Design of a Treatment Wetland for the North Acton Recreational Area, Acton, MA

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Abstract

The Assabet River, part of the Assabet River Basin in Massachusetts, is in a eutrophic state due to nutrient loading, particularly phosphorus, coming from various sources along the river. The Town of Acton, a community located in the Assabet River Basin, is interested in using urban best management practices (BMPs) to reduce NPS phosphorus loading to an adjacent Assabet River tributary.

In an effort to publicly demonstrate the advantages of using BMPs to improve local water quality, this paper will evaluate the use of a constructed wetland to reduce phosphorus loading to a swimming pond in the newly constructed North Acton Recreation Area (NARA). Since the swimming pond eventually discharges into the Assabet River Basin, improved water quality of the swimming pond is directly related to improved water quality of the Basin.

The proposed wetland will consist of two swales to channel storm water runoff to the wetland area, a detention or sedimentation pond, two emergent marsh cells, and a micro pool. The phosphorus removal methods used in the wetland are sedimentation, microbial uptake, and plant uptake. On average, the wetland will reduce the phosphorus concentration in storm water runoff from 0.35mg/L to 0.12mg/L. After the treated runoff mixes with the swimming pond water, the final phosphorus concentration in the swimming pond is expected to be around 0.043 mg/L, below the 0.05 mg/L permissible concentration. In addition to serving as a phosphorus removal mechanism, the wetland will also provide many auxiliary benefits such as providing a wildlife haven, serving as an educational tool for local citizens, and enhancing the overall aesthetic value of the park.

Thesis Supervisor: Harold F. Hemond

Title: Professor of Civil and Environmental Engineering

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1. Introduction

The Town of Acton, Massachusetts, is a community located in the Assabet River Basin that currently relies mostly upon individual sewage treatment via onsite septic systems. For the past several years, the regions of Acton known as South Acton and Kelley's Corner have been experiencing septic system failure due to shallow groundwater levels. As a result, the Town of Acton has begun designing a wastewater treatment plant (WWTP) to serve these regions of Acton. If approved by the United States Environmental Protection Agency (EPA), the Acton WWTP will discharge some of its effluent to the Assabet River, which is currently in a eutrophic state due to nutrient loading, particularly phosphorus, coming from existing WWTPs upstream of Acton.

In order to minimize the impact of the Acton WWTP on the impaired water quality in the Assabet River, the town is interested in using urban best management practices (BMPs) to reduce NPS phosphorus loading to an adjacent Assabet River tributary. In an effort to publicly demonstrate the advantages of using BMPs to improve local water quality, this paper will evaluate the use of a constructed wetland to reduce the nutrient loading to a swimming pond in the newly constructed North Acton Recreational Area (NARA). Since the swimming pond eventually discharges into the Assabet River Basin, improved water quality of the swimming pond is directly related to improved water quality of the Basin.

1.1. Assabet River Overview

The Assabet River Basin is located in east central Massachusetts (See Figure 1). The

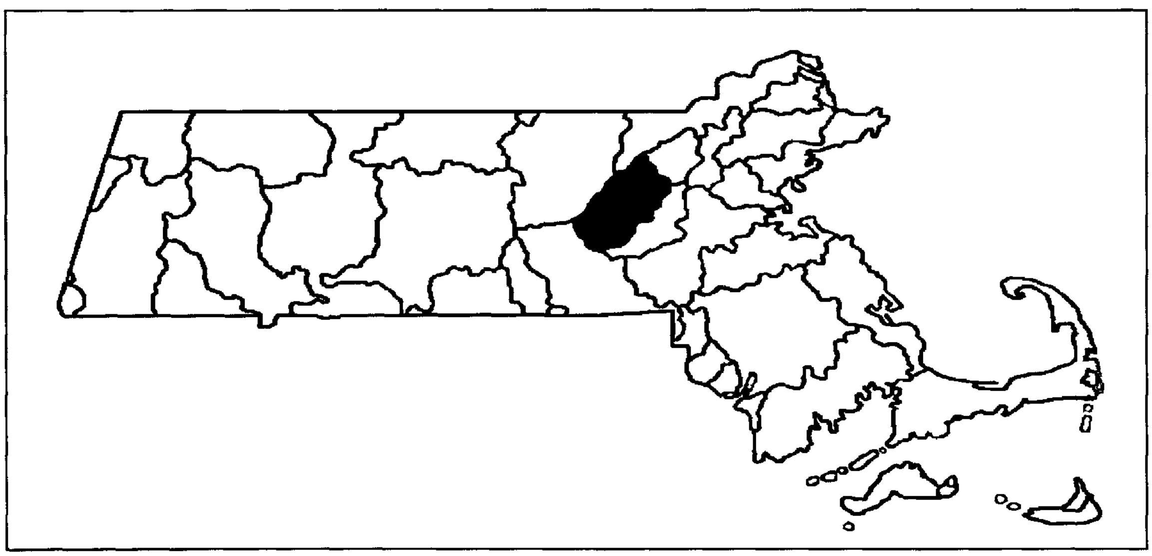


Figure 1: Location of Assabet River Basin (Source: U.S. EPA, 1999).

basin drains approximately 135 square miles and contains nineteen small towns and one city. As can be seen in figure 2, the Assabet River originates in an impounded swampy area located in Westborough, Massachusetts, and stretches 31 miles through a number of highly populated areas. Just past the Town of Concord, the Assabet River merges with the Sudbury River to form the Concord River, which feeds the Merrimack River (Organization for the Assabet River, 1999).

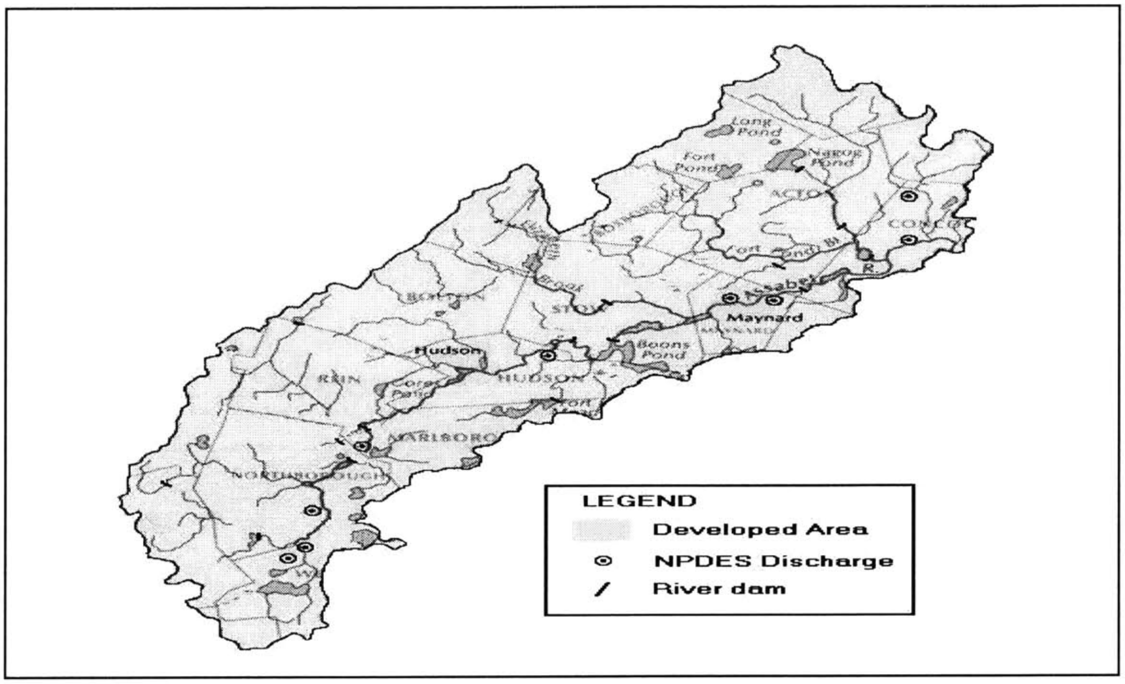


Figure 2: Map of Assabet River Basin (Source: U.S. EPA, 1999).

1.2. Assabet River Basin Water Quality History

The Assabet River has been laden with water quality and environmental problems for many years. Poor water quality in the river first prompted the Massachusetts Department of Environmental Protection Division of Water Pollution Control to undertake extensive water quality sampling in 1965. However, the primary emphasis of the sampling was to determine dissolved oxygen and biochemical oxygen demand rather than nutrient concentrations. Subsequent sampling endeavors to assess the condition of water quality ensued in 1969, 1974, 1979, 1986, and 1987 (Hanley, 1989).

A report on the pollution of the Assabet River issued in 1971 found that phosphates from WWTP discharges were resulting in an average river phosphate concentration 60 times the allowable limit. In addition, worse conditions were observed in the numerous impoundment areas. As a result of its findings, the report strongly urged communities along the Assabet River to develop phosphate removal programs (Cooperman and Jobin, 1971). The poor Assabet River water quality conditions prevailed, despite the passage of the 1970 Clean Water Act and subsequent assignment of National Pollution Discharge Elimination System (NPDES) permits to the discharging WWTPs. The 1979 sampling report also found that the Assabet River "impoundments are highly eutrophic with large amounts of aquatic growth, especially algal blooms during certain periods of the summer." Additionally, the report stated that all sections of the Assabet River were in violation of the Class B standard that had been assigned to the Assabet

River in 1978. The entire river violated total phosphorus and fecal coliform standards, and only one section passed the dissolved oxygen standard for this classification (Massachusetts Department of Environmental Quality Engineering, 1981).

The poor water quality in the Assabet River prompted the Massachusetts Department of Environmental Quality Engineering (DEQE) to develop the first water quality management plan for the Assabet River in 1981. The plan noted the problems caused by nonpoint sources, but maintained that the poor water quality in the Assabet River was largely due to excessive point source discharges from the WWTPs located along the river (Massachusetts Department of Environmental Quality Engineering, 1981). The 1981 water quality management report was subsequently revised in 1989. The 1989 water quality management plan stressed increased nutrient studies and strict adherence to discharge limits to improve water quality in the Assabet River. Although $50 million in WWTP improvements from 1972-1989 increased overall dissolved oxygen levels, water quality studies of the Assabet River performed in 1989 indicated that WWTP nutrient loadings were still affecting the trophic state of the river (Hanley, 1989). In 1986, the poor water quality conditions in the Assabet River spurred the development of the Organization for the Assabet River (OAR), a non-profit organization of local residents dedicated to improving the water quality in the Assabet River. The OAR maintains a substantial water quality monitoring program and sponsors related environmental protection programs. The group utilizes the water quality data to help enforce wastewater discharge regulations on the five WWTPs that discharge into the Assabet River (Organization of the Assabet River, 1999).

1.3. Current Water Quality Conditions

The water quality problems suffered by the Assabet have become commonplace in many areas of Massachusetts. In addition to continued water quality difficulties resulting from municipal WWTPs, industrial discharges have also increased as several computer technology companies have located within the Assabet River Basin. Steep growth rates throughout the Assabet River Basin have forced many communities to struggle with demanding periods of rapid residential development. The trophic state of the river has continued to worsen due to excessive nutrient loading (Hanley, 1989). During the summer of 1995, the flows in the Assabet River were recorded by the United States Geological Survey to be less than the sum of the wastewater discharges into the river (Roy, 1998). As a result, the entire stretch of the Assabet River was listed by the State of Massachusetts on its most recent “List of Impaired Waters in Massachusetts.”

The Assabet River remains in a highly eutrophic state characterized by excessive algal blooms. Throughout the warm months, the river is covered by an algae mat (Figure 3).

Figure 3: Assabet River Algae Mat (Source: Steve McGinnis, 1998).

During the summer, the layer of vegetation on the Assabet River often becomes thick enough to significantly impede canoeing through impoundment areas (Roy, 1998). The excessive algae growth in the river remains the direct result of the presence of the excessive nutrients required to support such growth, specifically the phosphorus and nitrogen inputs (Biswas, 1997).

This paper will evaluate the effectiveness of a wetland to remove phosphorus from storm water runoff. Although this BMP, by itself, will not improve the water quality of the Assabet Basin, it will provide some respite to nearby tributaries.

2. Background

The town of Acton recently constructed a 40-acre municipal park in North Acton, Massachusetts (Figure 4). The North Acton Recreational Area (NARA) was designed to include several soccer and baseball fields, an amphitheater, and a large swimming pond. While the newly founded park will benefit the town by providing recreational opportunities for its citizens, it will undoubtedly also generate or expose non-point sources of pollution that could affect the water quality of the swimming pond. An excessive inflow of phosphorus could eutrophy the pond, making it unsuitable for swimming and reducing its function as a wildlife habitat. Additionally, the pond's water eventually flows into the Nashoba Brook, which is part of the Assabet River Basin. Hence, the quality of the Assabet River Basin is directly related to the quality of the swimming pond.

Addressing the concern of eutrophication, Acton's natural resources director Tom Tidman suggested creating a treatment wetland in the park. Not only will a wetland reduce phosphorus inflow to the swimming pond, it will also indirectly reduce phosphorus inflow to the Assabet River Basin. Additionally, it will create a wildlife corridor for animals to cross the park, create a wildlife conservation area, and enhance the overall aesthetic value of the park. The wetland will be one of the many Best Management Practices (BMPs) that the town is implementing to reduce phosphorus loads to the Assabet River. Moreover, the constructed wetland will replace a smaller wetland that was flooded during the construction of the swimming pond.

Non-point sources (NPS) of phosphorus include the athletic fields (mostly through the application of fertilizer), the Town Forest, Quarry Road, the park's parking lot, and bird droppings. The wetland will intercept 3 of the 5 NPS of phosphorus: the Town Forest, Quarry Road, and the parking lot. Runoff from the athletic fields is collected and rerouted to a dry pond east of the park. Bird droppings from seagulls and geese are especially noticeable on the shoreline of the lake and are a great nuisance. Unfortunately, this non-point source is hard to control and no method is 100% effective at keeping the birds away.

Several parameters must be taken into account in the design of the treatment wetland. Listed in order of importance, these are:

1. *Provide Phosphorus Treatment*
   The wetland must be able to reduce phosphorus loading from approximately 0.2-0.5 mg/l to 0.05 mg/l, or a 75-90% reduction. Methods for removing phosphorus loading are detailed in section 4.
2. *Limit Costs*
   Cost is an issue in every construction project. The cost of constructing the wetland is estimated to exceed $30,000. In order to minimize costs, large construction works such as building embankments, excavating areas, and leveling terraces will be kept to a minimum. Apart from these major endeavors, most of the wetland construction will be done on a volunteer basis or by employing Concord Prison labor.
3. *Safety*

Because the recreational area will be used by children, safety is a fundamental concern. Major efforts will be made to reduce the risk to Acton's children and adults alike by posting signs and by using plants to create a living barrier around the wetland.

4. *Aesthetics*
   Because of its high visibility in the recreational park, the wetland should be as attractive as possible. This will be achieved through extensive planting and using boardwalks and nature trails. A more detailed discussion is presented in section 6.7.
5. *Education*
   The town has placed a heavy emphasis on the educational value of the wetland. This will be achieved through educational kiosks placed on nature trails around the wetland, as explained in section 6.7.
6. *Biota diversification*
   The wetland will also be utilized to increase the number of native plant species in Acton and will serve as a wildlife corridor for Acton's numerous and diverse animals. Additionally, the wetland will attract water-friendly animals such as snapping turtles and frogs.

