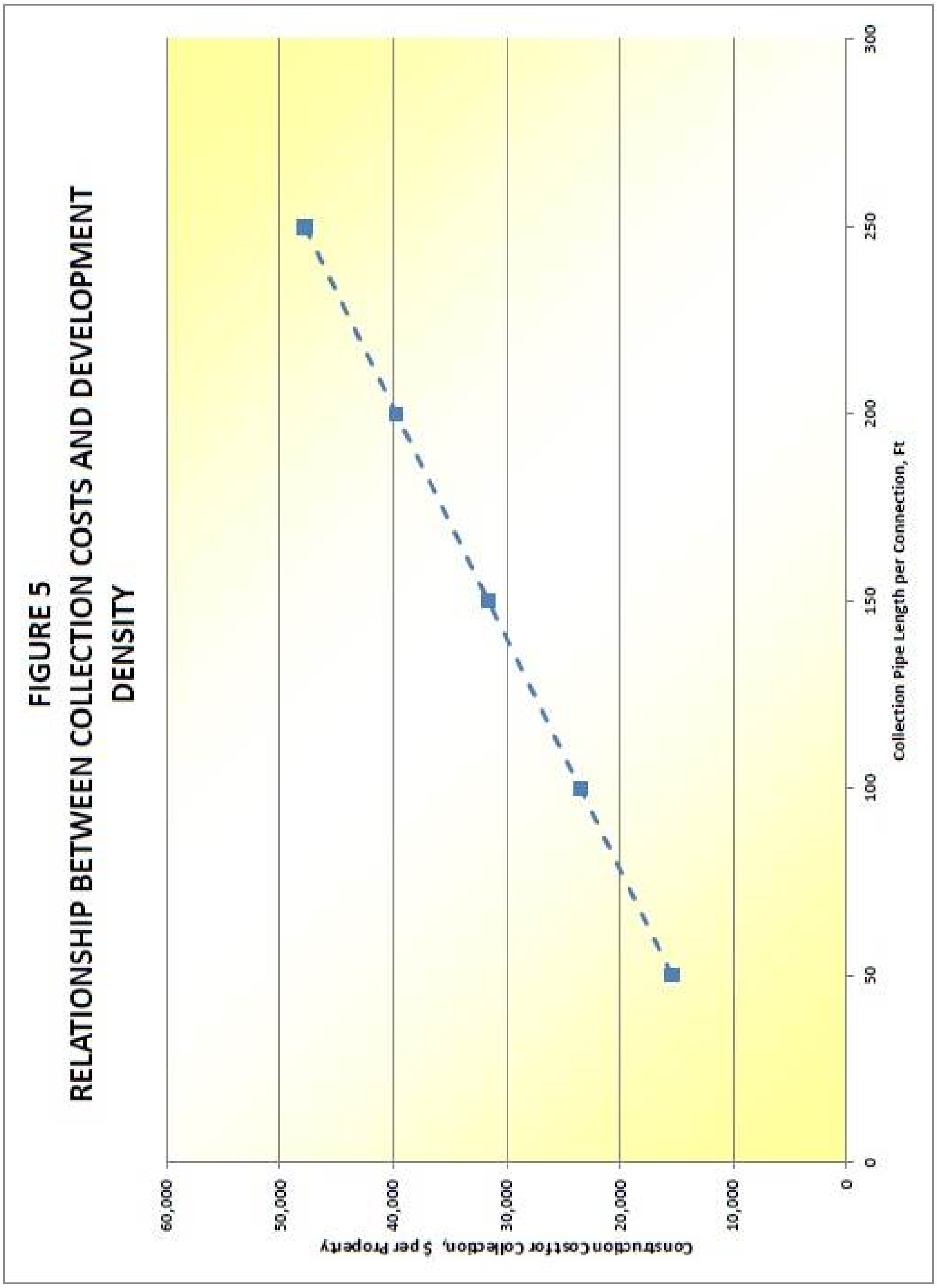


FIGURE 5
RELATIONSHIP BETWEEN COLLECTION COSTS AND DEVELOPMENT DENSITY
Construction Cost for Collection, $ per Property
60,000
50,000
40,000
30,000
20,000
10,000
0
Collection Pipe Length per Connection, Ft
0
50
100
150
200
250
300

BASIS FOR EVALUATION OF SCENARIOS

Description of Baseline Scenarios

Baseline scenarios were developed to portray typical circumstances on Cape Cod and to serve as the basis for a sensitivity analysis. Table 1 summarizes the assumptions included in the "base case" for each type of wastewater management system. A total of *12* scenarios were considered:

Individual systems (4 scenarios)

1. Conventional Title 5. These systems produce an average nitrogen concentration of 26 mg/l reaching the groundwater, as documented in the work of the Massachusetts Estuaries Project. This scenario is presented only as a benchmark and is not a viable alternative as the sole solution in nitrogen-sensitive watersheds.

2. Individual denitrifying *(I/A)* systems as currently installed and operated, estimated to produce an effluent nitrogen concentration of 19 mg/l. Although these systems are capable of better performance, their success has been hindered by the driving forces of reducing initial cost and minimizing ongoing expense. Costs are reported here only to illustrate a full accounting of typical current practices, based on a *$22,400* first cost and *$1,375* in annual O&M costs. This scenario has been termed "current practice" in the exhibits that follow.

3. Individual denitrifying *(I/A)* systems enhanced over current practice to achieve an average nitrogen concentration of 13 mg/l. This scenario assumes per-property capital costs of $26,000 and an annual O&M cost of $2,000. Costs and performance at this level have been demonstrated in the Pinelands of New Jersey. In the tables and figures that follow, this scenario has been termed "enhanced current practice". *It should be noted that the use of individual denitrifying I/A systems designed to achieve an average nitrogen concentration of 13 mg/l will require a more stringent review and approval process by the MassDEP.*

4. Individual denitrifying *(I/A)* systems, enhanced over current practice to achieve an average nitrogen concentration of 13 mg/l and monitored to document the level of nitrogen removal. When part of a comprehensive plan aimed at complying with a TMDL, the capital costs would be $28,000 and the O&M costs would be *$3,850*, reflecting a more robust long-term design and more oversight and monitoring. This scenario *has* been termed "for TMDL compliance" in the exhibits that follow. This nomenclature is used with the understanding that achieving only 13 mg/l effluent nitrogen precludes this approach as the sole means for TMDL compliance where more than 50% of the septic nitrogen load must be eliminated. *It should be noted that the use of individual denitrifying I/A systems designed to achieve an average nitrogen concentration of 13 mg/l will require a more stringent review and approval process by the MassDEP.*

TABLE 1
DESCRIPTION OF "BASE CASE" CONDITIONS

Description	Title 5 System	Individual N-Removing Systems		Cluster Systems		Satellite Systems	Centralized Systems
		Enhanced Current Practice	For TMDL Compliance	Current Practice	For TMDL Compliance		
Groundwater Discharge Permit Needed?	No	No	No	No	Yes	Yes	Yes
Facilities Procured Publically?	No	No	No	Yes	Yes	Yes	Yes
Collection System Needed?	No	No	No	Yes	Yes	Yes	Yes
Collection System Elements							
Length of Pipe per Connection, ft	N/A	N/A	N/A	*100*	*100*	100	100
Grinder Pumps per 100 Properties Served	N/A	N/A	N/A	5	5	5	5
Pump Stations per 100 Properties Served	N/A	N/A	N/A	1	1	1	1
Overall Construction Cost per Property	N/A	N/A	N/A	*$38,400*	*$38,400*	*$18,800 (avg)*	*$18,000 (avg)*
Wastewater Flows							
Design[1]	350 gpd	350 gpd	350 gpd	8,800 gpd	8,800 gpd	25,000 gpd to 300,000 gpd	1.5 mgd and 3.0 mgd
Typical Annual Average	175 gpd	175 gpd	175 gpd	4,400 gpd	4,400 gpd	Varies	Varies
Land costs, $/acre	N/A[2]	N/A[2]	N/A[2]	$250,000	$250,000	$250,000	$250,000
Transport Distances, feet							
Collection to Treatment	0	0	0	200	200	250 to 750	3,000 to 7,000
Treatment to Disposal	0	0	0	100	100	200 to 500	10,000
Disposal in N-Sensitive Watershed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Effluent Nitrogen Concentration, mg/l	26	19	13	15	8	8	5
Time Value of Money, interest rate, term	5%, 20 Yr	5%, 20 Yr	5%, 20 Yr	5%, 20 Yr	5%, 20 Yr	5%, 20 Yr	5%, 20 Yr

Refer to Footnotes on the next page.

Footnotes for TABLE 1 - DESCRIPTION OF "BASE CASE" CONDITIONS

Note 1: For individual systems, estimates are based on a mix of 3-bedroom (80%) and 4-bedroom (20%) homes, consistent with an average of 3.2 bedrooms per home.

Note 2: It is assumed land would be available on the property served by the individual system.

Note 3: The Title 5 System Effluent Nitrogen Concentration of 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.

Note 4: Unlike the Title 5 System Effluent Nitrogen Concentration, a concentration less than 26.25 mg/l does not include the additional reduction in the soils beneath the discharge since the sampling location is prior to the effluent discharge to the ground.

Cluster Systems (2 scenarios)

1. Cluster systems with single-stage treatment facilities producing an effluent nitrogen concentration of 15 mg/l. These systems are now in place serving commercial facilities and some residential developments, and are governed by Title 5. They generally rely on the recycle of effluent to the septic tank to provide partial denitrification. They perform somewhat better than individual denitrifying systems due to the benefits of more uniform flow and waste characteristics. In subsequent exhibits, this scenario is termed "current practice".

2. Cluster systems with two-stage treatment facilities producing an effluent nitrogen concentration of 8 mg/l. This scenario assumes that the treatment system will have separate processes for nitrification and denitrification, chemical feed facilities, a standby generator housed in a small control building, and groundwater monitoring wells. Capital and O&M costs reflect the MassDEP position that these systems must be built and operated under the same conditions as the groundwater discharge permit program, including influent, effluent and groundwater monitoring. For simplicity, this scenario is called "for TMDL compliance" in the tables and figures that follow.

Satellite Systems (*4* scenarios). Costs have been prepared for *four* design capacities (50,000 gpd, 100,000 gpd, 200,000 gpd and 300,000 gpd). In all cases, the standard provisions of the MassDEP groundwater discharge permit apply. Effluent quality is estimated to fall between 6 and 8 mg/l in the Base Case, with the larger facilities producing the better effluent.

Centralized Systems (2 scenarios). Costs have been prepared for two design capacities (1.5 mgd and 3.0 mgd). In all cases, the standard provisions of the MassDEP groundwater discharge permit program apply. Due to the quantities of wastewater to be treated and disposed of, much larger transport distances are included in this analysis compared with other scenarios, because of the presumed difficulty in finding sites of sufficient size near the collection area. The size of these facilities and the level of operational oversight justify the use of 5 mg/l as the baseline effluent quality for these scenarios.

Basis for Reporting of Costs and Performance

The fundamental elements of the cost analysis are capital cost and O&M cost. To be able to compare hypothetical Option #1 (that costs a lot to build but little to operate) with a low-capital-high-O&M alternative (hypothetical Option #2), the "equivalent annual cost" (EAC) of each scenario has been computed. The equivalent annual cost is the sum of the O&M cost and the amortized capital cost. For example, one could take a bank loan to offset a $31 million capital cost, and pay $2.5 million per year back to the bank over 20 years, assuming interest at 5%. If the operation and maintenance costs were $500,000 per year, the equivalent annual cost would be $3.0 million ($2.5 million in amortized capital plus $0.5 million in O&M). This one number reflects the combined impact of the capital and O&M costs, and it allows a consistent comparison with other alternatives.

Each of the treatment systems under consideration has a different ability to remove nitrogen, the driving force for wastewater management in most places on Cape Cod. To factor in the effectiveness of a given treatment system, the equivalent annual cost has been compared with the annual nitrogen removal effected by that option. The result can be converted to dollars per pound of nitrogen removed. In the example above, assume that the treatment system can remove 8,700 pounds of nitrogen per year. The unit cost for nitrogen removal would be $350 per pound ($3.0 million of equivalent annual cost divided by an annual removal of 8,700 pounds).

Figure 6 illustrates, in diagrammatic form, the computation of this measure of wastewater treatment cost effectiveness. Actual calculations are illustrated in Appendix C for two cases.

Each of the evaluated treatment systems was compared to the basic option of allowing individual properties to continue to use individual on-site septic systems. Based on the methodology of the Massachusetts Estuaries Project, individual septic systems are assumed to have 26 mg/l of nitrogen remaining in the system effluent. If a more sophisticated nitrogen-removing option can produce an effluent with, say, 6 mg/l of nitrogen, and provide for effluent disposal within the watershed, then that option "removes" 20 mg/l from the watershed. (If the untreated wastewater entering the treatment system is at 50 mg/l, the system actually removes about 44 mg/l from the wastewater. However the removal quantity reported herein is "removed from the watershed", not "removed from the wastewater".) If the nitrogen removing system discharges outside the watershed, it removes all of the 26 mg/l that would otherwise be discharged on site through a Title 5 system.

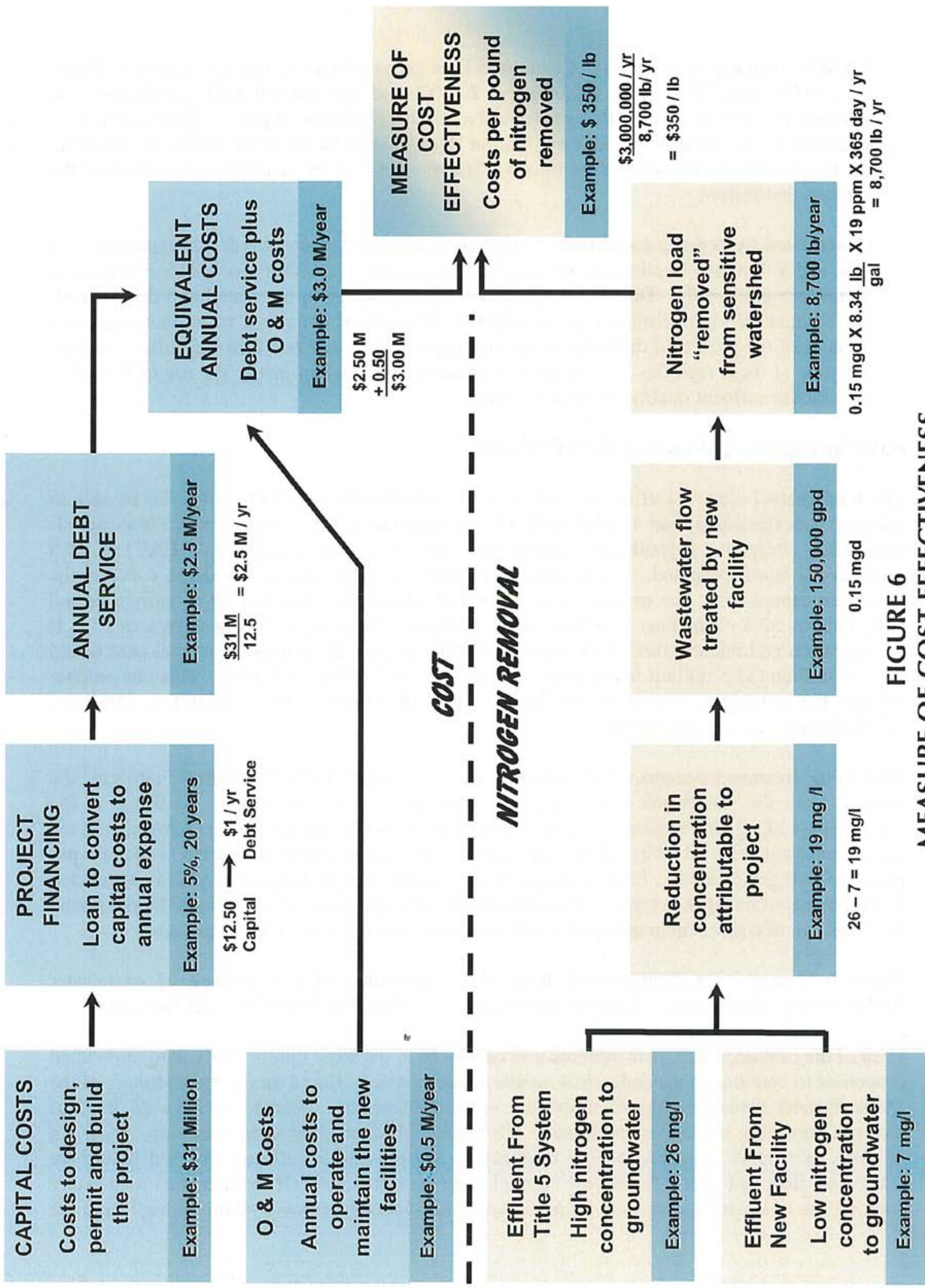


FIGURE 6
MEASURE OF COST EFFECTIVENESS

EVALUATION RESULTS

Results of Base Cases

Table 2 summarizes the cost estimates prepared for the Base Cases. These estimates relate directly to the assumptions shown in Table 1. These costs cover all pertinent elements of a municipal wastewater system, including collection (all but individual systems), treatment, transport, and disposal.

The first column of Table 2 reports the estimated capital costs for each scenario and includes construction, engineering, permitting, legal, land, and contingencies. These costs are expressed on a per-property basis to allow comparison across scenarios that serve different numbers of properties. The estimated costs range from *$22,400* to *$71,120* per property, compared with the estimated $13,000 for a simple Title 5 system. These costs do not reflect actual betterment charges that a town may levy; towns may choose to spread some of these costs across the entire tax base.

Estimates of O&M costs are tabulated in the second column of Table 2. They range from *$190* to *$3,850*, compared with *$165* for a Title 5 system. The O&M costs are also expressed on a per-property basis to allow comparison among scenarios that serve different numbers of parcels.

In general, the individual systems have a lower capital cost and the centralized options have a smaller O&M cost. Combining capital costs and O&M expenses into an equivalent annual cost provides a methodical way to approximate total life-cycle costs, and this measure is reported in the third column of Table 2. Equivalent annual costs range from *$2,560* to *$9,040* per property, compared with *$1,210* for the simple Title 5 system.

The data are further refined by incorporating an estimate of the nitrogen removed from the watershed. The fourth column of Table 2 presents the equivalent annual cost divided by the nitrogen removal, on a dollar-per-pound basis. See Figure 6 for a depiction of this computation approach. These estimates range from about *$250* for centralized systems to over *$1,500* for some of the smaller-scale scenarios.

Figure 7 summarizes the costs for the Base Case scenarios, in the form of four sets of bar charts. The heights of the bars represent either the capital cost per property served (Fig. 7A), the O&M cost per property (Fig. 7B), the equivalent annual cost per property (Fig. 7C) or the cost per pound of nitrogen removed (Fig. 7D). The cost estimates are presented on a per-property-served basis to account for the fact that the various systems all serve a different number of properties. The reader should carefully review the discussion in a later section of this report related to the need to consider both the average per-property costs and the number of properties that must be served.

Conclusions Related to the "Base Case"

Figure 7 allows some conclusions to be drawn, specific to the assumptions of the Base Cases:

1. Individual denitrifying systems have the lowest capital cost, primarily because they avoid the need for a wastewater collection system. Cluster and small satellite systems have the highest capital cost per property served, in part because they benefit little from economies of scale.

2. With respect to O&M cost per property, centralized and large satellite systems are the least expensive, along with cluster systems designed for small amounts of nitrogen removal. Cluster systems designed for lower levels of effluent nitrogen have the highest per-property O&M costs, as do individual denitrifying systems.

3. When both capital cost and O&M expenses are combined into an equivalent annual cost per property, the centralized systems have a cost advantage.

4. When nitrogen removal capability is included in the analysis, centralized systems are clearly the lowest cost. The individual, cluster and small satellite systems are considerably more expensive in terms of equivalent annual cost per pound of nitrogen removed.

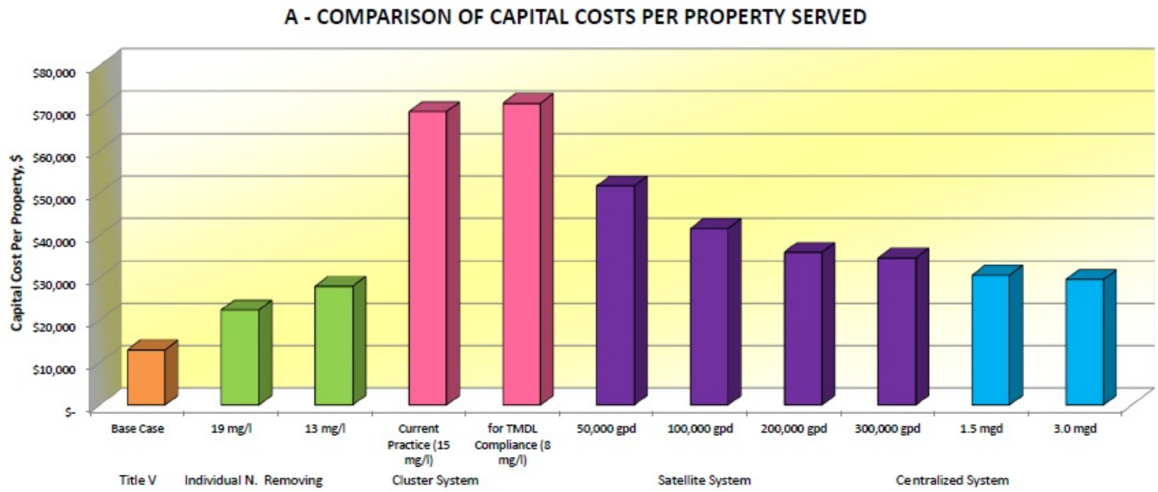
These conclusions are specific to the assumptions that form the basis for the Base Cases (see Table 1). To gauge how important the assumptions are to the conclusions, a sensitivity analysis was conducted. Appendix C contains illustrations of the computational procedure and descriptions of the assumptions used in the sensitivity analyses.

TABLE 2
SUMMARY OF COST ESTIMATES

	Estimated Cost per Property Served			**Equivalent Annual Cost per Pound of Nitrogen Removed**	
	Capital Cost	Annual O&M Cost	Equivalent Annual Cost	$/lb N	Premium over 3.0-mgd Centralized System
Individual Systems					
Title 5	*$13,000*	*$165*	*$1,210*	*N/A*	*Not Applicable*
Nitrogen-removing --current practice	*$22,400*	*$1,375*	*$3,170*	*$820*	*228%*
Nitrogen-removing --for TMDL compliance	*$28,000*	*$3,850*	*$6,100*	*$860*	*244%*
Cluster Systems					
Current practice	*$69,170*	*$2,780*	*$8,330*	*$1,520*	*508%*
For TMDL compliance	*$71,120*	*$3,330*	*$9,040*	*$1,020*	*308%*
Satellite Systems					
50,000 gpd	*$51,650*	*$1,050*	*$5,200*	*$580*	*132%*
100,000 gpd	*$41,640*	*$790*	*$4,130*	*$460*	*84%*
200,000 gpd	*$36,010*	*$590*	*$3,480*	*$390*	*56%*
300,000 gpd	*$34,670*	*$500*	*$3,280*	*$370*	*48%*
Centralized Systems					
1.5 mgd	*$30,640*	*$250*	*$2,710*	*$260*	*4%*
3.0 mgd	*$29,600*	*$190*	*$2,560*	*$250*	----

Notes: Equivalent annual costs are based on 5%, 20-year financing.
Watershed-wide costs must consider the number of properties served and the average cost per property; see Figure 9 and text.

FIGURE 7 (1st Page)



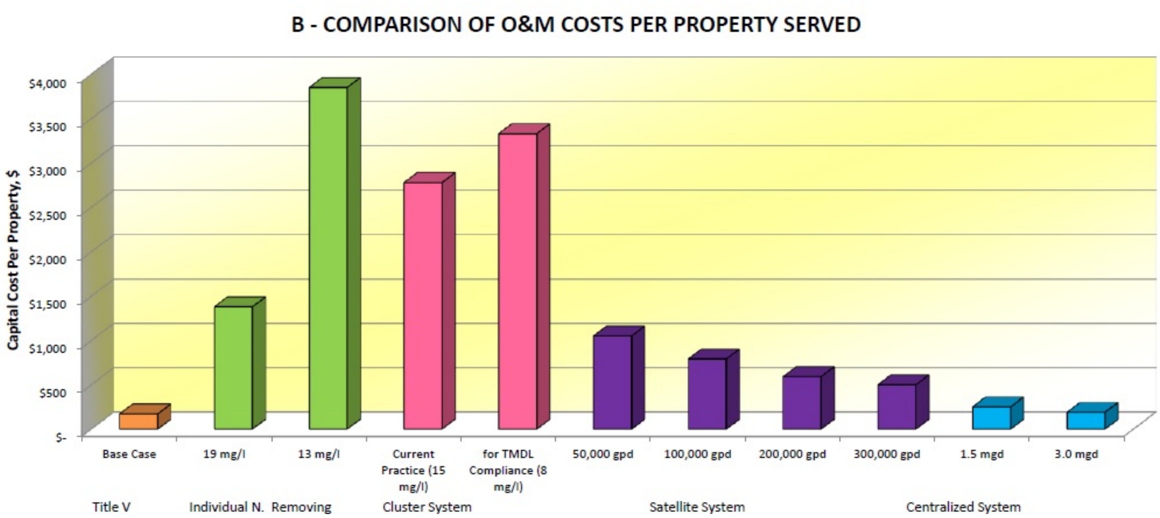
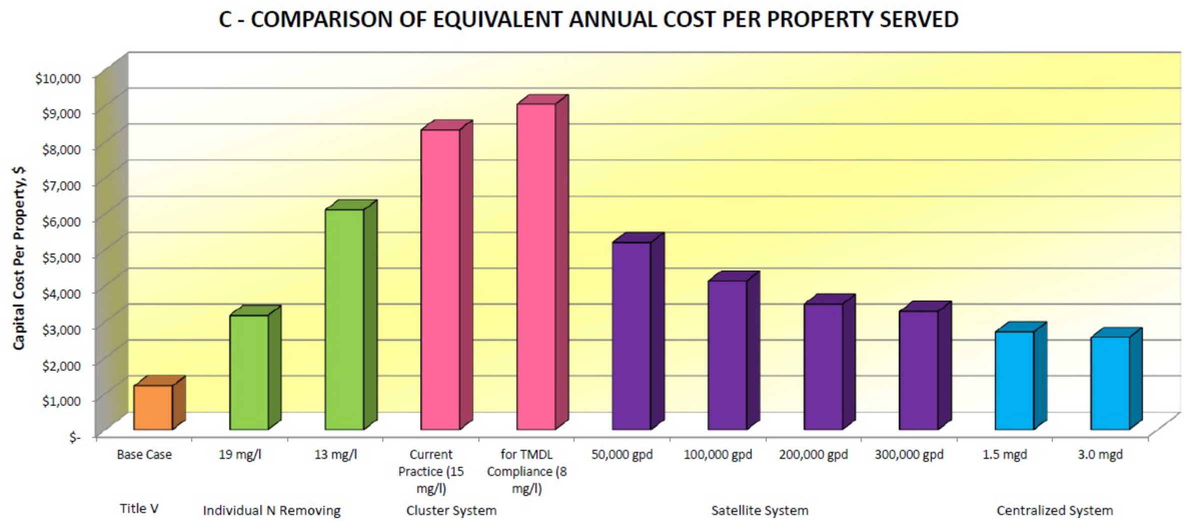
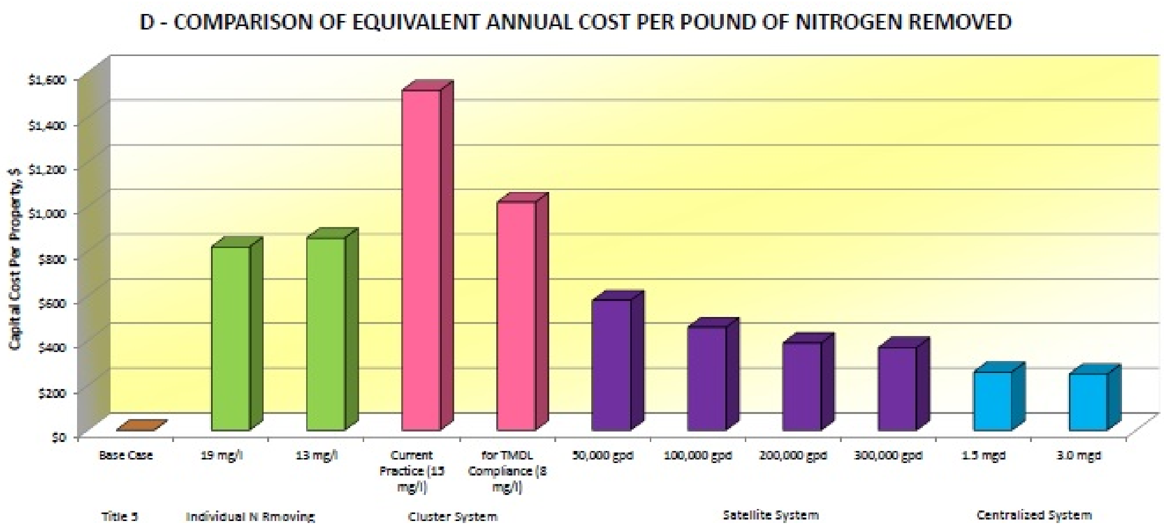


FIGURE 7 (2nd Page)





Sensitivity Analysis for Individual Denitrifying Systems

For the Base Case, individual nitrogen-removing *or Innovative/Alternative (I/A)* systems were evaluated at 19 mg/l (approximating the current practice) and at 13 mg/l (assuming more rigorous design and operational oversight and, also with added monitoring to demonstrate TMDL compliance). The principal cost parameters were estimated as follows, with the lower capital and O&M costs typically pertaining to the 19 mg/l scenario:

Capital cost per property	*$22,400* to $28,000
O&M cost per property	*$1,380* to *$3,850*
Equivalent annual cost (EAC) per property	*$3,170/yr* to *$6,100/yr*
EAC per pound of N removed	*$820* (19 mg/l) to *$860* (13 mg/l)

The sensitivity analysis considered the impact of reusing existing Title 5 systems by adding new denitrifying equipment, a more conservative estimate of site restoration costs, possible reductions in monitoring requirements, added costs for municipal procurement and oversight, higher or lower effluent nitrogen concentrations, and the potential for future cost reductions related to advances in technology. The results are presented below, expressed as equivalent annual cost (EAC) per pound, and as a percentage reduction from the Base Case.

