FEASIBILITY STUDY FOR CONSTRUCTED TREATMENT WETLANDS AT THE PLYMOUTH WASTEWATER TREATMENT FACILITY TOWN OF PLYMOUTH, MA

Prepared for

TOWN OF PLYMOUTH
ENVIRONMENTAL MANAGEMENT DIVISION

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SECTION 1 - INTRODUCTION

1.1 BACKGROUND

The Town of Plymouth's Wastewater Treatment Facility (WWTF), located within the Eel River watershed, began operation in the summer of 2002. The Town of Plymouth is currently in the process of developing an Eel River Watershed Management Plan with the goal of reducing nutrient loading in the watershed. The Town is also developing a feasibility study for constructing wetlands at the Plymouth WWTF to reduce any potential nutrient loading. The project goals are to improve water quality, increase wetland acreage, and enhance wildlife habitat within the Eel River watershed.

1.2 EEL RIVER WATERSHED

The Eel River watershed is "recognized as an area of outstanding aesthetic and biological value and contains rural landscapes, landscapes of historic importance, and agrarian landscapes of regional significance" (Eel River Watershed Association, 2006). It encompasses approximately 15 square miles and contains approximately 650 residential units (see Figure 1).

The Eel River Watershed Study prepared by MIT Eel River Investigation Team (MERIT) in 2001 characterizes the watershed as largely undeveloped consisting of mixed forests, agricultural land, and open space. Although the watershed is relatively healthy at current pollution levels, the U.S. Environmental Protection Agency (USEPA) has designated the Eel River watershed as having a high vulnerability water quality (MERIT, 2001).

Beneath the Eel River watershed is the Plymouth-Carver aquifer, which is designated by the USEPA as a sole source aquifer. The aquifer contains an estimated 500 billion gallons of water and covers approximately 199 square miles. The Towns of Plymouth, Carver, and parts of Bourne, Plympton, Kingston, and Wareham rely exclusively on the Plymouth-Carver sole source aquifer for their drinking water.

1.3 NUTRIENT LOADING

Several groups, including the Eel River Watershed Association (ERWA), the Nutrient Technical Advisory Committee (TAC), MERIT, and the Town of Plymouth, have conducted evaluations of the watershed and the potential for water quality degradation. These reports suggest that proposed residential and recreational development, in addition to the new WWTF, may impact the water quality of the aquifer due to nutrient loading via anthropogenic processes.

The 2001 MERIT report suggests three options to mitigate for the nutrient load and reduce nitrogen in the Eel River watershed: (1) dispose WWTF effluent out of the watershed; (2) reclaim wastewater for non-potable uses; and (3) increase treatment at the WWTF (MERIT, 2001). The first two options, disposing effluent outside the watershed and reclaiming wastewater for non-potable uses, are not prudent or feasible mitigation alternatives at this time. The third option, creating additional treatment at the WWTF, may be prudent and feasible. Construction of a wetland is an option for additional treatment.

1.4 PROJECT GOALS AND OBJECTIVES

The Town of Plymouth WWTF, located at Camelot Industrial Park, has five infiltration basins and one stormwater infiltration basin. The Town is interested in converting an existing $\pm$1.37-acre wastewater infiltration basin to a constructed wetland to reduce nitrogen loading in the Eel River watershed. The long-term project goals are to improve water quality, increase wetland acreage, and enhance wildlife habitat within the Eel River watershed. In order to achieve the long-term goals, this feasibility study focuses on the following objectives:

1. Inventory of the existing site characteristics.
2. Evaluation of potential obstructions.
3. Conceptual design development.
4. Refining wetland design alternatives.
5. Analysis of costs and benefits for alternatives.

SECTION 2 – SITE INVENTORY

2.1 SITE LAYOUT

The 3.0 million gallons per day (mgd) Plymouth WWTF was recently constructed and began operation in 2002. The WWTF is located within Camelot Industrial Park, south of Route 3. To the east of the site are second-growth mature forests. Commercial and industrial land uses dominate the area to the west of the site.

The WWTF is comprised of primary treatment structures on the south side of the property with five wastewater infiltration beds to the north. In addition to the infiltration basins, there are two sediment basins for on-site stormwater management. The site also contains parking, roadways, vehicular access, and municipal buildings.

The basin selected for this feasibility study (Basin No. 5) is located in the southwest corner. This infiltration basin is approximately 300 feet by 200 feet for a total area of about 60,000 square feet ($\pm$1.37 acres). Basin No. 5 is fed treated wastewater effluent from an inlet at elevation 85 feet. The basin received an average daily flow of 150,000 gallons per day (gpd) (or one fifth of 0.75 mgd) of treated effluent. This effluent contains approximately 3 to 4 parts per million nitrogen. As designed, the basins have an infiltration rate of 2.50 gpd per square foot (150,000 gpd). This results in each basin retaining the treated effluent for a one-day cycle.

2.2 PHYSICAL FEATURES

Basin No. 5 is a sand infiltration bed, approximately 300 by 200 feet, and approximately 8 feet deep with wastewater effluent inlet pipe. The basin consists of 2:1 side slopes which are heavily vegetated.

A. **Site Hydrology.** Site hydrology consists of flows resulting from both plant operations and the natural drainage courses surrounding the site, such as streams and wetlands. Up to 1.75 mgd of the treated wastewater effluent will be discharged via an existing outfall into Plymouth Harbor. An additional 0.75 mgd of treated effluent will be discharged to the five infiltration basins. There is potential for expansion from 0.75 to 1.25 mgd for all five beds.

The effluent infiltrates to groundwater, which has the potential to recharge the surrounding wetlands and streams. A review of published data indicates the presence of wetlands and waterbodies surrounding the Plymouth WWTF (see Figure 4).

B. **Soils.** The bottom of the infiltration basin consists of a uniform sand matrix to allow treated effluent to infiltrate to groundwater. Although the basin bottoms are relatively devoid of vegetation, the side slopes are heavily vegetated with wildflowers and warm season grasses, as are areas near the inlets.

The purpose of a sand infiltration basin is to discharge treated effluent from the WWTF to groundwater. Therefore, the sand matrix under the bed needs to be uniform, with a high enough permeability rate to allow the average daily flow to pass through to the groundwater. Typical infiltration basins are comprised of a 4- to 8-foot deep sand bed to accommodate necessary infiltration. Preliminary investigation of the site plans did not reveal specific depths of the sand bed below the bottom elevation of Basin No. 5. Basin No. 5 receives 150,000 gpd, and with a bed bottom area of approximately 60,000 square feet, has a permeability rate of 2.5 gpd/SF.

2.3 GEOGRAPHIC AND SPATIAL DATA

A review of available on-line spatial data (2005-2006 MassGIS) was conducted. This review focused on issues pertaining to natural resources, specifically wildlife habitat and local hydrology at or near the Plymouth WWTF. Reference is made to Figures 3 and 4 (NHESP and wetland data).

A. **Wildlife Habitat.** Research and geographic spatial data suggest that some of the state-listed rare species found in Plymouth depend upon the Eel River and its watershed for their survival, and approximately 43 percent of the watershed is considered BioMap habitat. BioMap habitat consists of core habitat and land supporting natural landscapes. The combination of these state designations refers to viable habitat, natural communities, and contiguous land. However, the Plymouth WWTF is located outside of the area designated BioMap Supporting Natural Landscapes. In addition, there are no NHESP Estimated Habitats of Rare Wildlife or NHESP 2005 Priority Habitats of Rare Species or NHESP Certified Vernal Pool within at least 2,000 feet of the WWTF.

B. **Local Hydrology.** A review of published data focusing on wetlands and hydrology was conducted. The National Wetlands Inventory Maps and the Massachusetts Department of Environmental Protection (MassDEP) South Coastal Wetlands data revealed the presence of several large wetland systems around the Plymouth WWTF, one of which is located just off the northwest corner of the property.

SECTION 3 – POTENTIAL OBSTRUCTIONS

3.1 REGULATORY ISSUES

A review of the various federal, state, and local regulatory parameters, which may impact the construction of treatment wetlands at the Plymouth WTTF, was conducted. This review focused on wetland issues, groundwater discharge, and zoning.

Any work in or within a 100-foot buffer zone around any fresh water or coastal resource may be subject to federal, state, and/or local jurisdiction. The work at Basin No. 5 will not be within 100 feet of a jurisdictional wetland; however, proper sedimentation and erosion control will need to be implemented to limit the area of disturbance.

In addition, any work that may alter the previously permitted groundwater discharge rates, specified in MassDEP Permit No. SE No. 0-677, shall be prepared under the jurisdiction of the MassDEP. The MassDEP should be consulted prior to the design and construction of the treatment wetlands.

The Plymouth WWTF is an active municipal wastewater facility, so this work will likely not require a zoning variance from the Town of Plymouth. However, prior to design and construction of the wetland, the Town of Plymouth Planning Board should be consulted to address any potential concerns they may have.

3.2 SITE CONSTRAINTS

There are three major site constraints which pose potential obstructions to the construction of a treatment wetland:

- permeability of Basin No. 5
- inadequate inlet/outlets
- the cold climate

The high rate of infiltration (150,000 gpd) will need to be modified significantly in order to construct a treatment wetland with a greater hydraulic retention time (HRT). This problem can be resolved by incorporating a liner into the wetland design. Treatment wetlands are typically lined with either low permeability soil such as clay, or by using a permanent plastic liner such as HDPE.

Once a liner is installed, the average daily flows of 150,000 gallons will need to be discharged to some location, as the infiltration capacity of Basin No. 5 will no longer exist. Therefore, an adequate outlet structure(s) system will need to be developed. At a minimum, an outlet structure that can pump 104 gpm (150,000 gpd) will be required. The destination of pumped effluent from the wetland will need to be determined. The ideal solution would be to pump to the existing infiltration basin via the WWTF distribution boxes. In addition to inadequate outlets, the inlet systems will need to be addressed. As currently designed, the basin received treated effluent from a single 18-inch pipe. This single source could limit the efficiency of the treatment wetlands, as water will not be evenly distributed.

Lastly, the cold climate can reduce the constructed wetland's potential for nitrogen removal. Low winter temperatures can reduce the rate of biological reactions responsible for nitrification and denitrification (USEPA, 1993). This is a common problem with treatment wetlands in colder geographic areas, and can be overcome by increasing the HRT, adding aerators to open water zones, and by designing the treatment wetland to be large enough to overcome reduced nitrogen removal rates in colder areas.

SECTION 4 – CONCEPTUAL DESIGN APPROACHES

4.1 PROCESSES

Donald Hammer, Project Manager at the Tennessee Valley Authority, and Robert Bastian of the USEPA, define constructed wetlands as "designed and man-made complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for human use and benefits" (1990). They further describe constructed wetlands as having five principal components:

1. Substrates with various rates of hydraulic conductivity.
2. Plants adapted to water-saturated anaerobic substrates.
3. A water column (water flowing in or above surface of substrate).
4. Invertebrates and vertebrates.
5. An aerobic and anaerobic microbial population.

Research suggests it is the fifth principal component described by Hammer & Bastian which is critical for the treatment of wastewater with constructed wetlands (Chan et al., 1982; and Gersberg et al., 1985). The majority of pollutant removal in wetlands is conducted by bacterial transformations and through physio-chemical processes. Establishing physical conditions under which these processes and transformation can occur is essential to purifying wastewater with constructed wetlands. The physical features of the constructed wetland should coincide with the physical and biological processes of ammonification, nitrification, and denitrification.

A. **Ammonification.** The biological transformation of organically combined nitrogen to ammonium nitrogen during organic matter degradation is referred to as ammonification (USEPA, 2000). The process of ammonification can occur under both aerobic and anaerobic conditions. Once the ammonium has formed, it can then be absorbed by plant material or converted back to organic matter by microbes.

B. **Nitrification.** The process of nitrification may occur in aerobic conditions, such as an area of open water when atmospheric contact is significant. In the presence of dissolved oxygen, ammonium is converted to nitrite and nitrate nitrogen. At this stage, the nitrate remains in the water column and may be absorbed by plant materials through assimilation.

C. **Denitrification.** Nitrate which is not assimilated undergoes dissimilatory nitrate reduction, or denitrification. In anaerobic conditions, organic carbon, such as decomposing wetland plant material, reacts with the nitrates to produce N_2 and N_2O gases. These gases easily escape from the wetland into the atmosphere.

Plants rhizomes, leaf litter, and organic debris add to the entire process by providing surfaces for bacteria growth as well as filtration of solids. As such, plants play an important role in the purification of wastewater, as they are responsible for developing aerobic conditions through the translocation of oxygen. It is this process which stimulates the decomposition of organic material and the growth of nitrifying bacteria. The nitrifying bacteria can convert ammonia to nitrate, which can then be diffused through anaerobic zones where they are removed through denitrification (Gersberg et al., 1985).

A critical step in designing treatment wetlands is coordinating the biological processes with the physical wetland character. This can take a number of forms; however, as a starting point, the USEPA has identified two types of constructed wetlands: free water surface wetlands and subsurface flow wetlands. Although both wetland types are comprised of a substrate and emergent aquatic vegetation, the final elevation of the water is different, and therefore, the two types possess unique characteristics which are described below.

4.2 FREE WATER SURFACE (FWS) WETLANDS

FWS wetlands are defined as "wetland systems in which the water surface is exposed to the atmosphere" (USEPA, 2000). The majority of naturally occurring wetlands are FWS systems. It was the ability of natural FWS wetland systems to improve water quality that originally led to the development of constructed wetlands to purify wastewater.

FWS wetlands are commonly comprised of a series of basins or channels with barriers to prevent seepage to groundwater, a soil layer to support the roots of emergent vegetation, and water at a relatively shallow depth. The most common vegetation used in constructed FWS wetlands includes bulrush, common reed, and cattail.

