COMPARATIVE ECOSYSTEM ANALYSIS OF HYDROLOGIC RESTORATION OF TATES HELL SWAMP

Northwest Florida Water Management District

Florida Department of Environmental Protection Contract WM 691

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in cooperation with

University of Florida Center for Wetlands (CFW)
Florida State University Department of Biology
Florida Department of Environmental Protection (DEP)
U.S. Environmental Protection Agency (EPA)
Florida Department of Agriculture and Consumer Services (DACS)
Florida Division of Forestry (DOF)

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Carolyn Kindell of the Florida Natural Areas Inventory (FNAI) provided many valuable insights into the historic characteristics of the study area and expected responses to restoration.

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EXECUTIVE SUMMARY

In 1998 the Northwest Florida Water Management District (NWFWMD), in cooperation with the Florida Department of Environmental Protection (DEP), the Florida Division of Forestry (DOF), and the Florida Game and Fresh Water Fish Commission (FGFWFC) completed a hydrologic restoration demonstration project in Tates Hell Swamp in the Florida Panhandle. A major portion of this project consisted of restoring a 3,000-acre tract located in the Big Slough Branch sub-basin. NWFWMD was awarded $225,000 in EPA Section 319 funds to establish baseline ecosystem status and evaluate initial ecosystem response hydrologic restoration of this tract.

Monitoring was conducted beginning three months prior to restoration and continued for a total of eighteen months. Hydrologic and water quality monitoring was conducted by NWFWMD. Biological and additional water quality monitoring were conducted under subcontract by the University of Florida Center for Wetlands. Plant community analysis was conducted under separate subcontract by the Florida State University Department of Biology.

Hydrologic monitoring established that restoration efforts were successful in raising and stabilizing water levels in the demonstration site. Wetland hydroperiods in the demonstration site have been significantly increased over those observed at the topographically similar control site. No consistent water quality response to restoration was observed. Water quality was excellent at all three sites, both prior to and after restoration.

Over one hundred macroinvertebrate taxa, thirteen fish species, and more than three hundred plants were identified in this biologically rich and interesting area. Comprehensive baseline data was collected for benthic macroinvertebrate and zooplankton communities but no consistent response of these groups to hydrologic restoration was seen. A noteworthy finding was that corer sampling of macroinvertebrates yielded more consistent results than the more commonly employed sweep-net sampling method, suggesting that corer sampling may be appropriate for use in developing a wetland condition index.

Tentative evidence was observed for increased post-restoration use of wetlands by the fish species *Lepomis gulosus* (warmouth), as well as evidence of a species shift from pygmy killifish (*Leptolucania ommata*) to mosquitofish (*Gambusia holbrooki*). Drought conditions during pre-restoration monitoring and erratic rainfall throughout the study prevented definitive comparisons between the pre- and post-restoration conditions, and rendered comparisons among sites difficult. Longer-term studies capable of addressing inter-annual variability will be necessary to firmly establish the effects of restoration. Significant positive long-term biological responses to hydrologic restoration combined with a comprehensive management plan are expected.

INTRODUCTION

Over the past 200 years, more than 53% of the total area of wetlands in the continental United States have been lost, including over 46% of historical coverage in Florida (Mitsch and Gosselink 1993). Wetland loss in Florida represents over 10% of the U.S. total. Large expanses of wetlands still exist in the state, including the Everglades, Okefenokee Swamp, Tates Hell Swamp, Mallory Swamp, Gulf Hammock, Green Swamp, Big Cypress Swamp, and numerous riparian wetlands, salt marshes, and mangrove swamps. However, many of the remaining wetlands have been altered by humans and no longer resemble pre-Columbian conditions.

Tates Hell Swamp extends over approximately 200,000 acres of lowlands in Franklin and Liberty counties in the Florida Panhandle (Figure 1-1). The area was originally dominated by a diversity of wetland types, including wet savanna, cypress strand, and hardwood swamp. These wetlands have historically supported—and to a limited extent continue to support—a variety of rare plants, animals, and natural communities. The western portion of Tates Hell drains to East Bay, the primary nursery area for Apalachicola Bay.

Starting in the 1960s and 1970s, the hydrology of Tates Hell was altered by an extensive network of access roads and associated ditches constructed for the purpose of establishing pine plantations. Excavated fill from either side of the proposed roadway was used to establish routes across the low, poorly drained terrain. Excavations on either side of the roads aided in draining the land, thereby enhancing pine production potential. This ditching and subsequent draining has significantly lowered the water table, resulting in extensive loss of wetland habitat and alteration of wetland community structure. These alterations have adversely impacted water quality in East Bay by reducing storage and disturbing freshwater delivery patterns. The road-ditch system, in conjunction with silvicultural operations in the area, results in intense pulses of turbid, low pH runoff reaching the estuary following substantial rainfall events.

Efforts to stem the further alteration of Tates Hell Swamp were initiated in 1992. A 30,000-acre parcel was cooperatively acquired by the Northwest Florida Water Management District (NWFWMD), the Department of Environmental Protection (DEP), and the Florida Game and Fresh Water Fish Commission (FGFWFC) in 1994. Further acquisitions have brought over 150,000 acres of Tates Hell into public ownership.

In 1994, NWFWMD was awarded a grant from the EPA through the Florida DEP for a hydrologic restoration and BMP demonstration project in Tates Hell Swamp. Two areas, each approximately 3,000 acres, were selected for restoration—Big Slough Branch in the headwaters of Whiskey George Creek, a major tributary of East Bay; and Sand Beach/Blounts Bay, which contains approximately three miles of East Bay shoreline (Figure 1-1). Goals of the project were to initiate and implement nonpoint source pollution control strategies to protect and restore the natural watershed functions and the