	Individual Nitrogen-Removing Systems	Enhanced Current Practice (19 mg/l)	For TMDL Compliance (13 mg/l)
	Base case	***$820***	***$860***
A	Adding $4,000 for site restoration	*$910*	*$910*
	(Change from base case)	*11%*	*6%*
B	Municipal procurement (+20%)	*$910*	*$920*
	(Change from base case)	*11%*	*7%*
C	Municipal oversight of operations	*$860*	*$880*
	(Change from base case)	*5%*	*2%*
D	Reusing 50% of existing systems	*$590*	*$700*
	(Change from base case)	*-28%*	*-19%*
E	Dropping BOD and TSS sampling	*$490*	*$370*
	(Change from base case)	*-40%*	*-57%*
F	Reducing the effluent N by 3 mg/l	*$580*	*$700*
	(Change from base case)	*-29%*	*-19%*
G	Reducing effluent to 5 mg/l	*$280*	*$540*
	(Change from base case)	*-66%*	*-37%*

This evaluation has considered a scenario where individual nitrogen-removing systems are designed, constructed and operated to be more effective than is the current situation on Cape Cod, on the premise that such steps would be necessary to enable these systems to be part of a town's plan for TMDL compliance. While there may be circumstances where individual systems are competitive with other options, there are two very important points to consider:

- *Mass*DEP has stated that complete reliance on individual denitrifying systems may not be an acceptable means to achieve TMDL compliance, from an administrative and regulatory perspective. *It should be noted that MassDEP will determine the operational requirements on the use of I/A systems as a sole approach for watershed restoration*; and

- If these systems can reliably achieve only 13 mg/l (the base case assumption here), then they would be applicable as the sole approach only in circumstances where less than 50% removal of the septic load in an embayment is needed.

- *While Title 5 System Effluent Nitrogen Concentration of 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. Where effluent nitrogen concentration proposed is less than 26.25 mg/l it does not include the additional reduction that occurs in the soils beneath the discharge since the sampling location is prior to the effluent discharge to the ground.*

Nonetheless, individual nitrogen-removing systems have been evaluated here because they may have some limited applicability moving forward, and there needs to be a better understanding of their relatively high cost among the planning boards, boards of health and conservation commissions that routinely require them.

Sensitivity Analysis for Cluster Systems

For the Base Case, cluster systems were evaluated for two scenarios. In the first approach, the systems would be developed under Title 5, as is standard for most or all cluster systems in operation today, with an estimated effluent quality of 15 mg/l nitrogen. In the second approach, the cluster system would be designed, permitted and operated under the groundwater discharge permitting program of *Mass*DEP. The second approach would entail more costs for construction and operation, but would attain a lower effluent nitrogen concentration (8 mg/l assumed in the Base Case). With a groundwater discharge permit, the cluster system would cost more to build and to operate, but might be approvable by *Mass*DEP as part of a TMDL compliance plan. One additional advantage of the second approach is a smaller effluent disposal system, because the groundwater permitting program allows higher loading rates than under Title 5. The principal cost parameters were estimated as follows, with the lower capital and O&M costs typically pertaining to the 15 mg/l (Title 5) scenario:

Capital cost per property	*$69,170* to *$71,120*
O&M cost per property	*$2,780* to *$3,300*
Equivalent annual cost *(EAC)* per property	*$8,330* to *$9,040*
EAC per pound of N removed	*$1,020* (15 mg/l) to *$1,520* (8 mg/l)

	Cluster Systems	Under Current Program (15 mg/l)	For TMDL Compliance (8 mg/l)
	Base Case	***$1,520***	***$1,020***
A	Serving one-third seasonal homes (change from base case)	*$1,620* *7%*	*$1,080* *6%*
B	Eliminating land costs (change from base case)	*$1,470* *-3%*	*$990* *-3%*
C	Serving only denser developments (change from base case)	*$1,360* *-11%*	*$920* *-10%*
D	Reducing treatment costs by 20% (change from base case)	*$1,490* *-2%*	*$990* *-3%*
E	Reducing on-site operator time by 20% (change from base case)	*$1,450* *-5%*	*$960* *-6%*
F	Discharging outside sensitive watersheds (change from base case)	*$650* *-57%*	*$710* *-30%*
G	Reducing the effluent N by 2 mg/l (change from base case)	*$1,290* *-15%*	*$920* *-10%*
H	Reducing effluent to 5 mg/l (change from base case)	*$810* *-47%*	*$870* *-15%*

In this case, the added expense of construction, operation and monitoring are more than offset by the demonstrated reduction in nitrogen load, resulting in a substantial decline in cost per pound removed. The sensitivity analysis considered the impact of using town-owned parcels to avoid land costs, serving only dense development of small lots to reduce collection costs, achieving lower effluent nitrogen concentrations, the potential for future cost reductions related to advances in technology, and possible reductions in labor costs assuming use of remote sensing capabilities. The results are presented below, expressed as EAC per pound, and as a percentage reduction from the Base Case.

This sensitivity analysis establishes a wide range of costs for cluster systems. The equivalent annual costs per pound of nitrogen removed fall in the following broad ranges for the two scenarios:

Current Practice	*$650* to *$1,620*
For TMDL Compliance	*$710* to *$1,080*

The greatest reductions in cost per pound result from eliminating land costs, discharging outside sensitive watersheds, and reducing effluent nitrogen concentrations.

Sensitivity Analysis for Satellite Systems

For the Base Case, satellite systems were evaluated at 50,000 gpd, 100,000 gpd, 200,000 gpd, and 300,000 gpd. The principal cost parameters were estimated as follows, with the higher end of the range typically pertaining to the smaller facilities:

Capital cost per property	*$34,670*to *$51,650*
O&M cost per property	*$500* to *$1,050*
Equivalent. annual cost *(EAC)* per property	*$3,280* to *$5,200*
EAC per pound of N removed	*$370* to *$580*

The sensitivity analysis considered the impact of land costs, the transport distances to treatment and disposal sites, the location of the effluent disposal site inside or outside the watershed of a nitrogen-sensitive embayment, higher or lower effluent nitrogen concentrations, and the potential for future cost reductions related to advances in technology. The results are presented below, expressed as EAC per pound, and as a percentage reduction from the Base Case.

	Satellite Systems	50,000 gpd (8 mg/l)	100,000 gpd (8 mg/l)	200,000 gpd (8 mg/l)	300,000 gpd (8 mg/l)
	Base case	***$580***	***$460***	***$390***	***$370***
A	Tripling the transport distances	*$590*	*$470*	*$390*	*$370*
	(change from base case)	*2%*	*2%*	*0%*	*0%*
B	Discharging in Zone II	*$580*	*$460*	*$380*	*$350*
	(change from base case)	*0%*	*0%*	*-3%*	*-5%*
C	Reducing the land cost to zero	*$580*	*$460*	*$390*	*$360*
	(change from base case)	*0%*	*0%*	*0%*	*-3%*
D	Discharging outside sensitive watersheds	*$410*	*$320*	*$270*	*$260*
	(change from base case)	*-29%*	*-30%*	*-31%*	*-30%*
E	Reducing the effluent N by 2 mg/l	*$530*	*$420*	*$350*	*$330*
	(change from base case)	*-9%*	*-9%*	*-10%*	*-11%*
F	Reducing effluent N to 5 mg/l	*$500*	*$400*	*$340*	*$320*
	(change from base case)	*-14%*	*-13%*	*-13%*	*-14%*
G	Reducing capital costs by 20%	*$560*	*$450*	*$380*	*$360*
	(change from base case)	*-3%*	*-2%*	*-3%*	*-3%*

This sensitivity analysis establishes a range of costs for satellite systems. The equivalent annual costs per pound of nitrogen removed fall in the following ranges for these two sizes of satellite systems:

50,000 gpd	*$410* to *$590*
200,000 gpd	*$270* to *$390*

It is also possible to combine multiple variables in this analysis. For example, if land costs could be eliminated and effluent disposal could be outside sensitive watersheds, then the cost would be *$400* and *$270* for the 50,000 gpd and 200,000 gpd examples, a reduction of *30%* to the Base Case *for both examples*. Discharging outside sensitive watersheds is the largest single factor reducing costs.

Sensitivity Analysis for Centralized Systems

For the Base Case, centralized systems were evaluated at 1.5 mgd and 3.0 mgd. The principal cost parameters were estimated as follows, with the higher end of the range typically pertaining to the smaller facility:

Capital cost per property	*$29,600* to *$30,640*
O&M cost per property	*$190* to *$250*
Equivalent. annual cost *(EAC)* per property	*$2,560* to *$2,710*
EAC per pound of N removed	*$250* to *$260*

The sensitivity analysis considered the impact of land costs, the transport distances to treatment and disposal sites, the location of the effluent disposal site inside or outside the watershed of a sensitive embayment or a water supply Zone II, higher or lower effluent nitrogen concentrations, and the potential for cost reductions related to regionalization. The results are presented below, expressed as EAC per pound, and as a percentage reduction from the Base Case.

	Centralized Systems	**1.5 mgd (5 mg/l)**	**3.0 mgd (5 mg/l)**
	Base case	***$260***	***$250***
A	Tripling the transport distances	*$270*	*$250*
	(change from base case)	*4%*	*0%*
B	Discharging in Zone II	*$280*	*$260*
	(change from base case)	*8%*	*4%*
C	Reducing the land cost to zero	*$260*	*$240*
	(change from base case)	*0%*	*-4%*
D	Discharging outside sensitive watersheds	*$210*	*$200*
	(change from base case)	*-19%*	*-20%*
E	Reducing effluent to 3 mg/l	*$240*	*$230*
	(change from base case)	*-8%*	*-8%*
F	Reducing costs by 10% by regionalization	*$260*	*$240*
	(change from base case)	*0%*	*-4%*

This sensitivity analysis establishes a range of costs for central systems. The equivalent annual costs per pound of nitrogen removed fall in the following ranges for two sizes of central systems:

1.5 mgd	*$210* to *$280*
3.0 mgd	*$200* to *$260*

It is also possible to combine multiple variables in this analysis. For example, if transport costs were tripled and effluent disposal could only occur in a Zone II, then the *equivalent annual* cost *per pound of nitrogen* would be *$290* and *$260* for the 1.5 mgd and 3.0 mgd examples, an increase of *12%* to *4%* over the *respective* Base Cases.

Figure 8 illustrates the results of this sensitivity analysis, in graphical form. The horizontal bar represents the range of costs developed from the sensitivity evaluation, and the vertical red bar denotes the Base Case for each type of system. The letters on each bar refer to the individual sensitivity analyses as noted above.

DISCUSSION OF RESULTS

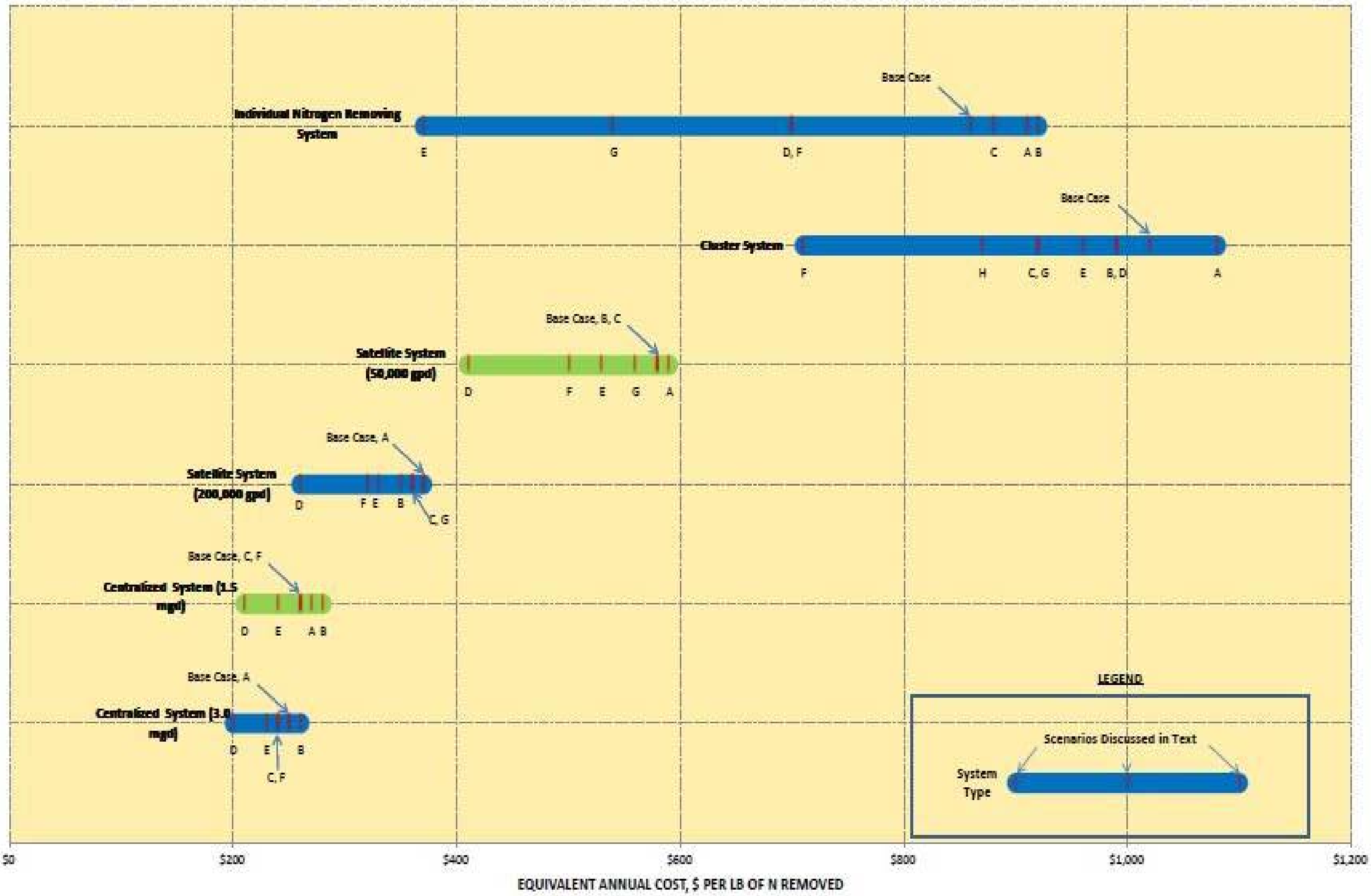
There are two general purposes of this evaluation. The first is to make an "apples-to-apples" comparison of treatment systems in these categories. The second is to identify the circumstances under which each type of system is most cost-effective.

One striking feature of Figure 8 is the very broad range of costs for these systems, indicating the importance of many variables. Another important observation from Figure 8 is the fact that even the most favorable scenarios for TMDL-compliant individual *and* cluster systems all cost measurably more than the least favorable scenarios for the centralized systems.

For the assumptions of the Base Cases, the 3.0-mgd centralized system has the least cost when capital costs, O&M expenses and nitrogen removal capability are all considered. One way to view these data is to consider the "premium" associated with all other options compared to that low-cost alternative. The last column of Table 2 shows that premium as a percentage over the larger centralized option. Considering both cost and performance, the individual denitrifying systems are at least twice as expensive as the 3.0-mgd scenario, and the cluster systems are at least *three times* more expensive. The satellite systems are *about 50% to 130%* more expensive.

The first three columns of Table 2 list average per-property costs, without considering the fact that some scenarios require more properties to be served that other. The use of the dollar-per-pound-removed metric provides a more meaningful measure, because it accounts for the variable number of parcels that must be served among the scenarios.

FIGURE 8
SUMMARY OF ESTIMATED COSTS PER POUND OF NITROGEN REMOVED



The Base Cases were developed to provide a fair comparison of options under a uniform set of conditions as a tool to help guide more detailed analyses. If a town is faced with conditions similar to the Base Case, it is likely to find that centralized systems are the most cost-effective. However, a town should closely review these sensitivity analyses to see if conditions exist that warrant a detailed review of the other options. The ranges of costs depicted in Figure 8 can be used to judge the importance of many factors that impact cost. If circumstances exist that reduce the cost of the smaller-scale options and increase the cost of the larger-scale alternatives, the cost premiums may be significantly less than show in Table 2.

Example Project Costs

The cost estimates presented above are the result of the application of a generic cost model to a prescribed set of circumstances, where every effort was made to use a common set of assumptions. To help illustrate that these hypothetical costs are realistic, several "real-life" projects were analyzed to compute their equivalent cost per pound of nitrogen removed. Table 3 is the result of that analysis. Nine projects, with design capacities ranging from 8,000 gpd to 2.3 mgd, were evaluated as to capital costs, O&M costs and actual annual nitrogen removal.

The computed costs per pound of nitrogen removed are shown at the bottom of Table 3, based on reported costs. The first set of unit costs (in bold print) represents direct calculations from the data in Table 3. The second set of unit costs reflects an adjustment to the collection costs to make them consistent with the density of sewered area (100 feet of collector pipe per connection) used in the hypothetical costs reported earlier. This adjustment was made to equalize a significant cost factor and aid in the understanding of the differences among the projects.

A third estimate of unit costs is included for the Brackett Landing project and the proposed Orleans project. The Brackett Landing project's current oversight and monitoring costs do not reflect the *Mass*DEP requirements that would pertain if such a facility were to be used in a municipal setting with sufficient documentation to demonstrate TMDL compliance. The last adjusted unit cost for Brackett Landing ($723 per pound) is intended to approximate compliance with those *Mass*DEP requirements. Table 3 also includes the costs for the proposed Orleans wastewater system, based on the CWMP. Those data are included in Table 3 to illustrate the results of the Town's evaluation of regionalization opportunities. A recent detailed study showed that Orleans could reduce the *equivalent annual* cost *per pound of nitrogen removed for* its wastewater project by about 10% by expanding it to include capacity for wastewater from portions of Eastham and Brewster.

Appendix D is a summary of the sources of data and assumptions and adjustments used to compile Table 3.

TABLE 3
COSTS FOR EXAMPLE PROJECTS

Example Projects	Brackett Landing, Eastham	Camp Jewell, Colebrook Conn.	New Silver Beach, Falmouth	Mashpee Commons	West Island, Fairhaven	Tisbury	Province-town	Orleans CWMP	Chatham
Wastewater flows, gpd									
Design	8,230	19,000	60,000	80,000	100,000	104,000	575,000	1,440,000	2,300,000
Annual average	3,300	6,700	25,000	18,900	25,100	37,000	150,000	504,000	1,011,000
Groundwater Discharge Permit?	No	No	Yes	Yes	Yes	Yes	Yes	N/A	Yes
Public Procurement?	No	No	Yes	No	Yes	Yes	Yes	N/A	Yes
Treatment Technology	SeptiTech and Nitrex	BioClere	SBR	RBC	RBC	SBR	SBR	Bardenpho	Oxidation Ditch
Collector Length per Connection, ft	58	---	50	--	68	68	64	138	82
Capital Cost, $M	0.98	1.49	8.55	2.37	8.9	12.2	35	152	210
O&M Cost, $1000/yr	25.5	83.9	151	222	165	360	780	1,200	1,900
Equivalent Annual Cost (5%, 20 yr), $1000/yr	104	203	837	412	880	1,340	3,560	13,400	18,800
Nitrogen Load Removed, lb/yr	228	331	1,240	1,220	1,470	2,400	12,000	40,300	75,110
Unit Cost, $/lb N removed									
Based on data above	**455**	**613**	**677**	**337**	**596**	**560**	**297**	**333**	**250**
Adjusted for collection	551	953	852	754	704		328	296	265
Other computations	723							270	
(Basis)	(For TMDL Compliance)							(Regional-ization)	

Note: See Appendix D for sources, notes and assumptions.

These examples show that the costs for small systems can be over $700 per pound, versus larger systems at less than $300 per pound. These are the same conclusions that can be drawn from the hypothetical estimates presented above. The data in Table 3 also show the importance of reducing costs by focusing sewer systems on densely developed areas. The example projects that have only 50 to 70 feet of collection pipe per connection have costs that are over $100 per pound less than would be predicted for the 100-foot assumption in the conceptual analysis. The Brackett Landing example also illustrates that increased oversight and testing (as would be required by *Mass*DEP to demonstrate TMDL compliance) increases costs by more than $100 per pound at this small scale, even with the very high level of treatment that has been demonstrated at that project.

Cost Impacts of Effluent Disposal within a Nitrogen-Sensitive Watershed

Caution is warranted in reviewing the estimated per-property capital costs presented above. Two alternative solutions with approximately the same per-property capital costs may have significantly different costs watershed-wide. This concept is illustrated in Figure 9, which contrasts a solution using a disposal site within a nitrogen-sensitive watershed (on the right) with one using out-of-watershed disposal (on the left). In this example, 44% more septic systems must be eliminated in the case of in-watershed-disposal to account for the nitrogen in the treatment plant effluent that remains in the watershed. Disposal of that residual nitrogen in a non-sensitive watershed allows fewer properties to be connected to the collection system. Figure 8 is based on an assumed 8 mg/l in the treatment plant effluent. The added burden of in-watershed disposal varies with the quality of the treatment plant effluent, as follows:

In-watershed effluent disposal at 13 mg/l	100% more parcels served
In-watershed effluent disposal at 10 mg/l	62% more parcels served
In-watershed effluent disposal at 8 mg/l	44% more parcels served
In-watershed effluent disposal at 5 mg/l	23% more parcels served

It is clear that the watershed-wide cost must consider both the average cost per property served and the total number of properties whose septic systems would be eliminated to meet a TMDL. That consideration is inherently incorporated in the dollar-per-pound measure of cost-effectiveness reported here, and therefore that cost measure should be the one given most consideration in CWMPs.

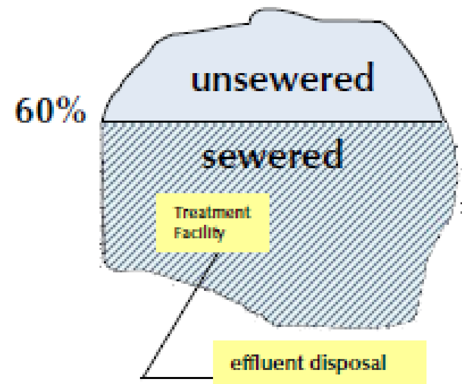
FIGURE 9

IMPACT OF IN-WATERSHED DISPOSAL ON THE EXTENT OF SEWERS

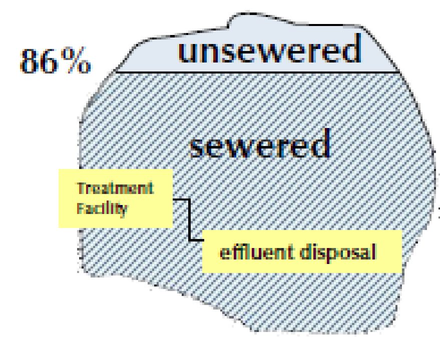
Example Watershed

- 1,000 homes on septic systems
- Septic nitrogen load = 10,000 lb/yr
- TMDL = 4,000 lb/yr
- Required septic load removal = 60%

A. Effluent Disposal Outside Watershed



B. Effluent Disposal Inside Watershed



	A. Effluent Disposal Outside Watershed	B. Effluent Disposal Inside Watershed
Nitrogen from unsewered parcels (26 mg/l)	4,000 lb/yr	1,400 lb/yr
Nitrogen from effluent disposal in watershed (8mg/l)	0	2,600
Total wastewater-related load	4,000 lb/yr	4,000 lb/yr
Parcels sewered	**600**	**860** (44% more)

Applicability of Title 5 Systems

The inability of traditional septic-tank-and-leaching-field systems to control nitrogen and phosphorus is at the heart of the wastewater management problem on Cape Cod. Nonetheless, Title 5 systems are a very cost-effective way to deal with basic sanitary needs of wastewater disposal. This evaluation shows that the typical cost of a Title 5 system is only about a third that of centralized system and a much smaller percentage of other options that involve nitrogen removal. Therefore, towns should develop wastewater plans that allow maximum use of Title 5 systems. In a nitrogen-sensitive watershed, the lowest cost plan for nitrogen control will involve two parts:

- A sewer system to collect wastewater that will be treated and disposed of in the most economical way, and

- Title 5 systems for everyone else in the watershed.

There are other reasons to eliminate or supplement Title 5 systems, such as to correct unsanitary conditions, avoid unsightly mounded systems, reduce the costs of frequent septage pumping, etc. Those reasons should be determined in a definitive needs assessment during the development of the CWMP. The most cost-effective wastewater plan will maximize the use of Title 5 systems (consistent with nitrogen control and all other needs) and efficiently deal with the wastewater collected to meet those overall needs.

Applicability of Individual Nitrogen-Removing Systems

It is currently the opinion of *Mass*DEP that these systems may not be suitable as the sole means of TMDL compliance, given the difficulty faced by a municipality to build them on large numbers of private parcels, monitor their nitrogen removal capabilities and provide for long-term operation and maintenance. Even in the absence of these concerns, *these systems are limited in the removal of septic nitrogen, so they are only applicable in watersheds where 50% removal or less is required*. However, there are circumstances where individual denitrifying systems can be a valuable adjunct to other options.

Conditions Most Favorable. The greatest benefit of individual denitrifying systems is the avoidance of a collection system, since they provide for treatment and disposal on the same parcel where the wastewater is generated. In neighborhoods where the average length of collection pipe per property served would exceed 200 feet, the substantial cost of wastewater collection may make other systems more expensive. In these circumstances, individual systems should be evaluated, considering all costs as well as the administrative issues related to property access and TMDL compliance.

Conditions Least Favorable. Where septic nitrogen control needs exceed 50%, these systems are not applicable. This percentage may rise over time as technology improvements result in better routine nitrogen removal. Even in those watersheds where relatively small percentages of nitrogen removal are needed, the very high cost per pound of nitrogen removed (greater than *$800* per pound) should preclude their consideration if the collection system requires less than 150 feet per connection. Unless larger-scale systems must include very large transport distances to available treatment/disposal sites, and effluent disposal must occur in very sensitive watersheds or in water supply Zone IIs, these systems need not be evaluated in detail except for serving isolated areas.

Applicability of Cluster Systems

Wastewater treatment systems smaller than 10,000 gpd suffer significantly from "dis-economies of scale", but there are circumstances where they can be applicable. *Mass*DEP is not inclined to allow a series of cluster systems as the primary means of TMDL compliance (for many reasons similar to the issues related to individual systems), but those *Mass*DEP concerns may be addressed by developing cluster systems under the groundwater discharge permit program. It is for this reason that two types of cluster systems were evaluated in this analysis.

Conditions Most Favorable. Cluster systems may be viable components of a CWMP in these circumstances:

- Existing neighborhoods of small lots (and therefore low collection costs) that are remote from proposed sewered areas, and that have publically-owned vacant land nearby;
- New cluster developments where the developer can install alternative collection systems at the time of construction and later turn the project's wastewater infrastructure over to the town; and
- Shore-front neighborhoods near small, poorly-flushed embayments where the cluster system can provide an early benefit of nitrogen control, and later be converted to a pumping station in later phases of a centralized system.

Non-cost factors should also be considered, such as the need to maintain water balance within watersheds.

Conditions Least Favorable. Given their high cost per pound of nitrogen removed (greater than *$1,000* per pound), cluster systems do not warrant detailed consideration unless larger-scale systems must include very large transport distances to available treatment/disposal sites, and effluent disposal must occur in very sensitive watersheds or in water supply Zone IIs.

Applicability of Satellite Systems

Satellite systems, by definition, are designed to serve portions of a town or large individual developments. There are more than 50 such systems on Cape Cod, most privately developed. Most of the publically-owned satellite plants serve schools, but the New Silver Beach facility in Falmouth is a good example of a municipal system serving a specific portion of a town.

Conditions Most Favorable. Satellite systems may be viable components of a CWMP in these circumstances:

- A remote watershed in need of nitrogen control that is more than 5 miles from the existing sewer system or other areas or need, and that has publically-owned vacant land nearby;

- New large-scale residential or commercial developments where the developer can install collection, treatment and disposal facilities at the time of construction and later turn the project's wastewater infrastructure over to the town; and

- An existing or proposed private facility that can be taken over by the town and expanded to provide wastewater service to existing nearby properties currently on septic systems, particularly if the town-wide system may *not* be available for many years and the developer is prepared to proceed in the near future.

Satellite systems of 150,000 gpd or larger have a distinct cost advantage over those 50,000 gpd and smaller.

Conditions Least Favorable. Given their high cost per pound of nitrogen removed (greater than *$450* per pound), satellite systems smaller than 100,000 gpd have limited applicability unless they serve areas particularly remote from larger-scale wastewater infrastructure. If centralized facilities exist or can be developed within 5 miles, satellite facilities do not warrant detailed consideration. If regionalization is possible and desirable, satellite options have an added disadvantage.

Applicability of Centralized Systems

Wastewater infrastructure that relies on a single treatment plant and effluent disposal system has both advantages and disadvantages. From a cost perspective, the "best" and "worst" circumstances are as follows:

Conditions Most Favorable. Centralized systems are likely to be the most viable wastewater systems where:

- 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, placing a cost premium on small-scale systems that discharge in sensitive watersheds;
- Areas of dense development in sensitive watersheds are within 3 miles of desirable effluent treatment and disposal sites;
- Opportunities are available for cost reductions through regionalization.

Conditions Least Favorable. Smaller-scale systems should be closely considered as alternatives to centralized systems where:

- Development in nitrogen-sensitive watersheds is relatively sparse;
- Available effluent disposal sites are remote, costly, and located in water supply Zone IIs or nitrogen-sensitive watersheds;
- Only small amounts of nitrogen must be removed, allowing individual denitrifying systems to be applicable;
- Water balance considerations favor local disposal; and
- Otherwise favorable sites are poorly located with respect to nearby development or have unacceptable impacts on natural resources.

Figure 8 is a graphical comparison of the range of costs estimated herein for all of the technologies. It shows that centralized systems are generally much less expensive, although there are certain circumstances where smaller-scale systems are cost competitive.

Identification of Most Important Cost Factors

This evaluation of large and small wastewater systems, including this sensitivity analysis, reveals some important points with respect minimizing costs for wastewater infrastructure. The most important cost factors facing any town are as follows, in approximate order of importance (most important first):

1. **Economies of Scale**. One 1.5-mgd centralized facility can cost less than the aggregate cost of 10 facilities each 150,000 gpd in size, other things being equal.
2. **Density of Development**. Wastewater collection costs are often more than 50% of the cost of the overall wastewater system. Collection costs for neighborhoods of lots with 75-foot frontage cost only about half as much as those with average 150-foot frontage. Towns should make every effort to identify those portions of sensitive watersheds with the least amount of collection pipe required per pound of nitrogen collected.