Each constructed FWS wetland has an inlet and an outlet structure and the water flow is horizontal. To maximize nitrogen removal, an HRT of at least three days is required, and care should be taken to stagger the FWS wetland design to include both shallow emergent zones with a deeper zone of submerged aquatics (USEPA, 2000). The deep water zones (6 feet) provide for atmospheric reaeration, while the shallow emergent zones provide aeration through the roots of the vegetation.

A. **Advantages of FWS Wetlands.**

1. Low cost to construct and operate.
2. Effective treatment.
3. Incorporation of wildlife habitat and/or education benefits.
4. Removal of BOD, TSS, COD, nitrogen, metals, and persistent organics.

B. **Disadvantages of FWS Wetlands.**

1. Requires significant HRT for effective nitrogen and phosphorous removal.
2. Requires large land area.
3. Low winter temperatures may reduce nitrogen removal processes.
4. Pests (insects, geese).

4.3 SUBSURFACE FLOW (SF) WETLANDS

SF wetlands were originally used to treat wastewater effluent in Western Europe. The works of K. Siedel in the 1960s and R. Kikuth in the 1970s set the stage for research in the United States, which began in the early 1980s with the work of Wolverton, et al. and Gersberg, et al. Current models of SF wetlands consist of beds or cells composed of gravel substrate which supports emergent aquatic vegetation. Treated wastewater effluent flows horizontally, below the upper limits of the gravel substrate, to an outlet.

SF wetlands are also lined to prevent seepage. The basic design attributes for an efficient SF wetland include a significant hydraulic gradient, sufficient substrate dimensions, proper substrate size, full penetration of root depth, an optimal HRT of at least three days, and adjustable inlet and outlet structures.

A. **Advantages of SF Wetlands.**

1. Effective at removing BOD, TSS, and nitrogen.
2. Odor control.
3. Greater surface area for treatment.

B. **Disadvantages of SF Wetlands.**

1. Requires a long HRT.
2. Potential for surface flow.
3. Dependent upon full penetration of roots.
4. Possible blockages in flow path.
5. More potential expenses than FWS (e.g., cost of substrate).

4.4 LINERS

Liners for treatment wetlands can either be soils with low rates of permeability (clay) or plastic liners such as HDPE. An HDPE liner is a suitable option to prevent seepage beneath the constructed wetland as there is no clay readily available at the site. HDPE is commonly used for constructed wetlands. Stearns & Wheler recommends a minimum of 1 foot of material be spread over HDPE. The sand in the basin will be a suitable material.

Approximately 8,000 square yards of HDPE will need to be installed within Basin No. 5 and the adjacent side slope areas. Because each design alternative will require a liner 1 foot below the base elevation, this cost will be similar for each design alternative.

4.5 EARTHWORK

Constructing a wetland within a flat infiltration basin will require significant earthwork and coordination. The proper installation of the HDPE liner is the first requirement. To do so, the existing sand must be moved to a corner of the basin, then portions of the HDPE may be installed. Once the remaining sand is moved onto the lined area, the remaining HDPE may be installed. Once installed and anchored according to specifications, a minimum 1-foot depth of sand may be spread uniformly over the liner.

This elevation will serve as the base elevation. How much earthwork occurs above this base is contingent upon which wetland design alternative is selected. For the FWS design alternative, an estimated 6,000 cubic yards of material will need to be graded. This includes the existing sand, new substrate, and a 0.5-foot layer of topsoil required for a planting medium.

For the SF design alternative, an estimated 2,500 cubic yards of existing sand and new substrate material will be regraded. In addition, the SF wetland requires approximately 2 to 3 feet of gravel substrate for the effluent to travel through. The results in an estimated 4,500 cubic yards of gravel needed for the SF wetland.

4.6 VEGETATION

The emergent zone layouts will include dense plantings of herbaceous plant material. The density of the plantings will affect the level of nitrogen removal. Therefore, the plants should be installed at a small spacing (dense) to limit the number of growing seasons required for full coverage in the treatment wetland. If possible, planting should occur prior to June 15.

The herbaceous plants to be installed in the emergent zones are cattail (*Typha latifolia*) and bulrush (*Scirpus sp*). Research suggests these two plant species, along with common reed (*Phragmites australis*), have shown the highest rates of effectiveness for nitrogen removal in a variety of treatment wetlands. Since common reed is a non-native invasive species, it may result in detrimental effect in the surrounding infiltration basins, wetlands, and waterbodies. Therefore, common reed is not a feasible option for planting and cattail and bulrush should be installed.

The total area of Basin No. 5 is approximately 60,000 square feet. The FWS design alternatives will each consist of approximately 2/3 emergent marsh and 1/3 open water. Therefore, an area of +40,000 square feet will require planting with cattail and bulrush, while +20,000 will remain open water which can support some submerged aquatics. For the SF alternative, the entire system (approximately 60,000 square feet) will require vegetation.

To minimize the number of growing seasons required for full coverage, plants should be densely planted at a spacing no greater than 2 feet on center. Although 1 foot on center is ideal, this will greatly increase the plant quantity and substantially increase costs. Therefore, at a 2-foot spacing (one plant per 4 square feet), a treatment wetland at Basin No. 5 will require the installation of approximately 10,000 plants (5,000 cattail and 5,000 bulrush) or 15,000 plants (7,500 cattail and 7,500 bulrush) for the SF wetland.

It is recommended the plants be installed by knowledgeable professionals, familiar with wetland plantings. The vegetation may be planted as 2-inch plugs or as rooted tubers. Rooted tubers are less expensive, but will require more growing seasons to mature and may be less reliable than established plugs.

4.7 INLET

The existing inlet to Basin No. 5 consists of a single 18-inch pipe discharging to a single point within the basin. This type of inlet will not allow for maximum effluent exposure to the constructed wetlands. The objective of the new inlet feature shall be to distribute effluent flow to maximize the HRT by initiating effluent contact with wetland features - gravel, soil, vegetation, and oxygen.

In addition, the existing distribution boxes at the WWTF offer many options for controlling the discharged effluent prior to entering the basin. These options include controlling flow directly to the wetland based on desired quantity or current plant flow conditions.

An inlet manifold should be constructed within the basin. An inlet manifold will uniformly distribute effluent to the various zones and sections of the constructed wetland. An alternative to the manifold will be to develop a SF wetland at the single discharge point. The effluent can travel within the gravel beds to the various sections of the constructed wetland. However, the manifold may be better suited and more efficient because the single discharge point will segregate the far corners of the constructed wetland.

4.8 HYDRAULIC RESIDENCE TIME (HRT)

Once the effluent is in the constructed wetland, a HRT of four to six days should be achieved for effective removal of nitrogen (UESPA, 2000). Flow in each zone should be two to three days to limit the growth of algae. A critical component to maintaining the correct HRT is capacity. Does Basin No. 5 contain enough capacity to hold six days' worth of effluent from the WWTF? The answer to this question is detailed below.

Basin No. 5 is approximately 200 feet by 300 feet for a total ±60,000 square feet. At a depth of 8 feet, Basin No. 5 has a volume of 480,000 cubic feet. However, for safety and design consideration, the entire 8-foot depth will not be utilized. Assuming a conservative maximum depth of 2 feet (rather than the available 8 feet) over ±60,000 square feet gives Basin No. 5 a volume of approximately 120,000 cubic feet.

The current flow into Basin No. 5 is approximately 150,000 gpd. Assuming a 6-day HRT, Basin No. 5 must have the capacity to hold 900,000 gallons, or 120,312 cubic feet, of water. Therefore, assuming a 6-day HRT and a conservative maximum depth of 2 feet, Basin No. 5 should have the capacity to accommodate the suggested HRT. It should be noted that each FWS design alternative system includes an open water zone of 5- to 6-foot depth.

Simply having the capacity to hold the necessary flow does not guarantee that the ideal HRT will be established. Therefore, to determine whether a treatment wetland can be designed to hold the ideal HRT, Stearns & Wheler landscape architects and engineers utilized the following HRT calculation:

$T = (V)/Q_{ave}$

T = Time

V = Volume (cubic feet)

Q = Flow (cubic feet)

For a FWS wetland, two-thirds of the 60,000 square foot basin (40,000 square feet) will become emergent marsh with a 1.5-foot depth. The remaining one third will consist of open water at a depth of 5 to 6 feet. This gives the FWS treatment wetland a total volume of approximately 180,000 cubic feet. The average daily flow into Basin No. 5 is 150,000 gallons per day, or roughly 20,000 cubic feet per day. Therefore, the HRT of a FWS treatment wetland will be approximately six to seven days. Subtracting the volume required for necessary berms yields a final volume of approximately 140,000 cubic feet.

For a SF wetland, average depth of the gravel bed will be a uniform 2 to 3 feet throughout the 60,000 square foot basin, less the volume of any berms, resulting in approximately the same overall cubic feet measurement of a FWS wetland and an HRT of six to seven days.

4.9 OUTLET

The construction of a wetland within a basin designed for infiltration will create a problem regarding the outflow of water. Therefore, an outlet system will need to be designed and constructed to accommodate the proposed flow from within the wetland. One option is to pump the effluent from the constructed wetland to the other four infiltration basins. Assuming an average daily flow of 150,000, a pump that can handle a minimum of 104 gpm is required.

To handle the outflow, a concrete effluent control weir shall be located in each wetland cell. This weir will establish the base water elevation at the lower end of the wetland. Overflow will top the weir and flow through a screen and collect in a catchment area. Within this catchment chamber will be a pump, or series of pumps, which will be controlled by floats. As needed, the pump(s) will pump water from the catchment to either the distribution boxes or another infiltration basin. This solution allows for constant water elevations within the wetland.

This outlet design also allows for flexibility. For example, if the daily flow increases and the outlet structure(s) is required to handle higher flows, additional pumps can be added to the catchment area.

4.10 OPERATION AND MAINTENANCE

During the initial startup period (first six weeks after construction), an inspection of any berms, dikes, plant materials, and inlet and outlet structures should be conducted several times per week to monitor water levels, structure integrity, and plant health. It should be noted that the initial water quality levels may not be representative of the overall long-term goals. Not until the plant material has fully established itself will the constructed wetland operate at maximum efficiency.

Overall O&M goals should focus on hydraulic monitoring, water quality monitoring, wetland biota monitoring, and civil issues. This should be done at both the long-term (yearly) scale as well as during the short-term (monthly or weekly) scale. Weekly and monthly monitoring should also include the removal of debris and trash. The day-to-day and week-to-week monitoring may be conducted by WWTF staff and be supplemented by monthly and yearly specialized monitoring by environmental specialists.

Descriptions of general O&M and monitoring procedures as well as potential yearly O&M costs are described below.

A. **Hydraulic Monitoring.** The hydraulic conditions should be inspected weekly to determine if the correct HRT, water depth, and flow rates are being achieved. In addition, the monitoring of hydrological conditions should include routine inspection for algae blooms in the water, as algae can be a sign of prolonged HRT, increased levels of phosphorous, and decreased water quality. This monitoring can be done in a number of ways, including simple visual analysis of the wetland and mechanical analysis by installed flow meters at the inlet and outlet. The monitoring of water level and flow is crucial to the nitrogen removal capacity and therefore should be conducted on a weekly basis. Research suggests a minimal HRT of six days is required for optimal nitrogen removal rates. During the initial stages (the first six weeks following construction of the wetland), visual observation of water levels should be conducted multiple times per week. The costs associated with the visual monitoring of the water level and flows can be minimal. However, if problems do arise, the required repairs may be more cost intensive. Our opinion of probable costs for weekly monitoring of water levels is $4,000 per year.

B. **Water Quality Monitoring.** Water quality monitoring should be conducted as part of routine WWTF operating practices. To monitor water quality and determine the rates at which nitrogen is being removed, permanent testing points should be established at the inlet and outlet structures and should follow USEPA-approved methodology. Water quality should be monitored for nutrient removal as well as to test for algae. Algae must be controlled within the constructed wetland, as its presence is an indicator of ineffective HRT, increased nutrients, and general lack of water quality, and can impact vegetation growth. Our opinion of probable costs for monthly water quality monitoring is $4,000 per year.

C. **Wetland Biota Monitoring.** Monitoring of wetland biota includes the monitoring of vegetation coverage, plant health, and potential wildlife, including potential nuisance animals at the treatment wetlands. Long-term vegetation monitoring should include bi-annual inspection and vegetation monitoring by a wetland scientist. Monitoring by a wetland professional should occur at the beginning and end of each growing season, particularly for the first three years in conjunction with routine monitoring by Town staff. The health of the plant materials is a good indicator of the overall health of the wetland and is a critical component to the biological processes which remove nitrogen. The goal of the monitoring is to determine whether the plants are growing as intended and whether adjustments in plant quantities and/or species are required. The results of plant material monitoring may also be indicative of other hydrology and water quality issues. Our opinion of probable costs for yearly wetland biota monitoring, vegetation management, and associated plant replacement costs is $8,000 per year.

D. **Civil Issues.** Based on visual inspection of the water level, the failure of the pumping structures, inlets, outlets, or berms may or may not be easily recognized. Therefore, monthly review of the inlet and outlet manifold as well as a general review of the side berms, liners, and pumping structures should be conducted during routine WWTF O&M procedures. Although the costs for actual monitoring may be minimal, if repairs are required, they may prove costly.

Without being able to anticipate potential breakdowns and/or necessary repairs, our opinion of probable costs for monthly monitoring of civil issues including flow structures, pumps and berms is $5,000 per year.

As scheduled, our opinion of probable cost for one year of O&M is $21,000, excluding any required repairs or replacement of pumps, structures, and earthwork. This cost estimate is not based on current wages of the Plymouth WWTF staff; rather, it is an estimated amount based on published USEPA cost information for other constructed treatment wetlands of similar scale. It should be noted that much of the weekly and monthly monitoring is conducted by visual analysis. If routine visual observation indicates any significant damages, a more intensive O&M effort will be required.