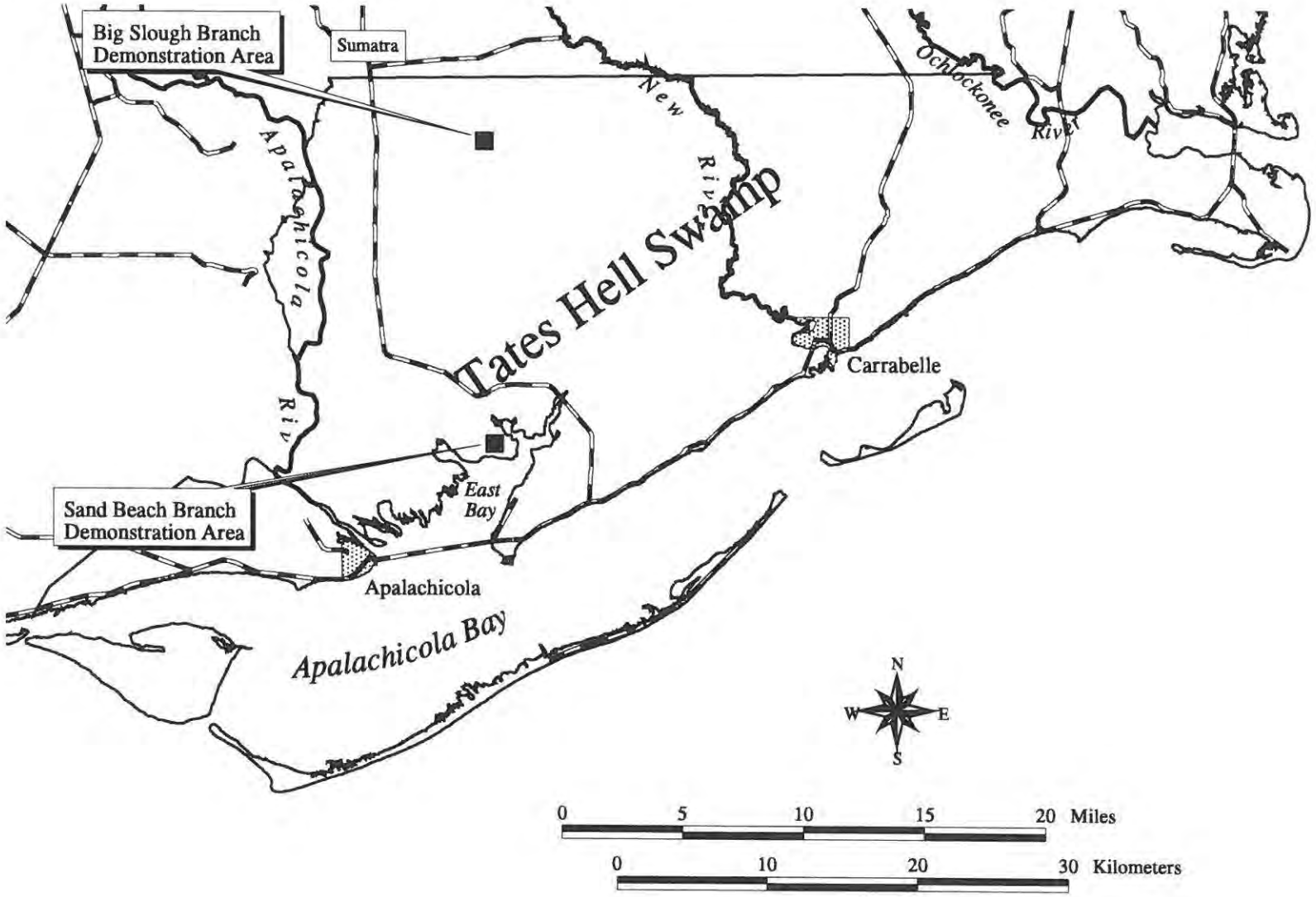
water quality of the East Bay drainage basin, and to restore the natural hydrology and wetland habitat of portions of Tates Hell Swamp. To accomplish these goals, 16 low water crossings (LWCs; segments of roads lowered to natural grade to re-establish natural flow patterns) and associated ditch plugs were installed at the two sites. In addition, four miles of roadside ditches were partially filled in order to restrict flow and redirect it to natural drainages. Numerous culverts were also plugged in order to facilitate the diversion of water into natural drainages.

Construction of the demonstration project was completed in the summer of 1998, and a final project report was submitted the following year (NWFWMD 1999). In addition to construction details, the report presented the results of the limited hydrologic and water quality monitoring component of the project. In 1997, NWFWMD was awarded $225,000 in additional EPA Section 319 funding (through DEP) for a separate, comprehensive ecological assessment of the Big Slough Branch demonstration site—the work presented in this report. This study was designed to evaluate the effects of restoration work by collecting pre- and post-restoration data at the demonstration site, as well as at nearby control (unrestored) and reference (relatively pristine) sites. Objectives were:

1) to monitor changes in hydrology and wetland community structure to determine effects of restoration on system ecology,
2) to measure changes in ecosystem function during hydrologic restoration using physical, chemical and biological water quality data collected from comparative restored, unrestored and reference sites, and
3) to establish standards of plant community response to hydrologic restoration.

An integrated hydrologic, water quality, and biological monitoring program was developed to accomplish these goals. Biological monitoring was performed under subcontracts with the University of Florida Center for Wetlands (CFW) and the Florida State University (FSU) Department of Biology. CFW examined fish, zooplankton, benthic macroinvertebrates, algae, and field-measurable water quality parameters. Vascular plant monitoring was done by FSU. NWFWMD performed hydrologic monitoring, additional water quality sampling, land surveying, and soil analysis. Data collection began in April 1998, two months prior to initiation of restoration work at the Big Slough Branch site, and continued through November 1999.

Figure 1-1. Location of Tates Hell Swamp.



METHODS

Study Organization

Site Selection

This study focused on the Big Slough Branch restoration demonstration site near the headwaters of Whiskey George Creek (Figure 2-1). This site was selected in preference to the Sand Beach Branch demonstration site because the level of disturbance at Big Slough Branch has been much greater than at Sand Beach Branch. Furthermore, the Big Slough Branch site contains significant areas of dwarf cypress swamp and remnant wet savanna habitats, both of which are of considerable ecological interest, and can be considered signature habitats of Tates Hell (Kindell 1997).

In order to help distinguish the effects of restoration from random variation, a relatively pristine (reference) site in a nearby area of the Apalachicola National Forest and a disturbed but non-restored (control) site in Tates Hell State Forest were also incorporated into the study (Figure 2-1). Every effort was made to select reference and control sites as similar as possible to the demonstration site in terms of original hydrology, historic plant community types, and soils.

The reference site is located in the headwaters of Fort Gadsden Creek, approximately six miles southwest of the demonstration site. The site is dominated by cypress swamp and wet savanna. Cypress at this site are somewhat stunted, but are larger than those in the demonstration site. While this site has been subjected to minor ditching, the level of disturbance is much less than at the demonstration site. The reference site has been managed by the United States Forest Service (USFS) to promote native plant communities.

The control site is located approximately two miles west of the demonstration site. The site is dominated by dwarf cypress-dwarf blackgum swamp with limited acreage of wet savanna. Both the control and pre-restoration demonstration sites were intersected by deep drainage ditches, and the two sites have undergone similar levels of hydrologic disturbance.

Biological, water quality, and hydrologic monitoring stations were established in all three of these sites. Exact distribution of stations varied for different types of sampling (Figure 2-1).

Biological and associated water quality sampling was conducted by CFW at three stations in the demonstration site (1, 2, and 3, Figure 2-1), and one station each in the control and reference sites (C and R, Figure 2-1). Sampling stations were selected to represent long-hydroperiod, relatively open, cypress-dominated wetlands. Stations in the demonstration and control sites were located where road-ditch systems cross broad natural cypress

swamp drainageways, while the reference station was placed in a similar unimpacted drainageway. Low water crossings were installed at the demonstration site stations during the course of the study.

Sampling of chemical water quality parameters was conducted by NWFWMD at four stations in the demonstration site (S533, S534, S537, S541), as well as upstream and downstream stations in the control (S538, S505) and reference (S539, S540) sites. Stations S537 and S541 in the northern (upstream) portions of the demonstration site correspond to biological sampling stations, while stations S533 and S534 at the lower end of the demonstration site do not. The latter stations were established to examine water quality leaving the site and to determine if the site functions as either a source or sink for nutrients.

Continuous stage monitoring equipment was installed at the lower end of the demonstration site (S533), an additional location in the interior of the demonstration site (S536), and at the downstream end of the control site (S505). Equipment was concealed in dense vegetation (primarily titi) in order to avoid vandalism. The NWFWMD had previously lost several thousand dollars worth of equipment to vandalism in this area. The biological and water quality sampling sites further north in the demonstration site, as well as the station in the reference site, lacked sufficiently dense vegetation in which to conceal stage measuring equipment, and equipment was therefore not installed at these locations.

Arrays of ground water monitoring wells were installed at locations G1 and G2 (Figure 2-1). The G1 array had been installed during an earlier study (NWFWMD 1999), and serves as a control ground water elevation site. The G2 array was installed during the present study, and reflects ground water conditions at a location in the demonstration site adjacent to partially filled drainage ditches.