3. **Location of Effluent Disposal.** Significant cost advantages accrue to towns that can locate their effluent discharges within watersheds leading to the open ocean or to coastal systems with adequate nitrogen-assimilative capacity. For a 1.5-mgd centralized system, the ideal effluent disposal site offers a 20% to *30%* benefit, in terms of cost per pound of nitrogen removed. For discharges to nitrogen-sensitive watersheds or water supply Zone IIs, a premium must be paid for both a higher level of wastewater treatment and *a sewer system which is widespread enough to remove enough Title 5 systems to account for the effluent nitrogen load that remains in the watershed.*

4. **Land Costs**. While land costs may vary substantially across a town, use of town-owned land (or land that can be obtained at low cost) is, in general, a significant cost factor. In a decentralized plan with multiple treatment or disposal sites, more land is needed than in the comparable single-site alternative because of the buffer zones and set-backs needed at each site. Further, the chances for neighbor opposition increases, along with potential costs for delays, litigation and perhaps even eminent domain proceedings. (A countervailing factor is the potential for smaller sites, such as town parks, to be more readily available than larger sites.)

The sensitivity analysis reported herein indicates that projects that benefit from cost advantages in all four of these categories will be significantly less expensive than other options.

Readers should be cautioned to carefully consider the role of the efficiency of the wastewater treatment in overall system economics. While treatment System A that produces 5 mg/l effluent nitrogen may seem to be "twice as good" as System B treating to 10 mg/l, System A eliminates 21 of the 26 mg/l otherwise discharged from a septic system, while System B eliminates 16 mg/l. If Systems A and B cost the same to build and operate, System A will have a cost per pound of nitrogen removed that is 24% lower, not 50% lower. That cost advantage is largely eliminated if System A discharges within a sensitive watershed and System B discharges in a non-sensitive area.

OTHER ISSUES OF NOTE

Role of Collection System Costs in this Analysis

Except for individual denitrifying systems, which do not need a public collection system, collection system costs are a significant component of the overall cost of a public wastewater system. For this analysis, collection costs *were estimated for each scenario evaluated.*. It was assumed that the density of development tributary to any of the options would require 100 feet of collector pipe per property served, and that 5% of the properties would require grinder pumps to access the sewer. *A minimum of* one pumping station was assumed, *and another pumping station was added* for every one *thousand* properties. These assumptions lead to *average* estimated construction costs of *about $38,400* per property served for *cluster* systems, *$18,800 for satellite systems, and $18,000 for centralized systems.. These estimates* were included in all of the *evaluated scenarios,* except for the individual on-lot systems. The collection system for a 200,000 gpd satellite system accounts for *$170* of the *$390* per pound figure reported here for the Base Case. There are alternative collection approaches, such as low-pressure systems and septic-tank-effluent-pump systems, which also can be used to reduce collection cost in certain circumstances. When those favorable circumstances present themselves, it is assumed that these alternative collection systems would be implemented, regardless of the size of the treatment facility receiving the collected wastewater. Any cost reductions associated with these alternative collection systems should not be attributed to one scenario and not another.

Many communities may be faced with higher costs than presented herein due to the density of the sewered area. Whereas 100 feet of collector pipe per connection was assumed for this analysis, there may be areas of Cape Cod where 150 feet or more are needed, increasing the capital costs of any option requiring public sewers. The collection costs for neighborhoods requiring 150 feet of collector pipe per connection would translate to an extra *$110* per pound of nitrogen compared to the base case of 100 feet per connection.

Including collection costs in this analysis provides a more appropriate comparison among alternatives, and allows these figures to be compared with actual costs that have been incurred in some communities. However, the inclusion of a constant cost factor tends to mask the differences in treatment costs among the options. If the costs in Table 2 did not include collection costs, the percentage premiums for the small-scale options would be larger than those shown.

Optimizing Town Expenditures for Comprehensive Wastewater Management Planning

The Base Cases evaluated in this report represent one set of typical circumstances, but those circumstances may not reflect the situation that exists in any one town on Cape Cod. A town embarking on comprehensive wastewater management planning should review this evaluation of both the Base Cases and the sensitivity analysis to determine how its circumstances compare. Then that town can focus on the types of wastewater management systems that are likely to be best for its circumstances, and avoid expensive analyses of systems that can be determined from this evaluation to have limited applicability. For example, a town with large lots, moderate nitrogen control needs and available public lands for local systems should plan to conduct an intensive evaluation of small-scale systems. Conversely, a town with publically-owned sites near collection areas and outside sensitive watersheds or Zone IIs can plan to focus its planning budget on centralized systems and minimize time and expense in evaluation smaller-scale systems.

Use of Individual Denitrifying Systems for Other Purposes

In most Cape Cod towns, individual nitrogen-removing systems are routinely required by Town boards and commissions to address real or perceived environmental or public health impacts unrelated to nitrogen. This analysis shows how such systems can be expensive and ineffective for nitrogen control. Boards and commissions should focus on the particular environmental issue of concern and be cautious in requiring individual denitrifying systems.

Water Balance Considerations

Smaller-scale systems provide a benefit with respect to maintaining the water balance between watersheds. In some circumstances, this relocation of water that otherwise would be recharged locally is a significant factor; in other areas it is not. Each town should closely consider water balances to be sure that this factor is appropriately addressed.

Applying These Costs to Specific Properties

In translating these cost estimates to specific amounts that might be paid by specific properties in sewered areas, the following factors should be considered:

- Towns must decide how to apportion capital costs between betterments (paid only by property owners served by the public infrastructure) and property taxes (paid by property owners town-wide). Amounts allocated to property taxes reduce the costs to properties that are served by the system.

- Betterments may be separately applied to collection costs and treatment costs, and collection system betterments may rely on one or more property features (such a total lot area or parcel frontage).

- The County Septic Loan Program may reduce costs for some property owners, although funding for this program is unlikely to be sufficient for widespread application.

- No consideration has been given here to possible increases in property values for parcels connected to public sewers.

Need for Treatment Capability for Septage and Other Trucked Wastes

For the smaller-scale systems considered in this evaluation, it was assumed that sludge would be removed periodically and transported by truck to a regional septage facility, such as the Yarmouth-Dennis plant in Yarmouth, or the Tri-Town facility in Orleans. Separate sludge dewatering equipment is not warranted at these small-scale systems. Costs for centralized systems include facilities for handling septage from unsewered areas of the town. The ability of a town to reduce its wastewater-related expenses by providing septage or liquid sludge handling services to nearby towns has not been accounted for in this cost analysis.

Importance of Low-Interest Loans

This analysis of costs has been based on the traditional debt service assumptions of 5% interest over a 20-year loan period. Alternative assumptions were also evaluated to reflect the current favorable municipal bond market, and the availability of low interest loans under the State Revolving Fund (SRF). Using the Base Case for a 200,000-gpd satellite system as an example, costs were computed (expressed as equivalent annual costs per pound of nitrogen removal) for several interest rates over 20 years, with the following results:

5% (basis for costs reported in this report)	*$390* per lb.
4% (current municipal rate)	*$360* per lb. (*7%* less than 5% loan)
2% (SRF rate for most projects)	*$310* per lb. (*20%* less than 5% loan)
0% (SRF rate under some circumstances)	*$250* per lb. (*35%* less than 5% loan)

The equivalent annual cost is reduced with a lower interest rate because the annual debt service costs are lower; O&M costs are unaffected. By availing themselves of the SRF loans, towns can save 16% to 40% of the cost reported in this document for the traditional 5%, 20-year loan. For this example, the savings in debt service expenses with a zero-percent loan are slightly greater than the total O&M cost; that is, the savings in debt service are enough to pay for all of the O&M costs for 20 years.

NON-TRADITIONAL TECHNOLOGIES

The previous sections focused on the four most common methods of addressing wastewater treatment and nutrient removal (Individual on-lot Systems, Cluster Systems, Satellite Systems, and Centralized Systems). However, there are many alternatives to those systems which may be relevant to the unique needs of some Cape Cod Communities. The following provides a description of these "nontraditional" technologies, as well as estimated associated costs, key references and sources of assumptions. Reference is made to the Technology Matrix prepared as part of the 208 Water Quality Management Plan Update for Cape Cod Massachusetts which allows the user conduct a comparison of options.

The Technology 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 wastewater issues. The Technology 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. Although it is not intended to be all inclusive, the Technology Matrix presents information on various non-traditional technologies. The Technology Matrix should be considered a flexible and dynamic source of information that is updated as additional information becomes available.

Information that is presented in the Technology Matrix includes:

- *Technology Description*
- *Influent Source and Concentration*
- *Pollutant Treated / Reason for Use*
- *Potential Permitting Agencies*
- *Siting Requirements*
- *Reduction per Planning Period*
- *Construction, Project and O&M Costs*
- *System Considerations*
- *Average Life Cycle Cost*
- *Cost per Kg of Nutrient Reduction*

- *Flow and Nutrient Influent Load*
- *Nutrient Reduction*
- *Impact on Surface Water Quality*
- *Nutrient Removed per Year*
- *Unit Metric*
- *Advantages / Disadvantages*
- *Eco Services (Habitat, Green Space, Energy, and Flooding)*
- *Monitoring*
- *References*

It should be noted that during the review and analysis of non-traditional technologies, consideration needs to be given as to the development of a conceptual design for a specific set of local conditions and regulatory requirements, by experienced professionals. In addition, the review and analysis needs to consider the current federal and state rules and regulations in effect, specifically with regards to wastewater reuse and surface water discharges.

As with traditional technologies, when creating solutions with non-traditional technologies, the experienced professional needs to consider all of the components required to make a complete solution. These items include but, are not limited to, the following: (a) Collection System; (b) Wastewater Treatment; (c) Effluent Disposal; and (d) Solids Collection, Treatment and Disposal. In addition, the economy of scale of the various components needs to be considered including system size, and configuration.

The project and operation and maintenance costs have been adjusted for some non-traditional technologies to account for pilot testing, relative complexity of the technology, local oversight, and regulatory compliance, short and long term monitoring all of which ultimately can be used for refinement to performance and cost data.

Constructed Wetlands-Surface Flow

Description *- After primary treatment in a septic tank or WWTF or secondary treatment at a WWTF, water is fed into a free water surface (FWS) constructed wetland. Free water constructed wetlands closely mimic the ecosystem of a natural wetland by utilizing water loving plants to filter wastewater through their root zone, a planted medium, and open water zones. FWS wetlands are systems where open water is exposed much like in a natural marsh. The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater. This technology can be used as an alternative to conventional polishing (i.e. mechanical and/or chemical) of secondary and advanced wastewater treatment.*

Cost (Capital and O&M) - *Costs are presented on a per acre basis. More detail regarding these estimates is presented in Appendix E.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$307,500	*$512,500*	*$410,000*	*$4,688*	*$7,813*	*$6,250*

References, Sources and Assumptions

1. *Average Removal Rate (P 419) and Median Total Nitrogen Removal Rate (P 308), Median Phosphorus Removal Rate (P 378) from Kadlec and Wallace, Treatment Wetlands 2nd Ed.*

   http://www.firelandstributaries.net/pdfs/Local%20workgroup/Treatment_Wetlands.pdf

2. *Range of wetland costs (P 132-133) and Wastewater effluent concentrations (converted to lbs/gal) data taken from Table 3-1 from Constructed Wetlands Treatment of Municipal Wastewaters. EPA.1999*

   http://water.epa.gov/type/wetlands/restore/upload/constructed-wetlands-design-manual.pdf

3. *Range of O&M values from Jim Kreissl, Constructed Wetlands Treatment for Nutrient Treatment for Nutrient Reduction, Presentation at POTW Nutrient Reduction and Efficiency Workshop, 2008.*

   http://www.tetratech-ffx.com/potwconf/pdf/112008_1200_Kreissl.pdf

4. *Average Gal./day/acre derived from Table 2. Ogden, Michael. Costs of Constructed Wetland Systems. Prepublication copy for presentation at WEFTEC '98, 1998.*

   http://www.brownandcaldwell.com/Tech_Papers/700.pdf

5. *Flow range of 5 precedents evaluated by Offshoots, Inc, June 2013.*

   http://link.springer.com/article/10.1007%2Fs13157-013-0444-7#

6. *1 acre of FWS CTW at 330 gpd = 45-70 homes/acre for Total Nitrogen. Assumptions: Q = 330 gpd (1.25 m^3/d); Ci = 20 mg/l (Total N); Ce = 5 mg/l (Total N); k (areal rate constant) = 10-20m/yr., C* = 1.5 mg/l (background value). Equates to 0.010 to 0.020 acres/330 gpd.*

7. *Influent Concentrations: (a) For Primary WWTF Effluent assume: (N) =.0004 lbs/gal (52.5 mg/l), (P)=7.92 × 10^{-5} lbs/gal (9.5 mg/l), and (b) For Secondary WWTF effluent assume: (N)=.0001 lbs/gal (15 mg/l), and (P)=2.92 × 10-5 lbs/gal (3.5 mg/l).*

8. *Improving Winter Performance of Constructed Wetlands for Wastewater Treatment in Northern China: A Review*

   http://link.springer.com/article/10.1007%2Fs13157-013-0444-7#

9. *USEPA Wetlands Subsurface Flow Fact Sheet:*

   http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_wetlands-subsurface_flow.pdf

10. *Without the use of water aeration such as Solar Bees, Free Water Surface systems will not typically meet discharge limits for BOD and TSS. However, water aeration augments protozoan, invertebrate, and fish populations which harvest large amounts of algae.*

11. *Systems not designed to remove phosphorus. Phosphorus removal in these smaller systems requires lengthy retention times and/or use of specialized media to increase sorption.*

12. *Based on 44,000 GPD / 2.08 acre total treatment area for Fields of St Croix constructed wetland system in Lake Elmo, MN.*

Constructed Wetlands-Subsurface Flow

***Description** - After primary treatment in a septic tank or WWTF or secondary treatment at a WWTF, wastewater is treated by pumping water slowly through subsurface gravel beds where it is filtered through plant root zones and soil media. Water flows 3 to 8-inches under the surface to prevent public exposure to wastewater and mosquito breeding. A combination of horizontal and vertical flow subsurface systems must be utilized to provide total nitrogen removal. The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater. This technology can be used as an alternative to conventional polishing (i.e. mechanical and/or chemical) of secondary and advanced wastewater treatment.*

***Cost (Capital and O&M)** - Costs are presented on a per acre basis. More detail regarding these estimates is presented in Appendix E.*

Project Cost			**Annual O&M Cost**		
Low	**High**	**Average**	**Low**	**High**	**Average**
$326,250	$543,750	$435,000	$4,800	$8,000	$6,400

References, Sources and Assumptions

1. *Average Removal Efficiency (P 417) and Median Total Nitrogen Removal Rate (P 309) from Kadlec and Wallace. Treatment Wetlands, 2nd Ed.*

   http://www.firelandstributaries.net/pdfs/Local%20workgroup/Treatment_Wetlands.pdf

2. *Range of cost and O&M values adjusted for inflation from Jim Kreissl, Constructed Wetlands Treatment for Nutrient Treatment for Nutrient Reduction, Presentation at POTW Nutrient Reduction and Efficiency Workshop, 2008.*

   http://www.tetratech-ffx.com/potwconf/pdf/112008_1200_Kreissl.pdf

3. *Average Removal Rate from Vymazal Jan. Removal of Phosphorus in Constructed Wetlands with Horizontal Sub-Surface Flow in the Czech Republic. Water, Air and Soil Pollution: Focus. June 2004, Volume 4, Issue 2-3, pp. 657-670.*

   http://link.springer.com/article/10.1023%2FB%3AWAFO.0000028385.63075.51

4. *Gal./day/acre Value averaged from Table 6. Ogden, Michael. Costs of Constructed Wetland Systems. Prepublication copy for presentation at WEFTEC '98, 1998.*

   http://www.brownandcaldwell.com/Tech_Papers/700.pdf

5. *Data on Phosphorus removal from Subsurface flow wetlands is highly varied and dependent on retention time and media used. This value is calculated at 50% of the phosphorus removal rate of a FWS constructed wetland system.*

6. *1 acre of SSF CTW will treat 50-75 homes/acre Total Nitrogen at 330 gpd. Assumptions: Q= 330 gpd (1.25 mg/l); Ci = 20 mg/l; Ce = 5 mg/l (TN), k (areal removal rate constant): 4-15 m/yr. C* = 0 mg/l (background). Equates to 0.015 to 0.025 acres/330gpd.*

7. *USEPA Wetlands Free Surface Water Flow Fact Sheet:*

   http://water.epa.gov/infrastructure/septic/upload/wetlands-subsurface_flow.pdf

Constructed Wetlands-Cluster Subsurface Flow

Description *- After collection in a septic tank type system, wastewater is treated by pumping water slowly through subsurface gravel beds where it is filtered through plant root zones and soil media. Water flows 3" to 8" under the surface to prevent public exposure to wastewater and mosquito breeding. A combination of horizontal and vertical flow subsurface systems must be utilized to provide total nitrogen removal. These systems occasionally use additional treatment steps to remove nutrients from wastewater. The preferred disposal method is an infiltrator chamber system similar to a leach field but larger in size and designed for overflows. The reclaimed water from the wetland can be discharged into a water body or used for open space irrigation after treatment. The reclaimed water can also be discharged into a leach field or similar system for discharge to the groundwater.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$594,000	*$972,000*	*$783,000*	*$4,000*	*$8,000*	*$6,000*

References, Sources and Assumptions

1. *Removal efficiency based on Fields of St. Croix constructed wetland project. Data provided by Bruce Douglas of Natural Systems Utilities. 2012. Interview.*

2. *Median Total Nitrogen Removal Rate from Kadlec and Wallace. Treatment Wetlands 2nd Ed. (p 309).*

3. *Capital costs of Fields of St. Croix constructed wetlands system derived by multiplying number of homes connected to system (133) by capital cost per connection ($5524) to derive total capital cost (731,159). This number was then divided by the total treatment area of the project (2.08 acres) to give $351,519/acre which was adjusted for inflation. Data derived from Table 2. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.*

4. *O&M costs derived by multiplying monthly service charge per connection by total number of connections for the Fields of St. Croix project. The result was then divided by the total treatment area of the project (2.08 acres). Table 3. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.*

5. *Wastewater effluent concentrations converted to lbs/gal. Data taken from Table 3-1. Constructed Wetlands Treatment of Municipal Wastewaters. EPA. 1999.*

6. *Costs per connection were extrapolated based on total number of connections to derive capital cost. Capital costs were then divided by design flow (GPD) for each project to derive $/Gal. Data from Tables 2 and 3. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.*

7. *Monthly service charge costs were multiplied by number of homes connected to system and then by 12 to determine yearly service charge. This product was then divided by design flow to derive $/gal/yr. However, this is the cost to users, not necessarily the O&M cost, because it includes a cost for future necessary replacements. Data from Tables 2, 3 and 4. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.*

8. *Flow range of 3 precedents evaluated by Offshoots, Inc, June 2013.*

9. *1 acre of SSF CTW will treat 50-75 homes/acre Total Nitrogen at 330 gpd. Assumptions: Q= 330gpd (1.25 mg/l); Ci = 20mg/l; Ce = 5 mg/l (TN), k (areal removal rate constant): 4-15 m/yr. C* = 0 mg/l (background). Equates to 0.015 to 0.025 acres/330 gpd.*

10. *USEPA Wetlands Free Surface Water Flow Fact Sheet:*

    http://water.epa.gov/infrastructure/septic/upload/wetlands-subsurface_flow.pdf

Hydroponic Treatment

Description *- Hydroponic treatment and Photo Bioreactors (PBRs - Clears) are natural systems that treat septic tank effluent or primarily 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 roots 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 and completes the pollutant removal process. 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 also be used for wastewater treatment with primary, secondary, or advanced effluent generally for flows less than 500,00 gpd.*

Cost (Capital and O&M) *- Costs are presented on a per unit basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$1,507,000	*$1,815,000*	*$1,661,000*	*$450,000*	*$550,000*	*$500,000*

References, Sources and Assumptions

1. *Range of summary denitrification numbers provided by John Todd Ecological Design.*

   http://www.toddecological.com/clients/list.php

2. *Cost/gallon averaged from 3 living machine projects. EPA Wastewater Technology Fact Sheet: Living Machines. 2002.*

   http://water.epa.gov/scitech/wastetech/upload/2002_12_13_mtb_living_machine.pdf

3. *Averaged mass reduction based on Nitrogen influent-effluent numbers provided for 4 Eco-machine projects and 890,000 gal/27,000 sq.ft. facility size provided by Todd Ecological.*

4. *Data based on 890,000 gal/day facility requiring 27,000 sq.ft. (0.61 acres) by John Todd Ecological Design.*

5. *Data derived from South Burlington Living machine data only - 80,000gpd system removed 5548 lbs of nitrogen/day at a capital cost of $1.7 million dollars, 0.14 acre site cost $70,625 to run annually, $70,625 annual O&M cost / 5,548 lbs of N removed / year.*

   http://toddecological.com/clients/PDFs/100623.casestudy.southburlington.pdf

6. *From Eco-Cities to Living Machines: Principles of Ecological Design*

Phytoirrigation

Description *- After secondary treatment, WWTF effluent is irrigated onto plants to remove nutrients and other contaminates. Fast growing poplar and willow trees are typically used. Phytoirrigation requires periodic maintenance and removal of the vegetation being irrigated.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$342,000	*$384,000*	*$363,000*	*$6,000*	*$18,000*	*$11,000*

References, Sources and Assumptions

1. *CH_2M Hill, 2012, J. Smeasrod Interview, Offshoots, Inc. Precedent Study-3 Projects.*
2. *Nitrogen concentrations in groundwater are difficult to test. This is the minimum standard that is known to be removed, but the numbers are likely much higher.*
3. *Cost per acre can be as low as $5,000 when small cuttings and no irrigation is used.*

Phytobuffers

Description *- Stormwater treatment by using plants to remove nutrients and other contaminates. Fast growing poplar and willow trees as well as other plants are typically used.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$38,500	*$154,000*	*$96,250*	*$11,000*	*$22,000*	*$16,500*

References, Sources and Assumptions

1. *CH_2M Hill, 2012, J. Smeasrod Interview, Offshoots, Inc. Precedent Study- 3 projects.*
2. *Nitrogen concentrations in groundwater are difficult to test. This is the minimum standard that is known to be removed, but the numbers are likely much higher.*
3. *Cost per acre can be as low as $5,000 when small cuttings and no irrigation is used.*

Stormwater Bioretention/Soil Media Filters

Description *- Bioretention is the process in which contaminants and sedimentation are removed from stormwater runoff through physical, biological and chemical treatment processes. Stormwater is collected into the treatment area which consists of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. Runoff passes first over or through a sand bed, which slows the runoff's velocity, distributes it evenly along the length of the ponding area, which consists of a surface organic layer and/or groundcover and the underlying planting soil. The ponding area is graded, its center* *depressed. Water is ponded and gradually infiltrates the bioretention area or is evapotranspired. The bioretention area is graded to divert excess runoff away from itself. Stored water in the bioretention area planting soil exfiltrates over a period of days into the underlying soils.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$426,000	*$552,000*	*$489,000*	*$4,400*	*$6,600*	*$5,500*

References, Sources and Assumptions

1. *A Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management, ASCE Journal of Environmental Engineering; January 25, 2013.*

   http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/asce_jee_maintenance.pdf

2. *University of New Hampshire Stormwater Center, 2013 Annual Report.*

   http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf

3. *2009 UNHSC Specs.*

   http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/2009_unhsc_report.pdf

4. *EPA Fact Sheet: Bioretention Winogradoff, 2001, Claytor & Schueler, 1996.*

5. *Design of Stormwater Filtering Systems, 1996, R. Claytor, T. R. Schueler*

   http://academic.research.microsoft.com/Paper/2943904.aspx

6. *US DOT, Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring.*

7. *Fact Sheet - Filter Strips*

   http://www.environment.fhwa.dot.gov/(S(kmqmwz45xwbdsd2xihcmnifc))/ecosystems/ultraurb/3fs11.asp

8. *State of Vermont, State of the Practice: Enhanced Nutrient Removal in Stormwater Treatment.*

   http://www.watershedmanagement.vt.gov/stormwater/docs/manualrevision/sw_Fact_Sheet_Enhanced_Nutrient_Removal.pdf

9. *USEPA Stormwater Technology Fact Sheet - Bioretention:*

   http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_biortn.pdf

Stormwater Constructed Wetlands

Description *- Constructed wetlands provide aerobic chambers followed by subsurface anaerobic chambers that facilitate nitrification followed by denitrification, respectively. This process mimics that of natural systems coupled with engineering design guaranteeing residence time within a chamber containing anaerobic conditions. This partnership allows for year round removal efficiencies of nitrogen. The reclaimed water from the wetland can be discharged into a water body or used for open space irrigation after treatment. The reclaimed water can also be discharged into a leach field or similar system for discharge to the groundwater.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$375,100	*$390,500*	*$382,800*	*$4,400*	*$6,600*	*$5,500*

References, Sources and Assumptions

1. *A Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management. Journal of Environmental Engineering; January 25, 2013*

   http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/asce_jee_maintenance.pdf

2. *University of New Hampshire Stormwater Center, 2013 Annual Report;*

   http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf.

3. *In general very similar principals, removal and sizing/removal rates as FWS wetlands but need to take into consideration episodic flow events vs. regular flow events.*

4. *USEPA Fact Sheet:*

   http://water.epa.gov/infrastructure/septic/upload/wetlands-subsurface_flow.pdf

5. *USEPA Fact Sheet:*

   http://water.epa.gov/infrastructure/septic/upload/wetlands-subsurface_flow.pdf

Aquaculture/Shellfish

Description - *Shellfish, and specifically oysters, remove nitrogen from their environment. The growing and removal of the mature oysters can remove nitrogen from an estuary, reducing the estuary's nitrogen load. Aquiculture can become a dual purpose project where shellfish are harvested for market while there will be a local reduction in nitrogen in the overlying water column during the growth and maturation of the oysters.*

Shellfish cultivated in the Estuary Bed cultivates the shellfish in the benthic soils of the estuary or estuary bed. Harvesting a portion of the oysters is required to remove nitrogen. Cultivating shellfish in the estuary bed can be used in combination with other types of aquiculture as well as floating constructed wetlands designed for brackish water.

Shellfish cultivated above the Estuary Bed cultivates shellfish above the estuary bed in containers. Harvesting a portion of the oysters is required to remove nitrogen. Mariculture can be used in combination with other types of aquiculture as well as floating constructed wetlands designed for brackish water.

Mariculture cultivates marine vegetation such as seaweed to remove nitrogen. Harvesting a portion of the vegetation may be required to remove nitrogen. Mariculture can be used in combination with other types of aquiculture as well as floating constructed wetlands designed for brackish water.

Cost (Capital and O&M) - *Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$42,400	*$84,000*	*$63,000*	*$0*	*$11,000*	*$5,500*

References, Sources and Assumptions

1. *Carmichael, R.H. and W. Walton, H. Clark, June 2012, Bivalve Enhanced Nitrogen Removal from Coastal Estuaries.*

   http://www.auburn.edu/~wcw0003/products/publications/carmichael-rh-w-walton--h.html

2. *The Nature Conservancy: Oyster Reef Building and Restoration for Coastal Protection*

   http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/louisiana/oyster-reef-restoration-in-louisiana.xml

3. *Sisson, M. et al. Assessment of Oyster Reefs in Lynnhaven River as a Chesapeake Bay TMDL BMP 2011.*

   http://web.vims.edu/GreyLit/VIMS/sramsoe429.pdf

4. *Various studies have quantified removal rates, though there is variation depending on shellfish type and environmental conditions.*

5. *Assessment of Oyster Reefs in Lynnhaven River as a Chesapeake Bay TMDL Best Management Practice, MacSisson, Lisa Kellogg, Mark Luckenbach, Rom Lipcius, Allison Colden, Jeff Cornwell, and Michael Owens Final Report to the U. S. Army Corps of Engineers, Norfolk District*

   http://web.vims.edu/GreyLit/VIMS/sramsoe429.pdf

6. *Estuarine Fish and Shellfish Species in U.S. Commercial and Recreational Fisheries: Economic Value as an Incentive to Protect and Restore Estuarine Habitat, K. A. Lellis-Dibble, K. E. McGlynn, and T. E. Bigford, November 2008.*

7. *Bay Area Monitor, Scientists Set Seashells by the Seashore, Aleta George, October 1, 2013*

   http://bayareamonitor.org/index.php?option=com_content&view=article&id=366&Itemid=66

8. *Range of 250 to 1,000 Kg of N per acre based ongoing pilot studies in Falmouth, MA and Wellfleet, MA. Analysis uses a conservative value of 250 Kg of N per acre.*

9. *Kellogg, Lisa, Virginia Inset of Marine Science, Denitrification and Nutrient Assimilation on a Restored Oyster Reef, May 2013.*

   http://www.int-res.com/abstracts/meps/v480/feature/

10. *Rice, Michael A,, Et. Al., Changes in Shellland Soft Tissue Growth, Tissue Compositions of Quohogs and Sovt-Shelled Clams in Response to Eutrophic Driven Changes in Food supply and Habitat. Boston University, Journal of Experimental Marine Biology and Ecology. August 2004,*

11. *STAC Report, Evaluation of the Use of Shellfish as a Means of Nutrient Reduction in the Chesapeake Bay, September, 3013d*

12. *Circle C Oyster Ranchers Association: http://www.oysterranching.com/background.html*

13. *Food and Agricultural Organization of the United States: Hatchery Culture of Bivalves Fisheries Technical Paper 471*

    (http://www.fao.org/docrep/007/y5720e/y5720e02.htm#TopOfPage)

Phytoremediation

Description - *Green plants with deep tap roots are planted as a buffer to intercept high nitrogen (nitrogen enriched) groundwater. The plants and microorganisms in their root zone reduce/use the nitrogen, removing it from the groundwater and watershed. Phytoremediation can be used to redirect a plume of nitrogen enriched groundwater or pull it up from deeper in the aquifer, allowing the plants to treat the plume. Ongoing, passive interception of the impacted ground water plume via shallow/deep interception of capillary fringe by roots during growing season and has seasonal limitations.*

Cost (Capital and O&M) - *Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$316,800	*$333,600*	*$325,200*	*$5,500*	*$8,250*	*$6,875*

References, Sources and Assumptions

1. *Sand Creek Consultants, 2012, Chris Rog Interview- Offshoots, Inc. precedent study - 4 projects.*

   http://sand-creek.com/

2. *Nitrogen concentrations in groundwater are difficult to test. This is the minimum standard that is known to be removed, but the numbers are likely much higher.*

3. *Cost per acre can be as low as $5,000 when small cuttings and no irrigation are used. Best if used close to nitrogen source so as to prevent dispersion of the nitrogen into the surrounding groundwater. It is possible for the plantings to use enough groundwater to form a cone of depression, pulling in groundwater from surrounding areas.*

4. *USEPA phytotechnologies Fact Sheet.*

   http://www.epa.gov/tio/download/remed/phytotechnologies-factsheet.pdf

Permeable Reactive Barriers (PRBs)

Description *- A permeable reactive barrier (PRB) is an in-situ (installed within the aquifer) treatment zone designed to intercept nitrogen enriched groundwater. Through use of a carbon source, microbes in the groundwater uptake the nitrogen, denitrifying the groundwater.*

The trench method PRB uses large trenching equipment to install a mixture of course sand, wood chips, compost and/or other materials in the trench created by the trencher. The vertical wall can be installed to a depth of 40 feet with a width of 1.5 to 3 feet. In certain circumstances, the PRB can also be installed in large diameter columns as compared to a continuous trench. The trench or column style PRB can be used in combination with the injection well PRB described below.

