US Army Corps
of Engineers ®
New York District

THE PORT AUTHORITY OF NY & NJ

Liberty State Park
Hydrology and Hydraulics of Freshwater Wetlands

April 2004

TABLE OF CONTENTS

1. INTRODUCTION ... 1
1.1. General ... 1
1.2. Study Area Location ... 1
1.3. Overall Study Background ... 2
1.4. Purpose ... 2
1.5. Freshwater History ... 2
1.6. Freshwater Project Objectives ... 3
1.7. Freshwater Project Constraints ... 4
2. SITE DESCRIPTION ... 6
2.1 General ... 6
2.2 Land Use ... 6
2.3 Soils ... 7
2.4 Topography ... 7
2.5 Existing Drainage ... 8
2.6 Groundwater Data ... 8
3. HYDROLOGIC ANALYSIS ... 9
3.1 General ... 9
3.2 Watershed Description ... 9
3.2.1 General ... 9
3.2.2 Liberty State Park ... 10
3.2.3 Liberty Science Center ... 10
3.2.4 Liberty Science Center Wetland ... 11
3.2.5 New Jersey Transit Light Rail Terminal ... 11
3.3 Climatology ... 11
3.3.2 Climate ... 11
3.3.3 Precipitation Data Used ... 12
3.3.4 Annual and Monthly Precipitation ... 14
3.4 Infiltration ... 14
3.4.2 Test Procedure ... 15
3.4.2 Results ... 15
3.4.3 Rates Used in the Analysis ... 17
3.5 Evapotranspiration ... 17
3.6 Estimated Runoff Volume ... 18
3.6.1 General ... 18
3.6.2 Simple Method ... 18
3.6.3 Annual Runoff ... 18
4. ENVIRONMENTAL DESIGN CRITERIA ... 21
4.1 Biological Considerations ... 21
4.1.1 Introduction ... 21
4.1.2 Wildlife Considerations ... 21
4.2 Minimum Water Requirements ... 22
5. Hydrologic Design Criteria ... 24
5.1. General ... 24
5.2. Hydrologic Setting ... 24
5.3. Flooding Duration and Timing ... 25
5.4. Water Depth ... 25
5.5. Flow Velocity ... 25

5.6. Flow Resistance 25
5.7. Hydraulic Retention Time (HRT) 26
5.8. Storage Capacity 26
5.9. Surface Area 26
5.10. Fetch 27
6. FRESHWATER WETLAND SYSTEM 28
6.1 Existing Freshwater Wetlands 28
6.2 Description of the Proposed Freshwater Wetland Components 28
6.3 Description of the Modeled Alternatives 32
7. HYDROLOGIC BUDGET ANALYSIS 35
7.1 Water Balance 35
7.2 Hydrologic Budget 35
8. HYDRAULIC ANALYSIS 37
8.1 General 37
8.2 Basis of Design 37
8.3 Hydraulic Design Criteria 38
8.3.1 Water Containment 38
8.3.2 Sediments and Debris 38
8.3.3 Design Event 39
8.3.4 Conduits 39
8.3.5 Materials 40
8.4 SWMM Model Development 41
8.4.1 General 41
8.4.2 RUNOFF Block 41
8.4.3 HYDRAULICS Block 45
8.4.4 ALTERNATIVES ANALYSIS 50
8.4.4.1 General 50
8.4.4.2 Alternative A – Addition of LSC Runoff 50
8.4.4.3 Alternative B – Addition of LSC and LSC Wetland Runoff 52
8.4.4.4 Alternative C – Additional Runoff and Enhanced LSC Wetland 52
8.4.5 Groundwater Impacts 40
8.4.6 10-year NJDOT Design Event Performance 53
9. SEDIMENT LOADING ESTIMATES 37
9.1 Methodology And Assumptions 56
9.2 Sediment Loading And Deposition Estimates 58
10. COST ANALYSIS 59
11. REFERENCES 60

1. INTRODUCTION

1.1. General

The New York District Corps of Engineers (hereafter referred to as the District) is presently conducting a Feasibility Study of ecosystem restoration opportunities within the Hudson-Raritan Estuary, which is delineated as the surrounding greater metropolitan New York City region, within an approximate 25-mile radius of the Statue of Liberty. During the reconnaissance phase, the District conducted an extensive restoration-opportunity identification and screening process within the study area, in cooperation with Federal and state resource agencies, and environmental interest groups. The reconnaissance study identified over 80 sites that may meet Federal budgetary criteria and were recommended for inclusion in the Feasibility Study. The non-Federal partner, the Port Authority of New York and New Jersey (PANYNJ), in consensus with the New York/New Jersey Harbor Estuary Program (HEP) Habitat Work Group and agencies from both states, identified 13 sites as initial Building Blocks of the Feasibility Study's Comprehensive Restoration Implementation Plan (CRIP).

Liberty State Park is the first Building Block to move forward with an individual Feasibility Study.

1.2. Study Area Location

Liberty State Park is located on a 1,122-acre site near the confluence of the Hudson River and the Upper New York Bay in Jersey City, New Jersey (see Figures 1-1 and 1-2.) It is bounded by Morris Canal to the north and Black Tom to the south. The east side of the park faces New York and New Jersey Harbor, and the west side is bounded by Phillip Street and the New Jersey Turnpike. The interior 215 acres of the park are restricted for public access due to the presence of sediment contaminants that exceed residential exposure levels. The overall study focuses on environmental restoration opportunities within the 215 acres and the existing wetland area adjacent to Liberty Science Center, which is immediately west of the park.

1.3. Overall Study Background

Environmental restoration opportunities being considered for Liberty State Park include the creation of a tidal marsh in the center of the park, and enhancements to the uplands and freshwater wetlands within the undeveloped area in the park. Materials will be excavated from the proposed tidal marsh area, capped and used to create a grassland berm in the southwestern section of the park. A narrow channel will connect the tidal marsh to the North Cove. Storm water will be collected from adjacent areas and will be diverted to feed freshwater wetlands on the site, creating shallow and deep emergent marshes. Nuisance plant species will be controlled, and native grasslands, shrublands and forests will be planted. The uniqueness of the three primary restoration components in analysis, function, and habitat, requires that each be evaluated separately. Therefore, the restoration feasibility analysis and evaluation has been broken into three separate components: (1) a tidal wetland, (2) a freshwater wetland system, and (3) upland areas.

1.4. Purpose

This report documents the analysis and evaluation of the feasibility of freshwater wetlands enhancement and restoration within Liberty State Park.

1.5. Freshwater History

Liberty State Park occupies an area previously dominated by intertidal mud flats and salt marshes. Since the cessation of rail operations, nature has begun to reclaim the area and successional forests and fields have begun to emerge in the undeveloped areas. Interspersed between the successional forest and fields, natural wetlands have emerged. Generally, these wetland areas have been increasing in number and size over the last few decades, based on wetland delineations in 1990 and 2004. With the exception of the Liberty Science Center wetland, the growth of the wetlands has been a wholly natural, albeit slow, occurrence.

In the General Management Plan for the park (NJDEP, 2001), the NJDEP has expressed a desire to maintain and expand the wetland areas within the park to improve the natural habitat, increase the wildlife diversity, and assist nature in the reclamation of the park. The results of this analysis will assist in furthering that effort.

1.6. Freshwater Project Objectives

The southeast section of the 215-acre restricted area contains a significant number of small wetlands. The number of existing wetlands in this area and its distance from additional stormwater runoff sources preclude this area from consideration for wetlands enhancement. In the center of the park, a natural freshwater wetland area (shallow emergent marsh) exists immediately west of the 45-acre dredge spoil area being evaluated for saltwater wetland restoration (see Figure 1-3.) The enhancement and expansion of existing freshwater wetlands in the vicinity of this wetland has been proposed by the State of New Jersey as part of the overall Liberty State Park environmental restoration plan. The enhancement is expected to require additional water sources; thus, the Liberty State Park Science Center and the nearby New Jersey Transit (NJ Transit) Light Rail Terminal parking lot are being considered as potential sources of stormwater runoff.

An evaluation of the existing and potential sources of freshwater is necessary to determine the feasibility of the wetlands expansion. A hydrologic budget was developed to analyze the viability of various wetland restoration alternatives with regard to wetland sustainability. The objective of the hydraulic design process is to establish conduit dimensions for transporting stormwater runoff, evaluate the hydraulic impacts (e.g., flooding or draining) to existing areas, and analyze the expected hydraulic performance of the wetland system. The hydraulic performance of the system will help determine the target vegetative structure and wetland functions.

In this report, “conceptual plans” are referred to, which are preliminary scenarios used in an initial screening level of analysis. In Section 7 hydrologic budgets for these conceptual plans are discussed. In addition, a series of “alternatives” are also presented in Section 6, and a comparative hydraulic analysis for these alternatives using the SWMM model is performed in Section 8. Conceptual Plan 3 is the basis for Alternatives B and C.

1.7. Freshwater Project Constraints

Within Liberty State Park, the natural reclamation process is resulting in a gradual improvement of the environment. Outside the park is an urban environment, which has developed independent of the park ecological system. The intent of this project is to accelerate the natural reclamation processes in combination with restoring some of the historical ecological functions to the park through the redirection of some of the stormwater drainage from the adjacent, urban areas. However, the stormwater drainage in the urban environment has been designed to meet regulatory drainage requirements. Therefore, the effort to redirect the stormwater drainage requires marrying the hydrologic needs of the enhanced wetlands with the regulatory drainage requirements in the urban areas.

The stormwater drainage for the Liberty Science Center and parking lot, and the NJ Transit Light Rail Terminal and parking lot was not necessarily designed for wetland sustainability, but rather, it was designed for maximum drainage to prevent flooding. Any constrictions or diversion of flow from these urban sources will require that no induced flooding occurs up to the original design criteria.

Wetland hydraulic design is an iterative process, consisting of: (1) developing a proposed hydraulic design, (2) conducting a site drainage analysis and surface flow hydrodynamic analysis with the proposed features in place, (3) evaluation of the proposed design against the design criteria, and (4) modification of the proposed design. The development of the proposed wetland alternatives was based on typical wetland environmental, hydrologic, and hydraulic design criteria.

2. SITE DESCRIPTION

2.1 General

Liberty State Park was an intertidal mud flat and salt marsh that was filled and used as a railroad yard during the growth of the New York City metropolitan area. A majority of the soils within the park consist of historic fill materials that were deposited to stabilize the surface between 1860 and 1919 (MacFarlane 2001). Materials from construction projects and refuse from New York City were also included in the fill material. Between 1864 and 1967, the Central Railroad of New Jersey (CRRNJ) used the site as a rail yard for both freight and passenger service. In 1967, the CRRNJ discontinued operations at the site, and over the next few years the land was abandoned and subsequently acquired by the New Jersey Department of Environmental Protection (NJDEP) Division of Parks and Forestry (NJDPF) (LSP 2003).