SECTION 5 – DESIGN ALTERNATIVES

5.1 FREE WATER SURFACE WETLAND SYSTEMS

A. **Alternative No. 1 – Linear Three-Zone System.** The basic system involves segmenting the basin into three zones. These zones are not separate cells; rather, they consist of two shallow emergent zones with one centrally located open zone of deeper water. Zone width is equal to the existing dimension of the basin. Effluent flows in a linear path from inlet to outlet.

The three zones are considered to be an effective means of nitrogen removal (USEPA, 2000). The open water zone is exposed to the atmosphere and oxygen transfer can occur while the emergent marshes contain limited oxygen. The transition from an emergent zone (anaerobic) to open water (aerobic) to emergent zone (anaerobic) can facilitate the ammonification, nitrification, and denitrification processes.

Advantages	Disadvantages
• Simple design and construction • Lower cost • Lack of interior berm increase volume	• Potential for odor • Single cell limits ability to take system "off-line • Treatment may not extend to far corners of wetland • Requires manifold inlet/outlet

B. **Alternative No. 2 – Naturalistic or Organically Shaped.** This wetland system consists of curvilinear zones and forms. The emergent and open water zones do not correspond directly to the dimension of the existing basin, but are designed to reflect a more naturalistic appearance. The effluent will flow in an indirect route within the naturalistic wetland.

Alternative No. 2 is based on the idea that varying zones of emergent marsh and open water can facilitate the removal of nitrogen, as in Alternative No. 1. However, this alternative consists of naturalistic shapes and flow paths, which results in more transitions between zones (greater nitrogen removal) and a naturalistic aesthetic. The total quantities of emergent and open water zones are similar to those in Alternative No. 1; however, this option breaks up the zones and creates more transitional opportunities. As this alternative consists of one cell, it does not allow for continued treatment of effluent if the treatment wetland is to be taken "off-line" for maintenance or repairs. Due to the effort required for earthwork, this alternative may be considered more expensive than other simpler alternatives.

Advantages	Disadvantages
• Aesthetics • Wildlife habitat potential • Good opportunity for public outreach • Lack of interior berm increase volume	• Requires extensive design and earthwork • Cannot be taken "off-line" • Potential for odor

5.2 SUBSURFACE FLOW WETLAND SYSTEM

A. **Alternative No. 3 – Series of Three Linear Subsurface Wetland Cells.** Each SF wetland is divided by a series of earthen berms which run the entire length of the basin. Water flows from an inlet manifold placed at the upper level of the linear cells, in a direct route towards an outlet at the other end of the cell. The effluent flow is one way.

SF systems were originally used in the late 1960s and 1970s and continue to be used to improve water quality. This alternative calls for effluent to travel horizontally and vertically through a porous gravel bed from the inlet to an outlet structure. The root zones of emergent plants on top of the gravel bed provide oxygen and the plant debris provides the carbon sources needed for the nitrogen removal processes. Research suggests that the gravel bed provides additional space for biofilms and plant debris, enhancing the nitrogen removal process. In addition, subsurface wetlands provide an additional level of odor control and safety as the effluent remains beneath the surface.

This alternative does not offer much in terms of aesthetics and wildlife benefit. The construction costs for this system will be moderate to high, as significant quantities of gravel and earthen berms are required.

Advantages	Disadvantages
• Individual cells can be taken "off-line" if needed • Water below grade (safety and odor control) • Removes BOD, TSS, and nutrients	• Cost • Extensive design and grading • Limited aesthetically appealing • Limited wildlife habitat • Berms reduce volume • Potential for clogging

5.3 HYBRID SYSTEMS

A. **Alternative No. 4 – Linear Two-Cell System.** This system contains a divider berm extending the length of the basin, dividing the basin into two cells. Each cell consists of emergent and open water zones, with an additional subsurface drainage zone located at the inlet. The effluent will travel horizontally from inlet to outlet.

The hybrid Alternative Nos. 4 and 5 provide many of the benefits of both FWS wetlands and SF wetlands, including the facilitation of ammonification, nitrification, and denitrification processes. Also, discharging effluent into a subsurface wetland provides more opportunity for even distribution throughout the emergent zones.

In addition, the two cells allow for one system to remain in operation while one may be taken off-line for maintenance or repairs. The two-cell system also increases the aspect ratio, which can allow for water to travel more directly from inlet to outlet. The transitions from the various zones increase the potential for nitrogen removal, as well as provide aesthetic and wildlife benefits. However, construction of a berm will remove basin volume, thereby forcing greater depths to achieve the same HRT.

Advantages	Disadvantages
• Incorporates two types of wetland • Subsurface portions defuse effluent evenly • Can make one new "off-line" if needed	• Significant design and earthwork • Potential for clogged gravel • Interior berm requires greater depth

B. **Alternative No. 5 – Linear Two-Cell System with Alternate Effluent Flow Paths.** This alternative consists of a linear divider running the length of the basin, dividing the basin into two cells. Cell 1 consists of subsurface wetland at the inlet, emergent wetland, and open water. Effluent travels linearly from inlet to outlet structure in Cell 1, where it is re-routed to flow through Cell 2 back toward the original inlet. Cell 2 also consists of subsurface wetland, emergent, and open water wetlands.

Alternative No. 5 provides all of the benefits of Alternative No. 4; however, it allows for an increase in HRT by re-routing flow back toward the inlet in Cell 2 and an increase in zone transition, resulting in a greater chance of nitrogen removal. Placing a pump at the base of Cell 1 allows for the possibility to bypass Cell 1 or Cell 2. This option offers the most in terms of flexibility and nitrogen removal; however, it may also be the most expensive. This alternative is the most comprehensive and complex, and as such, involves very detailed earthwork.

Advantages	Disadvantages
• Increases HRT	• Requires extensive design and construction • Cost

5.4 ALTERNATIVES ANALYSIS

Each of the five design alternatives in this feasibility study was developed based on best management practices for effective nitrogen removal from wastewater effluent. The location and physical parameters of Basin No. 5 dictate that the size, volume, HRT, quantity of plant material, and layout for each alternative will be similar; as such, nitrogen removal rates per each design alternative will not vary substantially. Therefore, the factors that distinguish one alternative from another are largely related to cost, site programming, and construction effort, as well as indirect benefits such as opportunities for wildlife habitat enhancement, open space, and aesthetics.

Design Alternative	Cost	Operations and Maintenance	Effective-ness	Indirect Benefits
Alternative No. 1 FWS Single-Cell, Three-Zone System	$277,000	Approximately $21,000 per year	Polishing effluent	Wildlife habitat, increased open space, public outreach
Alternative No. 2 FWS Naturalistic Shape	$317,000	Approximately $21,000 per year	Polishing effluent	Wildlife habitat, aesthetics, increased open space, public outreach

Design Alternative	Cost	Operations and Maintenance	Effective-ness	Indirect Benefits
Alternative No. 3 Subsurface Wetland	$454,000	Approximately $21,000 per year; potential for gravel clogging	Polishing effluent	Odor control and Safety, public outreach
Alternative No. 4 Hybrid System with Two Cells	$406,000	Approximately $21,000 per year; potential clogging of gravel	Polishing effluent	Limited wildlife habitat and aesthetics, public outreach
Alternative No. 5 Hybrid System with Re-Routed Flow	$423,000	Approximately $21,000 per year; potential for gravel clogging	Polishing effluent	Limited wildlife habitat and aesthetics, public outreach

SECTION 6 – COSTS

6.1 TOTAL COST

Our opinion of probable costs for the construction of FWS and/or SF treatment wetlands at the Plymouth WWTF ranges from $277,000 to $454,000.[1] A 30 percent contingency for design and permitting services was added to the total estimated construction costs. These construction costs do not include any costs associated with short- and long-term monitoring and maintenance of the constructed wetlands. Also, these costs do not reflect potential upgrades to the existing distribution boxes controlling effluent flow into the wetland.

[1] Estimated costs are to be used for cost comparison purposes, as all cost items are not fully accounted for within estimate and would need full contractor breakdown for same. The unit prices are estimated or from RS Means (2006).

Proposed Cost Estimate for Design Alternative No. 1 Free Water Surface Wetland	
Mobilization (LS)	$1,500
Site Layout, 3 days at $500/day	1,500
Excavate and Place 5,000 CY at $5/CY	25,000
HDPE Liner 8,000 SY at $5/SY	40,000
Earthwork (Common Borrow) 1,000 CY at $15/CY	15,000
Earthwork (Screened Loam) 2,000 CY at $30/CY	60,000
Wetland Plantings (LS)	35,000
Drain Structures (LS)	15,000
Drain Piping 500 LF at $30/LF	15,000
Pumps Two Units at $500	1,000
Site Cleanup (LS)	2,000
Project Closeout (LS)	2,000
Subtotal (Rounded)	**$213,000**
30%	64,000
Total	**$277,000**

Proposed Cost Estimate for Design Alternative No. 2 Naturalistic Free Water Surface Wetland	
Mobilization (LS)	$1,500
Site Layout, 5 days at $500/day	2,500
Excavate and Place 5,000 CY at $5/CY	25,000
HDPE Liner 8,000 SY at $5/SY	40,000
Earthwork (Common Borrow) 1,500 CY at $15/CY	22,500
Earthwork (Screened Loam) 2,500 CY at $30/CY	75,000
Wetland Plantings (LS)	40,000
Drain Structures (LS)	15,000
Drain Piping 500 LF at $30/LF	15,000
Pumps Two Units at $500	1,000
Site Cleanup (LS)	3,000
Project Closeout (LS)	3,000
Subtotal (Rounded)	**$244,000**
30%	73,000
Total	**$317,000**

Proposed Cost Estimate for Design Alternative No. 3 Subsurface Wetland	
Mobilization (LS)	$1,500
Site Layout 5 Day at $500/day	2,500
Excavate and Place 2,500 CY at $5/CY	25,000
HDPE Liner 8,000 SY at $5/SY	40,000
Earthwork (common borrow) 500 CY at $15/CY	7,500
Earthwork (gravel) 4,500 CY at $45/CY	202,500
Wetland Plantings (LS)	45,000
Drain Structures (LS)	15,000
Drain Piping 500 LF at $30/LF	15,000
Pumps Two Units at $500	1,000
Site Cleanup (LS)	3,000
Project Closeout (LS)	3,000
Subtotal (Rounded)	**$349,000**
30%	105,000
Total	**$454,000**

Proposed Cost Estimate for Design Alternative No. 4 Hybrid System – Free Water and Subsurface Wetlands	
Mobilization (LS)	$1,500
Site Layout 5 Day at $500/day	2,500
Excavate and Place 5,000 CY at $5/CY	12,500
HDPE Liner 8,000 SY at $5/SY	40,000
Earthwork (Common Borrow) 1,500 CY at $15/CY	22,500
Earthwork (Screened Loam) 3,500 CY at $30/CY	105,000
Earthwork (Gravel) 1,000 CY at $45/CY	45,000
Wetland Plantings (LS)	45,000
Drain Structures (LS)	15,000
Drain Piping 500 LF at $30/LF	15,000
Pumps Two Units at $500	1,000
Site Cleanup (LS)	3,500
Project Closeout (LS)	3,500
Subtotal (Rounded)	**$312,000**
30%	94,000
Total	**$406,000**

Proposed Cost Estimate for Design Alternative No. 5 Hybrid System – Free Water and Subsurface Wetlands	
Mobilization (LS)	$1,500
Site Layout 5 day at $500/day	2,500
Excavate and Place 5,000 CY at $5/CY	12,500
HDPE Liner 8,000 SY at $5/SY	40,000
Earthwork (common borrow) 1,500 CY at $15/CY	22,500
Earthwork (screened loam) 3,500 CY at $30/CY	105,000
Earthwork (gravel) 1,000 CY at $45/CY	45,000
Wetland Plantings (LS)	45,000
Drain Structures (LS)	20,000
Drain Piping 750 LF at $30/LF	22,500
Pumps 2 units at $500	1,000
Site Cleanup (LS)	3,500
Project Closeout (LS)	3,500
Subtotal (Rounded)	**$325,000**
30%	98,000
Total	**$423,000**

6.2 FUNDING

Phases and aspects of the planning, design, construction, and operation of treatment wetlands at the Plymouth WWTF may be eligible for MassDEP grant and loan programs consisting of federal funds from USEPA as authorized by the Clean Water Act Sections 604(b) and 319. The following information can be found in Grant and Loan Programs: Opportunities for Watershed Protection Planning and Implementation (MASSDEP, 2006) included in an Appendix of this report:

A. **604(b) Water Quality Management Planning Grant Program.** The 604(b) Grant Program is designed to assist regional planning agencies and other eligible recipients in providing water quality assessment and planning. The focus of these grants will be for watershed or sub-watershed-based non-point source assessment activities that support the Department's assessment and planning initiatives, including the Massachusetts Estuaries Project, TMDL development efforts, water supply source protection planning projects, or activities identified in EOEA Watershed action plans.

B. **USEPA 104(b)(3) Wetlands Demonstration Grant.** Under the authority of Section 104(b)(3) of the Clean Water Act, the Wetland Program Development Grants (WPDGs) provide applicants an opportunity to develop and refine comprehensive wetland programs. The grants are for the purposes of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution.

C. **Clean Water State Revolving Loan Fund (SRF) Program.** Financial assistance is available for the planning and construction of existing wastewater facilities as well as for pollution remediation strategies. The SRF is jointly administered by the Division of Municipal Services of the Department of Environmental Protection and the Massachusetts Water Pollution Abatement Trust. Current subsidies are provided through 2 percent interest loans.