An injection Well PRB system typically uses a series of injection wells to introduce the carbon source into the groundwater. The injection wells can be installed to depth greater than the PRB trench method. The injection well PRB method can be used in combination with the PRB trenching method described above.

As groundwater flows through the wall, the wall provides a carbon source (food) for microbes living in the groundwater. The carbon food source provides a food source for microbes in the groundwater. The microbes consume the carbon source as well as oxygen developing an anaerobic environment which releases nitrogen gas to the atmosphere, reducing the groundwater nitrogen load before reaching the estuary.

Cost (Capital and O&M) *- Costs are presented on a linear foot basis. More detail regarding these estimates is presented in Appendix F.*

PRB Type	**Project Cost**			**Annual O&M Cost**		
	Low	**High**	**Average**	**Low**	**High**	**Average**
Trench	$2,087	$3,479	$2,783	$1,697	$2,828	$2,262
Injection	$1,113	$1,855	$1,484	$2,404	$4,006	$3,205

References, Sources and Assumptions

1. *Interstate Technology & Regulatory Council, PRB Technology Update, 2011.* [*http://www.clu-in.org/conf/itrc/prbtu/prez/ITRC_PRBUpdate_092012ibtpdf.pdf*](http://www.clu-in.org/conf/itrc/prbtu/prez/ITRC_PRBUpdate_092012ibtpdf.pdf)
2. *Construction cost based on 3 foot wide trench at 24 feet deep.*

3. *Groundwater denitrification capacity and nitrous oxide flux of former fringing salt marshes filled with human-transported materials.*

   http://link.springer.com/article/10.1007/s11252-012-0266-z

4. *CICEET - Effectiveness of Reactive Barriers for Reducing N-Loading to the Coastal Zone - 02-28-08.*

   http://ciceet.unh.edu/news/releases/spring08_progress_reports/pdf/vallino.pdf

Fertigation Wells

Description *- The capturing of a nitrogen enriched groundwater using irrigation wells and using it to irrigate plants that use the nitrogen is called fertigation. Fertigation wells can capture nutrient enriched groundwater, typically from a WWTF discharge, and recycle it back to irrigated and fertilized turf grass areas. These irrigated areas include golf courses, athletic fields and lawns. Fertigation can significantly reduce nutrient loads to down gradient surface waters while reducing fertilizer costs to the irrigated areas. The capturing of a nitrogen enriched groundwater using irrigation wells and using it to irrigate plants that use the nitrogen is called fertigation. Fertigation wells can capture nutrient enriched groundwater, typically from a WWTF discharge, and recycle it back to irrigated and fertilized turf grass areas. These irrigated areas include golf courses, athletic fields and lawns. Fertigation can significantly reduce nutrient loads to down gradient surface waters while reducing fertilizer costs to the irrigated areas.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Type	***Project Cost***			***Annual O&M Cost***		
	Low	***High***	***Average***	***Low***	***High***	***Average***
Turf	*$1,540*	*$,30,80*	*$2,310*	*$550*	*$1,00*	*$825*
Bogs	*$4,620*	*$9,240*	*$^,330*	*$1,650*	*$3,300*	*$2,475*

References, Sources and Assumptions

1. *Construction cost based on 8 to 12-inch in diameter and 20 to 30 foot deep wells.*

Toilets: Composting

Description *- A toilet system which separates human waste from shower, sink and other household water uses. The Composting toilets use no or minimal amounts of water. The human wasted captured by the composting toilets is decomposed and turned into compost. The compost generated from composting toilets can be used as fertilizer to replace synthetic fertilizers or can be removed from the site. Composting toilets require the installation of a separate toilet(s) and room in the basement for a container to capture and compost the human waste. Household water use (i.e.. sink and shower uses) continue to flow to the septic system.*

Cost (Capital and O&M) *- Costs are on a per unit basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$11,200	*$16,800*	*$14,000*	*$275*	*$550*	*$413*

References, Sources and Assumptions

1. *95% of average nutrient mass excreted per person per day.*
   http://richearthinstitute.org/?page_id=739
2. *Falmouth DPW and WQMC presentation 7-29-13 re Draft FCWMP/FEIR/TWMP.*
3. *SSWR5.1 analysis.*
4. *Estimated that if 30% of Falmouth households use composting toilets, the saved fertilizer cost could amount to $10,000.*
5. *US EPA Composting Toilets Fact Sheet.*
   http://water.epa.gov/aboutow/owm/upload/2005_07_14_comp.pdf
6. *EcoSanRes, Toilets That make Compost, 2007.*
   http://www.ecosanres.org/pdf_files/ESR-factsheet-13.pdf
7. *Peter Morgan, Toilets That Make Compost, 2007.*
   http://www.ecosanres.org/pdf_files/ToiletsThatMakeCompost.pdf
8. *SunMar Toilets.*
   http://www.sun-mar.com/

9. *SanCor Industries Toilets.*

   http://www.sancor.ca/

10. *Construction costs include cost for plumbing modifications based on 50% the cost of the toilet.*

Toilets: Incinerating

Description - *Incinerating toilets are self-contained waterless systems that do not require being hooked-up to a sewer system or in ground septic system (except to dispose of gray water). They rely on electric power or natural or propane gas to incinerate human waste to sterile clean ash. When properly installed these systems are simple to use, safe, clean and relatively easy to maintain. Composting toilets require the installation of a separate toilet(s) and room in the basement for a container to capture and compost the human waste. Household water use (i.e.. sink and shower uses) continue to flow to the septic system.*

Cost (Capital and O&M) - *Costs are presented on a per unit basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$8,960	*$16,800*	*$12,880*	*$825*	*$1,100*	*$963*

References, Sources and Assumptions

1. *Barnstable County Department of Health and Environment.*

   http://www.barnstablecountyhealth.org/ia-systems/information-center/compendium-of-information-on-alternative-onsite-septic-system-technology/incinerating-toilets

2. *Eco Toilets, Incinerating Toilets As An Alternative To Flushing Toilets.*

   http://www.eco-toilets.com/incinerating-toilets.php

3. *Incinolet Electric Incinerating Toilets.*

   http://www.incinolet.com/

4. *Construction costs include cost for plumbing modifications based on 50% the cost of the toilet.*

Toilets: Packaging

Description *- A packaging toilet encapsulates human waste in a durable material for removal from the site. The package is stored beneath the toilet and removed and taken away when full. The nutrients can be recycled by the servicing company that picks up the packages. Household water use (i.e.. sink and shower uses) continue to flow to the septic system.*

Cost (Capital and O&M) *- Costs are presented on a per unit basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$4,480	*$8,960*	*$6,720*	*$550*	*$825*	*$688*

References, Sources and Assumptions

1. *100% of average nutrient mass excreted per person per day adjusted based on 3 persons / household for Cape Cod.*

   http://richearthinstitute.org/?page_id=739

2. *Construction costs include cost for plumbing modifications based on 50% the cost of the toilet.*

Toilets: Urine Diverting

Description *- Urine diversion systems divert urine into a holding tank where the urine is stored and periodically collected by a servicing company. The servicing company empties the tank for disposal or conversion to a fertilizer. Through these means, the nitrogen is removed from the watershed. With the urine diverting toilets, the remainder of the human waste and all other water uses (sink and shower) continue to go to the septic system.*

Cost (Capital and O&M) *- Costs are presented on a per unit basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$8,960	*$13,440*	*$11,200*	*$297*	*$495*	*$396*

References, Sources and Assumptions

1. *Estimated price range for 3 UD systems. Urine Diversion Systems. Lauren Cole et al. Tufts University. Semester Research Project. UEP 0279 Water Resources Policy, P 18.*

2. *Earle Barnhart and Hilde Maingay. Let No Waste Go to Waste. Presentation at Howe's House West Tisbury MA, Nov. 30, 2011.*

   http://mvgazette.com/news/2011/12/01/composting-toilets-pitched-better-sewers-protecting-ponds?k=vg524595282974b&r=1

3. *80% of average nutrient mass excreted per person per day adjusted based on 3 persons/household for Cape Cod.*

   http://richearthinstitute.org/?page_id=739

4. *SSWR5.1*

5. *Stockholm Environment Institute - Urine Diversion One Step Towards Sustainable Sanitation – 2006.*

   http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf

6. *Ecovita West*

   http://www.ecovita.net/

7. *Construction costs include cost for plumbing modifications based on 50% the cost of the toilet.*

N+P+K MGMT

Fertilizer Management

***Description** - Managing fertilizer application rates to lawns, golf courses, athletic facilities and cranberry bogs. Residential lawn loading rates could be reduced on existing developed parcels through an intensive public education/outreach program. This could include a "Cape Cod Lawn" branding program, replacing some turf areas with native vegetation, establishing naturally-vegetated buffer strips on waterfront lots, and reducing application rates. Fertilizer loading rates for new development could be accomplished by reducing lot sizes (cluster development), by restricting lawn sizes and/or by incorporating more naturally-vegetated open space areas. Municipalities could directly reduce fertilizer applications on athletic fields and other properties. Golf courses can significantly reduce nitrogen loading rates by using slow-release fertilizers and reducing application rates in rough areas. Cranberry bog fertilizer exports from the bogs can be reduced using tail water recovery systems. Site-specific assessments are needed to estimate load reductions.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$0	*$0*	*$0*	*$55*	*$110*	*$83*

References, Sources and Assumptions

1. *Pleasant Bay Fertilizer Management Plan prepared for the Town of Chatham by Horsley Witten Group, Inc. (2010).*

   http://www.pleasantbay.org/wp-content/uploads/101216_FinalReport_10002.pdf

2. *Schueler, Tom et al. 2013. Recommendations of the Expert Panel to Define Removal Rates for Urban Nutrient Management: CBP Approved Final Report.*

   http://plna.membershipsoftware.org/files/Home%20Page/Final_CBP_Approved_Expert_Panel_Report_on_Urban_Nutrient_Management--short.pdf

3. *Reported nutrient removal rates taken from Chesapeake Bay Project report, which reviewed over 200 research studies and reports regarding urban nutrient management programs.*

4. *Assumes average 1/2 acre lot size with 1/4 acre landscaped and average Cape Cod rainfall = 45 inches/year of which 25 inches/year to groundwater.*

Stormwater BMPs

Description *- Non-Structural Stormwater strategies. These strategies include street sweeping, maintenance of stormwater utilities, education and public outreach programs, land use planning, and IC reduction and control.*

Cost (Capital and O&M) *- Costs are presented on a curb mile basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$75,600	*$140,000*	*$107,800*	*$3,740*	*$9,020*	*$6,380*

References, Sources and Assumptions

1. *EPA Stormwater BMPs*

   http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=99

   http://www.epa.gov/owow/watershed/outreach/documents/getnstep.pdf

2. *California Stormwater Quality Association (CASQA). 2003. Best Management Practices (BMP) Handbook, Municipal.*

   http://www.cabmphandbooks.com/Documents/Municipal/SC-70.pdf

3. *Pennsylvania BMP manual.*

   http://www.stormwaterpa.org/assets/media/BMP_manual/chapter_5/Chapter_5-7-1.pdf

4. *Deriving Reliable Pollutant Removal Rates for Municipal Street Sweeping and Storm Drain Cleanout Programs in the Chesapeake Bay Basin. Center for Watershed Protection. September 2008.*

   http://www.worldsweeper.com/Street/Studies/CWPStudy/CBStreetSweeping.pdf

5. *Effective street sweeping programs can remove several tons of debris a year from city streets minimizing pollutants, including sediment, debris, trash, road salt and trace metals in stormwater runoff. Options for effective street sweeping programs include: (1) Maintaining logs of the number of curb miles swept and the amount of waste collected to quantify effect; (2) A study conducted by the Center for Watershed Protection in the Chesepeake Bay Basin indicated that pollutant removal rates for street sweeping and municipal drain cleanout programs can range between 9-31% (TS), 3-7% (TP), and 3-7% (TN); (3) Land use planning: Minimize overall disturbance at individual lot levels as well as construction sites (TSS reduction 40%); (4) Reduction and control: Minimize pavement by using alternative road layouts, restricting on-street parking, minimizing cul-de-sac radii, and using permeable pavers. A preventative measure for TSS, TP and NO^3.*

6. *Maryland Guidance street sweeping typically shows: (a) a 5%TN, 6%TP, and 25% TSS removal when sweeping occurs once every two weeks; (b) Impervious surface elimination can significantly reduce nutrient loads; (c) Converting from impervious to grassed pervious has been shown to reduce TN by 13%, TP by 72%, and TSS by 84%; (d) Converting from impervious to forest has been shown to reduce TN by 71%, TP by 94%, and TSS by 93%; and (e) Similar potential exists for strict redevelopment standards which require introduction of stormwater management to existing impervious cover which is being redeveloped.*

7. *Tree planting or reforestation also has significant potential. Converting from grassed pervious to forest can reduce TN by 66%, TP by 77%, and TSS by 50%.*

8. *Stream restoration is also a potentially very important strategy. In the Chesapeake Region, new planning guidance for stream restoration removal rates has been issued.*

This research suggests TN removal of 0.2 lbs per linear foot, TP removal of 0.068 lbs per linear foot, and TSS removal of 310lbs per linear foot.

http://chesapeakestormwater.net/bay-stormwater/baywide-stormwater-policy/urban-stormwater-workgroup/urban-stream-restoration/

9. *Similar potential is available for shoreline stabilization. Some guidance estimates these removal rates at 0.16 lbs TN/linear foot, 0.11 lbs TP/linear foot, and 451 lbs TSS/linear foot.*

10. *Fertilizer management is also potentially a critical strategy for controlling the discharge of nutrients in stormwater. Recent guidance suggests nutrient management can reduce nutrient loading in urban stormwater by 17% for TN and 22% for TP.*

11. *Highly feasible to implement an O&M plan and public outreach/education programs; however, dependent upon funding. Land use planning and IC reduction and control can be implemented through local boards, commissions and ordinances.*

12. *Costs not included as regulatory agencies require stormwater BMPs to be implemented by the municipalities.*

13. *Treatment level for typical stormwater BMPs may not meet the requirements for N and P reduction. Enhancements beyond stormwater MS4 should be considered on a case by case basis.*

Remediation of Existing Development

Description *- Existing developments or schools with excess wastewater treatment capacity allow existing nearby developments to connect to their underutilized wastewater treatment infrastructure.*

Cost (Capital and O&M) – *Costs to be determined based on a site specific analysis. Cost would be presented on a gallon per day basis*

References, Sources and Assumptions

1. *This technology should be encouraged, but would be difficult to quantify potential nitrogen reductions without conducting site specific analyses.*

Compact and Open Space Development

***Description** - Both Compact Development and Open Space Residential Development (OSRD) of subdivisions result in smaller lots and less maintained lawn acres. The higher density development reduces wastewater collection costs while providing a common disposal area.*

***Cost (Capital and O&M) –** Costs to be determined based on a site specific analysis. Cost would be presented on a gallon per day basis.*

References, Sources and Assumptions

1. *This technology should be encouraged, but would be difficult to quantify potential nitrogen reductions without conducting site specific analyses.*

Transfer of Development Rights

***Description** - A regulatory strategy that transfers development and development rights from one property (sending area) to another (receiving area) to direct growth and associated nutrient loading away from sensitive receiving watersheds or water bodies. The protected parcels (sending areas) receive a deed restriction that limits the future the level of future development. The deed restriction can limit the number of homes or tie development to the availability to future WWTF infrastructure.*

***Cost (Capital and O&M) –** Costs to be determined based on a site specific analysis. Cost would be presented on a gallon per day basis.*

References, Sources and Assumptions

1. *Rick Pruetz, Beyond Takings and Givings, 2003.*
2. *Massachusetts Smart Growth / Smart Energy Toolkit.*

   http://www.mass.gov/envir/smart_growth_toolkit/pages/mod-tdr.html

   http://www.mass.gov/envir/smart_growth_toolkit/bylaws/TDR-Bylaw.pdf
3. *This technology should be encouraged, but would be difficult to quantify potential nitrogen reductions without identifying specific preservation areas (sending areas) and specific development districts (receiving areas).*

Inlet/Culvert Widening

Description **-** *Re-engineering and reconstruction of bridge or culvert openings to increase the tidal flux through the culvert or inlet. Increasing the tidal flux will decrease the nitrogen residence time, lowering the nutrient concentration in the estuary and/or tidal marsh upstream of the widened inlet or culvert.*

Cost (Capital and O&M) - Costs are presented on a per cubic yard basis.

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$210	*$252*	*$231*	*$6*	*$11*	*$8*

References, Sources and Assumptions

1. *Bournes Pond.*
2. *Actual costs will be site specific.*
3. *In general increasing the capacity of bridges and culverts is a good way to increase upstream and downstream water quality and enhance upstream habitats. However, care must be taken in the design so as not to adversely affect upstream and downstream habitats and or negatively impact upstream or downstream properties and structures. The design requires detailed modeling (preferably 2-dimensional hydrodynamic modeling) to quantify the potential upstream and downstream impacts.*

Restoration of Coastal Habitats

Description **-** *Restoration of coastal habitats includes establishing and/or enhancing estuary salt marshes, eel grass beds, as well as shellfish and oyster beds together as an ecosystem. When considering restoration of coastal habitats, implementing these ecosystems jointly should be considered. The installation of riparian buffer zones and floating islands (next subheading) should be considered when restoring coastal habitats. Habitat restoration should focus on creating or rehabilitating habitats, consideration to creating communities that are natural to the area should be considered.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$58,800	*$126,000*	*$92,400*	*$3,300*	*$8,800*	*$6,050*

References, Sources and Assumptions

1. *Carmichael, R.H. and W. Walton, H. Clark, June 2012, Bivalve Enhanced Nitrogen Removal from Coastal Estuaries.*

   http://www.auburn.edu/~wcw0003/products/publications/carmichael-rh-w-walton--h.html

2. *The Nature Conservancy: Oyster Reef Building and Restoration for Coastal Protection*

   http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/louisiana/oyster-reef-restoration-in-louisiana.xml

3. *Sisson, M. et al. Assessment of Oyster Reefs in Lynnhaven River as a Chesapeake Bay TMDL BMP 2011.*

   http://web.vims.edu/GreyLit/VIMS/sramsoe429.pdf

4. *Various studies have quantified removal rates, though there is variation depending on shellfish type and environmental conditions.*

5. *Assessment of Oyster Reefs in Lynnhaven River as a Chesapeake Bay TMDL Best Management Practice, MacSisson, Lisa Kellogg, Mark Luckenbach, Rom Lipcius, Allison Colden, Jeff Cornwell, and Michael Owens Final Report to the U. S. Army Corps of Engineers, Norfolk District*

   http://web.vims.edu/GreyLit/VIMS/sramsoe429.pdf

6. *Estuarine Fish and Shellfish Species in U.S. Commercial and Recreational Fisheries: Economic Value as an Incentive to Protect and Restore Estuarine Habitat, K. A. Lellis-Dibble, K. E. McGlynn, and T. E. Bigford, November 2008.*

7. *Bay Area Monitor, Scientists Set Seashells by the Seashore, Aleta George, October 1, 2013*

   http://bayareamonitor.org/index.php?option=com_content&view=article&id=366&Itemid=66

8. *Range of 250 to 1,000 Kg of N per acre based ongoing pilot studies in Falmouth, MA and Wellfleet, MA. Analysis uses a conservative value of 250 Kg of N per acre.*

9. *Kellogg, Lisa, Virginia Inset of Marine Science, Denitrification and Nutrient Assimilation on a Restored Oyster Reef, May 2013.*

   http://www.int-res.com/abstracts/meps/v480/feature/

10. *Rice, Michael A,, Et. Al., Changes in Shellland Soft Tissue Growth, Tissue Compositions of Quohogs and Sovt-Shelled Clams in Response to Eutrophic Driven Changes in Food supply and Habitat. Boston University, Journal of Experimental Marine Biology and Ecology. August 2004,*

11. *STAC Report, Evaluation of the Use of Shellfish as a Means of Nutrient Reduction in the Chesapeake Bay, September, 3013d*

12. *Circle C Oyster Ranchers Association: http://www.oysterranching.com/background.html*

13. *Food and Agricultural Organization of the United States: Hatchery Culture of Bivalves Fisheries Technical Paper 471*

   (http://www.fao.org/docrep/007/y5720e/y5720e02.htm#TopOfPage)

Floating Constructed Wetlands

Description *- Manmade floating "islands" that act as floating wetlands that treat waters within ponds and estuaries. The islands are made of recycled materials that float on ponds or estuaries, exposing the plant's roots to the pond and estuarine waters. The root zones provide habitat for fish and microorganisms while reducing nitrogen and phosphorus levels. The floating islands can also be designed to allow shellfish and seaweed to grow which can be harvested, offsetting some of the systems costs. Some systems circulate surface water through the island, exposing the water to the root zones of the plants. The islands can be installed with shellfish beds and/or salt marsh grasses potentially assisting with their establishment. The islands are generally stationary and can be installed with walkways to access and maintain the plants growing on the islands. The islands require little O&M and do not need to be removed during the winter months, even if freezing water is a concern.*

Cost (Capital and O&M) *- Costs are presented on a square foot basis.*

Project Cost			Annual O&M Cost		
Low	High	Average	Low	High	Average
$34	$50	$42	$1	$2	$2

References, Sources and Assumptions

1. *Communications with Robert Crook of Floating Islands International.*

2. *Project Descriptions at Floating Islands International http://www.floatinislandinteranational.com*

3. *Floating Islands West LLC http://floatingislandwest.com*

Surface Water Remediation Wetlands

Description *- 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 potable water reuse systems. Surface water remediation wetlands are generally used with FWS wetlands due to their larger size, and lower capital and O&M Costs.*

Cost (Capital and O&M) *- Costs are presented on a per acre basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$426,000	*$510,000*	*$468,000*	*$3,000*	*$8,000*	*$5,500*

References, Sources and Assumptions

1. *Average Removal Rate from Kadlec and Knight. Treatment Wetlands (P 419).*

2. *Average treatment capacity of two remediation wetland projects (Des Plaines River Wetland Demonstration Project and Richland Chambers Wetland).*

3. *Range of wetland costs adjusted to 2012 dollars from Constructed Wetlands Treatment of Municipal Wastewaters. EPA. 1999. (P 132-133.)*

4. *Range of O&M values adjusted for inflation from Jim Kreissl. Constructed Wetlands Treatment for Nutrient Treatment for Nutrient Reduction. Presentation at POTW Nutrient Reduction and Efficiency Workshop, 2008.*

5. *Kadlec and Knight. Treatment Wetlands (P 463).*

6. *1 acre of SSF CTW will treat 50-75 homes/acre Total Nitrogen at 330 gpd. Assumptions: Q= 330 gpd (1.25 mg/l); Ci = 20 mg/l; Ce = 5 mg/l (TN), k (areal removal rate constant): 4-15 m/yr. C* = 0 mg/l (background). Equates to 0.015 to 0.025 acres/330 gpd.*

7. *These are Constructed Treatment Wetland Cells often designed as FWS cells constructed in an upland location, lined and sized accordingly based on design flow (Q) , influent pollutant concentration (Ci), and target goal for effluent concentration (Ce) along with a decay constant (k) (areal rate constant). Much of the information presented above for FWS wetlands is applicable here. Direct gravity discharge is preferred over pumping and many pollutants can be managed with these systems including nutrients (N, P), TSS, BOD, pH, suspended metals, TPH and pathogens. These systems can often be integrated as tertiary polishing units depending on the pollutant for existing surface waters to be directed through. If a system like this is integrated with existing impaired surface water, flood management/mitigation needs to be fully evaluated. There are some passive benefits of these systems including creating aquatic habitat for a wide range of fish, amphibians and other wildlife.*

Pond and Estuary Dredging

Description - *Lakes, ponds, streams and estuaries store nutrients within their sediments. These sediments tend to accumulate over time. Subsequently, these nutrients can be release into the overlying water column and can become a major source of nitrogen and phosphorus. Dredging and removing these sediments and accumulated nutrients removes the nutrients from the water body and potentially the watershed. TN>0.3 mg/L*

Cost (Capital and O&M) - *Costs are presented on a per cubic yard basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$210	*$252*	*$231*	*$6*	*$11*	*$8*

References, Sources and Assumptions

1. *Massachusetts Generic Impact Report, Eutrophication and Aquatic Plant Management, 2003.*

2. *Pond and estuary dredging is a more conventional mechanism to conduct "source removal" of accumulated nutrients (N and P) and provides the opportunity to remove other anthropogenic compounds from the environment. Dredging can be extremely expensive (including removal, testing and disposal of dredged materials), involves extensive environmental permitting, and can alter habitats. However as a source*

removal option dredging is a proven technology. Care needs to be taken during dredging operations to avoid releases of the nutrients (to downstream sources) from the anoxic sediments when they become exposed. Dredging is routinely done across the US for removal of toxics from accumulated sediments. Dredging can be conducted in a wide range of aquatic habitats including deep ponds and lakes, rivers, freshwater and saltwater wetlands, mudlflats and floodplains. Active restoration of these habitats post-dredging is commonly done and with success including large scale planting and monitoring programs.

The following 12 technologies (Title 5 Septic, I/A, I/A Enhanced, Cluster Treatment (single stage), Cluster Treatment (two stage), Conventional Treatment, Advanced Treatment, Satellite Treatment, Satellite Treatment-Enhanced, Collection Systems, STEG Collection and STEP Collection) were discussed as aspects of the four traditional treatment methods. They are presented here in the same format as the "nontraditional" systems for comparative purposes and are presented as costs per unit (system) unless otherwise noted.

