



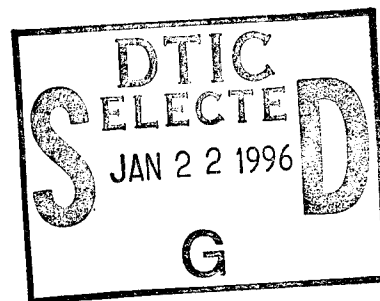
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Wetlands Research Program Technical Report WRP-SM-16

Monitoring of Nonpoint Source Pollutants and Sediments at the Ray Roberts Reservoir Wetland Complex, Texas

by Charles W. Downer



The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	<u>Task</u>		<u>Task</u>
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

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Monitoring of Nonpoint Source Pollutants and Sediments at the Ray Roberts Reservoir Wetland Complex, Texas

by Charles W. Downer

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
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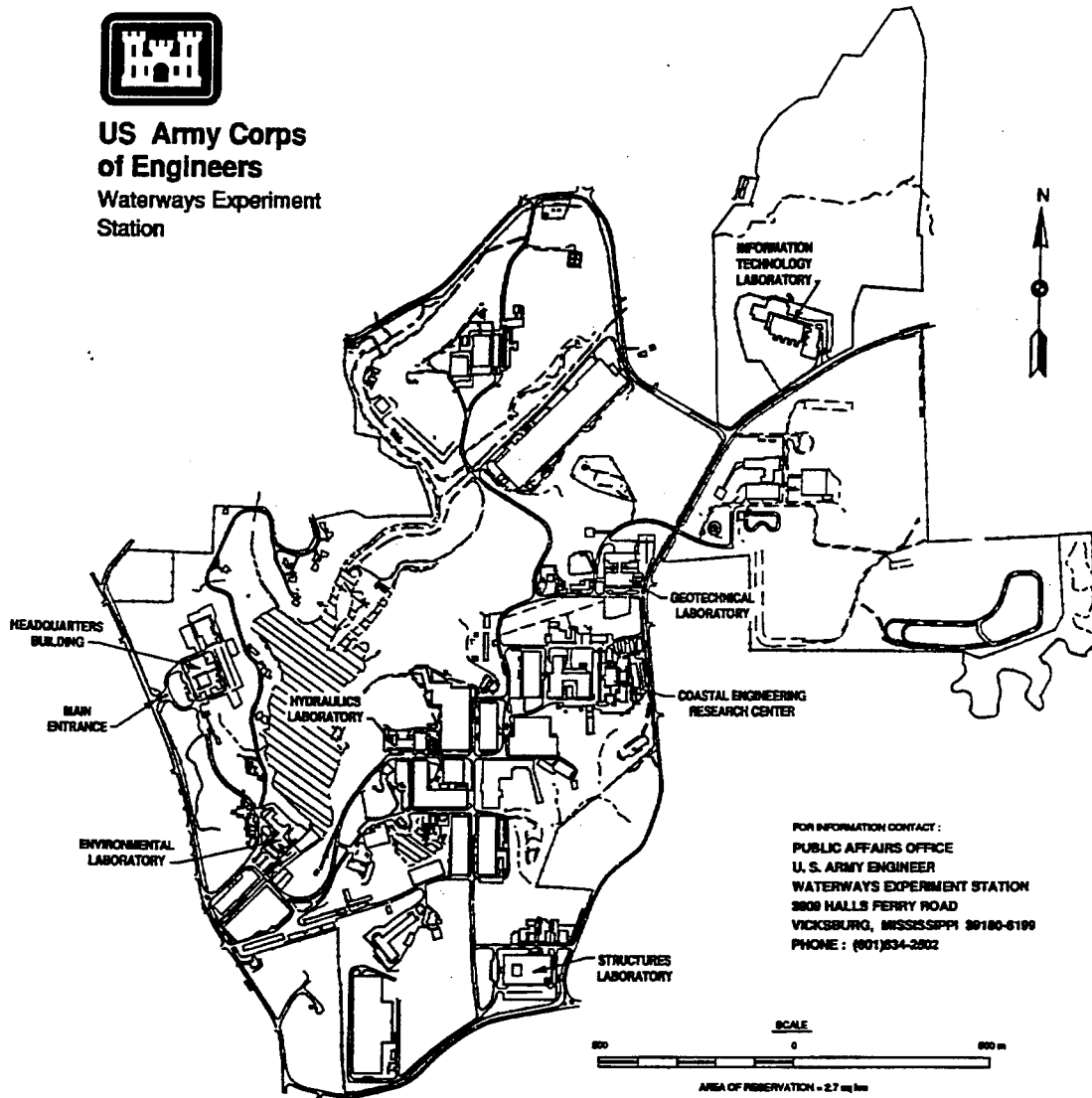
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Sedimentation and Nonpoint Source Pollution Abatement in Wetlands



Monitoring of Nonpoint Source Pollutants and Sediments at the Ray Roberts Reservoir Wetland Complex, Texas (TR WRP-SM-16)

ISSUE:

The U.S. Army Corps of Engineers owns and operates hundreds of reservoirs for flood control and water supply. Nonpoint source pollution is a concern at many of these reservoirs. Lake managers have an opportunity to construct wetlands in the fluctuation zone of the reservoir to possibly alleviate nonpoint pollution problems. Such wetlands can also provide valuable habitat.

RESEARCH:

Wetlands constructed at Ray Roberts Reservoir, north of Dallas, TX, were monitored for their ability to remove total suspended solids (TSS), nutrients, and the herbicide atrazine from inflows after storm events. Sampling was conducted in the spring and summer of 1993. Automated water samplers were used in conjunction with automated water level meters to monitor the site. Baseline water quality samples were collected between storm events. Sediment accretion in the wetlands was monitored with Plexiglas sediment disks.

SUMMARY:

Three major storm events were sampled. Sampling efforts indicated that the wetland had lim-

ited effect on water quality. The wetland was capable of reducing peak TSS concentrations by approximately 30 percent. The wetland was less successful at removing nutrients and had no effect on herbicide concentrations. Baseline and sediment samples did not indicate a buildup in the system of any of the measured pollutants. The annual sediment accretion rate is estimated to be around 4 mm/year, based on 4 months of data.

AVAILABILITY OF REPORT:

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About the Author:

Mr. Charles W. Downer is a research hydraulic engineer with the WES Hydraulics Laboratory. Point of contact at WES is Mr. Downer, phone (601) 634-2473.

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Stewardship and Management Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32766, "Wetland Stewardship and Management Demonstration Areas," for which Mr. Chester O. Martin, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was Technical Manager. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for this work.

Mr. David Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitors' Representative; Dr. Russell F. Theriot, EL, was the Wetlands Program Manager. Mr. Martin was the Task Area Manager.

The work was performed under the direct supervision of Mr. Charles W. Downer, Hydraulics Laboratory (HL), WES, principal investigator, and Mr. Tommy E. Myers, EL, co-principal investigator and primary technical reviewer. Mr. David Honnell of Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX, collected field samples and conducted chemical analysis. Dr. Robert Doyle and Dr. Mike Smart, LAERF, also assisted in the project. Dr. Doyle and Mr. Honnell also provided technical review. Field assistance was provided by Mr. Calvin Buie, WES. Messrs. Mack Wood and J. M. Taylor of the United States Geological Survey, Fort Worth, TX, established and maintained the water level sampling stations. This report was written under the general direction of Messrs. Glenn A. Pickering, Chief, Hydraulic Structures Division, HL, and Acting Chief of the Reservoir Water Quality Branch, Hydraulic Structures Division; Mr. Richard A. Sager, Assistant Director, HL; and Mr. Frank A. Herrmann, Jr., Director, HL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander of WES was COL Bruce K. Howard, EN.

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1 Introduction

Project Description

The fluctuation zone of reservoirs (that area between flood and conservation pool) provides lake managers an opportunity to develop water quality and wildlife enhancement projects on U.S. Army Corps of Engineers (USACE) lands. In 1991 the U.S. Army District, Fort Worth, embarked upon a large-scale wetland construction project intended to create 70 ha of wetlands along Range Creek, a major tributary into Ray Roberts Lake, Texas. The wetlands were intended to provide wildlife habitat, primarily feeding and resting areas for migratory waterfowl. There was also the possibility that the wetlands could function to improve the quality of water routed through them by removing suspended solids and other nonpoint source pollutants.

Construction of the wetlands was completed in November of 1992. Five dikes were constructed to form six wetland areas encompassing a total area of 70 ha. The wetlands range in size from less than 2 to greater than 20 ha. The Texas Parks and Wildlife Department (TPWD) assumed the role of wetland managers and is operating the wetlands to maximize waterfowl use by implementing moist soil management practices (Fredrickson and Taylor 1982) at the project. The Fort Worth District was interested in promoting research at the site, as long as it did not interfere with the operation of the wetlands by the TPWD.

Water quality monitoring of Wetland 1 was conducted in the spring and summer of 1993. Three major storm events were sampled. Baseline water quality samples were taken in the wetlands when water was available. Water levels were recorded at both the upstream and downstream control structures. Sediment accumulation in the wetlands was also monitored during this same period. The monitoring program was intended to demonstrate the ability of constructed wetlands to provide sediment trapping and water quality improvements at USACE reservoirs.

Ray Roberts Reservoir

Ray Roberts Reservoir is located near Pilot Point, TX, about 50 km north of Dallas (Figure 1) (University of North Texas (UNT) 1992). The reservoir was constructed on the Elm Fork of the Trinity River in 1987. In 1990 the reservoir had reached its conservation pool level of 192.8 m above mean sea level (msl). The surface area of the reservoir is 11,880 ha at conservation pool and 14,940 ha at flood pool (195.3 m msl). Lake levels for the period of record are shown in Figure 2.

Drainage Basin

The Ray Roberts Lake drainage basin encompasses an area of approximately 1,190 km² in Cooke, Denton, and Grayson counties. The terrain consists of gentle rolling uplands and flat bottomlands. Soils on the hillsides are well drained, gently to moderately steep, loamy and clayey soils with moderate to very slow permeability. The bottomlands are well drained and moderately well drained, nearly level, clayey soils that have a moderately slow and very slow permeability. Natural vegetation consists primarily of prairie grasses with scattered oaks on the hillsides and hardwoods in the bottomlands. Areas of upland forest and shrub also occur. Principal land uses are for row crop agriculture and cattle range. Generalized information on soils and land uses are inferred from the soil surveys of the three counties (Putman et al. 1979; Ford and Paulus 1980; Cochran 1980).

Climate

North-central Texas is a subtropical region with hot dry summers and cool winters. Average annual rainfall is about 86 cm (UNT 1992). The greatest rainfall occurs in April and May with more than 10 cm of rainfall in each of these months (National Oceanic and Atmospheric Administration (NOAA) 1993a). Another smaller rainfall peak occurs in September and October with about 10 cm of rainfall in each of these months (NOAA 1993a). Winters are dry with January being the driest month of the year. Average monthly rainfall amounts measured at Pilot Point (NOAA 1993a) are shown in Figure 3. Summers are long and hot with several days having high temperatures greater than 38 °C. Winters are cool with about half the nights having subfreezing temperatures (UNT 1992). Average monthly temperatures measured at Pilot Point (NOAA 1993a) are shown in Figure 4.