A vascular plant survey was conducted throughout the demonstration and reference sites. Permanent intensive plant quadrats were established at locations near low water crossings at biological sampling stations 1 and 3. Specific quadrat locations were chosen to examine both dwarf cypress-dwarf blackgum swamp and wet savanna habitats.

Monitoring Schedule

Due to a variety of legal, administrative, and technical delays (NWFWMD 1999), monitoring did not begin until April 1998. Restoration construction activities on the demonstration site began in May of that year, and were essentially complete by late July. Thus, pre-restoration data was collected for only three months.

Biological sampling was conducted on approximately a 28-day cycle beginning April 1998 and continuing through October 1999. Dry conditions interfered with sampling on several scheduled collection dates, especially during the summer of 1998. However,

limited sampling (ditches, wetland benthic infauna) was conducted even during dry periods, and the resulting data set consists of 19 sampling events.

Water quality sampling was scheduled monthly from April 1998 through November 1999. Dry conditions prevented sampling on several occasions—samples were only collected during months when water was observed in natural drainageways. In order to assess storm runoff water quality, double samples were collected at short (one or two day) intervals following two major rainfall events. A total of 13 sampling events were conducted.

Continuous stage and rainfall data were collected from April 1998 through October 1999. Ground water elevations were measured on six occasions between March and November 1999. Soil samples were collected and intensive plant quadrats established and sampled in October 1999.

Hydrology

Continuous surface water stage data were collected with Handar 555 data loggers and Druck pressure transducers installed at the three locations indicated in Figure 2-1. Transducers were placed in ditches in order to monitor water levels lower than natural grade. Stations S533 and S505 are located at the outflows of the demonstration and control sites, respectively. Road/ditch systems intersect broad, relatively well defined natural flow-ways at both of these stations. Detailed cross-sectional elevation surveys of both drainageways were conducted for the purpose of examining the relationship between stage and wetland elevation. Station S533 is adjacent to LWC 7 on Gully Branch Road. Prior to restoration, a deep ditch on the north side of the road intercepted water flowing south in Big Slough Branch, diverting flow to the west. Subsequent to LWC construction, plugging of culverts, and partial backfilling of the ditch system, flow was restored to the natural flow path. At station S505, the ditch at West Boundary Road intercepts eastward flow from Hog Branch, diverting it southward. Conditions at the control site station are thus analogous to pre-restoration conditions at station S533. A third station, S536, represents the interior of the demonstration site. Both stage and rainfall (Handar tipping bucket gage) were monitored at this station.

An array of ground water piezometers had been established prior to this study at G1, a short distance west of the demonstration site on Tower Road (Figure 2-1). This array, which consists of one deep (12 ft) and seven shallow (5-6 ft) wells distributed from 0 to 170 ft from the roadside drainage ditch, served as a control in the present study. Another array, G2, was installed along North Boundary Road in the demonstration site in late 1998. This array consists of three deep (8 ft) and four shallow (4 ft) wells ranging from 15 to 300 ft from the roadside ditch. In both arrays, deep wells penetrate a low permeability clay loam stratum found through much of Tates Hell at depths varying from 3 to 7 feet. All piezometers were of two-inch PVC, with the lowest two feet consisting of slotted well screen, and all were grouted with bentonite (control site) or neat cement

(demonstration site). Piezometers were measured approximately bimonthly from March 1999 through October 1999.

Water Quality

Grab samples were collected at each of the water quality stations identified in Figure 2-1. Sampling was conducted monthly when there was water in natural wetlands, and on two occasions, in September 1998 and January 1999, paired sampling events were conducted following storm events in order to assess runoff quality. In locations with low water crossings, samples were collected at the upstream side of the LWC where it intersects the natural wetland channel. In locations without LWCs, samples were taken in the natural wetland channel. Samples were transported to the DEP Central Laboratory and analyzed for ammonium, nitrate-nitrite, total Kjeldahl nitrogen, total organic carbon, total phosphorus, ortho-phosphorus (field-filtered), and total suspended solids. Chlorophyll a analysis was performed for the first few sampling events, but was discontinued after it was found that all samples were at or below the DEP minimum detection limit of 1.0 µg/L.

Field water quality parameters were measured in conjunction with monthly biological sampling events. Measurements were taken adjacent to LWCs or, where LWCs were absent, adjacent to wetland channels. Temperature, dissolved oxygen, and specific conductance were measured with a YSI model 85 meter. One measurement of specific conductance was taken from the surface of each ditch and wetland, and in the absence of standing water, no measurement was taken. Oxygen and temperature were taken from the surface and bottom of each ditch and the surface of each wetland if standing water was present. A Fisher Scientific Accumet AP63 pH/mV/ion meter was used to measure pH. One measurement was taken from the surface of each ditch and wetland when standing water was present.

Benthic Macroinvertebrates

For core sampling, a stainless steel cylindrical corer 7.1 cm in diameter and 26.5 cm in length with a 64 cm attached handle was used. Sampling occurred every 28 days for the first three months (beginning in April 1998) prior to and three months after restoration and bimonthly after these initial six months through October 1999. Cores were collected regardless of whether there was standing water in the wetlands. Five cores were taken to a depth of approximately 15 cm in each wetland along a randomly chosen (0-180° from line perpendicular to road) 20 m transect. Water depths were taken at each coring location along the transect. Each core was deposited in a sieve bucket with 600 µm mesh (U.S. Standard no. 30) and rinsed in the field. The contents of the sieve bucket were then transferred to soil bags, the bags tied shut, and placed into a bucket containing 70% ethyl alcohol and the vital stain Rose Bengal.

Sweep nets with a mouth diameter of 20.2 cm and a net mesh of 800 x 900 μm were also used to sample benthos. Sampling occurred every 28 days for the first three months (beginning in April 1998) prior to and three months after restoration and bimonthly after these initial six months through October 1999. Sweep nets were utilized only when there was standing water in a wetland. Ditches were sampled bimonthly. Sampling consisted of five 0.5 meter sweeps through the bottom sediments in each ditch and wetland. These samples were then pooled and deposited into a sieve bucket and washed as done for cores. The contents of the sieve bucket were placed into individually labeled soil bags indicating the wetland or ditch from which they were sampled, the bags tied shut, and were placed into a bucket containing 70% ethyl alcohol and the vital stain Rose Bengal.

In the laboratory, the contents of each soil bag (cores or sweep) were washed with tap water and placed into white-bottomed trays for sorting. Macroinvertebrates were separated from the substrate, identified to order, and placed into separate, labeled one dram vials for further identification. For samples with large numbers of invertebrates, subsamples were taken. Soil bag contents were placed onto a gridded tray, and a square was randomly selected to be picked. Invertebrates were counted and placed into vials containing 70% ethyl alcohol. This process was repeated until at least 100 specimens were placed into a vial.

Each sample was sorted twice to ensure complete isolation of all macroinvertebrates from the substrate. As part of quality control, every tenth sample was resorted to check the efficiency of the sorters. Furthermore, new pickers had their samples routinely repicked until they were acceptably efficient.

Identification primarily took place under a 4.5x (with 10x oculars) Meiji stereoscope, though chironomid and ceratopogonid dipterans were mounted in CMC-10 mounting medium on a clean glass slide and viewed under a Fisher Scientific Micromaster CK compound microscope (4x to 100x with 10x oculars). Organisms were identified to the lowest practical taxonomic level using the most relevant taxonomic references, including: Pennak (1989), Daigle (1991), Thorp (1991), Daigle (1992), Epler (1995), Pescador (1995), Epler (1996), and Merritt (1996). Quality control consisted of a second qualified person re-identifying the contents of every fifth sample to check the accuracy of identifications. A reference collection was also maintained, and indentifications were verified by Dr. David Evans of Water and Air Research in Gainesville Florida.