Title 5 Septic System Replacement (Base Line Condition)

Description - *Standard septic system consisting of a septic tank and soil adsorption system (leaching field).*

Cost (Capital and O&M) - *Costs are presented on a per unit (system) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$8,960	*$16,800*	*$12,880*	*$138*	*$193*	*$165*

References, Sources and Assumptions

1. *Low end reflects only a basic system with no new grading or pump required for raised leaching field. Many replacement systems that require upgrade to meet current Title 5 standards (1994 vs 1978) may require greater groundwater offset or other site restriction that demands pumped effluent to leaching field. New septic tanks should include effluent Tee filter to minimize solids carry-over to field.*

Innovative/Alternative (I/A) Systems

Description *- Innovative/Alternative (I/A) on-site denitrifying systems typically consist of standard septic system components augmented to remove nutrients. I/A systems are commercial, proprietary systems intended to be designed as recirculating sand filter (RSF) equivalent by meeting the same treatment limits in a smaller footprint. Total N <19 mg/L.*

Cost (Capital and O&M) - *Costs are presented on a per unit (system) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$11,200	*$33,600*	*$22,400*	*$1,100*	*$1,650*	*$1,375*

Innovative/Alternative (I/A) Enhanced Systems

Description *- Enhanced I/A systems for TMDL compliance. Enhanced I/A (RSF Equivalent) to achieve 50% would definitely require chemical systems to reliably meet such limits that would target near 10 mg/L for TN to consistently meet design of 13 mg/L. Nitrogen levels are typically treated to 10 to 13 mg/L.*

Cost (Capital and O&M) - *Costs are presented on a per unit (system) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$16,800	*$39,200*	*$28,000*	*$3,300*	*$4,400*	*$3,850*

Cluster Treatment System-Single Stage

Description *- A single-stage cluster system is an I/A system generally treating wastewater flows greater than 2,000 gallons per day. Several homes or businesses discharge to and are treated at a common I/A system. Nitrogen levels are typically treated to below 15 mg/L.*

Cost (Capital and O&M) *- Costs are presented on a per unit (system) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$425,000	*$495,000*	*$460,000*	*$55,000*	*$82,500*	*$68,750*

References, Sources and Assumptions

1. *Additional construction and O&M costs from various AECOM projects.*

Cluster Treatment System-Two Stage

Description *- Two-stage cluster systems are similar to a single-stage cluster system (treating flows greater than 2,000 gallons per day), but require a separate denitrifying process and other facilities to reduce nitrogen levels below that of a single-stage system. Two-stage systems may require chemical systems and an operator to run the system. Disinfection may be required if the discharge is located within a Zone II of a public water supply well. Nitrogen levels are typically reduced to below 8 mg/L.*

Cost (Capital and O&M) *- Costs are presented on a per unit (system) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$495,000	*$600,000*	*$547,500*	*$66,000*	*$99,000*	*$82,500*

References, Sources and Assumptions

1. *Additional construction and O&M costs from various AECOM projects with 25 percent increase for additional infrastructure/operations.*

Conventional Treatment

Description *- A conventional wastewater treatment facility typically treats wastewater from more than 1,000 homes. Wastewater flows are generally between 330,000 and 1,000,000 gpd. Nitrogen levels are typically treated to around 10 mg/L.*

Cost (Capital and O&M) *- Costs are presented on a per unit (facility) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$21,250,000	*$35,250,000*	*$28,250,000*	*$50,000*	*$1,500,000*	*$1,125,000*

References, Sources and Assumptions

1. *Additional construction and O&M costs from various AECOM projects.*

Advanced Treatment

Description *- An Advanced wastewater treatment facility typically treats wastewater from more than 1,000 homes (between 330,000 and 1,000,000 gpd). Nitrogen levels are typically treated to around 5 mg/L.*

Cost (Capital and O&M) *- Costs are presented on a per unit (facility) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$25,450,000	*$42,250,000*	*$33,850,000*	*$850,000*	*$1,650,000*	*$1,250,000*

References, Sources and Assumptions

1. *Additional construction and O&M costs various AECOM projects with 10 percent increase for additional infrastructure/operations.*

Satellite Treatment

Description *- Wastewater treatment facility typically treating wastewater from up to 300 homes. Wastewater flow is between 25,000 and 330,000 gpd. Nitrogen levels are typically treated to around 10 mg/L.*

Cost (Capital and O&M) *- Costs are presented on a per unit (facility) basis.*

Project Cost			Annual O&M Cost		
Low	High	Average	Low	High	Average
$4,450,000	$11,450,000	$7,950,000	$150,000	$250,000	$200,000

References, Sources and Assumptions

1. *Additional construction and O&M costs from various AECOM projects.*

Satellite Treatment-Enhanced

Description *- Satellite wastewater treatment facilities typically treat wastewater from up to 1,000 homes (between 25,000 and 330,000 gpd). Enhanced wastewater treatment facilities are similar to a satellite wastewater treatment facility, but require a separate denitrifying process and other facilities to reduce nitrogen levels below that of a satellite wastewater treatment facility. Enhanced facilities will require chemical systems and an operator to run the system. Disinfection may be required if the discharge is located within a Zone II of a public water supply well. Nitrogen levels are typically reduced to below 8 mg/L.*

Cost (Capital and O&M) *- Costs are presented on a per unit (facility) basis.*

Project Cost			Annual O&M Cost		
Low	High	Average	Low	High	Average
$5,850,000	$14,250,000	$10,050,000	$250,000	$600,000	$425,000

References, Sources and Assumptions

1. *Additional construction and O&M costs from various AECOM projects.*

Collection Systems

Description – *A conventional collection system is a system of piping and pumps used to collect and convey raw wastewater from homes and businesses to a WWTF. The system may consist of a combination of gravity and force mains, low pressure sewer with individual service pumps, and vacuum systems with a dedicated vacuum station serving multiple collection structures.*

Cost (Capital and O&M) - *Unit prices are as presented in the table below.*

Unit Metric	Cost / Unit Metric					
	Project Cost			Annual O&M Cost		
	Low	High	Average	Low	High	Average
Linear Foot (Gravity Sewer)	$210	$245	$228	$2	$3	$2
Linear Foot (Low Pressure Sewer)	$175	$210	$193	$2	$4	$3
Linear Foot (Vacuum Sewer)	$175	$210	$193	$2	$4	$3
Linear Foot (Force Main)	$175	$210	$193	$1	$1	$1
Each (Pump Station)	$350,000	$1,050,000	$700,000	$50,000	$75,000	$62,500
Each (On-site PS)	$14,000	$21,000	$17,500	$60	$80	$70

References, Sources and Assumptions

1. *O&M Costs for gravity sewers and force mains based on recommended regular maintenance by staff, and include 10-year cycle servicing/inspections; $2/lf x 2 (5 yr.) Cleaning, $2/lf TV, $75/MH, $500/service connection; Total $1.65-$2.00 per lf. Regular pump station and force main maintenance by staff including force main and siphon flushing annually; Daily pump station inspections x 2 staff @$75/hr.*

2. *F.R. Mahoney based on Marion service contract for low pressure pump stations; O&M costs typically $45 per year over lifetime plus $22 per year power. Pump replacement $2,100/unit (2013) based on 25-yr life.*

3. *O&M Costs for vacuum sewers 30% higher than conventional systems. Regular maintenance of main vacuum pump station (daily), vacuum structures (2 per year) by staff @ $75/hr (burdened).*

4. *O&M for pump stations based on one staff at half time at $75,000/year plus operating costs (electrical, spare parts, etc.).*

STEP/ STEG

STEG-Collection

Description *- A septic tank effluent gravity (STEG) system consists of on-site piping that collects wastewater from septic tanks and conveys it to a WWTF for treatment. Gravity sewers convey the wastewater from on-site tanks to the sewer system. Only the liquid component of the wastewater can be conveyed by gravity.*

Cost (Capital and O&M) *- Unit prices are as presented in the table below.*

Unit Metric	Cost / Unit Metric					
	Project Cost			Annual O&M Cost		
	Low	High	Average	Low	High	Average
Linear Foot	$175	$210	$193	$2	$4	$3

References, Sources and Assumptions

1. *Construction and O&M costs from various AECOM projects.*

STEP/ STEG

STEP-Collection

Description *- A septic tank effluent pump (STEP) system consists of on-site piping and pumps that collects wastewater from septic tanks and conveys it to a WWTF for treatment. Small diameter low-pressure sewers convey the wastewater from on-site tanks to the sewer system. Only the liquid component of the wastewater can be conveyed by pumps.*

Cost (Capital and O&M) *- Unit prices are as presented in the table below.*

Unit Metric	Cost / Unit Metric					
	Project Cost			Annual O&M Cost		
	Low	High	Average	Low	High	Average
Linear Foot	$175	$210	$193	$2	$4	$3
Each (On-site PS)	$14,000	$21,000	$17,500	$60	$80	$70
Each (Interior Plumbing Reconfiguration)	$1,120	$8,400	$4,760	$2	$4	$3

References, Sources and Assumptions

1. *Construction and O&M costs from various AECOM projects.*

Effluent Disposal-Infiltration Basins

Description *- Once the wastewater has been collected and treated at a WWTF, the treated wastewater (effluent) is generally disposed to groundwater through an infiltration basin. An infiltration basin is an unlined basin or pit excavated at the ground surface. The effluent is discharged into the pit where it percolates into the underlying soils, recharging the groundwater.*

Cost (Capital and O&M) *- Costs are presented on a per square foot basis.*

Project Cost			Annual O&M Cost		
Low	High	Average	Low	High	Average
$12	$15	$14	$5	$10	$8

References, Sources and Assumptions

1. *O&M of 4 hours per week at $75,000/year for a 1 acre basin.*
2. *Sizing at 4 gallons per day per square foot.*
3. *Construction and O&M costs are based on various AECOM projects.*

Effluent Disposal-Soil Absorption System (SAS)

Description *- Once the wastewater has been collected and treated at a WWTF, the treated wastewater (effluent) is generally discharged to groundwater. A subsurface soil absorption system (SAS) is a subsurface means of discharging WWTF effluent. A SAS is similar to a leachfield, and can be installed below ball fields, parks, parking lots and open space areas.*

Cost (Capital and O&M) *- Costs are presented on a per square foot basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$9	*$11*	*$10*	*$2*	*$4*	*$3*

References, Sources and Assumptions

1. *Sizing at 3 gallons per day per square foot.*
2. *Construction and O&M costs are based on various AECOM projects.*

Effluent Disposal-Injection Well

Description *- Once the wastewater has been collected and treated at a WWTF, the treated wastewater (effluent) is generally disposed to groundwater. Injection wells are a series of wells that are capable of injecting WWTF effluent into groundwater. If geologic conditions are favorable, an injection well can discharge the effluent deep in the aquifer where it may not resurface until it reaches the ocean. 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 SAS systems.*

Cost (Capital and O&M) *- Costs are presented on a per unit (system) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$1,885,000	*$2,795,000*	*$2,340,000*	*$55,000*	*$110,000*	*$82,500*

References, Sources and Assumptions

1. *US EPA Website on Basic information about Injection Wells.* *http://water.epa.gov/type/groundwater/uic/basicinformation.cfm*

Effluent Disposal-Wick Well

Description *- Once the wastewater has been collected and treated at a WWTF, the treated wastewater (effluent) is generally disposed to groundwater. Wicks are large diameter conduits of stone that allow for the rapid infiltration of effluent to the underlying groundwater. The effluent is discharged into a wick (two to six feet in diameter) where it is infiltrated into the aquifer until it reaches the ocean. 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.*

Cost (Capital and O&M) *- Costs are presented on a per unit (system) basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$732,000	*$1,068,000*	*$900,000*	*$5,500*	*$11,000*	*$8,250*

References, Sources and Assumptions

1. *Construction and O&M costs are based on various AECOM projects.*

Effluent Disposal-Ocean Outfall

Description *- Instead of discharging the WWTF effluent to groundwater, the effluent is conveyed to an ocean outfall. Ocean outfall discharges are ideally located offshore in deep water where currents disperse and dilute the discharge. Ocean outfalls have the advantage of removing the nitrogen load from the watershed.*

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.*

Cost (Capital and O&M) - *Costs are presented on a per linear foot basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$1,820	*$3,640*	*$2,730*	*$2*	*$6*	*$4*

References, Sources and Assumptions

1. *Construction and O&M costs are based on various AECOM projects.*

Disposal: Outside Watershed

Effluent Transport out of Watershed to Recharge, Reuse Facility or Ocean Outfall

Description *- Gravity or force main conveyance of treated effluent from the WWTF site to groundwater recharge, reuse or disposal site outside of the watershed. Effluent Transport out of the watershed has the advantage of removing the nitrogen load to another watershed. Transport to another watershed requires the receiving watershed to be able to accommodate the additional nitrogen load.*

Cost (Capital and O&M) *- Costs are presented on a per linear foot basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$210	*$280*	*$245*	*$2*	*$3*	*$2*

References, Sources and Assumptions

1. *Additional construction and O&M costs are based on various AECOM projects.*

Septage Processing

Description *- Contract with a service company to pick-up, haul and dispose of sludge. The service company is responsible for providing tank trucks to pick-up 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.*

Cost (Capital and O&M) *- Costs are presented on a per gallon basis.*

Project Cost			Annual O&M Cost		
Low	High	Average	Low	High	Average
N/A	N/A	N/A	$0.10	$0.20	$0.15

References, Sources and Assumptions

1. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*

   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

2. *Project costs are not included as they are completely dependent on local pricing. Many times hauling and tipping fee costs are the main drivers for exploring different technologies.*

Commercial Disposal

Description *- Contract with a service company to pick-up, haul and dispose of sludge. The service company is responsible for providing tank trucks to pick-up 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.*

Cost (Capital and O&M) *- Costs to be determined based on a site specific analysis. Costs would be presented on a Dry Tons per Day (DTPD) basis.*

References, Sources and Assumptions

1. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*

   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

2. *Project costs are not included as they are completely dependent on local pricing. Many times hauling and tipping fee costs are the main drivers for exploring different technologies.*

Dewater and Haul to Landfill

***Description** - Requires a dewatering device onsite to increase the solid content to a level that will meet a paint filter test and other local requirements. The degree of stabilization required for the landfill needs to be coordinated with landfill(s) in the region.*

***Cost (Capital and O&M)** - Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$100	*$139*	*$119*	*$65*	*$210*	*$138*

References, Sources and Assumptions

1. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*

   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

2. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

Composting

***Description** - 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 according to regulatory guidelines produces Class A Biosolids. Composting that is performed properly produces a nuisance-free humus like material. The three different methods of composting typically used for wastewater sludge are aerated static pile, windrow, and in-vessel composting. 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 25 – 35 to one ratio of carbon to nitrogen (mass basis). Next, 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. Finally, after the "active composting" period is complete, the material is cured and distributed.*

Cost (Capital and O&M) *- Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			*Annual O&M Cost*		
Low	***High***	***Average***	***Low***	***High***	***Average***
$108	*$162*	*$135*	*$215*	*$490*	*$353*

References, Sources and Assumptions

1. *More than 300 installations nationwide.*
2. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*

   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm
3. *Metcalf & Eddy (1991). Wastewater Engineering Treatment and Reuse 3rd Edition.*
4. *EPA (2002) Biosolids Technology Fact Sheet – Use of Composting for Biosolids Management.*

   http://water.epa.gov/scitech/wastetech/mtbfact.cfm
5. *EPA (2002) Biosolids Technology Fact Sheet – In-Vessel composting of Biosolids.*

   http://water.epa.gov/scitech/wastetech/mtbfact.cfm
6. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

Incineration

Description *- 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. Fluid bed and multiple hearth incineration are established technologies and are the most common types of incineration used for sewage sludge. Multiple hearth incineration is now considered an outdated technology and very few if any new systems are being constructed. Incineration of sludges converts the waste into ash, flue gas, and heat. Flue gas treatment is required and the 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.*

Cost (Capital and O&M) *- Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$331	*$424*	*$377*	*$135*	*$330*	*$233*

References, Sources and Assumptions

1. *More than 204 installations nationwide (144 Multiple Hearth and 60 Fluid Bed).*
2. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*

   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm
3. *Metcalf & Eddy (1991). Wastewater Engineering Treatment and Reuse 3rd Edition.*
4. *EPA (2003) "Biosolids Technology Fact Sheet – Use of Incineration for biosolids Management".*

   http://water.epa.gov/scitech/wastetech/mtbfact.cfm
5. *"Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Sewage Sludge Incineration Units," 76 Federal Register 54 (March 21, 2011), pp. 15372-15454.*

   https://www.federalregister.gov/articles/2011/03/21/2011-4495/standards-of-performance-for-new-stationary-sources-and-emission-guidelines-for-existing-sources
6. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

Lime Stabilization

Description *- 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 EPA's 40CFR Part 503 regulations for pathogen destruction for either Class A or Class B biosolids. 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.*

***Cost (Capital and O&M)** - Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$123	*$185*	*$154*	*$100*	*$275*	*$188*

References, Sources and Assumptions

1. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*
   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

Digestion-Conventional High Rate

***Description** - 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 (~65%) and carbon dioxide (~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 (~35°C) but some plants also operate at thermophilic conditions (~55°C) to increase reaction rate and provide a greater degree of pathogen reduction.*

***Cost (Capital and O&M)** - Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$85	*$200*	*$142*	*$100*	*$200*	*$150*

References, Sources and Assumptions

1. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*
   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

2. *One of the most common solids processing technologies used with hudreds of installations.*

3. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

4. *Capital and O&M do not include dewatering costs.*

Digestion-Aerobic

***Description** - Aerobic digestion 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. This stage of the process is known as endogenous respiration. Aerobic digestion is most commonly practiced at WWTFs rated for less than 5 MGD. Aerobic digestion typically yields high volatile solids destruction, has a low BOD 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.*

***Cost (Capital and O&M)** - Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$108	*$231*	*$169*	*$9*	*$52*	*$31*

References, Sources and Assumptions

1. *One of the most common solids processing technologies used with hundreds of installations.*

2. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

3. *Capital and O&M do not include dewatering costs.*

Thermal Drying

Description *- Thermal 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% 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 spreading. 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 as either direct (convective) dryers or indirect (conductive) 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. 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.*

Cost (Capital and O&M) *- Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$193	*$308*	*$250*	*$205*	*$510*	*$358*

References, Sources and Assumptions

1. *Relatively common process but there are a wide range of dryer types available.*
2. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*
   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm
3. *EPA/625/R-92/013, Chapter 4*
   http://epa.gov/nrmrl/pubs/625r92013/625r92013.htm
4. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

Drying and Gasification

***Description** - 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, CO2, H2 and CH4 and has a low heating value of 120-150 British Thermal Units (BTU)/cubic feet (cu. ft.), which is approximately 25% of the heat value of biogas generated from anaerobic digestion. However 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. Although gasification is common in many industries, gasification of biosolids is still considered innovative as defined by the EPA. 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.*

***Cost (Capital and O&M)** - Costs are presented on a Dry Tons per Day (DTPD) basis.*

Project Cost			***Annual O&M Cost***		
Low	***High***	***Average***	***Low***	***High***	***Average***
$270	*$393*	*$331*	*$115*	*$330*	*$223*

References, Sources and Assumptions

1. *New process with only a few references in North America with the most well known being Sanford, FL.*
2. *A Plain English Guide to the EPA Part 503 Biosolids Rule.*

   http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm
3. *EPA (2006) Biosolids Technology Fact Sheet - Heat Drying.*

   http://water.epa.gov/scitech/wastetech/mtbfact.cfm
4. *Cost information from EPA Fact sheets as available and previous AECOM projects.*

BARNSTABLE COUNTY WASTEWATER COST TASK FORCE

The 2010 version of this report was prepared by a task force that was established to compile and evaluate information on the costs of various wastewater management options that are applicable to Cape Cod. Members of the Wastewater Cost Task Force were selected based on their experience and expertise with a wide variety of technologies and system sizes. *The task force included*:

- **Thomas Cambareri.** A hydrogeologist and planner, Mr. Cambareri is the Water Resources Program Manager for the Cape Cod Commission. He and his staff review all Comprehensive Wastewater Management Plans prepared on Cape Cod, as well as the wastewater facilities implemented in Developments of Regional Impact. He was one of the principal authors of the 2003 Cape Cod Comprehensive Regional Wastewater Management Strategy report and the 2010 Cape Cod Regional Wastewater Management Plan.

- **Brian Dudley.** Mr. Dudley is an environmental engineer and the senior staff member at the Hyannis Office of the Massachusetts Department of Environmental Protection. He is also MassDEP's manager of the Massachusetts Estuaries Project. Mr. Dudley oversees the issuance of groundwater discharge permits on Cape Cod, and has reviewed the design and operation of over one hundred projects involving most applicable wastewater technologies. Prior to joining DEP, he worked in the private sector designing small wastewater treatment plants and developing innovative treatment systems.

- **Michael Giggey**. Mr. Giggey is a registered professional engineer and Senior Vice President of Wright-Pierce. He was the principal author of the 2004 report "Enhancing Wastewater Management on Cape Cod: Planning, Administrative and Legal Tools", and continues to advise the Cape Cod Commission on wastewater planning issues. He has designed or provided peer review for several dozen small-scale wastewater systems in the region, and is a well-known advocate for new and appropriate technology.

- **George Heufelder.** As director of the Barnstable County Department of Health and Environment, Mr. Heufelder oversees the County's water quality laboratory, the community septic loan program and other public health initiatives. He is also the director of the Massachusetts Alternative Septic System Test Center, and in that capacity has installed and operated many new wastewater treatment technologies. Mr. Heufelder is a registered sanitarian and member of the Falmouth Board of Health. He is the author of several publications related to the performance of small-scale wastewater treatment systems.

- **Susan Rask**. Ms. Rask is a registered sanitarian and former member of the Barnstable Board of Health. As Environmental Health Specialist for the Barnstable County Department of Health and Environment, she manages the County's internet-based reporting system that compiles operating data for over 1,400 small wastewater systems in 14 towns. She was the principal author of the 2007 report "Projected Use of Innovative/Alternative On-site Sewage Treatment Systems in Eastham" and served as project manager for the "Sewers and Smart Growth" project completed in 2009

Funding for the Task Force's work was provided by Barnstable County and by grants to the Association to Preserve Cape Cod from the Cape Cod Five Charitable Trust Foundation and the Horizon Foundation. The report was developed with the assistance of the GIS and technical staff of the Cape Cod Commission.

This 2014 update was prepared by AECOM. A Fortune 500 company with clients in more than 150 countries, AECOM is a global provider of professional technical and management support services to a broad range of markets, including transportation, facilities, environmental, energy, water and government. AECOM and its subconsultants, using individuals with experience in design, permitting and cost estimating of wastewater systems, gathered the information presented in this update from various federal, state and local regulatory agencies, municipalities, special interest groups and the public at large.

Appendix A

Survey of Project Costs for Wastewater Treatment Facilities

APPENDIX A
SURVEY OF PROJECT COSTS FOR WASTEWATER TREATMENT FACILITIES

#	Facility	Location	Design Flow, ADF (gpd)	Project Cost		Unit Cost ($/gpd)	Sources and Notes
				End of Construction	Mar-14		
				Variable ENR	*Current ENR*		
					9,702		
1	Anonymous	E. Bridgewater	15,000	970,000	1,197,000	79.8	Wright-Pierce
	(residential)			*7,864*	*9,702*		preconstr. estimate
2	Camp Jewell	Western Conn.	19,000	1,010,000	1,341,000	70.6	Wright-Pierce
				7,308	*9,702*		includes upgrade
3	Anonymous	So. New England	17,500	648,000	810,000	46.3	Aquapoint
	(school)			*7,763*	*9,702*		
4	Cotuit Stop'n Shop	Barnstable	22,000	760,000	1,128,000	51.3	VHB
				6,538	*9,702*		
5	Massachusetts Correctional Facility	Plymouth	31,000	2,300,000	2,705,000	87.3	Horsley-Witten
				8,250	*9,702*		
6	Harvard Ridge	Boxborough	34,000	3,000,000	4,344,000	127.8	AECOM
				6,700	*9,702*		
7	Anonymous	Cohasset	38,000	1,280,000	1,581,000	41.6	RH White
	(residential)			*7,856*	*9,702*		
8	Berkshire School	W. Mass.	40,000	1,000,000	1,484,000	37.1	Zenon
				6,538	*9,702*		
9	Camp Beckett	W. Mass.	40,000	1,500,000	1,842,000	46.1	CDMSmith
				7,900	*9,702*		
10	Bolton - Municipal	Bolton	40,000	1,800,000	2,199,000	55.0	Tata & Howard
				7,940	*9,702*		
11	Anonymous	Weston	40,000	2,100,000	2,579,000	64.5	RH White
	(residential)			*7,900*	*9,702*		
12	Shops at Derby Street	Hingham	54,000	2,500,000	3,675,000	68.1	Martinage Eng. Assoc.
				6,600	*9,702*		
13	New Silver Beach	Falmouth	60,000	4,000,000	4,851,000	80.9	Town of Falmouth
				8,000	*9,702*		
14	Anonymous	No. Reading	63,000	2,400,000	3,024,000	48.0	RH White
	(residential)			*7,700*	*9,702*		
15	Anonymous	Acton	96,000	2,879,000	3,541,000	36.9	Developer
	(residential)			*7,888*	*9,702*		
16	West Island	Fairhaven	100,000	2,300,000	3,831,000	38.3	Town of Fairhaven
				5,825	*9,702*		
17	Tisbury - Municipal	Tisbury	104,000	5,170,000	7,717,000	74.2	Town of Tisbury
				6,500	*9,702*		
18	Pine Hills	Plymouth	150,000	4,800,000	7,485,000	49.9	Wright-Pierce
				6,222	*9,702*		Phase 1 only
19	Oak Bluffs - Municipal	Oak Bluffs	320,000	6,800,000	10,603,000	33.1	Wright-Pierce
				6,222	*9,702*		
20	Provincetown - Municipal	Provincetown	650,000	13,000,000	19,707,000	30.3	Town of Provincetown
				6,400	*9,702*		Phase 1 thru 5
21	Edgartown - Municipal	Edgartown	750,000	11,400,000	20,361,000	27.1	Town of Edgartown and AECOM
				5,432	*9,702*		Upgrade of Existing Facility
22	Jaffrey - Municipal	Jaffrey, NH	1,250,000	11,000,000	13,595,000	10.9	Wright-Pierce
				7,850	*9,702*		Upgrade of Existing Facility
23	Falmouth - Municipal	Falmouth	2,200,000	12,500,000	17,325,000	7.9	Town of Falmouth
				7,000	*9,702*		
24	Chatham - Municipal	Chatham	2,300,000	36,000,000	40,613,000	17.7	Town of Chatham
				8,600	*9,702*		some existing facil.
25	Linden Ponds	Hingham	306,000	$ 6,500,000	$ 9,355,000	30.6	AECOM
				6741	*9,702*		
26	Fruit Street	Hopkinton	250,000	$ 8,900,000	$ 9,312,000	37.2	AECOM
				9273	*9,702*		
27	New Seabury	Mashpee	300,000	$ 9,555,000	$ 12,005,000	40.0	AECOM
				7722	*9,702*		Added 15% for Engineering
28	Westborough/Shrewsbury	Westborough	7,680,000	$ 55,177,000	$ 62,407,000	8.1	AECOM

APPENDIX A
SURVEY OF PROJECT COSTS FOR WASTEWATER TREATMENT FACILITIES

#	Facility	Location	Design Flow, ADF (gpd)	Project Cost End of Construction	Project Cost Mar-14	Unit Cost ($/gpd)	Sources and Notes
				8578	*9,702*		Upgrade of Existing Facility
29	Hudson - Municipal	Hudson	3,050,000	$ 17,227,000	$ 19,453,000	6.4	Wright-Pierce
				8592	*9,702*		Upgrade of Existing Facility, Add 15
30	Marlborough Westerly - Municipal	Marlborough	4,150,000	$ 31,625,000	$ 32,907,000	7.9	CDMSmith
				9324	*9,702*		Upgrade of Existing Facility, Add 15
31	Siasconset - Municipal	Nantucket	220,000	$ 10,947,200	$ 16,619,000	75.5	AECOM, Adjusted for Island Factor
				6391	*9,702*		
32	Surfside - Municipal	Nantucket	3,500,000	$ 36,917,600	$ 49,403,000	14.1	AECOM, Adjusted for Island Factor
				7250	*9,702*		Upgrade of Existing Facility
33	Oak Hill Village	Franklin	23,000	$ 1,439,000	$ 1,808,000	78.6	AECOM
				7721	*9,702*		
34	Ridge Path and PB Center	West Springfield	24,600	$ 2,500,000	$ 2,714,000	110.3	AECOM - Planning Estimate
				8938	*9,702*		
35	Acton - Municipal	Action	200,000	$ 16,900,000	$ 22,744,000	113.7	Town of Acton
				7209	*9,702*		
36	Maynard - Municipal		1,450,000	$ -	$ -	0.0	
				9011	*9,702*		

Appendix B

Survey of O&M Costs for Wastewater Treatment Facilities

APPENDIX B
SURVEY OF O&M COSTS FOR WASTEWATER TREATMENT FACILITIES

			FLOWS, gpd		O&M COST, $/yr		UNIT COST,	
FACILITY	#	TOWN	DESIGN	ANNUAL AVG	9011	9702	$/yr/gpd	SOURCES AND NOTES
Patriot Square	1	Dennis	17,000	6,000	85,000	92,000	15.3	Coastal Engineering
Camp Jewell	2	Western Conn.	19,000	6,700	84,000	90,000	13.4	Owner
Comm. of Jesus	3	Orleans	21,700	6,500	87,900	95,000	14.6	Owner
Skaket Corner	4	Orleans	22,000	6,000	85,200	92,000	15.3	Coastal Engineering
Martha's Vineyard Airport	5	Edgartown	37,000	9,000	156,500	169,000	18.8	Dukes County
Anonymous (residential)	6	Cohasset	38,000	21,000	174,000	187,000	8.9	Weston & Sampson
Horace Mann School	7	Barnstable	42,000	10,000	103,000	111,000	11.1	Town of Barnstable
Mashpee Commons	8	Mashpee	80,000	19,000	222,000	239,000	12.6	Owner
West Island	9	Fairhaven	100,000	16,300	165,000	178,000	10.9	Town of Fairhaven
Tisbury Municipal	10	Tisbury	104,000	36,000	360,000	388,000	10.8	Town of Tisbury
Pine Hills	11	Plymouth	300,000	125,000	623,000	671,000	5.4	Veolia
Oak Bluffs Municipal	12	Oak Bluffs	320,000	89,000	603,000	649,000	7.3	Town of Oak Bluffs
Provincetown Mun.	13	Provincetown	575,000	150,000	780,000	840,000	5.6	Town of Provincetown
Edgartown Municipal	14	Edgartown	750,000	170,000	850,000	915,000	5.4	Town of Edgartown
Spencer Municipal	15	Spencer	1,080,000	780,000	1,820,000	1,960,000	2.5	Town of Spencer
Falmouth Municipal	16	Falmouth	1,200,000	400,000	1,137,000	1,224,000	3.1	Town of Falmouth
Jaffrey Municipal	17	Jaffrey, NH	1,250,000	500,000	832,000	896,000	1.8	Town of Jaffrey
Wareham Municipal	18	Wareham	1,560,000	1,067,000	2,980,600	3,209,000	3.0	Town of Wareham
Chatham Municipal	19	Chatham	2,300,000	1,300,000	1,900,000	2,046,000	1.6	Town of Chatham
Plymouth Municipal	20	Plymouth	3,000,000	1,650,000	1,996,000	2,149,000	1.3	Veolia
Hyannis Municipal	21	Barnstable	4,200,000	1,800,000	2,265,000	2,439,000	1.4	Town of Barnstable
Linden Ponds	23	Hingham	306,000	306,000		$ 450,000	1.5	AECOM
Fruit Street	24	Hopkinton	100,000	90,000		$ 325,000	3.6	AECOM
New Seabury	25	Mashpee	300,000	250,000		$ 400,000	1.6	AECOM Added 15% for Engineering
Westborough/Shrewsbury	26	Westborough	7,680,000	6,000,000		$ 4,100,000	0.7	Veolia Water and AECOM Upgrade of Existing Facility
Hudson - Municipal	27	Hudson	3,050,000	1,950,000		$ 2,750,000	1.4	Wright-Pierce Upgrade of Existing Facility, Add 15% for Engineering
Marlborough Westerly - Municipal	28	Marlborough	4,150,000	1,970,000		$ 3,250,000	1.6	CDMSmith Upgrade of Existing Facility, Add 15% for Engineering
Siasconset - Municipal	29	Nantucket	220,000	120,000		$ 600,000	5.0	Town and AECOM, Adjusted for Island Factor
Surfside - Municipal	30	Nantucket	3,500,000	2,000,000		$ 5,500,000	2.8	Town and AECOM, Adjusted for Island Factor Upgrade of Existing Facility
Oak Hill Village	31	Franklin	23,000	18,000		$ 135,000	7.5	AECOM
Acton - Municipal	33	Action	200,000	125,000		$ 550,000	4.4	Town of Acton
Maynard - Municipal	34	Maynard	1,450,000	1,000,000		$ 1,200,000	1.2	

Appendix C

Example Calculations and Assumptions Included in Sensitivity Analysis

ASSUMPTIONS INCLUDED IN SENSITIVITY ANALYSES

Individual Denitrifying Systems

Base Case--see Table 1

A. Additional site restoration--capital costs increased by $4,000 to reflect possible greater disruption of decks, patios and landscaping at currently developed properties, and/or for pumping.
B. Municipal procurement--capital costs increased by 20% to reflect public bidding requirements and prevailing wages.
C. Municipal oversight of operation--O&M costs increased by $150 per year to account for possible town staff overseeing the contract operations of these systems.
D. Reuse of existing on-site system components--one half of properties would incur reduced capital cost by reusing septic tank and leaching field. New construction would be limited to denitrifying system for one half of properties, resulting in a 50% reduction in construction costs.
E. Reduced effluent sampling--BOD and TSS tests eliminated from suite of effluent testing resulting in O&M costs of $125 or $350 per year.
F. Improved effluent quality--effluent nitrogen concentration reduced by 3 mg/l (to 16 mg/l for "current practice", and to 10 mg/l for "enhanced current practice" and "TMDL compliance").
G. Further improved effluent quality--effluent nitrogen concentration using the same process reduced to 5 mg/l for all scenarios and assumes no additional project or operation and maintenance costs.