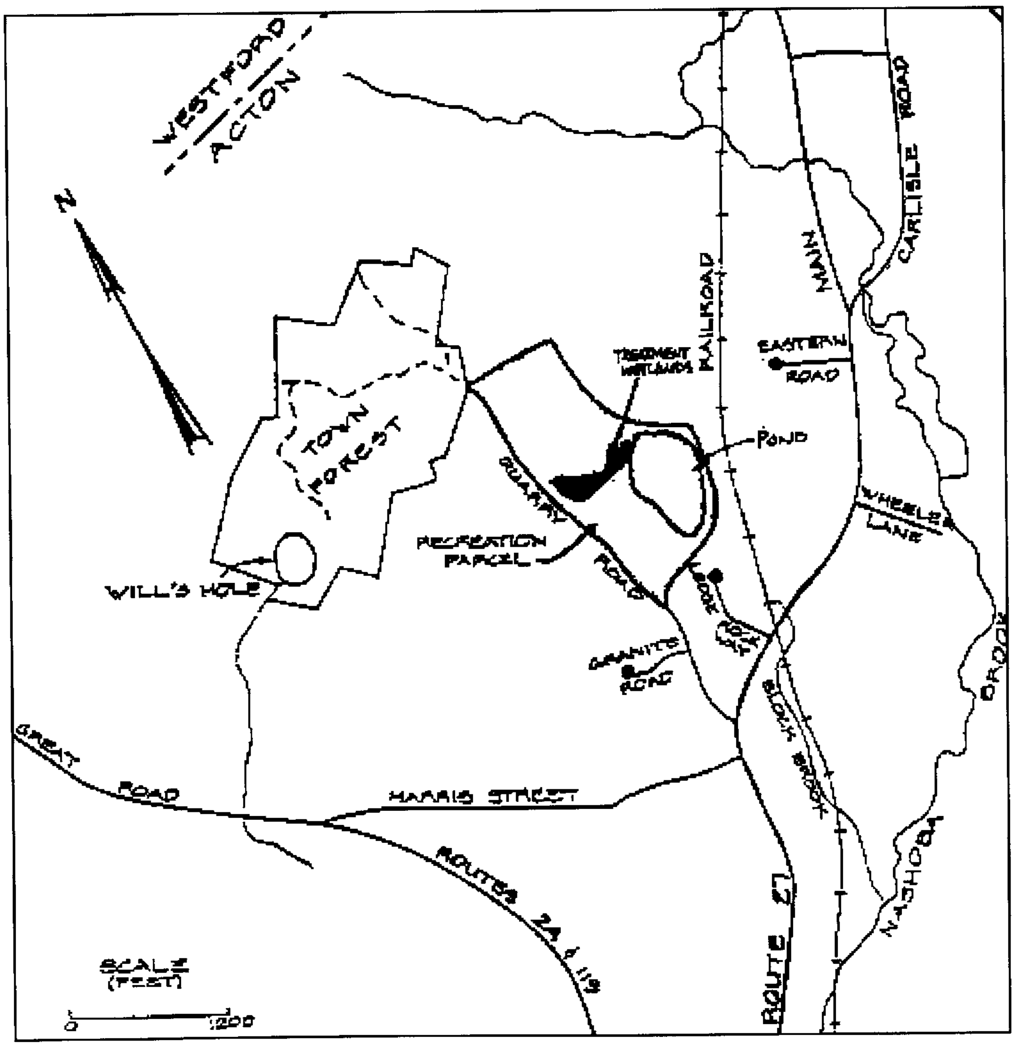


Figure 4: Site of the North Acton Recreational Area, Acton, MA.

3. Watershed Hydrology

The wetland site in NARA occupies an area of approximately 0.5 acres, and collects runoff from the parking lot, from Quarry Road, and from the town forest (Figure 5). If the swales (channels that collect runoff and guide it to the wetland) and the micro pool (at the bottom of the wetland) are included, the total wetland area is approximately 1 acre.

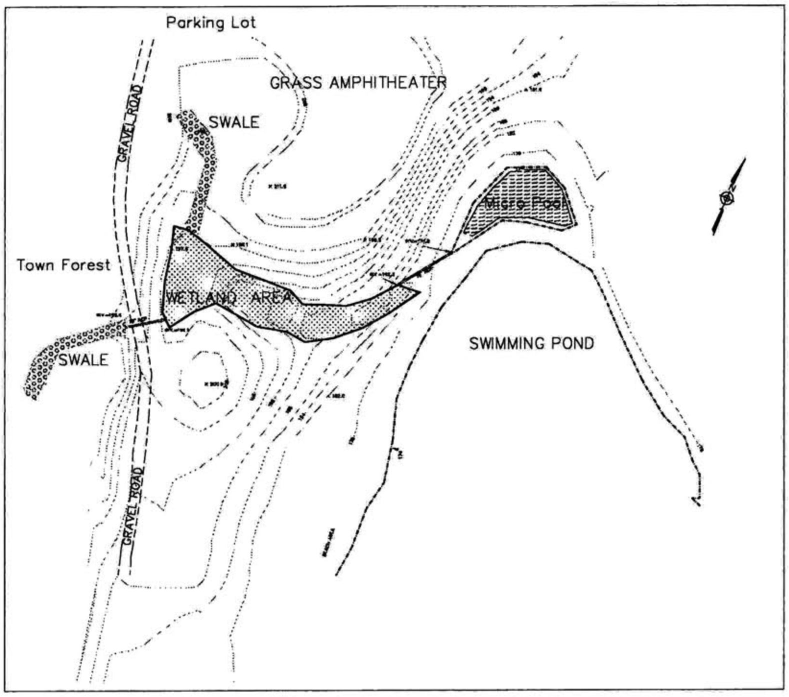


Figure 5: Map of the NARA wetland.

Several hydrologic considerations have to be taken into account during the design of the wetland. First of all, the wetland is fairly small compared to the watershed it is in, a largely forested area of approximately 51 acres. Because of the significant size of the watershed, concern arises over the capability of the wetland to accommodate large amounts of water during storm events. Second, because the wetland is located on a fairly steep stretch of land (gradient = 4.4%), washout and erosion are legitimate problems. Lastly, the wetland must be able to withstand drought years without drying out (and hence dying).

Thus, the first step in designing the wetland is to understand the hydrology of the watershed, to ensure that the wetland is able to manage runoff from a large storm without undergoing significant damage. Three different runoff scenarios were analyzed: average runoff, higher-than-average runoff (flood conditions), and lower-than-average runoff (drought conditions). To determine average and drought runoff rates, the Thornthwaite water balance was used. This method calculates mean monthly runoff conditions from average monthly rain depths. For calculating flood conditions, three different methods were used: the Rational method, the Soil Conservation Service (SCS) technical release 55 (TR55), and the SCS technical release 20

(TR20) method. TR55 and TR20 are in essence the same calculation method, except that TR20 is a computer program and slightly more complex. The Rational method will be used as a check.

The weather in Acton is typical of New England: wet spring and fall seasons, dry and cold winters, and dry and hot summers. Since climatologic data specific to Acton is not available, data from Boston Logan Airport (approximately 25 miles east of Acton) was used. Because the wetland's main function is to maintain the quality of the water of the swimming pond, we are mostly concerned with the hydrology and climatology typical of the summer months, when the pond is in heavy use and when many people will be exposed to the water.

3.1. Thornthwaite Water Balance

The Thornthwaite water balance is one of the many ways to calculate the amount of runoff that is generated during an average monthly rainstorm (Thornthwaite, 1955). All it requires in terms of data are the mean monthly air temperatures, the mean monthly precipitation values, information on the water holding capacity of the soil and the latitude of the area of interest. In addition, the Thornthwaite method also calculates the potential evapotranspiration of the area of interest. Table 1 shows average monthly temperatures and precipitation depths, obtained from the NOAA (1974).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Rain Inches	3.94	3.32	4.22	3.77	3.34	3.48	2.88	3.66	3.46	3.14	3.93	3.63
Temp. Celcius	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55.0	44.9	33.3

Table 1: Monthly average temperatures and precipitation depths for Logan Airport, Boston, Ma.

The results of the Thornthwaite water balance are shown in table 2 and 3. Both average rainfall and minimum rainfall have been examined to calculate expected runoff. The results of the Thornthwaite water balance for average rain events show that a large amount of water is expected to enter the wetland. Total volumes entering can be calculated based on the depth of runoff, the total surface area and the mean number of storms in one month (mean storm events based on Perrich, 1992). We also know that the wetland can only retain approximately 14,000ft^3 before the wetland overflows (section 5), so flooding will occur on a regular interval. In the next section (TR55) we analyze a greater-than-usual storm, and the volume of runoff consequently discharged to the wetland. This runoff volume will be used to design the wetland so that no or minimal damage will be caused to the wetland.

The results of the low flow Thornthwaite water balance show that in some cases, no runoff can be expected in a month. Note that the probability of experiencing twelve months in a row without runoff is zero. Table 2 merely indicates that months with no runoff are possible, and should be anticipated in the wetland design.

Boston, WSFO, Massachusetts. Latitude = 42.22. watershed area of interest = 50.6 acres. 10 inches soil retention													
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum
Temp., F	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55	44.9	33.3	
Heat index, I	0	0	0.5	2.37	5.22	8.09	10.19	9.45	7.25	4.14	1.72	0.05	49.0
Unadjusted Potential ET	0	0	0.015	0.048	0.087	0.126	0.15	0.142	0.114	0.071	0.036	0	
Correction factor	24.6	24.6	30.9	33.6	37.8	38.1	38.4	35.7	31.2	28.5	24.6	23.7	
Adjusted Potential ET, PE	0	0	0.46	1.61	3.29	4.80	5.76	5.07	3.56	2.02	0.89	0.00	27.46
Precipitation, P	3.94	3.32	4.22	3.77	3.34	3.48	2.88	3.66	3.46	3.14	3.93	3.63	
P-PE	3.94	3.32	3.76	2.16	0.05	-1.32	-2.88	-1.41	-0.10	1.12	3.04	3.63	15.31
Accumulated Water Loss	0	0	0	0	0	-1.32	-4.20	-5.61	-5.71	0	0	0	
Storage, ST	13.94	17.26	10	10	10	8.78	6.60	5.73	5.67	6.79	9.83	10.00	
Change soil moisture	0	0	0	0	0	-1.22	-2.18	-0.87	-0.06	1.12	3.04	0.17	
Actual ET	0	0	0.46	1.61	3.29	4.7	5.06	4.53	3.52	2.02	0.89	0	26.08
Moisture Deficit, D	0	0	0.00	0.00	0.00	0.10	0.70	0.54	0.04	0.00	0.00	0.00	1.38
Moisture Surplus, S	0	0	3.76	2.16	0.05	0	0	0	0	0	0	3.63	9.6
Water Runoff, RO	0.91	0.45	2.11	2.13	1.09	0.55	0.27	0.14	0.07	0.03	0.02	1.82	9.58
Snow Melt Runoff	0	0	0.73	3.27	1.63	0.82	0.41	0.20	0.10	0.05	0.03	0.01	7.25
Total Runoff, inches	**0.91**	**0.45**	**2.83**	**5.40**	**2.73**	**1.36**	**0.68**	**0.34**	**0.17**	**0.09**	**0.04**	**1.83**	**16.83**
Total Runoff, mm	22.09	11.04	71.38	137.17	69.42	34.71	17.36	8.68	4.34	2.17	0.65	44.49	423.49
Mean number of storms	5.69	5.03	5.80	5.89	5.86	5.36	5.11	5.28	4.50	4.47	5.56	5.94	
Volume Runoff, ft^3	**29315**	**16573**	**89713**	**168526**	**85406**	**46686**	**24485**	**11855**	**6952**	**3498**	**1408**	**56480**	

Table 2: Results from the Thornthwaite water balance using average precipitation values.

Boston, WSFO, Massachusetts. Latitude = 42.22. watershed area of interest = 50.6 acres. 10 inches soil retention													
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum
Temp., F	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55	44.9	33.3	
Heat index, I	0	0	0.5	2.37	5.22	8.09	10.19	9.45	7.25	4.14	1.72	0.05	49.0
Unadjusted Potential ET	0	0	0.015	0.048	0.087	0.126	0.15	0.142	0.114	0.071	0.036	0	
Correction factor	24.6	24.6	30.9	33.6	37.8	38.1	38.4	35.7	31.2	28.5	24.6	23.7	
Adjusted Potential ET, PE	0	0	0.46	1.61	3.29	4.80	5.76	5.07	3.56	2.02	0.89	0.00	27.46
Precipitation, P	0.92	1.15	1.48	1.24	0.53	0.48	0.52	1.25	0.35	0.96	1.72	1.03	
P-PE	0.92	1.15	1.02	-0.37	-2.76	-4.32	-5.24	-3.82	-3.21	-1.06	0.83	1.03	-15.83
Accumulated Water Loss			-5.61	-5.98	-8.74	-13.06	-18.03	-22.12	-25.32	-26.38			
Storage, ST	3.56	4.71	5.73	5.52	4.18	2.72	1.65	1.10	0.80	0.78	1.61	2.64	
Change soil moisture	0.92	1.15	1.02	-0.21	-1.34	-1.46	-1.07	-0.55	-0.30	-0.02	0.83	1.03	
Actual ET	0	0	0.46	1.45	1.87	1.94	1.59	1.8	0.65	0.98	0.89	0	11.63
Moisture Deficit, D	0	0	0	0.16	1.42	2.86	4.17	3.27	2.91	1.04	0.00	0.00	15.83
Moisture Surplus, S	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Runoff, RO	0	0	0	0	0	0	0	0	0	0	0	0	0
Snow Melt Runoff	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Runoff	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3: Results from the Thornthwaite water balance using minimum precipitation values.

3.2. Technical Release 55 (TR55)

Technical release 55 (TR55), released by the Soil Conservation Service (SCS), provides a method for analyzing the runoff generated during a rainstorm event. TR55 is designed for small watersheds of less than 1 square mile (wetland watershed is less than 0.1 square mile). It is assumed that runoff for a current storm event is independent of the rainfall of previous storm events, which is a reasonable assumption for small watersheds. In addition to rainfall, other factors that affect runoff include land cover and use, soil type, watershed slope, and antecedent moisture conditions (McCuen, 1998, 1982).

3.2.1 SCS 24 hour Rainfall-Runoff Depth Relation

The equation relating precipitation and runoff is:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}, \text{ inches,}$$

where P is the depth of precipitation for a certain design storm, and S is the potential maximum retention in inches. The depth of precipitation is chosen for a certain return period. For large construction projects such as the building of dams, often a return period of 100 years is chosen to be entirely within safety limits. As the name suggests, this is a storm that has a probability of occurring, on average, once every 100 years, and may cause serious damage. For the NARA wetland however, no human lives are at stake and no serious property damage will ensue if the wetland fails. Therefore a return period of 10 years is sufficient in terms of safety limits.

The SCS method requires the 24-hour storm data input for the chosen return period. For Acton, the 10-year, 24hr storm depth value is 4.5 inches (Hershfield, 1961). Empirical studies indicate that S, the potential maximum retention, can be estimated as follows (McCuen, 1982):

$$S = \frac{1000}{CN} - 10, \text{ inches,}$$

where CN is the runoff curve number. The runoff curve number is a function of land use, antecedent soil moisture, soil type and hydrologic conditions. Curve numbers are well tabulated and can be found in most hydrology text books (McCuen 1998, 1982).

Once S is determined, the time-of-concentration can be found from the following equation:

$$L = \frac{l^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}, \text{ hrs,}$$

where L is the time lag (i.e. the time from the center of mass of rainfall excess to the peak discharge,) Y is the slope in percent, and l is the hydraulic length in feet (McCuen, 1982). Empirical evidence shows that the time-of-concentration, in hours, is related to the time lag by:

$$t_c = \frac{5}{3}L, \text{ hrs.}$$

The time-of-concentration is a measure of the time for a particle of water to travel from the most distant point in the watershed (hydrologically speaking) to the point where the design is to be made.

3.2.2 Area and Curve Number

Curve numbers are dependent on the soil type of the area. The SCS developed a soil classification system that consists of four groups (A,B,C,D) and are described as follows:

Group A	Deep sand, deep loess, aggregated silts;
Group B	Shallow loess, sandy loam;
Group C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay;
Group D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils.