To be considered eligible, a community must submit a Project Evaluation Form and the MassDEP will rank projects based on:

- demonstrable water quality benefits
- elimination or mitigation of risk to public health
- potential for compliance with discharge permits
- consistency with watershed plans and regional growth plans
- borrower's support of the Commonwealth Sustainable Development Initiative

More information regarding the SRF and other MassDEP funding sources is included in Appendix D. Additional funding opportunities, such as the USEPA Region 1 WPDG, may be available if, in addition to water quality improvements, the constructed wetland project at the Plymouth WWTF incorporates:

- a level of programmatic education and/or outreach
- opportunities for study and is viewed as a demonstration project
- the coordination and facilitation of research

SECTION 7 – CONCLUSION

7.1 REVIEW

In the 1960s and 1970s, when scientists began researching the ability of constructed wetlands to improve water, much of the focus was on SF wetlands. At that time, FWS wetland systems were not thought to be as effective at removing pollutants and nutrients. As more research on SF wetlands was conducted, their effectiveness at improving water quality became clear and they remained a staple for the next 20 years.

Since the 1980s, FWS wetlands have been the focus of much research. Once thought ineffective at nutrient removal, changes in FWS system design has changed the research community's opinion. Early FWS wetlands were 100 percent vegetated emergent beds. Research found that this design did not allow for the necessary level of oxygen into the system and limited the FWS wetland's capacity to facilitate nitrification. Therefore, the design present in Alternative Nos. 1, 2, 4, and 5 includes significant areas of deep open water. This allows for oxygen transfer through atmospheric mixing. To date, 32 states have FWS treatment wetlands for treating municipal wastewater.

7.2 DIRECT BENEFITS FOR NITROGEN REMOVAL

The installation of the Free Water Surface (FWS) wetland system would provide the most appropriate mechanism for nitrogen removal at the Town's Wastewater Treatment Facility (WWTF). The proposed FWS wetland system provides the environment for the removal of Total Kjeldahl Nitrogen (TKN) (nitrification) and Total N (denitrification).

The Water Environmental Research Foundation publication summarizes more than 750 measurements of TKN removal achieved by 159 FWS wetland systems. Of these systems, the mean TKN in the influent was 3.4mg/L, and the mean TKN of the effluent was 1.9 mg/L corresponding to a 44 percent reduction in TKN. The relatively low concentration in the influent of systems used in the WERF analysis is consistent with nitrified wastewater similar to the Plymouth application. At that rate, it is estimated that approximately 1.74 mg/l of TKN would be removed via constructed wetlands.

Denitrification is dependant on the availability of organic carbon. In FWS wetlands, wetland plant detritus is typically the primary source of organic carbon. The concentration of biochemical oxygen demanding-material (BOD) in the Plymouth effluent is low; consequently, decaying wetland plants would be the primary source of organic carbon to support the denitrifying microbial populations. The total amount of denitrification taking place in a constructed wetland can be estimated by the total amount of plant biomass production. Using an average production estimate for temperate wetlands of 3,000 g/m^2-yr of plant material (WERF 2006), there would theoretically be enough available organic carbon to reduce 558 g/m^2-yr of nitrate N. Reference is made to Appendix E.

7.3 INDIRECT BENEFITS

Indirect benefits are those benefits which result from a constructed wetland, in addition to the stated purposes of nutrient removal and water quality enhancement. Typical indirect benefits of treatment wetlands include increased wildlife habitat, increased green space, and increased wetland acreage, as well as potential for educational outreach and recreational opportunities. Each of the design alternatives in this report offers a host of indirect benefits.

Constructed treatment wetlands are widely considered beneficial to the environment and valuable to a community, and incorporating opportunities for public outreach and education may be worth investigating. This can be as simple as a transfer of information to a public forum, or as comprehensive as establishing a series of programmatic elements revolving around the wetland operations (i.e., field trips for local schools). Although this technology is becoming more common, a constructed treatment wetland may provide a unique opportunity to showcase a community asset not typically in public focus. In addition, projects of this nature, which include public outreach and educational components, may qualify for additional sources of funding. If this type of indirect benefit is desired, landscape elements such as boardwalks, overlooks, gathering spaces, and signage could be developed as part of the final design and planning efforts.

7.4 RECOMMENDATIONS

The Town of Plymouth is interested in developing a feasibility study for constructed wetlands at the Plymouth WWTF to reduce nutrient loading in the Eel River watershed. The project goals are to increase water quality as well as increase wetland acreage and enhance wildlife habitat. To determine the feasibility of a constructed treatment wetland at the Plymouth WWTF, Stearns & Wheler landscape architects, engineers, and wetland scientists have conducted a review of the existing site characteristics, evaluated potential obstructions, developed conceptual designs, prepared five potential wetland design alternatives, and provided an analysis of the costs and benefits for each alternative.

Although quantifiable rates of nitrogen removal cannot be predicted at this time, we do conclude that through polishing of treatment effluent, water quality will be improved through constructing treatment wetlands at the WWTF. Our previous experience designing various environmental systems shows that any additional pathway, such as fore-bays, swales or emergent wetlands, will yield water quality improvements through the settling of particle pollutants, biological removal of nutrients, and/or plant uptake.

In addition to water quality improvements, our recommendation to construct a treatment wetland at the WWTF is based on a broad view of the environmental and community benefits which may result from construction of that wetland. These benefits include:

- Increased wetland acreage and open space
- Potential for wildlife habitat enhancement
- Community asset
- Potential for public outreach and education

To maximize the community and environmental benefits resulting from treatment wetlands while minimizing costs, we recommend Design Alternative No. 2, which consists of an organically shaped naturalistic wetland combining emergent and open water zones. This design alternative provides many of the benefits listed above and can be adjusted during the design and planning to incorporate opportunities for public outreach, if desired. In addition, this design alternative is more cost effective compared to Design Alternatives No. 3, 4 and 5. Please reference the Proposed Wetland Layout and Site Plan for Treatment Wetlands at the WWTF included in Appendix C.

Although constructing a treatment wetland within an existing infiltration basin at the WWTF does have its challenges, it is feasible. Our opinion of probable costs for the construction of treatment wetlands similar to that illustrated in Design Alternative No. 2 is approximately

$317,000. However, portions of this project may be eligible for funding under programs such as the Clean Water SRF Program and the 604(b) Water Quality Management Planning Grant Program. If public outreach and educational components are included in the program, additional funding sources may become available.

SECTION 8 – REFERENCES

1. Gersberg, R., B. Elkins, S. Lyon, C. Goldman. 1986. Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands. Water Resources Vol. 20, pp. 363-368.

2. Hammer, D., Ed. 1990. Constructed Wetlands for Wastewater Treatment. Municipal, Industrial, and Agricultural. Lewis Publishers, Chelsea, MI.

3. Hammer, D. and R. Bastian. 1990. Wetland Ecosystems: Natural Water Purifiers? Chapter in Constructed Wetlands for Wastewater Treatment. Municipal, Industrial and Agricultural, Edited by Hammer. Lewis Publishers, Chelsea, MI.

4. MERIT (The MIT Eel River Investigation Team). 2001. The Eel River Watershed Study.

5. U.S. Environmental Protection Agency. 1993. Subsurface Flow Constructed Wetlands for Wastewater Treatment, EPA 832-R-93-008.

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7. U.S. Environmental Protection Agency. 2000. Wastewater Technology Fact Sheet: Free Water Surface Wetlands, EPA 832-F-00-024.

8. U.S. Environmental Protection Agency and Cape Cod Commission, 2006. Massachusetts Estuaries Project: Status of Application of Approach Workshop on Restoring and Protecting Coastal Waters.

9. Moshiri, Gerald A., 1993. Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, FL.

APPENDICES

APPENDIX A

PHOTOGRAPHS

PHOTOGRAPHS
OF EXISTING CONDITIONS

Photo of Infiltration Basins

Photo of Basin No. 5 looking west

PHOTOGRAPHS
OF EXISTING CONDITIONS

Photo of Basin No. 5 northern berm- looking east toward WWTF

Photo of Basin No. 5 looking south from inlet

APPENDIX B

FIGURES

Data Source: Mass GIS
File Location: J:\GIS\GIS Project Folder\Job#\Plymouth\Figures\Watershed.mxd

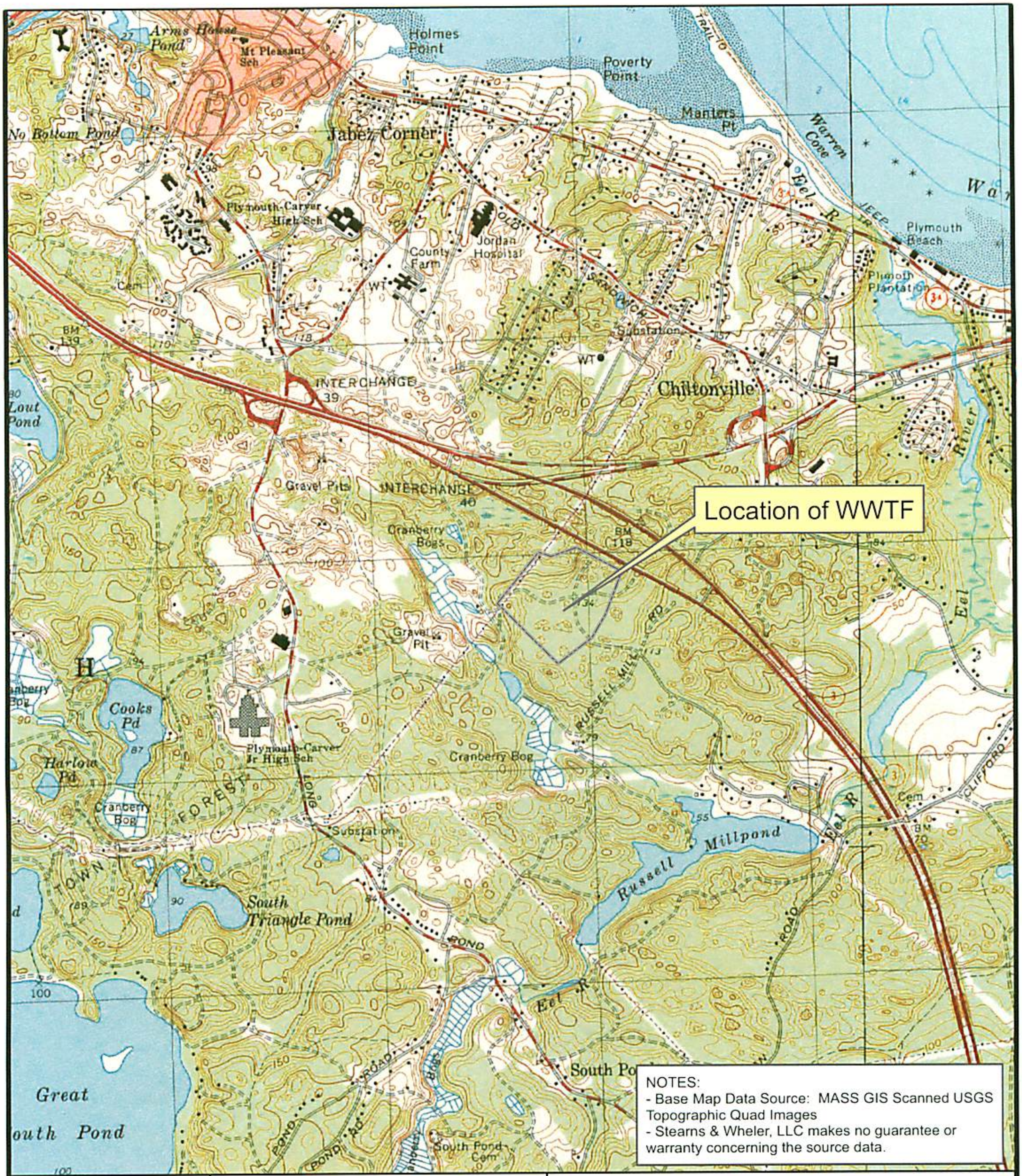
Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MASSACHUSETTS

Date: 11/2006 Project No. 00074

TOWN OF PLYMOUTH, MASSACHUSETTS

WATERSHED MAP

FIGURE 1



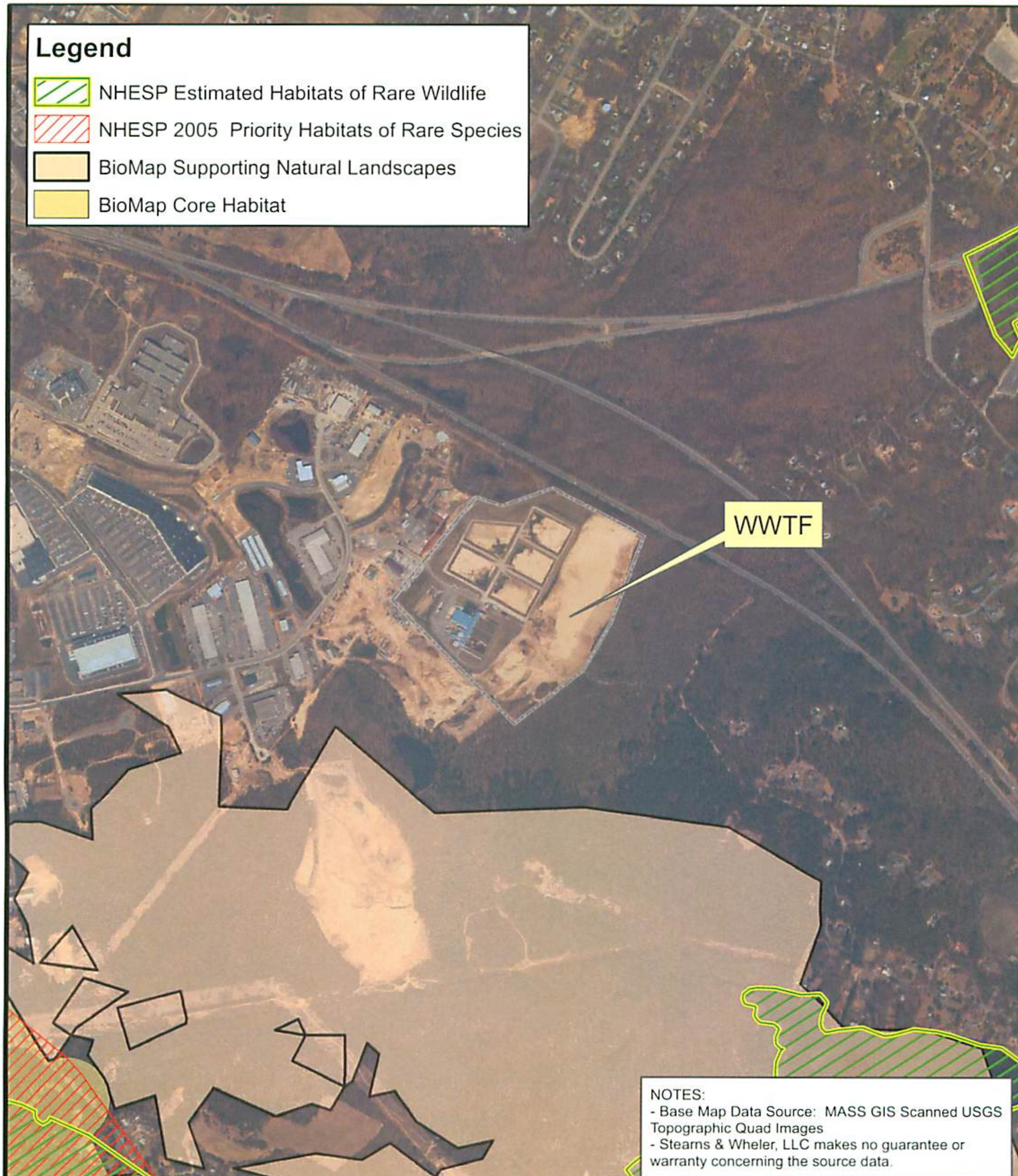
Stearns & Wheler, LLC
Environmental Engineers and Scientists

