USE OF A CONSTRUCTED REEDBED WETLAND IN THE MITIGATION OF HIGHWAY RUNOFF ON THE GROUND-WATER QUALITY IN A CARBONATE ROCK AREA

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SUSQUEHANNA RIVER BASIN COMMISSION

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to effect coordinated planning, conservation, management, utilization, development and control of basin water resources among the government and private sectors.

**Statutory Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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The Pennsylvania Department of Transportation (PennDOT) was very cooperative and supportive throughout this project. The Pennsylvania Department of Environmental Protection, Bureau of Laboratories performed all of the chemical analyses of water samples.

The participation and project knowledge of Paula Ballaron and John Hauenstein, Commission employees, was very valuable in writing this report. Special appreciation goes to several other present and former employees of the Commission, who initiated this project in 1994, because they recognized the potential value of constructed wetlands to protect ground-water quality in carbonate areas.

This report is based on information and documentation from others and not from personal involvement in the planning, execution, or monitoring of this project.

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ABSTRACT

The project was designed to evaluate the potential for collecting and treating highway and parking lot runoff in an area underlain by carbonate rock. The project was performed in cooperation with the Pennsylvania Department of Transportation (PennDOT), under the Transportation Enhancement Program in compliance with the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Three major elements of the project were: (1) the collection of data on the quality of stormwater runoff from highways crossing carbonate areas; (2) the evaluation of the feasibility of constructed wetlands to mitigate any adverse water quality effects due to highway runoff; and (3) the development of criteria for the design and installation of wetland treatment systems for highway runoff.

A free water surface system constructed wetland, designed to function as a first-flush water treatment system to treat the heaviest load of pollutants, was installed at the project site. A basin 50 feet wide and 70 feet long was excavated, lined with 30-millimeter (mil) HDPE and filled to a depth of 6 inches with washed bar sand. It was planted with a variety of native, emergent, herbaceous plant species, including swampy milkweed, blue flag iris, great bulrush and soft rush.

The wetland was design to allow runoff discharge to flow across the wetland surface via sheetflow (Munro, 1996). Vegetation would provide surface area for adhesion of oil and grease materials and reduce flow velocity to increase sediment deposition. Plant roots would assimilate nutrients from the stormwater discharge. Bacteria and algae growth in the wetland would assist with chemical process that precipitate the metals from the sheetflow and retain the precipitate within the wetland basin. Moderately high runoff discharges saturate the 6-inch substrate and result in ponding. Larger storm events result in the flow exiting over the basin's emergency spillway. Even during periods of increased runoff, the vegetation could assist with oil, grease, and sediment removal. The degree of stormwater pollutant reduction by vegetation could not be determined due to the lack of sufficient seed germination and plant growth in the spring of 1997.

Water sampling conducted in fall 1994 and spring 1995 indicated that the highway runoff contained a variety of nutrients, metals, and pesticide/herbicide by-products. Analyses of samples conducted following storm events in May 1997 did not show a significant reduction of water pollutants. The pollution treatment efficiency of the constructed wetland cannot be determined due to limited water sampling events and water chemistry parameters analyzed.

INTRODUCTION

Highway runoff pollutants can include sediment, trace metals, toxicants, hydrocarbons, nitrogen, and phosphorus that originate from atmospheric deposition, metal corrosion, material from worn brake linings and tires, organic matter, litter, and debris. These materials accumulate rapidly on impervious surfaces and are easily washed off by stormwater runoff into stormwater collection systems and other receiving waters (Linker, 1989). Highway runoff pollution is of special concern in areas with carbonate geology. Highway runoff discharges to these areas can result in direct ground-water contamination through solution enlarged cracks and fissures in the bedrock.

Historically, the practice of treating highway runoff to protect carbonate areas is limited. Highway runoff collection systems and basins were primarily designed to accommodate peak discharge volumes, not for pollution treatment. Conventional water treatment facilities have been used to treat highway runoff, but only in areas where the discharge volume or frequency was great enough to justify the costs associated with operation and maintenance of a treatment facility.

Pollutants in stormwater can be removed by wetlands through a combination of several processes: (1) incorporation into or attachment to wetland sediments or biota; (2) degradation; or (3) exportation to the atmosphere or ground water. Both physical and chemical pollutant-removal mechanisms are thought to occur in wetlands. These mechanisms include sedimentation, absorption, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. Because of the many interactions among physical, chemical, and biological processes in wetlands, these mechanisms are not independent (Strecker, 1992).

The initial step in site selection was to identify regions with known carbonate geology that were transected by major highways. Potential wetland construction sites were evaluated in Lancaster, Perry, and Cumberland Counties, Pennsylvania. The hydrology of a site in Lancaster County was determined inadequate; therefore, the site was eliminated from consideration. A suitable site near the town of Amity Hall, Perry County, was evaluated but not considered since PennDOT already proposed a constructed wetland adjacent to the highway. The Cumberland County site (Figure 1) was selected because it had the potential for adequate water runoff and presented the need for a stormwater treatment system.

Purpose and Scope

The project had three major elements: (1) the collection of data on the quality of stormwater runoff from highways; (2) the evaluation of the feasibility of constructed wetlands to mitigate any adverse water quality effects due to highway runoff; and (3) the development of criteria for the design and installation of wetland treatment systems for highway runoff.