The soil type of the NARA wetland watershed was determined by the SCS and USDA, and maps of the area are available (SCS, 1991). In addition to soil type, the curve number depends on the antecedent soil moisture. The SCS developed three antecedent soil moisture conditions (I, II, III):

Condition I	Soil is dry, but not to wilting point, satisfactory cultivation has taken place;
Condition II	Average conditions;
Condition III	Heavy rainfall, or light rainfall and low temperatures have occurred within the last 5 days; saturated soil.

Condition II is the typical average condition for Acton. Group types, sub areas and curve numbers are shown in table 4. The total curve number for the watershed can be calculated by adding each individual curve number weighed over its area.

Area Name	Area, acres	Group type	Curve number	% of total area
Upland Forest: swamps	8.46	D	77	0.16
Upland Forest: sandy	3.21	A	25	0.06
Upland Forest: forest	35.87	B	55	0.70
Houses: roofs	1	-	98	0.02
Houses: residential lot	1.5	B	70	0.03
Road	0.66	-	98	0.01
Parking Lot	0.77	-	98	0.01
Total	51.47	-	59.21	1.0

Table 4: Curve number and area for the NARA watershed.

With the curve number determined, the potential maximum retention and the potential runoff depth can be calculated:

$$S = \frac{1000}{59.21} - 10 = 6.89 \text{ inches maximum retention.}$$

$$Q = \frac{[4.5 - 0.2(6.95)]^2}{[4.5 + 0.8(6.95)]} = 0.97 \text{ inches potential runoff depth.}$$

3.2.3 Slope and Hydraulic Length

The slope of the watershed area was calculated by averaging individual slopes over their hydraulic length, and is approximately 4.62%. By contrast, the total hydraulic length is not an average of the individual components, but rather the longest possible path from the watershed to the outlet, approximately 3200ft.

Now that the slope and hydraulic length are known, the time lag and the time-of-concentration can be found:

$$L = \frac{(3200)^{0.8}(6.95+1)^{0.7}}{1900(4.62)^{0.5}} = 0.67 \text{ hours time lag.}$$

$$t_c = \frac{5}{3}(0.67hrs) = 1.1 \text{ hours time-of-concentration.}$$

3.2.4 Peak Discharge

Once the area, slope, curve number, return period, and 24-hour precipitation storm depth are determined, the peak discharge can be calculated (McCuen, 1982):

1. Required Input
   A = 51.5 Acres (Drainage Area)
   T = 10 Years (Return Period)
   P = 4.5 inches (Rainfall depth for 24-hour, 10 year storm event, in Acton)
   Y = 4.62 % (average watershed slope)
   CN = 59 (runoff curve number)

2. Compute Volume of Runoff, Q
   S = 6.89 inches
   Q = 0.97 inches

3. Watershed Slope Interpolation Factor, SF
   HL = 3200 ft (Hydraulic Length)
   EA = 80 Acres (equivalent drainage area, McCuen, 1982)
   HF = 0.64 (HF = A/EA)

4. Obtain Unit Peak Discharge, QU
   QU = 36 cfs/inch (McCuen, 1982)

5. Watershed Slope Interpolation Factor, SF (McCuen, 1982)
   SF = 1.05

6. Ponding and Swamp Storage Adjustment Factor, PF
   PPS = 16% (percent of ponds and swampy areas, based on actual drainage area, A)
   Location in watershed: Center/Spread out.
   PF = 0.58 (McCuen, 1982)

7. Peak Discharge QP, Calculations with Adjustment
   QP = QU * Q * HF * SF * PF
   QP = 13.47 cfs

8. Additional Parameters
   L = 0.67 hours (time lag)
   t_c = 1.1 hours (time of concentration)

The TR-55 method thus predicts a peak runoff off 13.47cfs for a 24-hour storm event with a 10-year return period.

3.3. Rational Method

As a check on the TR55 method, the rational method will similarly be used to calculate the peak runoff flow rate. The rational method is primarily used for small watershed design problems, where short duration storms are critical (McCuen, 1998). This method relates the peak discharge to the drainage area, the rainfall intensity and the runoff coefficient as follows (McCuen, 1998):

$$q_p = CiA,$$

where q_p = peak discharge, ft^3/sec,
C = runoff coefficient,
A = drainage area, acres,
i = rainfall intensity, inches/hr.

The rainfall intensity is obtained from an intensity-duration-frequency curve (Hershfield, 1961), using a return period and duration equal to the time of concentration. The time of concentration was found to be 1.1 hours, as explained in the TR55 method. Using a time of concentration of 1 hour, the 10-year storm predicts a rainfall intensity of 1.8 inches/hr (Hershfield, 1961). The runoff coefficient varies with land cover, land use, soil group and watershed slope. For the watershed of our interest, the total runoff coefficient will be the sum of the runoff coefficient multiplied by the area of each subunit.

$$CA = \sum C_i A_i$$

The calculated runoff coefficients are shown in table 5.

Land Use	Ci	Ai	Ci*Ai
Forest	0.11	47.54	5.23
Streets	0.85	0.66	0.56
Housing: residential lot	0.23	1.5	0.35
Housing: roofs	0.85	1	0.85
Parking Lot	0.85	0.77	0.65
overall area, Ci		51.47	7.64

Table 5: Runoff coefficient using the Rational method.

The peak discharge can now be calculated:

$$q_p = 1.8\frac{in}{hr}(7.64acres)(\frac{1ft}{12in})(\frac{43560ft^2}{acre})(\frac{hr}{3600\sec}) = 13.87\frac{ft^3}{\sec}.$$

The Rational method predicts a peak runoff discharge similar to TR55.

3.4. Technical Release 20 (TR20)

The SCS also developed a FORTRAN based program, TR20, to develop runoff hydrographs with a design storm as input. It's a single-event model that uses the SCS runoff equation and the SCS curvilinear unit hydrograph (McCuen, 1998). The SCS developed four dimensionless rainfall distributions using the Weather Bureau's Rainfall Frequency Atlases (McCuen, 1982). These distributions can be applied to different areas around the United States. The distributions are based on generalized rainfall depth-duration-frequency relationships, and they calculate incremental depths of rainfall over the storm duration (24 hours). A type III distribution was used for Acton, and the rainfall hyetograph is shown in figures 6 and 7.

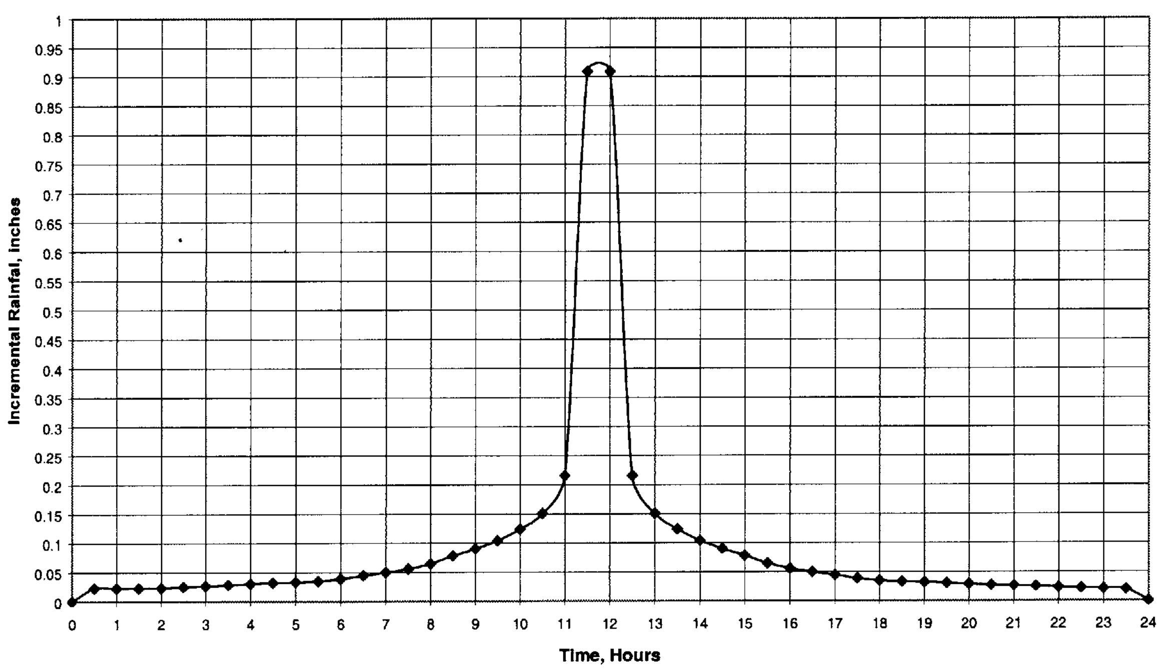


Figure 6: Hyetograph for Acton. Incremental Depths for 24 hour, type III storm, 10-year return period.

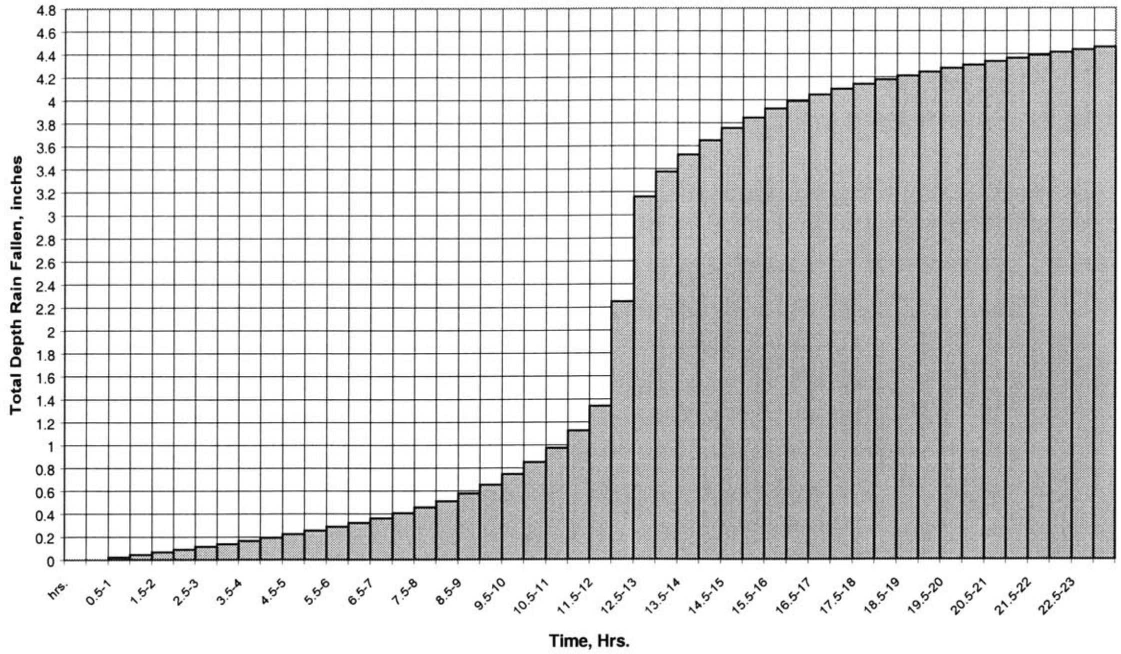


Figure 7: Hyetograph for Acton. Cumulative Depth for 24 hour, type III storm, 10-year return period.

3.4.1 Runoff Hydrograph

A hydrograph·is a graph of the runoff discharge rate, which passes a particular point, versus time (McCuen, 1982). The hydrograph is a function of precipitation, watershed characteristics and geologic factors. A total runoff hydrograph consists of both surface runoff and baseflow. In the NARA wetland design, the baseflow will be assumed zero because we are mostly interested in the hydrology of the wetland during the summer months, when baseflow is very low.

A total runoff hydrograph shows the runoff over the whole duration of the storm and emphasizes four important concepts (McCuen, 1982):

1. Runoff occurs from precipitation excess, which equals the total precipitation minus any losses incurred such as interception, depression storage and infiltration.
2. The excess precipitation is applied at a constant, uniform rate.
3. The excess is applied with a uniform spatial distribution.
4. The intensity of the rainfall excess in constant of over a specified period of time, called the duration.

3.4.2 Model Results

TR20 requires limited input: time of concentration, design storm data, rainfall depth for a 24 hour storm (any return period), curve number, watershed area, and antecedent soil condition. The output is shown in figure 8. From the graph and table, the peak discharge is calculated to be 18.1cfs and the runoff depth was found to be 0.96inches, approximately the same results as TR55. Since this is the greatest discharge yet, it will be used in the design of the wetland. The total runoff volume from the watershed is approximately:

$$V = Q \times A = (0.96in)(\frac{1ft}{12in})(51.47acres)(\frac{43560ft^2}{acre}) = 179{,}363ft^3.$$

Since the detention pond can only hold a maximum volume of 8000 cubic feet (see section 5), there will be significant flooding during such a rainstorm. This will be addressed in section 6.

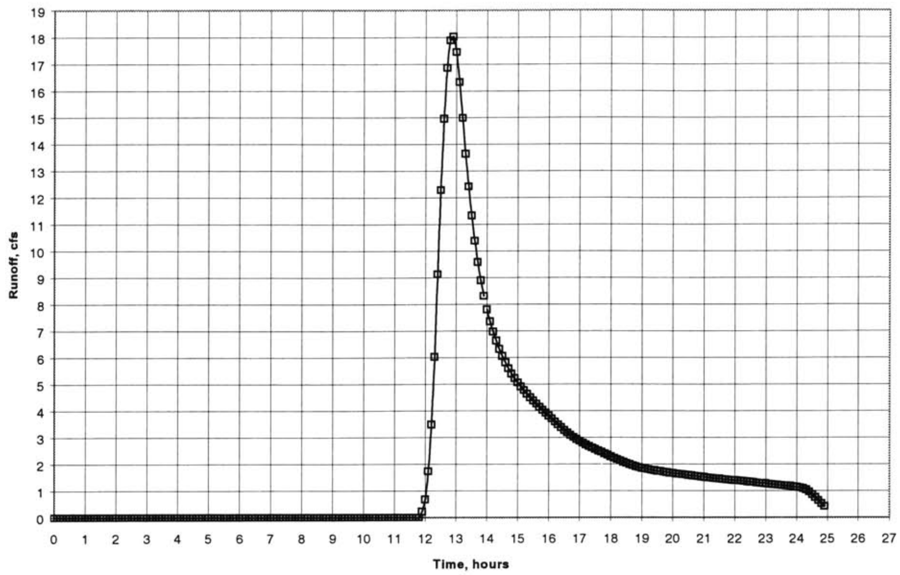


Figure 8: Total runoff hydrograph for NARA.

4. Phosphorus Removal Techniques

Phosphorus is a nutrient present in storm water discharge, and is often the limiting nutrient in fresh bodies of water. Excessive amounts of this element will cause rivers, lakes and ponds to eutrophy at a faster than normal rate. Eutrophication causes algal blooms, and is of primary concern because eutrophied waters are characterized by a foul smelling odor, lack of biota life, and high turbidity.

Phosphorus in wetlands exists in several states including dissolved phosphorus, solid mineral phosphorus and solid inorganic phosphorus. Inorganic phosphorus, i.e. phosphate, dissociates as follows (Kadlec, 1996):

$$H_3PO_4 \Leftrightarrow H_2PO_4^- + H^+$$
$$H_2PO_4^- \Leftrightarrow HPO_4^{2-} + H^+$$
$$HPO_4^{2-} \Leftrightarrow PO_4^{3-} + H^+$$

Phosphorus entering a wetland can be removed through sedimentation, soil adsorption, microbial metabolism, chemical precipitation, and plant uptake. Some trace amounts of phosphorus may be emitted as phosphine, a gaseous form of this element (Kadlec, 1996). Specific storages of phosphorus in a peat-based wetland are shown in figure 9 (Kadlec, 1996).