S&W Job Number: 61174
Filename & Path:J:/GIS/Plymouth MA/Maps/Plymouth Location 8 x 11.mxd

TOWN OF PLYMOUTH, MA

Feasibility Study for
Constructed Wetlands at the WWTF

Figure 2: Site Location Map



N W E S

1 inch equals 1,000 feet

Stearns & Wheler, LLC
Environmental Engineers and Scientists

S&W Job Number: 61174
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TOWN OF PLYMOUTH, MA

Feasibility Study for
Constructed Wetlands at the WWTF

Figure 3: Potential Habitat Areas

N
W E
S

1 inch equals 1,000 feet

Stearns & Wheler, LLC
Environmental Engineers and Scientists

S&W Job Number: 61174
Filename & Path:J:/GIS/Plymouth MA/Maps/Plymouth Wetlands8 x 11.mxd

TOWN OF PLYMOUTH, MA

Feasibility Study for Constructed Wetlands at the WWTF

Figure 4: NWI and DEP Wetlands

APPENDIX C

PLANS AND CROSS SECTIONS

GENERAL NOTES

1. DESIGN ALTERNATIVE #1 IS A SINGLE CELL TREATMENT WETLAND DIVIDED INTO THREE ZONES. THE THREE ZONES CONSIST OF TWO EMERGENT WETLANDS WITH A CENTRAL AREA OF OPEN WATER.

2. THE THREE ZONES COORDINATE AND FACILITATE THE BIOLOGICAL PROCESSES OF AMMONIFICATION, NITRIFICATION AND DENITRIFICATION.

3. AS THE SUBSTRATE AT BASIN NO. 5 CONSISTS OF A HIGH PERMEABILITY RATE, ALL DESIGN ALTERNATIVES REQUIRE A LINER IN ORDER TO MAINTAIN THE PROPER HYDRAULIC RESIDENCE TIME (HRT). HDPE LINER SHALL BE INSTALLED BELOW THE BASIN FLOOR AND BERMS OF THE INFILTRATION BASIN NO.5 PRIOR TO THE CREATION OF THE TREATMENT WETLAND.

4. A MINIMUM OF ONE FOOT OF COMPACTED BACKFILL IS REQUIRED OVER THE HDPE LINER. THIS BACKFILL CAN BE EXISTING SAND FROM WITHIN THE BASIN. LINER INSTALLATION TO BE COORDINATED WITH EARTHWORK TO ACCOMODATE DEEP WATER ZONES.

5. ONCE THE LINER IS INSTALLED AND BACKFILLED WITH 1 FOOT OF SAND, SUITABLE WETLAND SUBTSRATE TO BE INSTALLED TO FINAL WETLAND ELEVATIONS.

6. CATTAIL AND BULRUSH TO BE PLANTED IN THE EMERGENT MARSH AT A SPACING NO GREATER THAN 2 FOOT ON CENTER. SUBMERGED AQUATICS MAY BE PLANTED IN THE OPEN WATER ZONES. SUBMERGED AQUATIC SPECIES MAY INCLUDE WILD CELERY AND WHITE WATER LILY.

7. SIDE SLOPES, BERMS AND AREA IMMEDIATELY ADJACENT TO TREATMENT WETLAND TO BE SEEDED WITH PROPOSED ENVIRONMENTAL SEED MIX. FOR MAINTENANCE PURPOSES, WOODY PLANT MATERIAL SHOULD NOT BE PLANTED IN OR IMMEDIATELY AROUND TREATMENT WETLAND. IF WOODY PLANTS DESIRED FOR AESTHETIC OR WILDLIFE PURPOSES, PLANT LOCATIONS SHOULD COORDINATE WITH WWTF OPERATING PROCEDURES.

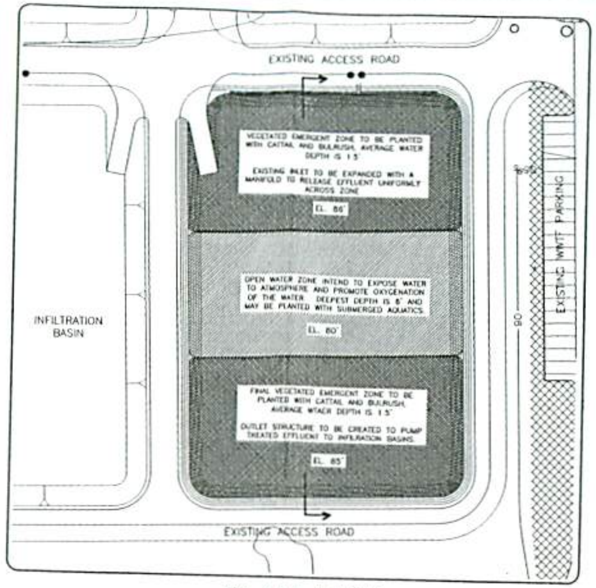
ALTERNATIVE NO.1 PLANT LIST

HERBACEOUS PLANT MATERIAL TO BE PLANTED IN EMERGENT ZONES AT A SPACING NO GREATER THAN 2' ON CENTER (ONE PLANT PER FOUR SQUARE FEET). CATTAIL AND BULRUSH ARE COMMON SPECIES TYPICALLY USED TO IMPROVE WATER QUALITY IN TREATMENT WETLANDS. HERBACEOUS PLANT TO BE PURCHASED FROM NEW ENGLAND WETLAND PLANTS, AMHERST, MA PLANT TYPES (PLUG OR TUBERS) TO BE APPROPRIATE FOR THE YEARLY TIME OF PLANTING.

WETLAND/ENVIRONMENTAL SEED

WETLAND FRINGE, BERMS AND SIDE SLOPES

SEED MIX FOR MOIST GROWTH (DEER TONGUE, ALSIKE CLOVER, ROUGH BLUE-GRASS, MEADOW FESCUE, RED TOP, CREEPING BENT GRASS, SWITCHGRASS, MEADOW FOXTAIL, EASTERN GAMA-GRASS, FOX SEDGE, VIRGINIA WILD-RYE, COREOPSIS, GRASS-LEAVED GOLDENROD, CANADA GOLDENROD, BLUE VERVAIN, JOE-PYE WEED, BONESET, AND FLAT-TOP ASTER). SEED AT A RATE OF 35 LBS/ACRE. SEED MIX FROM NEW ENGLAND WETLAND PLANTS INC, AMHERST MASSACHUSETTS, OR AN APPROVED SUBSTITUTE.



PLAN VIEW

100 0 100 200

EFFLUENT FLOW PATH

EFFLUENT FROM WWTF HIGH IN ORGANIC NITROGEN AND AMMONIUM

⇩

PROPOSED VEGETATED EMERGENT ZONE WITH BOTTOM ELEVATION OF 86'. EFFLUENT FLOW UNIFORM, CONVERT ANY REMAINING ORGANINC NITROGEN TO AMMONIUM

⇩

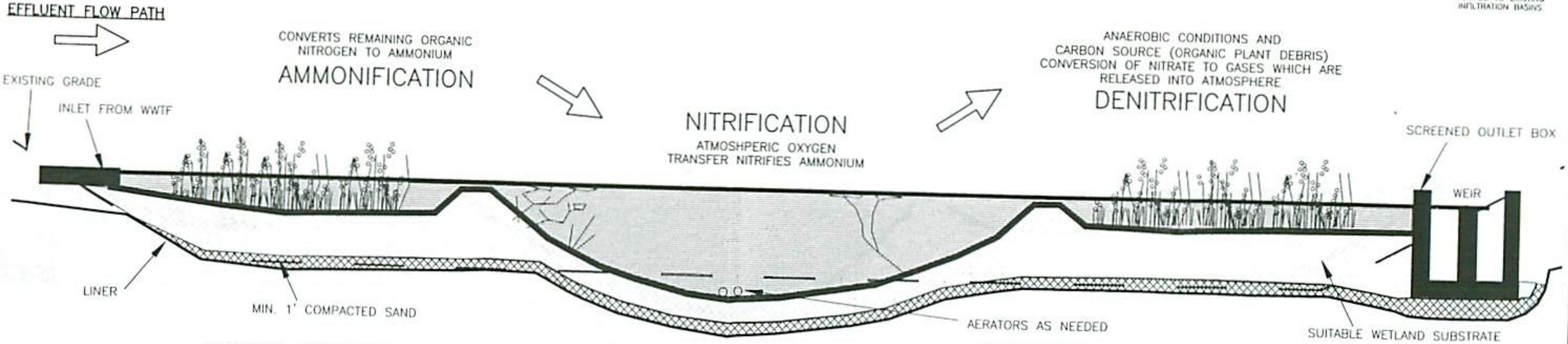
PROPOSED OPEN WATER ZONE BOTTOM EL. 80'. SIX FOOT DEPTH OF WATER TO FOSTER AERATION AND PROMOTE NITRIFICATION

⇩

PROPOSED EMERGENT ZONE WITH BOTTOM ELEVATION OF 85'. ANAEROBIC CONDITIONS AND EXCESS CARBON SOURCE (DECOMPOSING PLANT MATERIAL) SUITABLE FOR DENITRIFICATION

⇩

TREATED EFFLUENT PUMPED TO EXISTING INFILTRATION BASINS



CROSS SECTION OF DESIGN ALTERNATIVE #1
SINGLE CELL WETLAND WITH THREE ZONES

NOT TO SCALE

CALLED NORTH

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MA

DATE:2/2007 JOB No.:61167

FEASIBILITY STUDY FOR CONSTRUCTED WETLANDS
PLYMOUTH WWTF
TOWN OF PLYMOUTH, MA

FREE WATER SURFACE WETLAND
DESIGN ALTERNATIVE #1

GENERAL NOTES

1. DESIGN ALTERNATIVE #2 IS A SINGLE CELL TREATMENT WETLAND WITH A NATURALISTIC LAYOUT. OPEN WATER IS CONTAINED IN ORGANIC SHAPED POOLS WHIILE EMERGENT VEGETATION IS PRESENT THROUGHOUT..

2. THE VARYING EMERGENT AND OPEN WATER ZONEZ COORDINATE AND FACILITATE THE BIOLOGICAL PROCESSES OF AMMONIFICATION, NITRIFICATION AND DENITRIFICATION. HOWEVER, THIS IS ACCOMPLISHED THROUHG A NATURALISTIC WETLAND RATHER THAN DEFINED CELLS.

3. AS THE SUBSTRATE AT BASIN NO. 5 CONSISTS OF A HIGH PERMEABILITY RATE, ALL DESIGN ALTERNATIVES REQUIRE A LINER IN ORDER TO MAINTAIN THE PROPER HYDRAULIC RESIDENCE TIME (HRT). HDPE LINER SHALL BE INSTALLED BELOW THE BASIN FLOOR AND BERMS OF THE INFILTRATION BASIN NO.5 PRIOR TO THE CREATION OF THE TREATMENT WETLAND.

4. A MINIMUM OF ONE FOOT OF COMPACTED BACKFILL IS REQUIRED OVER THE HDPE LINER. THIS BACKFILL CAN BE EXISTING SAND FROM WITHIN THE BASIN. LINER INSTALLATION TO BE COORDINATED WITH EARTHWORK TO ACCOMODATE DEEP WATER ZONES.

5. ONCE THE LINER IS INSTALLED AND BACKFILLED, SUITABLE WETLAND SUBSTRATE TO BE INSTALLED TO FINAL WETLAND ELEVATIONS. THIS ALTERNATIVE REQUIRES SPECIFIC ATTENTION BE PAID TO AESTHETICS OF THE LAYOUT OF THE OPEN WATER AND EMERGENT ZONES.

6. CATTAIL AND BULRUSH TO BE PLANTED IN THE EMERGENT MARSH AT A SPACING NO GREATER THAN 2 FOOT ON CENTER. SUBMERGED AQUATICS MAY BE PLANTED IN THE OPEN WATER ZONES. SUBMERGED AQUATIC SPECIES MAY INCLUDE WILD CELERY AND WHITE WATER LILY.