The 215-acre undeveloped area in the center of the park has remained undeveloped and access is restricted to the public due to the presence of polynuclear aromatic hydrocarbons (PAHs), pesticides, and metals that exceed the NJDEP residential clean up criteria (MacFarlane 2001). Some of the fill in the undeveloped area is comprised of materials dredged from the Upper Bay during construction of the LSP causeway.

2.2 Land Use

The area surrounding Liberty State Park is essentially fully developed. Commercial and industrial development is immediately adjacent to the park to the west and south. Due to the historic use of the park as a rail yard, there is little historic drainage from outside the park into the park. Recent construction, such as the Liberty Science Center and the New Jersey Transit Light Rail Terminal and parking lot, contribute stormwater runoff to the fringes of the park but not to the interior.

Review of aerial photographs and a field survey of the watershed confirmed the land use patterns.

2.3 Soils

The results of the geotechnical analysis indicate that the soils vary considerably across the site. Both fine-grained and course grained soils are present. Soils in virtually all of USCS soil classification are found on site. Based upon the material recovered from the drilling and sampling program, approximately 60% of the on-site soil is poorly graded/silty Sand and approximately 38% of the soil is Clay. At surface depths from 0.0-ft to 4.5-ft below grade, approximately 90% of the on-site soil is poorly graded/silty Sand and approximately 6% of the soil is Clay. Blow count analyses suggest that the soil be classified as ‘loose,’ although some ‘very loose’ and ‘dense’ soils were also encountered. Near surface excavation of this material should present no unusual excavation problems.

Specific soil samples in the vicinity of the proposed wetlands indicated a surface layer (0-4.5 ft) of silty Sand with Gravel, with a mixture of sand, gravel, cinders, and ash. Silty Sand is present below 4.5 feet to approximately 10 feet. In the vicinity of the shallow emergent marsh adjacent to the 45-acre dredge spoil site, a fat Clay layer was noted at a depth of approximately 7.5 feet.

2.4 Topography

The park is relatively level as a result of its historical use. Small, linear berms between the old railroad tracks were created during the construction of the railroad yard. Changes in elevation exist typically only as a result of the additional deposition of dredged materials or construction of dredged material containment berms following cessation of rail operations. Additional changes in the relief within the park occurred with the commencement of development of the park, which included the creation of the shorefront promenade and the removal of the pier system that serviced the rail operations.

Inland from the flat ground of the park, the elevations increase gradually. The slope of the land draining to the edge of the park generally ranges from only 0 to 2%. The highest point in the area which drains toward the park, with the exception of the nearby elevated NJ turnpike and Conrail rail line, is within the NJ Transit Light Rail parking lot, at 20.4 ft NAVD. The lowest point in the area is at the outlet to the Morris Canal, at elevation –1.56 ft NAVD. The slope of the drainage ditches on either side of Phillip Street is approximately 0.2 %.

2.5 Existing Drainage

As part of the data collection effort, planned and as-built drainage drawings were obtained for the Liberty Science Center, the NJ Transit Light Rail System terminal and parking lot, and Millenium Park, which is part of Liberty State Park. Historic drainage plans were also obtained from Liberty State Park for the drainage ditches along Phillip Street.

2.6 Groundwater Data

Piezometric groundwater levels are being measured by the USACE across the site. Synoptic groundwater readings were taken on 15 November 2003. A plan view of the groundwater contour map of the 15 November 2003 groundwater readings is shown in Figure 2-1. The results indicate that the groundwater table is relatively shallow throughout most of the site, with the exception of the southwestern corner of the park. These readings are consistent observations made during the NJDEP's previous soil sampling effort (NJDEP 1995) Groundwater sampling as part of this study is ongoing.

3. HYDROLOGIC ANALYSIS

3.1 General

This section presents basic hydrologic data, and its analysis and interpretation in conjunction with the development of proposed alternatives for the freshwater wetlands system. The basic hydrologic data analyzed herein includes precipitation, surface runoff, the development of annual and monthly runoff volumes, and runoff routing in the derivation of existing and improved conditions. Inflows include direct rainfall and snowmelt; rainfall and snowmelt runoff from tributary areas; and groundwater inflow. Outflows are evaporation; groundwater infiltration; and surface runoff. These computations were accomplished using two techniques, the Simple Method and a Stormwater & Wastewater Management Model (SWMM).

The Simple Method and SWMM were selected for this analysis in order to attempt to accurately predict and model runoff *volumes* available for input to the proposed wetlands. Other models, such as HEC-1, HEC-HMS, and TR-55 are typically event-driven models, more appropriate for drainage capacity design for predicted events. The Simple Method and SWMM model were used to model annual and monthly runoff volumes and detention within the proposed wetlands system.

3.2 Watershed Description

3.2.1 General

The watershed area considered in this analysis consists of four catchment areas: (1) the interior of Liberty State Park, (2) the Liberty Science Center and parking lot, (3) the existing wetland area immediately adjacent to the Science Center, and (4) the NJ Transit parking lot and adjacent drainage area.

3.2.2 Liberty State Park

Because of the lack of significant relief within the park and the presence of old berms, dredged material mounds, and other debris mounds, there are several small drainage areas within the park itself. As shown in Figure 1-3, the southwest portion of the 215-acre restricted area has numerous small drainage areas and several existing freshwater wetlands areas (the restricted area is delineated in Figure 3-1.) These numerous wetland areas will be retained in the proposed plan; therefore, wetland enhancement in this area is not necessary.

Near the center of the park, immediately adjacent to the 45-acre dredged spoils area (see Figure 1-3) is an existing shallow emergent marsh. North and west of this wetland is upland area. This upland area was the focus of this analysis as it presented a likely place for restoration due to the lack of existing freshwater wetlands and relatively close proximity to potential sources of additional freshwater runoff.

The drainage area for the existing, two-acre shallow emergent marsh is approximately 20 acres. This area is 100% pervious as it is entirely within the 215-acre restricted area. No additional impervious areas provide runoff to this area.

3.2.3 Liberty Science Center

The drainage area within the Liberty Science Center complex was divided into two main subcatchment areas: the Science Center parking lot and the Science Center itself, which consists of roof drains, walkways, and nearby mowed areas. The Science Center parking lot is approximately 10.4 acres, 89% of which is impervious. Along Phillip Street, within the 215-acre area, is a drainage ditch referred to as the East Ditch. This ditch primarily provides the conduit for runoff from the Liberty Science Center parking lot to the Morris Canal.

The drainage area of the Science Center itself is approximately 8.48 acres, with 50% impervious. Runoff from the LSC has two destinations: either to the West Ditch along Phillip Street or to the adjacent wetland.

3.2.4 Liberty Science Center Wetland

An existing wetland is currently located immediately north of the Liberty Science Center. The wetland area is approximately 2.3 acres in size, with an additional drainage area of 8.17 acres or a total of approximately 11.13 acres, of which 9% is impervious.

No drainage structures for the wetland were located during the data searches and field visits. Therefore, it is assumed that excess runoff in the wetland drains by flowing across the grassy area between the wetland and the west Phillip Street ditch. Topographic maps from the Liberty Science Center construction supported this conclusion by showing a small drainage depression across the grassy area.

3.2.5 New Jersey Transit Light Rail Terminal

Across the NJ Turnpike from the Liberty Science Center is the NJ Transit Light Rail Liberty State Park Station, which provides service to Bayonne, Jersey City and Hoboken. The terminal consists of an outdoor station and an approximately 800-car parking lot. The NJ Transit terminal area is divided into the three subcatchment areas: the parking lot and interior detention basin, the southern terminal area and detention basin, and the northern terminal area and drainage swale. The total drainage area is approximately 17.59 acres, of which 78% is impervious. The runoff from the entire drainage area is consolidated at a manhole which outlets into the LSC wetland through a 36-inch pipe. The descriptions of these subcatchment areas as well as the other existing subcatchment areas are shown in Table 3-1.

3.3 Climatology

3.3.1 Climate

The climate of Jersey City, New Jersey is characteristic of the Middle Atlantic seaboard. Marked changes in weather are frequent, particularly during the spring and fall. The winters are moderate, and the summers are hot and humid with frequent thunderstorms. Precipitation is also moderate, with about 45 inches falling annually, well distributed throughout the year. Summer totals of precipitation are slightly higher than those of winter. Average monthly temperature ranges from 38 to 78 degrees F with extremes ranging from 22 degrees below zero to 105 degrees F at Newark, NJ. The growing season averages 174 days and the mean annual relative humidity varies from 53 to 73 percent. Prevailing winds are from the northwest with an average annual velocity of approximately 10 miles per hour. The number of days with rainfall of 0.01 inch or greater averages about 122 per year.

The meteorological periods used in the hydrologic budget analysis are as follows:

- January – September 2003
- Last 10 years (1993-2002)
- Average of driest three years (1976, 1981, 2001)
- Average of wettest three years (1983, 1984, 1996)

The period of record from which dry and wet years were selected is 1971-2002. By developing a water budget for these various periods, the performance of alternative plans could be tested under a wide range of hydrologic conditions.

The meteorological parameters needed for the hydrologic budget calculations are precipitation, snowfall, temperature, and pan evaporation.

3.3.2 Precipitation Data Used

Monthly and hourly precipitation data was obtained from the National Climatic Data Center for the period 1948-2003 for Newark International Airport (cooperative station ID 286026), approximately 5 miles to the west of the study area.

Development of the hydrologic budget involved in quantifying sources of inflow or outflow to the deep emergent marsh. Runoff from the catchment (including snowmelt), direct precipitation on the wetlands, evapotranspiration, and groundwater inflow were defined by a combination of National Weather Service data, in situ measurements, and model results.

Total monthly precipitation for the first nine months of 2003 and ten preceding years are compared in Figure 3-1. The two periods have comparable rainfall, except for the months of June and August which were wetter in 2003. The monthly average precipitation for the wettest and driest three years was calculated for the period 1971 – 2002 and is shown in Figure 3-2. Although precipitation and snowfall data were also available for the period 1948-1970, since estimated pan evaporation data were not available for this earlier period the earlier period could not be used. Consequently, the period 1971 – 2002, for which all meteorological parameters (precipitation, snowfall, temperature, and pan evaporation) needed to develop the hydrologic budget were available, was used as the period of record to select dry and wet years.

Although some data for Jersey City were available, Newark Airport was selected as the data station. The reason for this choice is that the observation station at Jersey City was closed beginning in June 1997. Also, no evaporation estimates or evaporation data were available for Jersey City. Rather than mix data from two stations, Newark Airport data was used for all parameters for overall consistency. A comparison of monthly average precipitation amounts for 1993-1996, the period for which data were available for both stations, is shown in Figure 3-3. For most months other than October, the data suggest that, while the Jersey City meteorological station is closer to Liberty State Park, Newark Airport data is an acceptable surrogate.