Wetland Complex

The wetlands are located along Range Creek, which enters the reservoir

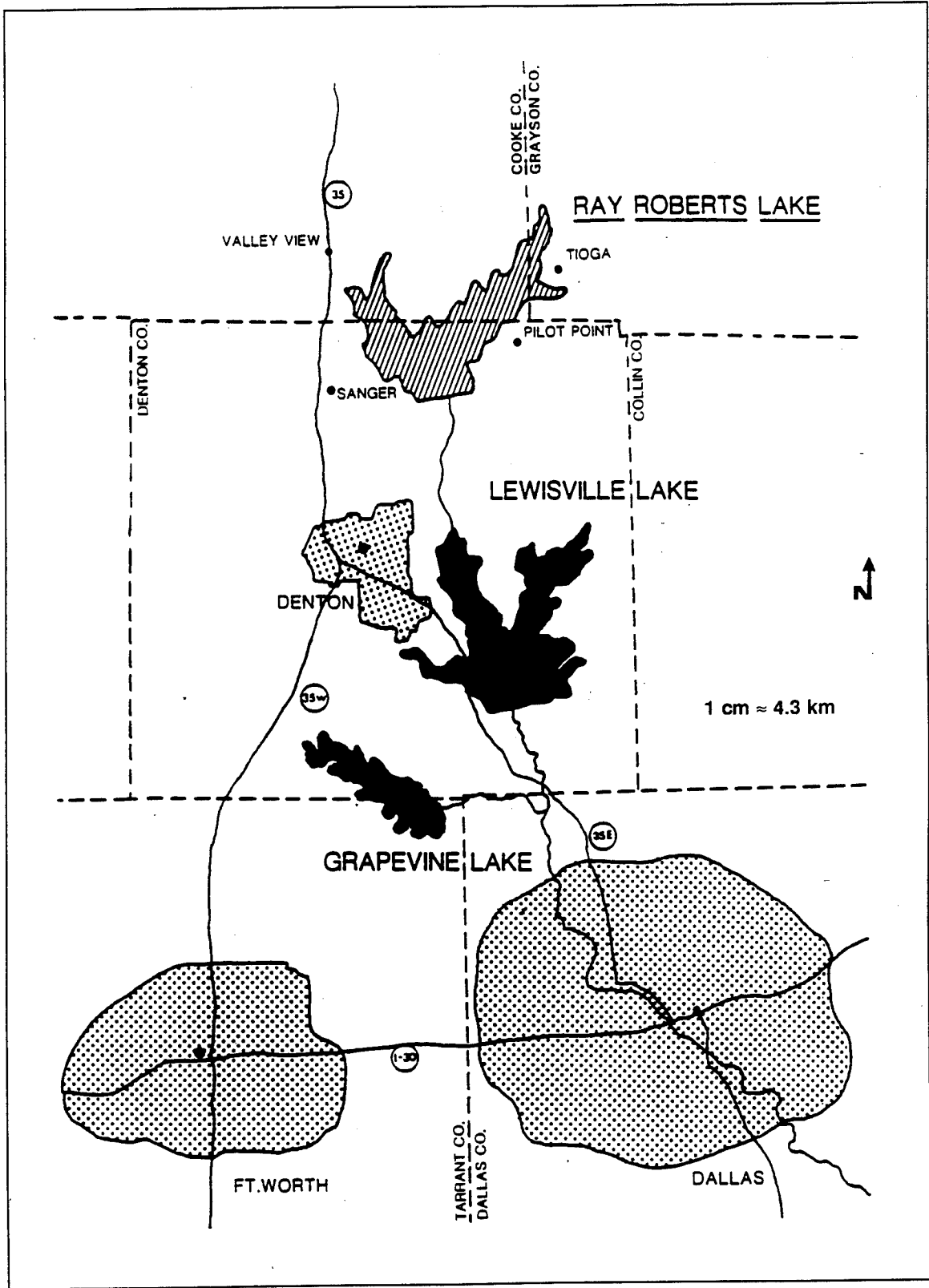


Figure 1. Ray Roberts Reservoir location map

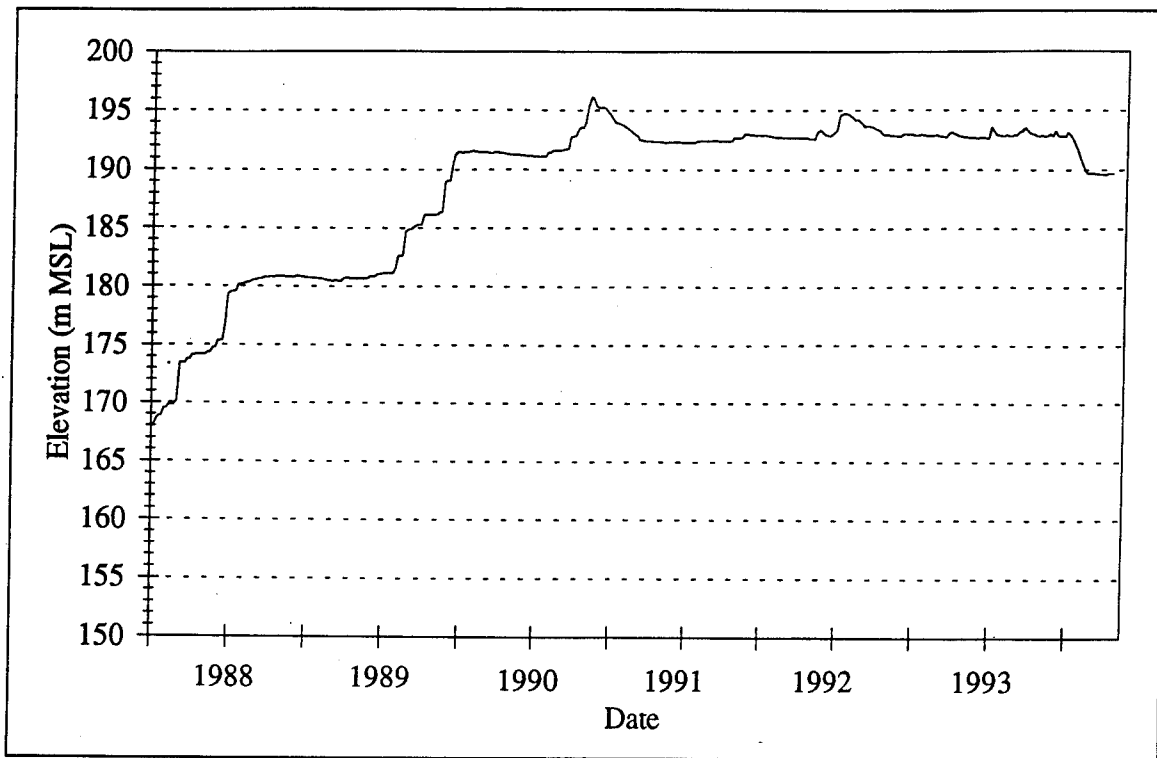


Figure 2. Ray Roberts Lake period of record water-surface elevations (Unpublished Data, 1994, U.S. Army Engineer District, Fort Worth, Fort Worth, TX)

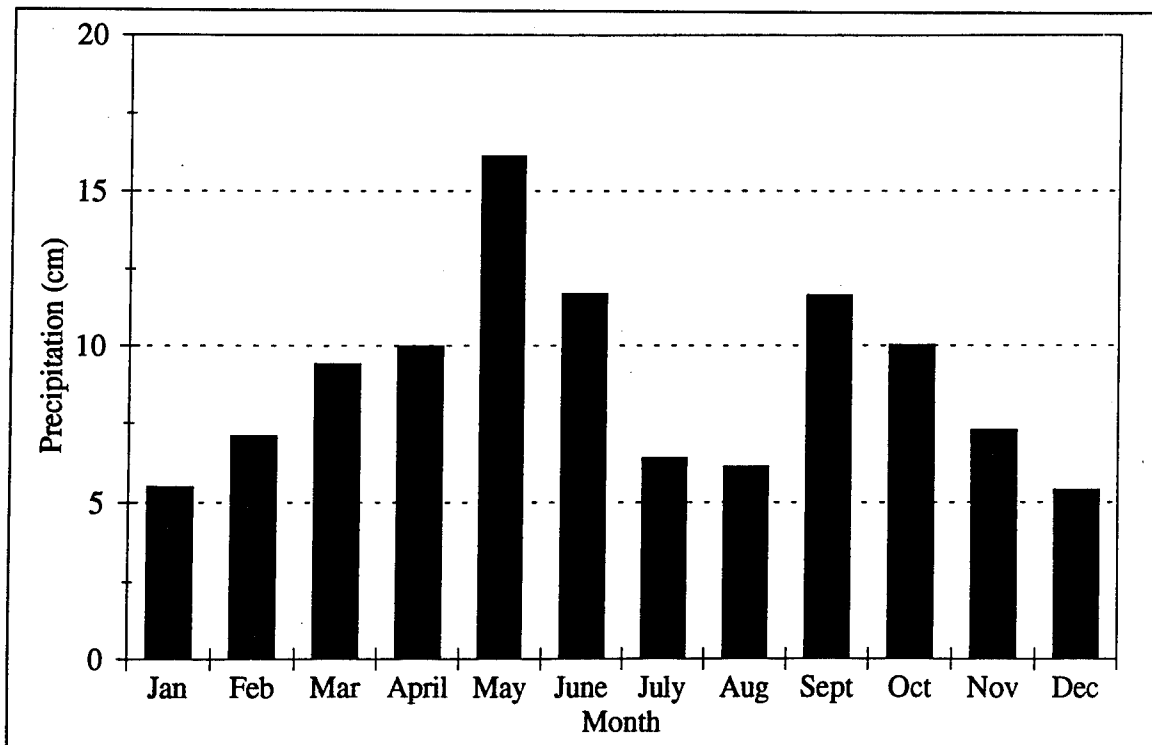


Figure 3. Average monthly rainfall at Pilot Point, TX

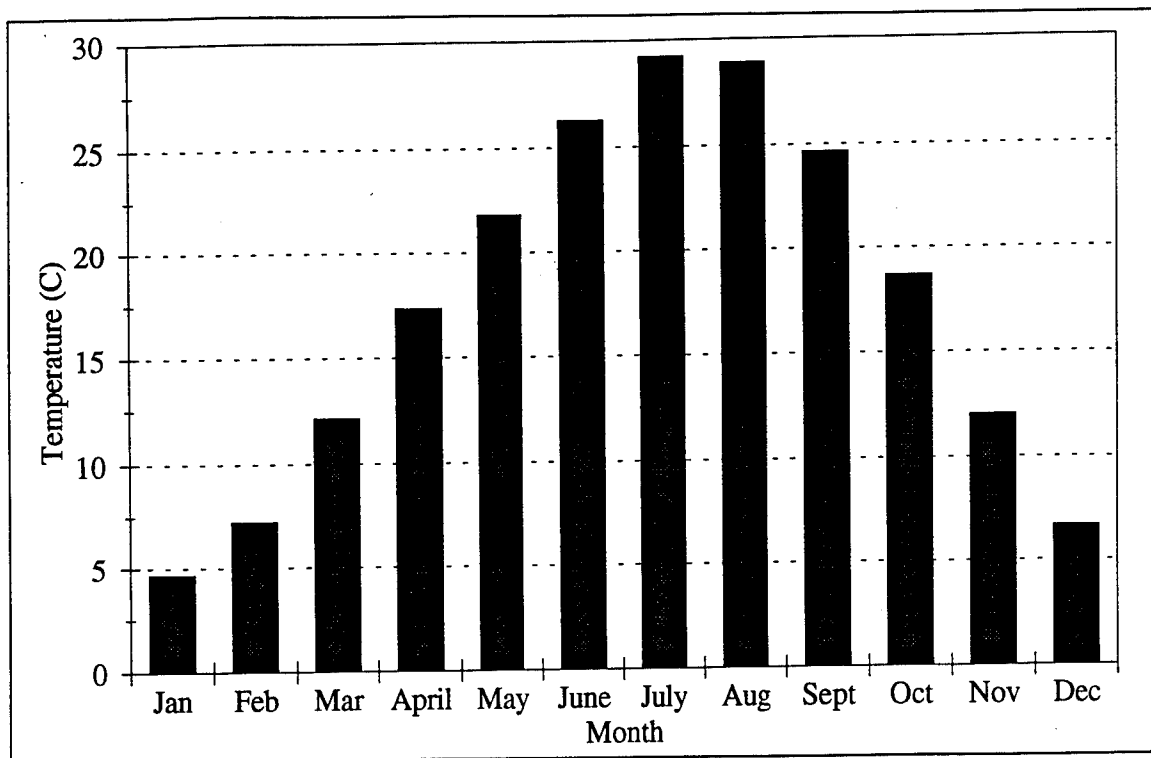


Figure 4. Average monthly temperatures at Pilot Point, TX

from the northeast (Figure 5) (Doyle et al. 1993). Range Creek drains 17,000 ha of primarily agriculture lands (67 percent) and pasture lands (24 percent) above the wetland complex (Doyle et al. 1993). The wetlands are located on the clayey soils of the bottomlands. All six wetlands receive water from small drainage basins and from creek overflows. Wetland 1 also receive overflows from upstream wetlands (Figure 5). All six wetlands are located within the reservoir fluctuation zone and can be inundated by the reservoir.