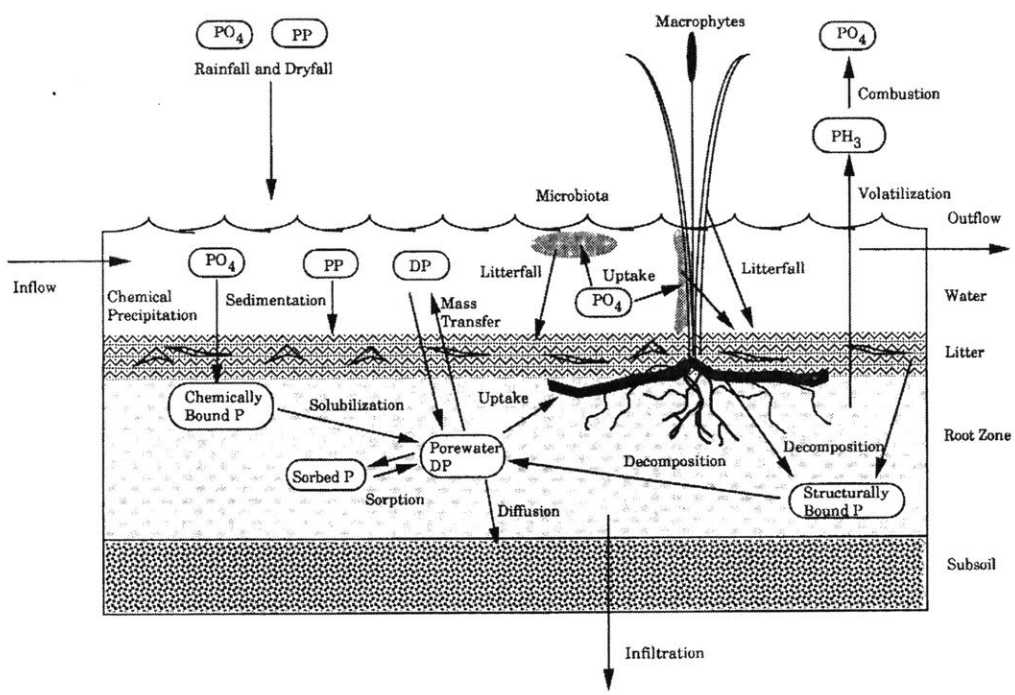


Figure 9: Phosphorus removal and cycling in a peat-based wetland (Kadlec, 1996).

4.1. Chemical Precipitation

Chemical precipitation involves the addition of chemicals (i.e. alum, ferric chloride, lime or ferric sulfate) to enhance precipitation of phosphorus to facilitate its removal (Tchobanoglous, 1991). Even though it is an effective method of removing phophorus, it is also costly, requires supervision by technical personnel, increases sludge production, and generally is not appropriate for a natural system. Therefore, chemical precipitation will not further be considered or discussed.

4.2. Sedimentation

Sedimentation is the separation of suspended particles from water by gravitational settling. Generally, if total suspended sediment (TSS) removal in a detention basin is high, removal of other pollutants that bind to particles is high as well (Stanley, 1996). Since phosphorus binds to sediment particles quite well, it is expected that a significant amount of this nutrient will be removed. For particles with a Reynold's number less than approximately 0.5, settling can be described by Stokes' law (Tchobanoglous, 1991):

$$V_0 = \frac{1}{18}\frac{g}{\mu}(\rho_s - \rho)D^2,$$

Where V_0 = settling velocity,
μ = viscosity of fluid,
ρ_s = density of particle,
ρ = density of fluid,
g = acceleration due to gravity, and
D = diameter of particle.

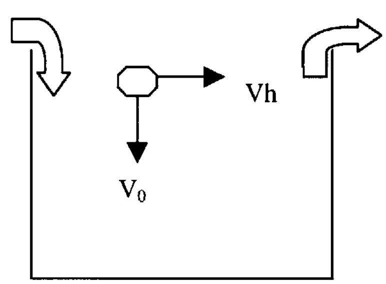


Figure 10: Shematic diagram of the detention pond.

Figure 10 shows a schematic diagram of a single particle, where V_0 is the settling or vertical velocity, and V_h is the horizontal velocity (the velocity of the water). In the design of wastewater treatment facilities, it is common to design a basin such that all particles that have a terminal velocity equal or greater to V_0 will be removed. This terminal velocity, or overflow rate, is defined as:

$$V_0 = \frac{Q}{A},$$

Where A = surface of the sedimentation basin, and
Q = rate of incoming water.

As for all settling basins, the terminal velocity is independent of depth, up to the extent that scouring is not a factor.

For an ideal settling tank, sedimentation removal efficiency ranges from 50% to 70% (Tchobanoglous, 1991). Field data collected by Donald Stanley show slightly different values. A stormwater detention pond in Greenville, NC was used to measure pollutant concentration removal in runoff. The mean stormwater concentrations were comparable to ranges found in

Acton, approximately 0.35mg/l of total phosphorus. The removal efficiences observed were 30-58% particulate phosphorus removal, 11-46% of dissolved phosphorus, 11-46% phosphate removal (Stanley, 1996). The specific removal efficiency of the NARA wetland will further be discussed in section 7.

4.3. Soil Adsorption

Another sink for phosphorus in wetlands is soil, where the nutrient is buried in organic form (National Small Flows Clearinghouse, vol.5). The length of the removal period depends on the adsorption capacity of the sediment and the available wetland area; removal decreases as the adsorption sites fill up. Although the adsorption capacity of soils is finite, it can be quite large, even for sandy soils. A municipal wastewater treatment plant, using soil adsorption for the removal of phosphorus, still reports low (0.1-0.4 mg/L) concentrations after 88 years (Tchobanoglous, 1991). The degree of removal depends heavily on the contact between water and the soil matrix, so the smaller the surface area to volume ratio, the more contact there will be. Thus, shallow depths work better than deep trenches for removing phosphorus in wetlands.

Phosphorus adsorption is governed by a set of equations relating porewater concentration, soil depth, total volume, water-filled volume, particle density, water content, and mass of soil particles. The concentration between porewater and sorbed phosphorus can be defined using the Freundlich isotherm, a power-fit law (Kadlec, 1996):

$$C_s = a_p C_W^b,$$

where a_p = Freundlich phosphorus capacity factor, [mg P/kg]/[mg P/l],

b = Freundlich exponent, dimensionless,

C_S = sorbed phosphorus concentration, mg/kg, and

C_W = porewater phosphorus concentration, mg/L.

In wet soil, total phosphorus storage may be represented by the total concentration multiplied by the total volume (Kadlec, 1996):

$$V_T C_T = V_W C_W + M_S (a_p C_W^b),$$

where V_T = total volume = $V_W + V_S$, L,

V_W = water filled void, L,

V_S = soil volume, L ,

C_T = total concentration, kg/L, and

M_S = mass soil particles, kg.

The total concentration can further be defined as:

$$C_T = \theta C_W + \rho_b(a_p C_W^b) = [\theta + \rho_b(a_p C_W^{b-1})]C_W = fC_W,$$

where $\theta = V_W/V_T$, water content,

$\rho_b = M_S/V_T$, soil bulk density, kg/L, and

f = phosphorus soil storage factor, dimensionless.

Moreover, the phosphorus soil storage is defined as:

$$f = [\theta + \rho_b(a_p C_W^{b-1})].$$

The phosphorus soil capacity is

$$S = f\,C_W\,\delta,$$

where S = phosphorus soil capacity, g/m^2, and
δ = soil depth, m.

Typical values for water content (θ) in wetlands range between 0.3-0.9, bulk densities range from 0.1 g/cm^3 for peats to 1.5 g/cm^3 for mineral soils, and typical values of f range from 5 to 50. An order of estimate on the time needed to saturate the phosphorus adsorption capacity of a soil is (Kadlec, 1996):

$$t = S/J,$$

where: t = time, yr.,
S = phosphorus soil capacity, g/m^2, and
J = phosphorus removal rate, $g/m^2/yr$.

Typical saturation times range from 1.5 months to 4.5 months. This time does not take into account any phosphorus absorbed by plants. Nor do these equations take into account temporal factors such as the age of the wetland and seasonal fluctuations. As a result, these regression equations have large standard errors. To more accurately represent phosphorus uptake, other parameters such as geographical region, age of wetland, seasonal dependence, types and density of plants, depth and duration of storm events, and temperature dependence should be accounted for. Since soil adsorption occurs over such a small time frame, it becomes somewhat negligible in our analysis of phosphorus adsorption.

Another factor that determines phosphorus uptake is the downward diffusion into soil media. Diffusion is governed by Fick's equation (Hemond, 1994):

$$J = -D\,(dC/dX),$$

where J = flux density, $g/m^2/yr$,
D = diffusion coefficient, m^2/yr ,
X = downward distance, m, and
C = concentration, g/m^3.

The diffusion coefficient in wetlands is approximately half of the free water diffusion coefficient (Kadlec, 1996).

$$D \cong 0.5 \times 10^{-5}\ cm^2/s = 0.016\ m^2/yr$$

Even at high gradients, the flux downward is slow and phosphorus will not penetrate to very deep depths in any significant amount of time.

4.4. Microbial Metabolism

Microbiota (i.e. bacteria, fungi, algae, microinvertabrates, etc…) are able to take up phosphorus at a much faster rate than other organisms such as plants (Kadlec, 1996). Most often they are found in colonies, forming slimy films on plant stems and roots, or on rocks and sediments. Sometimes these organisms can live as free-floating entities in the water, in which case they physically displace phosphorus from one place to another.

Microorganisms act as a sink by assimilating inorganic phosphate, mineralizing organic phosphorus, and being involved in the solubilization and mobilization of phosphate compounds. Unlike other elements such as nitrogen or sulfur, phosphorus does not act as a source of energy. Hence, microorganisms do not oxidize or reduce phosphorus; they use phosphates without altering the oxidation level. Moreover, only organic phosphates are available for consumption, not phosphate precipitates (Atlas, 1995). Microbes utilize phosphorus during cell synthesis and energy transport, consuming anywhere from 10 to 30% of influent phosphorus during wastewater treatment (Tchobanoglous, 1991).

Certain microbes effectively incorporate inorganic phosphate during the production of ATP, reducing total phosphorus levels in storm water. The organism found to accomplish this most effectively (in activated sludge) belongs to the genus *Acinetobacter*. Specific bacteria that may prove useful in the uptake of phosphorus include *A. calcoaceticus*, *Pseudomonas vesicularis*, *A. lwoffii*, and *A. junii* (Jenkins, 1991). Bacteria such as these are often naturally present in wetlands, and do not need to be introduced. ATP production is a two step process mediated by two enzymes, polyP-AMP phosphotransferase and adenylate kinase (Jenkins, 1991):

$$(polyP)_n + AMP \rightarrow (polyP)_{n+1} + ADP, \text{ and}$$

$$2\ ADP \rightarrow ATP + AMP.$$

In addition to utilizing phosphorus for ATP production, for operation, and for maintenance, organisms also store phosphorus for future use. The overall reaction for aerobic respiration can be summarized as follows (Kadlec, 1996).

$$C_6H_{12}0_6 + 6H_20 + 6O_2 + 38ADP + 38P = 6CO_2 + 12H_2O + 38\ ATP$$

Microbiota may also behave as a source when their cell structure breaks down after death, hence releasing phosphorus in the surroundings. Just as they are able to take up this element at a much faster rate than other organisms, they are also able to release it much faster. Additionally, anoxic conditions in a wetland may cause the release of phosphorus from microorganisms (Tchobanoglous, 1991). This is a potential problem, since increasing the phosphorus content in soil can result in a shift from aerobic to anaerobic conditions in soil, which can further result into anoxic conditions. Some undesirable effects of anaerobic wetlands are death of vegetation and undesirable odors, both of which can be a nuisance, especially in a recreational area. However, since the wetland in question will have fairly shallow depths, and some aeration will be provided by the spillway (creating turbulence that increases the oxygen level of the water), it is safe to assume that the area will remain aerobic.

4.5. Plant Uptake

Plant uptake is a slower method of phosphorus removal, as less than 1% of vegetation biomass is actually phosphorus. Increased phosphorus concentrations in a wetland, however, can spur an increase in tissue phophorus content by a factor of two to ten (Kadlec, 1996). Plants take 70% of their phosphorus from sediments and the remainder from water (Vincent, 1994). Phosphorus buried in wetland soil can thus be recycled by plant uptake. This action will also prolong the capacity of wetland soils to adsorb phosphorus.

Plant uptake is only a temporary form of storage; the nutrient is re-released when the vegetation dies and decays. Periodic harvesting or burning of the vegetation may remove this phosphorus source from the wetland, but care should be taken that the disposed vegetation is not near the swimming pond, as this could introduce phosphorus into the pond.

The plant species *Phragmites australis* seems especially effective at removing phosphorus, but since it is an invasive species, it should not be used to plant the wetland (House, 1994). Plants compete heavily with microorganisms for phosphorus intake; in most cases, the microorganisms use most of the available phosphate. Still, one author reports that emergent macrophytes may have an uptake capacity in the range of 50 to 150 kg $ha^{-1}year^{-1}$, and free-floating vegetation may take up phosphorus on the order of 50 to 300 kg $ha^{-1}year^{-1}$(Brix, 1994).

4.6. Mechanism Summary

There are five main processes by which phosphorus can be removed in stormwater runoff: chemical precipitation, sedimentation, soil uptake, microbial metabolism, and plant uptake. Chemical precipitation is not a feasible mechanism to use in a natural setting, and soil uptake was shown to be negligible compared to sedimentation, plant uptake, and microbial metabolism. Thus, the three most important removal processes at work in this wetland will be sedimentation, plant uptake, and microbial metabolism (if the microbes are retained, and not transported elsewhere).

5. Wetland Design

The layout of the NARA wetland was almost completely predetermined by land availability and land topography. Only a small section of approximately 0.5 acres was appropriated to the treatment of stormwater. The land is located on a terraced hill; to keep the amount of construction to a minimum, the terraces will be disturbed as little as possible.

Several details apply to the entire wetland. To increase diversity, an irregular shoreline should be maintained everywhere; this will create visual isolation that will increase breeding success. Additionally, an impermeable layer of clay should be applied to the whole wetland area, to prevent infiltration of groundwater and exfiltration to the groundwater.

The wetland system will consist of two swales, a detention pond, two marshes and a micro pool, as shown in figures 11 and 12.

5.1. Swales

The swales leading to the detention pond are large enough to provide three key services: reduce incoming water velocities, provide preliminary treatment through planting, and increase retention through ponding. From personal observation at the site of interest, ponding occurs in all of the swales. Ponding can furthermore be encouraged by increasing the depression depth through excavation, or by placing stones behind the depression to create a damming effect. Note that such a small stone barrier is very susceptible to vandalism. Planting will cause the flow rates to decrease and will also provide preliminary phosphorus treatment.

5.2. Detention Pond

The upper terrace of the wetland will be transformed into a detention pond. Runoff from the parking lot, from Quarry Road, and from the Town Forest will be collected in this pond. The high bedrock elevation will limit the depth of the pond to approximately 1 to 2 feet. In addition to excavating, the pond's sides may have to be built up to achieve the desired average depth of 1 foot and the wet weather depth of 2 feet. The total surface area of the pond will be approximately $4000ft^2$ and the pond has an average width of 46 feet and average length of 95 feet. For safety reasons, the slope of the pond should not exceed a 7:1 ratio. The pond's shoreline should be irregularly shaped to increase wildlife establishment. Details are shown on figures 11 and 12.

5.3. Embankment I

Embankment I serves to retain runoff coming in the detention pond and serves to redistribute water slowly to marsh I. Since the bedrock is close to the surface, a bedrock foundation will be used to stabilize the dam. To prevent underseepage, cement grouting should be applied underneath the dam (US Department of the Interior, 1973). The dam will rise approximately 2 feet above ground level, and will be constructed out of granite rocks, already available on site. The first foot above ground level will be mortared or grouted to prevent infiltration through the embankment. The top foot should not be grouted or mortared, and will act as a sieve, letting water pass through to marsh I. For safety reasons, the downstream side of the dam will be stepped and each step should not exceed 30 vertical inches. The total elevation drop from the top of the dam to marsh I is 4 feet. A schematic drawing of the dam is shown in figure 12.