Inflows in the hydrologic budget include precipitation falling directly on the wetland, surface water runoff, groundwater, and pumped flow. Both direct precipitation and surface water runoff may be composed of rainfall and snowmelt.

The equivalent precipitation from snowmelt was calculated using daily average temperature data from the period 1 January 1993 to 31 July 2003. For each of the twelve calendar months, the number of days where the daily average temperature exceeded 32° F was tallied. Thus, it was assumed that on days when the average temperature did not exceed 32° F, significant snowmelt did not occur. For each month, the percentage of total snow melting was then calculated. Different sets of snowmelt percentages were calculated for the last ten years, for a dry year within the data set (2001), and for a wet year within the data set (1996). Snowpack carried over from previous months was also included in the calculation. To account for snow falling directly on the wetland, the snowmelt was converted to equivalent rainfall. To account for snow falling elsewhere on the catchment, the total precipitation (rainfall plus equivalent precipitation from snowmelt) was input into the rainfall-runoff model.

3.3.3 Annual and Monthly Precipitation

The average annual precipitation for the study area is approximately 45.65 inches. The observed extreme annual values were 65.50 inches in 1983 and 31.44 inches in 2001. The monthly extremes ranged from 0.36 to 11.53 inches.

3.4 Infiltration

Subcatchment infiltration is the water that infiltrates into the ground and does not become runoff (directly) during a precipitation event. Due to the heterogeneous nature of the fill material within the park as a result of years of fill, an effort was made to measure infiltration rates within the limited-access area. A series of 11 double ring infiltrometer tests were conducted within the park at the locations shown in Figure 3-4.

In-situ infiltration rates were measured using a TURF-TEC double-ring infiltrometer. Of the 11 sites where measurements were taken, the mean infiltration rate was 32.0 in/hr, with individual rates varying between 4.5 to 59.4 in/hr. Seven of the results had rapid infiltration rates making accurate measurements difficult. Using the four most reliable results, which were in the vicinity of the proposed wetlands (sites 5, 6, 10, 11 on Figure 3-4) the mean was 13.2 in/hr with an individual measurement range of 4.5 to over 30.0 in/hr. These results are consistent with similar testing of sandy/gravel sites reported in published literature (USEPA 1999).

3.4.1 Test Procedure

TURF-TEC Double-Ring Infiltrometers were used to measure the soil infiltration rates. These small devices have an inner ring about 64 mm (2.5 in.) in diameter and an outer ring about 110 mm (4.25 in.) in diameter. The water depth in the inner compartment starts at 125 mm (5 in.) at the beginning of the test, and the device is pushed into the ground 50 mm (2 in.). The rings are secured in a frame with a float in the inner chamber and a pointer next to a stop watch. These units are smaller than standard double-ring infiltrometers, but their ease of use allowed many tests during a single day.

First, the infiltrometer was pushed into the soil. Then, the inner and outer compartments of the infiltrometer were filled with clean water by first filling the inner compartment and then allowing it to overflow into the outer compartment. As soon as the measuring pointer reached the beginning of the unit's measuring scale, the timer was started. Readings of the water elevation change within the inner ring were taken every five minutes for 15 minutes. The maximum and minimum infiltration rates were calculated by curve-fitting Horton's Equation to the points using SigmaPlot®.

3.4.2 Results

The 5-minute interval data were then plotted to develop curves matching Horton's equations, as follows:

$$fp = fc + (fo-fc)e^{-kt} \qquad (3\text{-}1)$$

where:

fp	= infiltration capacity into soil, ft/sec
fc	= minimum or ultimate value of fp, ft/sec
fo	= maximum or initial value of fp, ft/sec
t	= time from beginning of storm, sec, and
k	= decay coefficient, sec^{-1}

Infiltration starts at a rate of fo and decreases exponentially over time to a steady rate of fc. Using the curve fitting function of SigmaPlot®, an exponential decay curve (3 parameter) was fitted to the values and fc was determined. The measured infiltration rates were relatively high but varied greatly throughout the park and where consistent with published rates of hydraulic conductivity.

Since downward flow (through substrate) is controlled by hydraulic conductivity, K, the final, saturated (steady rate) fc is equivalent to K (USACE 1999).

Of the 11 sites where measurements were taken, 7 sites had rapid infiltration rates, making accurate measurements difficult. The rapid rates were most likely due to debris, gravel and rail bed material at the ground surface. The other four sites had initial infiltration rates ranging from 4.5 in/hr to 59.4 in/hr, with a mean of 32.0 in/hr.

Moisture content was not evaluated for this analysis; however, observations in the field at the time of the measurements indicated that the ground surface was relatively dry. Therefore, the low antecedent moisture would be expected to result in maximum initial infiltration rates.

From the measured results, it is clear that the soil on the surface of the park varies greatly and uniform infiltration and runoff does not occur.

3.4.3 Rates Used in the Analysis

The results of the geotechnical analysis indicate that the on-site soils beneath the surface also vary considerably across the site. Both fine-grained and course grained soils are present. Based upon the material recovered from the drilling and sampling program, from depths of 0.0-ft to 4.5-ft below grade approximately 90% of the on-site soil is poorly graded/silty Sand and approximately 6% of the soil is Clay. From these results, it was assumed that beneath an often coarser surface layer of debris and sandy gravel lays a relatively low-porosity silty Sand. In areas of existing wetlands, it is assumed that the wetlands are underlain by a more imperious clay or well-graded silty Sand layer.

For the SWMM modeling, the maximum and minimum infiltration rates of 4.5 and 0.02 inches per hour, respectively, were used within the wetland areas of park. These rates are typical of a relatively impervious clay or other geo-lining, as planned for the wetlands. The typical maximum and minimum values of 3.0 and 0.02 inches per hour, respectively were used for the pervious, mowed surfaces outside the park. These values are consistent for landscaped turf. The decay coefficient was set at 4 hr^{-1} which is equivalent to a decline in infiltration of 98 percent towards the limiting value after the first hour.

From the results of the analysis, it is assumed that due to the high infiltration rates and relatively shallow grades that there will be minimal runoff from the drainage areas within the park.

3.5 Evapotranspiration

Outflows may include surface water, groundwater, and evapotranspiration. Evapotranspiration is the combination of the net rate of vapor transfer (evaporation) and the transfer of moisture to the atmosphere by vegetation (transpiration). A model developed at the Northeast Regional Climate Center was used to provide estimates of monthly pan evaporation (DeGaetano 1994). The physically-based model relates net radiation, air density, and soil moisture to evapotranspiration and was adapted and validated for use in the northeastern United States. Evaporation primarily is calculated as a function of shortwave and net long wave radiation. Evapotranspiration was then calculated as 75% of pan evaporation estimates based on research results by others (Hammer 1992, Hubbard et al. 1988).

3.6 Estimated Runoff Volume

3.6.1 General

Runoff volumes for the subcatchments in the study area were initially estimated using the Stormwater Manager's Resource Center's Simple Method. The Simple Method provides an easy way to evaluate potential runoff from the watershed using annual and monthly precipitation values.

3.6.2 Simple Method

The Simple Method (SMRC 2003) is generally used to estimate stormwater runoff pollutant loads for urban areas. For the hydrologic budget, the method was used to calculate runoff only; for sediment transport calculations described in Section 8.1 the Simple Method was also used to simulate total suspended solids. The technique requires a modest amount of information, including the subwatershed drainage area and impervious cover, and annual precipitation. With the Simple Method, the investigator can either break up land use into specific areas, such as residential, commercial, industrial, and roadway and calculate annual pollutant loads for each type of land, or utilize more generalized pollutant values for land uses such as new suburban areas, older urban areas, central business districts, and highways.

3.6.3 Annual Runoff

The Simple Method calculates annual runoff as a product of annual runoff volume, and a runoff coefficient (Rv). Runoff volume is calculated as:

$R = P * P_j * Rv$ (3-2)

where:

R = annual runoff (inches)

P = annual rainfall (inches)

P_j = fraction of annual rainfall events that produce runoff (usually 0.9)

Rv = runoff coefficient

The runoff coefficient is calculated based on impervious cover in the subwatershed. The following equation best represents actual data:

$Rv=0.05+0.9Ia$ (3-3)

where:

Ia = impervious fraction

The Simple Method provides reasonable estimates of stormwater runoff volumes. Unlike other hydrologic methods, preliminary volumes can be estimated based on average rainfall rather than specific storm events.

Computed volumes were checked by comparison to XP-SWMM model results. The scenario selected for this comparison was Alternative A (Liberty Science Center runoff added to the Deepwater Emergent Marsh (DEM)). Results are presented in Figure 3-5. The unusually low volume computed by XP-SWMM for June 1976 is due to relatively high evaporation rates during June. Also, there was minimal antecedent rainfall before major storms in June 1976, allowing for maximum storage in the wetlands and minimal discharge downstream. Although significant disparities between SWMM and Simple Method results are sometimes seen for individual months, the total yearly volumes for the simple method are only 12% higher than SWMM for 1976 and 15% lower than SWMM for 1983. In light of the inherent differences between the two modeling approaches, these differences are relatively small. Therefore, the Simple Method results are validated by the SWMM computations.

In Figure 3-5, for both 1976 and 1983 XP-SWMM computed volumes are generally lower than Simple Method results for the warmer months of May – September, when evaporation is most significant. This difference is in part due to the fact that the XP-SWMM model includes evaporation but the Simple Method does not. However, calculations using the Simple Method results take evaporation into account in the hydrologic budget analysis, thereby accounting for this difference.

4. ENVIRONMENTAL DESIGN CRITERIA

4.1 Biological Considerations

4.1.1 Introduction

As indicated in the General Management Plans, NJDEP, 2001 and discussed in the regular LSP) feasibility study team meetings, water depth and drawdown must be controlled to the degree that will maintain a viable and attractive wetland and pond community and to provide wildlife habitat value to the park.

The deepwater emergent pond/wetland has been designed to provide a permanent source of water with a depth of approximately 4-6 feet.. This along with very shallow (5%) side slopes will provide a controlled proportion of deeper and shallower habitats throughout the growing season.

4.1.2 Wildlife Considerations

The Threatened and Endangered listed bird species do not have habitat requirements that include a specific hydroperiod. They can be expected to use wetland or upland habitats provided that the vegetative structure of these habitats meets their needs. For example, the northern harriers prefer grassland habitat with few trees and shrubs. Harriers will nest in both uplands or wetlands, but the pair nesting at Liberty State Park seems to prefer uplands for nesting. For winter roosts, harriers prefer upland sites. Many sources indicate harriers prefer to nest and roost in fields that are 50 acres or more in size; however, the species has also been documented to nest in habitat blocks as small as 20 acres.