Wetland Study Site

Wetland 1, located nearest to the reservoir, was chosen as the study site. Wetland 1 is approximately 2 ha in area and has an average depth of less than 1 m when levee full. Wetland 1 receives water from Wetland 1A, which is used primarily as a reservoir for Wetland 1. A gated box culvert controls flow from Wetland 1A to Wetland 1. In addition to water released from Wetland 1A, Wetland 1 receives runoff from a very small vegetated watershed that totals 2.31 ha, including the wetland. The wetland receives floodwaters from Range Creek. At the time the study was initiated, the possible frequency, duration, and depth of flooding from Range Creek were essentially unknown. Because of rainfall patterns, it was anticipated that overbank

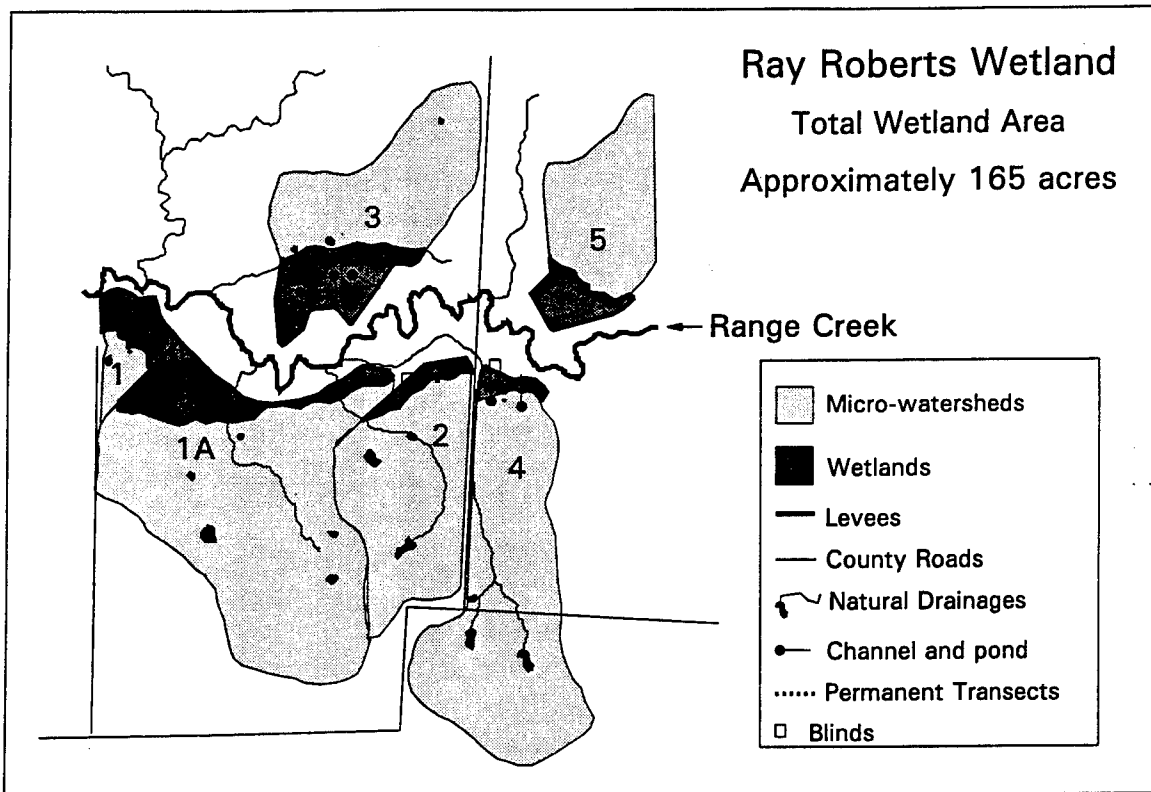


Figure 5. Wetlands complex (from Doyle et al. 1993)

flooding would most likely occur during April and May. The levees defining the wetland could also be inundated by the reservoir during or after this time.

Because calculating a water budget for the wetland when flow was occurring was not possible due to levee overtopping, treatment efficiencies based on mass balance also could not be calculated. However, general treatment effectiveness could be inferred from reductions in inflow pollutant concentrations, which could be measured at the site. Such an analysis assumes uniform flow through the wetland. That is, flow in equals flow out. Under controlled conditions (i.e., when the only source of water was Wetland 1A), the flow through the system could be calculated and a mass balance for the wetlands could be determined.

Water Quality Parameters

A list of water quality parameters was compiled based on probable constituents in the water column, a need for controlling or monitoring such constituents, and the uncertainty about whether such a wetland could treat these constituents. A brief description of these parameters follows.

Total Suspended Solids

The total suspended solids (TSS) is a measure of all particulate matter in suspension. The TSS typically comprises silt and clay size particles and organic material. TSS is a potential water quality problem in lakes because it impairs light penetration, reducing productivity of algae and larger organisms. Excessive TSS may harm fishes by coating their gills or by silting in spawning beds. TSS is also associated with other contaminants such as nutrients, herbicides, insecticides, and heavy metals. These substances may bind to the fine materials and be transported with the suspended particles. Agricultural runoff can have a high TSS loading (Novotny and Chesters 1981). Because such a high percentage of the Range Creek watershed above the wetland project is in agricultural lands, there was potential for high TSS concentration runoff at the site.

Wetlands have been shown to be generally successful in removing suspended solids from inflows (Phillips et al. 1993). Wetlands spread, slow, and temporarily detain flowing waters, allowing suspended materials to settle.

Nutrients

Nitrogen and phosphorous are important nutrients in aquatic plant growth, affecting both algae and macrophytes. Small amounts of these nutrients are needed in order to sustain a quality fishery. Algae provide a food base for larger organisms, and macrophytes provide cover and feeding areas for large predator (game) fishes. Excessive levels of these nutrients can lead to explosions of algae and macrophyte growth. Excessive algae growth can lead to "pea soup" green water. Such water can pose drinking water problems such as bad taste and smell. Excessive algae and macrophyte growth may discourage recreational use of a reservoir because the reservoir may be perceived as polluted. The decay of excessive algae and macrophyte growth can lead to low dissolved oxygen levels and result in fish kills.

Agricultural lands are a known source of nutrient enrichment. The use of fertilizers on row crops and large animal farming are potential sources of both nitrogen and phosphorous. Several examples are listed in Spooner et al. (1989). Since 67 percent of the watershed above the wetlands comprises row crop agriculture and 24 percent comprises range land, it was anticipated that flows into the wetlands would be nutrient enriched.

Nitrogen and phosphorous are present in many chemical forms. Typical ways of expressing nitrogen concentrations are total nitrogen (TN), nitrogen as nitrite ($N-NO_2$), nitrogen as nitrate ($N-NO_3$), ammonia nitrogen, and total Kjeldahl nitrogen (TKN). Each provides a measure of a different component or components of nitrogen. For this study TKN and $N-NO_3$ were monitored to measure the organic and the inorganic nitrogen load. TKN is composed of both organic nitrogen and ammonia. Nitrate nitrogen is inorganic and is the most bioavailable form of nitrogen. The combination of TKN and $N-NO_3$

constitutes the total nitrogen load. Total phosphorous (TP) and the soluble reactive phosphorous (SRP) were also measured. The TP measurement includes all phosphorous in both dissolved and particulate form. SRP is dissolved phosphorous only, and is the most bioavailable form. Nutrients are considered harmful to man and aquatic organisms only at very high levels. The U.S. Environmental Protection Agency (USEPA) has established drinking water standards for nitrates and nitrites at 10 and 1 mg/l, respectively (USEPA 1991). No water quality criteria have been established for phosphorous.

Wetlands have been shown to remove nutrients to varying degrees (Phillips et al. 1993; Johnston 1991). Nitrogen is thought to be removed by nitrification/denitrification. Phosphorous may be removed by sedimentation and absorption to soils. Absorption is greatest in soils of high mineral content, particularly aluminum. Both nutrients may be temporarily tied up in plant biomass. Nutrients contained in plant biomass may be released after fall die-off (Johnston 1991).

Atrazine

Atrazine (2-chloro-4(ethylamino)-6(isopropylamino)-s-tiazine) is a commonly used preemergent herbicide for corn and other row crops applied in the spring to prevent seed germination of weeds. Atrazine is potentially harmful to both man and aquatic organisms. The USEPA has established a drinking water standard for atrazine of 3.0 $\mu\text{g}/\ell$ (USEPA 1991). Because of the prevalence of row crops in the watershed, atrazine was a likely waterborne pollutant. The ability of the wetland to remove atrazine would be indicative of the wetland's ability to remove pesticides in general. Little information is available on the removal of pesticides in wetlands. Pesticides attached to suspended sediments are subject to sedimentation and burial. Pesticides in solution may be removed by photodecay, biodegradation, or volatilization. Degradation of pesticides in wetlands is thought likely because wetlands provide both reducing and oxidizing zones and support a wide variety and abundance of microorganisms that may metabolize the pesticides. The breakdown and removal of pesticides in wetlands may be slow processes, requiring days to occur. Wetland mesocosm experiments indicated a half-life of 9 days for atrazine (Doyle, Myers, and Adrian 1993).

Basic Water Quality Parameters

The basic water quality parameters of pH, conductivity, and alkalinity give a general indication of the water quality conditions in the wetland. pH and alkalinity are measures of the acidity and acid-neutralizing capacity of the water, respectively. Most freshwater organisms prefer a pH that is near neutral or slightly alkaline, 6.5-9.0. Conductivity is an indirect measure of total dissolved solids (TDS). At very high levels TDS can be toxic to

freshwater organisms and results in poorer quality drinking water. Levels of TDS above 250 mg/l exceed drinking water criteria (USEPA 1991). Extreme changes in TDS can also harm freshwater organisms and animals that use the water as a drinking supply. The general water quality conditions also affect the wetland's ability to remove certain pollutants.

2 Materials and Methods

Water levels, water quality during storm events, baseline water quality, and sediment accretion were monitored in Wetland 1. Two water level/quality sampling stations and 27 sediment accretion measuring stations were established in the wetland. Sampling locations are shown in Figure 6.

Water Level Sampling

Sampling equipment was installed during 14-23 April 1993. In cooperation with the U.S. Geological Survey (USGS), two water level/quality sampling stations were installed at Wetland 1. The stations were located at the inlet and outlet structures in front of the inlet and outlet dikes. A ball and float, punched tape water level recorder powered by a battery and solar panel was installed at each station. Water level readings were recorded every 15 min. Water level measurements are accurate to the nearest 0.3 cm. Maintenance of the water level equipment was the responsibility of the USGS.

Water Quality Sampling

An ISCO 3700 automatic water sampler was also installed at each sampling station. Each unit was battery/solar panel powered. A water-sensitive sensor activated the samplers when contacted by the water. When this sensor was placed above the water level, the sampler could be activated during a storm event when the water level in the wetland rose to the height of the sensor. Once actuated, the samplers collected 24 samples over a 24-hr period. If the storm hydrograph had not passed, sample bottles in the sampler could be replaced and the sampler could continue to take samples. Multiple-day sampling routines were preprogrammed into the samplers, and the samplers could collect samples for up to 5 days. Storm samples were augmented with baseline/low-flow samples when water was available. Baseline samples were collected at the Wetland 1 intake, the outlet, and in Range Creek at a point adjacent to the wetlands. Baseline samples were taken by the grab method in 1-ℓ plastic bottles. Samples were placed on ice until transferred to the appropriate analysis bottle and were kept refrigerated until analyzed.

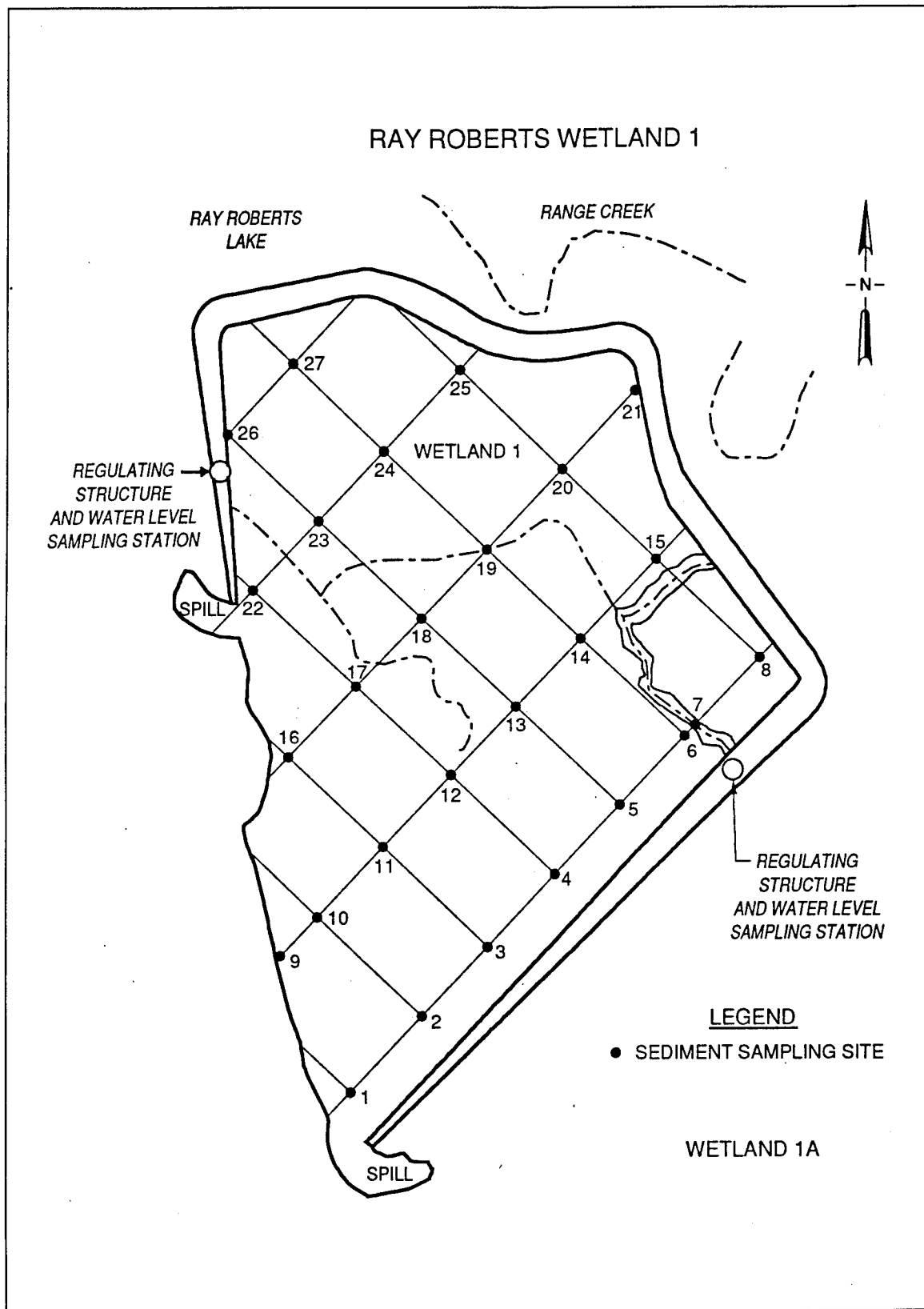


Figure 6. Wetland 1 sampling locations

Samples were collected and analyzed by personnel at the Lewisville Aquatic Ecosystems Research Facility (LAERF) in Lewisville, TX. Laboratory analyses were conducted for TSS, TKN, nitrate (NO₃), TP, SRP, pH, alkalinity, conductivity, and atrazine. Depending on water conditions, baseline samples were taken semiweekly. The sampling routine and parameters remained flexible throughout the sampling period.