The Susquehanna River Basin Commission's (Commission's) objective was to construct a wetland that provided pollutant reduction of highway stormwater runoff. Water quality samples, collected at both the inlet and outlet pipes of the wetland, after each rain event were to be analyzed to determine the pollution reduction and design efficiency of the wetland. Local precipitation records were to be used to assist in developing a correlation between wetland performance and precipitation rates**.**

Description of the Study Area

The study area is located in Dickinson Township, Cumberland County, Pennsylvania (Figure 2). A highway drainage site with carbonate geology, stormwater drainage, and ground-water pollution concerns was selected at the northbound rest area along Interstate 81 (Plainfield rest area), near the town of Newville. Thick sequences of structurally-deformed carbonates comprise the bedrock of a sizeable area in central, southcentral, and southeastern Pennsylvania that have developed into karstic landforms, resulting in significant land-subsidence problems (Wilshusen and Kochanov, 1999). The Cambrian Elbrook Formation, described as inerbedded calcareious shaly argillaccous limestone, and limestone carbonate bedrock, underlies the Plainfield rest area (Becher and Root, 1981). The study area has known sinkholes, a characteristic of the land subsidence problems within the region.

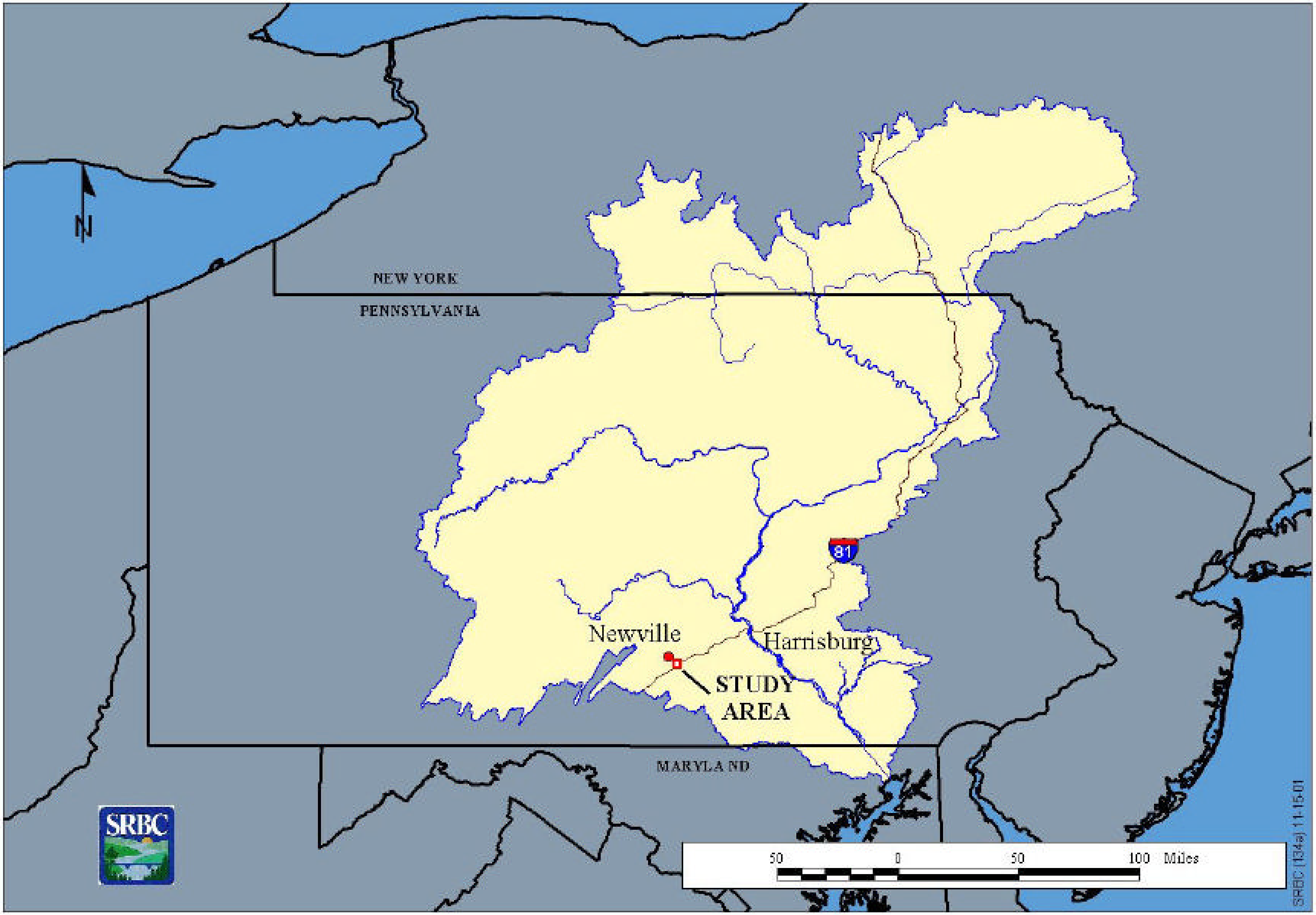

Figure 1. Regional Location Map

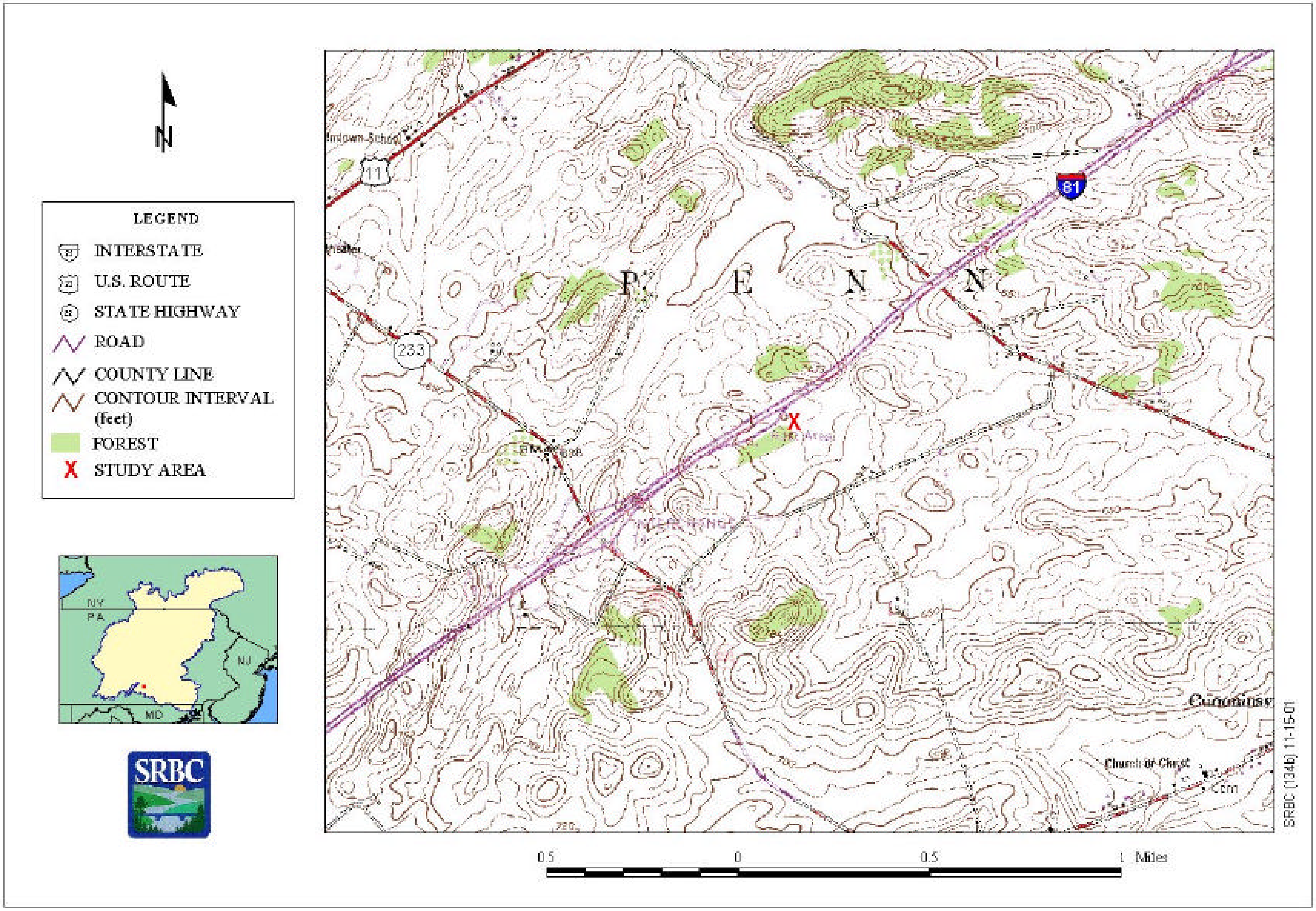

Figure 2. Location of the Study Area in Cumberland County, Pennsylvania

PennDOT highway blueprints illustrate that the stormwater runoff collection system drains 0.012 square miles. Half of the drainage area is covered by the impervious pavement surfaces of the interstate and a 2.5-acre parking lot. The high percentage of impervious surface indicated that the wetland would receive adequate runoff volumes, while the close proximity of the wetland to highway activities provided a substantial pollutant load.

CONSTRUCTED WETLAND

Design and Construction

The Commission contracted wetland consultants to design the constructed reedbed wetland (Table 1). A stormwater chemistry profile (Appendix, Table A2) was established to assist with the design and vegetation selection. The initial design included a lined diversion channel that would convey excess water during periods of high runoff discharge. However, this diversion channel would have flowed through a known sinkhole area. To