Aside from the northern harrier, none of the other Threatened and Endangered bird species of special concern that were observed during inventory surveys have been documented as breeding in the park. As mentioned previously, their use of habitat relies more on habitat with the correct vegetative structure and adequate food resources rather than hydroperiod.

One listed plant species, Torrey's rush, was found on the site. This species has hydrologic requirements and is adapted to specific types of soils. It is a facultative wetland (FACW) species, which means it has the probability of being found in a wetland 67-99% of the time. The Natural Resource Conservation Service's (NRCS) Plant Database indicates this species is adapted to medium to coarse-textured soils and has a low-tolerance for drought conditions. The NRCS lists the minimum and maximum amount of precipitation needed as 14 and 50 inches per year, respectively. The minimum root depth is 10 inches and the species is intolerant of both shade and salinity. This species was identified in a freshwater wetland on-site. That wetland area should be protected during construction while also considering the habitat requirements for the species when enhancing other freshwater wetland habitats on-site.

4.2 Minimum Water Requirements

The minimum water requirements for wetland sustainability are determined by a combination of factors that need to be balanced. In order to maintain a wetland with a permanent pool of water and sufficient flow to maintain good water quality, sufficient drainage area is required. Without supplementing the water supply through pumping, a minimum watershed of about ten acres is required for maintaining a year round permanent pool of approximately one acre. A second rule of thumb is that four acres of contributing watershed are needed for each acre-foot of storage (Md SCS, 1976; Schueler, 1987). For this plan, from five to nine acres of contributing urban watershed are available for each acre-ft of planned wetland storage. This range of ratios suggests that the watershed is sufficiently large to support the planned wetlands. Relying on a smaller watershed than this would make maintaining a permanent pool difficult and would produce large fluctuations in the water level due to evaporation and infiltration losses. Examination of the water balance diagrams (Figure 4-1 and Appendix A) indicates that the base flow entering the wetland would run out during the summer months, and input cannot compensate for gradual drawdown. The result may be poor water quality, the production of algal matting and odor problems. During extremely dry periods such as 1976, it is possible that the existing wetland may completely dry up i.e., have almost no standing water yet still have saturated substrate as do most of the existing wetlands on the site.

5. HYDROLOGIC DESIGN CRITERIA

5.1. General

There are many hydrologic and hydraulic considerations important to wetland restoration and construction. The primary list of design criteria includes the following basic interrelated elements.

- Hydrologic setting,
- Flood duration and timing,
- Flooding depth,
- Flow velocities,
- Flow resistance,
- Hydraulic retention time,
- Storage capacity,
- Surface area,
- Fetch.

5.2. Hydrologic Setting

The hydrologic setting of the wetland describes the location of the wetland in relation to other waterbodies. The hydrologic setting is important to all wetland functions, but is of particular importance to groundwater recharge/discharge, sediment retention, flood-flow alteration, and production export. The existing and proposed freshwater wetlands within Liberty State Park are generally independent of any other waterbody (e.g., stream, river, lake, etc.). They occur in typically heterogeneous material which has a relatively shallow watertable. Thus, they are assumed to be influenced by a fluctuating watertable. The proposed wetlands would be constructed in the same general area (park interior) as the existing wetland in similar substrate types.

5.3. Flooding Duration and Timing

The existing wetlands within Liberty State Park are typically seasonally wet (i.e., during the spring and fall), with the exception of the Liberty Science Center wetland, which is frequently flooded from runoff from the NJ Transit terminal and parking lot. Similarly, the drainage ditches along Phillip Street are frequently flooded with runoff from the Liberty Science Center. Based on the hydrologic budget analysis it is expected that diversion of stormwater runoff from the parking lots adjacent to the park into the proposed wetlands will result in the proposed wetlands maintaining measurable pool depths most of the year.

5.4. Water Depth

Water depth is an important factor in determining the types and extent of vegetation supported by the wetland. The existing wetlands are shallow, seasonal wetlands, most likely augmented by a rising watertable during the wet seasons of the year. The proposed wetland system would have both shallow and deep water areas to support a greater abundance of plants and wildlife than the existing wetlands.

5.5. Flow Velocity

Maintaining a low velocity related level of flowing water shear stress are important to several wetland functions. As a result of the shallow gradient of the park and the detention-design of the wetlands, velocities will be minimal.

5.6. Flow Resistance

The depth and velocity of the flow in the wetland are somewhat dependent on flow resistance. Like the flow velocity, flow resistance is not critical for the proposed designs due to the detention design of the proposed wetlands.

5.7. Hydraulic Retention Time (HRT)

The HRT is defined as the average amount of time that a parcel of water stays within the wetland before exiting. The HRT is the key design criteria for water quality enhancement functions such as sediment/toxicant removal and nutrient removal/transformation. For this analysis, the focus was on flood frequency and duration, and depth. Because the runoff from adjacent impervious surfaces quickly drained out of the system to New York and New Jersey Harbor under the existing conditions, a decrease in the HRT is not likely in the proposed wetlands. Rather, it is expected that the wetland system will cause a measurable increase in HRT, which will further result in improved water quality entering the Harbor. Obviously, excessive HRT in the wetland could result in wetland water quality problems such as low dissolved oxygen and the production of sulfide and methane gases. However, frequent runoff is expected to provide frequent flushing of the wetland system.

5.8. Storage Capacity

The Storage capacity is most important in the flood-flow alteration function because the amount of available storage in the wetland determines how much of the runoff can be routed into and through the wetlands. The storage capacity may also affect aquatic abundance/diversity, in that larger wetlands will have more potential for groundwater recharge, have greater volume and surface area and may support more aquatic organisms. Storage capacity was used in this analysis to reach design water surface elevations based on seasonal inflows.

5.9. Surface Area

The wetland bottom area is important for groundwater recharge and discharge. The groundwater recharge will be a function of the bottom area, water depth, permeability of underlying soils and location of the water table.

The surface area of the wetland also affects evapotranspiration which can be important for groundwater discharge and water quality functions. Ground water recharge was not a primary concern of the proposed designs; it is anticipated that the wetlands will be lined with a low permeability liner. Runoff inflows were expected to be sufficient to overcome evapotranspiration, even during the drier months of the year.

5.10. Fetch

Fetch is the length of open water available for wind-induced waves. Fetch is typically an important hydraulic consideration in wetlands because they are usually shallow water bodies which can be easily affected by wave action. The fetch of the wetland is especially important in sediment stabilization. Long fetches will produce erosion of the downwind shoreline. Fetch is also important to water quality concerns because the greater the fetch the better the reaeration. The relative small size of the proposed wetlands and the existence of surrounding upland forests is expected to limit the fetch and wind-induced wave impacts.

6. FRESHWATER WETLAND SYSTEM

6.1 Existing Freshwater Wetlands

The existing wetlands are classified as Shallow Emergent Marsh and are located in the center of the park. They are hydrologically isolated wetlands and receive runoff only from the interior of the park. These wetlands are described in detail in the Draft Liberty State Park Environmental Resources Inventory (USACE 2004). During a typical year, the surface water in the wetland disappears in the later months of summer, limiting the overall habitat value of the wetland. To improve the habitat value of wetland and the park as a whole, a year-round presence of freshwater is desired. Therefore, the focus of the design efforts is to create a year-round source of water for wildlife through the creation of a Deep Emergent Marsh system, which should maintain a measurable depth of water during dry periods or periods of below-average precipitation. In addition, varying water depths spatially through the created wetland system will help maintain more diverse habitats throughout the year and facilitate the movement of storm water through the system.

6.1.1 Existing Liberty Science Center Wetlands

The existing wetland adjacent to the Liberty Science Center consists of mostly one wetland zone which is dominated with a monoculture of common reed (*Phragmites australis*). The wetland functions primarily as a treatment wetland for runoff from the NJ Transit terminal and parking lot.

6.2 Description of the Proposed Freshwater Wetland Components

In order to maximize habitat function and value, the freshwater wetland system may have four primary components: (1) an enhanced Liberty State Park wetland, (2) a Biofilter (BF) wetland, (3) a Deep Emergent Marsh (DEM), and (4) natural connecting swales. The proposed freshwater wetland system should be located in the center of the park, in close proximity to the proposed tidal wetland. Ideally, the DEM should be at least 400 or 500 feet away from the nearest road or heavily used area.

The proposed freshwater wetlands will contain a number of hydrologic/habitat zones, as follows:

Zone 1. Deep Water Pool (1-6 feet deep), to support submerged aquatic plants such as wild celery, sago pondweed, and redhead grass.

Zone 2. Shallow Water Bench (6-12 inches between groundwater level and the discharge invert), to support emergent aquatic plants. Proposed plants are obligates and are relatively intolerant to drawdowns. Typical plants in this zone include: Pickerelweed (*Pontederia cordata*), Duck potato, (*Sagittaria latifolia*), Three square (*Scirpus pungens* (*S. americanus*)), and Soft stem bulrush (*Scirpus validus*).

Zone 3. Shoreline Fringe. This is the regularly inundated area, which supports wet meadow scrub-shrub wetland, including plants such as sedges, switchgrass, and buttonbush. This zone is typically between the discharge invert and an overflow elevation.

Zone 4. Riparian Fringe. This is the periodically inundated area, which supports wet soils or scrub-shrub transition, including plants such as red osier dogwood, red maple, swamp oak. This zone is typically above the overflow elevation.

6.2.1 Enhanced LSC Wetland (Wetland 1)

The wetland will be enhanced through the removal of the common reed, regrading, and replanting. The enhanced wetland will contain Zones 2 through 5 as described above. Figures 6-1 and 6-2 (and B-1 in Appendix B) shows the enhanced LSC wetland. The area of the wetland will be 2.27 acres, and the perimeter 2,033 ft.

6.2.2 Biofilter Wetland. (Wetland 2)

The second wetland will be designed for water quality pre-treatment and contain wetland Zones 2 through 5 as described above. The wetland will provide pre-treatment by removing coarser sediments, trash, and debris. This pre-treatment should also provide for the significant removal of particulate pollutants. The deeper areas of the wetland will function as either a permanent pool or shallow marsh areas. The deep area will enhance the removal of soluble phosphorus and nitrogen. Figures 6-3 and 6-4 (and B-2 in Appendix B) shows the Biofilter wetland. The area of the wetland will be 0.79 acres, and the perimeter 1,442 ft.

6.2.3 Deepwater Emergent Marsh (Wetland 3)

As shown in Figure B-3 in Appendix B, the mean water elevation of the DEM will be approximately 5.0 ft NAVD with bottom elevation around 0.0 ft NAVD. The wetland area is about 1.8 acres and average volume is approximately 32,700 cubic feet. The perimeter is about 148 ft. these dimensions include all of the four wetland zones.

The DEM will include all four wetland zones discussed above.