Table 1 shows the analytical and preservation methods used. All analytical methods were derived from American Public Health Association (1989). Atrazine was analyzed by the Enzyme-Linked Immunosorbent Assay (ELISA) rapid assay method (Myers and Myers 1992).

Table 1 Analytical Methods		
Parameter	Method	Preservation
Alkalinity (mg/ℓ as CaCO ₃)	Electrometric titration SM 2320-B	None
TSS, mg/ℓ	Evaporation @ 105 °C SM 2540-D	None
TP, mg/ℓ	Persulfate digestion/ spectrometric SM 4500-P.B.E.	Preserving acid 1:1 H ₂ SO ₄
SRP, mg/ℓ	Ascorbic acid/spectro. SM 4500-P.E.	Filtered, 0.45μ
Nitrate/nitrogen, mg/ℓ	HPLC (anion column) SM 4500-NO ₃ .C.	Filtered, 0.45μ
TKN, mg/ℓ	Digest/selective-ion SM 4500-N _{org} .B.	Preserving acid 1:1 H ₂ SO ₄
Conductivity, μS/cm	Electrometric SM 2510-B.	None
pH (units)	Electrometric SM 4500-H ⁺ .B.	None

Sediment Accumulation Monitoring

Sediment accumulation in the wetlands was measured using Plexiglas disks (Kliess 1993). The disks had a 100-cm² surface that had been abraded with sandpaper to provide a rough area to collect sediments. Twenty-seven disks were laid on an approximate 90- by 90-m grid covering Wetland 1 (Figure 6). Disks were placed in standing water, less than 0.5 m deep, in April of 1993.

The disks were collected in August 1993 and analyzed for depth of sediments, mass of sediments, percent organic material, and the presence of atrazine in the sediments. The depth of sediments was measured with a dial caliper to the nearest 0.1 mm. Four measurements were taken on the disks and then averaged to determine accretion. The mass of sediments was determined to the nearest 0.01 g after drying in an oven at 105 °C. Organic content was determined by burning the samples at 550 °C and calculating the organic content as the preburn weight minus the postburn weight. Atrazine concentration of sediments on the disks was determined by the ELISA rapid assay technique after extraction with methanol.

3 Results

Climate Conditions

The rainfall conditions at Pilot Point, TX, are shown in Figure 7 for the period of April-September 1993 (NOAA 1993a). As can be seen in the figure, rainfall totals for April and May were both below the long-term averages. Rainfall in June and September far exceeded the long-term averages, and rainfall in July and August was again well below the long-term average. Two major storm events that occurred on 29 April and 9 May were sampled. These storms produced 6.1 and 4.3 cm of rainfall, respectively, at Pilot Point (NOAA 1993b, 1993c). Another sampled storm event that occurred on 9 and 10 June produced 5.3 and 3.6 cm of rain, respectively (NOAA 1993d). Pan evaporation measured at the Lavon Dam site is also shown for the study period in Figure 7 (NOAA 1993a). Evaporation exceeded precipitation in each month of the study.

Temperatures for the study period are shown in Figure 8 (NOAA 1993a). Temperatures were below normal for April and May and very near the long-term average for June, July, and August.

Lake Levels

The periods of record water levels in Ray Roberts Lake were shown in Figure 2. Lake levels for January through September 1993 are shown in Figure 9¹. As can be seen in Figure 9, the lake level exceeded the top of dike in Wetland 1 (elevation 193.3 m msl) in early March and approached the top of the dike in May and again in June. High lake levels were due to the intense storm events described in the previous section. In July the lake level decreased below the conservation pool level to 189.3 m msl.

¹ Unpublished Data, 1994, U.S. Army Engineer District, Fort Worth, Fort Worth, TX.

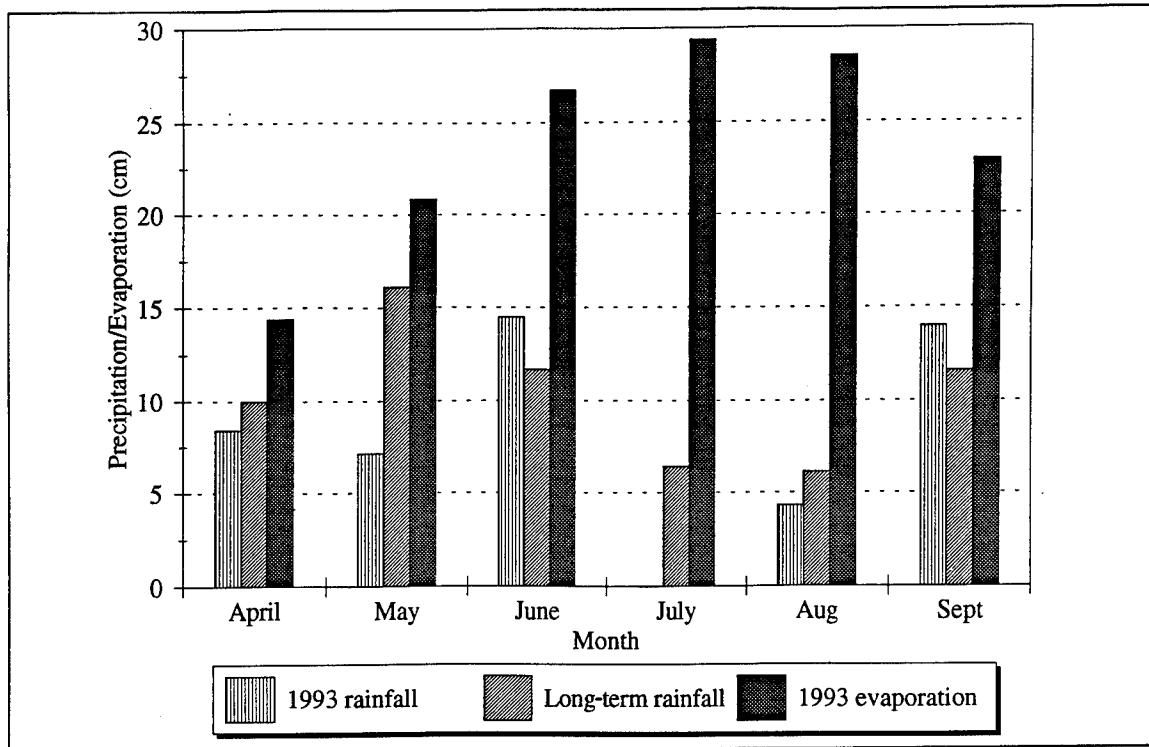


Figure 7. Total monthly precipitation and evaporation for study period, as measured at Pilot Point

Wetland Water Levels and Flows

Water levels for the period April 22-October 1 are shown in Figure 10. Upstream water levels were measured on the upstream side of the Wetland 1 inlet structure. Downstream water measurements were made on the upstream side of the Wetland 1 outlet. Water levels in Wetland 1 were held high throughout the sampling period due to a high reservoir level (Figure 9). The three sampled storm events are clearly depicted in Figure 10. The upstream water-surface elevation quickly rose in response to the storms and required several days to return to the prestorm elevations. The downstream water-surface elevations also rose quickly in response to the upstream rise. Hydrographs at both the upstream and downstream sites were very similar in shape and duration, though differing in magnitude. During the third storm event, the inlet gate was closed. This explains the increased duration of high water levels at the inlet sampling station. Water was later released on June 16. During the three sampled storm events, water overtopped both the inlet and outlet dikes. The elevations of the dikes are represented by horizontal lines in Figure 10. The overtopping of the dikes prevented the calculation of flows into and out of the wetland. Water levels in the wetlands quickly fell after the lake was drawn down in late July. Wetland 1 was completely dry by mid-July. The wetland remained dry until a mid-September rainfall event occurred.

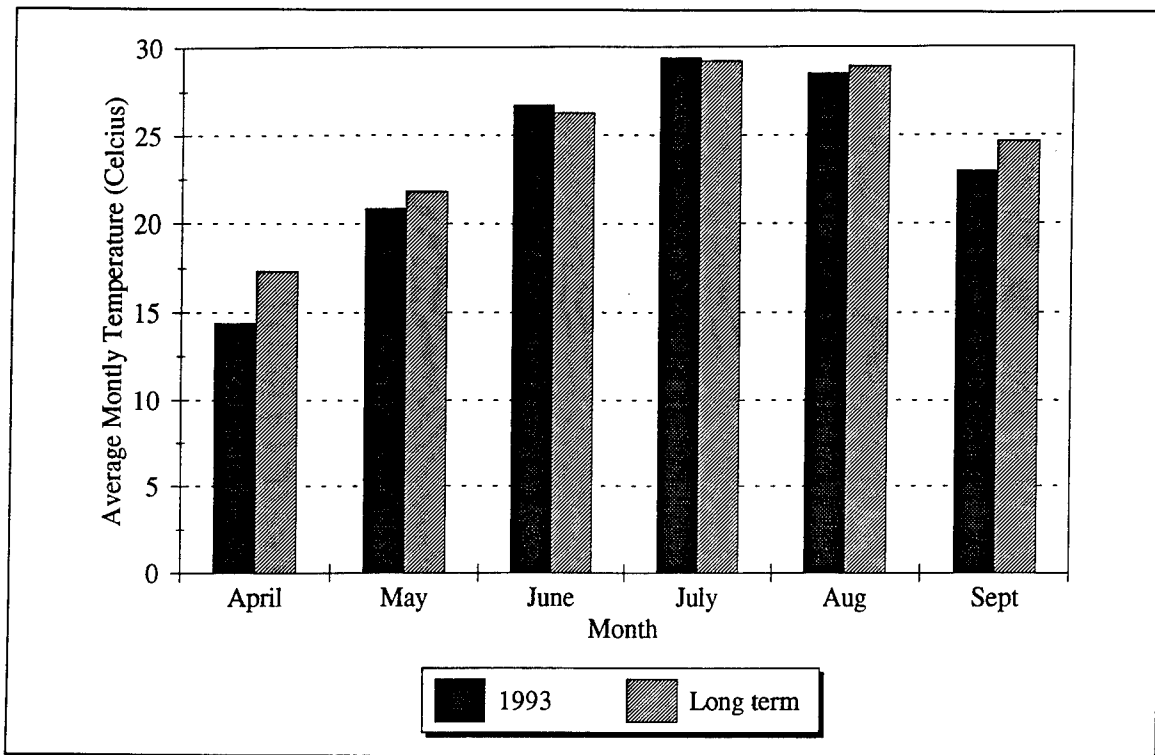


Figure 8. Average monthly temperatures for study period, as measured at Pilot Point