avoid the potential of a breech in the diversion channel and pollution of ground water, the design was modified to allow all the discharge to enter the wetland (Munro, 1996). An emergency spillway was added to the design to accommodate the excess flow. A depression approximately 12 inches deep and 12 feet wide in the embankment was built to serve as an emergency spillway. The original design included a lined outlet channel, but during construction, it was determined that an adjacent preexisting channel would be sufficient.

Stormwater runoff discharge was conveyed to the wetland through three stormwater collection pipes (Figure 3). Two 18-inch diameter collection pipes drained the rest area parking lot and northbound Interstate 81 entrance ramp. One 30-inch diameter collection pipe drained the northbound travel lanes of Interstate 81. The three pipes drained into the wetland entrance, which was protected by 20 large boulders (average size 12 inch diameter) positioned to dissipate energy and reduce erosion and scour during high discharge conditions.

The constructed wetland is an excavated basin that is 50 feet wide and 70 feet long. The perimeter was formed with 2 inch by 12 inch pressure-treated planks to provide support and the basin lined with 30-mil HDPE plastic to prevent leakage. During construction, the HDPE liner was accidentally measured too short, and several pieces were required to line the basin.

The basin was filled with 62 cubic yards of sterile washed bar sand to form a 6-inch deep sand bed. The wetland was generally level with minor unintentional microtopographic alterations. The entire wetland was surrounded by a 3-foot embankment, which was constructed from the native soils removed during excavation. The embankment was constructed to allow the wetland to provide some stormwater retention during periods of high flow.

Discharge from the wetland was determined by water depth within the wetland. Minor discharge volumes flowed through the wetland and exited through a 6-inch slotted pipe that was positioned at the top of the sand bed (Figure 4). Moderate discharges, which resulted in a 1-foot water depth in the basin, were drained through a second 6-inch slotted pipe that was positioned through the earth embankment. Large storm events would result in the stormwater runoff exiting the wetland over the emergency spillway. A capped 4-inch pipe was installed at the bottom of the wetland to completely drain the wetland for any future maintenance procedures.