The deep water areas of the wetland should be permanently flooded. The zone between the typical low level and the overflow outlet may be seasonally flooded. Above the overflow elevation will be a transition zone to upland areas. Figures 6-5 and 6-6 (and B-3 in Appendix B) shows the DEM.

The vegetative zones and elevations associated with each of the proposed wetlands are presented in Appendix C. These zones are portrayed in Figure 6-5. The area of the wetland will be 1.82 acres, and the perimeter 1,397 ft.

6.2.4 Connecting Swales

In order to limit structural components in the freshwater system, provide additional functional value, and maintain the ecological nature of the site, natural swales will connect the wetland system within the park.

Swale slopes should be graded as close to zero as drainage will permit. Between the biofilter (5.5) and the deep emergent marsh (5.0) there is a .5 foot elevation drop in about 400 feet or a slope of about 0.125%. Side slopes of the swale will be about 3:1 (h:v) or less. The swales will be planted with a dense cover of water tolerant, erosion resistant grass. This grass will not be mowed close to the ground to avoid impeding the filtering and hydraulic functions of the swale. Since the system will be using parking lot runoff, sensitive grass species with a low salt tolerance such as bluegrass, should be avoided. Reed canary grass is ideal but is also considered an invasive species.

6.2.5 Infiltration Basin

One method of returning excess stormwater to the interior of the site would be to direct this excess to an infiltration basin. This would ensure that the water is being discharged to an area with high permeability and allow quick groundwater recharge. Infiltration basins are also effective in removing both soluble and fine particulate pollutants that may still be in the stormwater discharged. The basin would be receiving this water during wet months and/or during larger storms. While this water will have been treated by the other constructed wetlands, during large storms the discharge may still contain some pollutants. In this case this basin would serve as a final polishing system along with providing control of peak discharges for large design storms. The high permeability soils are well suited for use as an infiltration basin with little soil augmentation required.

The infiltration basin, shown in Figures 6-7 and 6-8 (and in Figures B-3 and B-7 in Appendix B), would provide an impoundment by excavating the soil to an elevation of approximately elevation of 4.5 NAVD. The impoundment will store a defined quantity of about 3 acre feet of runoff, allowing it to slowly exfiltrate through the permeable soils of the basin floor. The floor would be graded as flat as possible and a dense native grass cover would be established to promote infiltration, add habitat value and bind up deposited sediments.

6.3 Description of the Modeled Alternatives

The alternatives considered in this analysis are modifications of one primary freshwater wetland system consisting of the three of the previously described components. The alternatives primarily differ in their source or sources of stormwater. The alternatives are shown in Table 6-1 and described in the following sections.

6.3.1 Alternative A

The primary alternative consists of a Deep Emergent Marsh and Biofilter wetland receiving stormwater input from the Liberty Science Center drainage area, which includes the Science Center and the adjacent parking lot as shown in Figure 6-9 (and B-4 in Appendix B). Stormwater will pass through the Biofilter wetland and eventually reach the DEM. Excess stormwater in the DEM will be routed back to the drainage ditch to the east of Phillip Drive through an 800-foot swale, for eventual discharge into the Morris Canal.

The Biofilter wetland will be upstream (west) of the DEM, connected by a 430-foot swale. The mean water elevation of the BF will be approximately 5.5 feet NAVD with bottom elevation of approximately 3.0 feet NAVD. The wetland area is about 0.8 acres and the storage volume is approximately 59,800 cubic feet. The perimeter is approximately 1,400 feet.

Four wetland communities will be established among the sequence of wetlands leading to the DEM. From the wetter to the drier zones these will include: (1) emergent marsh (semi-permanently flooded); (2) wet meadow (seasonally flooded); (3) scrub-shrub (temporarily flooded); and (4) forested (transitional zone) wetland communities.

6.3.2 Alternative B

The primary features of Alternative B are the same as Alternative A: a DEM and Biofilter, supplemented with stormwater runoff from the Liberty Science Center. In addition, excess stormwater stored in the existing Liberty Science Center wetland will be routed to the Biofilter wetland, as shown in Figures 6-10 (and B-5 in Appendix B).

Stormwater from the NJ Transit parking lot currently drains to the LSC wetland, which maintains a surface water elevation from 5.6 to 7.5 feet NAVD. Alternative 2 includes an overflow pipe with an invert of 6.5 feet NAVD at the LSC wetland, which will convey excess stormwater to a detention pool on the west side of Phillip street. From there, it will flow into the Biofilter wetland.

6.3.3 Alternative C

The primary features of Alternative C are the same as Alternative B: a DEM and Biofilter, supplemented with stormwater runoff from the Liberty Science Center and the LSC wetland. This alternative, as shown in Figures 6-11 (and B-6 in Appendix B), also includes the environmental enhancement of the LSC wetland.

The LSC wetland will be enhanced to improve the water quality treatment ability over the existing condition. The new mean water elevation will be approximately 6.5 feet NAVD with a bottom invert elevation at approximately 3.0 feet NAVD. The wetland area is about 2.3

acres and the storage volume is approximately 110,000 cubic feet. The perimeter is approximately 2,000 feet.

6.3.4 Alternative D

The primary features of Alternative D are the same as Alternative C: a DEM and Biofilter, supplemented with stormwater runoff from the Liberty Science Center and the enhanced LSC wetland. As shown in Figures 6-12 (and B-7 in Appendix B), instead of returning excess stormwater to the Phillips Drive Ditch and eventually to Morris Canal, this alternative will discharge the excess water into the interior of the Liberty State Park site.

The excess water will be discharged to an infiltration basin adjacent to the DEM. The new bottom elevation of the basin will be approximately 4.5 feet NAVD with an overflow invert elevation at approximately 6.0 feet NAVD. The basin area is about 2.2 acres and the storage volume is approximately 134881 cubic feet. The perimeter is approximately 1,703 feet. If water does go over the spillway it will be directed to the adjacent freshwater wetland.

7. HYDROLOGIC BUDGET ANALYSIS

7.1 Water Balance

To assure a predictable water supply and to assure viability of the restored wetland, multiple water sources can be utilized or developed for the wetland as a way of dealing with the uncertainty associated with rainfall frequency and groundwater levels (Pierce 1993). The hydrologic budget for a wetland area can be shown as:

$$I - Q = dS/dt \qquad (7\text{-}1)$$

where

I = Inflows
Q = outflows
dS/dt = change in water storage in the wetland per time

Inflows may include precipitation, surface water, and groundwater. Outflows may include surface water, groundwater, and evapotranspiration (Viessman 1977).

Monthly results are presented in the form of a bar chart showing the net total of inflows and outflows. An example of this format is shown in Figure 4-1 for existing conditions, Plan 1.

7.2 Hydrologic Budget

The hydrologic budgets for the matrix of combinations of meteorological conditions and restoration scenarios can be shown in a “balance sheet” format that summarizes yearly average inflows and outflows as well as the monthly average net flow through the wetland. The restoration scenarios considered are shown in Figure 7-1. Conceptual Plan 1 considers runoff from adjacent upland in Liberty State Park; Conceptual Plan 2 also covers runoff from the Liberty Science Center parking lot and adjacent wetland areas; and Conceptual Plan 3 further includes New Jersey Transit property runoff.

Because of the wide range of infiltration rates measured in-situ and found in the literature, a sensitivity analysis was performed on the water budget for this parameter. Two analyses were performed, one for the year 2003 and one for the 1993-2002 ten-year period. In each instance, the monthly water budget was evaluated for infiltration rates of 0.00, 0.02, 0.04, and 0.08 in/hr. For a rate of 0.00, the water budget showed mostly positive net flow, i.e., inflows exceeded outflows, for most months. For a rate of 0.02, the budget showed a more likely balance of positive net flow during spring and fall but mostly negative flow during the summer. This pattern is corroborated by visual observations made during 2003. The higher rates of 0.04 and 0.08 produced unrealistically negative net flows. Likewise, substituting the average in-situ, measured initial infiltration rate of 32 in/hr produced excessively negative net flows. The probable reason for this result is that the site is characterized by high groundwater elevations which would possibly result in groundwater inflow to the deepwater emergent marsh. Consequently, although the soil exhibits high infiltration properties, groundwater probably is a source of inflow for the wetlands. Thus, an infiltration rate of 0.02 in/hr was used in the calculations.

Results for all combinations of meteorological periods and runoff scenarios are shown in Table 7-1. Summary sheets showing key budget assumptions, inputs, and results, and bar charts showing the resulting monthly water budgets are presented in Appendix A. As expected, the average monthly storage changes shown in Table 7-1 are successively higher for the driest three years, last ten years, current year, and wettest three years, reflective of changes in precipitation and resulting runoff.

The wetlands in the analysis were sized to ensure that minimum water levels required to maintain the vegetative structure could be maintained throughout the year. Spillways and weirs will be set at the appropriate elevations to maintain the design water surface elevations (WSELs).

8. HYDRAULIC ANALYSIS

8.1 General

For this analysis, the hydraulic evaluation of the proposed freshwater wetland alternatives was conducted using XP Software's Stormwater & Wastewater Management Model (XP-SWMM or SWMM). The SWMM results were used in conjunction with the hydrologic budget analysis to evaluate the potential performance of the proposed wetland alternatives.

8.2 Basis of Design

The analysis presented herein is based on the concepts and guidelines contained in U.S. Army Corps of Engineers' Engineer Research and Development Centers' *Wetlands Engineering Handbook* (USACE 2001).

Initial stormwater runoff volumes used in the hydrologic budget were estimated using the Simple Method. The Simple Method values were checked for reasonableness using the SWMM output (see the Hydrologic Budget Analysis presented in Section 7).

The performance of the existing and proposed conduits, such as pipes, drainage ditches, and swales integral to the freshwater wetland system were analyzed using SWMM. Typically, conduits proposed as additions to the existing drainage network were sized to convey the modeled volumes and maintain the wetland system target water surface elevations. The objective of the conduit sizing was not to provide drainage to meet any regulatory requirements (e.g., providing sufficient drainage for a specific frequency event), rather, the conduits were sized to adequately convey the typical runoff volumes without inducing flooding. The only design limitation was to ensure that changes in the drainage as a result of the rerouting of runoff did not result in induced flooding in the drainage area during the 10-year NJDOT design event (NJDOT 2003; 5.25 in./24 hr).

8.3 Hydraulic Design Criteria

Man-made wetlands require means to control the quantity and depth of water at a given location. Consequently, hydraulic structures are a basic part of creating, restoring, and enhancing wetlands. The following sections describe the hydraulic design criteria and assumptions for the Liberty State Park freshwater wetlands system.

8.3.1 Water Containment

Due to the relatively flat topography of the site, the inverts of the existing drainage structures, and the distances between drainage areas and the wetlands, it is expected that the proposed wetlands would be constructed primarily by excavation. Levees or berms to retain water were not considered in the design with the exception of berms adjacent to outlet structures where it was necessary to direct and control outflow.