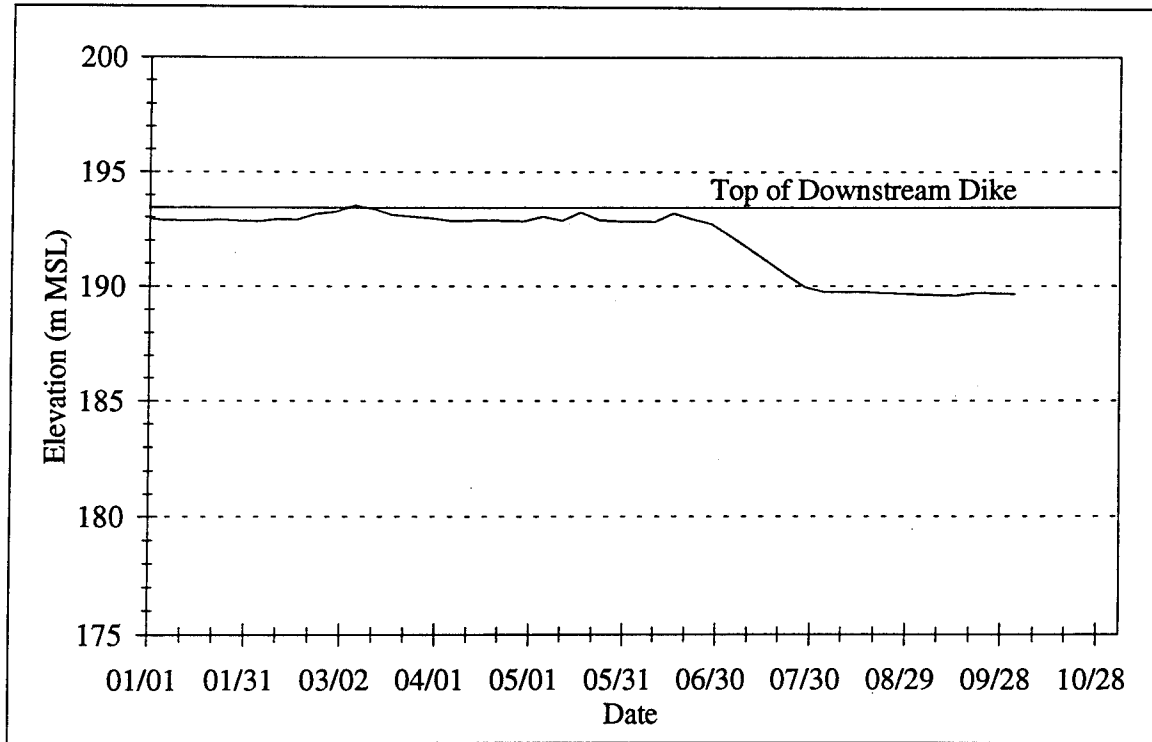


Figure 9. Ray Roberts Lake water-surface elevations, January-September 1993

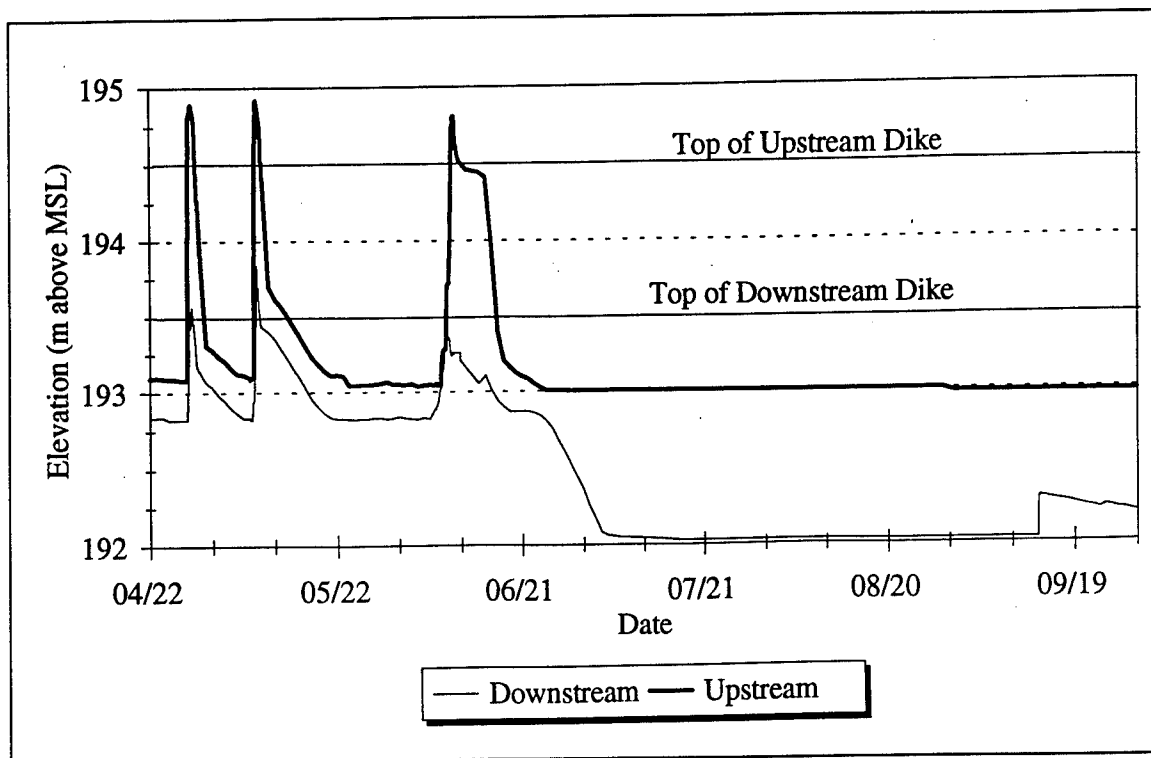


Figure 10. Wetland 1 water-surface elevations for study period

Wetland Detention Time

On 16 June 1993 a dye study was conducted to estimate the hydraulic retention time (HRT) of the wetland. The dye study began with Wetlands 1 and 1A almost bank-full and the culvert between the wetlands closed. The gate to the Wetland 1 inlet culvert was fully opened at 0932. Two hundred milliliters of rhodamine WT 20 percent solution was mixed in approximately 95 l of water and poured in at the upstream side of the inlet culvert at 0935. The slug of dye passed through the culvert almost instantaneously. It was assumed that the dye was well mixed after passing through the culvert. Dye concentrations were monitored at the outlet pipe with a Turner Designs model 10-AU-005 fluorometer, with internal data logger and flow through cuvette. Water was pumped through the fluorometer with a submersible bilge pump. Both the fluorometer and pump were powered by a deep cycle marine battery. The fluorometer was previously calibrated in the laboratory.

Fluorometer readings vary with temperature and tend to be fluorometer specific. A temperature correction factor n can be used to adjust the readings to a standard temperature. This correction factor can be determined in the laboratory for an equation of the form:

$$F_{TC} = F_T e^{n(TC-T)} \quad (1)$$

where F_{TC} is the fluorescence at the fluorometer calibration temperature TC , and F_T is the fluorescence at temperature T (Baker and Holley 1987).

Data collection at the downstream sampling site began at 0935 on 16 July 1993. The peak concentration of 1.71 ppb occurred at 1512, 5 hr and 37 min after the dye release (Figure 11). Sampling continued until 2158, when the battery would no longer power the fluorometer and pump. Data were logged every 10 min.

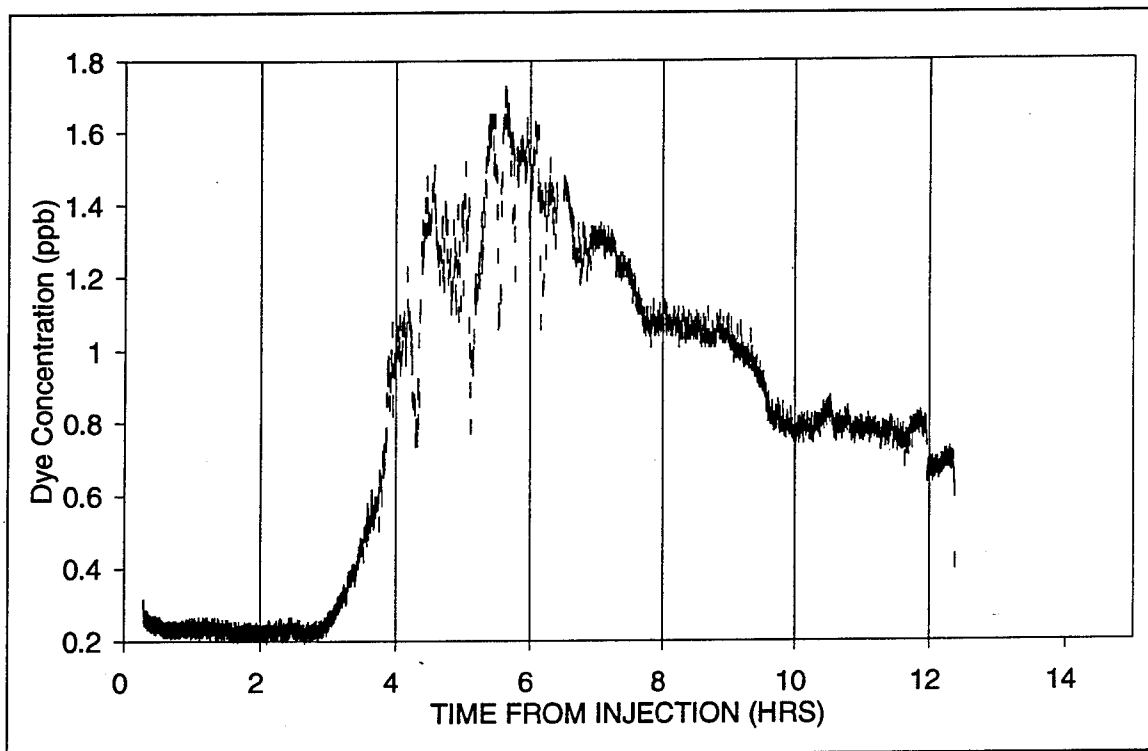


Figure 11. Hydraulic retention time dye study data

Analysis of the data by Levenspiel's method (Levenspiel 1972) indicated that for the average flow rate of 0.82 m^3 during the test the wetland had a HRT of 4.5 hr. Because the tail of the concentration curve was missed, the value returned by Levenspiel's method is low, and the actual detention time is probably around 6 hr.

Inflows were confined to the Wetland 1 inflow culvert. Outflows left the wetland through the outflow culvert, with some flow going over the Wetland 1 spillway. The water level in Wetland 1A continued to fall throughout the test. Flow into the wetland was determined by measuring the velocity at the end of the inlet culvert and then multiplying the average velocity by the culvert area. The culvert was flowing full at the end of the inlet culvert. Velocity at the end of the inlet culvert was determined with a Marsh McBurny flowmeter with pressure transducer. Velocity measurements were taken at the center of the 0.76-m-diam pipe. Measurements were also made every 0.15 m

of depth to determine the relationship between middepth velocity and velocity at other depths. These velocities were then weighted by the area of concentric circles around the measurement points to determine a mean velocity. It was determined that the mean velocity of the pipe was 0.85 the center-line velocity. Mean flow for the test period was 0.82 m³/sec. Upstream and downstream elevations, resulting heads, center-line velocity measurements, calculated average velocities, and flows are shown in Table 2.

Table 2 Hydraulic Conditions During Ray Roberts Dye Study, 16 June 1993						
Time	Water-Surface Elevation, m msl		Head m	Velocity at Center of Inlet Culvert m/sec	Average Velocity m/sec	Discharge m ³ /sec
	Upstream	Downstream				
0932	194.18	193.10	1.10	2.47	2.10	0.96
1149	194.13	193.12	1.01	2.36	2.01	0.91
1340	194.10	193.12	0.94	2.01	1.71	0.76
1520	194.07	193.12	0.91	1.77	1.50	0.68
1632	194.05	193.12	0.92	2.04	1.74	0.79

Water Quality Sampling

Three storm events that occurred on 29 April, 9 May, and 9 and 10 June 1993 were sampled. In addition, baseline water quality samples were collected during low flow conditions. Problems with the downstream sampling equipment caused several downstream sampling points to be missed. These sampling problems caused almost a total loss of the downstream concentration profile for the third storm event.

Water quality entering and leaving the wetland followed the same general pattern during each storm event. For each storm event, TSS, NO₃, TKN, SRP, and atrazine levels quickly rose in response to runoff, which contained high levels of these constituents. The timing of peak concentrations of nutrients and atrazine lagged several hours behind the peak TSS concentrations. The peak concentrations of TSS and TKN fell to near prestorm levels over the next 48 hr. The NO₃, TP, and SRP concentrations required several days to return to prestorm levels. High atrazine levels persisted for several days after the peak flow event had passed.

TSS

Peak inflow TSS levels were around 800 mg/l for the first two storm events and 500 mg/l for the third storm event (Figure 12). Baseline TSS in the wetland was typically less than 100 mg/l (Table 3). The high baseline TSS readings during the last three samples, 7/12/93, 7/26/93 and 8/09/93, were the result of a lack of water at the sampling stations. This resulted in a water/sediment sample being collected that was not representative of the conditions in the water column.

Problems with the downstream sampling equipment led to the peaks of storms 1 and 3 being missed at this station. For storm event 2, the peak concentration at the outflow was approximately 30 percent lower than the peak inflow concentration. This indicates there may be some positive effect on sediment removal. Inflow and outflow concentrations of TSS at other times during storms 1 and 2 were essentially equivalent, indicating very little removal. Because a mass balance for the system could not be calculated, the removal efficiency of the wetland cannot be directly determined.