Wetland Vegetation

The goal of planting wetlands for stormwater treatment is to generate dense, diverse vegetation that resembles natural wetlands. Abundant vegetation increases sedimentation and supports a variety of microorganisms. Some wetland microorganisms reduce pollution through biological and chemical processes. Vegetation diversity reduces susceptibility to disease, provides wildlife habitat and is more aesthetically pleasing. To maintain abundant and diverse vegetation, it is important to maintain a shallow water depth and ensure that sufficient soil moisture is maintained between rain events (Davis, 1995).

Table 1. Chronology of the Constructed Wetland Project

Fall 1994 – Spring 1995	Collected highway and parking lot runoff samples.
April 1995	Selected site at the Plainfield rest area in Cumberland County.
Winter 1995	Prepared site and filled in an existing sinkhole.
February 1996	Contracted with Munro Ecological Service to design the reedbed water treatment system.
Summer 1996	Modified wetland design to account for adjacent sinkhole area.
September 1996	Constructed the wetland.
October 1996	Planted wetland vegetation and scattered seed.
Spring 1997	Designed a sampling plan.
April 1997	Installed sampling instrumentation.
May 1997	Collected water quality samples at the inlet and outlet structures after two rainfall events.
June 1997	Observed a gray crust on the sand surface and limited plant growth and germination during a routine monitoring session.
November 1997	Collected water quality sample at inlet during a rainfall event.
Early Spring 1998	Commission staff began investigating causes of the plant kill and lack of germination. Ceased monitoring and maintenance activities.

NOTE: In July 1997, the Commission declared a basinwide drought watch.