5.4. Marsh I and II

Both marsh I and II consist of shallow areas and deep areas. This system of alternating water depths will increase the retention effect of the wetland, will enhance phosphorus uptake, and will favor wildlife and vegetation establishment. Convention suggests that the shallow marsh should hold between 0 to 6 inches of water, while the deep marsh should hold between 6 to12 inches of water (Kadlec, 1996, Schueler, 1992, National Small Flows Clearinghouse, 1997). The average dimensions of marsh I are 121 ft long by 60 feet wide, and marsh II is 50 feet long by 43 feet wide (see figures 11 and 12).

5.5. Embankment II and III

Embankment II and III are similar to embankment I in that they will be made out of the same materials, but unlike embankment I, they will be completely impermeable (they will be cemented or grouted throughout). Water will only be able to flow over the bank into the adjacent marsh. The total elevation drop from the top of the embankment II to marsh II is 3 feet while the drop from embankment III to marsh III is 4 feet. Like embankment I, the downstream side of the dam will be stepped, with a maximum vertical step of 30 inches, and the dams' foundations will also be similar. However, the foundation of embankment III should have a lip that extends beyond the base of the dam. The water in Marsh III flows much more rapidly than anywhere else in the wetland, and the lip will prevent erosion and scouring that could compromise the stability and safety of embankment III (figure 12).

5.6. Marsh III

Unlike marsh I and II, which have very gentle slopes, marsh III will be heavily sloped. The total drop from the top of the marsh to the outlet pipe is approximately 6 feet, over an average length of 96 feet, or a 6.25% gradient. The average width of the marsh is 25 feet. The stones and small rocks that presently line this area should remain to prevent erosion. Some areas of deep water may be desired as indicated on figure 11. Planting this area is also recommended, both to prevent erosion and to provide phosphorus treatment. Only trees or sturdy shrubs that can resist high flow rates should be used.

6. Wetland Physics

Now that all hydrologic and design parameters of the wetland have been ascertained, we can determine what will happen to the wetland during dry and wet weather.

6.1. Velocities

Velocity is a function of slope, friction, and discharge rates. Between storms, when the discharge is small or non-existent, the Manning equation is used to relate velocity to the channel friction and slope. Even though the Manning equation has been shown not to be very accurate for wetlands it will be used due to lack of a better equation (Kadlec, 1996):

$$v = \frac{1.49}{n} R^{2/3} S^{1/2},$$

where v = velocity, ft/s,

n = roughness coefficient,

R = hydraulic radius, ft, and

S = slope, ft/ft.

Values for the roughness coefficient are widely available in many publications. The closest approximated value for a wetland is (McCuen, 1992).

n = 0.095 (grassed waterway).

The hydraulic radius is calculated as:

$$R = \frac{cross\,sectionarea}{wettedperimeter} = \frac{(depth)(width)}{2(depth) + (width)}.$$

For optimum uptake of nutrients, suggested velocities in surface wetlands are between 0.7 and 5 cm/day or 2.66×10^{-7} and 19×10^{-7} ft/s (Kadlec, 1996). To be within reasonable limits, the wetland will be designed for a velocity of 12×10^{-7} ft/s or 3.2 cm/day. From this velocity, we can calculate the required slope of marsh I and II. Note that the velocity in the detention pond is zero unless a discharge is applied. To achieve the desired flow rates, the slopes of marshes I and II should be very small, as shown in table 6.

	Velocity, ft/s	n	X-Area,ft	Wet perimeter, ft	R, ft	Slope, ft/ft
Marsh I	12×10^{-7}	0.095	60	62	0.968	6.11×10^{-15}
Marsh II	12×10^{-7}	0.095	43	45	0.956	6.22×10^{-15}

Table 6: Slope calculations for marshes I and II for low flow rates.

Because the slopes are near zero, we can assume that, during low flow rates, the velocity in the wetland is independent of the friction provided by the wetland. Rather, the velocity becomes a function of the wind, of local micro-topography, and of the discharge through the wetland. The velocity in Marsh III is predetermined by its slope, as shown in table 7.

	Slope, ft/ft	n	X-Area,ft	Wet perimeter, ft	R, ft	Velocity, ft/s
Marsh III	0.0625	0.095	25	27	0.926	3.73

Table 7: Velocity calculation for marsh III for low flow rate.

For the purpose of calculating velocities during the 24-hour, 10-year design storm (high flow), we will assume that the velocity is uniform in each wetland cell. Average velocity is defined as the flow rate divided by the cross sectional area. Since this velocity will be used to check against scouring velocity, the most shallow depths in the wetlands have been used to calculate the greater flow rates. Note that the vegetation and the varying depth profiles are likely to produce velocities different from what is given table 8.

	Flow rate, cfs	Depth, ft	Width, ft	Average X-Area, ft^2	Velocity, ft/s
Detention Pond	18	1	46	46	.40
Marsh I	18	0.5	60	30	.60
Marsh II	18	0.5	43	21.5	.84

Table 8: Velocities in the wetland during high flow.

Note that the velocity in Marsh III still follows Manning's equation during periods of high flow.

6.2. Scour Potential

The high flow velocities must to be compared to the maximum permissible flow velocities that do not cause scour (ASCE, 1992). The ASCE manual on *Design and Construction of Urban Stormwater Management Systems* lists a maximum permissible velocity of 4ft/sec, much greater than what is theoretically expected in marsh I & II. Marsh III comes closer to the maximum permissible velocity, but it is still below. As a safety factor, the small rocks and stones that are already in place should remain to prevent scouring and erosion.

The critical scouring velocity in detention ponds is given by Tchobanoglous (1996):

$$V_H = \left[\frac{8k(s-1)gd}{f}\right]^{1/2},$$

where V_H = minimum horizontal velocity that will just produce scour, ft/sec,

k = constant which depend on type of material being scoured (0.04 for sandy material, 0.06 for more sticky, interlocking matter),
s = specific gravity of particles,
g = acceleration due to gravity,
d = diameter of particles, and
f = Darcy-Weisbach friction factor (typical values: 0.02-0.03).

If we assume an average particle size of 0.043mm (See section 6.6), the minimum scouring velocity becomes:

$$V_H = \left[\frac{8(0.05)(2.75-1)(\frac{9.8m}{s^2})(0.043\times10^{-3}m)(\frac{ft^2}{0.3048^2m^2})}{0.025}\right]^{1/2} = 0.356\frac{ft}{s}.$$

The calculated maximum horizontal velocity during a high intensity storm is approximately 0.40 ft/s (from the velocity of water in the detention pond), which is slightly higher than allowable.

Hence, small rocks and stones should be placed at the discharge region of the swales to slow down incoming water to prevent scouring. The floating aquatic vegetation will slow down the runoff as well.

6.3. Detention time

Detention time is a function of rain events and can therefore fluctuate widely. In general, the longer the detention time, the better the removal of phosphorus is in a wetland. During dry weather, the water will be mostly stagnant in the pond, in marsh I, and in marsh II. Under these dry weather conditions, the detention time is a function of the average velocity,

$$time = \frac{length\ \ of\ \ path}{average\ \ velocity}.$$

Detention times in each section of the wetland is shown in table 9 for low flow rates. Note again that the velocity is high in marsh III because the water is mostly driven by gravity.

	Velocity, ft/s	Length, ft	Detention Time, **days**
Detention Pond	0	96	indefinite
Marsh I	$12x10^{-7}$	121	1167
Marsh II	$12x10^{-7}$	50	482
Marsh III	3.73	96	.0003
Total			~1649

Table 9: Detention times for low flow rates, days.

Since the average time between storms is roughly between 5 and 6 days, and since almost complete flushing occurs during this time (section 3) the actual detention time will be much less than 1649 days. Average detention times for high flow rates is shown in table 10. Under high flow conditions, the detention time becomes a function of the flow rate:

$$time = \frac{volume}{flow\ \ rate}.$$

Note that this residence time is not nearly long enough for any significant phosphorus removal to occur.

	Volume, ft^3	Flowrate, cfs	Detention Time, **min**
Detention Pond	4370	18	4.05
Marsh I	3630	18	3.36
Marsh II	1075	18	1.00
Marsh III	2400	18	2.22
Total			~10.63

Table 10: Detention times for high flow rates, minutes.

6.4. Pump Sizing

As demonstrated in section 3, there will be times when the wetland will go through periods of drought. Such an occurrence could be disastrous to the wetland vegetation and to the wetland treatment capability. To prevent this from happening, a pump should be installed in the micro pool to deliver a steady flow of water exceeding the evapotranspiration rate of the wetland. In addition to keeping the wetland functional, the recycling of water will also provide additional treatment of the swimming water, which will prove especially beneficial during months of heavy use (summer). Recall from table 2 that evapotranspiration peaks in July, at a rate of 5.76 inches/month. Applying this water loss over the whole wetland, the desired pump flow rate then becomes:

$$Q_{pump} \geq evaporationrate \times surfacearea$$

$$Q_{pump} \geq \frac{5.76in.}{month}(21780 ft^2)(\frac{1ft}{12in})(\frac{7.48 gallons}{ft^3})(\frac{1month}{31days})(\frac{1day}{1440\min}) = 1.75GPM = 0.004\frac{ft^3}{s}$$

To be within a margin of safety, the pump will be designed to deliver a flow rate up to 4GPM. To calculate the required horsepower of the pump, the total head must be calculated (Lydersen, 1994):

$$H_m = (z_2 - z_1) + (P_2 - P_1) + \frac{v^2}{2g} + f\frac{L}{d}\frac{v^2}{2g},$$

where z_2 is the discharge elevation, 196ft,

z_1 is the suction elevation, 174ft,

P_2 is the pressure at discharge, 33.9 ft (atmospheric pressure),

P_1 is the pressure at section, 33.9 ft (atmospheric pressure),

v is the velocity in the pipe at maximum reading, ft/s,

g is the acceleration of gravity, 32.2 ft/s^2,

f is the friction factor, dimensionless,

L is the length of run, ft, and

D is the diameter of the pipe, ft.

Since the flow rate is very small, we can choose a standard 1.5" schedule 40 PVC pipe. The velocity head, $v^2/2g$, is related to pipe size and flow rate. Tables exist to facilitate calculations (Lydersen, 1994). Using a 1.5" pipe and a flow rate of 4GPM, the velocity is 0.63ft/s. Hence, the velocity head is 0.01ft.

Similarly, the friction head, $f(L/d)(v^2/2g)$ can be found from using tables (Lydersen, 1994). Assuming that two elbows will be used in laying the pipe, the equivalent length is 4.5ft per elbow = 9ft. The approximate distance between the detention pond and the micro pool is 680ft so the total combined length is 689ft. The friction loss of a 1.5" PVC pipe equals 0.12ft/ft*689ft = 82.68ft of friction loss.

Total mechanical head is equal to:

H_m = (196-174)ft + 0.01ft + 82.68ft = 104.69ft

A pump that can develop 4GPM flow rate against 105 feet of total head should be selected.

Horsepower is related to the mechanical head as follows:

$$HP = \frac{(Q)(H_m)(SpecificGravity)}{efficiency} = (\frac{2gal}{\min})(105 ft)(\frac{\min - hp}{33000lb - ft})(\frac{8.34lb}{gal})(\frac{1}{0.55}) = 0.096hp$$

7. Phosphorus Removal Analysis

Now that all the wetland parameters (hydrology, layout, flow rates, detention times, etc…) are known, the phosphorus removal capability of the wetland should be re-explained. Recall that runoff is collected by the swales, enters the detention pond, flows through the marsh and empties in the detention pond. Assuming that the swales do not remove any significant amounts of phosphorus, the first site of treatment is the detention pond, removing this nutrient through sedimentation.

From section 6.3, the overflow rate is:

$$V_0 = \frac{Q}{A},$$

and as explained in section 5, the dimensions of the detention pond in the wetland are already predetermined. Thus, the overflow rate is:

A = 4000 ft^2,
Q = 18 ft^3/sec → design flow, and
$\therefore V_0 = 0.0045 ft/\sec = 16.2 ft/hr$.

Recall that if the vertical velocity is greater than this, good settling will be achieved. To determine what fraction of particles will be removed, solve for the minimum diameter needed for a particle to settle. Recall Stokes' equation from section 4:

$$v = \frac{1}{18}\frac{g}{\mu}(\rho_s - \rho)D^2,$$

Where v = 0.0045 ft/sec,
g = 9.8 m/sec^2,
μ = 1.3cp, at 10°C (CRC handbook of chemistry and physics, 1989),
ρ_s = 2.6-2.9 g/cm^3 for most minerals, avg. value = 2.75 g/cm^3 (Das, 1990), and
ρ = 1, for water.

Solving for the diameter:

$$D = \left[\frac{18 v \mu}{(\rho_s - \rho) g}\right]^{1/2},$$

$$D = \left[18(0.0045\frac{ft}{\sec})(1.3cp)(\frac{10^{-2} g}{cp - cm - \sec})(\frac{cm^3}{(2.75-1)g})(\frac{\sec^2}{980.7cm})(\frac{30.48cm}{ft})\right]^{1/2} = 0.043mm.$$

Only particles with a diameter greater than 0.043mm will settle in the detention pond. Using the US Army Corps of Engineers' and the US Bureau of Reclamation's average diameters values for soil particles (table 11), we can see that gravel and sand will settle quite easily, but only the largest of the silt and clay particles will be retained in the detention pond.

Type of Soil	Gravel	Sand	Silt & Clay
Diameter, mm	76.2-4.75	4.75-0.075	<0.075

Table 11: Average soil particles diameters (Das, 1990)

Phosphorus mostly associates with clay particles and organic matter on soil constituents. A more thorough investigation of the runoff constituents needs to be undertaken to determine with accuracy the amount removed in the detention pond. The best removal estimates that can be given at this point are given by the study conducted by Stanley: 30-58% particulate phosphorus removal, 11-46% of dissolved phosphorus, 11-46% phosphate removal (Stanley, 1996). A conservative value for total phosphorus removal through sedimentation is approximately 40%.

As seen in section 4, microbes have the capacity to remove anywhere from 10-30% of incoming phosphorus. Similarly, we saw that plant uptake can be in the order of 50 to 150 kg $ha^{-1}year^{-1}$ for emergent macrophytes, and 50 to 300 kg $ha^{-1}year^{-1}$ for free-floating vegetation (Brix, 1994). This corresponds to an annual removal capability of 4.37-13.1 kg/year for the emergent vegetation in the NARA wetland, and 4.37-26.22 kg/yr for free-floating vegetation. We can also calculate the annual influx of phosphorus into the wetland from the yearly runoff volume: C_{avg} = 48 kg/yr. Thus, average removal capabilities of the vegetation runs between 9.1% and 54.6% removal capacity.

It is hard to estimate the total removal of phosphorus from the individual removal mechanisms; it is impossible to estimate to what extent one mechanism dominates over another. However, Kadlec suggests using a simple mass balance to determine the output concentration of phosphorus in runoff (Kadlec, 1996):

$$q\, dC/dy = -k(C-C^*) = -kC,$$

where q = hydraulic loading rate, m/day,
C^* = phosphorus background levels, usually zero,
C = concentration of phosphorus,
y = x/L = fraction distance from inlet to outlet,
x = distance from inlet, m,
L = total distance from inlet to outlet, m, and
k = uptake rate constant, m/day.

Integrating this equation gives the concentration profile:

$$\ln (C/ C_i) = (k/q)\cdot y,$$

$$C = C_i \exp(-ky/q),$$

where k/q = Da = Damkohler number.

At the outlet of the wetland, the concentration then becomes:

$$C_o = C_i \exp(-k/q),$$

where C_o = concentration of phosphorus at the outlet, and
C_i = concentration of phosphorus at the inlet.

Since the NARA wetland will be a surface wetland, it can be modeled as an emergent marsh system, for which the uptake rate constant, k, equals 12.1 ± 6.1 m/yr. If no parameters but the inlet concentration is known, a simplified equation can be used to determine the outlet concentration (Kadlec, 1996).

$$C_o = 0.34\,(C_i)^{0.96},$$

Where: $0.02 < C_i < 20$ mg/l, and

$0.009 < C_O < 20$ mg/l.