Nitrogen

Maximum TKN concentrations were around 1 mg/l for both storm events 1 and 2. Peak TKN levels occurred shortly after the beginning of the storm event and then dropped back to baseline levels, around 0.3 mg/l or less, within 48 hr of the peak. For the first storm event, the peak TKN value recorded at the outlet was about 30 percent less than the peak TKN value at the inlet (Figure 13). This was not observed during the second storm event (Figure 13). The data collected during this study indicate very little effect on TKN by the wetland.

Maximum NO₃ levels were between 1 and 2 mg/l for both storm events. The peak NO₃ levels occurred shortly after the beginning of the storm event. Peak levels of NO₃ required several days to return to prestorm levels (Figure 14). Inflow and outflow concentrations were nearly identical. The wetland did not reduce NO₃ for either of these storm events. Baseline samples indicated that very little nitrate remained in the wetland after the storm events had passed (Table 3). Some processing of nitrate may be occurring in waters that are detained in the wetland for long periods of time.

Phosphorous

Peak TP concentrations were around 0.7 mg/l for both storm events 1 and 2. Peak levels rose rapidly but required several days to return to prestorm levels (Figure 15). Baseline samples indicated that the concentration in the wetland after storm events was on the order of 0.1 mg/l or less. No reduction of TP concentrations occurred in the wetlands.

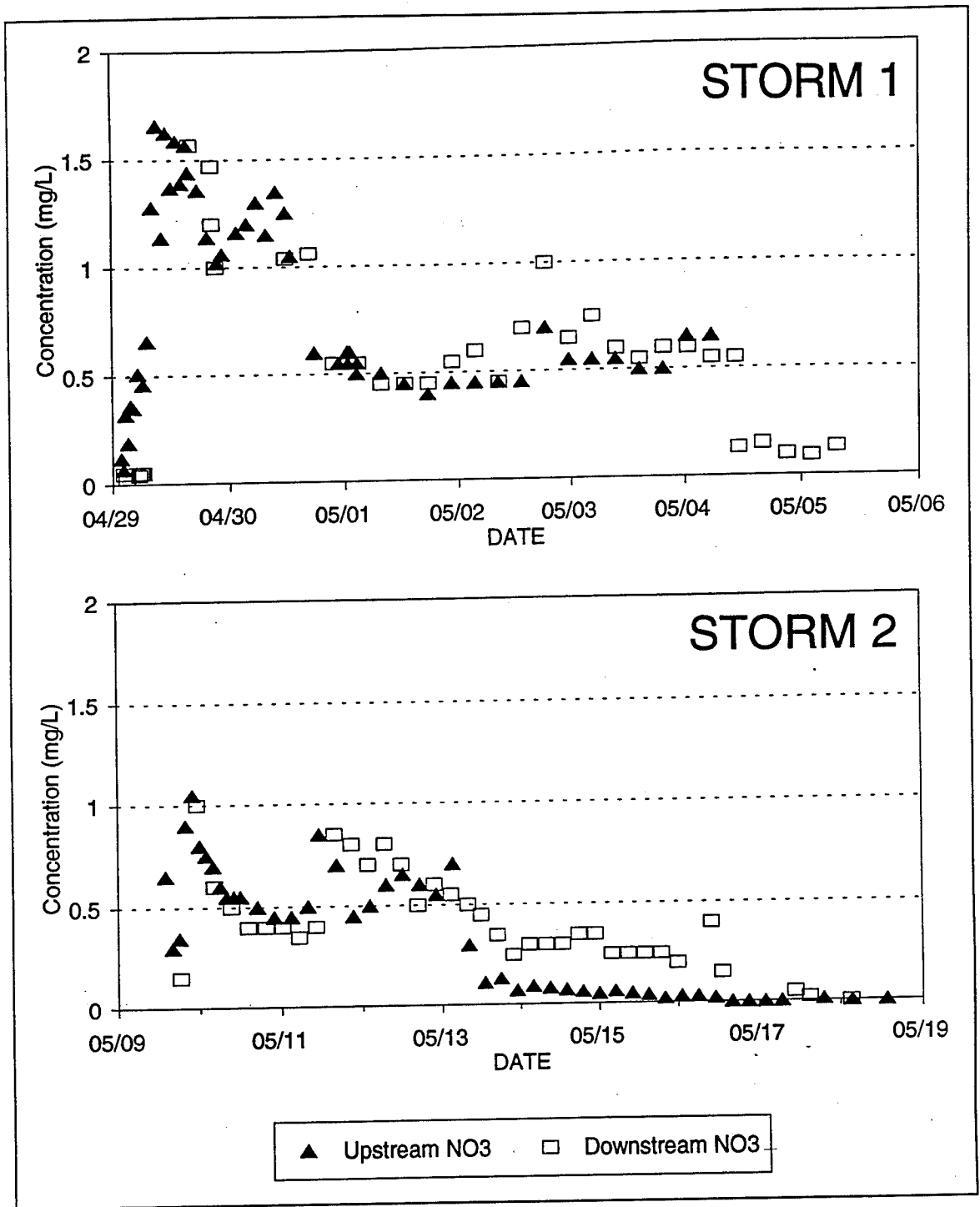


Figure 14. NO₃ concentrations for storm events

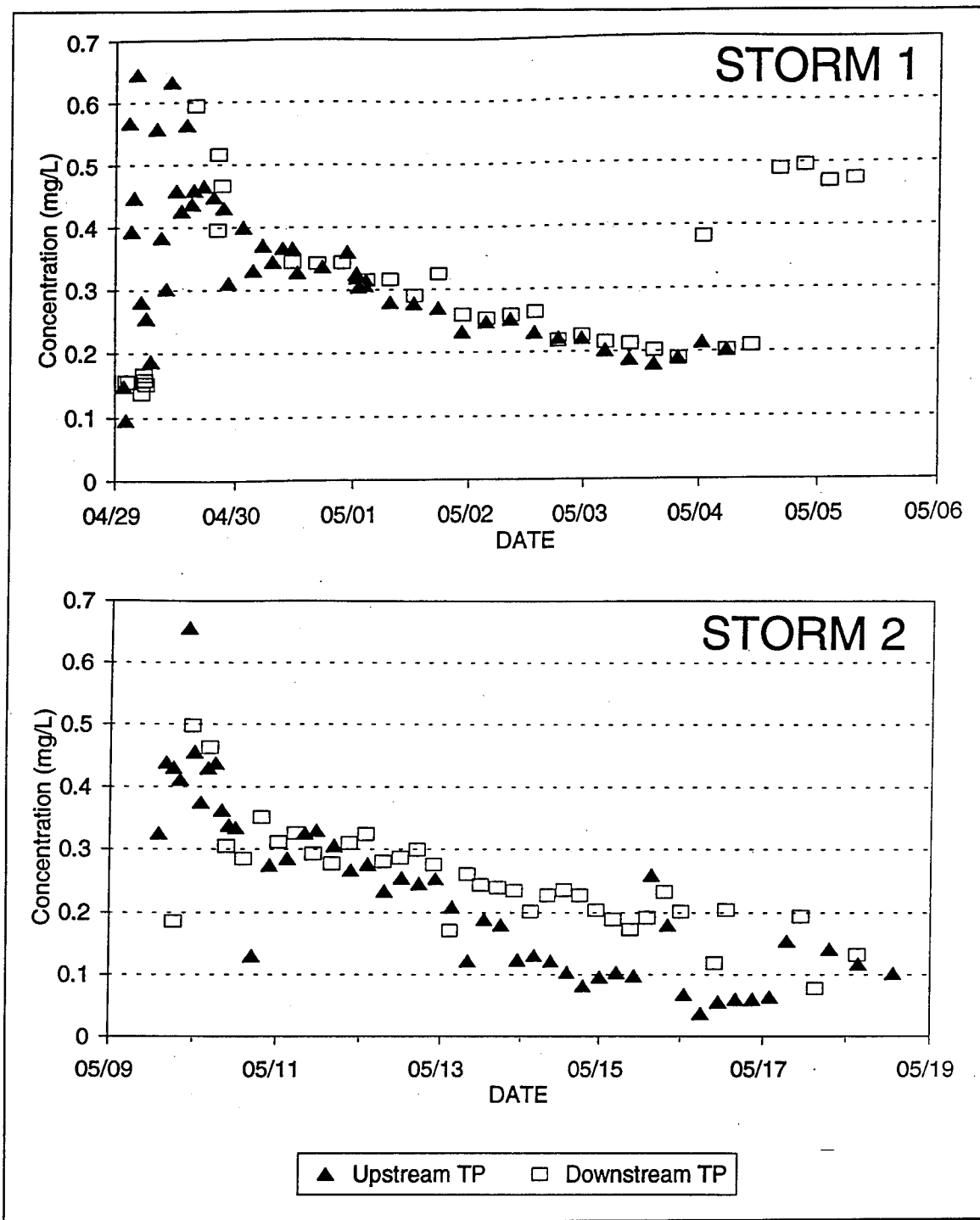


Figure 15. TP concentrations for storm events

**Table 3
Wetland 1 Baseline Water Quality Data**

Date	Sample ID ¹	pH	Conductivity $\mu\text{S/cm}$	Alkalinity mg/l	TSS mg/l	TP mg/l	SRP mg/l	N-NO ₃ mg/l
04/21/93	inlet	8.12	NA	116	52	0.054	0.001	NA
06/01/93	inlet	8.19	361	111	112	0.183	0.006	0.11
06/15/93	inlet	8.39	230	64	9	NA	0.119	0.60
06/28/93	inlet	7.82	300	98	52	0.123	0.004	0.02
07/12/93	inlet	8.30	463	145	321	0.065	0.002	0.01
07/26/93	inlet	8.37	659	126	277	0.125	0.002	0.01
08/09/93	inlet	8.60	NA	116	327	0.046	0.005	0.00
04/21/93	outlet	8.00	NA	116	81	0.072	0.007	NA
06/01/93	outlet	7.87	252	110	50	0.172	0.015	0.00
06/15/93	outlet	7.93	236	78	15	NA	0.009	0.01
06/28/93	outlet	7.72	279	133	14	0.119	0.016	0.01
07/12/93	outlet	7.86	300	110	350	NA	0.007	0.02
07/26/93	outlet	7.75	652	187	3130	NA	0.020	0.01
08/09/93	outlet	NA	NA	NA	NA	NA	NA	NA
04/21/93	RC	7.70	NA	143	59	0.091	0.014	NA
06/01/93	RC	7.72	550	201	36	0.140	0.015	0.04
06/15/93	RC	7.44	303	104	52	NA	0.121	0.35
06/28/93	RC	7.44	324	136	5	0.114	0.021	0.03
07/12/93	RC	7.70	393	205	7	0.107	0.018	0.00

(Continued)

¹RC = Range Creek
NA = No Data

Table 3 (Concluded)								
Date	Sample ID	pH	Conductivity $\mu\text{S}/\text{cm}$	Alkalinity mg/ℓ	TSS mg/ℓ	TP mg/ℓ	SRP mg/ℓ	N-NO ₃ mg/ℓ
07/26/93	RC	7.72	513	224	7	0.077	0.006	0.01
08/09/93	RC	8.15	NA	187	26	0.015	0.003	0.03

Maximum SRP concentrations were around 0.15 mg/ℓ for both storm events 1 and 2. Like TP, the peak concentration occurred shortly after the beginning of the storm event but several days were required for concentrations to return to prestorm levels (Figure 16). The wetland did not show any reduction of SRP concentrations for the first storm event, yet showed a consistent reduction during the second storm event. Samples indicated an approximate 20 to 30 percent reduction in SRP concentration between upstream and downstream locations during the second storm event. Baseline SRP concentrations were low, typically 0.01 mg/ℓ or less (Table 3).

Atrazine

Peak atrazine levels were approximately 8 mg/ℓ for storm 1, 5.5 mg/ℓ for storm 2, and 4 mg/ℓ for storm 3 (Figure 17). Atrazine is applied in the spring to prevent the germination of weed seeds. The high atrazine levels in the first storm are probably attributable to a first flush effect where freshly applied atrazine on bare soil is washed away by the first significant rainfall/runoff event. This effect has been observed in the Corn Belt of Nebraska (Thurman et al. 1991). After quickly rising, atrazine concentrations leveled off and stayed high for the entire sampling periods during storms 1 and 2. Incoming atrazine levels during storm 3 rose and then began to drop quickly before sampling ended. The wetland did not demonstrate any atrazine removal during the first two storm events.