7. SIDE SLOPES, BERMS AND AREA IMMEDIATELY ADJACENT TO TREATMENT WETLAND TO BE SEEDED WITH PROPOSED ENVIRONMENTAL SEED MIX. FOR MAINTENANCE PURPOSES, WOODY PLANT MATERIAL SHOULD NOT BE PLANTED IN OR IMMEDIATELY AROUND TREATMENT WETLAND. IF WOODY PLANTS DESIRED FOR AESTHETIC OR WILDLIFE PURPOSES, PLANT LOCATIONS SHOULD COORDINATE WITH WWTF OPERATING PROCEDURES.

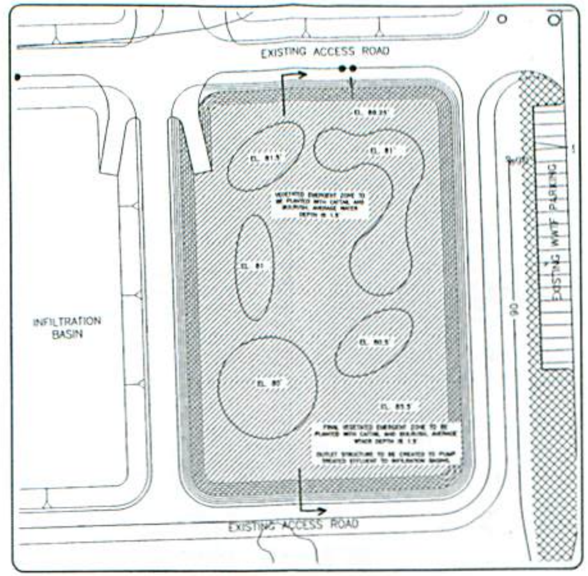
ALTERNATIVE No.2 PLANT LIST

HERBACEOUS PLANT MATERIAL TO BE PLANTED IN EMERGENT ZONES AT A SPACING NO GREATER THAN 2' ON CENTER (ONE PLANT PER FOUR SQUARE FEET). CATTAIL AND BULRUSH ARE COMMON SPECIES TYPICALLY USED TO IMPROVE WATER QUALITY IN TREATMENT WETLANDS. HERBACEOUS PLANT TO BE PURCHASED FROM NEW ENGLAND WETLAND PLANTS, AMHERST, MA. PLANT TYPES (PLUG OR TUBERS) TO BE APPROPRIATE FOR THE YEARLY TIME OF PLANTING.

WETLAND/ENVIRONMENTAL SEED

WETLAND FRINGE, BERMS AND SIDE SLOPES

SEED MIX FOR MOIST GROWTH (DEER TONGUE, ALSIKE CLOVER, ROUGH BLUE-GRASS, MEADOW FESCUE, RED TOP, CREEPING BENT GRASS, SWITCHGRASS, MEADOW FOXTAIL, EASTERN GAMA-GRASS, FOX SEDGE, VIRGINIA WILD-RYE, COREOPSIS, GRASS-LEAVED GOLDENROD, CANADA GOLDENROD, BLUE VERVAIN, JOE-PYE WEED, BONESET, AND FLAT-TOP ASTER). SEED AT A RATE OF 35 LBS/ACRE. SEED MIX FROM NEW ENGLAND WETLAND PLANTS INC, AMHERST MASSACHUSETTS, OR AN APPROVED SUBSTITUTE.



PLAN VIEW

100 0 100 200

EFFLUENT FLOW PATH

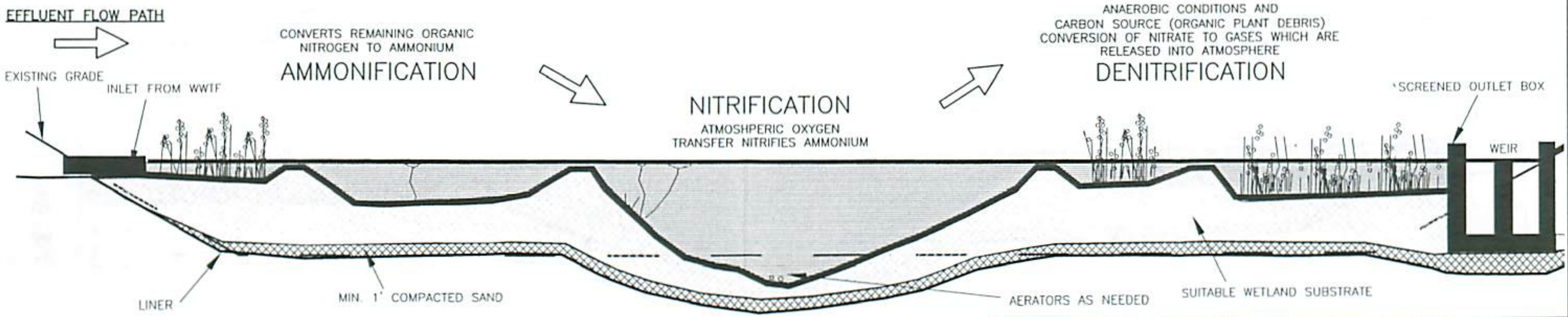
EFFLUENT FROM WWTF HIGH IN ORGANIC NITROGEN AND AMMONIUM

PROPOSED VEGETATED EMERGENT ZONES WITH BOTTOM ELEVATION OF 86.25' - 85.5'. EFFLUENT FLOW MEANDERS, CONVERTING ANY ORGANIC NITROGEN TO AMMONIUM

PROPOSED OPEN WATER ZONES BOTTOM EL. 81.5' - 80'. SIX FOOT DEPTH OF WATER TO FOSTER AERATION AND PROMOTED NITRIFICATION

PROPOSED EMERGENT ZONE WITH BOTTOM ELEVATION OF 85.5'. ANAEROBIC CONDITIONS AND EXCESS CARBON SOURCE (DECOMPOSING PLANT MATERIAL) SUITABLE FOR DENITRIFICATION

TREATED EFFLUENT PUMPED TO EXISTING INFILTRATION BASINS



CROSS SECTION OF DESIGN ALTERNATIVE #2
NATURALISTIC SHAPES WITH VARIOUS ZONES

NOT TO SCALE

CALLED NORTH

Stearns & Wheler, LLC Environmental Engineers and Scientists HYANNIS, MA DATE:2/2007 JOB No.:61167	FEASIBILITY STUDY FOR CONSTRUCTED WETLANDS PLYMOUTH WWTF TOWN OF PLYMOUTH, MA FREE WATER SURFACE WETLAND DESIGN ALTERNATIVE #2

X-REF NAMES?
2006/SEP/OSL/CAZ
DRAWING PATH WITH NAME AND EXTENSION

GENERAL NOTES

1. DESIGN ALTERNATIVE #3 IS A MULTI-CELL SUBSURFACE TREATMENT WETLAND. BIOLOGICAL PROCESS FOR NITROGEN REMOVAL OCCUR BELOW THE SURFACE WITHIN A GRAVEL BED.

2. EFFLUENT WILL FLOW THROUGH A GRAVEL BED WITHIN BASION NO. 5. A DENSE LAYER OF HERBACEOUS PLANTS SHALL BE PLANTED ON THE TOP OF THE GRAVEL BED. HERBACEOUS PLANT MAY BE TYPHA AND SCIRPUS PLANTED AS PLUGS OR MAY BE SEEDED WITH LEERSIA ORYZOIDES (RICE CUTGRASS).

3. AS THE SUBSTRATE AT BASIN NO. 5 CONSISTS OF A HIGHLY PERMEABLE SAND, ALL WETLAND DESIGN ALTERNATIVES REQUIRE A LINER IN ORDER TO MAINTAIN THE PROPER HYDRAULIC RESIDENCE TIME (HRT). HDPE LINER SHALL BE INSTALLED BELOW THE BASIN FLOOR AND BERMS OF THE INFILTRATION BASIN NO.5 PRIOR TO THE CREATION OF THE TREATMENT WETLAND.

4. A MINIMUM OF ONE FOOT OF COMPACTED BACKFILL IS REQUIRED OVER THE HDPE LINER. THIS BACKFILL CAN BE EXISTING SAND FROM WITHIN THE BASIN OR GRAVEL.

5. ONCE THE LINER IS INSTALLED AND BACKFILLED, GRAVEL MAY BE INSTALLED TO FINAL ELEVATIONS.

6. SIDE SLOPES, BERMS AND AREA IMMEDIATELY ADJACENT TO TREATMENT WETLAND TO BE SEEDED WITH PROPOSED ENVIRONMENTAL SEED MIX. FOR MAINTENANCE PURPOSES, WOODY PLANT MATERIAL SHOULD NOT BE PLANTED IN OR IMMEDIATELY AROUND TREATMENT WETLAND. IF WOODY PLANTS DESIRED FOR AESTHETIC OR WILDLIFE PURPOSES, PLANT LOCATIONS SHOULD COORDINATE WITH WWTF OPERATING PROCEDURES.

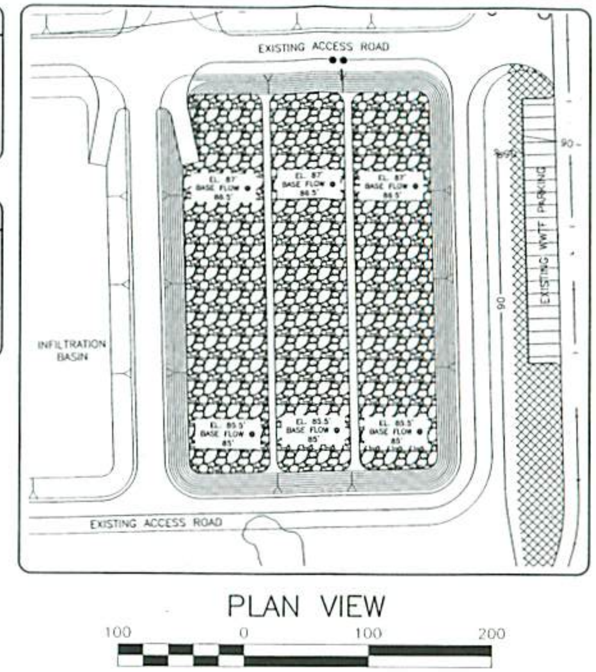
ALTERNATIVE NO.3 PLANT LIST

HERBACEOUS PLANT MATERIAL TO BE PLANTED IN EMERGENT ZONES AT A SPACING NO GREATER THAN 2' ON CENTER (ONE PLANT PER FOUR SQUARE FEET). CATTAIL AND BULRUSH ARE COMMON SPECIES TYPICALLY USED TO IMPROVE WATER QUALITY IN TREATMENT WETLANDS. HERBACEOUS PLANT TO BE PURCHASED FROM NEW ENGLAND WETLAND PLANTS, AMHERST, MA. PLANT TYPES (PLUG OR TUBERS) TO BE APPROPRIATE FOR THE YEARLY TIME OF PLANTING. IF CONDITIONS ALLOW, RICE CUTGRASS MAY BE BROADCAST OVER ENTIRE GRAVEL WETLAND.

WETLAND/ENVIRONMENTAL SEED

WETLAND FRINGE, BERMS AND SIDE SLOPES

SEED MIX FOR MOIST GROWTH (DEER TONGUE, ALSIKE CLOVER, ROUGH BLUE-GRASS, MEADOW FESCUE, RED TOP, CREEPING BENT GRASS, SWITCHGRASS, MEADOW FOXTAIL, EASTERN GAMA-GRASS, FOX SEDGE, VIRGINIA WILD-RYE, COREOPSIS, GRASS-LEAVED GOLDENROD, CANADA GOLDENROD, BLUE VERVAIN, JOE-PYE WEED, BONESET, AND FLAT-TOP ASTER). SEED AT A RATE OF 35 LBS/ACRE. SEED MIX FROM NEW ENGLAND WETLAND PLANTS INC, AMHERST MASSACHUSETTS, OR AN APPROVED SUBSTITUTE.



PLAN VIEW

EFFLUENT FLOW PATH

EFFLUENT FROM WWTF HIGH IN ORGANIC NITROGEN AND AMMONIUM

SUBSURFACE WETLANDS PROVIDE ANAEROBIC CONDITIONS. THE ROOTS ZONES IF IN PROPER CONTACT WITH WATER, WILL PROVIDED OXYGEN.

THE ROOT ZONES, IN CONJUNCTION WITH SURFACES OF THE GRAVEL ALLOW FOR NECESSARY BIOLOGICAL PROCESSES TO OCCUR

AS THE EFFLUENT REMAINS BELOW THE SURFACE, ODOR CONTROL AND SAFETY ARE AN ADVANTAGE OF SUBSURFACE WETLANDS

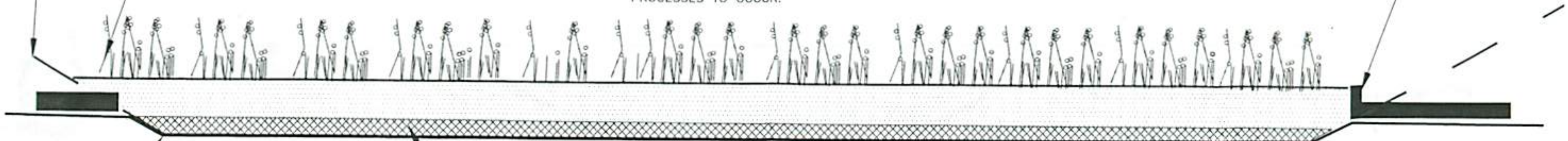
EFFLUENT FLOWS TO AN OUTLET AT THE BOTTOM OF THE SUBSURFACE CELL AND THE TREATED EFFLUENT PUMPED TO EXISTING INFILTRATION BASINS

EFFLUENT FLOW PATH

BIOLOGICAL PROCESSES CONTINUALLY OCCUR WITHIN GRAVEL BED

SUBSURFACE CONDITIONS PROVIDE ANAEROBIC ATMOSPHERE, THE ROOT ZONES SUPPY OXYGEN, AND THE PLANT DEBRIS UNDER SURFACE PROVIDE CARBON SOURCE

THE GRAVEL MEDIA PROVIDES A LARGE AMOUNT OF SURFACE AREA FOR TREATMENT PROCESSES TO OCCUR.