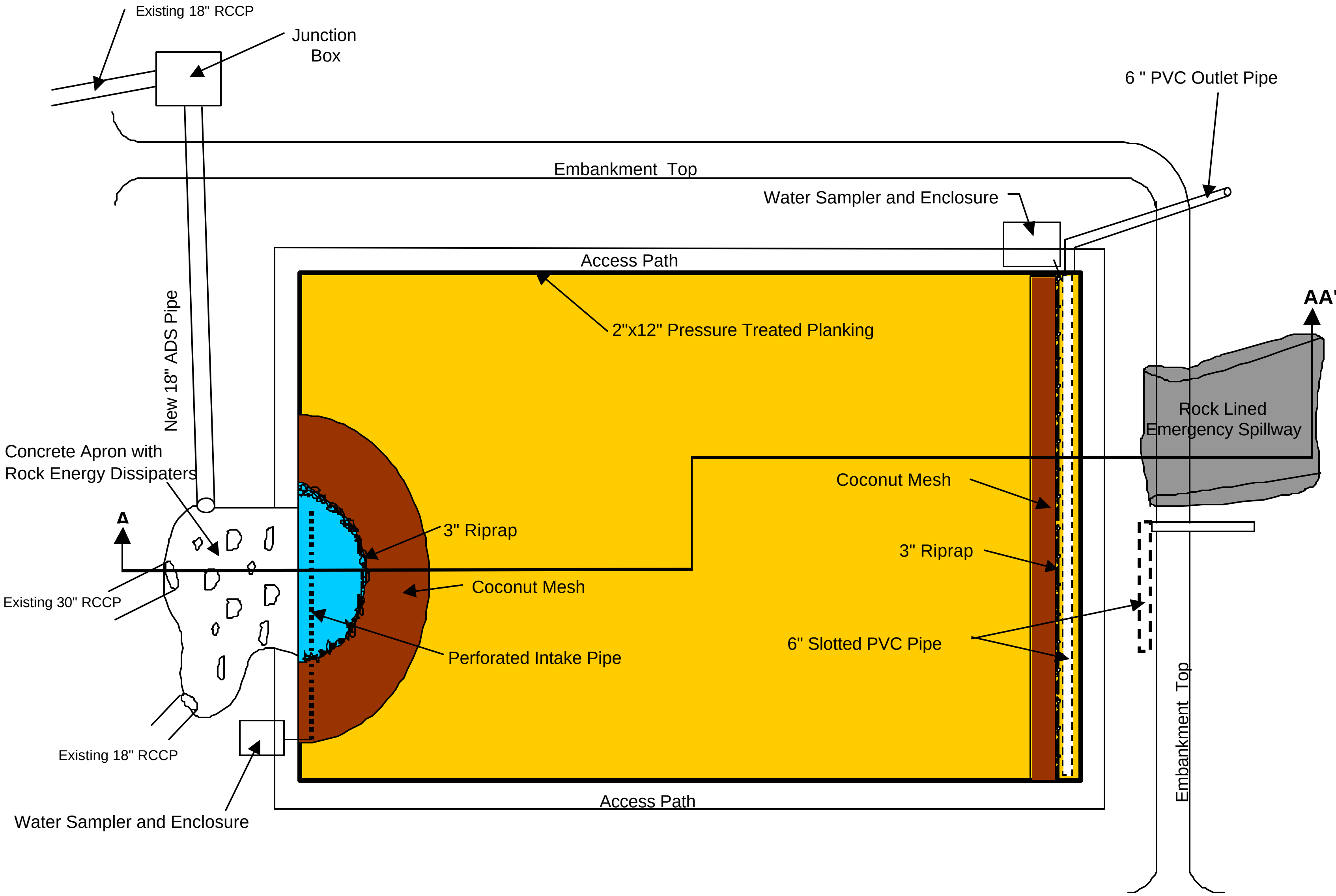

Figure 3. Plan View of Constructed Reedbed Wetland *(not to scale)*

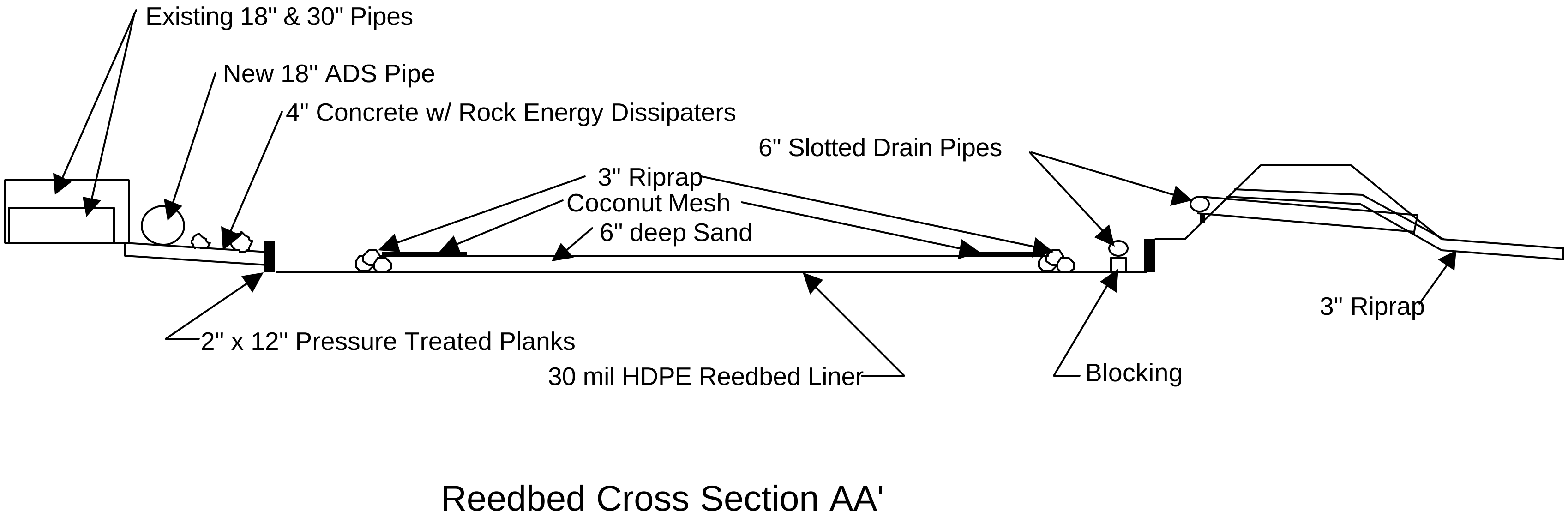

Figure 4. Cross- Sectional Schematic View of Constructed Reedbed Wetland *(not to scale)*

In October 1996, the Plainfield rest area wetland was planted with over 7,000 herbaceous emergent plant plugs of eight different species (Table 2). Wetland sedge seeds also were sowed to ensure an adequate seed bank for the following spring (Table 3). This abundance and diversity was representative of natural wetlands of southern Pennsylvania. The embankment was sowed with a variety of upland plant seeds (Table 4).

Monitoring Facilities and Sampling Procedures

The wetland vegetation and hydrology were monitored, and highway runoff samples were collected to evaluate design performance and pollution treatment efficiency. Universal rain gages (Belfort Instrument Co., Model 3887) were installed at the wetland and at a residence along Walnut Bottom Road. These local precipitation records were to be used to assist in developing a correlation between wetland performance and precipitation rates.

The pollution treatment effectiveness in the wetland was to be tested by a series of runoff samples collected by automatic samplers (Sigma Streamline) positioned near the inlet and outlet structures (Figure 3). Samples were to be collected at the beginning of the storm event, during the peak of the hydrograph, and at the conclusion of the storm event. Sample collection during storm events of different magnitudes was preferred. Storm events sampled during the growing season would provide an accurate representation of pollution treatment efficiency. The 1997 growing season was characterized by short infrequent storm events, which resulted in a drought watch declaration in July that remained in place through the end of the year. The reduced precipitation frequency and durations limited sampling opportunities.

Highway runoff samples collected during the fall of 1994 and spring of 1995 were used to characterize highway runoff chemistry and served as the basis for identifying parameters to be analyzed for future storm events. Temperature, conductivity, pH, and color were analyzed at the inlet and outlet sample points. The Pennsylvania Department of Environmental Protection, Bureau of Laboratories, analyzed the stormwater discharge samples for various nutrients, metals, and semivolatile compounds. A suspended-sediment analysis of all samples was to be completed by the Commission.

Inspection and maintenance visits were conducted during the 1997 growing season. Most site visits were conducted in conjunction with storm events and, therefore, offered the opportunity for runoff sample collection. During the visit, the inlet area, auto-sampler intakes, and outlet pipe areas were freed of any debris. Vegetation type, growth characteristics and location, and the hydrologic condition of the wetland were documented in the beginning of the growing season, but ceased after July. Commission staff cancelled all monitoring and maintenance in the spring of 1998 due to the absence of any hydrophytic vegetation growth or seed germination.

WATER CHEMISTRY

Highway runoff pollutants can include sediment, trace metals, toxicants, hydrocarbons, nitrogen, and phosphorus that may originate from atmospheric deposition, metal corrosion, material from worn brake linings and tires, organic matter, litter, and debris. These materials accumulate rapidly on impervious surfaces and are easily washed off by stormwater runoff into stormwater collection systems and other receiving waters (Linker, 1989).