Conductivity

High conductivity values in the wetlands before storm events of up to 500 $\mu\text{S}/\text{cm}$ were quickly lowered by the freshwater inflows during storm events (Figure 18). High conductivities in the wetlands prior to storms are attributable to the concentrating of dissolved solids in the wetlands as the water evaporates. The low conductivities persisted after the storm event had passed, indicating that water remaining in the wetland was from the fresh inflows (Table 3). Baseline samples indicate that conductivity began to rise in the wetlands after the storm events. This is the result of evaporation

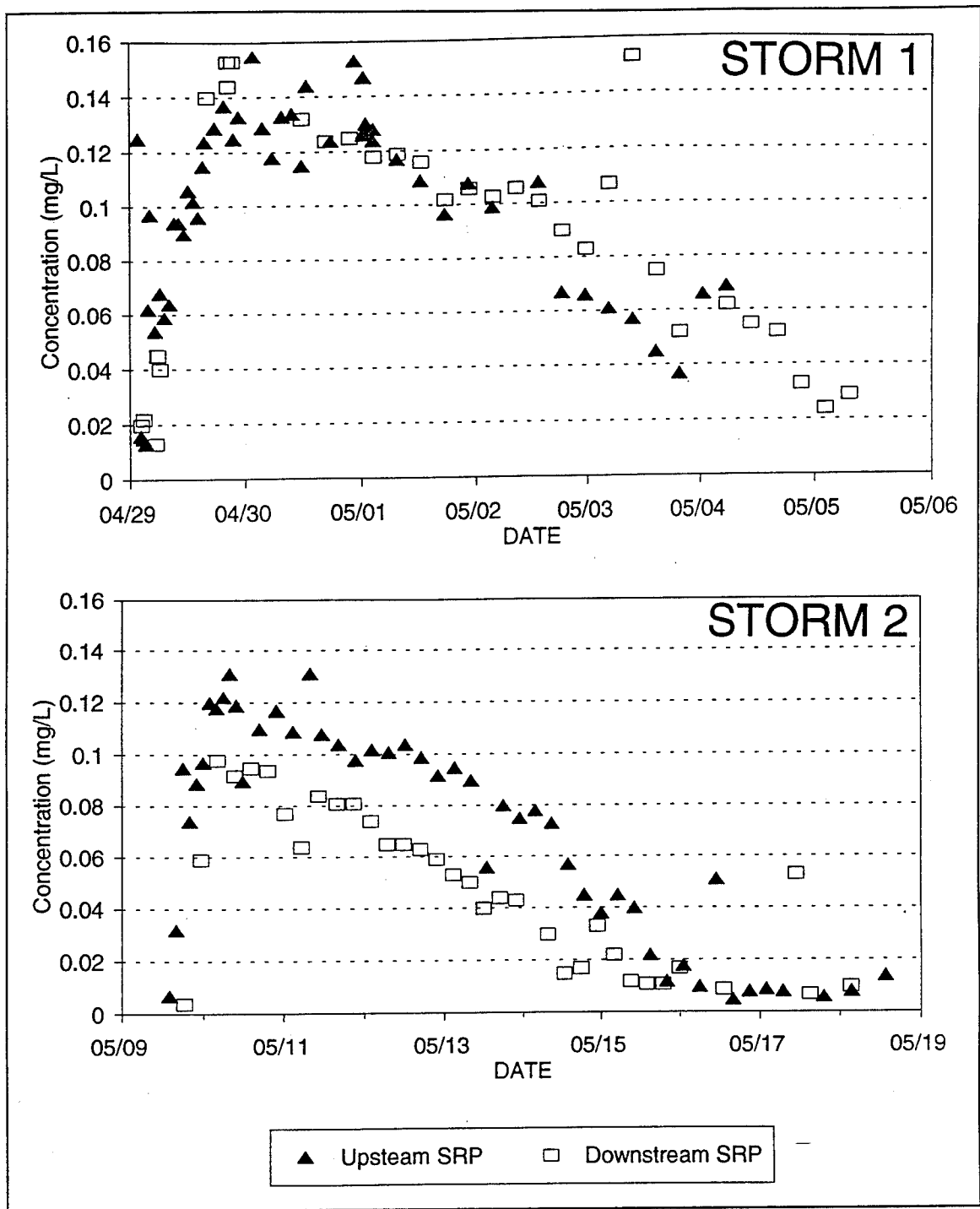


Figure 16. SRP concentrations for storm events

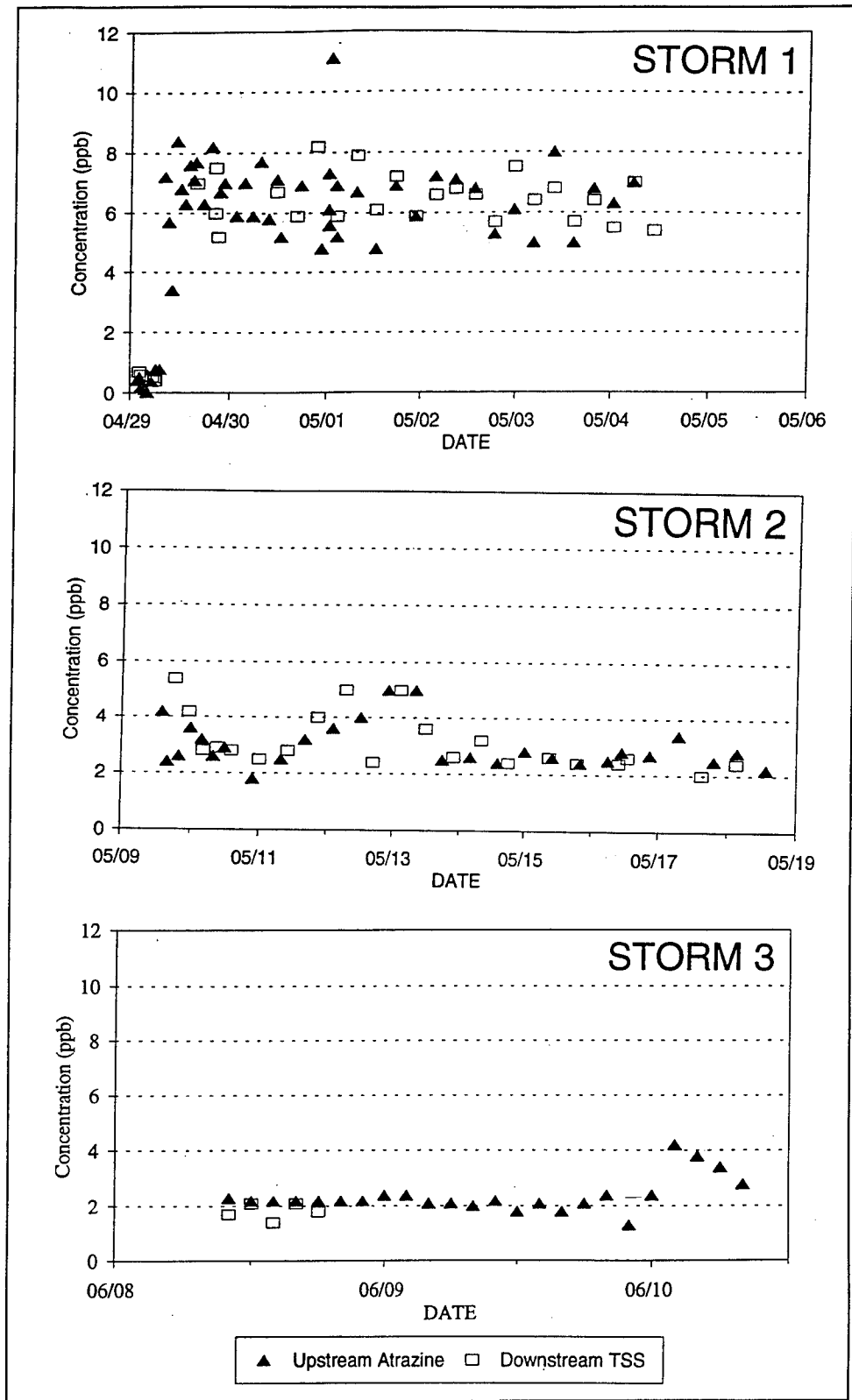


Figure 17. Atrazine concentrations for storm events

concentrating the dissolved solids in the water column. Baseline conductivities were nearly equivalent at both sampling sites in the wetland. The wetland did not appear to have any effect on conductivity during storm events. Conductivity readings were the same at both inlet and outlet sampling stations. Holding the water in the wetland after a storm event tended to increase the conductivity.

pH and Alkalinity

Baseline sampling indicated that at low flow conditions the wetland had a pH near 8 (Table 3). pH at the inlet was consistently higher than pH at the outlet (Table 3). pH at the outlet was consistently higher than pH in Range Creek (Table 3). The decay of organic material in the wetlands and in Range Creek may account for this difference in pH during low flow conditions. Alkalinity was nearly the same at the inlet and outlet, yet alkalinity was lower in the wetland than in Range Creek. During a storm event the pH and alkalinity behaved in the same manner as the conductivity. pH and alkalinity values fell rapidly and then slowly began to increase after the storm peak had passed (Figures 19 and 20, respectively). The wetland did not appear to affect pH or alkalinity during storm events.

Discussion

Under controlled flow conditions, the HRT of the wetlands is only about 5 hr. Under the flooding conditions experienced during the sampled storm events, the HRT is probably much shorter. Information available on nitrogen removal in wetlands indicates that a 5-day HRT is necessary (Watson et al. 1989). Mesocosm studies conducted at LAERF indicate that atrazine has a half-life of 9 days in these wetlands. In order to significantly affect nutrients or herbicides in these constructed wetlands, the HRT of the wetlands should be on the order of weeks, not hours. To provide the necessary retention time, the surface area of the wetlands would have to be greatly increased. A detailed hydrologic study of Range Creek would be necessary to properly size and locate the wetlands. A detailed hydrologic analysis would also avoid potential problems related to hydraulically overloading the wetlands, such as erosion of dikes. Additional area is available on project lands along Range Creek; however, the expense of constructing large wetlands area may make such a project cost prohibitive. Large areas of wetlands may also be seen as competing with other lake and water uses.

Sediment Accumulation

The sediment disks were collected on 18 and 19 August 1993. During this field trip the lake had been drawn down and the wetland had dried out. No water was in Wetland 1 and very little water was in Wetland 1A. Because it