Cluster Systems

Base Case--see Table 1

A. Seasonal nature of service area--annual average flow (and therefore annual nitrogen load reduction) decreased by 10% to approximate a neighborhood with one-third seasonal homes.
B. Reduced land costs--land for treatment and disposal assumed to be available at no cost to project.
C. More densely-developed service area--construction costs for collection reduced by 20% to reflect serving a neighborhood with smaller lots.
D. Reduced treatment costs--construction costs for treatment system reduced by 20% to anticipate possible future technology breakthroughs.
E. Reduced operator oversight--use of remote sensing of treatment system performance to reduce operator time by 20%, resulting in a reduction of $21,200 to $25,400 in annual O&M costs.
F. Discharge outside sensitive watersheds--effluent disposal site located in watershed with adequate assimilative capacity.
G. Improved effluent quality--effluent nitrogen concentration reduced by 2 mg/l (to 13 mg/l for "current practice", and to 6 mg/l for "TMDL compliance").
H. Further improved effluent quality-- effluent nitrogen concentration using the same process reduced to 5 mg/l for all scenarios and assumes no additional project or operation and maintenance costs.

Satellite Systems

Base Case--see Table 1

A. Increasing the transport distances--both the distance from the collection area to the treatment plant site and the distance between the treatment and disposal sites are increased by a factor of 3.0.
B. Discharging within a water supply zone II--construction costs for treatment are increased by 35% to address the requirements of the groundwater discharge permitting program, and O&M costs are increased by 40%. The effluent nitrogen concentration is reduced to 5 mg/l.
C. Reduced land costs--land for treatment and disposal assumed to be available at no cost to project.
D. Discharge outside sensitive watersheds--effluent disposal site is located in watershed with adequate assimilative capacity.
E. Improved effluent quality--effluent nitrogen concentration reduced by 2 mg/l.
F. Further improved effluent quality-- effluent nitrogen concentration reduced to 5 mg/l for all scenarios.
G. Reduced treatment costs--construction costs for treatment system reduced by 20% to anticipate possible future technology breakthroughs.

Centralized Systems

Base Case--see Table 1

A. Increasing the transport distances--both the distance from the collection area to the treatment plant site and the distance between the treatment and disposal sites are increased by a factor of 3.0.
B. Discharging within a water supply zone II--construction costs for treatment are increased by 35% to address the requirements of the groundwater discharge permitting program, and O&M costs are increased by 40%. The effluent nitrogen concentration is reduced to 5 mg/l.
C. Reduced land costs--land for treatment and disposal assumed to be available at no cost to project.
D. Discharge outside sensitive watersheds--effluent disposal site is located in watershed with adequate assimilative capacity.
E. Improved effluent quality--effluent nitrogen concentration reduced to 3 mg/l for all scenarios.
F. Regionalization--construction and O&M costs for treatment system reduced by 10% to account for economies of scale in a regional system.

Appendix D

Sources of Data and Summary of Adjustments and Assumptions For Example Projects

APPENDIX D

SOURCES OF DATA
AND
SUMMARY OF ADJUSTMENTS AND ASSUMPTIONS
FOR
EXAMPLE PROJECTS

BRACKETT LANDING, EASTHAM

Sources

McShane Construction and SeptiTech

Adjustments and Assumptions--"Current Practice" Scenario

Capital cost. McShane Construction quoted a cost of $530,000 for the wastewater facilities that were completed in early 2006. To this figure was added 10% for engineering, legal and permitting, and $300,000 for land (estimated 1.2 acres at $250,000 per acre). This project was not subject to public procurement requirements.

Operation and Maintenance Costs. McShane quoted $12,000 for the operator and for testing. Added to this figure were: $2,600 for electricity, $5,400 for sludge disposal, $3,500 for administrative costs including engineering and insurance, and $2,000 for equipment repair and replacement.

Flow. Current annual average flows are approximately 1,600 gpd, reflecting less than full development of the project. This analysis is based on an estimated flow at project completion of 3,300 gpd, approximately 40% of the design flow, consistent with other example projects.

Nitrogen Load. Load is based on 3.5 mg/l average effluent quality (as reported by Barnstable County) and in-watershed disposal.

Adjustments and Assumptions--"For TMDL Compliance" Scenario

Operation and Maintenance Costs. Based on DEP input on the level of oversight and testing associated with this scenario (see text), upward adjustments were made to the "current practice" costs to a revised total of $64,500. Labor costs were increased to $41,600 to reflect 10-hour-per-week oversight at $80 per hour. Testing costs were increased to $6,900 for monthly testing of influent and effluent and quarterly testing of monitoring wells. An allowance of $1,000 was added for chemicals (alkalinity). Also added were $1,000 for additional engineering, and $500 for additional equipment repair and replacement.

CAMP JEWELL, COLEBROOK CONNECTICUT

Sources

Greater Hartford YMCA and Wright-Pierce

Adjustments and Assumptions

Capital cost. Costs are based on amounts paid to the construction contractor for Phase 1 and on the engineer's estimates for a proposed upgrading. To these figures was added

25% for engineering, legal and permitting expenses. No land costs or collection costs are included. This project was not subject to municipal procurement requirements.

Operation and Maintenance Costs. The YMCA's quoted costs were increased by $3,000 for power and $500 for engineering. Recent repair costs were assumed to represent once-in-three-year expenditures.

Nitrogen Load. Load is based on the expected 10 mg/l average effluent quality (after upgrading) and in-watershed disposal.

NEW SILVER BEACH, FALMOUTH

Sources

Falmouth Department of Public Works

Adjustments and Assumptions

Capital cost. Costs are based on amounts paid to contractors for construction of collection, treatment and disposal facilities. To these figure was added 25% for engineering, legal and permitting expenses. No land costs are included.

Flow. Connections are still being made to this system. This analysis is based on the expected flow of 25,000 gpd, approximately 40% of the design flow, consistent with other example projects.

Nitrogen Load. Since the plant is in the start-up phase, the load is based on an expected 10 mg/l average effluent quality and in-watershed disposal.

MASHPEE COMMONS, MASHPEE

Sources

Cornish LP

Adjustments and Assumptions

Capital cost. Costs include construction, engineering, permitting and legal expenses, and land. No collection costs are included. Municipal procurement requirements did not apply.

Nitrogen Load. Load is based on 5 mg/l average effluent quality and in-watershed disposal.

WEST ISLAND, FAIRHAVEN

Sources

Fairhaven Department of Public Works

Adjustments and Assumptions

Capital cost. Costs are based on amounts paid to contractors for the original construction plus 25% for engineering, legal, permitting and land acquisition expenses.

Operation and Maintenance Costs. The DPW's quoted costs were increased by $30,000 for labor, $15,000 for sludge handling and $4,000 for administrative and engineering cost.

Nitrogen Load. Load is based on 7 mg/l average effluent quality and in-watershed disposal.

TISBURY MUNICIPAL FACILITIES

Sources

Tisbury Department of Public Works

Adjustments and Assumptions

Capital cost. Costs are based on actual amounts paid to contractors and engineers for the original construction. No land costs are included; treatment and disposal sites were Town-owned.

Nitrogen Load. Load is based on 5 mg/l average effluent quality and in-watershed disposal.

PROVINCETOWN MUNICIPAL FACILITIES

Sources

Provincetown Department of Public Works

Adjustments and Assumptions

Capital cost. Costs are based on amounts paid to contractors for the Phases 1 and 2 of construction plus 20% for engineering, legal, permitting, land acquisition and DBO procurement expenses.

Nitrogen Load. Load is based on out-of-watershed disposal.

PROPOSED ORLEANS MUNICIPAL FACILITIES

Sources

Orleans Comprehensive Wastewater Management Plan, April 2009

Adjustments and Assumptions

Capital cost. Costs are based on CWMP estimates and include construction, land, engineering, legal and contingencies. Costs for proposed supplemental cluster systems are not included. The proposed treatment and disposal sites are town-owned.

Operation and Maintenance Costs. Costs are based on CWMP estimates for all standard expenses, and exclude costs for treatment of out-of-town septage.

Nitrogen Load. Load is based on out-of-watershed disposal.

Regionalization. Cost advantages of regionalization are based on 2009 Wastewater Regionalization Study, assuming participation by Orleans, Eastham and Brewster.

CHATHAM MUNICIPAL FACILITIES

Sources

Chatham Department of Health and Environment and Stearns & Wheler

Adjustments and Assumptions

Capital cost. Costs are based on CWMP estimates for Phase 1 facilities updated for construction bids received in early 2010. Costs for proposed Phase 2 facilities are not included. Treatment and disposal site is town-owned.

Operation and Maintenance Costs. Costs are based on CWMP estimates for all standard expenses and exclude Phase 2 O&M costs.

Nitrogen Load. Load is based on out-of-watershed disposal.

Appendix E

Construction and O&M Cost Estimates for Surface and Subsurface Flow Constructed Wetlands

Constructed Wetlands - Surface Flow Optimized for Nitrogen Removal : Planning Level Itemized Cost Estimate in 2014 Dollars

Constructed Wetland

Constructed Wetland Acreage	Inflow Treatment Level	Estimated Inflow Concentration (N mg/L)	Inflow Treatment Level	Desired Treatment Level (N mg/L)	Flow per Acre (GPD/acre)	Total Flow (GPD)	Nitrogen Removed (kg/acre/yr)
1	Primary	55	Secondary	10	15,000	15,000	934
5	Primary	55	Secondary	10	15,000	75,000	934
10	Primary	55	Secondary	10	15,000	150,000	934
1	Secondary	20	Secondary	10	15,000	15,000	208
5	Secondary	20	Secondary	10	15,000	75,000	208
10	Secondary	20	Secondary	10	15,000	150,000	208
1	Secondary	20	Advanced	5	15,000	15,000	311
5	Secondary	20	Advanced	5	15,000	75,000	311
10	Secondary	20	Advanced	5	15,000	150,000	311
						Average	484

Estimated Design and Construction Costs

Constructed Wetland Acreage	Engineering (Design, etc.)	Engineering (Permitting)	Engineering (Construction Oversite)	Construction	Construction Costs (Engineering and Construction)	Construction Costs Per Acre ($/acre)
1	$37,500	$15,000	$20,000	$200,000	$272,500	$272,500
5	$80,000	$20,000	$50,000	$900,000	$1,050,000	$210,000
10	$135,000	$25,000	$100,000	$1,700,000	$1,960,000	$196,000
1	$37,500	$15,000	$20,000	$150,000	$222,500	$222,500
5	$80,000	$20,000	$50,000	$675,000	$825,000	$165,000
10	$135,000	$25,000	$100,000	$1,275,000	$1,535,000	$153,500
1	$37,500	$15,000	$20,000	$175,000	$247,500	$247,500
5	$80,000	$20,000	$50,000	$787,500	$937,500	$187,500
10	$135,000	$25,000	$100,000	$1,487,500	$1,747,500	$174,750
						$203,250.00

Adjusted Design and Construction Costs

Constructed Wetland Acreage	Land Cost	Construction Costs	Construction and Land Costs	Average Construction and Land Costs per Acre		Construction and Land Costs Per Acre ($/acre)	Flow Based Construction Cost ($/GPD)
1	$250,000	$200,000	$450,000	$425,000	55 mg/L to 10 mg/L	$450,000	$30.00
5	$1,250,000	$900,000	$2,150,000	$2,037,500	20 mg/L to 10 mg/L	$430,000	$28.67
10	$2,500,000	$1,700,000	$4,200,000	$3,987,500	20 mg/L to 5 mg/L	$420,000	$28.00
1	$250,000	$150,000	$400,000			$400,000	$26.67
5	$1,250,000	$675,000	$1,925,000			$385,000	$25.67
10	$2,500,000	$1,275,000	$3,775,000			$377,500	$25.17
1	$250,000	$175,000	$425,000			$425,000	$28.33
5	$1,250,000	$787,500	$2,037,500			$407,500	$27.17
10	$2,500,000	$1,487,500	$3,987,500			$398,750	$26.58
	Average					$410,416.67	Average

Estimated Annual O&M Costs

Constructed Wetland Acreage	O&M Costs	Annual Performance Monitoring (Short-term - Two Years)	Annual Complience Monitoring (Long-term)	O&M Cost ($/yr)	O&M Cost Per Acre ($/acre)	Flow Based O&M Cost ($/GPD)	Total Costs 20 years no inflation or Financing	Life Expectancy Before Major Rehabilitation (years)
1	$5,000	$6,000	$3,000	$8,300	$8,300	$0.55	$366,000	25
5	$22,500	$9,000	$5,500	$28,350	$5,670	$1.89	$1,467,000	25
10	$40,000	$11,500	$7,500	$47,900	$4,790	$3.19	$2,658,000	25
1	$5,000	$6,000	$3,000	$8,300	$8,300	$0.55	$316,000	35
5	$22,500	$9,000	$5,500	$28,350	$5,670	$1.89	$1,242,000	35
10	$40,000	$11,500	$7,500	$47,900	$4,790	$3.19	$2,233,000	35
1	$5,000	$6,000	$3,000	$8,300	$8,300	$0.55	$341,000	35
5	$22,500	$9,000	$5,500	$28,350	$5,670	$1.89	$1,354,500	35
10	$40,000	$11,500	$7,500	$47,900	$4,790	$3.19	$2,445,500	35

Notes:

1. Assumed 330 gpd wastewater/household. Inflow (Ci) and outflow (Ce) scenarios above would predict 35-55 homes/acre (11,600 to 18,200 gpd/acre, average approx 15,000 gpd/acre) of SF Treatment Wetlands for Nitrogen removal only. Does not include area for pre-treatment/solids removal.

2. Variation in operable lifespan a function of different loading scenarios. Higher initial loading

3. Permitting cost variation a function of variation in effluent concentration. Lower Target N = Lower costs to permit.

4. Land acquistion costs not summarized above.

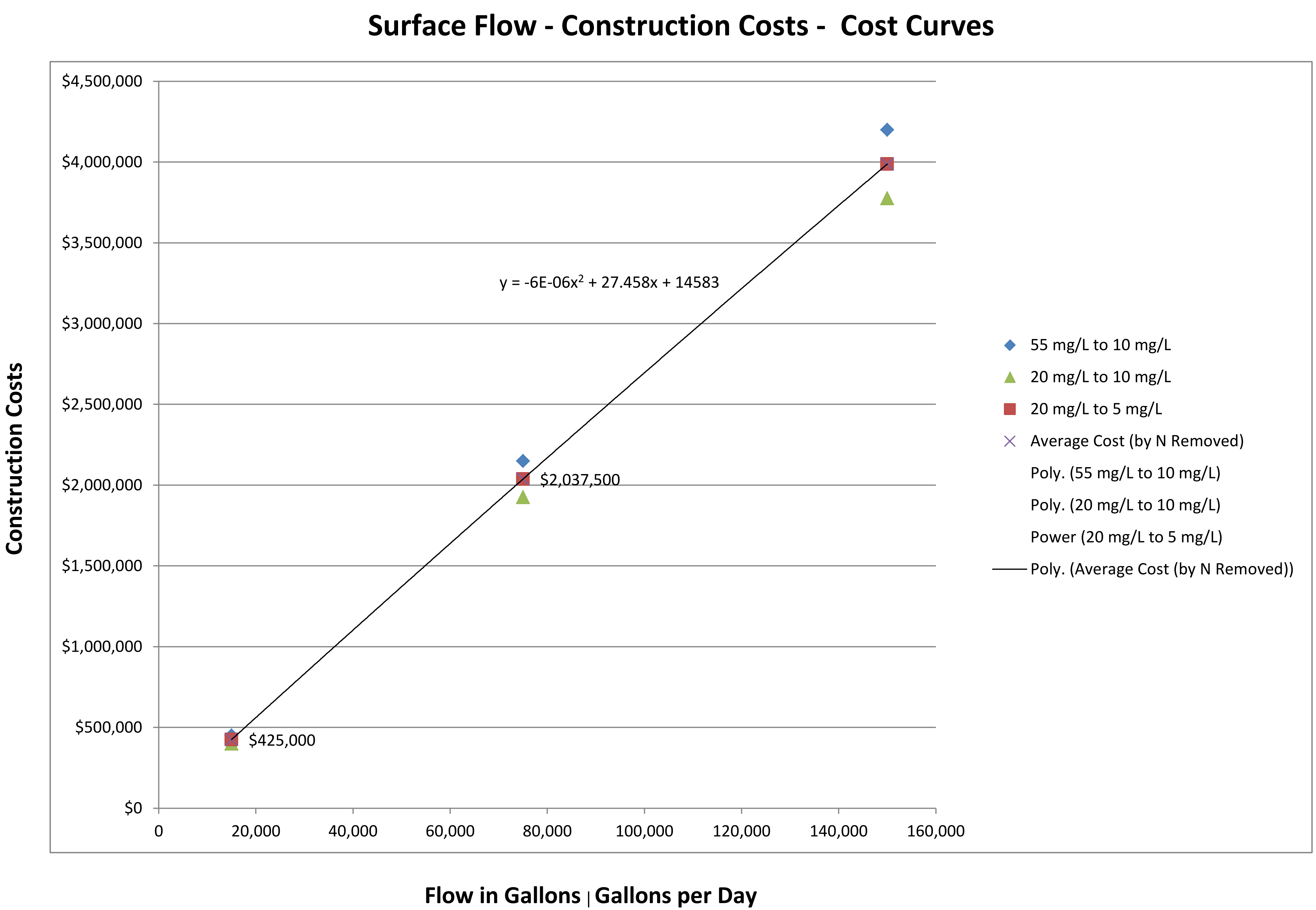
5. Synthetic liner assumed in construction costs for all scenarios

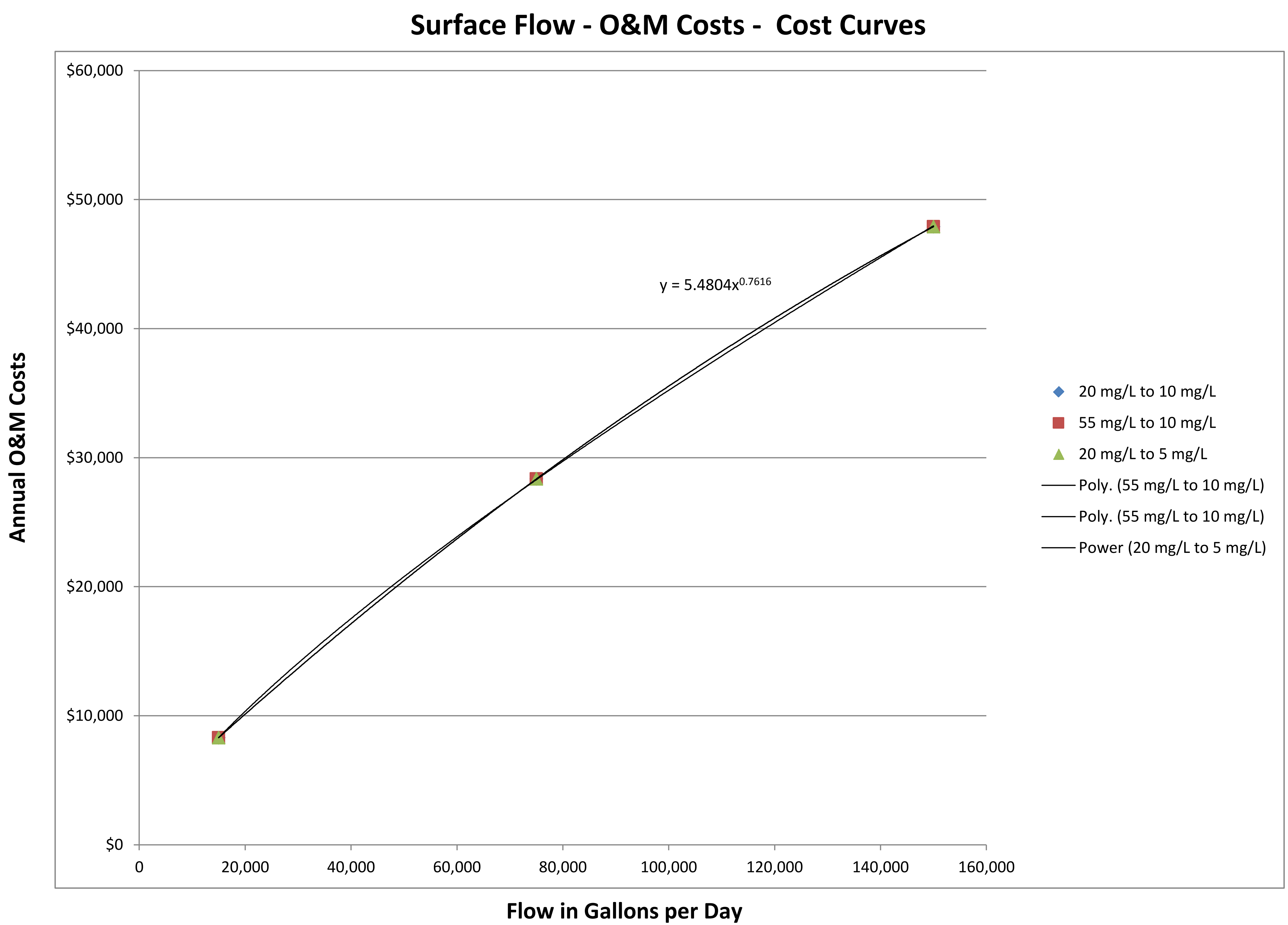
6. Assumed construction duration: 1 acre system: 1 month, 5 acre = 3 months, 10 acre = 5 months

7. Annual monitoring costs (short-term and long-term are annual cost estimates). Need to multiply by duration.

8. Annual compliance costs include lab analytical, sampling and minor maintenance activities.

9. Cost of land per acre: $ 250,000


Surface Flow - Construction Costs - Cost Curves
Construction Costs
$4,500,000
$4,000,000
$3,500,000
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
y = -6E-06x2 + 27.458x + 14583
$2,037,500
$425,000
55 mg/L to 10 mg/L
20 mg/L to 10 mg/L
20 mg/L to 5 mg/L
Average Cost (by N Removed)
Poly. (55 mg/L to 10 mg/L)
Poly. (20 mg/L to 10 mg/L)
Power (20 mg/L to 5 mg/L)
Poly. (Average Cost (by N Removed))
Flow in Gallons | Gallons per Day


Surface Flow - O&M Costs - Cost Curves
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
y = 5.4804x^0.7616
Annual O&M Costs
Flow in Gallons per Day
20 mg/L to 10 mg/L
55 mg/L to 10 mg/L
20 mg/L to 5 mg/L
Poly. (55 mg/L to 10 mg/L)
Poly. (55 mg/L to 10 mg/L)
Power (20 mg/L to 5 mg/L)

Constructed Wetlands - Surface Flow Optimized for Nitrogen Removal : Planning Level Itemized Cost Estimate in 2014 Dollars

Constructed Wetland								Estimated Design and Construction Costs					
Constructed Wetland Acreage	Inflow Treatment Level	Estimated Inflow Concentration (N mg/L)	Inflow Treatment Level	Desired Treatment Level (N mg/L)	Flow per Acre (GPD/acre)	Total Flow (GPD)	Nitrogen Removed (kg/yr/acre)	Engineering (Design, etc.)	Engineering (Permitting)	Engineering (Construction Oversite)	Construction	Construction Costs (Engineering and Construction)	Project Costs Per Acre ($/acre)
1	Primary	55	Secondary	10	16,500	16,500	1,027	$37,500	$15,000	$20,000	$225,000	$297,500	$297,500
5	Primary	55	Secondary	10	16,500	82,500	1,027	$80,000	$20,000	$50,000	$1,012,500	$1,162,500	$232,500
10	Primary	55	Secondary	10	16,500	165,000	1,027	$135,000	$25,000	$100,000	$1,912,500	$2,172,500	$217,250
1	Secondary	20	Secondary	10	16,500	16,500	228	$37,500	$15,000	$20,000	$175,000	$247,500	$247,500
5	Secondary	20	Secondary	10	16,500	82,500	228	$80,000	$20,000	$50,000	$787,500	$937,500	$187,500
10	Secondary	20	Secondary	10	16,500	165,000	228	$135,000	$25,000	$100,000	$1,487,500	$1,747,500	$174,750
1	Secondary	20	Advanced	5	16,500	16,500	342	$37,500	$15,000	$20,000	$200,000	$272,500	$272,500
5	Secondary	20	Advanced	5	16,500	82,500	342	$80,000	$20,000	$50,000	$900,000	$1,050,000	$210,000
10	Secondary	20	Advanced	5	16,500	165,000	342	$135,000	$25,000	$100,000	$1,700,000	$1,960,000	$196,000
						Average	533						$226,166.67

Constructed Wetland Acreage	Adjusted Design and Construction Costs						
	Land Cost [9]	Construction Costs	Construction and Land Costs	Average Construction and Land Costs per Acre		Construction and Land Costs Per Acre ($/acre)	Flow Based Construction Cost ($/GPD)
1	$250,000	$225,000	$475,000	$450,000	55 mg/L to 10 mg/L	$475,000	$28.79
5	$1,250,000	$1,012,500	$2,262,500	$2,150,000	20 mg/L to 10 mg/L	$452,500	$27.42
10	$2,500,000	$1,912,500	$4,412,500	$4,200,000	20 mg/L to 5 mg/L	$441,250	$26.74
1	$250,000	$175,000	$425,000			$425,000	$25.76
5	$1,250,000	$787,500	$2,037,500			$407,500	$24.70
10	$2,500,000	$1,487,500	$3,987,500			$398,750	$24.17
1	$250,000	$200,000	$450,000			$450,000	$27.27
5	$1,250,000	$900,000	$2,150,000			$430,000	$26.06
10	$2,500,000	$1,700,000	$4,200,000			$420,000	$25.45
	Average					$433,333.33	Average

Constructed Wetland Acreage	Estimated Annual O&M Costs							
	O&M Costs	Annual Performance Monitoring (Short-term - Two Years)	Annual Complience Monitoring (Long-term)	O&M Cost ($/yr)	O&M Cost Per Acre ($/acre)	Flow Based O&M Cost ($/GPD)	Total Costs 20 years no inflation or Financing	Life Expectancy Before Major Rehabilitation (years)
1	$5,000	$6,000	$3,000	$8,300	$8,300	$0.50	$391,000	20
5	$22,500	$9,000	$5,500	$28,350	$5,670	$1.72	$1,579,500	20
10	$40,000	$15,000	$9,000	$49,600	$4,960	$3.01	$2,904,500	20
1	$5,000	$6,000	$3,000	$8,300	$8,300	$0.50	$341,000	25
5	$22,500	$9,000	$5,500	$28,350	$5,670	$1.72	$1,354,500	25
10	$40,000	$15,000	$9,000	$49,600	$4,960	$3.01	$2,479,500	25
1	$5,000	$7,500	$3,500	$8,900	$8,900	$0.54	$378,000	20
5	$22,500	$10,500	$6,000	$28,950	$5,790	$1.75	$1,479,000	20
10	$40,000	$15,000	$9,500	$50,050	$5,005	$3.03	$2,701,000	20

Notes:

$0

-

1. Assumed 330 gpd wastewater/household. Inflow (Ci) and outflow (Ce) scenarios above would predict 40-60 homes/acre (13,200 to 19,800 GPD/acre, average of HSSF Treatment Wetlands for Nitrogen removal only. Does not include area for pre-treatment/solids removal.