Zooplankton

Zooplankton were collected using a U.S. Standard No. 20 (64 μm) Wisconsin plankton net with a mouth width of 10 cm towed over a horizontal distance of 2.5 m. Samples were collected monthly beginning in May 1998 through October 1999. Zooplankton were not collected in wetlands when the depth of the water was less than 10 cm, the diameter of the mouth of the plankton net. At the completion of each tow, the sides of the plankton net were washed with water into the receptacle bottle, and contents of the bottle were transferred to individually labeled Nalgene storage bottles, fixed with

Lugol's iodine solution, and placed on ice. Bottles were refrigerated in the laboratory prior to identification.

Zooplankton were counted and identified to the lowest practical taxonomic level using the most relevant identification manuals: Pennak (1989) and Thorp (1991). For identification, samples were filtered through a U.S. Standard No. 230 sieve (63 μm), washed with tap water, and then washed into a plankton wheel to aid in counting. Identification primarily took place under a Nikon SMZ-10 stereoscope (4.5x with 10x oculars), though finer morphological characters could only be viewed under a Fisher Scientific Micromaster Model CK compound microscope (4x to 100x with 10x oculars). In the case of samples with large numbers of organisms, a subsample of one quarter of the total was taken, and the contents counted and identified until 200 individuals were counted. If the quarter subsample did not contain at least 200 individuals, another quarter subsample was counted and identified. This procedure was continued until at least 200 total individuals were counted. The final number of each zooplankton taxon was divided by the fraction of the total subsampled to calculate a total for each taxon. Once counted and identified, samples were returned to the bottles and archived in a refrigerator.

Fish

Fish were collected monthly using standard galvanized steel minnow traps covered with window screening to reduce escape by smaller fishes through the mesh sides of the trap. The minnow traps measured 41.5 cm x 22.5 cm, had a 2.2 cm diameter funnel opening, and were constructed from 0.63 cm square mesh. Each month, five traps were baited with bread and randomly placed in each ditch, wetland, and low water crossing for a 24-hour period. Fish traps were placed a minimum of ten meters apart to decrease sampling bias. Traps were placed in the water so the funnel entrances were just below the water surface and about a third of the trap was above the water surface. Traps were tied with a rope to a tree branch to hold them in place. Tests prior to the project showed more fish were collected with the traps set in this manner as opposed to completely submerging them. Exposing the top third of the traps to the atmosphere also allowed fish to gain access to the surface so that they could engage in aquatic surface respiration (ASR) in the event of hypoxic conditions developing in the water. Those wetlands not having sufficient water to allow the entrances to the traps to be submerged completely were not sampled for fish that month. Each trap was removed from the water and the contents placed into a five-liter reclosable, clear plastic bag containing approximately 0.20 L of ditch water. Each fish was identified to species, measured total length to the nearest millimeter, and recorded. Once identified and measured, the fishes were returned unharmed to the water from which they were collected.

Community Metabolism

Diel dissolved oxygen curves were obtained using a YSI Model 600 probe and recorded on a Campbell Scientific CR500 Basic Data Logger. Temperature was recorded

simultaneously. At the end of the 24-hour data collection, all data were downloaded from the data logger to a notebook computer. Data were collected each month from the control site ditch and from the upstream ditch adjacent to the LWC at biological monitoring station 1 in the demonstration site. Ditches at these locations functioned as quasi-natural stream channels, having natural bottom substrates, and collecting flow from natural wetland drainageways.

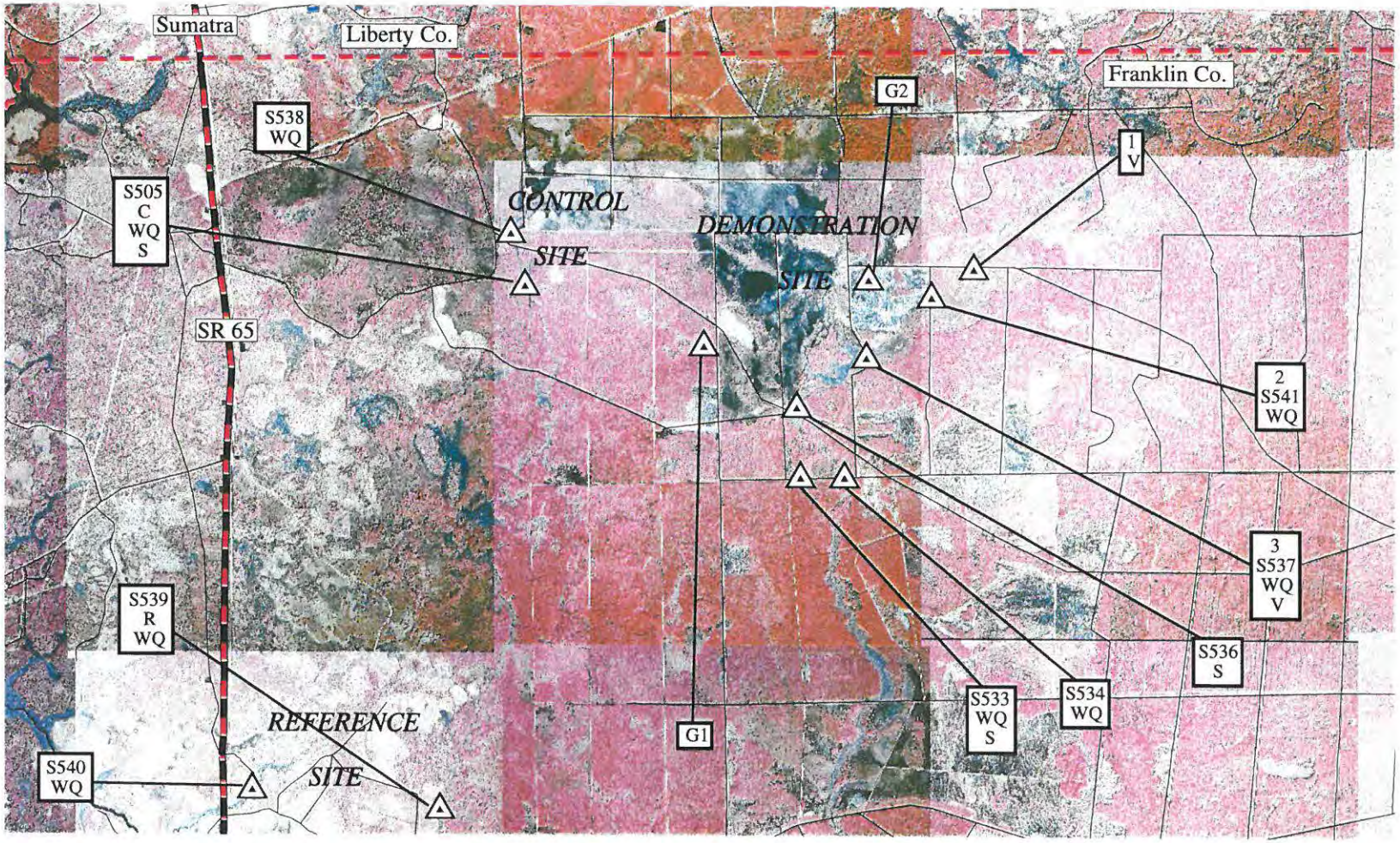
Metabolism was calculated by the single point diel oxygen curve method of Greeson (1985). Changes in dissolved oxygen were calculated over fixed 30-minute time increments for a 24-hour period. Respiration was calculated from the rate of DO decline during darkness, when productivity was zero. Gross primary productivity (GPP) was calculated from the rate of daytime DO increase, adjusted for daytime respiration, which was estimated by extrapolation from nighttime respiration values. Respiration and productivity values calculated in this way were then adjusted for oxygen exchange with the atmosphere. A literature-based oxygen exchange estimate of 0.05 g/m^2-hr at zero percent saturation, corrected for temperature, was used (Odum 1956). Net primary productivity (NPP) was calculated by subtracting adjusted respiration from adjusted GPP.