A 2000 highway usage study conducted near the Plainfield rest area by PennDOT determined that 19,460 vehicles, of which 4,865 were tractor-trailer trucks, travel through the study area (unpublished data, Sykes, personal conversation).

Table 2. Wetland Herbaceous Emergent Plants

Genius/Species	Common Name	Wetland Indicator Status	Water Tolerance	Salt Tolerance*	Height Range (ft)	Rate of Spread
Asclepias incarnata	Swampy milkweed	Obligate wetland	Seasonal inundation	None	Up to 6	Slow
Carex gynandra	Fringed sedge	Facultative wetland	Irregular inundation	None	1-5	Medium
Carex lurida	Lurid sedge	Obligate wetland	Irregular inundation	None	1-4	Medium
Carex stipata	Sawbreak sedge	Obligate wetland	Regular inundation	None	Up to 3	Medium
Iris versicolor	Blue flag iris	Obligate wetland	Regular inundation 0-6 inches	Slight	1-3	Slow
Juncus effusus	Soft rush	Facultative wetland	Irregular inundation	None	3-4	Slow
Lobelia siphilitica	Great lobelia	Facultative wetland	Irregular inundation	None	Up to 3	Slow
Scripus validus	Great bulrush	Obligate wetland	Permanent inundation 0-12 inches	None	6-10	Rapid

***** As determined by Pinelands Nursery & Supply, 2001.

Table 3. Wetland Seeds

Genius/Species	Common Name	Wetland Indicator Status	Water Tolerance	Salt Tolerance*	Height Range (ft)	Rate of Spread
Eleocharis obtuse	Blunt spike rush	Obligate wetland	Regular inundation 0-6 inches	None	0.5-1	Slow
Juncus effusus	Soft bulrush	Facultative wetland	Irregular inundation	None	3-4	Slow
Scirpus polyphyllus	Leafy bulrush	Obligate wetland	Regular inundation 0-6 inches	None	3-5	Slow

***** As determined by Pinelands Nursery & Supply, 2001.

Table 4. Upland Grass Seed Composition

Genius/Species	Common Name	Percent of Mixture
Andropogon gerardii	Big bluestem	24
Elymus canadensis	Canada wild rye	8
Panicum clandestinum	Deertongue	8
Sorghastrum nutans	Indian grass	24
Schyzachyrium scoparius	Little bluestern	17
Tridens flavus	Purple top grass	3
Panicum virgatum	Switchgrass	16

This traffic volume was assumed to be average for Pennsylvania's interstate highways and representative of the traffic volume in 1997. This traffic volume and the existing sinkholes in the study area confirmed the high potential for ground-water pollution.

Stormwater runoff samples collected and analyzed in November 1994 and March 1995 characterized the water quality as containing various nutrients, oil and greases, antifreeze, metals, and hydrocarbons (Appendix, Table A2). These pollutants are consistent with what would be expected from highway runoff (Meyer, 1985).

Water chemistry analyses of stormwater runoff samples collected from the inlet and outlet sample points did not show significant pollution treatment (Appendix, Tables A3 and A4). Review of these data suggests that the wetland did have the potential to remove nitrogen, most likely as nitrate-nitrogen. Nitrogen is a required nutrient for plant growth and, therefore, is readily assimilated by plant roots. Higher metals and hydrocarbon concentrations at the outlet pipe, in respect to the inlet pipe, could be the result of previous precipitation and sedimentation mechanisms within the wetland. Smaller rain events that occurred before the May 9, 1997, sample date (National Climatic Data Center, 1997a and 1997b) may have washed metals and hydrocarbons off the impervious surfaces into the wetland, where the slow flows allowed them to settle and accumulate in the wetland. The subsequent larger discharge, resulting from the May 9 storm event, resuspended the materials and flushed them through the outlet sample point. Discrete samples collected over the storm hydrograph conducted on November 7, 1997 (National Climatic Data Center, 1997c) illustrate the higher pollution concentrations during the first flush of a storm event. Many pollutants, such as ammonia, total organic carbon, oil and grease, sodium, calcium, phosphorus, and sulfate, were at concentrations greater than previously noted at the inlet pipe.

EFFECTIVENESS

The treatment process consisted of collecting the highway and rest area stormwater runoff and directing it to the wetland. A small wooden shelter was installed near the wetland entrance for an automatic water sampler (Sigma Streamline). Water leaves the wetland through the outlet, where it flows into an adjacent channel. A second automatic water sampler installed at the outlet of the cell provided additional water quality monitoring.

Tables A3 and A4 provide a summary of the water quality data from the inlet and outlet of the wetland treatment system. Effectiveness of the wetland treatment system is, at best, characterized as inconclusive. The limited number of storm events sampled, the inconsistency in the water quality parameters analyzed, and lack of vegetation growth and germination prohibited determining the wetland's potential to significantly reduce pollutant concentrations. Interpretation of the laboratory results does not suggest a trend in pollution treatment efficiency of any individual pollutant.

Sedimentation and precipitation are dominating treatment mechanisms within the wetland system. A suspended-sediment laboratory analysis of the discharge samples would have quantitatively measured these mechanisms in the constructed wetland and served as a good indicator of treatment efficiency. Without an understanding of the sedimentation and precipitation mechanisms within the constructed wetland, treatment efficiency cannot accurately be determined.

The 1997 growing season was characterized by small, infrequent storm events. This precipitation pattern restricted analysis of hydrologic conditions in the wetland. No moderate or high discharge volumes occurred and would be analyzed; therefore, the design criteria for the wetland and emergency spillway design could not be evaluated. The limited hydrologic field observations were inadequate to determine if the inundation period, duration and frequency were sufficient for planted hydrophytic vegetation.