It is known that the inlet concentration in the NARA wetland is on average 0.35 mg/L. Thus, the outlet concentration becomes:

$$C_o = 0.34\,(0.35)^{0.96} = 0.12 \text{ mg/L.}$$

This concentration is still approximately a factor of two greater than the outflow desired. However, the last step in the phosphorus treatment is a dilution step in the micro pool area. An investigative report done for the North Acton Recreational Park indicates that natural phosphorus levels in the pond are approximately 0.04mg/L (Pine and Swallow, 1989). The total volume of the pond is approximately 15 million gallons at low level. Additionally, the micro pool occupies 3.9% of the total volume of the pond, so the approximate volume of water in the micro pool is 585,000 gallons. The new concentration of phosphorus in the micro pool is now (after a detention time of several days in the wetland):

<u>Existing phosphorus in micro pool:</u>

$$P = 585{,}000gal(\frac{0.04mg}{L})(\frac{3.785L}{gal})(\frac{kg}{10^{-6}mg}) = 0.086kgP$$

<u>Phosphorus concentration in wetland outflow:</u>

$$P = 71676ft^3(\frac{0.12mg}{L})(\frac{28.32L}{ft^3})(\frac{kg}{10^{-6}mg}) = 0.244kgP$$

<u>Phosphorus concentration in micro pool after mixing:</u>

$$C = \frac{(0.244+0.086)kg}{(585000+536316)gal}(\frac{10^6 mg}{kg})(\frac{gal}{3.785L}) = 0.078\frac{mg}{L}$$

Note that the concentration is still slightly higher than the acceptable standard of 0.05mg/L. The natural phosphorus levels in the swimming pond are on average 0.04mg/L. Thus, after the treated runoff mixes with the swimming pond water, the total phosphorus concentration in the pond will be approximately 0.043mg/L.

As a comparison, if the runoff were allowed to flow into the swimming pond without treatment (i.e. without going through the wetland), the average phosphorus concentration in the pond would be approximately 0.051mg/L, slightly higher than what is acceptable, but not much different than the concentration after wetland treatment. Note that the time frame of the comparison is different, the assumption is that this mixing would occur almost instantaneously. One would expect that after a detention time of several days in the swimming pond (the same detention time as obtained by water flowing through the wetland), some of the phosphorus entering the swimming pond would disappear due to sedimentation or plant/microbial uptake. Hence, when there is flooding in the wetland, the total possible phosphorus concentration in the swimming pond is still fairly low.

8. Landscaping

8.1. Vegetation

To ensure an aesthetically pleasing wetland, care should be taken to plant the wetland with desired species before invasive species appear. The establishment of native vegetation will limit the number of invasive species. The appendix divides species that are native to this region in three categories: herbaceous emergent vegetation, submerged and floating vegetation, shrubs, and trees. Note that this database only contains a sample of wetland species; their availability should be checked with a wetland species retailer, who might also be able to suggest other species. Figure 13 shows the relative areas that should be planted with each respective category.

To obtain the wetland vegetation, local nurseries should be contacted that specialize in wetland vegetation (such as Environmental Research Corps (ERC) and its sister company BioMass Farms (www.wetlandsandwildlife.com) in Massachusetts, or Fiddley Frond's Nursery (www.angelfire.com/biz/fiddleyfrondsnsy/index.html) in Maine.

8.2. Wildlife

One of the original requirements of the wetland is that it needs to serve as a wildlife corridor, so that animals may safely cross the recreational park. The wetland will also serve as a small wildlife preservation area. One important step in achieving this goal is to diversify the vegetation in the wetland, and create irregular shorelines that promote small and numerous niches to form. Choosing plants that have a high wildlife value can also increase the number of animal species present. If desired, certain animals could be introduced artificially, such as snapping turtles and frogs, but is not a necessary step in attracting wildlife. Birds can be attracted by planting shrubs and trees where they can nest, and by installing bird houses around the wetland. Most important, the wildlife diversification of the wetland will greatly depend on the amount of human intrusion into the wetland. Providing a living barrier of shrubs and other plants around the wetland will limit human intrusion into the wetland.

8.3. Additional Landscaping Plans

Figure 14 shows additional features that may be desirable in and around the wetland. Trails around the wetland will both ensure that people can enjoy the wetland, while also limiting off-trail hiking in the wetland. Educational kiosks can be placed around the wetland, explaining the function of the wetland, and indicating the different plant species as well as animal species present. A small wooden bridge can be placed near embankment I that overlooks both the detention pond and the marshes. Both the trails and the pedestrian bridge should be wheel chair accessible.

9. Conclusion

Because the Town of Acton needs to meet strict water quality regulations, especially regulations concerning the release of phosphorus into the Assabet River, town officials are interested in exploring Best Management Practices (BMPs) to reduce non point sources (NPS) of phosphorus. The specific BMP analyzed in this paper is a constructed treatment wetland to be build in a park in North Acton.

The proposed wetland will consist of two swales to channel storm water runoff to the wetland area, a detention or sedimentation pond, two emergent marsh cells, and a micro pool. The wetland's main function will be to remove phosphorus in storm water runoff to prevent the eutrophication of a swimming pond. The maximum phosphorus limit in this pond, to prevent eutrophication, is 0.05 mg/L. The phosphorus removal methods used in the wetland are sedimentation, microbial uptake, and plant uptake. On average, it will reduce the phosphorus concentration in storm water runoff from 0.35mg/L to 0.12mg/L. After the treated runoff mixes with the swimming pond water, the final phosphorus concentration in the swimming pond is expected to be around 0.043 mg/L. In addition to serving as a phosphorus removal mechanism, the wetland will also provide many auxiliary benefits such as providing a wildlife haven, serving as an educational tool for local citizens, and enhancing the overall aesthetic value of the park.

One wetland in the Assabet watershed will not have a noticeable effect on the water quality of the Assabet River. It will, however, have an immediate effect on the swimming pond and on nearby tributaries. A study should be undertaken to determine if using multiple wetlands, distributed evenly in the Assabet watershed, could significantly impact the Assabet River water quality.

The proposed treatment wetland in the North Acton Recreational Area is a prime example of a Best Management Practice that small communities throughout the United States can implement. Wetlands provide a natural alternative to treating minor water quality problems, and are cheaper to design, construct and maintain than most conventional nutrient removal technologies.

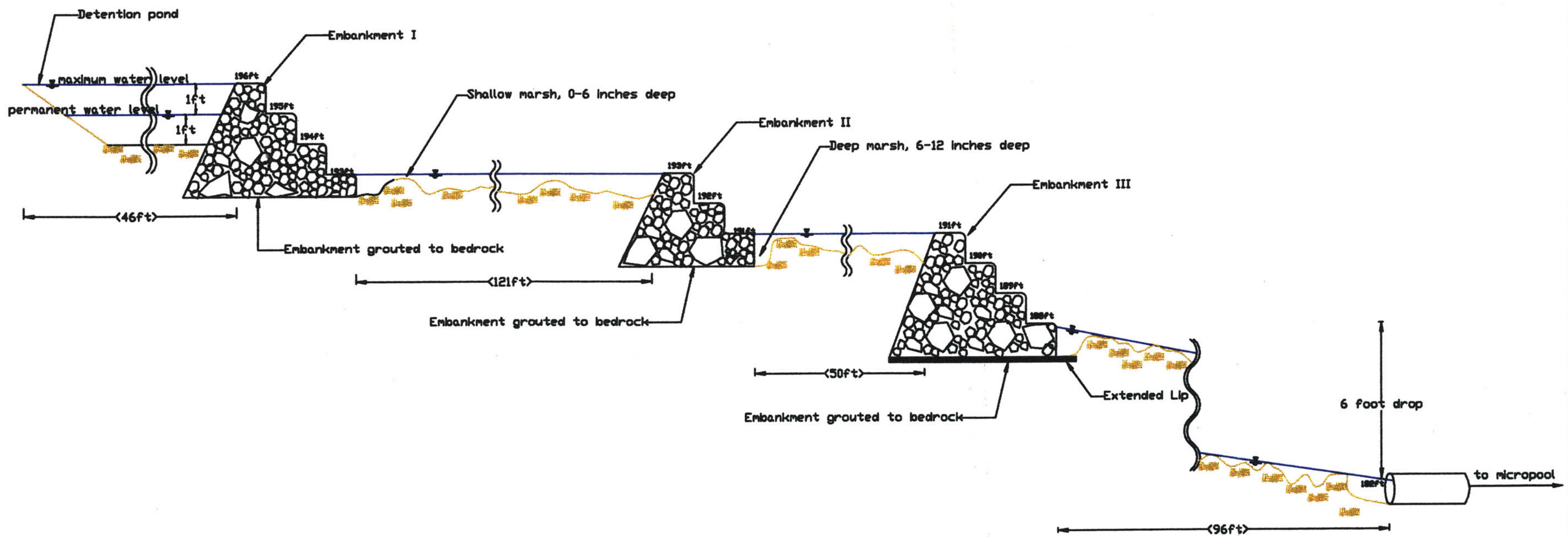
1 inch = 27 ft

Name:	Date:
Anouk Savineau	April 23, 1999

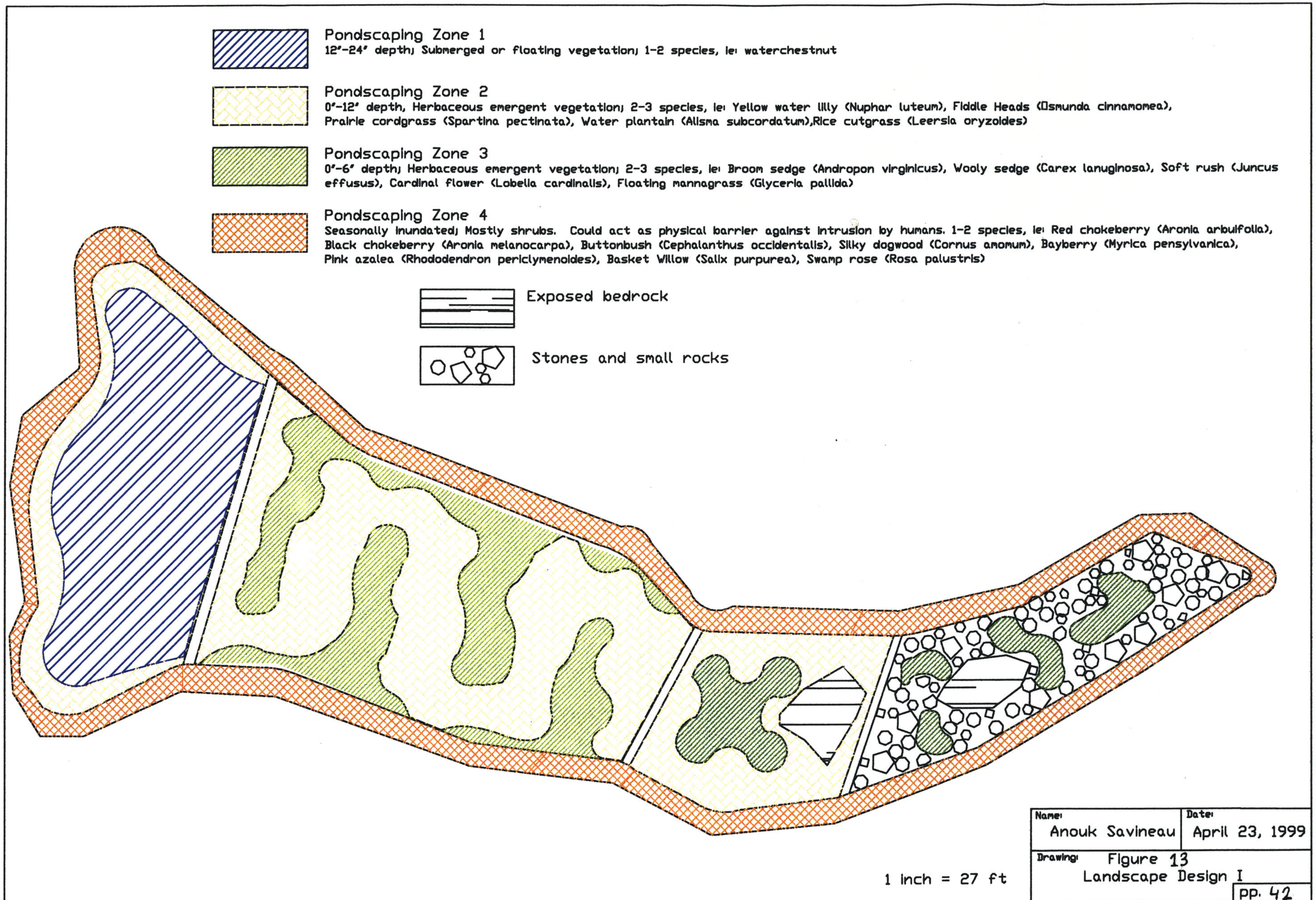
Drawing:
Figure 11
Top View of NARA Wetland

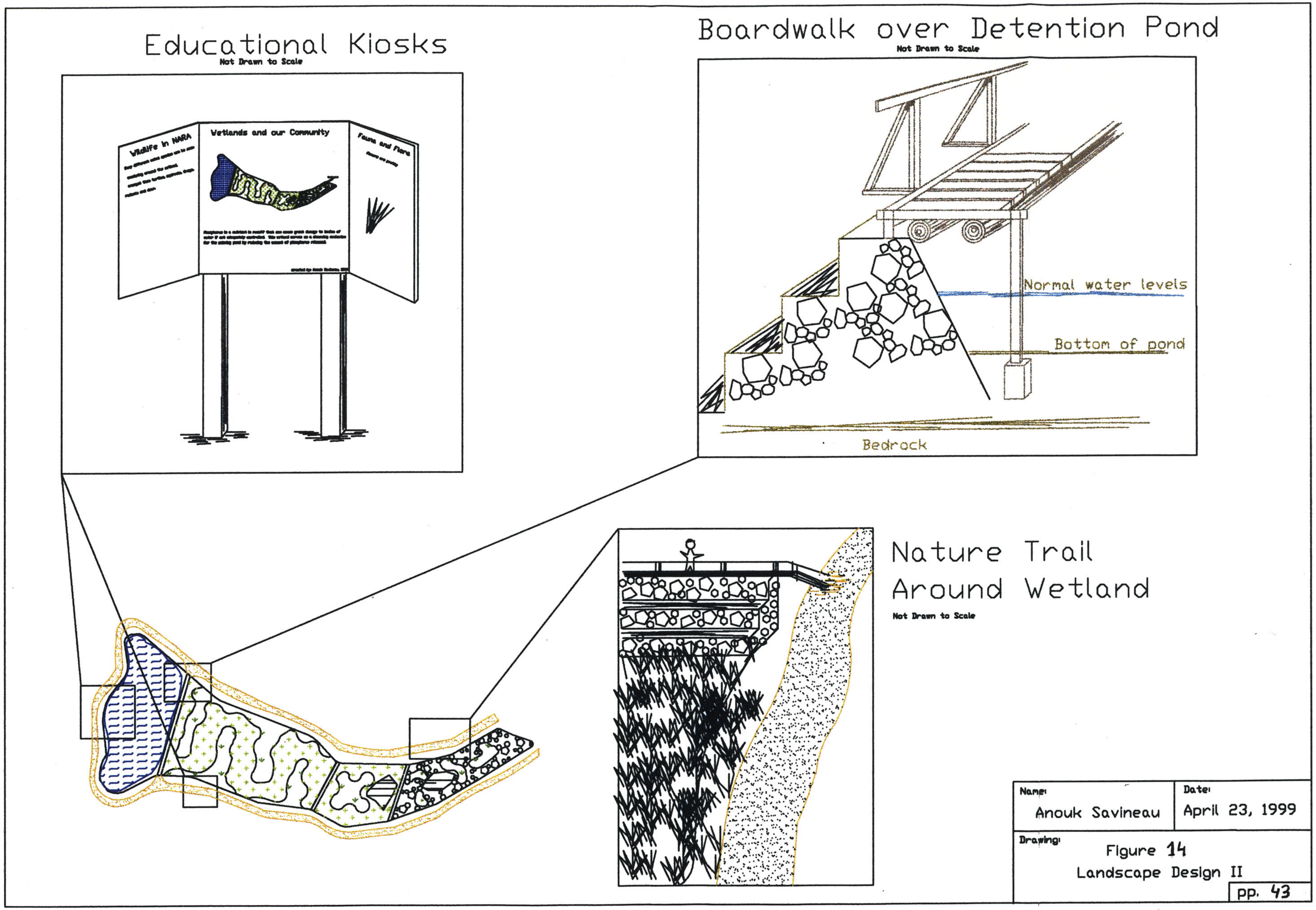
pp. 40

Note: Drawing is not to scale



Name: Anouk Savineau	Date: April 23, 1999
Drawing: Figure 12 Cross Section of NARA Wetland	