Periphyton samples were collected monthly at each biological sampling station (Figure 2-1) using an artificial substrate sampler modified from Patrick (1954). This sampler consisted of glass slides suspended vertically just under the surface of the water. The incubation period for samplers was one month. Upon retrieval, slides were placed into slide holders, covered with deionized water, and placed on ice for return to the laboratory. In the laboratory, standard method 10300 C (Greenberg et al. 1992) was used to extract chlorophyll-a.

Vascular Plants

Four intensive plant monitoring quadrats, each measuring 2 x 15 meters, were established adjacent to two LWCs in the demonstration site (Figure 2-1). Quadrat positions were established with GPS, and quadrat corners were marked with iron or PVC stakes. All plants within each quadrat were identified in October 1999, and percent cover was estimated for each species. General plant species inventories were conducted for the demonstration and reference sites through 1998 and 1999.

Figure 2-1. Location of sampling stations in the Big Slough Branch demonstration site, control site, and reference site.



HYDROLOGY

Any ecological benefits of the demonstration project are contingent on successful re-establishment of natural wetland hydrology. In its natural state, much of Tates Hell consisted of a network of broad, shallow, low-gradient drainageways with extensive fringing wetlands. Silvicultural ditching resulted in a general lowering of the water table and extensive loss of wetland habitat. A less obvious result of hydrologic alteration was an exaggeration of water level fluctuations within the wetlands that remained, caused by the damming effect of roadways during extremely wet periods and excessive drainage via the ditch-culvert system during dry periods. During extreme high water events the ditch-culvert system cannot convey water as rapidly as the broad natural drainageways had, but the ditches continue to convey water after levels have receded below the elevation of natural drainageways.

Hydrologic alteration of Tates Hell Swamp has also had an apparent impact on water quality in adjacent East Bay. The area had originally been characterized by continuous, gradually diminishing release of water for many weeks following rainy periods. This provided for relatively stable delivery of fresh water to the bay throughout both wet and dry seasons. Ditching caused rapid wet-season delivery and very limited dry-season delivery, resulting in large salinity fluctuations in the bay. Long-term studies have indicated that hydrologic alterations, together with extensive clear-cutting, cause periodic increases in nutrient levels and water color, and decreases in dissolved oxygen and pH in upper portions of the bay (Livingston and Duncan 1979).

In order to restore the natural wetland hydrology of the Big Slough Branch demonstration site, eight low water crossings (LWCs) were constructed at locations where roads obstructed natural drainage features (Figure 3-1). (Due to the large number of figures and tables in this and subsequent chapters, figures and tables are grouped at the end of each chapter.) Ditches were blocked in order to retain water on the site and direct flow toward the natural drainageways. To construct the LWCs, sections of road ranging from 100 to over 500 feet in length were reduced to natural grade in such a manner as to approximately duplicate cross sections of natural drainageways. The bottoms of some LWCs were lined with crushed limerock ("hardened") to allow vehicle passage, while others were left with natural bottoms. Restoration work is described in detail in the final construction report (NWFWMD 1999).

Surface Water Monitoring

Data collection began in April 1998, shortly before the onset of a severe summer drought that continued until after restoration activities were completed in July. Rainfall averaged less than two inches per month from April through June 1998, followed by nearly twelve inches in July, four inches in August, and over 20 inches in September (Table 3-1). Rainfall for the remainder of the study period was erratic, but generally high enough to

maintain hydrated conditions in the wetlands. Due to the drought, it is difficult to make meaningful pre- versus post-restoration comparisons. However, the data do allow comparison between the hydrology of the pre-restoration demonstration site and that of the control site.

The six weeks of stage data collected at the demonstration and control sites prior to the drought are presented in Figure 3-2. Conditions were already quite dry, and water levels at both sites were between 1.5 and 2.5 ft below median wetland elevation. The two stations are similar in terms of magnitude of response to rain events, slope and duration of recession curves, and water level relative to land elevation. Median stage was 1.8 ft below median land elevation at the demonstration site, versus 1.9 ft at the control site. The total stage range during this period was 0.78 ft at the demonstration site versus 0.81 ft at the control site. This strong pre-restoration resemblance suggests that post-restoration differences between the two sites can be at least partially attributed to the restoration.

Water levels fell below minimum recordable levels in middle May 1998, and did not rise to recordable levels until middle July, after restoration had been completed. (Due to lightning-induced equipment failure, recording of stage at station S505 did not resume until September.) Post-restoration stage data indicate that restoration was successful in raising and stabilizing water levels in the demonstration site. For the period October 1998 through October 1999 median stage at the demonstration site was approximately 0.1 ft above median land elevation, with a range of 1.58 ft (Figure 3-3). In contrast, median stage at the control site was approximately 0.6 ft. lower than median land elevation, with a range of 2.40 ft (Figure 3-4).

Examination of wetland hydroperiods provides additional perspective on differences between the demonstration and control sites. Detailed elevation cross-sections were developed for the two sites, both of which are broad sloughs distinctly defined by bordering uplands. Hydroperiods were determined by combining elevation data with stage data for water year 1998-1999, the only complete year for which data are available. (Rainfall in water year 1998-1999 totaled 62 inches at station S536, approximately an average year for this location.) Median hydroperiod at the demonstration site was 230 days, with 70% of the site exhibiting a hydroperiod of 120 days or longer (Figure 3-5). Median hydroperiod at the control site was only 34 days, and more than 60% of this site had a hydroperiod of less than 60 days. The long hydroperiods seen in the demonstration site are more consistent with the wooded swamp communities that exist at both the demonstration and control sites, and are likely to discourage the encroachment by pines and other inappropriate species observed at both sites.

Restoration did not raise water levels in the interior of the demonstration site (station S536) to the degree it had at the lower end of the demonstration site (Figure 3-6). However, the magnitude of post-restoration stage fluctuations were similar at the two stations. No detailed ground elevation survey was done at station S536 due to the poorly defined wetland cross section at this location.

Ground Water Monitoring

Piezometric ground water levels at the control well array ranged from 0.3 ft to six ft below land elevation (Figure 3-7). A great deal of variation was observed among individual wells, with levels generally rising with increasing distance up to 170 ft from the road-ditch system. This suggests that the approximately four foot deep ditches at this site influence the water table at considerable distances. Water levels at the demonstration site well array ranged from 0.2 ft above land surface to 3.5 ft below (Figure 3-8). Inter-well variation was less than that at the control site, with only the closest well, 15 ft from the ditch, showing significantly depressed water levels. Thus, the influence of the partially backfilled, approximately 2 ft deep ditches at the demonstration site appears small. While the differences between the two well arrays may be attributable to the restoration work, they may simply be due to the differing locations of the arrays, since no pre-restoration data are available to indicate otherwise.