8.3.2 Sediments and Debris

Reduced flow velocities found in wetlands allow sediments transported into the wetland with the inflow to settle to the bottom. Trapped sediments eventually occupy part of the wetland volume, thereby reducing its effectiveness at removing future sediments from the inflow. Therefore, the inclusion of a forebay in the Biofilter wetland is necessary to trap incoming sediments and prevent them from settling in the main section of the wetland and potentially moving downstream to the deepwater wetland.

Wetlands immediately adjacent to impervious surfaces such as roadways and parking lots are also subject to the inclusion of debris and trash in stormwater runoff. The construction of a forebay will also help capture debris which would otherwise enter the wetland system and potentially degrade habitat and threaten wildlife.

8.3.3 Design Event

Hydraulic drainage structures are typically designed to routinely pass flow up to some design event. For the proposed freshwater wetlands at Liberty State Park, the construction of the wetlands within the environmental area of the park reduces the need to design the wetlands for a specific event because any potential overflow of the wetlands would occur within the existing ecological area. The only area of concern is in the vicinity of Phillip Street, which may be impacted if the outflow structures cannot convey flow quickly enough during extreme precipitation events and flooding occurs. To reduce the potential for induced flooding during extreme events, the existing drainage ditches along Phillip Street will remain in place, separated from the wetland system by overflow berms or weirs. This will allow any overflow from the wetlands to drain through the drainage ditches before flooding the roadways.

Current New Jersey Department of Transportation guidance (NJDOT 2003) requires that longitudinal systems and cross drain pipes for land service highways be of sufficient capacity to pass the runoff from a storm with a 10-year recurrence interval. Therefore, the performance of the freshwater wetland system was analyzed to ensure that no induced roadway flooding occurs during the design event (5.25in/24hr).

8.3.4 Conduits

Ideally, the conduits between the wetlands and the outlets should be environmentally beneficial, that is, natural. Therefore, the wetland system was designed using natural, trapezoidal channels to convey flow within the park. These channels are expected to contain vegetative growth and were modeled using a roughness coefficient (Manning's n-value) to reflect vegetation similar to the vegetation presently in the existing drainage ditches within the park. Vegetated swales were designed with a 5-foot bottom width and 1:4 side slope. The channels will initially be lined with grass; however, additional vegetation growth is expected over time. Flow under the roadways will be conveyed through pipes.

8.3.5 Materials

Pipes are needed to convey the flows beneath the roadways. For this analysis, it is assumed that the outlet pipes are reinforced concrete pipes (RCP). The outlet weirs within the wetlands will be constructed of natural materials, such as logs or stones.

8.3.6 Infiltration Basin

An infiltration basin is a facility constructed within highly permeable soils that provides temporary storage of runoff during rain events. The basin does not normally have a structural outlet to discharge runoff except during very high flow events. Instead, outflow from an infiltration basin is through the surrounding soil. Preliminary infiltration rates measured at the site indicate relatively high surface permeability; however, the permeability of the soils at and below the basin invert must be measured to ensure adequate basin performance. Typical tests such as a percolation test, pit-bailing test, or piezometer test, as outlined in N.J.A.C. 7:9A *Standards for Individual Subsurface Sewage Disposal Systems*, are necessary to ensure adequate soil permeability. For this analysis, a conservative infiltration rate of 1 in/hr was used based on preliminary infiltration measurements.

8.3.7 Groundwater

Preliminary data indicates that the groundwater table within Liberty State Park is relatively shallow. It is likely that the groundwater table may even rise above the lowest land surfaces within the park during the wettest periods of the year. However, there is not yet sufficient data to confirm this fact. Furthermore, there is no groundwater quality data available to date. Therefore, for this analysis it is assumed that the wetlands are constructed with a clay or other impervious liner to limit groundwater flow to the wetlands. Potential hydrostatic or buoyant forces on the liner as a result of groundwater are expected to be offset by the presence of water within the wetlands. It is also assumed that groundwater will not impact the infiltration basin.

8.4 SWMM Model Development

8.4.1 General

The model used for the hydraulic analysis of the proposed wetlands alternatives is a version of the EPA-SWMM: XP-SWMM2000, version 8.52. This version of SWMM has both graphical input and output routines making it easier to make changes in the model and to visualize results. SWMM is a comprehensive model that can perform both hydrologic and hydraulic calculations.

The Liberty State Park SWMM used the RUNOFF and HYDRAULICS (known as EXTRAN in other versions) blocks. The HYDRAULICS block solves the complete St. Venant (Dynamic Flow) equations throughout the drainage network and includes modeling of backwater effects, flow reversal, surcharging, looped connections, pressure flow and tidal outfalls and interconnected ponds.

8.4.2 RUNOFF Block

The RUNOFF block of SWMM simulates the quantity of runoff.   "The program accepts an arbitrary rainfall and makes a step by step accounting of infiltration losses in pervious areas, surface detention, overland flow and channel flow, leading to the calculation of a number of inlet hydrographs" (Huber et. al., 1988). The program generates hydrographs by a "non-linear reservoir" routing method, which is similar to the kinematic wave approach used in the US Army Corps of Engineer's HEC-1 model and other hydrologic simulation programs.

8.4.2.1 Non-linear Reservoir Representation

The areas selected to provide additional stormwater runoff to the proposed wetland system were divided into 6 subcatchments (see Figure 8-1) each with different hydraulic properties (i.e., slope, Manning's roughness coefficient, etc.) Each one of the subcatchments was further divided into pervious and impervious areas. SWMM uses a non-linear representation of each subcatchment to produce a hydrograph of a rainfall event utilizing a combination of a continuity equation and Manning's equation. According to Huber (1988) the continuity equation for a subarea is written as:

$$(dV/dt) = A(dd/dt) = Ai^{*} - Q \qquad (8\text{-}1)$$

where:

V	= Ad = volume of water on the subarea, ft^3
d	= water depth, ft
t	= time, sec.
A	= surface area of subarea, ft^2
i^{*}	= rainfall excess (rainfall/snowmelt intensity minus evaporation/infiltration rate, ft/sec)
Q	= outflow rate, cfs

The outflow is generated using Manning's equation:

$$Q = W\,(1.49/n)\,(d-dp)^{5/3}\,S^{1/2} \qquad (8\text{-}2)$$

where:

W	= subcatchment width, ft.,
n	= Manning's roughness coefficient,
dp	= depth of depression storage, ft.,

S = subcatchment slope, ft/ft

These equations are combined into one non-linear differential equation that may be solved for one unknown (depth) as follows:

$$\frac{dd}{dt} = i^{*} - [(1.49W)/(An)]\,(d-dp)^{5/3}\,S^{1/2} = i^{*} + WCON\,(d-dp)^{5/3} \quad (8\text{-}3)$$

where:

$$WCON = (1.49WS^{1/2})/(An) \quad (8\text{-}4)$$

This equation is then solved by a finite difference scheme at each time step to produce a hydrograph for a rainfall event.

8.4.2.2 Subcatchment data

The subcatchment data includes the area, percent impervious, slope, Manning's n-value (pervious and impervious), subcatchment width, depression storage, evaporation, and infiltration. The subcatchment data is shown in Table 3-1.

The subcatchment slope is the average slope of a typical overland flow path from the point of rainfall to the collection in a catch basin, channel, storm sewer, or detention basin. Drainage areas, flow paths, and slopes for each subcatchment were estimated based on the topographic mapping.

The subcatchment percent impervious represents the percent of impervious surface (such as parking lots and roadways) which are directly connected to the storm sewer system. The southern roof drains at the Liberty Science Center drain directly into the storm sewer system; therefore, these drainage areas were considered impervious. The northern roof drains empty into the LSC wetland area; therefore, these drainage areas were not considered impervious.

Each subcatchment is assigned two Manning's roughness coefficients: one for the pervious area and the other for the impervious area. The roughness coefficients for the pervious areas were between 0.05 to 0.1, and for impervious, coefficients were 0.014.

Depression storage represents the volume of water which does not run off and is not subject to infiltration. Depression storage also includes water that falls on tree canopies and does not reach the ground. Depression storage is typically used as a calibration parameter; however, because there is insufficient existing data to calibrate the model to, depression storage was not used in the analysis. However, because the primary drainage areas are predominantly impervious, depression storage would likely be minimal and have little impact on the analysis.

The subcatchment infiltration is the water that infiltrates into the ground. The maximum and minimum infiltration rates were set at 4.5 and 0.02 inches per hour for pervious surfaces within the park and 3.0 and 0.02 inches per hour for pervious surfaces outside the park. The pervious surfaces outside the park consist primarily of mowed grass or grass swales. The pervious surfaces inside the park are grasslands and upland forests. The decay coefficient was set at 4 $hr^{-1,}$ which is equivalent to a decline in infiltration of 98 percent towards the minimum rate after the first hour. Use of these infiltration rates results in a majority of the rainfall events occurring throughout the year, which are less than 0.5 inches per hour, infiltrating into the soil of the pervious areas. For example, as shown in Figure 8-2, much of the rainfall from the 10-year/24-hour even infiltrates into a pervious soil surface (i.e., LSC wetland drainage area). In comparison, as shown in Figure 8-3 much of the rainfall falling on a primarily impervious surface (i.e., LSC parking lot) results in runoff.

Evaporation data in the model were applied to all the open water in drainage areas and natural channels within the network.

Evapotranspiration was not considered in the SWMM analysis. Because the drainage areas are primarily impervious, losses due to evaporation from the soil surface and transpiration from vegetation, are negligible. It is also assumed that evaporation from open water areas within the channel and wetlands would be significantly greater than evapotranspiration from areas adjacent to the wetlands and channels. Furthermore, it is difficult to model the saturated soil zone without sufficient groundwater data.

8.4.3 HYDRAULICS Block

The HYDRAULICS block of the SWMM receives input flow hydrographs from the RUNOFF block and routes flow downstream, explicitly taking into account backwater conditions along the way. Parallel pipes, culverts, open channels, weirs, orifices, and detention ponds as well as complex hydraulic systems can all be modeled in this block. The HYDRAULICS block uses a node and conduit representation of the physical system. Channels, culverts and pipes are represented by conduits, and manholes, detention basins, ponds or boundaries between channel segments are represented by nodes.

The existing and proposed wetlands were modeled as natural channels within SWMM. Through the use of natural channel links, the wetland dimensions and subsequent storage, as well as flow of water through the wetlands, could be more accurately modeled. This helped make the model more representative of actual conditions at the site.