Pondscaping Zone 1
12"-24" depth; Submerged or floating vegetation; 1-2 species, ie: waterchestnut
Pondscaping Zone 2
0"-12" depth, Herbaceous emergent vegetation; 2-3 species, ie: Yellow water lilly (Nuphar luteum), Fiddle Heads (Osmunda cinnamomea), Prairie cordgrass (Spartina pectinata), Water plantain (Alisma subcordatum),Rice cutgrass (Leersia oryzoides)
Pondscaping Zone 3
0"-6" depth; Herbaceous emergent vegetation; 2-3 species, ie: Broom sedge (Andropon virginicus), Wooly sedge (Carex lanuginosa), Soft rush (Juncus effusus), Cardinal flower (Lobelia cardinalis), Floating mannagrass (Glyceria pallida)
Pondscaping Zone 4
Seasonally inundated; Mostly shrubs. Could act as physical barrier against intrusion by humans. 1-2 species, ie: Red chokeberry (Aronia arbuifolia), Black chokeberry (Aronia melanocarpa), Buttonbush (Cephalanthus occidentalis), Silky dogwood (Cornus amomum), Bayberry (Myrica pensylvanica), Pink azalea (Rhododendron periclymenoides), Basket Willow (Salix purpurea), Swamp rose (Rosa palustris)
Exposed bedrock
Stones and small rocks
1 inch = 27 ft
Name: Anouk Savineau
Date: April 23, 1999
Drawing: Figure 13
Landscape Design I
pp. 42



Name: Anouk Savineau	Date: April 23, 1999
Drawing: Figure 14 Landscape Design II	pp. 43

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11. Appendix - Wetland Vegetation

Submerged and floating aquatic vegetation

From: Wetland Planting Guide for the Northeastern United States; Plants for Wetland Creation, Restoration and Enhancement. By Gwendolyn A. Thunhorst, 1993

Nymphea odorata	
common name: Fragrant water lily, Pond lily, White water lily	
notes	permanently inundated from 1-3 ft.
wildlife benefit	low-moderate
aesthetic value	high, white flowers
rate of spread	NA
characteristics	rooted, floating, perennial, nonpersistent
height	floats on water
community	ponds, lakes, fresh tidal waters
shade	tolerates partial shade

Polygonum amphibium	
common name: Water smartweed	
notes	regularly/permanently inundated up to 3ft or saturated (~26-100% of growing season)
wildlife benefit	low, mostly ducks & shorebirds
aesthetic value	high, bright pink flowers
rate of spread	NA
characteristics	rooted, floating aquatic or erect emergent, perenniall, nonpersistent
height	up to 3ft.
community	nontidal waters and fresh marshes
shade	NA

Potamogeton nodosus/P. americanus	
common name: Long-leaved pond plant	
notes	occurs in muddy/sandy soils, inundated at least 1 ft, depth lies b/w 1-6ft.
wildlife benefit	moderate
aesthetic value	some flowers, wind polinated
rate of spread	rapid, over 1ft/yr
characteristics	rooted, submerged, perennial, nonpersistent
height	up to 6ft.
community	streams, lakes, ponds
shade	NA

Vallisneria americana

common name: freshwater eelgrass, tapegrass, wild celery

notes	SUPPORTS HIGH NUTRIENT LOADS, tolerates some turbidity, permanently inundated to at least 1 ft. prefers coarse silt to slightly sandy soil
wildlife benefit	moderate
aesthetic value	low
rate of spread	fast, over 1ft/yr
characteristics	rooted, submerged, perennial, non persistent
height	up to 7 feet
community	non tidal and tidal waters
shade	NA

Herbaceous emergent vegetation

From: Wetland Planting Guide for the Northeastern United States; Plants for Wetland Creation, Restoration and Enhancement. By Gwendolyn A. Thunhorst, 1993

Agrostis alba/ A. stolonifera

common name: Redtop

notes	irregularly to seasonally inundated\saturated (up to 25% of growing season)
	TOLERATES DROUGHT, STABILIZES SEDIMENT WHILE OTHER SPECIES BECOME ESTABLISHED
	TRANSITIONAL AREA GRASS
wildlife benefit	low, rabbits & some birds
aesthetic value	low
rate of spread	moderate
characteristics	herbaceous/perennial/semi-persistent
height	up to 4ft.
shade	prefers full sun
community	swales, thickets
pH preference	none

Alisma plantago-aquatica/ A.subcordatum

common name: Water plantain, Mud plantain

notes	regularly-permanently inundated up to 1 ft. or saturated (~26-100% of growing season)
wildlife benefit	low
aesthetic value	white flowers
rate of spread	NA
characteristics	herbaceous, perennial, nonpersistent
height	up to 3.5ft.
shade	NA
community	ditches, seeps, edges of ponds&lakes
pH preference	none

Andropogon glomeratus	
common name: Lowland broom sedge, Bushy beardgrass	
notes	irregularly to seasonally inundated/saturated (~25% of growing season), TOLERATES DROUGHT, grows in tufts
wildlife benefit	low, mostly birds, deer
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	herbaceous, perennial, persistent
height	up to 5ft.
shade	NA
community	wet soils, freshwater marshes
pH preference	none

Andropon virginicus	
common name: Broom sedge	
notes	irregularly inundated/saturated (12% of growing season), TOLERATES DROUGHT, TRANSITIONAL/BUFFER PLANT
wildlife benefit	moderate, mostly birds and deer
aesthetic value	low
rate of spread	slow, less than 0.2ft.yr
characteristics	harbaceous, perennial, persistent
height	1-3ft
shade	full sun required
community	wet meadows, transitional areas
pH preference	none

Asclepias incarnata	
common name: Swamp milkweed	
notes	irregularly, seasonally or regularly inundated/saturated (75% of growing season), TOLERATES DROUGHT
wildlife benefit	low, attracts butterflies
aesthetic value	pink/purplish red flowers
rate of spread	slow, less than 0.2ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	up to 6ft.
shade	tolerated partial shade
community	ditches, fresh tidal marshes, wet meadows, forested wetlands, shrub swamps
pH preference	none

Carex lanuginosa

common name: Wooly sedge

notes	irregularly, seasonally or regularly inundated up to 0.5ft. or saturated (up to 75% of growing season); TOLERATES DROUGHT, BANK STABILIZER
wildlife benefit	moderate-high
aesthetic value	low
rate of spread	NA
characteristics	Herbaceous, perennial, nonpersistent
height	1-3ft.
shade	NA
community	wet meadows, pond shores
pH preference	none

Carex retrosa

common name: Retrose sedge

notes	irregularly, seasonally, regularly or permanently inundated to 0.5ft or saturated (up to 100% of growing season)
wildlife benefit	moderate-high
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	Herbaceous, perennial, nonpersistent
height	1-3ft.
shade	tolerates full shade
community	wet meadow, forested seasonal wetland
pH preference	none

Carex stipata

common name: Awl-fruited sedge

notes	irregularly to seasonally/regularly inundated (up to 25% of growing season), TOLERATES DROUGHT
wildlife benefit	high
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	1-3ft
shade	tolerates partial shade
community	nontidal marshes, wet meadows
pH preference	none

Carex stricta

common name: Tussock sedge, Uptight sedge

notes	seasonally, regularly or permanently inundated up to 0.5ft. (13-100% of growing season), TOLERATES ACIDIC CONDITIONS
wildlife benefit	moderate
aesthetic value	low
rate of spread	moderate, ~0.5ft/yr.
characteristics	herbaceous, perennial, semi-persistent
height	up to 3.5ft.
shade	requires full sun
community	nontidal marshes, wet swales, shrub swamps
pH preference	none

Glyceria pallida/ Puccinellia fernalidii, Pr. Pallida

common name:Floating mannagrass

notes	regularly to semipermanently inundated up to 1ft (25-100% of growing season)
wildlife benefit	moderate
aesthetic value	low
rate of spread	rapid, over 1ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	1-3ft.
shade	tolerates partial shade
community	pond edges, pools, sloughs.
pH preference	none

Glyceria striata

common name: Fowl mannagrass, Nerved mannagrass

notes	irregularly to seasonally inundated (25% of growing season or less)
wildlife benefit	moderate, deer esp.
aesthetic value	low
rate of spread	NA
characteristics	herbaceous, perennial, nonpersistent
height	up to 4ft.
shade	prefers partial shade, may tolerate full shade
community	freshwater marshes, seeps, shrub and forested wetlands
pH preference	none

Hydrocotyle umbellata

common name: Water-pennywort

notes	regularly to permanently inundated up to 1 ft. or saturated (~26-100% of growing season)
wildlife benefit	low, mostly birds
aesthetic value	white flowers
rate of spread	NA
characteristics	herbaceous, perennial, nonpersistent
height	up to 1 ft.
shade	tolerates partial shade
community	ditches, shores, tidal marshes
pH preference	none

Juncus balticus

common name: Salt rush, Baltic rush

notes	seasonally, regularly or permanently inundated up to 0.5ft. Or saturated (~13-100% of time) LIMITS ESTABLISHMENT OF INVASIVE SPECIES
wildlife benefit	moderate-high
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	Herbaceous, perennial
height	1.5-3ft.
shade	tolerates partial shade
community	calcerous nontidal marshes, dunes, salt/brakish tidal marsh
pH preference	none

Juncus effusus

common name: Soft rush

notes	regularly to permanently inundated up to 1ft. Or saturated (~26-100% of growing season)
wildlife benefit	high
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	Herbaceous, perennial, persistent
height	up to 3.5ft.
shade	prefers full sun, may tolerate partial shade
community	fresh tidal marches, nontidal marshes, shrub swamps, wet meadows, ditches
pH preference	none

Juncus torreyi

common name: Torrey rush

notes	irrefularly to seasonally inundated or saturated (up to 25% of growing season), TOLERATES DROUGHT, ALKALI TOLERANT
wildlife benefit	moderate
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	Herbaceous, perennial
height	1-3ft.
shade	tolerates partial shade
community	sedge meadows
pH preference	none

Leersia oryzoides

common name: Rice cutgrass

notes	irregularly to permanently inundated up to 0.5ft (up to 100% of growing season)
	TOLERATES DROUGHT, GOOD FOR SEDIMENT STABILIZATION AND EROSION CONTROL
wildlife benefit	high
aesthetic value	low
rate of spread	moderate, up to 0.5ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	up to 5ft
shade	tolerates partial shade
community	ditches, wet meadowns, fresh tidal marshes, muddy shores
pH preference	none

Lobelia cardinalis

common name: Cardinal flower

notes	regularly to permanently saturated (~26-100% of growing season)
wildlife benefit	low, attracts hummingbirds and butterflies
aesthetic value	high, scarlet flowers
rate of spread	slow, less than 0.2 ft/yr
characteristics	Herbaceous, perennial, nonpersistent
height	2-4ft.
shade	tolerates partial shade
community	fresh tidal and nontidal marshes, wooded swamps, seeps, pond, river and stream banks
pH preference	none

Nuphar luteum

common name: Spatterdock, Yellow water lily, Cowlily

notes	regularly to permanently inundated from 1-3ft (~50-100% of growing season), may grow in water which is 6ft. Deep.
wildlife benefit	moderate
aesthetic value	yellow flowers
rate of spread	slow, less than 0.2ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	erect or floating-leaved
shade	tolerates partial shade
community	nontidal marshes, swamps, ponds
pH preference	over pH = 5, tolerates acidic water

Osmunda cinnamomea

common name: Cinnamon fern, Buckhorn, Fiddle-heads

notes	irregularly, seasonally, regularly or permanently saturated (up to 100% of growing season) TOLERATES DROUGHT, TRANSPLANTS EASILY
wildlife benefit	low-moderate
aesthetic value	low-moderate
rate of spread	slow, less than 0.2ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	up to 5ft.
shade	tolerates full shade, prefers at least partial shade
community	forested wetlands, stream banks, seepage slopes, bog edges
pH preference	none

Peltandra virginica

common name: Arrow arum, Tuckahoe, Wampee, Duck corn

notes	regularly to permanently inundated up to 1ft or saturated (~25% of growing season)
	HAS SHOWN SOME ALLELOPATHIC CHARACTERISTICS
wildlife benefit	moderate, NOT EATEN BY GEESE
aesthetic value	low
rate of spread	slow, less than 0.2ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	up to 2ft
shade	tolerates partial shade
community	swamps, shallow waters of ponds and lakes, nontidal marshes
pH preference	5.0-6.5

Sagittaria latifolia

common name: Duck potato, Big-leaved arrowhead, Wapato

notes	regularly to permanently inundated up to 2ft (or saturated~26-100% of growing season), loses much water through transpiration
wildlife benefit	high BUT: MALLARD DUCKS AND MUSKRAT CAN RAPIDLY CONSUME TUBERS IN AN AREA
aesthetic value	white flowers with yellow center
rate of spread	rapid, over 1ft/yr.
characteristics	herbaceous, perennial, nonpersistent
height	up to 4ft
shade	tolerates partial shade
community	nontidal marshes, swamps, borders of streams, lakes and ponds
pH preference	none

Spartina pectinata

common name: Prairie cordgrass

notes	regularly to permanently inundated up to 0.5ft or saturated(~26-100% of growing season), good for shore stabilization
wildlife benefit	high
aesthetic value	low
rate of spread	moderate, ~0.5ft/yr.
characteristics	herbaceous, perennial
height	4-6ft.
shade	requires full sun
community	nontidal marshes, wet meadows
pH preference	none

Thelupteris noveboracensis

common name: New York fern

notes	irregularly, seasonally or regularly saturated (up to 75% of growig season), TOLERATES DROUGHT
wildlife benefit	low-moderate
aesthetic value	low
rate of spread	NA
characteristics	Herbaceous, perennial, nonpersistent
height	1-2ft.
shade	tolerates full shade
community	forested wetlands
pH preference	none

Trees

From: Wetland Planting Guide for the Northeastern United States; Plants for Wetland Creation, Restoration and Enhancement. By Gwendolyn A. Thunhorst, 1993

Acer negundo

common name: Box elder, Ash-leaved maple

notes	irregularly to seasonally or regularly inundated/saturated (frequent inundation up to ~75% of growing season)
	SUSCEPTIBLE TO WIND AND ICE DAMAGE, TOLERATES DROUGHT
	SUSCEPTIBLE TO ANTHRACNOCE, POWDERY MILDEW AND SOME CANKER DISEASES, BOXELDER BUG, STRIPED MAPLE WORM AND MANY SPECIES OF BORERS
wildlife benefit	high
aesthetic value	yellow green flowers
rate of spread	fast, 15-20ft in 5 years
characteristics	Broad-leaved, deciduous
height	35-75ft
aerial spread	35-50ft
community	forested seasonal wetlands, alluvial woods
shade	requires full sun
pH preference	6.0-8.0 (will tolerate down to 5.0)