Deep and shallow piezometers were installed in pairs at the demonstration site in order to examine the piezometric surface above and below the clay loam flow-restricting layer located at a depth of 4 to 6 ft at this site. These data can be used to detect any evidence of either downward infiltration or upward flow from the aquifer—the "diffuse upward leakage" hypothesized by Parker and Rasmussen (1998). Darcy's Law dictates that a lower piezometric surface at lower depths results in downward flow, while the opposite situation causes upward flow. Data collected to date (Table 3-2) tentatively indicate that flow direction varies according to conditions. The two measurements taken when the water table was low, on 3/30/99 and 9/18/99 both show an upward pressure gradient consistent with diffuse upward leakage. The four high water table measurements show either very little gradient, or a downward gradient, indicating infiltration. Depending on the hydraulic conductivity of the clay loam soil stratum, the magnitude of these pressure differentials may be sufficient to drive substantial upward or downward flow. Hydraulic conductivities for soils of this type can range from less than 0.01 to over 0.1 inches per hour (Chow 1964). Assuming a value of 0.1 inches per hour and a thickness of 1.5 ft for the low permeability stratum, a pressure differential of 0.2 ft will produce a flow of 0.32 inches per day. Actual measurement of hydraulic conductivity (a difficult procedure to perform correctly), as well as extensive additional water level measurements, will be necessary to clarify this complex issue.

Figure 3-1. Location of low-water crossings in the Big Slough Branch demonstration site.

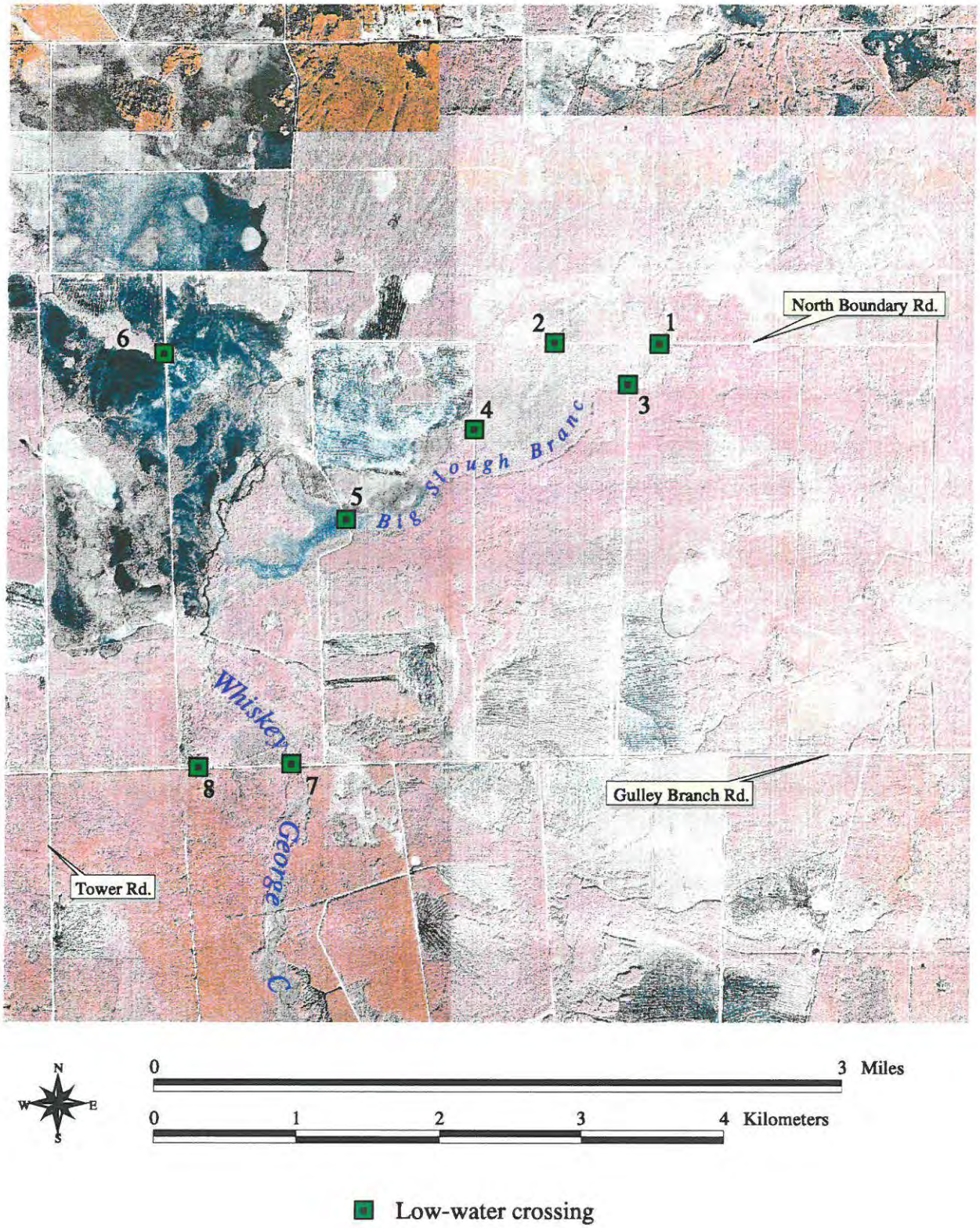


Table 3-1. Monthly rainfall at the demonstration site.

Month	Rainfall (in)	Month	Rainfall (in)
Apr-98	1.9	Jan-99	6.8
May-98	2.3	Feb-99	3.2
Jun-98	1.5	Mar-99	3.4
Jul-98	11.6	Apr-99	7.0
Aug-98	4.2	May-99	7.8
Sep-98	21.8	Jun-99	4.7
Oct-98	1.8	Jul-99	10.1
Nov-98	1.2	Aug-99	6.1
Dec-98	2.1	Sep-99	8.8
		Oct-99	4.11

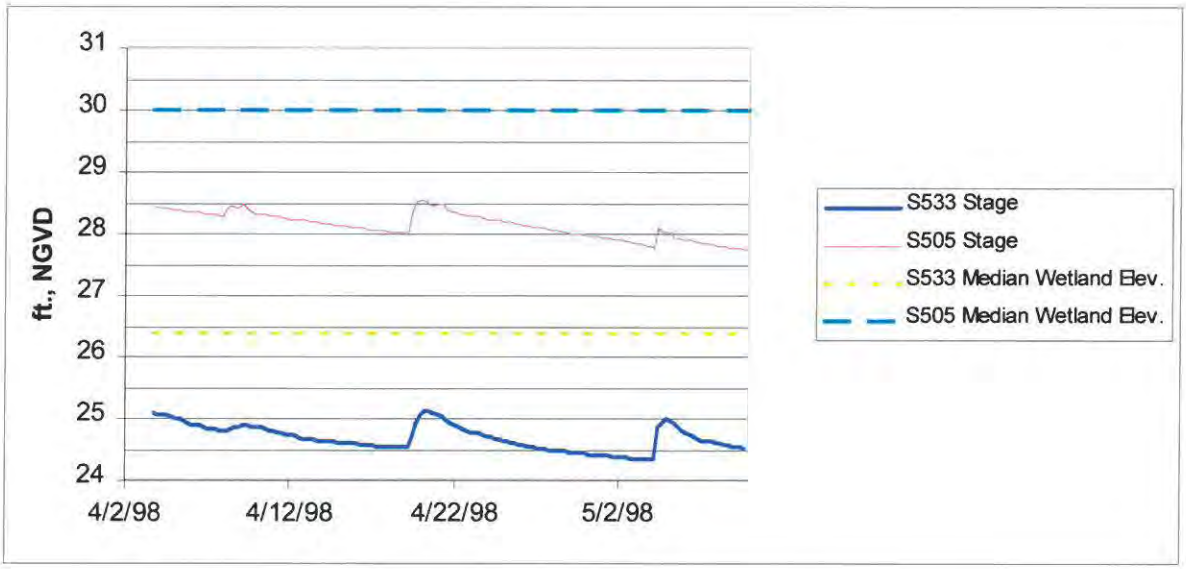


Figure 3-2. Pre-restoration stage at the demonstration (S533) and control (S505) sites