CONCLUSIONS

Using the limited water quality monitoring data collected at the Plainfield rest area, no conclusions can be made on the effectiveness of using constructed wetlands for the treatment of highway stormwater runoff in a carbonate rock area. There are several possible explanations for the demise of wetland vegetation:

1. To maintain abundant and diverse vegetation, it is important to maintain a shallow water depth and sufficient soil moisture between rain events (Davis, 1995). Sparse precipitation during the monitoring period resulted in a minimal inundation frequency and duration in the wetland. Short inundation periods also suggest that leaks may have developed between the pieces of the wetland's HDPE liner. Insufficient hydrology was an environmental stress on the community, which resulted in reduced plant growth and seed germination.

2. The abundance and diversity of vegetation planted in the cell was representative of natural wetlands, but vegetation species selection was less than optimal. Tables 2 and 3 illustrate that three of the eight herbaceous emergent plant species and two of the three wetland seed species planted in the wetland required regular or permanent inundation. PennDOT winter deicing practices also were not considered during vegetation selection. Current PennDOT operating procedures require a minimum loading rate of 400 pounds of deicing material per highway mile, and no maximum loading rate is established for highways or rest areas (Sykes, personal conversation). The majority of the plant species installed in the constructed wetland were salt intolerant (Tables 2 and 3). Commission staff observed a white crystal layer on the wetland surface in July 1997. No laboratory analysis was conducted, but upon visual inspection, Commission staff suspected the layer to be residual deicing material. Discharge with a high salinity concentration could be fatal to nontolerant vegetation that is already in a hydrological stressed environment.

3. The exclusive use of sterile wash bar sand may not have been the optimum choice as the basin filler material. Sand has a large amount of surface area per volume, which allows it to retain water through surface tension, but limits the sand's potential to develop and maintain hydric conditions. Anaerobic wetland soils would be ideal for removing a variety of pollutants (Meyer, 1985). No fertilizer was applied to the sterile sand during construction or the following spring, which may have resulted in an inadequate nutrient supply for plant growth and germination.

Currently, the Plainfield rest area constructed wetland does not exhibit wetland characteristics. An upland herbaceous and woody plant community has established itself in the constructed basin and embankments. Poor growing conditions have limited plant growth and diversity along the basin bottom. Two areas of deicing material accumulation and vegetation absence still exist. The basin may retain some of the stormwater detention functions and current vegetation may provide some stormwater pollution treatment, but no further analysis has been conducted to support this suggestion.

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APPENDIX

Table A1. Materials List for the Constructed Wetland Treatment System

Quantity	Material
1	52' x 72' 30-mil HDPE reedbed liner
1	4' x 50' 30 mil HDPE reedbed rock protector
1	10' x 20' 30 mil HDPE reedbed rock protector
1	11' x 100' 30 mil HDPE outlet channel liner
4 rolls	Asphalt tape
5.3 cu. yd.	Dry mix concrete for inlet
4.0 cu. yd.	Dry mix concrete for outlet
3.2 cu. yd.	Dry mix concrete spreader
26	2" x 12"x 10' pressure treated planks for the reedbed frame
88	0.5" x 36" steel reinforcing rod
48	0.5" x 24" steel reinforcing rod
300	0.5" grip diameter drive spikes
5 lb	4" galvanized nails
5 lb	1" galvanized roofing nails
62 cu. yd. (approx,)	Sterile washed bar sand for reedbed
3 cu. yd.	0.5" gravel
2	6" black HDPE pipe boots
2	6" black HDPE pipe boots
40'	Schedule 40 4" dia. pipe
3	Schedule 40 4" dia. sleeve
3	Schedule 40 4" dia. end cap
1	Schedule 40 4" dia. tee
40'	Schedule 40 6" dia. pipe
60'	Schedule 40 6" dia. slotted pipe
7	Schedule 40 6" dia. sleeve
4	Schedule 40 6" dia. 90^o elbow
2	Schedule 40 6" dia. 60^o elbow
2	Schedule 40 6" dia. 45^o elbow
4	Schedule 40 6" dia. endcap
60'	18" smooth interior wall ADS pipe
2	Smooth interior wall ADS pipe sleeves
1	Smooth interior wall ADS pipe 90^o elbow
6	4" x 4" x 8' western red cedar posts for pipe supports
10 (approx)	4" and 6" pipe clamps and U-bolts
1 cu. yd.	3" average size riprap
20	12" (average) diameter rock
10 lb	Upland seed mix
3,000 sq. ft.	Jute
35' x 6' (approx)	Coconut fabric mesh
7,350	1" plugs of specified wetland plants
2 lb	Reed species seed mix

Table A2. Site Characterization of Water Quality for the Plainfield Rest Area Runoff (November 1994 and March 1995)

Parameter	Chemical Analyses Results November 1994	Chemical Analyses Results March 1995
Total Nitrogen	5.63 mg/	NA
NH_3 as Nitrogen	1.06 mg/l	NA
Total NO_2 / NO_3	0.75 mg/l	NA
Total Phosphorus	0.00 mg/l	NA
Total Organic Carbon	11.6 mg/l	NA
Ethylene glycol	NA	70.2 mg/l
Propylene glycol	NA	< 0.423 mg/l
Oil and Grease	NA	4.3 mg/l
Sodium	3.0 ppm	NA
Magnesium	2.5 ppm	NA
Aluminum	0.3 ppm	NA
Silicon	1.7 ppm	NA
Potassium	9.6 ppm	NA
Calcium	9.4 ppm	NA
Manganese	0.014 ppm	NA
Iron	0.55 ppm	NA
Copper	0.013 ppm	NA
Zinc	0.108 ppm	NA
Strontium	0.052 ppm	NA
Thallium	0.13 ppm	NA
Lead	0.003 ppm	NA
Bis-2-ethyl hexyl phthalate	NA	9.37 µg/l
C_8-C_{22} hydrocarbon envelope	NA	Present
Carbonic acid derivative	NA	Present
Salicyclic acid	NA	Present
Pyridine derivative	NA	Present
Caffeine	NA	Present
Acetophenone	NA	Present
Benzoic acid	NA	Present
Benzamide	NA	Present
Nicotine	NA	Present
Furan derivative	NA	Present
Benzeneacetic acid	NA	Present
C_8 – C_{20} hydrocarbon envelope	NA	Present
Carbamic acid	NA	Present

NA= Parameter not analyzed.