Betula nigra

common name: River birch

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season)
	TOLERATES DROUGHT, USED FOR STREAMBANK STABILIZATION, SUSCEPTIBLE TO WIND/ICE DAMAGE
wildlife benefit	moderate
aesthetic value	light green/yellow flowers
rate of spread	fast, 30-40 ft in 10 yrs.
characteristics	Broad-leaved, deciduous
height	50-75 ft.
aerial spread	35-50 ft.
community	streambanks, floodplain forest, forested seasonal wetlands
shade	requires full sun
pH preference	none

Fraxinus nigra

common name: Black ash

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) SUSCEPTIBLE TO WIND AND ICE, TOLERATES DROUGHT SUSCEPTIBLE TO LEAF SPOT, ANTHRACNOSE, RUST, CANKER, OYSTERSHELL SCALE AND ASH BORER
wildlife benefit	high
aesthetic value	purple flowers
rate of spread	fast, 2-3 ft/yr.
characteristics	Broad-leaved, deciduous
height	50-75 ft.
aerial spread	NA
community	forested wetlands
shade	requires full sun
pH preference	4.6-6.5

Fraxinus pennsylvanica

common name: Green Ash

notes	irregularly, seasonally or regularly inundated/saturated (~75% of growing season), male/femal parts grow on separate plants SUSCEPTIBLE TO WIND OR ICE DAMAGE, TOLERATES DROUGHT, FAIRLY INSENSITIVE TO DISEASE SOME SPECIES SUSCEPTIBLE TO ASH BORER, OYSTERSHELL SCALE, BROWN HEADED ASH SAWFLY, LILAC LEAF MINOR, AND LILAC BORER. COMPETES WELL IN A VARIETY OF CONDITIONS.
wildlife benefit	high
aesthetic value	pruple flowers
rate of spread	fast, 2.5-3ft/yr.
characteristics	Broad-leaved, deciduous
height	50-75ft.
aerial spread	35-50ft.
community	tidal and nontidal freshwater forested wetlands
shade	tolerates partial shade
pH preference	6.1-7.5

Nyssa sylvatica

common name: Black gum, Black tupelo, Sour gum

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO DISEASE/INSECT/WIND/ICE, TOLERATES DROUGHT MALE/FEMALE PARTS ON SEPARATE PLANTS
wildlife benefit	high, may attract black bears and foxes
aesthetic value	greenish white flowers, blue fruit
rate of spread	slow, 4-5 in/yr., spreads by suckers
characteristics	Broad-leaved, deciduous
height	50-75 ft.
aerial spread	35-50ft.
community	forested seasonal wetlands, dry woods, moist upland woods
shade	tolerates partial shade
pH preference	6.0-7.0

Quercus bicolor

common name: Swamp white oak

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO DISEASE/INSECT/WIND/ICE, TOLERATES DROUGHT SUSCEPTIBLE TO IRON CHLOROSIS AND GYPSY MOTHS
wildlife benefit	HIGH
aesthetic value	yellowish green flowers, brown acorns (acorn produced after 25-30 yrs)
rate of spread	fast, 1.5-2 ft/yr.
characteristics	Broad-leaved, deciduous
height	75-100 ft.
aerial spread	50-75 ft.
community	forested seasonal wetlands
shade	tolerates partial shade
pH preference	5.0-7.5

Quercus palustris

common name: Pin oak, Spanish oak

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO DISEASE/INSECT/WIND/ICE, TOLERATES DROUGHT SUSCEPTIBLE TO IRON CHLOROSIS AND GYPSY MOTHS
wildlife benefit	moderate
aesthetic value	yellow green flowers, acorns produced after 15-25 years
rate of spread	fast, 30ft in 12-15 years
characteristics	Broad-leaved, deciduous
height	50-75 ft.
aerial spread	50-75 ft.
community	forested seasonal wetlands, moist alluvial woods
shade	requires full sun
pH preference	5.0-6.5

Salix nigra

common name: Black willow

notes	irregularly, seasonally or regularly inundated/saturated (up to 75% of growing season with dry periods b/w inundations) USED FOR STREAMBANK STABILIZATIONS, SUSCEPTIBLE TO WIND AND ICE SUSCEPTIBLE TO FUNGUS SCAB AND BLACK CANKER
wildlife benefit	very high
aesthetic value	yellow green flowers, green yellow strobile
rate of spread	very fast, 3-6 ft/yr., spreads by suckers
characteristics	Broad-leaved, deciduous
height	35-50 ft.
aerial spread	20-35 ft.
community	fresh tidal marshes/swamps, forested wetlands, floodplains, wet meadows
shade	requires full sun
pH preference	6.0-8.0

Thuja occidentalis

common name: Northern white cedar, Arbor vitae

notes	seasonally or regularly saturated (13-75% of the growing season) SUSCEPTIBLE TO WIND OR ICE DAMAGE (WEAK WOODED)
wildlife benefit	low food value
aesthetic value	red brown cones, adds diversity, stays through the winter
rate of spread	medium to fast, 2ft/yr (can be slower in wetland areas)
characteristics	Needle-leaved, evergreen
height	50-75ft.
aerial spread	35-50ft.
community	forested swamps, shrub swamps, bogs, forested seasonal swamps
shade	tolerates partial shade
pH preference	6.0-8.0

Ulmus americana

common name: American elm, White elm

notes	irregularly to seasonally inundated (up to 25% of growing season)
	TOLERATES DROUGHT, FAIRLY INSENSITIVE TO WIND AND ICE DAMAGE
	SUSCEPTIBLE TO DUTCH ELM DISEASE, CANKERS, VERTICULLIUM WILT
	SUSCEPTIBLE TO GYPSY MOTH, BARK BEETLES, ELM BORER, CANKERWORMS, ELM COCKSCOMB GALL
wildlife benefit	very high
aesthetic value	red brown flowers
rate of spread	medium, 20ft in 10 yrs.
characteristics	Broad-leaved, deciduous
height	75-100ft.
aerial spread	75-100ft.
community	forested seasonal wetlands, moist&rich upland woods
shade	tolerates full shade
pH preference	6.0-8.0

Viburnum lentago

common name: Nannyberry, Sweet viburnum, Sheepberry

notes	seasonally inundated/saturated (~13-25% of growing season)
	FAIRLY INSENSITIVE TO WIND OR ICE DAMAGE, FORMS DENSE THICKETS, BERRIES LAST THROUGH FALL/WINTER.
wildlife benefit	high
aesthetic value	white flower, yellow/red/black berries
rate of spread	fast, 2-2.5 ft/yr., spreads by suckers
characteristics	Broad-leaved, deciduous
height	20-35ft.
aerial spread	10-35ft.
community	forested seasonal wetlands, stream and swamp edges
shade	tolerates full shade
pH preference	6.0-7.5

Shrubs

From: Wetland Planting Guide for the Northeastern United States; Plants for Wetland Creation, Restoration and Enhancement. By Gwendolyn A. Thunhorst, 1993

Amorpha fruticosa

common name: False indigo bush, Indigo bush

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season)
	SUSCEPTIBLE TO WIND AND ICE DAMAGE, SOIL STABILIZER, TOLERATES DROUGHT
wildlife benefit	high
aesthetic value	purple/bluish flowers
rate of spread	medium, 1-2ft/yr.
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	12-20ft.
community	shrub swamps, forested wetlands
shade	requires full sun
pH preference	6.0-8.5

Aronia arbutifolia/Pyrus arbutifolia

common name: Red chokeberry

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season)
	TOLERATES DROUGHT, SERVES AS EMERGENCY FOOD IN WINTER TO MANY SPECIES
wildlife benefit	moderate-high
aesthetic value	white flowers, red fruit
rate of spread	flow, less than 1ft/yr.
characteristics	broad-leaved, deciduous shrub
height	6-12ft
aerial spread	3-6ft
community	shrub bogs, forested seasonal wetlands, upland soil
shade	tolerates partial shade
pH preference	5.0-6.5

Aronia melanocarpa/Pyrus melanocarpa

common name: Black chokeberry

notes	irregularly to seasonally saturated (up to 25% of growing season)
	TOLERATES DROUGHT, RELATIVELY INSENSITIVE TO DISEASE/INSECTS/WIND/ICE
wildlife benefit	high
aesthetic value	white flowers, black fruit
rate of spread	slow, less than 1ft/yr.
characteristics	croad-leaved, deciduous shrub
height	3-6ft
aerial spread	3-6ft
community	swamp and bog edges, clearings
shade	tolerates partial shade
pH preference	5.1-6.5

Cephalanthus occidentalis

common name: Buttonbush

notes	irregularly to permanently innundated up to 3ft (up to 100% of growing season)
	tolerates wide range of conditions, DROUGHT RESISTANT, FAIRLY INSENSITIVE TO DISEASE/INSECTS/WIND/ICE
wildlife benefit	high, hummingbird attractant
aesthetic value	white flowers
rate of spread	medium, 1-2ft/yr
characteristics	Broad-leaved, deciduous shrub
height	6-12ft.
aerial spread	12-20ft.
community	non tidal marshes, shrub swamps, forested wetlands, borders of streams, lakes and ponds
shade	tolerates full shade, blooms best in partial shade and full sun
pH preference	6.0-8.5

Cornus amomum

common name: Silky dogwood

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO INSECTS/WIND/ICE, DROUGHT TOLERANT
wildlife benefit	very high
aesthetic value	yellowish white flowers, blue fruit
rate of spread	fast, 2ft/yr or more
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	6-12ft.
community	forested seasonal wetlands, shrub wetlands, stream and pond banks, moist woods
shade	prefers full sun, tolerates partial shade
pH preference	5.5-7.5, tolerates up to 8.5

Cornus sericea/C. stolonifera

common name: Red-osier dogwood

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO WIND/ICE DAMAGE, TOLERATES DROUGHT, USED IN STREAM BANK STABILIZATION
wildlife benefit	high
aesthetic value	white flowers, white fruit
rate of spread	fast, more than 2ft/yr.
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	6-12ft.
community	forested seasonal wetlands, stream banks, shrub wetlands
shade	tolerates partial shade
pH preference	5.5-8.5

Ilex verticillata

common name: Common winterberry, Winterberyy holly, Black alder, Swamp holly

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO DISEASE, INSECT, WIND, ICE; MALE AND FEMALE PARTS ON SEPARATE PLANTS TOLERATES DROUGHT
wildlife benefit	high
aesthetic value	high, greenish white flowers, red/orange berries persisting through winter
rate of spread	slow, less than 1ft/yr.
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	6-12ft.
community	fresh tidal swamps, shrub swamps, forested wetlands
shade	prefers at least partial shade, tolerates full shade
pH preference	4.5-6.0, tolerates up to 8.0

Leucothoe racemosa

common name: Fetterbush

notes	seasonally to regularly inundated/saturated (13-75% of growing season, with dry-down intervals during inundations)
wildlife benefit	low to moderate
aesthetic value	white flowers
rate of spread	NA
characteristics	Broad-leaved, deciduous
height	up to 13ft.
aerial spread	NA
community	shrub swamps, forested wetlands, moist acid woods
shade	tolerates full shade
pH preference	5.0-6.0

Lindera benzoin (Benzoin aestivale)

common name: Common spicebush

notes	seasonally inundated/saturated (~13-25% of growing season) FAIRLY INSENSITIVE TO DISEASE, INSECT, WIND, ICE; MALE AND FEMALE PARTS ON SEPARATE PLANTS TOLERATES DROUGHT
wildlife benefit	high
aesthetic value	greensih yellow flowers, red fruit
rate of spread	slow, less than 1ft/yr.
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	6-12ft.
community	forested seasonal wetlands, moist upland woods, floodplains
shade	tolerates full shade
pH preference	4.5-6.5

Myrica pensylvanica

common name: Bayberry

notes	irregularly to seasonally inundatred/saturated (up to 25% of growing season) NITROGEN FIXING, MALE AND FEMALE LOWERS ON SEPARATE PLANTS, TOLERATES DROUGHT, FAIRLY INSENSITIVE TO DISEASE, INSECT AND WIND/ICE DAMAGE
wildlife benefit	high
aesthetic value	green flowers, white/gray fruit
rate of spread	medium, 1 to 2ft.
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	6-12ft.
community	tidal fresh and brakish marshes/swamps, nontidal marshes/swamps, sand flats and dunes
shade	tolerates partial shade
pH preference	5.0-6.5

Rhododendron periclymenoides (r. nudiflorum, Azalea nudiflorum)

common name: Pinxterbloom azalea, Pink azalea, Purple honeysuckle, Election-pink

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season) FAIRLY INSENSITIVE TO WIND, ICE; SUSCEPTIBLE TO LEAF SPOTS, CROWN ROT, SHOESTRING ROOT ROT, POWDERY MILDEW, SHOOT BLIGHT, GRAY BLIGHT, NEMATODES, RHODODENDRON WHITEFLY, SCALES, RHODODENDRON TIP MIDGE, PITTED AMBROSIA BEETLE, AND OTHERS
wildlife benefit	low, but native of MA
aesthetic value	high, pink/purplish flowers
rate of spread	slow, less than 1ft/yr.
characteristics	Braod-leaved deciduous shrub
height	6-12ft.
aerial spread	6-12ft.
community	swamps and bog edges, woodlands
shade	tolerates full shade, doesn't tolerate full sun
pH preference	4.5-5.5

Rosa palustris

common name: Swamp rose

notes	irregularly, seasonally or regularly saturated (up to 75% of growing season)
wildlife benefit	high
aesthetic value	large pink flowers
rate of spread	NA
characteristics	Broad-leaved, deciduous
height	up to 7ft.
aerial spread	NA
community	nontidal marshes, forested wetlands, stream banks, shrub swamps
shade	prefers full sun
pH preference	none

Salix purpurea

common name: Basket willow, Streamco willow, Purplosier willow

notes	regularly to permanently inundated/saturated (~26-100% of time)
	TOLERATES DROUGHT, SPECIFICALLY DEVELOPED FOR STREAMBANK STABILIZATION
wildlife benefit	very high
aesthetic value	low
rate of spread	fast, up to 2ft/yr.
characteristics	Broad-leaved, deciduous
height	8-18ft
aerial spread	NA
community	streambanks
shade	tolerates partial shade
pH preference	6.0-7.0

Sambucus canadensis

common name: Elderberry, American elder

notes	irregularly to seasonally inundated/saturated (up to 25% of growing season)
	TOLERATES DROUGHT, SUSCEPTIBLE TO WIND AND ICE DAMAGE, GROWS WELL ON DISTURBED SITES
wildlife benefit	very high
aesthetic value	white flowers, purple/black fruit, plant bears fruit after 4 years
rate of spread	fast, up to 2ft/yr.
characteristics	Broad-leaved, deciduous shrub
height	6-12ft.
aerial spread	6-12ft.
community	fresh tidal and nontidal marshes, swamps, wet meadows, moist woods, old fields
shade	tolerates ful shade, flowers best in partial shade and full sun
pH preference	6.0-8.0

Vaccinium corymbosom

common name: Highbush blueberry

notes	seasonally inundated/saturated (~13-25% of growing season) FAIRLY INSENSITIVE TO WIND OR ICE DAMAGE
wildlife benefit	high, very valuable fruit
aesthetic value	high, white/piniksh flowers, bluish/black fruit
rate of spread	slow, less than 1ft/yr.
characteristics	Broad-leaved, deciduous
height	6-12ft.
aerial spread	6-12ft.
community	forested wetlands, shrub wetlands, bogs, upland woods (rare)
shade	tolerates full shade
pH preference	3.5-6.0 (will tolerate 6.5)

Viburnum trilobum (V. opulus)

common name: Highbush cranberry, American cranberry bush

notes	irregularly or seasonally inundated/saturated (~13-25% of growing season) FAIRLY INSENSITIVE TO WIND/ICE, TOLERATEs DROUGHT, PROVIDES EMERGENCY FOOD IN WINTER
wildlife benefit	moderate
aesthetic value	white flowers, red/orange berries, berries fruit in fall and winter
rate of spread	medium, 1-2ft/yr.
characteristics	Broad-leaved, deciduous
height	6-16ft
aerial spread	6-12ft.
community	bogs, forested seasonal wetlands, shrub swamps
shade	tolerates full shade
pH preference	6.0-7.5