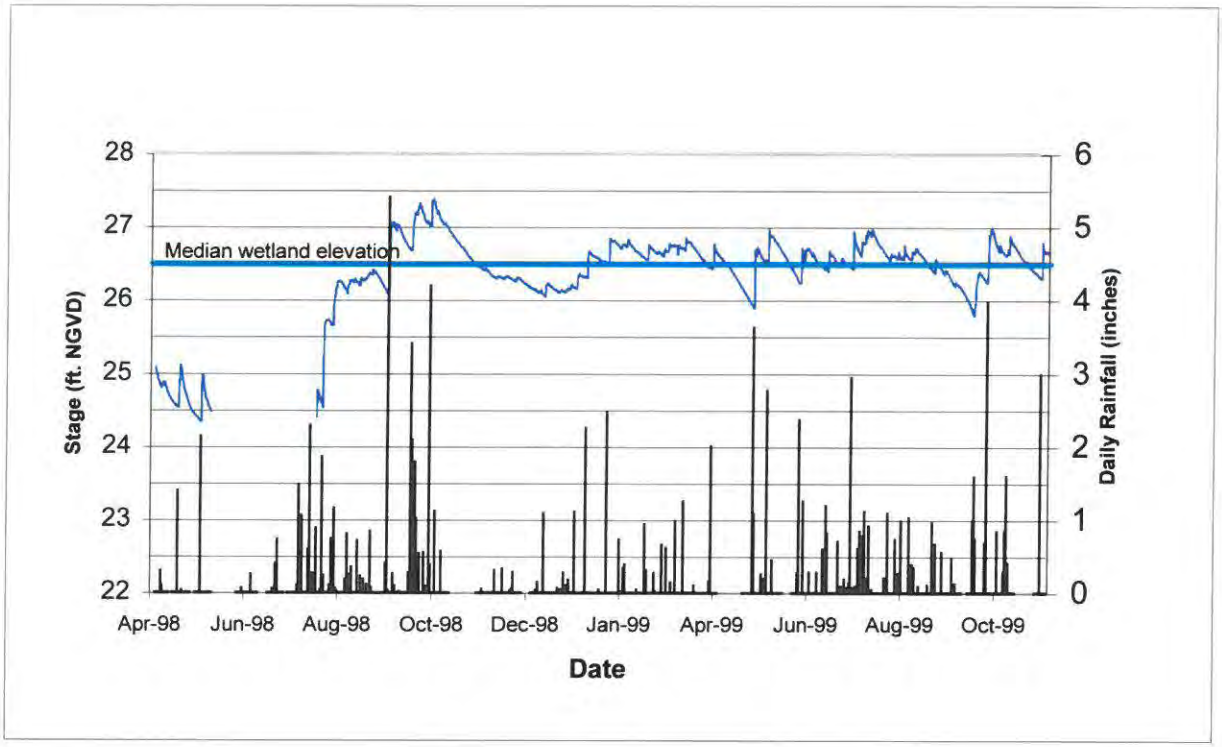


Figure 3-3. Stage and rainfall at the demonstration site (S533).

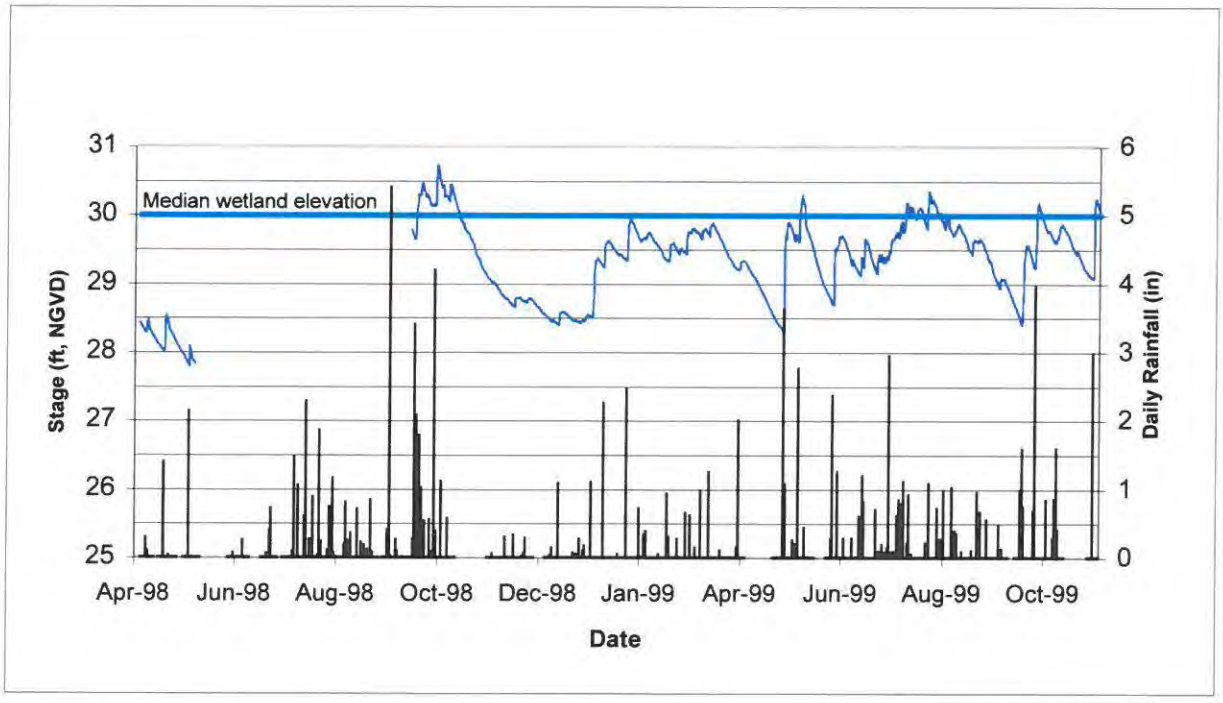


Figure 3-4. Stage and rainfall at the control site (S505).