2. Variation in operable lifespan a function of different loading scenarios. Higher initial loading

3. Permitting cost variation a function of variation in effluent concentration. Lower Target N = Lower costs to permit.

4. Land acquistion costs not summarized above.

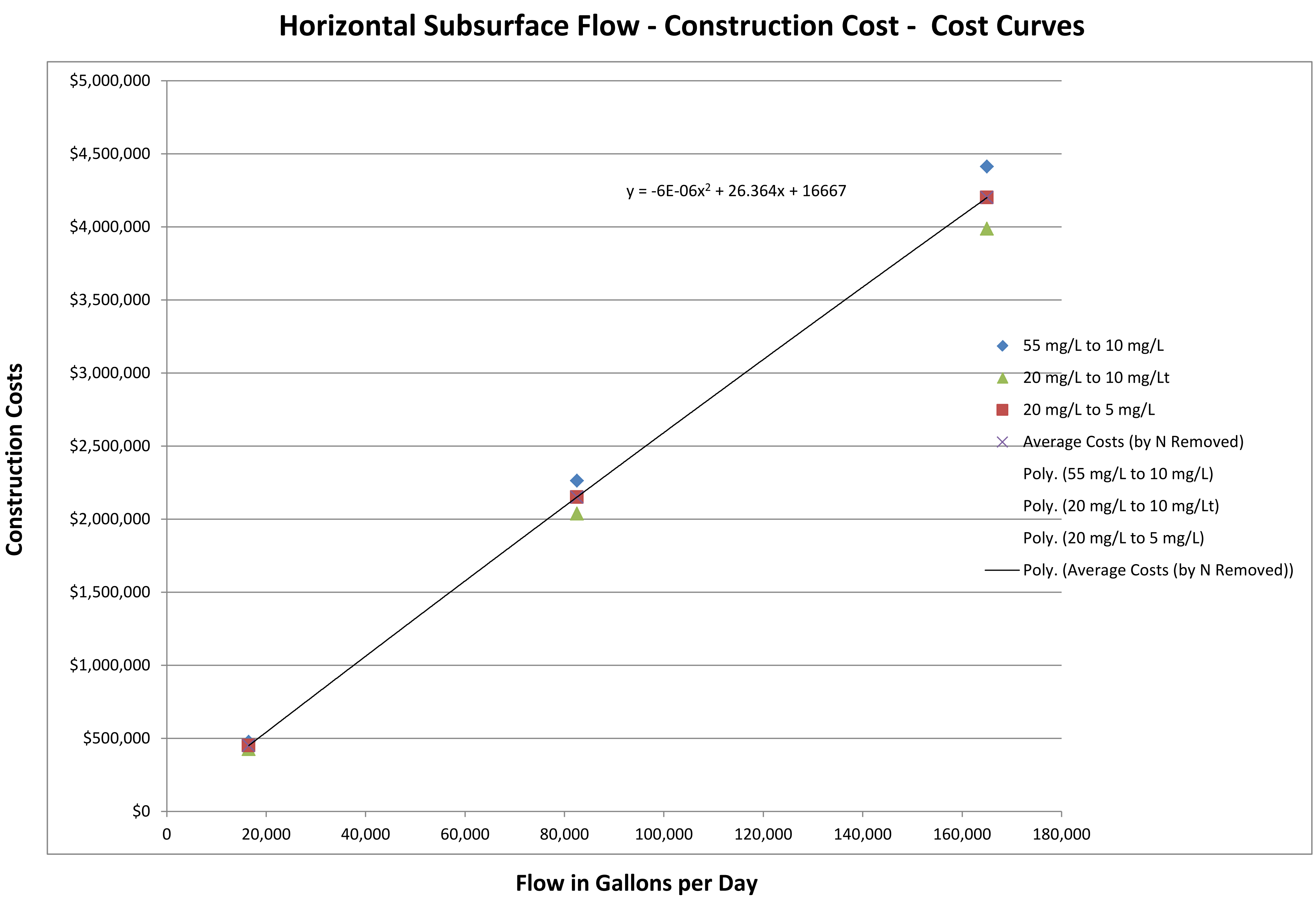
5. Synthetic liner assumed in construction costs for all scenarios

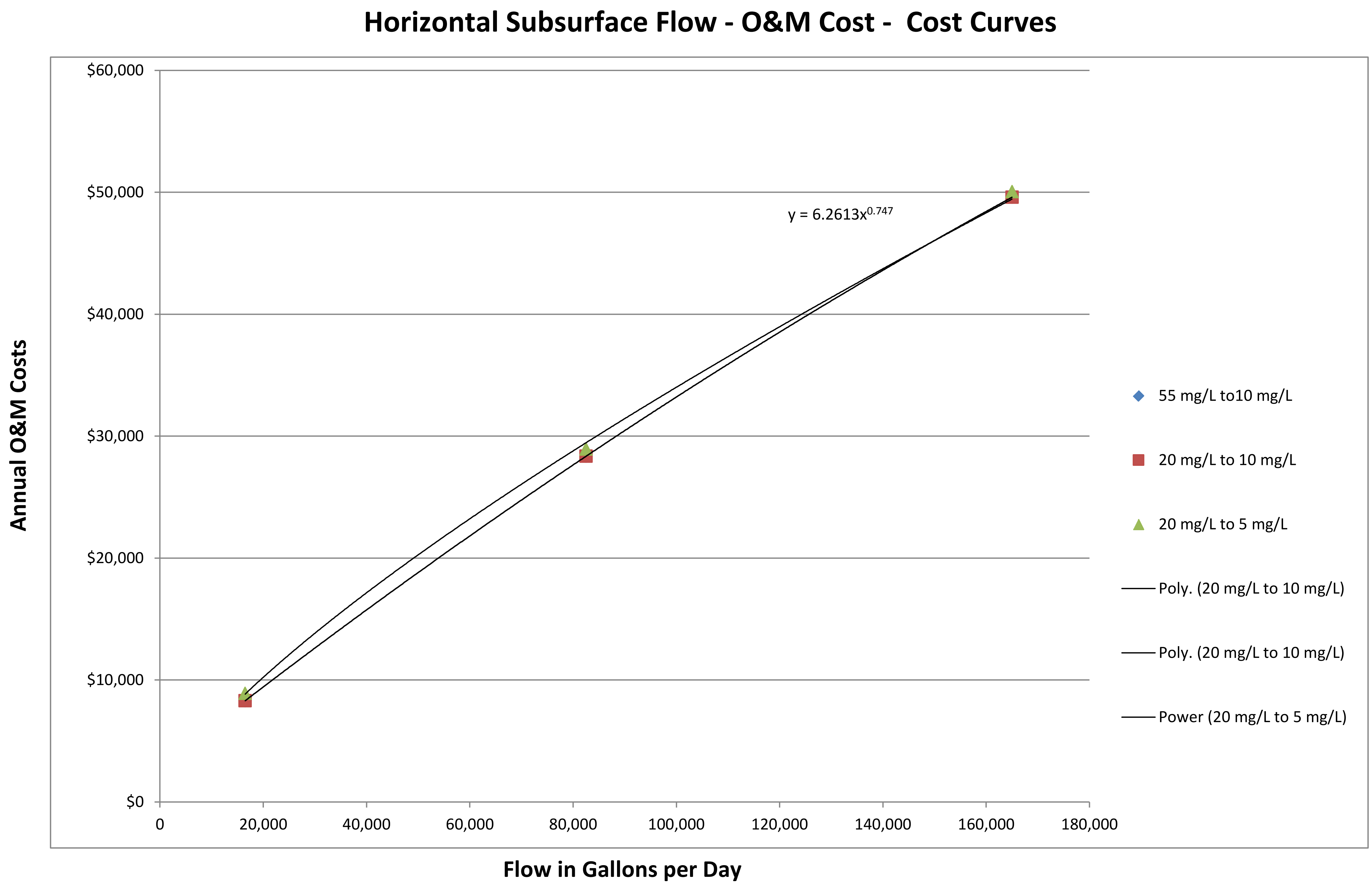
6. Assumed construction duration: 1 acre system: 1.25 month, 5 acre = 3.5 months, 10 acre = 6 months

7. Annual monitoring costs (short-term and long-term are annual cost estimates). Need to multiply by duration.

8. Annual compliance costs include lab analytical, sampling and minor maintenance activities.

9. Cost of land per acre: $ 250,000


Horizontal Subsurface Flow - Construction Cost - Cost Curves
Construction Costs
$5,000,000
$4,500,000
$4,000,000
$3,500,000
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
Flow in Gallons per Day
y = -6E-06x² + 26.364x + 16667
55 mg/L to 10 mg/L
20 mg/L to 10 mg/Lt
20 mg/L to 5 mg/L
Average Costs (by N Removed)
Poly. (55 mg/L to 10 mg/L)
Poly. (20 mg/L to 10 mg/Lt)
Poly. (20 mg/L to 5 mg/L)
Poly. (Average Costs (by N Removed))


Horizontal Subsurface Flow - O&M Cost - Cost Curves
Annual O&M Costs
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
Flow in Gallons per Day
y = 6.2613x^0.747
55 mg/L to10 mg/L
20 mg/L to 10 mg/L
20 mg/L to 5 mg/L
Poly. (20 mg/L to 10 mg/L)
Poly. (20 mg/L to 10 mg/L)
Power (20 mg/L to 5 mg/L)

Appendix F

Construction and O&M Cost Estimates for Permeable Reactive Barriers

PRB - Injection Well Design Information and Project Costs

(yellow) = calculated value

Site Information/Data from "Technical Memorandum No. 5b: Preliminary Design for the Three Potential Sites Selected for the Permeable Reactive Barrier (PRB) Demonstration Project Final" by CDMSmith dated January 14, 2014

		Units	Site 1	Site 4b	Site 5 (shallow)	Site 5 (deep)	Remarks
PRB length (lf)			590	525	350	350	*Table 2*
Septic conc.	35	ppm-N					
# Homes			41	46	73	73	*Table 5*
WW Flow	135	gpd/home	5523	6197	9834	9834	*gpd, compare w/ Table 3 & 4*
WW N Load	14.36	lbs/yr/home	589	660	1048	1048	*lbs/yr*
Fertilizer	1.08	lbs/yr/lawn	44	50	79	79	*lbs/yr*
N load (groundwater)		lbs/yr	633	710	1127	1127	*lbs/yr ppm-N*
N load (groundwater)		lbs/yr	363	418	1967	2808	*lbs/yr, Table 5*
N load removed		lbs/yr	290	334	1574	2246	*lbs/yr, Table 5* 80% *efficiency*
		lbs/yr/home	7.07	7.26	21.6	30.8	*lbs/yr/home*
		lbs/yr/lf	0.49	0.64	4.5	6.4	*lbs/yr/lf, Table 5*
		kg-N/yr/lf	0.22	0.29	2.04	2.91	
	26.25	ppm-N					
		lbs/yr	218	251	1181	1685	
		kg-N/yr/lf	0.17	0.22	1.53	2.18	
Cost (thousands $)							
Injection Wells							
		Construction	673	607	395	1065	*Table 6*
		Design	0	0	0	0	*Table 8, assumes low end*
		Permitting	0	0	0	0	*design cost*
		Total (Capital)	673	607	395	1065	
Performance Monitoring (1 yr)			159	159	159	180	*Table 7, Sec. 4.6 indicates that the demo period will occur over 1 year*
l Capital Cost, plus 1 yr performance monitoring)			832	766	554	1245	*Table 8*
		$/lf (thousands)	1.41	1.46	1.58	3.56	*Table 10*
Rejuvenation (thousands $)							
		Cost	234	211	143	367	*Table 9*

1,484 Average Construction Cost (Linear foot) for Injection Well PRB (Based on Sites 1, 4b and 5 Shallow)

PRB - Injection Well Design Information and Project Costs

[yellow] = calculated value

Site Information/Data from "Technical Memorandum No. 5b: Preliminary Design for the Three Potential Sites Selected for the Permeable Reactive Barrier (PRB) Demonstration Project Final" by CDMSmith dated January 14, 2014

Units	Site 1	Site 4b	Site 5 (shallow)	Site 5 (deep)	Remarks

Tech.	Rate		
Injection Wells	6.67	times over 20 years	3 yr term
Other	2	times over 20 years	10 yr term

5%	annual rate
20	yr term
12.46	EAC factor (used by BCCR)

16%	3-yr interest
6.67	3-yr term
3.95	EAC factor

3,205	Average O&M Cost for Injection Well PRB (Sites 1, 4b and 5 Shallow)

Units	Site 1	Site 4b	Site 5 (shallow)	Site 5 (deep)	Remarks
20-yr rejuvination cost (thousands $)					
Injection Wells	925	834	565	1451	<-- applied to
Regulatory Monitoring / yr (thousands)	55	55	55	55	*Table 7*
O&M Costs/lf./yr (thousands)	2.84	3.02	3.76	6.33	
Total 20-yr cost ($)	2,442,330	2,285,408	1,804,596	3,381,095	
$/lf	4,140	4,353	5,156	9,660	
$/home	59,569	49,683	24,720	46,316	
lf/home	14	11	5	5	
$/lb-N removed	421	342	57	75	
$/kg-N removed	929	754	126	166	
$/kg-N removed base conc 35 ppm-N	1278	1044	179	223	BCCR method (for direct comparison w/ MVP using 26.25 ppm-N)
$/kg-N removed base conc 26.25 ppm-N	1703	1392	239	298	

PRB - Injection Well Design Information and Project Costs

= calculated value

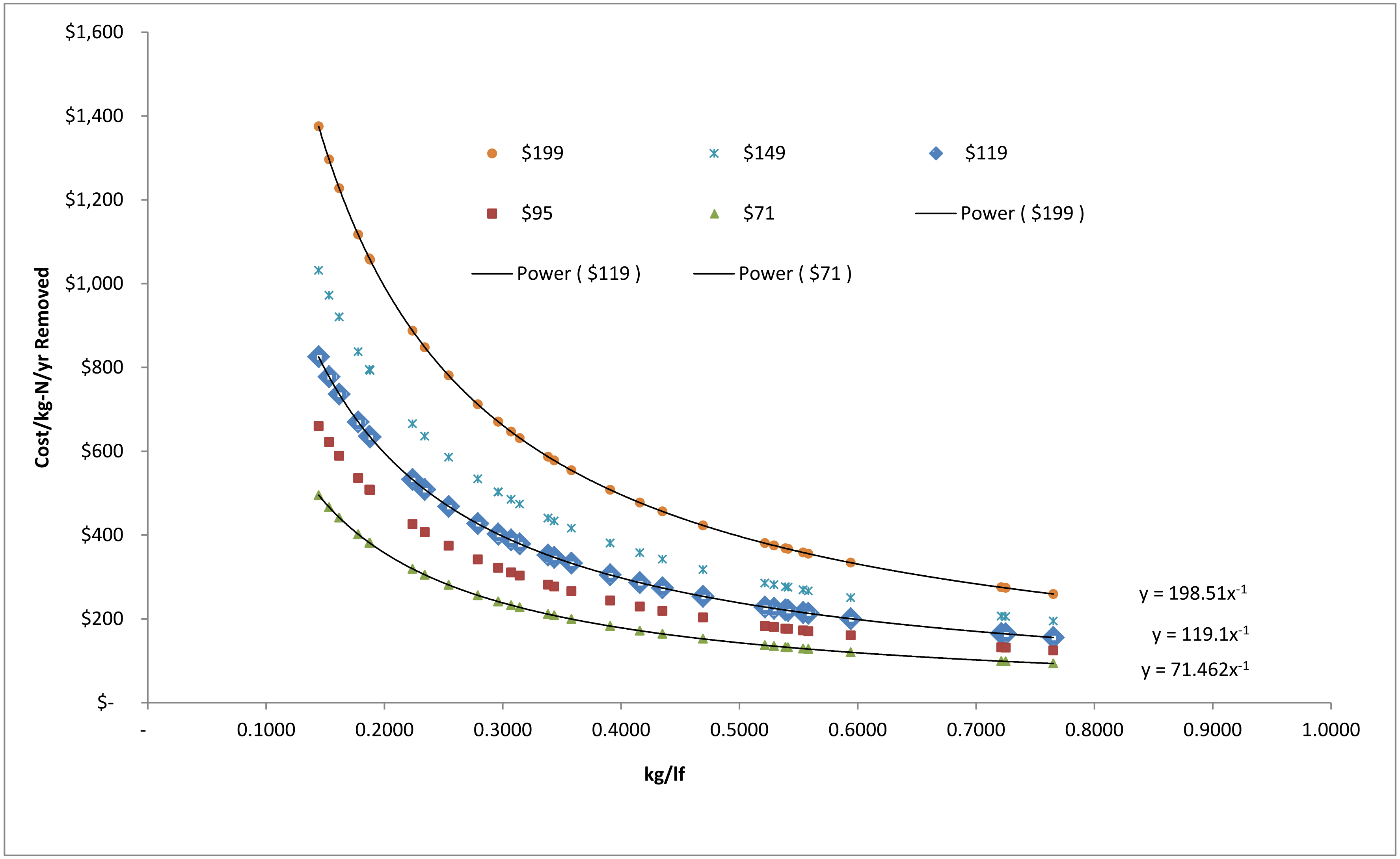
Site Information/Data from "Technical Memorandum No. 5b: Preliminary Design for the Three Potential Sites Selected for the Permeable Reactive Barrier (PRB) Demonstration Project Final" by CDMSmith dated January 14, 2014

	Units	Site 1	Site 4b	Site 5 (shallow)	Site 5 (deep)	Remarks

PRB Assessment - Injection Well Constuction Costs

Location	Parcels	Length	Removed Kg/Yr	Feet/Kg	Kg/Ft	$ 2,473 /lf/20 yr	$ 1,855 /lf/20 yr	$ 1,484 /lf/20 yr	$ 1,187 /lf/20 yr	$ 890 /lf/20 yr	$ 199 $/kg/yr/12.4	$ 149 $/kg/yr/12.4	$ 119 $/kg/yr/12.4	$ 95 $/kg/yr/12.4	$ 71 $/kg/yr/12.4	Ratio kg/lf
Herring River	98	1,600	503	3.18	0.31	$ 3,957,399	$ 2,968,050	$ 2,374,440	$ 1,899,552	$ 1,424,664	$ 631	$ 474	$ 379	$ 303	$ 227	0.3144
	224	1,500	1,148	1.31	0.77	$ 3,710,062	$ 2,782,546	$ 2,226,037	$ 1,780,830	$ 1,335,622	$ 259	$ 195	$ 156	$ 124	$ 93	0.7653
Bass River																
Grandview Drive	57	800	348	2.30	0.44	$ 1,978,700	$ 1,484,025	$ 1,187,220	$ 949,776	$ 712,332	$ 456	$ 342	$ 274	$ 219	$ 164	0.4350
Farm Lane	27	1,100	159	6.93	0.14	$ 2,720,712	$ 2,040,534	$ 1,632,427	$ 1,305,942	$ 979,456	$ 1,375	$ 1,031	$ 825	$ 660	$ 495	0.1443
Bellvue/Charles	131	1,100	516	2.13	0.47	$ 2,720,712	$ 2,040,534	$ 1,632,427	$ 1,305,942	$ 979,456	$ 423	$ 317	$ 254	$ 203	$ 152	0.4693
Blue Rock Road	169	2,600	879	2.96	0.34	$ 6,430,774	$ 4,823,080	$ 3,858,464	$ 3,086,771	$ 2,315,079	$ 587	$ 440	$ 352	$ 282	$ 211	0.3382
High Bank Road	214	1,900	1,129	1.68	0.59	$ 4,699,412	$ 3,524,559	$ 2,819,647	$ 2,255,718	$ 1,691,788	$ 334	$ 251	$ 200	$ 160	$ 120	0.5941
Vinland Drive	393	3,200	1,251	2.56	0.39	$ 7,914,799	$ 5,936,099	$ 4,748,879	$ 3,799,103	$ 2,849,328	$ 508	$ 381	$ 305	$ 244	$ 183	0.3908
Mayfair	903	5,200	2,802	1.86	0.54	$ 12,861,548	$ 9,646,161	$ 7,716,929	$ 6,173,543	$ 4,630,157	$ 368	$ 276	$ 221	$ 177	$ 133	0.5389
Eileen Street	62	1,600	245	6.53	0.15	$ 3,957,399	$ 2,968,050	$ 2,374,440	$ 1,899,552	$ 1,424,664	$ 1,296	$ 972	$ 778	$ 622	$ 467	0.1532
Centerville River																
S. Main Street	403	4,800	1,997	2.40	0.42	$ 11,872,198	$ 8,904,149	$ 7,123,319	$ 5,698,655	$ 4,273,991	$ 477	$ 358	$ 286	$ 229	$ 172	0.4160
Katherine Road	77	800	286	2.79	0.36	$ 1,978,700	$ 1,484,025	$ 1,187,220	$ 949,776	$ 712,332	$ 555	$ 416	$ 333	$ 266	$ 200	0.3580
Elliot Road	55	800	275	2.91	0.34	$ 1,978,700	$ 1,484,025	$ 1,187,220	$ 949,776	$ 712,332	$ 578	$ 433	$ 347	$ 277	$ 208	0.3435
Lewis Bay																
Gleason Ave	133	2,100	1,111	1.89	0.53	$ 5,194,087	$ 3,895,565	$ 3,116,452	$ 2,493,162	$ 1,869,871	$ 375	$ 281	$ 225	$ 180	$ 135	0.5293
Rte 28	60	1,700	887	1.92	0.52	$ 4,204,737	$ 3,153,553	$ 2,522,842	$ 2,018,274	$ 1,513,705	$ 381	$ 285	$ 228	$ 183	$ 137	0.5216
Standish	149	1,500	418	3.59	0.28	$ 3,710,062	$ 2,782,546	$ 2,226,037	$ 1,780,830	$ 1,335,622	$ 712	$ 534	$ 427	$ 342	$ 256	0.2789
Broadway/LewisBlvd	970	5,500	3,967	1.39	0.72	$ 13,603,560	$ 10,202,670	$ 8,162,136	$ 6,529,709	$ 4,897,282	$ 275	$ 206	$ 165	$ 132	$ 99	0.7213
Park Ave	74	1,800	337	5.34	0.19	$ 4,452,074	$ 3,339,056	$ 2,671,245	$ 2,136,996	$ 1,602,747	$ 1,060	$ 795	$ 636	$ 509	$ 382	0.1873
Poppy																
Santuit River LT 10	201	2,000	592	3.38	0.30	$ 4,946,749	$ 3,710,062	$ 2,968,050	$ 2,374,440	$ 1,780,830	$ 670	$ 503	$ 402	$ 322	$ 241	0.2962
Shoe String	219	2,800	626	4.47	0.22	$ 6,925,449	$ 5,194,087	$ 4,155,269	$ 3,324,215	$ 2,493,162	$ 887	$ 665	$ 532	$ 426	$ 319	0.2237
Removed **Mashpee River Lwer LT10**	39	1,700	2,050	0.83	1.21	$ 4,204,737	$ 3,153,553	$ 2,522,842	$ 2,018,274	$ 1,513,705						
Swan Pond																
Swan Pond River South - East	505	4,400	827	5.32	0.19	$ 10,882,848	$ 8,162,136	$ 6,529,709	$ 5,223,767	$ 3,917,825	$ 1,057	$ 793	$ 634	$ 507	$ 380	0.1878
Swan Pond River South - West	570	5,000	1,481	3.38	0.30	$ 12,366,873	$ 9,275,155	$ 7,420,124	$ 5,936,099	$ 4,452,074	$ 670	$ 503	$ 402	$ 322	$ 241	0.2962
Swan Pond River North - SE	124	1,000	554	1.81	0.55	$ 2,473,375	$ 1,855,031	$ 1,484,025	$ 1,187,220	$ 890,415	$ 358	$ 269	$ 215	$ 172	$ 129	0.5539
Swan Pond River North - SW	15	1,350	240	5.63	0.18	$ 3,339,056	$ 2,504,292	$ 2,003,433	$ 1,602,747	$ 1,202,060	$ 1,117	$ 838	$ 670	$ 536	$ 402	0.1778
Swan Pond River North SW PRB into GT 10	27		175	-							$ -	$ -	$ -	$ -	$ -	
Nauset																
Town Cove West	220	3,650	928	3.93	0.25	$ 9,027,817	$ 6,770,863	$ 5,416,690	$ 4,333,352	$ 3,250,014	$ 781	$ 586	$ 468	$ 375	$ 281	0.2542
Town Cove East and South	657	8,525	1,996	4.27	0.23	$ 21,085,518	$ 15,814,139	$ 12,651,311	$ 10,121,049	$ 7,590,787	$ 848	$ 636	$ 509	$ 407	$ 305	0.2341
Salt Pond	197	4,500	728	6.18	0.16	$ 11,130,186	$ 8,347,639	$ 6,678,111	$ 5,342,489	$ 4,006,867	$ 1,227	$ 920	$ 736	$ 589	$ 442	0.1618
Poppy																
Red Brook	255	2,700	829	3.26	0.31	$ 6,678,111	$ 5,008,584	$ 4,006,867	$ 3,205,493	$ 2,404,120	$ 647	$ 485	$ 388	$ 310	$ 233	0.3070
Quashnet	257	2,500	1,396	1.79	0.56	$ 6,183,436	$ 4,637,577	$ 3,710,062	$ 2,968,050	$ 2,226,037	$ 355	$ 267	$ 213	$ 171	$ 128	0.5584
Childs River N LT10	604	3,700	2,002	1.85	0.54	$ 9,151,486	$ 6,863,614	$ 5,490,892	$ 4,392,713	$ 3,294,535	$ 367	$ 275	$ 220	$ 176	$ 132	0.5411
Childs River S	269	1,426	1,034	1.38	0.73	$ 3,527,032	$ 2,645,274	$ 2,116,219	$ 1,692,975	$ 1,269,732	$ 274	$ 205	$ 164	$ 131	$ 99	0.7251
Three Bay																
	240		766					$ -								
													average			average
			average	3.06	0.41			$ 125,920,984					$ 373			0.3876
			median	3.06	0.42											

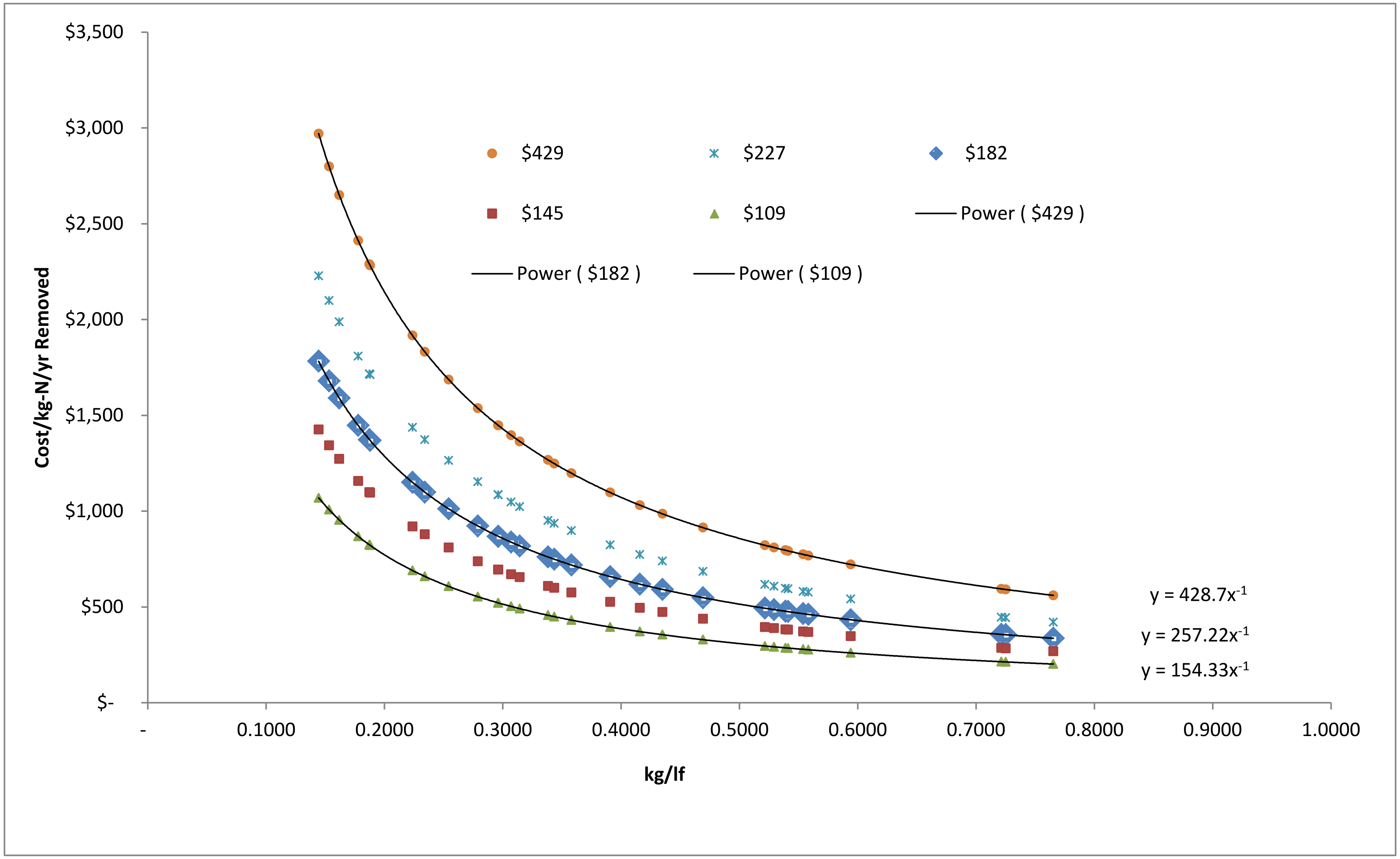
PRB - Injection Well Construction Cost Curve ($/kg/yr)