8.4.3.1 St. Venant equations

The HYDRAULICS block solves the one-dimensional non-steady state flow equations also known as the St. Venant or shallow water equations. The HYDRAULICS block solves a coupling of the continuity and momentum equations at each time step using a finite difference form of the following equation:

$$\frac{\partial Q}{\partial t} + \frac{gKQ|Q|}{R^{3/4}} - \frac{V\partial A}{\partial t} + \frac{Q\partial V}{\partial x} + gA\frac{\partial H}{\partial x} = 0 \tag{8-5}$$

where:

Q	= discharge through the conduit
V	= velocity in the conduit
A	= cross-sectional area of the flow
H	= hydraulic head (invert elevation plus water depth)
R	= Hydraulic radius
t	= time
x	= distance
g	= acceleration due to gravity
K	= $(n/1.49)^2$ [for English units n = 1]
n	= Manning's roughness coefficient

8.4.3.2 Node and Conduit Data and Coefficients

There are a number of different parameters that must be encoded into the HYDRAULICS block so that it can accurately reflect the storm drainage system. These parameters include conduit lengths, sizes and shapes as well as node inverts and ground elevations. Conduit lengths and wetlands dimensions were developed using the topographic mapping. Typical conduit and node data for the alternatives are included in Appendices E and F (Alternative D output). The data are typical for each alternative.

To calculate friction losses, Manning's roughness coefficients (n-values) were assigned for all conduits. For this analysis, a value of 0.014 was utilized for the storm drainage pipes. For the open channels and drainage ditches, two n-values are used: 0.05 for mowed or short grass surfaces and 0.1 for long grass and weed areas, such as the drainage ditches along Phillip Street.

Entrance and exit loss coefficients, contraction and expansion coefficients, and bend losses in pipes were considered minimal and were not used in the model.

8.4.3.3 Infiltration Modeling

XP-SWMM contains a module for modeling infiltration and percolation as it relates to groundwater elevation. However, use of the module requires more groundwater data than was available. Additionally, the module contains several adjustment coefficients, which are best determined through calibration with known data. Because data was unavailable, the infiltration basin was modeled using an outlet orifice to represent infiltration (outflow) from the basin.

The outlet was sized for a maximum outflow of approximately 2 cfs at 1.5 feet of head, which is equivalent to 1 in/hr over the 2 acre infiltration basin (9 in. diameter orifice). One and one-half feet of head in the basin is a reasonable maximum level (approximately 6.0 ft NAVD) based on the system's design elevations.

8.4.3.4 Boundary Conditions

The one free flowing outlet in the model was at Morris Canal. Tidal influence was modeled at this outlet using the Mean High Water and Mean Low Water elevations, 2.19 feet NAVD and –2.38 feet NAVD, respectively. Initial results indicated that the tidal boundary condition only impacted ponding in the immediate vicinity of the outlet. Therefore, any minor changes in the tidal elevations would not be expected to impact the results.

8.4.3.5 HYDRAULICS network

A schematic of the Existing Conditions HYDRAULICS network, shown in Figure 8-4, includes the major nodes, channel, and pipe segments of the drainage system. Each of the six subwatersheds includes pipes and channels to route flows. In Figure 8-, the circles are model nodes representing manholes or connections between open channel conduits. The lines are the links or conduits connect the nodes. The triangles represent storage nodes, such as detention basins and ditches.

Figures 8-5 and 8-6 show the SWMM networks for Alternatives A and Alternative B, respectively. The network for Alternative C is similar to Alternative B: only the dimensions of the Liberty Science Center wetland have changed. The nodes between the channel segments in the Biofilter wetland and Deep Emergent Marsh indicate changes in wetland or channel dimensions.

Figure 8-7 shows the SWMM network for Alternative D. Alternative D differs from Alternative C at the DEM outlet: the DEM outflow enters an infiltration basin, where groundwater recharge occurs. A second overflow outlet was added to the infiltration basin in the event inflow exceeds infiltration.

8.4.3.6 Calibration

No measured flow or water surface elevation data was available for the existing drainage system; therefore, calibration of the model was conducted using anecdotal information: model results were compared with observations made in the field during site visits and the environmental resources inventory work effort.

8.4.3.7 Hydrologic Risk and Uncertainty

Because the hydrologic budget was a volume-driven analysis, focused on monthly and annual runoff and storage volumes, the analysis of discrete storm events would not provide the necessary information to conduct the analysis over time. Furthermore, discrete runoff data would not provide the data needed to determine if there was sufficient annual runoff to support an additional wetland system in the park. Therefore, standard means of incorporating hydrologic uncertainty into a discrete event analysis, such as changes in the period of record, were not possible.

Rather, using the continual rainfall-record modeling capability of SWMM, actual rainfall from known historic periods could be modeled and the performance of the existing and proposed conditions could be evaluated using realistic rainfall periods. Hydrologic uncertainty was incorporated into the analysis by modeling one extreme wet year and one extreme dry year of recorded rainfall, 1983 and 1976, respectively. Successful performance of the wetland system during these two events, particularly the dry year, would indicate that the system should function satisfactorily during an average precipitation year, which would have typical rainfall events and amounts somewhere between the two modeled years.

8.4.3.8 Infiltration Basin Performance Uncertainty

Many factors influence the rate of infiltration including: soil structure, condition of the soil surface, moisture content, and chemical and physical nature of the soil and water used in the analysis. Therefore, surface infiltration measurements made with double-ring infiltrometers typically provide data useful only for comparison to published sources (ASTM 1986). The unique characteristics of soils at the Liberty State Park site, namely, coarse, gravelly-material on the surface and poorly-graded, silty Sand underneath, indicate that the surface infiltration rate will likely be different from the subsurface (>12 in.deep) rate. However, subsurface infiltration data is unavailable at this time. Furthermore, groundwater movement and elevation are also unpredictable, especially in the future if the proposed tidal wetland is constructed.

The rapid infiltration rates measured at the soil surface are indicative of gravelly-sand at the soil surface; however, subsurface geotechnical analyses indicate the presence of poorly-graded silty Sand, which has a relatively low permeability. However, permeability tests were not conducted on the deeper material. Therefore, infiltration rates at the invert of the proposed infiltration basin must be estimated.

Minimum measured surface infiltration rates (fc) ranged from <4.5 in/hr to over 30 in/hr. However, due the variables stated above, the accuracy of those rates across the soil stratigraphy is uncertain. While coarse gravel and sand have extremely high infiltration rates, it is unclear how deep the high infiltration layer extends. Since infiltration generally decreases with depth, an estimated value of 1 in/hr was considered appropriate for the analysis. A more accurate measurement will be required during the next phase of the study.

The presence of groundwater at or near (or above) the invert of the infiltration basin will impact its performance; however, the actual change in groundwater elevation throughout the year is unknown. It is reasonable to assume that the construction of the proposed tidal wetland may impact (lower) the groundwater elevation, reducing its impact on the infiltration basin. For this analysis, it is assumed that there is no groundwater impact and infiltration is not limited. A change in the infiltration rate is included in the Sensitivity Analysis.

8.5 Alternatives Analysis

8.5.1 General

The four freshwater wetland system alternatives were each modeled with hydrologic input for a wet year and a dry year to evaluate performance. The success of an alternative was predicated on: (1) maintaining the water surface elevation within the Biofilter wetland throughout a majority of the year, (2) maintaining a measurable depth of water within the Deep Emergent Marsh (DEM) throughout the entire year, and (3) achieving some periodic outflow through the DEM overflow in order to achieve circulation or flushing of the DEM. Table 8-1 shows how each alternative performed in meeting the success criteria. Specific discussions of the performance of each alternative are included in the following sections.

8.5.2 Alternative A – Addition of LSC Runoff

As shown in Figure 8-8, during the wet year of precipitation, the Biofilter easily maintains a design water surface elevation (WSEL) of 5.5 feet NAVD. Periodic lowering of the WSEL during the drier summer months occurs for relatively short durations and elevation losses are less than 6 inches. Frequent elevation spikes are representative of the frequent runoff input from the Liberty Science Center. As shown in this and the remaining WSEL timelines, the initial elevation is the invert of the wetland or channel. This is a result of starting the SWMM model with no surcharging or initial data. Starting from a surcharged condition would not have a significant impact on the overall water surface elevations and only a minor impact on outflow volume results during the initial months of modeling.

As shown in Figure 8-9, the DEM also maintains a design WSEL of 5.0 feet NAVD during a majority of the wet year. The duration of the low WSEL during the drier summer months is longer in the DEM than in the Biofilter. However, the deepwater pool maintains a depth of almost 4 feet in the summer.

During a dry year, the Biofilter wetland maintains the 5.5 feet NAVD WSEL during a majority the year as shown in Figure 8-10. The reduced number of elevation spikes demonstrates that input is significantly reduced as a result of less rainfall. Because much of the rainfall occupies existing storage in the Biofilter, there is minimal overflow to the DEM.

As shown in Figure 8-11, the WSEL of the DEM is at the design elevation during a majority the dry year. However, overflow from the DEM is less frequent, as indicated by the limited number of times the WSEL exceeds 5.0 feet NAVD, and as shown in Figure 8-12.

During a wet year there is comparatively significant overflow from the DEM, as shown in Figure 8-13.

Overall, Alternative A meets all the performance criteria and can be expected to provide sufficient water to maintain each of the wetland Zones described in the Freshwater Components section of the report.

8.5.3 Alternative B – Addition of LSC and LSC Wetland Runoff

Like Alternative A, the Biofilter maintains a design WSEL of 5.5 feet NAVD throughout much of the year, as shown in Figures 8-14 and 8-15.

The addition of a second source of stormwater to the freshwater wetland system increases the time the DEM maintains the design WSEL and increases outflow from the DEM, improving circulation and flushing. As shown in Figure 8-16, the DEM maintains the design WSEL of 5.0 feet NAVD during most of the wet year of precipitation. Frequent increases in the WSEL above the outflow invert result in periodic flushing of the wetland, as shown in Figure 8-17.

As shown in Figure 8-18, even during the dry year the DEM WSEL is at the design elevation for 10 of 12 months. Overflow from the DEM is less frequent than during a wet year, but still significant, as shown in Figure 8-19.

The performance of Alternative B is similar to Alternative A; however, the increased flushing from the additional stormwater provided by the LSC wetland should improve the water quality in the DEM.

8.5.4 Alternative C – Additional Runoff and Enhanced LSC Wetland

Hydraulically, the performance of Alternative C is virtually identical to the performance of Alternative B. This occurs because the only modification in Alternative C relative to Alternative B is the dimensions of the LSC wetland. Although there is a significant improvement in habitat as a result of the enhancement, the changes in the storage dimensions are minor; therefore, they have little impact on the hydraulic performance of the alternative in comparison to Alternative B.

8.5.5 Alternative D – Alternative C with Infiltration Basin

Alternative D is similar to Alternative C, including an enhanced LSC wetland and additional stormwater runoff from the LSC parking lot and overflow from the LSC wetland. However, in this alternative, the DEM outflow enters an infiltration basin, where groundwater recharge occurs.