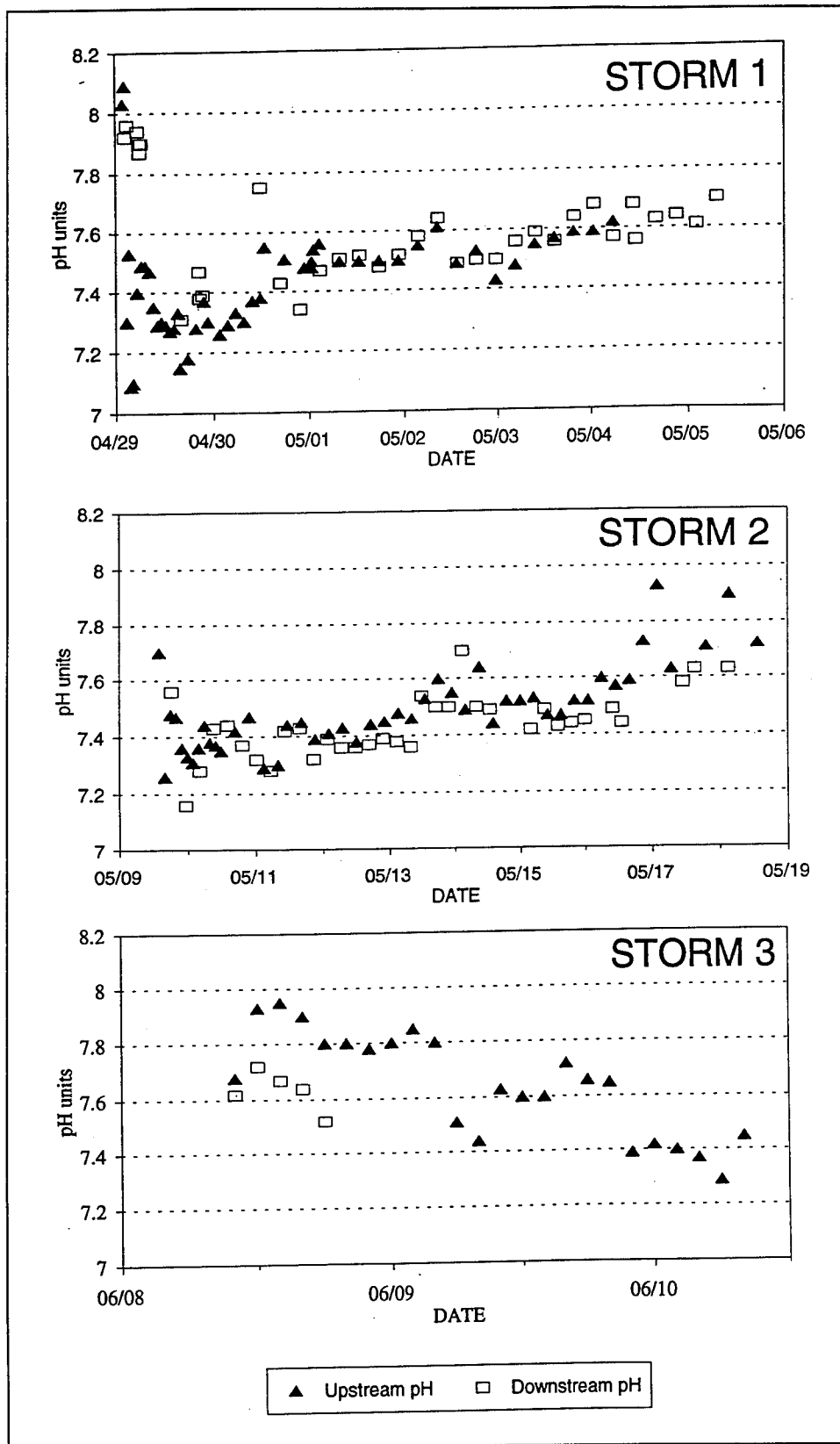


Figure 19. pH readings for storm events

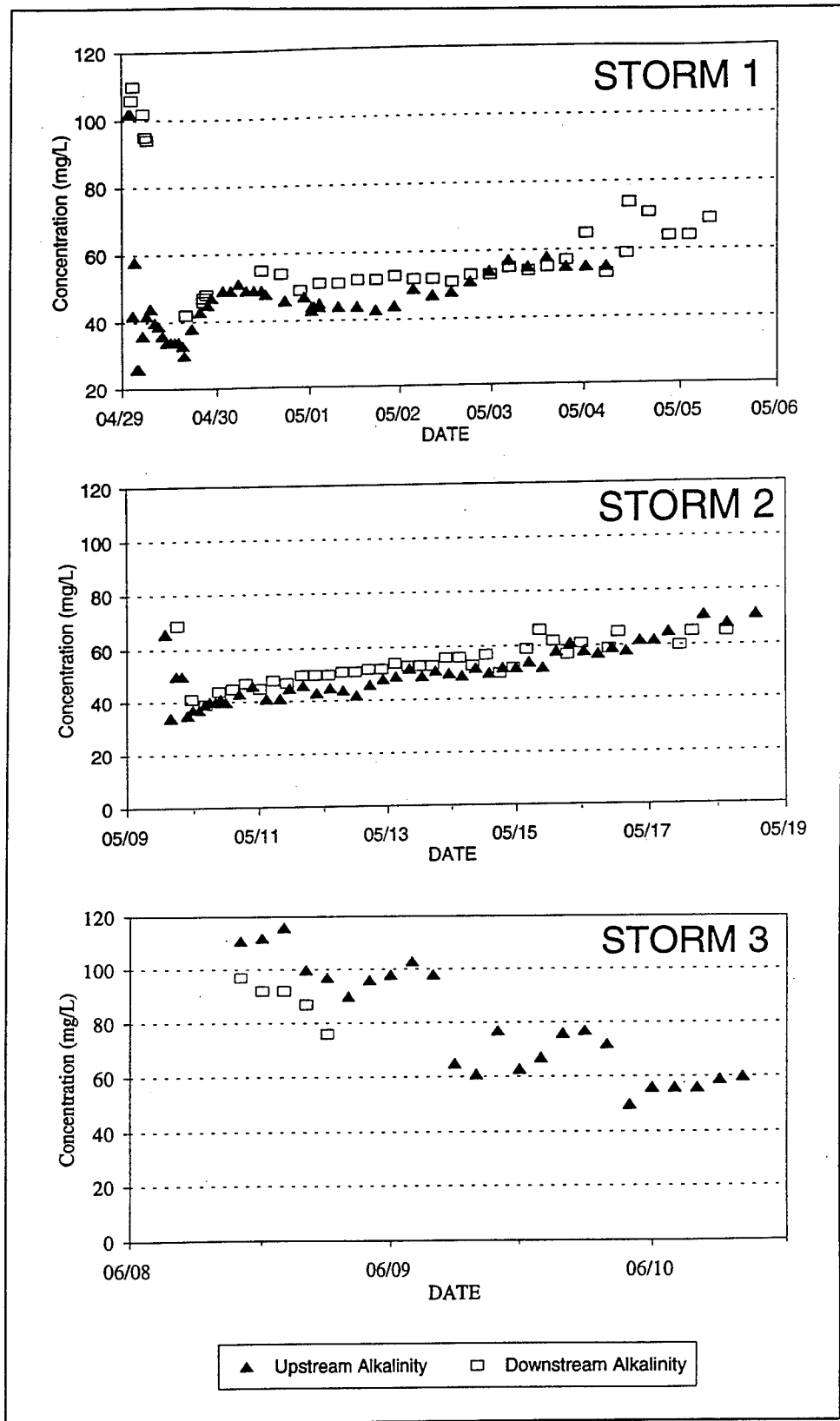


Figure 20. Alkalinity concentrations for storm events

was so dry, the sediments on the disks were cracked and difficult to recover. Also, it appeared as though the sediments on some of the disks were partly blown away. This may cause an underestimation of the sediment accumulation rate. All but one of the 27 sediment disks were located.

The results of the sediment sampling are shown in Table 4. The location and accumulation on the sediment disks are shown in Figure 21. The average sediment accretion on the disks was 2.2 mm and ranged from 0 to 8.3 mm on disk 22, near the spillway. Areal accumulation averaged 1.37 kg/m² and ranged from 0 to 7.07 kg/m² on disk 7, located immediately in front of the inlet.

Sediment pads on the southwestern end of the wetland that were at higher elevations and less frequently inundated had little accumulated sediments. Pads near the inlet and outlet both had high sediment accumulation on them. Some pads located in the center of the wetlands also had high sediment accretion on the disks, though the sediments were not evenly distributed on these disks. This indicates that high sedimentation rates measured on the disks may actually be caused by the shifting of loose bottom sediments due to waves and high flows after storm events as opposed to the deposition of new materials.

The sediments were high in organic content, averaging 18.61 percent. In general the wetlands had good vegetation growth, dominated by upland vegetation on the southwestern portion of the wetland and wetland/moist soil vegetation in the rest of the wetland. Because the wetland was inundated by the reservoir prior to construction, the wetland already had an opportunity to develop some wetland vegetation. This vegetation is probably a source of some of the organic matter. Incoming sediments may also be high in organic content. The areal organic loading of sediments in the wetland was 0.22 kg/m². There was no apparent trend in the percent organic material in the wetlands. All samples fell between 10 and 30 percent organic material.

Testing for atrazine in the sediment samples yielded very few positive findings. Only sediment disks 5 and 22 had detectable quantities of atrazine. These two samples had very low values near the detection limit of 0.1 ppb. This analysis indicates that atrazine is not accumulating in the bottom sediments of the wetland even though high atrazine levels exist in storm water flows.

The amounts of sediments reported in Table 4 represent approximately 4 months of accumulation, which encompass approximately 50 percent of the total yearly rainfall. Yearly accumulation rates may be to 2 to 3 times higher than the measured 4-month value. In comparison to literature values of sediment accretion/accumulation rates tabulated by Johnston (1991) for a variety of wetland types, sediment accretion values in Wetland 1 fell on the low side of the range of values -6 to 26 mm/year. Sediment accumulation rates in Johnston (1991) range from 0 to 7.84 kg/m²/year. Sediment accretion rates in similar projects constructed within the fluctuation zone of other USACE reservoirs ranged from a low of 3.0 mm/year at Bowman-Haley Reservoir in

**Table 4
Wetland 1 Sediment Measurements**

Disk	Average Accretion mm	Weight Sediments g	Areal Loading kg/m ²	Organic Material %	Weight Organic Matter g	Organic Loading kg/m ²	Atrazine Concentration ppb
1	<0.1	3.5	0.35	26.12	0.92	0.09	<0.10
2	<0.1	0.0	0.00		0.00	0.00	
3	<0.1	0.2	0.02		0.00	0.00	
4	<0.1	6.6	0.66	21.54	1.43	0.14	<0.10
5	1.6	13.8	1.38	16.72	2.31	0.23	0.14
6	1.2	3.0	0.30	17.56	0.54	0.05	<0.10
7		70.7	7.07	13.92	9.84	0.98	<0.10
8	7.9	21.1	2.11	16.14	3.41	0.34	
9	<0.1	0.2	0.02		0.00	0.00	
10	<0.1	0.3	0.03		0.00	0.00	
11	8.0	31.2	3.12	14.01	4.37	0.44	<0.10
12	6.8	31.7	3.17	11.98	3.80	0.38	<0.10
13		4.4	0.44	14.66	0.65	0.06	<0.10
14	1.7	4.4	0.44	24.3	1.08	0.11	<0.10
15	5.3	36.8	3.68	10.75	3.96	0.40	<0.10
16	3.5	11.4	1.14	22.37	2.55	0.26	<0.10
17	<0.1	1.6	0.16				
18	3.5	17.4	1.74	27.82	4.85	0.49	<0.10

(Continued)

Note: A blank indicates no data.

Table 4 (Concluded)							
Disks	Average Accretion mm	Weight Sediments g	Areal Loading kg/m ²	Organic Material %	Weight Organic Matter g	Organic Loading kg/m ²	Atrazine Concentration ppb
19	1.9	6.8	0.68	23.81	1.63	0.16	<0.10
20	<0.1	0.0	0.00		0.00	0.00	
21	<0.1	0.0	0.00	22.59	0.00	0.00	<0.10
22	8.3	70.5	7.05	14.74	10.39	1.04	<0.10
23	<0.1	0.0	0.00		0.00	0.00	
24		20.0	2.0	17.33	3.46	0.35	0.15
25	<0.1	0.0	0.00		0.00	0.00	
26							
27	<0.1	0.0	0.00		0.00	0.00	
Average	2.2	13.7	1.37	18.61	2.21	0.22	

North Dakota (Downer and Myers 1995) to 5 mm/year at Grenada Lake in Mississippi (Downer, DeLaune, and Nyman 1995) to a high of greater than 30 mm/year at Black Butte Reservoir in California (Downer 1995). The hydrologic conditions of the wetlands at Bowman-Haley Reservoir more closely mimic conditions at Ray Roberts than at the other two reservoirs.

With an approximate area of 2 ha, the wetland detained approximately 28,000 kg of sediments at a volume of 44 m³ over the sampling period. Yearly accumulation should be about twice this value. With an average depth of approximately 0.5 m the wetlands would require roughly 100 years to fill at the measured sediment accretion rate.

4 Conclusions

Wetland 1 at Ray Roberts Lake is subjected to high TSS and atrazine herbicide concentration flows in response to major storm events on the Range Creek watershed above the project. High TSS and atrazine levels are probably attributable to the prevalence of row crop agriculture in the watershed. The wetland was able to reduce peak TSS concentrations about 30 percent during the second storm event. Other data indicated little removal of TSS by the wetland. There was no apparent removal of atrazine during these storm events. Nutrient removal in the wetlands was inconclusive though the wetlands did not appear to consistently affect nutrient concentrations. The amount of pollutant removal experienced in these wetlands probably has little if any effect on reservoir water quality. Lack of removal of atrazine and nutrients in the wetlands is most likely due to the very short detention times in the wetlands.

Sediment accretion monitoring in the wetlands indicates that the accretion rate in the wetlands is low. Although peak sediment concentrations at the inflow are somewhat high during large storm events, such events occur infrequently during the year and the wetland appears to be retaining relatively little of the sediments. Sediment accretion should have minimum affect on wetland vegetation, fishes, and other organisms. The low sediment accretion rate should allow for the wetlands to be productive habitat for many years. The high organic content of sediments indicates that the wetlands are building the characteristic organic layer on the bottom of the wetlands. Such an organic layer is important in many wetland functions, including water quality improvements. Testing of sediments for the herbicide atrazine yielded very few positive samples indicating atrazine is not being permanently retained in the wetland substrate. High-concentration atrazine runoff is largely transported downstream to the reservoir. Atrazine remaining in the wetland after the passage of storm events is apparently degraded.

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13. ABSTRACT (Maximum 200 words)
Six wetlands, totaling 70 hectares in area, were constructed in the fluctuation zone of Ray Roberts Reservoir, north of Dallas, TX. The wetlands were constructed to provide waterfowl habitat and water quality improvements at the lake. The wetlands are operated under a moist soil management plan by the Texas Parks and Wildlife Department. In the spring and summer of 1993, one of the six wetlands was monitored for its ability to remove suspended sediments and other nonpoint source pollutants from inflows. Constituents included various forms of the nutrients nitrogen and phosphorous as well as the herbicide atrazine. Sampling of three major storm events indicated that flows to the wetland had high concentrations of total suspended solids and atrazine and lower concentrations of nutrients. While the wetland was able to reduce peak total suspended solids concentrations by approximately 30 percent, the wetland was ineffective at removal of nutrients and herbicides. A very short hydraulic retention time is thought to be a primary cause for the lack of removal. Sediment accretion measured in the wetland with Plexiglas disks averaged 2.2 mm over a 4-month sampling period.

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