PRB - Injection Well O&M Costs

Location	Parcels	Length	Removed Kg/Yr	Feet/Kg	Kg/Ft	$ 5,342 /lf/20 yr	$ 4,006 /lf/20 yr	$ 3,205 /lf/20 yr	$ 2,564 /lf/20 yr	$ 1,923 /lf/20 yr	$ 429 $/kg/yr/12.4	$ 322 $/kg/yr/12.4	$ 257 $/kg/yr/12.4	$ 206 $/kg/yr/12.4	$ 154 $/kg/yr/12.4	Ratio kg/lf
Herring River	98	1,600	503	3.18	0.31	$ 8,546,637	$ 6,409,977	$ 5,127,982	$ 4,102,386	$ 3,076,789	$ 1,364	$ 1,023	$ 818	$ 655	$ 491	0.3144
	224	1,500	1,148	1.31	0.77	$ 8,012,472	$ 6,009,354	$ 4,807,483	$ 3,845,986	$ 2,884,490	$ 560	$ 420	$ 336	$ 269	$ 202	0.7653
Bass River																
Grandview Drive	57	800	348	2.30	0.44	$ 4,273,318	$ 3,204,989	$ 2,563,991	$ 2,051,193	$ 1,538,395	$ 986	$ 739	$ 591	$ 473	$ 355	0.4350
Farm Lane	27	1,100	159	6.93	0.14	$ 5,875,813	$ 4,406,859	$ 3,525,488	$ 2,820,390	$ 2,115,293	$ 2,970	$ 2,228	$ 1,782	$ 1,426	$ 1,069	0.1443
Bellvue/Charles	131	1,100	516	2.13	0.47	$ 5,875,813	$ 4,406,859	$ 3,525,488	$ 2,820,390	$ 2,115,293	$ 914	$ 685	$ 548	$ 439	$ 329	0.4693
Blue Rock Road	169	2,600	879	2.96	0.34	$ 13,888,284	$ 10,416,213	$ 8,332,971	$ 6,666,376	$ 4,999,782	$ 1,267	$ 951	$ 760	$ 608	$ 456	0.3382
High Bank Road	214	1,900	1,129	1.68	0.59	$ 10,149,131	$ 7,611,848	$ 6,089,479	$ 4,871,583	$ 3,653,687	$ 722	$ 541	$ 433	$ 346	$ 260	0.5941
Vinland Drive	393	3,200	1,251	2.56	0.39	$ 17,093,273	$ 12,819,955	$ 10,255,964	$ 8,204,771	$ 6,153,578	$ 1,097	$ 823	$ 658	$ 527	$ 395	0.3908
Mayfair	903	5,200	2,802	1.86	0.54	$ 27,776,569	$ 20,832,427	$ 16,665,941	$ 13,332,753	$ 9,999,565	$ 796	$ 597	$ 477	$ 382	$ 286	0.5389
Eileen Street	62	1,600	245	6.53	0.15	$ 8,546,637	$ 6,409,977	$ 5,127,982	$ 4,102,386	$ 3,076,789	$ 2,799	$ 2,099	$ 1,679	$ 1,344	$ 1,008	0.1532
Centerville River																
S. Main Street	403	4,800	1,997	2.40	0.42	$ 25,639,910	$ 19,229,932	$ 15,383,946	$ 12,307,157	$ 9,230,367	$ 1,031	$ 773	$ 618	$ 495	$ 371	0.4160
Katherine Road	77	800	286	2.79	0.36	$ 4,273,318	$ 3,204,989	$ 2,563,991	$ 2,051,193	$ 1,538,395	$ 1,198	$ 898	$ 719	$ 575	$ 431	0.3580
Elliot Road	55	800	275	2.91	0.34	$ 4,273,318	$ 3,204,989	$ 2,563,991	$ 2,051,193	$ 1,538,395	$ 1,248	$ 936	$ 749	$ 599	$ 449	0.3435
Lewis Bay																
Gleason Ave	133	2,100	1,111	1.89	0.53	$ 11,217,460	$ 8,413,095	$ 6,730,476	$ 5,384,381	$ 4,038,286	$ 810	$ 608	$ 486	$ 389	$ 292	0.5293
Rte 28	60	1,700	887	1.92	0.52	$ 9,080,801	$ 6,810,601	$ 5,448,481	$ 4,358,785	$ 3,269,088	$ 822	$ 616	$ 493	$ 395	$ 296	0.5216
Standish	149	1,500	418	3.59	0.28	$ 8,012,472	$ 6,009,354	$ 4,807,483	$ 3,845,986	$ 2,884,490	$ 1,537	$ 1,153	$ 922	$ 738	$ 553	0.2789
Broadway/LewisBlvd	970	5,500	3,967	1.39	0.72	$ 29,379,063	$ 22,034,297	$ 17,627,438	$ 14,101,950	$ 10,576,463	$ 594	$ 446	$ 357	$ 285	$ 214	0.7213
Park Ave	74	1,800	337	5.34	0.19	$ 9,614,966	$ 7,211,225	$ 5,768,980	$ 4,615,184	$ 3,461,388	$ 2,289	$ 1,717	$ 1,373	$ 1,099	$ 824	0.1873
Poppy																
Santuit River LT 10	201	2,000	592	3.38	0.30	$ 10,683,296	$ 8,012,472	$ 6,409,977	$ 5,127,982	$ 3,845,986	$ 1,448	$ 1,086	$ 869	$ 695	$ 521	0.2962
Shoe String	219	2,800	626	4.47	0.22	$ 14,956,614	$ 11,217,460	$ 8,973,968	$ 7,179,175	$ 5,384,381	$ 1,916	$ 1,437	$ 1,150	$ 920	$ 690	0.2237
Removed Mashpee River Lwer LT10	39	1,700	2,050	0.83	1.21	$ 9,080,801	$ 6,810,601	$ 5,448,481	$ 4,358,785	$ 3,269,088						
Swan Pond																
Swan Pond River South - East	505	4,400	827	5.32	0.19	$ 23,503,250	$ 17,627,438	$ 14,101,950	$ 11,281,560	$ 8,461,170	$ 2,282	$ 1,712	$ 1,369	$ 1,095	$ 822	0.1878
Swan Pond River South - West	570	5,000	1,481	3.38	0.30	$ 26,708,239	$ 20,031,179	$ 16,024,943	$ 12,819,955	$ 9,614,966	$ 1,447	$ 1,085	$ 868	$ 695	$ 521	0.2962
Swan Pond River North - SE	124	1,000	554	1.81	0.55	$ 5,341,648	$ 4,006,236	$ 3,204,989	$ 2,563,991	$ 1,922,993	$ 774	$ 580	$ 464	$ 372	$ 279	0.5539
Swan Pond River North - SW	15	1,350	240	5.63	0.18	$ 7,211,225	$ 5,408,418	$ 4,326,735	$ 3,461,388	$ 2,596,041	$ 2,412	$ 1,809	$ 1,447	$ 1,158	$ 868	0.1778
Swan Pond River North SW PRB into GT 10	27	-	175	-							$ -	$ -	$ -	$ -	$ -	
Nauset																
Town Cove West	220	3,650	928	3.93	0.25	$ 19,497,015	$ 14,622,761	$ 11,698,209	$ 9,358,567	$ 7,018,925	$ 1,686	$ 1,265	$ 1,012	$ 809	$ 607	0.2542
Town Cove East and South	657	8,525	1,996	4.27	0.23	$ 45,537,548	$ 34,153,161	$ 27,322,529	$ 21,858,023	$ 16,393,517	$ 1,831	$ 1,373	$ 1,099	$ 879	$ 659	0.2341
Salt Pond	197	4,500	728	6.18	0.16	$ 24,037,415	$ 18,028,061	$ 14,422,449	$ 11,537,959	$ 8,653,469	$ 2,650	$ 1,988	$ 1,590	$ 1,272	$ 954	0.1618
Poppy																
Red Brook	255	2,700	829	3.26	0.31	$ 14,422,449	$ 10,816,837	$ 8,653,469	$ 6,922,776	$ 5,192,082	$ 1,396	$ 1,047	$ 838	$ 670	$ 503	0.3070
Quashnet	257	2,500	1,396	1.79	0.56	$ 13,354,120	$ 10,015,590	$ 8,012,472	$ 6,409,977	$ 4,807,483	$ 768	$ 576	$ 461	$ 369	$ 276	0.5584
Childs River N LT10	604	3,700	2,002	1.85	0.54	$ 19,764,097	$ 14,823,073	$ 11,858,458	$ 9,486,767	$ 7,115,075	$ 792	$ 594	$ 475	$ 380	$ 285	0.5411
Childs River S	269	1,426	1,034	1.38	0.73	$ 7,617,190	$ 5,712,892	$ 4,570,314	$ 3,656,251	$ 2,742,188	$ 591	$ 443	$ 355	$ 284	$ 213	0.7251
Three Bay																
	240	-	766					$ -								
													average			average
			average	3.06	0.41			$ 271,946,496					$ 806			0.3876
			median	3.06	0.42											

PRB - Injection Well O&M Cost Curve ($/kg/yr)



PRB - Trench Design Information and Project Costs

= calculated value (yellow)

Site Information/Data from "Technical Memorandum No. 5b: Preliminary Design for the Three Potential Sites Selected for the Permeable Reactive Barrier (PRB) Demonstration Project Final" by CDMSmith dated January 14, 2014

		Units	Site 1	Site 4b	Site 5 (shallow)	Site 5 (deep)	Remarks
PRB length (lf)			590	525	350	350	*Table 2*
Septic conc.	35	ppm-N					
# Homes			41	46	73	73	*Table 5*
WW Flow	135	gpd/home	5523	6197	9834	9834	*gpd, compare w/ Table 3 & 4*
WW N Load	14.36	lbs/yr/home	589	660	1048	1048	*lbs/yr*
Fertilizer	1.08	lbs/yr/lawn	44	50	79	79	*lbs/yr*
N load (groundwater)		lbs/yr	633	710	1127	1127	*lbs/yr ppm-N*
N load (groundwater)		lbs/yr	363	418	1967	2808	*lbs/yr, Table 5*
N load removed		lbs/yr	290	334	1574	2246	*lbs/yr, Table 5 80% efficiency*
		lbs/yr/home	7.07	7.26	21.6	30.8	*lbs/yr/home*
		lbs/yr/lf	0.49	0.64	4.5	6.4	*lbs/yr/lf, Table 5*
		kg-N/yr/lf	0.22	0.29	2.04	2.91	
	26.25	ppm-N					
		lbs/yr	218	251	1181	1685	
		kg-N/yr/lf	0.17	0.22	1.53	2.18	
Cost (thousands $)							
Injection Wells							
		Construction	1324	1329	891	N/A	*Table 6*
		Design	0	0	0	N/A	*Table 8, design cost prorata*
		Permitting	0	0	0	N/A	*using construction cost*
		Total (Capital)	1324	1329	891	0	
Performance Monitoring (1 yr)			159	159	159	N/A	*Table 7, Sec. 4.6 indicates that the demo period will occur over 1 year*
l Capital Cost, plus 1 yr performance monitoring)			1483	1488	1050	N/A	*Table 8*
		$/lf (thousands)	2.51	2.83	3.00	N/A	*Table 10*
Rejuvenation (thousands $)							
		Cost	234	211	143	N/A	*Table 9*

2,783 Average Construction Cost (Linear foot) for Injection Well PRB (Based on Sites 1, 4b and 5 Shallow)

PRB - Trench Design Information and Project Costs

(yellow) = calculated value

Site Information/Data from "Technical Memorandum No. 5b: Preliminary Design for the Three Potential Sites Selected for the Permeable Reactive Barrier (PRB) Demonstration Project Final" by CDMSmith dated January 14, 2014

Tech.	Rate		
Injection Wells	6.67	times over 20 years	3 yr term
Other	2	times over 20 years	10 yr term

5%	annual rate
20	yr term
12.46	EAC factor (used by BCCR)

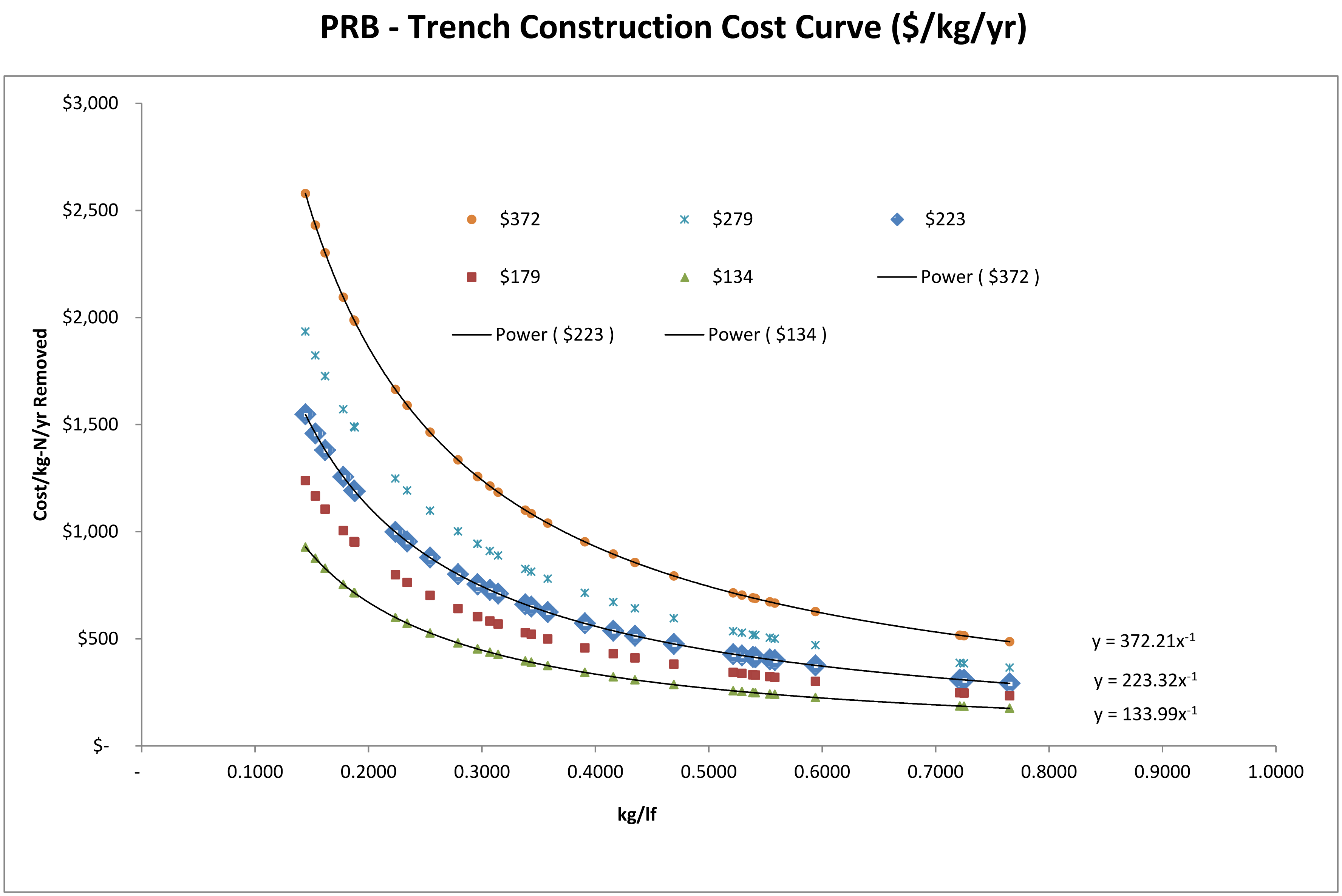
16%	10-yr interest
2.00	10-yr term
1.61	EAC factor

2,262	Average O&M Cost for Injection Well PRB (Sites 1, 4b and 5 Shallow)

Units	Site 1	Site 4b	Site 5 (shallow)	Site 5 (deep)	Remarks
20-yr rejuvination cost (thousands $)					
Injection Wells	377	340	230	N/A	<-- applied to
Regulatory Monitoring / yr (thousands)	55	55	55	N/A	*Table 7*
O&M Costs/lf./yr (thousands)	1.91	2.08	2.80	N/A	
Total 20-yr cost ($)	2,545,052	2,513,021	1,965,538	N/A	
$/lf	4,314	4,787	5,616	N/A	
$/home	62,074	54,631	26,925	N/A	
lf/home	14	11	5	N/A	
$/lb-N removed	439	376	62	N/A	
$/kg-N removed	968	830	138	N/A	
$/kg-N removed base conc 35 ppm-N	1466	1264	211	N/A	BCCR method (for direct comparison w/ MVP using 26.25 ppm-N)
$/kg-N removed base conc 26.25 ppm-N	1955	1685	282	N/A	

PRB Assessment - Trench Constuction Costs

Location	Parcels	Length	Removed Kg/Yr	Feet/Kg	Kg/Ft	$ 4,638 /lf/20 yr	$ 3,478 /lf/20 yr	$ 2,783 /lf/20 yr	$ 2,226 /lf/20 yr	$ 1,670 /lf/20 yr	$ 372 $/kg/yr/12.4	$ 279 $/kg/yr/12.4	$ 223 $/kg/yr/12.4	$ 179 $/kg/yr/12.4	$ 134 $/kg/yr/12.4	Ratio kg/lf
Herring River	98	1,600	503	3.18	0.31	$ 7,420,307	$ 5,565,230	$ 4,452,184	$ 3,561,747	$ 2,671,310	$ 1,184	$ 888	$ 710	$ 568	$ 426	0.3144
	224	1,500	1,148	1.31	0.77	$ 6,956,538	$ 5,217,403	$ 4,173,923	$ 3,339,138	$ 2,504,354	$ 486	$ 365	$ 292	$ 233	$ 175	0.7653
Bass River																
Grandview Drive	57	800	348	2.30	0.44	$ 3,710,153	$ 2,782,615	$ 2,226,092	$ 1,780,874	$ 1,335,655	$ 856	$ 642	$ 513	$ 411	$ 308	0.4350
Farm Lane	27	1,100	159	6.93	0.14	$ 5,101,461	$ 3,826,096	$ 3,060,877	$ 2,448,701	$ 1,836,526	$ 2,579	$ 1,934	$ 1,547	$ 1,238	$ 928	0.1443
Bellvue/Charles	131	1,100	516	2.13	0.47	$ 5,101,461	$ 3,826,096	$ 3,060,877	$ 2,448,701	$ 1,836,526	$ 793	$ 595	$ 476	$ 381	$ 286	0.4693
Blue Rock Road	169	2,600	879	2.96	0.34	$ 12,057,998	$ 9,043,499	$ 7,234,799	$ 5,787,839	$ 4,340,879	$ 1,100	$ 825	$ 660	$ 528	$ 396	0.3382
High Bank Road	214	1,900	1,129	1.68	0.59	$ 8,811,614	$ 6,608,711	$ 5,286,969	$ 4,229,575	$ 3,172,181	$ 626	$ 470	$ 376	$ 301	$ 226	0.5941
Vinland Drive	393	3,200	1,251	2.56	0.39	$ 14,840,613	$ 11,130,460	$ 8,904,368	$ 7,123,494	$ 5,342,621	$ 952	$ 714	$ 571	$ 457	$ 343	0.3908
Mayfair	903	5,200	2,802	1.86	0.54	$ 24,115,997	$ 18,086,998	$ 14,469,598	$ 11,575,678	$ 8,681,759	$ 691	$ 518	$ 414	$ 332	$ 249	0.5389
Eileen Street	62	1,600	245	6.53	0.15	$ 7,420,307	$ 5,565,230	$ 4,452,184	$ 3,561,747	$ 2,671,310	$ 2,430	$ 1,823	$ 1,458	$ 1,167	$ 875	0.1532
Centerville River																
S. Main Street	403	4,800	1,997	2.40	0.42	$ 22,260,920	$ 16,695,690	$ 13,356,552	$ 10,685,242	$ 8,013,931	$ 895	$ 671	$ 537	$ 430	$ 322	0.4160
Katherine Road	77	800	286	2.79	0.36	$ 3,710,153	$ 2,782,615	$ 2,226,092	$ 1,780,874	$ 1,335,655	$ 1,040	$ 780	$ 624	$ 499	$ 374	0.3580
Elliot Road	55	800	275	2.91	0.34	$ 3,710,153	$ 2,782,615	$ 2,226,092	$ 1,780,874	$ 1,335,655	$ 1,084	$ 813	$ 650	$ 520	$ 390	0.3435
Lewis Bay																
Gleason Ave	133	2,100	1,111	1.89	0.53	$ 9,739,153	$ 7,304,364	$ 5,843,492	$ 4,674,793	$ 3,506,095	$ 703	$ 527	$ 422	$ 338	$ 253	0.5293
Rte 28	60	1,700	887	1.92	0.52	$ 7,884,076	$ 5,913,057	$ 4,730,446	$ 3,784,356	$ 2,838,267	$ 714	$ 535	$ 428	$ 343	$ 257	0.5216
Standish	149	1,500	418	3.59	0.28	$ 6,956,538	$ 5,217,403	$ 4,173,923	$ 3,339,138	$ 2,504,354	$ 1,335	$ 1,001	$ 801	$ 641	$ 480	0.2789
Broadway/LewisBlvd	970	5,500	3,967	1.39	0.72	$ 25,507,304	$ 19,130,478	$ 15,304,383	$ 12,243,506	$ 9,182,630	$ 516	$ 387	$ 310	$ 248	$ 186	0.7213
Park Ave	74	1,800	337	5.34	0.19	$ 8,347,845	$ 6,260,884	$ 5,008,707	$ 4,006,966	$ 3,005,224	$ 1,987	$ 1,490	$ 1,192	$ 954	$ 715	0.1873
Poppy																
Santuit River LT 10	201	2,000	592	3.38	0.30	$ 9,275,383	$ 6,956,538	$ 5,565,230	$ 4,452,184	$ 3,339,138	$ 1,257	$ 943	$ 754	$ 603	$ 452	0.2962
Shoe String	219	2,800	626	4.47	0.22	$ 12,985,537	$ 9,739,153	$ 7,791,322	$ 6,233,058	$ 4,674,793	$ 1,664	$ 1,248	$ 998	$ 799	$ 599	0.2237
Removed Mashpee River Lwer LT10	39	1,700	2,050	0.83	1.21	$ 7,884,076	$ 5,913,057	$ 4,730,446	$ 3,784,356	$ 2,838,267						
Swan Pond																
Swan Pond River South - East	505	4,400	827	5.32	0.19	$ 20,405,843	$ 15,304,383	$ 12,243,506	$ 9,794,805	$ 7,346,104	$ 1,981	$ 1,486	$ 1,189	$ 951	$ 713	0.1878
Swan Pond River South - West	570	5,000	1,481	3.38	0.30	$ 23,188,458	$ 17,391,344	$ 13,913,075	$ 11,130,460	$ 8,347,845	$ 1,256	$ 942	$ 754	$ 603	$ 452	0.2962
Swan Pond River North - SE	124	1,000	554	1.81	0.55	$ 4,637,692	$ 3,478,269	$ 2,782,615	$ 2,226,092	$ 1,669,569	$ 672	$ 504	$ 403	$ 323	$ 242	0.5539
Swan Pond River North - SW	15	1,350	240	5.63	0.18	$ 6,260,884	$ 4,695,663	$ 3,756,530	$ 3,005,224	$ 2,253,918	$ 2,094	$ 1,570	$ 1,256	$ 1,005	$ 754	0.1778
Swan Pond River North SW PRB into GT 10	27	-	175	-							$ -	$ -	$ -	$ -	$ -	
Nauset																
Town Cove West	220	3,650	928	3.93	0.25	$ 16,927,575	$ 12,695,681	$ 10,156,545	$ 8,125,236	$ 6,093,927	$ 1,464	$ 1,098	$ 878	$ 703	$ 527	0.2542
Town Cove East and South	657	8,525	1,996	4.27	0.23	$ 39,536,322	$ 29,652,241	$ 23,721,793	$ 18,977,434	$ 14,233,076	$ 1,590	$ 1,192	$ 954	$ 763	$ 572	0.2341
Salt Pond	197	4,500	728	6.18	0.16	$ 20,869,613	$ 15,652,209	$ 12,521,768	$ 10,017,414	$ 7,513,061	$ 2,301	$ 1,726	$ 1,381	$ 1,105	$ 828	0.1618
Poppy																
Red Brook	255	2,700	829	3.26	0.31	$ 12,521,768	$ 9,391,326	$ 7,513,061	$ 6,010,448	$ 4,507,836	$ 1,212	$ 909	$ 727	$ 582	$ 436	0.3070
Quashnet	257	2,500	1,396	1.79	0.56	$ 11,594,229	$ 8,695,672	$ 6,956,538	$ 5,565,230	$ 4,173,923	$ 667	$ 500	$ 400	$ 320	$ 240	0.5584
Childs River N LT10	604	3,700	2,002	1.85	0.54	$ 17,159,459	$ 12,869,594	$ 10,295,676	$ 8,236,540	$ 6,177,405	$ 688	$ 516	$ 413	$ 330	$ 248	0.5411
Childs River S	269	1,426	1,034	1.38	0.73	$ 6,613,348	$ 4,960,011	$ 3,968,009	$ 3,174,407	$ 2,380,805	$ 513	$ 385	$ 308	$ 246	$ 185	0.7251
Three Bay																
	240	-	766					$ -								
													average			average
			average	3.06	0.41			$ 236,107,666					$ 700			0.3876
			median	3.06	0.42											


PRB - Trench Construction Cost Curve ($/kg/yr)
Cost/kg-N/yr Removed
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$-
-
0.1000
0.2000
0.3000
0.4000
0.5000
0.6000
0.7000
0.8000
0.9000
1.0000
kg/lf
$372
$279
$223
$179
$134
Power ($372)
Power ($223)
Power ($134)
y = 372.21x-1
y = 223.32x-1
y = 133.99x-1

PRB - Injection Well O&M Costs

Location	Parcels	Length	Removed Kg/Yr	Feet/Kg	Kg/Ft	$ 3,770 /lf/20 yr	$ 2,828 /lf/20 yr	$ 2,262 /lf/20 yr	$ 1,810 /lf/20 yr	$ 1,357 /lf/20 yr	$ 303 $/kg/yr/12.4	$ 227 $/kg/yr/12.4	$ 182 $/kg/yr/12.4	$ 145 $/kg/yr/12.4	$ 109 $/kg/yr/12.4	Ratio kg/lf
Herring River	98	1,600	503	3.18	0.31	$ 6,032,606	$ 4,524,455	$ 3,619,564	$ 2,895,651	$ 2,171,738	$ 963	$ 722	$ 578	$ 462	$ 347	0.3144
	224	1,500	1,148	1.31	0.77	$ 5,655,568	$ 4,241,676	$ 3,393,341	$ 2,714,673	$ 2,036,005	$ 395	$ 297	$ 237	$ 190	$ 142	0.7653
Bass River																
Grandview Drive	57	800	348	2.30	0.44	$ 3,016,303	$ 2,262,227	$ 1,809,782	$ 1,447,826	$ 1,085,869	$ 696	$ 522	$ 417	$ 334	$ 250	0.4350
Farm Lane	27	1,100	159	6.93	0.14	$ 4,147,417	$ 3,110,563	$ 2,488,450	$ 1,990,760	$ 1,493,070	$ 2,096	$ 1,572	$ 1,258	$ 1,006	$ 755	0.1443
Bellvue/Charles	131	1,100	516	2.13	0.47	$ 4,147,417	$ 3,110,563	$ 2,488,450	$ 1,990,760	$ 1,493,070	$ 645	$ 484	$ 387	$ 310	$ 232	0.4693
Blue Rock Road	169	2,600	879	2.96	0.34	$ 9,802,985	$ 7,352,239	$ 5,881,791	$ 4,705,433	$ 3,529,075	$ 895	$ 671	$ 537	$ 429	$ 322	0.3382
High Bank Road	214	1,900	1,129	1.68	0.59	$ 7,163,720	$ 5,372,790	$ 4,298,232	$ 3,438,586	$ 2,578,939	$ 509	$ 382	$ 306	$ 244	$ 183	0.5941
Vinland Drive	393	3,200	1,251	2.56	0.39	$ 12,065,213	$ 9,048,909	$ 7,239,128	$ 5,791,302	$ 4,343,477	$ 774	$ 581	$ 465	$ 372	$ 279	0.3908
Mayfair	903	5,200	2,802	1.86	0.54	$ 19,605,970	$ 14,704,478	$ 11,763,582	$ 9,410,866	$ 7,058,149	$ 562	$ 421	$ 337	$ 270	$ 202	0.5389
Eileen Street	62	1,600	245	6.53	0.15	$ 6,032,606	$ 4,524,455	$ 3,619,564	$ 2,895,651	$ 2,171,738	$ 1,976	$ 1,482	$ 1,185	$ 948	$ 711	0.1532
Centerville River																
S. Main Street	403	4,800	1,997	2.40	0.42	$ 18,097,819	$ 13,573,364	$ 10,858,691	$ 8,686,953	$ 6,515,215	$ 727	$ 546	$ 436	$ 349	$ 262	0.4160
Katherine Road	77	800	286	2.79	0.36	$ 3,016,303	$ 2,262,227	$ 1,809,782	$ 1,447,826	$ 1,085,869	$ 845	$ 634	$ 507	$ 406	$ 304	0.3580
Elliot Road	55	800	275	2.91	0.34	$ 3,016,303	$ 2,262,227	$ 1,809,782	$ 1,447,826	$ 1,085,869	$ 881	$ 661	$ 529	$ 423	$ 317	0.3435
Lewis Bay																
Gleason Ave	133	2,100	1,111	1.89	0.53	$ 7,917,796	$ 5,938,347	$ 4,750,677	$ 3,800,542	$ 2,850,406	$ 572	$ 429	$ 343	$ 274	$ 206	0.5293
Rte 28	60	1,700	887	1.92	0.52	$ 6,409,644	$ 4,807,233	$ 3,845,786	$ 3,076,629	$ 2,307,472	$ 580	$ 435	$ 348	$ 278	$ 209	0.5216
Standish	149	1,500	418	3.59	0.28	$ 5,655,568	$ 4,241,676	$ 3,393,341	$ 2,714,673	$ 2,036,005	$ 1,085	$ 814	$ 651	$ 521	$ 391	0.2789
Broadway/LewisBlvd	970	5,500	3,967	1.39	0.72	$ 20,737,084	$ 15,552,813	$ 12,442,250	$ 9,953,800	$ 7,465,350	$ 420	$ 315	$ 252	$ 201	$ 151	0.7213
Park Ave	74	1,800	337	5.34	0.19	$ 6,786,682	$ 5,090,012	$ 4,072,009	$ 3,257,607	$ 2,443,206	$ 1,616	$ 1,212	$ 969	$ 776	$ 582	0.1873
Poppy																
Santuit River LT 10	201	2,000	592	3.38	0.30	$ 7,540,758	$ 5,655,568	$ 4,524,455	$ 3,619,564	$ 2,714,673	$ 1,022	$ 766	$ 613	$ 490	$ 368	0.2962
Shoe String	219	2,800	626	4.47	0.22	$ 10,557,061	$ 7,917,796	$ 6,334,237	$ 5,067,389	$ 3,800,542	$ 1,353	$ 1,014	$ 812	$ 649	$ 487	0.2237
Removed Mashpee River Lwer LT10	39	1,700	2,050	0.83	1.21	$ 6,409,644	$ 4,807,233	$ 3,845,786	$ 3,076,629	$ 2,307,472						
Swan Pond																
Swan Pond River South - East	505	4,400	827	5.32	0.19	$ 16,589,667	$ 12,442,250	$ 9,953,800	$ 7,963,040	$ 5,972,280	$ 1,611	$ 1,208	$ 967	$ 773	$ 580	0.1878
Swan Pond River South - West	570	5,000	1,481	3.38	0.30	$ 18,851,895	$ 14,138,921	$ 11,311,137	$ 9,048,909	$ 6,786,682	$ 1,021	$ 766	$ 613	$ 490	$ 368	0.2962
Swan Pond River North - SE	124	1,000	554	1.81	0.55	$ 3,770,379	$ 2,827,784	$ 2,262,227	$ 1,809,782	$ 1,357,336	$ 546	$ 410	$ 328	$ 262	$ 197	0.5539
Swan Pond River North - SW	15	1,350	240	5.63	0.18	$ 5,090,012	$ 3,817,509	$ 3,054,007	$ 2,443,206	$ 1,832,404	$ 1,702	$ 1,277	$ 1,021	$ 817	$ 613	0.1778
Swan Pond River North SW PRB into GT 10	27	-	175	-							$ -	$ -	$ -	$ -	$ -	
Nauset																
Town Cove West	220	3,650	928	3.93	0.25	$ 13,761,883	$ 10,321,412	$ 8,257,130	$ 6,605,704	$ 4,954,278	$ 1,190	$ 893	$ 714	$ 571	$ 428	0.2542
Town Cove East and South	657	8,525	1,996	4.27	0.23	$ 32,142,480	$ 24,106,860	$ 19,285,488	$ 15,428,391	$ 11,571,293	$ 1,292	$ 969	$ 775	$ 620	$ 465	0.2341
Salt Pond	197	4,500	728	6.18	0.16	$ 16,966,705	$ 12,725,029	$ 10,180,023	$ 8,144,018	$ 6,108,014	$ 1,871	$ 1,403	$ 1,122	$ 898	$ 673	0.1618
Poppy																
Red Brook	255	2,700	829	3.26	0.31	$ 10,180,023	$ 7,635,017	$ 6,108,014	$ 4,886,411	$ 3,664,808	$ 986	$ 739	$ 591	$ 473	$ 355	0.3070
Quashnet	257	2,500	1,396	1.79	0.56	$ 9,425,947	$ 7,069,460	$ 5,655,568	$ 4,524,455	$ 3,393,341	$ 542	$ 406	$ 325	$ 260	$ 195	0.5584
Childs River N LT10	604	3,700	2,002	1.85	0.54	$ 13,950,402	$ 10,462,801	$ 8,370,241	$ 6,696,193	$ 5,022,145	$ 559	$ 419	$ 336	$ 268	$ 201	0.5411
Childs River S	269	1,426	1,034	1.38	0.73	$ 5,376,560	$ 4,032,420	$ 3,225,936	$ 2,580,749	$ 1,935,562	$ 417	$ 313	$ 250	$ 200	$ 150	0.7251
Three Bay																
	240	-	766					$ -								
													average			average
			average	3.06	0.41			$ 191,952,253					$ 569			0.3876
			median	3.06	0.42											

PRB - Trench O&M Cost Curve ($/kg/yr)