Like the other alternatives, the Biofilter maintains a design WSEL of 5.5 feet NAVD throughout much of the year, as shown in Figures 8-20 and 8-21. As shown in Figures 8-22 and 8-23, the DEM maintains the design WSEL of 5.0 feet NAVD during most of the wet year of precipitation and during the dry year the DEM WSEL is at the design elevation for 10 of 12 months.

Overflow from the DEM enters the infiltration basin and is lost from the system through infiltration. As shown in Figure 8-24, periods of higher rainfall surcharge the infiltration basin above the design WSEL of the DEM for brief periods of time. Infiltration for the basin, as modeled, is shown in Figure 8-25.

For the dry model year, input to the infiltration basin is less frequent (Figure 8-26). Subsequently, there is less infiltration (Figure 8-27).

8.5.6 10-year NJDOT Design Event Performance

The performance of the freshwater wetland system was evaluated to ensure that no induced roadway flooding occurs during the NJDOT roadway design event. The NJDOT design event is a 10-year/24-hour rainfall event of approximately 5.25 total inches of rainfall. Unlike the annual models, the design event was modeled using SWMM's "hot-start" feature, which enabled modeling of the events with antecedent conditions in the wetlands. Starting the model with existing water in the wetland more realistically represents the behavior of the WSELs in the system.

The primary areas of concern in the wetland system are: 1) the Biofilter and, 2) the detention/ponding area west of Phillip Street (the upstream end of the Phillip Street pipe). Excessive backwater flooding in these areas could overtop Phillip Street as a result of the proposed wetland system.

As shown in Table 8-2, the WSELs of both the Biofilter and upstream detention area just reach the minimum curb height of 7.0 feet NAVD along Phillip Street as a result of the 10-year/24-hour storm runoff in each alternative. This is shown in Figures 8-26 through 8-31. The smoothness of the hydrograph changes between Figures 8-29 and 8-30 due to modifications in the time step, which were made to improve model performance.

From these results, it is assumed that flooding is not likely to occur at Phillip Street following a 10-year/24-hour storm event as a result of the freshwater wetland system construction.

8.6 Sensitivity Analysis

Preliminary plan formulation results indicate that Alternative D is the preferred freshwater wetlands plan. Uncertainty has been incorporated into the hydrology through the use of precipitation from extreme wet and dry years of record. Evaporation uncertainty is incorporated through the use of monthly averages. However, at this point in the analysis there is some degree of uncertainty associated with the potential infiltration of the proposed infiltration basin. Small changes in the infiltration rate are not expected to be critical to the wetland system performance; however, a sensitivity analysis is appropriate to demonstrate the impact of potential changes in filtration.

As defined, a sensitivity analysis is a technique of varying assumptions to examine the effects of alternative assumptions on the determined outcome. In this case, how the wetland system will perform if the infiltration of the proposed infiltration basin is changed. To evaluate the system sensitivity to a change in the infiltration rate, the proposed infiltration rate was modeled during the wet year (1983) with an outlet sized for a maximum outflow of approximately 1 cfs at 1.5 feet of head, which is equivalent to maximum infiltration rate of 0.5 in/hr over the 2 acre infiltration basin or half of the assumed infiltration rate of 1 in/hr.

As shown in Figure 8-34, infiltration is half the rate originally modeled; however, the WSEL elevation increase in the infiltration basin is only approximately 0.4 feet during the largest storm (Figure 8-35). The greatest impact is a backwater impact into the DEM; however, this is minimal and quickly dissipates as the infiltration basin WSEL drops. It can be assumed that an increase in the infiltration rate will have the opposite effect on the WSEL of the infiltration basin and DEM during a given year. Regardless, minor changes in the infiltration rate should not detrimentally impact the freshwater system.

9. SEDIMENT LOADING ESTIMATES

The purpose of this analysis was to estimate the depositional rates in each of the three water bodies to be created in this project: the LSC Wetlands; the Biofilter; and the Deep Water Emergent Wetland. These projections are useful for determining the effort to be required to maintain the wetland depths in the future through dredging.

9.1 Methodology And Assumptions

9.1.1 Methodology

The monthly sediment loading is calculated as

$$L = Q * C * C_1 \tag{9-1}$$

where

L = sediment loading (lbs/month)
Q = flow (m^3/month)
C = total suspended solids concentration (mg/l)
C_1 = units conversion factor

The Simple Method was used to calculate monthly flows. In this respect, the sedimentation analysis was consistent with the runoff calculations for the hydrologic budget analysis. The solids settled in one of the water bodies is calculated as the solids loading passing through the water body times the solids removal efficiency (Schueler 1987):

$$S = L * R \tag{9-2}$$

S = solids settled (pounds/month)

R = solids removal efficiency (%)

This method was used to calculate sediment deposition for three water bodies: the LSC wetland, the biofilter, and the deep water emergent wetland.
Solids loadings are passed downstream as determined in the conceptual plan. A diagram showing the solids routing for the proposed plan is presented in Figure 9-1. The breakdown of solids sources for each of the water bodies is:

1. LSC Wetland: NJ Transit parking lot runoff
2. Biofilter: Flow through LSC wetland and LSC parking lot runoff
3. Deep Water Emergent Wetland: flow through Biofilter and Upland Catchment runoff

Once the solids loading is calculated, the total deposition for that month can then be estimated:

$$D = L/\{?*A *(1-n)\} * C_2 \quad (9\text{-}3)$$

where

D = sediment deposition (inches/month)

? = density (lb/ft^3)

A = surface area (acres)

n = porosity

C_2 = units conversion factor

9.1.2 Assumptions

Several simplifying assumptions were made to develop this analysis. It is assumed that each water body is at full capacity so that inflows are passed downstream within each month;

otherwise, a complete water balance would need to be developed for each water body. Another assumption is that results are time averaged over the one-month period. A suspended solids concentration of 31 mg/l was used, considered typical for urban runoff (Schueler 1987). Finally, because of the one-month time frame, storm-specific scouring is not specifically simulated. Instead, this effect is included in the overall solids removal efficiency, R, which is assumed to be 60%.

9.2 Sediment Loading And Deposition Estimates

Solids loadings and deposition rates are shown in Tables 9-1 and 9-2, respectively. The deposition rates for 1993-2002 are estimated at 0.0114 – 0.0462 inches/year for the three water bodies. The highest rates are for the average of the three wettest years (1983, 1984, and 1996), 0.0160 – 0.0647 inches/year.

10. COST ANALYSIS

First construction cost estimates were developed for each of the conceptual design alternatives. The cost estimating included direct construction expenditures such as demolition site work, landscaping, soil removal and disposal. The estimate also included indirect expenditures (soft costs) such as field engineering, administrative and legal costs. A contingency factor of 20% is also added. The costs were based on experience at other projects and published estimating tools, including RS Means©. The analysis was used to compare the estimated first construction costs for each of the four selected alternatives.

The estimated first costs of the alternatives are as follows:

- Alternative A: Deep Emergent Marsh, Liberty Science Center parking lot drainage (LSC) and Biofilter = $ 736,000.
- Alternative B: DEM, LSC, Biofilter, and Water from NJ Transit = $ 736,000.
- Alternative C: DEM, LSC, Biofilter, NJ Transit, and Enhanced LSC Wetland = $ 1,108,000.
- Alternative D: DEM, LSC, Biofilter, NJ Transit, Enhanced LSC Wetland and Infiltration Basin = $1,719,000.

Table 10-1 summarizes the comparative costs.

11. REFERENCES

Chow, Maidment, and Mays. 1988. *Applied Hydrology*. pp 108-117.

DeGaetano, A.T., K.L. Eggleston, and W.W. Knapp. 1994. Daily Evapotranspiration and Soil Moisture Estimates for the Northeastern United States. Northeast Regional Climate Center Research Series Publication No. RR 94-1.

Hammer, D.A. 1992. Creating Freshwater Wetlands. Lewis Publishers, Ann arbor, Michigan. 298 p.

Hubbard, D.E., J.L. Richardson, and D.D. Malo. 1988. Glaciated Prairie Wetlands: Soils, Hydrology, and Land Use Issues. P. 137-143 In: Kusler and Brooks 1988, Proceedings of the National Wetlands Symposium: Mitigation of Impacts and Losses, Association of State Wetland Managers, Berne, New York, Technical Report 3.

Huber W.C. and R.E. Dickinson. 1988. Storm Water Management Model, Version 4: Users Manual, US Environmental Protection Agency

Liberty State Park (LSP) 2003. History of Liberty State Park. http://www.libertystatepark.com/1/lsp_history/history.htm

MacFarlane, D.W. 2001. The Ecology of Liberty State Park: A Historical Perspective

Maryland Soil Conservation Service (Md SCS). 1983. Maryland Specifications for Soil Erosion and Sediment Control. Maryland Water Resources, Administration. Annapolis Maryland.

NCDC. 2000. Hourly Precipitation Data (1948-1999).

NJDEP. 1995. Liberty State Park Soil Sampling Report.

NJDEP. 2003. New Jersey Stormwater Best Management Practice Manual, Draft February 2003.

NJDOT. 2003. New Jersey Department of Transportation Design Manual – Roadway.

Pierce, G. 1993. Planning Hydrology for Constructed Wetlands. Prepared by the Wetland Training Institute.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Prepared for Washington Metropolitan Water Resources Planning Board.

SMRC. 2003. Stormwater Manager's Resource Center website, www.stormwatercenter.net.

Turf-Tec International. 2003. Coral Springs FL.

USACE. 1999. Groundwater Hydrology (EM 1110-2-1421).

USACE. 2001. Wetlands Engineering Handbook (ERDC/EL TR-WRO-RE-21). Engineer Research and Development Center.

USACE. 2002. South River, Raritan River Basin Hurricane and Storm Damage Reduction and Ecosystem Restoration Draft Integrated Feasibility Report and Environmental Impact Statement – Hydrology, Hydraulics & Design Appendix.

USEPA. 1999. Infiltration Through Disturbed Urban Soils and Compost – Amended Soil Affects on Runoff Quality and Quantity (EPA/600/R-00/016).

Viessman, W., J.W. Knapp, G.L.Lewis, and T.E. Harbaugh. 1977. Introduction to Hydrology. Harper & Row Publishers. New York.

XP Software. 1999. XP-SWMM2000 Version 8.0, Stormwater & Wastewater Management Model, Getting Started Manual.

APPENDIX A

HYDROLOGIC BUDGET RESULTS

APPENDIX B

PLANS OF FRESHWATER WETLAND COMPONENTS AND MODELED ALTERNATIVES

APPENDIX C

WETLAND ZONES

APPENDIX D

COST SHEETS

APPENDIX E

ALTERNATIVE 4 SWMM HYDRAULIC OUTPUT - 1976

APPENDIX F

ALTERNATIVE 4 SWMM HYDRAULIC OUTPUT - 1983