CROSS SECTION OF DESIGN ALTERNATIVE #3
SUBSURFACE WETLAND

NOT TO SCALE

CALLED NORTH

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MA

DATE:2/2007 JOB No. 61167

FEASIBILITY STUDY FOR CONSTRUCTED WETLANDS
PLYMOUTH WWTF
TOWN OF PLYMOUTH, MA

SUBSURFACE TREATMENT WETLAND
DESIGN ALTERNATIVE #3

X-REF NAMES?
2006/SEP/GSL/CAZ
DRAWING PATH, WITH NAME AND EXTENSION

GENERAL NOTES

1. DESIGN ALTERNATIVE #4 IS A HYBRID WETLAND SYSTEM WITH A SERIES OF SUBSURFACE, EMERGENT AND OPEN WATER WETLANDS.

2. THE VARYING ZONES COORDINATE AND FACILITATE THE BIOLOGICAL PROCESSES OF AMMONIFICATION, NITRIFICATION AND DENITRIFICATION.

3. AS THE SUBSTRATE AT BASIN NO. 5 CONSISTS OF A HIGH PERMEABILITY RATE, ALL DESIGN ALTERNATIVES REQUIRE A LINER IN ORDER TO MAINTAIN THE PROPER HYDRAULIC RESIDENCE TIME (HRT). HDPE LINER SHALL BE INSTALLED BELOW THE BASIN FLOOR AND BERMS OF THE INFILTRATION BASIN NO.5 PRIOR TO THE CREATION OF THE TREATMENT WETLAND.

4. A MINIMUM OF ONE FOOT OF COMPACTED BACKFILL IS REQUIRED OVER THE HDPE LINER. THIS BACKFILL CAN BE EXISTING SAND FROM WITHIN THE BASIN. LINER INSTALLATION TO BE COORDINATED WITH EARTHWORK TO ACCOMODATE DEEP WATER ZONES.

5. ONCE THE LINER IS INSTALLED AND BACKFILLED, GRAVEL AND SOIL SHALL BE INSTALLED.

6. CATTAIL AND BULRUSH TO BE PLANTED IN THE EMERGENT MARSH AT A SPACING NO GREATER THAN 2 FOOT ON CENTER. SUBMERGED AQUATICS MAY BE PLANTED IN THE OPEN WATER ZONES. SUBMERGED AQUATIC SPECIES MAY INCLUDE WILD CELERY AND WHITE WATER LILY.

7. SIDE SLOPES, BERMS AND AREA IMMEDIATELY ADJACENT TO TREATMENT WETLAND TO BE SEEDED WITH PROPOSED ENVIRONMENTAL SEED MIX. FOR MAINTENANCE PURPOSES, WOODY PLANT MATERIAL SHOULD NOT BE PLANTED IN OR IMMEDIATELY AROUND TREATMENT WETLAND. IF WOODY PLANTS DESIRED FOR AESTHETIC OR WILDLIFE PURPOSES, PLANT LOCATIONS SHOULD COORDINATE WITH WWTF OPERATING PROCEDURES.

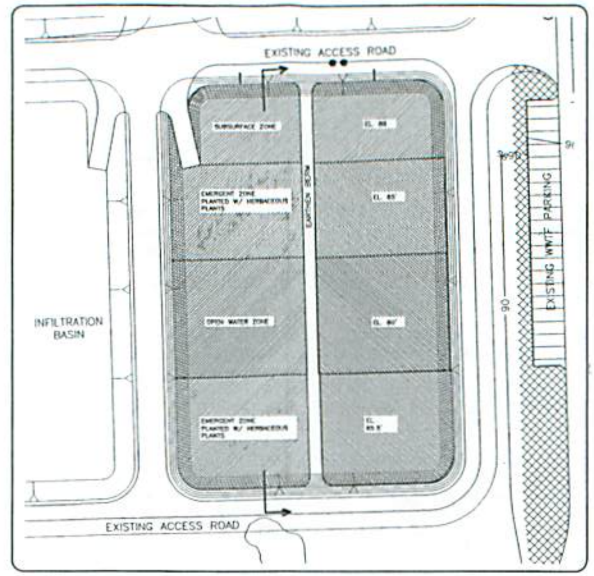
ALTERNATIVE NO.4 PLANT LIST

HERBACEOUS PLANT MATERIAL TO BE PLANTED IN EMERGENT ZONES AT A SPACING NO GREATER THAN 2' ON CENTER (ONE PLANT PER FOUR SQUARE FEET). CATTAIL AND BULRUSH ARE COMMON SPECIES TYPICALLY USED TO IMPROVE WATER QUALITY IN TREATMENT WETLANDS. HERBACEOUS PLANT TO BE PURCHASED FROM NEW ENGLAND WETLAND PLANTS, AMHERST, MA. PLANT TYPES (PLUG OR TUBERS) TO BE APPROPRIATE FOR THE YEARLY TIME OF PLANTING.

WETLAND/ENVIRONMENTAL SEED

WETLAND FRINGE, BERMS AND SIDE SLOPES

SEED MIX FOR MOIST GROWTH (DEER TONGUE, ALSIKE CLOVER, ROUGH BLUE-GRASS, MEADOW FESCUE, RED TOP, CREEPING BENT GRASS, SWITCHGRASS, MEADOW FOXTAIL, EASTERN GAMA-GRASS, FOX SEDGE, VIRGINIA WILD-RYE, COREOPSIS, GRASS-LEAVED GOLDENROD, CANADA GOLDENROD, BLUE VERVAIN, JOE-PYE WEED, BONESET, AND FLAT-TOP ASTER). SEED AT A RATE OF 35 LBS/ACRE. SEED MIX FROM NEW ENGLAND WETLAND PLANTS INC, AMHERST MASSACHUSETTS, OR AN APPROVED SUBSTITUTE.



PLAN VIEW

100 0 100 200

EFFLUENT FLOW PATH

EFFLUENT FROM WWTF HIGH IN ORGANIC NITROGEN AND AMMONIUM

SUBSURFACE WETLANDS PROVIDE ANAEROBIC CONDITIONS

EMERGENT ZONE PROVIDES ADDED OPPORTUNITY FOR AMMONIFICATION

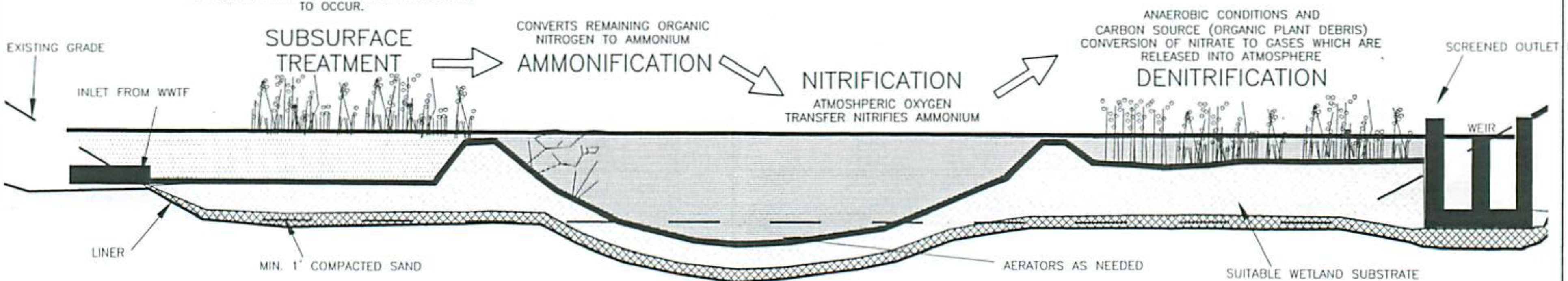
AERATION OCCURS IN OPEN WATER ZONE LEADING TO NITRIFICATION

FINAL EMERGENT ZONE PROVIDES PLANT DEBRIS (CARBON SOURCE) AND ANAEROBIC CONDITIONS FOR DENITRIFICATION

EFFLUENT FLOWS TWO OUTLETS AND THE TREATED EFFLUENT IS PUMPED TO EXISTING INFILTRATION BASINS

EFFLUENT FLOW PATH

THE GRAVEL MEDIA PROVIDES A LARGE AMOUNT OF SURFACE AREA FOR TREATMENT PROCESSES TO OCCUR.



CROSS SECTION OF DESIGN ALTERNATIVE #4 HYBRID FREE WATER AND SUBSURFACE SYSTEM

NOT TO SCALE

CALLED NORTH

Stearns & Wheler, LLC
Environmental Engineers and Scientists
HYANNIS, MA

DATE:2/2007 JOB No.:61167

FEASIBILITY STUDY FOR CONSTRUCTED WETLANDS
PLYMOUTH WWTF
TOWN OF PLYMOUTH, MA

HYBRID WETLAND SYSTEM
DESIGN ALTERNATIVE #4

X-REF: NAMES? 2006/SEP/COL/CAZ DRAWING PATH WITH NAME AND EXTENSION

APPENDIX D

STATE REVOLVING LOAN FUND

Massachusetts Clean Water State Revolving Fund Program

MassDEP
Division of Municipal Services
2006

Introduction

The Massachusetts State Revolving Fund (SRF) for water pollution abatement projects was established to provide a low-cost funding mechanism to assist municipalities in complying with federal and state water quality requirements. The SRF Program is jointly administered by the Division of Municipal Services of the Department of Environmental Protection (MassDEP) and the Massachusetts Water Pollution Abatement Trust. Each year MassDEP solicits projects from Massachusetts municipalities and wastewater districts to be considered for subsidized loans. The current subsidy is provided via a 2% interest loan. In recent years the program has operated with $300 to $350 million per year, representing the financing of 50 to 70 projects annually. The SRF Program continues to emphasize watershed management priorities. A major goal is to provide incentives to communities to undertake projects with meaningful water quality and public health benefits and which address the needs of the communities and the watersheds.

Eligible Projects

Financial assistance is available for planning and construction of projects, including CSO mitigation, new wastewater treatment facilities and upgrades of existing facilities, infiltration/inflow correction, wastewater collection systems, and nonpoint source pollution abatement projects, such as landfill capping, community programs for upgrading septic systems (Title 5), brownfield remediation, pollution prevention, and stormwater remediation. In addition, non-structural projects are eligible for SRF funding; e.g., planning projects for nonpoint source problems which are consistent with the MassDEP's Nonpoint Source Management Plan and that identify pollution sources and suggest potential remediation strategies.

Project Rating

In order to be considered for SRF funding, a community must complete a Project Evaluation Form (PEF) at the time of the project solicitation which MassDEP conducts during the summer/fall of each year. MassDEP will rank projects using a rating system which assigns points on the basis of various environmental, programmatic, and implementation criteria. These criteria include the extent to which the project:

- will have demonstrable water quality benefits;
- will eliminate or mitigate a risk to public health;
- is needed to achieve or maintain compliance with applicable discharge permits or other water pollution control requirements;
- will implement or be consistent with watershed management plans (or addresses a watershed priority) and is consistent with local and regional growth plans; and
- the borrower supports the Commonwealth Sustainable Development Initiative, as evidenced by its Commonwealth Capital Score.

CWSRF Process Steps

1. Project Solicitation/PEF
2. Annual Priority List
3. IUP Project List
4. Loan Application
5. Project Approval Certificate
6 Loan Commitment Issued
7 Project Regulatory Agreement
8 Loan Agreement Executed

Project Priority List and Intended Use Plan Project Listing

After evaluating the project requests submitted in response to the annual solicitation, MassDEP develops a list of projects eligible to receive financial assistance. From this annual list, and on the basis of projects' readiness to proceed and priority rating, MassDEP assigns projects to a fundable list, the Intended Use Plan Project Listing (IUP). Projects on the IUP are eligible to apply for financing in the coming year, with the total cost of all projects on the IUP not to exceed the amount of funding available for that year. To qualify for placement on the IUP, a project must have a high enough ranking, have received a local funding appropriation, or be scheduled for funding appropriation by June 30 of the coming year, and the applicant must be able to file a complete loan application no later than October 15 of the coming year.

Funding Commitments

To obtain funding for a project on the IUP, the borrower must file a loan application and obtain a Project Approval Certificate from MassDEP. The loan application must include information about funding authorization, repayment ability, and project schedule. A complete loan application also includes construction contract documents ready for bidding and evidence of compliance with any applicable environmental reviews and permits.

Once MassDEP certifies that costs are eligible for funding from the CWSRF Program, the Trust votes to issue the borrower a binding loan commitment. This commits MassDEP to finance the full eligible cost of the project, as described in the Borrower's initial application. MassDEP then issues a Project Regulatory Agreement (PRA). The PRA includes MassDEP's regulation and supervision conditions and limitations, cash drawdown schedule, and provisions from the PAC.

The Trust, MassDEP, and the borrower then enter into a loan agreement to secure the financing for the project. The loan agreement establishes the security of the loan, repayment schedule, interest rates, and subsidies, as well as various procedural and regulatory requirements related to the MassDEP's oversight of the project. Following MassDEP approval of the PAC, the project must commence in six months.

For More Information

To obtain additional information concerning the SRF Program, please contact one of the following regional program managers:

Northeast:	Kevin Brander	978/694-3236
Southeast:	Richard Keith	508/946-2784
Central:	Paul Anderson	508/767-2802
West:	Deirdre Cabral	413/755-2148

Municipal services staff in MassDEP's Boston office:

Steve McCurdy, Director 617/292-5779

Information also is available on MassDEP's web site:
http://www.mass.gov/dep/water/wastewater/srfhowto.htm
and
Massachusetts Water Pollution Abatement Trust web site:
http://www.mass.gov/treasury/mwpat/wpat.htm

A publication of the Commonwealth of Massachusetts, Executive Office of Environmental Affairs, Department of Environmental Protection, Bureau of Resource Protection, 1 Winter Street, Boston, MA 02108

This information is available in alternative format upon request by contacting the ADA Coordinator at 617/556-1057.