Table A3. Water Quality Analysis of Stormwater Runoff During the May 9, 1997, Storm Event

Parameter	Inlet Sample Site	Outlet Sample Site
Total Nitrogen	7.06 mg/l	7.16 mg/l
NH_3 as Nitrogen	1.38 mg/l	2.44 mg/l
Total NO_2 /NO_3	2.56 mg/l	1.26 mg/l
Total Phosphorus	0.55 mg/l	0.66 mg/l
Dissolved Orthophosphate	0.63 mg/l	0.72 mg/l
Total Organic Carbon	18.8 mg/l	32.6 mg/l
Total Sulfate	16.0 mg/l	18.0 mg/l
Oil and Grease	7.4 mg/l	7.4 mg/l
Ethylene glycol	< 10 mg/l	< 10 mg/l
Propylene glycol	< 10 mg/l	< 10 mg/l
Chloride	14.0 mg/l	140.0 mg/l
Dissolved Sodium	28.1 mg/l	62.7 mg/l
Dissolved Magnesium	1.15 mg/l	1.00 mg/l
Aluminum	126.0 µg/l	156.0 µg/l l
Cadmium	1.00 µg/l	0.91 µg/l
Dissolved Potassium	6.54 mg/l	7.93 mg/l
Dissolved Calcium	16.6 mg/l	16.2 mg/l
Manganese	28.4 µg/l	59.7 µg/l l
Iron	238.0 µg/l	491.0 µg/l
Copper	13.8 µg/l	27.2 µg/l
Zinc	160.0 µg/l	86.6 µg/l
Chromium	< 4.0 µg/l	< 4.0 µg/l
Nickel	< 4.0 µg/l	4.6 µg/l
Lead	1.40 µg/l	2.10 µg/l
Bis-2-ethyl hexyl phthalate	2.38 µg/l	3.89 µg/l
2,4-Dinitrophenol	0.928 µg/l	< 4.76 µg/l
Phenol	3.20 µg/l	5.26 µg/l
Benzyl alcohol	< 4.76 µg/l	3.11 µg/l
4-Methylphenol	< 4.76 µg/l	6.95 µg/l
Acetone	< 20.0 µg/l	12.0 µg/l

Table A4. Water Quality Analysis of Stormwater Runoff After the May 14, 1997, Storm Event

Parameter	Inlet Sample Site (mg/l)	Outlet Sample Site (mg/l)
Total Nitrogen	21.60	16.40
NH_3 as Nitrogen	<0.02	0.08
Nitrite as Nitrogen	0.02	0.02
Nitrate as Nitrogen	21.50	15.83
Total Phosphorus	0.03	0.16
Total Organic Carbon	<1.0	2.4

Table A5. Water Quality Analysis of Stormwater Runoff During the November 7, 1997, Storm Event at the Wetland Inlet

Parameter	4:24 p.m.	5:15 p.m.	6:06 p.m.
Total Nitrogen	8.50 mg/l	5.20 mg/l	5.43 mg/l
NH_3 as Nitrogen	31.0 mg/l	1.31 mg/l	1.29 mg/l
Total NO_2 / NO_3	0.54 mg/l	0.44 mg/l	0.66 mg/l
Total Phosphorus	1.73 mg/l	0.64 mg/l	0.70 mg/l
Dissolved Orthophosphate	0.93 mg/l	0.61 mg/l	0.67 mg/l
Total Organic Carbon	41.6 mg/l	6.3 mg/l	8.0 mg/l
Total Sulfate	60.0 mg/l	<10.0 mg/l	<10.0 mg/l
Oil and Grease	8.5 mg/l	6.6 mg/l	7.4 mg/l
Chloride	44.0 mg/l	13.0 mg/l	11.0 mg/l
Dissolved Sodium	29.9 mg/l	11.9 mg/l	11.2 mg/l
Dissolved Magnesium	1.410 mg/l	0.513 mg/l	0.611 mg/l
Aluminum	322.0 μg/l	62.8 μg/l	76.1 μg/l
Cadmium	0.40 μg/l	< 0.20 μg/l	0.30 μg/l
Dissolved Potassium	7.54 mg/l	2.89 μg/l	3.19 μg/l
Dissolved Calcium	25.1 mg/l	8.5 μg/l	10.8 μg/l
Manganese	116.0 μg/l	8.5 μg/l	8.3 μg/l
Iron	989.0 μg/l	160.0 μg/l	242.0 μg/l
Copper	54.0 μg/l	10.0 μg/l	10.7 μg/l
Total Chromium	< 20.0 μg/l	< 4.0 μg/l	< 4.0 μg/l
Lead	4.20 μg/l	1.10 μg/l	1.10 μg/l
Nickel	10.8 μg/l	4.0 μg/l	<4.0 μg/l
Zinc	252.0 μg/l	72.9 μg/l	94.7 μg/l
pH	8.5	6.6	6.6
Specific Conductance	595 μ ohms/cm	143 μ ohms/cm	155 μ ohms/cm