Obtaining SRF Loans

1. Project Gets on the Division's Annual Priority List.

In the early Spring of each year, the Division solicits proposed projects for financial assistance by mailing each community in the state Project Evaluation Forms. These forms, along with their supporting documentation, once completed and submitted by the community or its consulting engineer, provide the information necessary for the Division to rank projects in accordance with the rating systems established by regulation for each category of project.

All projects eligible for funding under the SRF are placed on the coming fiscal year's project priority list in order of priority points assigned by the rating system. The rating system assigns points on the basis of type of project, extent of environmental or public health protection improvement to be achieved, and other factors which are specific to each category of project. It is important that the problems to be corrected by a proposed project, and the benefits to be achieved, be adequately documented by the community in completing the Project Evaluation Form.

An important consideration in the Division's review of a Project Evaluation Form is the status and timing of the proposed project. From the list of all eligible projects that will be ready to proceed during the coming year, the Division establishes a proposed fundable list of projects (also called the Intended Use Plan) identifying those projects planned for financial assistance during the fiscal year. Projects are assigned to the fundable list in order of priority points, with the total cost of all projects on the list not to exceed the amount of funding available for the year. In order to be considered for the fundable list, the applicant must be able to submit an application for financial assistance in time to be reviewed and approved by the Division before the end of the coming fiscal year (generally, at the latest at least three months before the end of the fiscal year.) In order for the application to be approved, other steps would also have to have been accomplished before that time, such as a local appropriation of funds and, in the case of a construction project, the preparation of plans and specifications.

While only projects which appear on the current fundable list (Intended Use Plan) can receive financial assistance during a given year, it is possible for a project on the extended priority list to be moved up to the fundable list during the course of the year. This could occur if any of the fundable list projects encounter delays which would prevent their approval before the end of the fiscal year.

2. Community Submits Application and Supporting Documentation.

In order for a community to obtain funding for its project appearing on the fundable list (Intended Use Plan), it must file an Application for Financial Assistance and obtain a Project Approval Certificate from the Division. In addition to information about the project and documentation that applicable requirements are met by the project, the application requires community financial data needed to determine the applicant's ability to repay the loan.

3. The Division Approves the Project and Certifies the Application to the Trust.

The Division evaluates projects for compliance with engineering and environmental requirements as well as a number of specific legal, regulatory, and administrative requirements. Examples of such requirements would include the local appropriation of funds previously mentioned; existence of any necessary easements or legal title to land; presence of acceptable user charge systems, sewer use ordinances, and O & M programs; and evidence of compliance with other federal and state permitting requirements.

For a construction project, completed plans and specifications must be approved by the Division prior to or at the time of issuance of the Project Approval Certificate. The corresponding prerequisites for design and planning projects are an approved Facilities Plan and an approved Plan of Study, respectively.

Once the Division certifies the application to the Water Pollution Abatement Trust (TRUST), an applicant may proceed with construction of its project without loss of eligibility for financial assistance.

APPENDIX E

TECHNICAL MEMORANDUM

EcoLogic Memorandum

TO:	Greg Liberman, Stearns & Wheler
FROM:	Liz Moran, Ph.D.
RE:	Projected nutrient removal rates, constructed wetlands, Plymouth MA
DATE:	May 16, 2007

Introduction

At your request, EcoLogic has investigated the potential nitrogen removal achieved by construction of a treatment wetland at the Plymouth MA wastewater treatment facility. We reviewed the February 2007 Stearns & Wheler report entitled "Feasibility Study for Constructed Treatment Wetlands at the Plymouth WWTF", and files of influent and effluent data measured at the facility over the period May 1, 2005 – April 30, 2006.

After reviewing correspondence between Stearns & Wheler and the Town of Plymouth Environmental Management Division, we understood that there is a desire for clarification and (to the extent possible) quantification of the potential efficacy of the recommended alternative. The following questions were posed by representatives of the Town of Plymouth.

1. Is it possible to define the "polishing effect" for nitrogen? Is this a 1,2 mg/L reduction or less?
2. What would the reduction be if the plant was at or near the 10 mg/L? Is it still a polishing effect for nitrogen?
3. What are the reduction rates for phosphorus?
4. Lastly, in the report it states that there are 32 states that have FWS treatment wetlands for treating municipal wastewater (pg 25) - is it possible to list these in an appendix? And possibly show data results...reduction in nitrogen/phosphorus?

Data resources

We have reviewed recent scientific and technical publications detailing the range of nutrient removal achieved with various designs of constructed wetlands. Three primary sources are described below; additional references are included at the end of this memorandum.

The USEPA distributes a database tracking performance of constructed wetlands throughout North America. This is available on CD by request (contact Donald Brown 'brown.donald@epa.gov'

EPA 600/C-94/002 Treatment Wetland Habitat and Wildlife Use Assessment and North American Treatment Wetland Database V 2.0

The EPA database has not been updated since 1993. Much, but not all, of the information in the EPA database can be accessed on a web site maintained by Humboldt State University http://firehole.humboldt.edu/wetland/twdb.html

> *"This web site serves as an access point to a database on constructed treatment wetlands. The treatment wetland database (TWDB) contains system descriptions and performance data for a large number of pilot, and full-scale wetland systems treating a variety of sources, including municipal wastewater, stormwater runoff, industrial*

wastewater, and agricultural runoff. The database contains the bulk of the entries in the revised EPA-sponsored North American Database (NADB Version 2), and data from many additional treatment wetlands. While the emphasis is on constructed wetlands, natural wetlands are also included in the database."

A particularly useful resource was recently published by the Water Environment Research Foundation (WERF). EcoLogic environmental scientists relied on this report as a primary source of information to address the questions posed by the Plymouth town staff.

Wallace, Scott D. and Robert L. Knight. 2006. *Small-Scale Constructed Wetland Treatment Systems: Feasibility, Design Criteria and O&M Requirements*. Water Environment Research Foundation, Washington D.C. 304 pp.

Projected N removal rates

The recommended constructed wetland would be designed to receive a portion of the effluent from the Plymouth WWTF. Effluent quality data measured from May 1, 2005 – April 30, 2006 is summarized below.

Month	Year	Flow mgd	TP mg/l	TP load ppd	NO3 mg/l	TN mg/l	NO3 load ppd	TN load ppd
May	2005	0.187	6.45	10.2	2.4	4.3	3.7	6.7
June	2005	0.103	7.05	6.1	0.96	3.1	0.8	2.7
July	2005	0.06	6.28	3.2	0.66	3.7	0.3	1.9
August	2005	0.02	5.52	0.9	2.08	4.4	0.3	0.7
September	2005	0.019	5.35	0.9	2.53	4.8	0.4	0.8
October	2005	0.149	5.85	7.4	1.26	3.9	1.6	4.8
November	2005	0.15	4.5	5.7	1.15	4.2	1.4	5.3
December	2005	0.132	5.4	6.0	1.95	5.8	2.1	6.4
January	2006	0.176	4.85	7.2	1.3	3.6	1.9	5.3
February	2006	0.122	4	4.1	1.07	4	1.1	4.1
March	2006	0.115	3.95	3.8	0.68	3.7	0.7	3.5
April	2006	0.156	5.85	7.7	0.23	3.1	0.3	4.0
Average		0.12	5.42	5.3	1.4	4.1	1.4	3.8

The data are consistent with nitrified, secondary effluent. The treatment facility is achieving relatively consistent year-round nitrification of the effluent, as evident by the lack of distinct seasonality in nitrate concentration.

The recommended Free Water Surface (FWS) wetland is appropriate for treating effluent of this quality. The WERF publication summarizes more than 750 measurements of TKN removal achieved by 159 FWS wetland systems. Of these systems, the mean TKN in the influent was 3.4 mg/l, and the mean TKN of the effluent was 1.9 mg/l. corresponding to a 44% reduction in TKN. The relatively low concentration in the influent of systems used in the WERF analysis is consistent with nitrified wastewater.

As described in the Stearns & Wheler report, a FWS wetland has multiple pathways for transformation and removal of nitrogen species. All the major pathways (mineralization, nitrification, denitrification and volatilization) are likely to occur due to the range of oxidation-reduction (redox) conditions in the wetland sediments. Design criteria including loading rate and hydraulic retention time are significant factors affecting the efficiency of removal. Other factors, including seasonal temperature cycles and the duration of ice cover, will affect the rates of nitrogen transformation in the constructed wetland.

There is a significant difference in the reported efficacy of constructed wetlands to remove TKN (WERF reports an average 44% removal) and TN (EPA reports an average 12% removal). Some of the uncertainty originates from the nature of the EPA and WERF databases; they encompass a range of constructed wetlands of various sizes, climatic setting, influent quality, and hydraulic residence time. Additional uncertainty arises from the chemical fractions measured and reported. TKN includes organic and ammonia N; while TN includes these fractions as well as the oxidized fractions of nitrate and nitrite. It makes a difference if the wetland is designed to oxidize reduced TKN (optimize nitrification) or remove N (optimize denitrification).

For the Plymouth application, the wastewater effluent is low in TKN; most of the reduced nitrogen available for microbial decomposition is metabolized during the wastewater treatment process. The organic fraction that remains is likely to be recalcitrant. The design objective of the Plymouth treatment wetland would be to optimize denitrification. Data reporting TN removal, rather than oxidation of reduced N (reported as TKN) were therefore considered most relevant to this project.

The temperature fluctuations expected on Cape Cod also support a conservative estimate of the annual N removal. Because the processes affecting N transformations are biochemically-mediated, temperature fluctuations will produce significant monthly variations in removal. Data reported in the WERF study indicate a three-fold variation in TKN removal by a FWS wetland in Ontario over an annual cycle; removal rates of 75% during warm water declined to just over 20% during the winter (WERF 2006 pg. 84). The low oxidation of TKN in this system in winter was considered to reflect both water temperature and ice cover, which limited oxygen transfer. Recall that for the Plymouth system, the effluent is nitrified and the major removal process will be denitrification. Oxygen availability would consequently not be important; however, denitrification is a temperature-dependent process and high seasonal variability would be anticipated.

Denitrification is dependant on the availability of organic carbon. In FWS wetlands, wetland plant detritus is typically the primary source of organic carbon. The concentration of biochemical oxygen demanding-material (BOD) in the Plymouth effluent is low; consequently, decaying wetland plants would be the primary source of organic carbon to support the denitrifying microbial populations. The total amount of denitrification taking place in a constructed wetland can be estimated by the total amount of plant biomass production. Using an average production estimate for temperate wetlands of 3,000 g/m^2-yr of plant material (WERF 2006), there would theoretically be enough available organic carbon to reduce 558 g/m^2-yr of nitrate N. The loading from the Plymouth WWTF is well below this threshold.

This estimate also allows us to address the question of performance of the constructed wetland if the effluent nitrate-N concentration approached 10 mg/l. As calculated in the table below, the organic carbon in the wetland plants would be adequate to support denitrification of this loading level.

	Current	Projected
Average effluent NO3-N (mg/l)	1.4	10
Discharge (mgd)	0.12	0.12
NO3-N load (ppd)	1.40	10.0
NO3-N load (kg/day)	0.64	4.55
Wetland size (ha)	0.56	0.56
NO3 load (kg/ha-day)	1.14	8.12
NO3 load (kg/ha-yr)	415	2965
NO3 load (g/m2-yr)	41.5	296.5
Below critical value (558 g/m2-yr)?	yes	yes

The proposed constructed wetland can, in theory, produce sufficient organic carbon to achieve denitrification of the residual nitrate-N in the wastewater effluent from the Plymouth wastewater treatment facility. Substantial monthly variation in removal can be expected.

Projected P removal rates

In contrast to the nitrogen transformation, the processes affecting phosphorus (P) removal in the constructed wetlands are primarily physical and chemical, not biological. There will be an initial loss of phosphorus from the wastewater as P sorbs onto wetland sediments. This capacity will become saturated.

Direct settling of particulate P can increase removal. Based on the Plymouth WWTP data from May 1, 2005 – April 30, 2006, total suspended solids concentration in the effluent is relatively low (average 13.8 mg/l) and the P in the effluent is primarily in the soluble form. We conclude that settling of particulate material will not represent a substantial loss pathway for phosphorus.

Some of the P will be incorporated into biomass. However, this P becomes re-released to the water during senescence. Periodic harvesting of biomass can enhance this removal mechanism.

Long-term accretion and loss from the system will occur as P is mineralized and buried. Based on data reported from a comparable constructed wetland in Michigan, about 20% influent P was buried in sediment (WERF 2006). This removal rate was calculated to be about 4 gm/m^2-year. However, the primary factor affecting removal is the influent loading rate. WERF (2006) concluded that little TP reduction would occur unless the influent loading rate is below 1 kg/ha-yr. Our calculations of current effluent quality from the Plymouth WWTF indicate that the loading rate would exceed 4 kg/ha-yr. Because this is loading rate is over the critical threshold, it appears that long-term removal of P from the constructed wetland would be minimal.

Average effluent TP (mg/l)	5.42
Discharge (mgd)	0.12
TP load (kg/day)	2.47
Wetland size (ha)	0.56
TP load (kg/ha-day)	4.4
TP load (kg/ha-yr)	1607
TP load (g/m2-yr)	160.7
Below critical value (1 kg/ha-yr)?	no

REFERENCES

Stearns & Wheler and the Town of Plymouth are directed to the database of constructed wetland treatment systems for additional information on specific case studies http://firehole.humboldt.edu/wetland/twdb.html

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