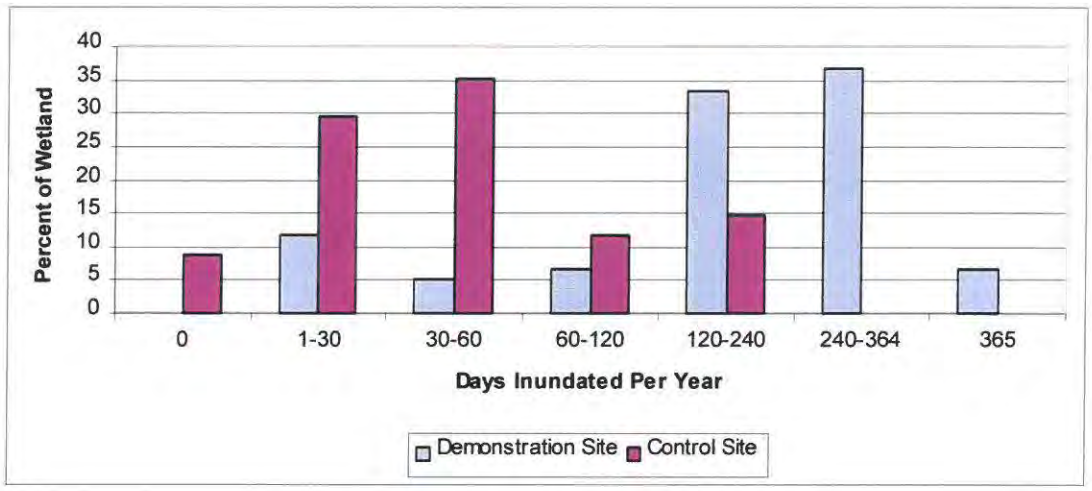
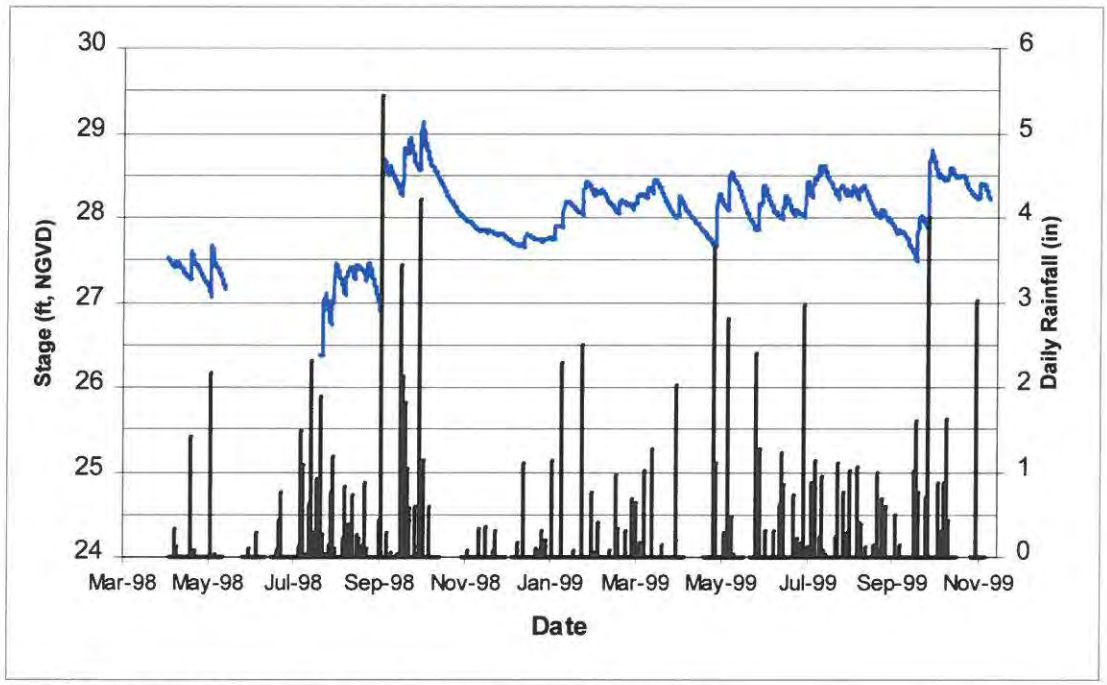


Figure 3-5. Wetland hydroperiods at the demonstration and control sites, water year 1998-1999.



Note: Median wetland elevation not determined at this site; see text.

Figure 3-6. Stage and rainfall at the interior of the demonstration site (S536).

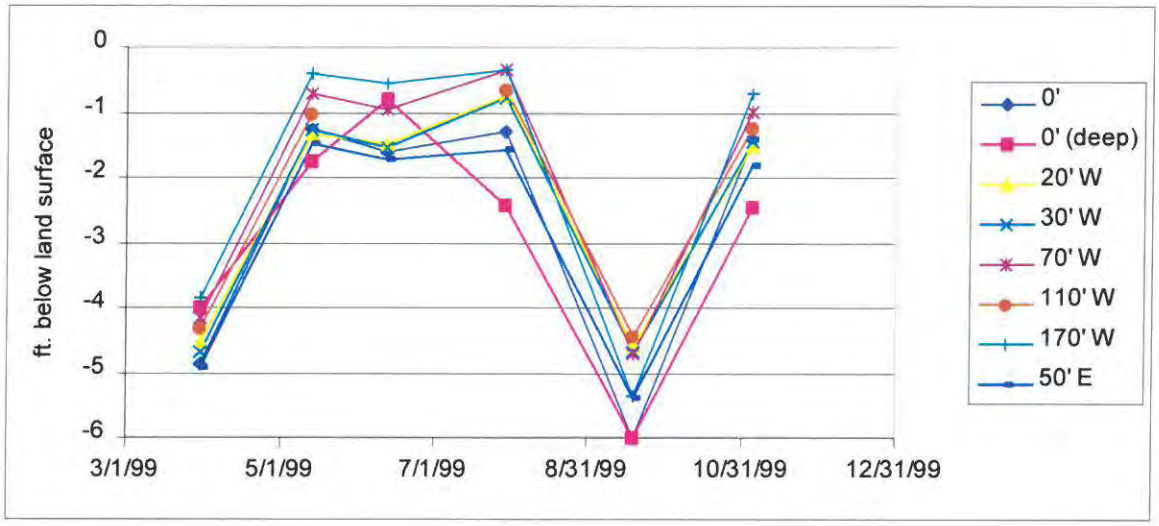


Figure 3-7. Piezometric ground water levels at the control site well array.

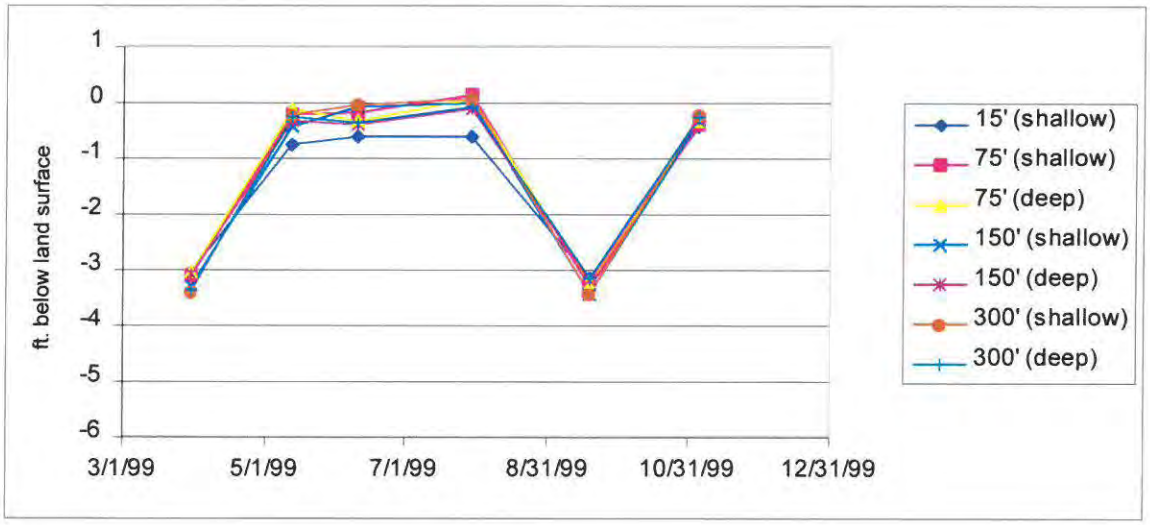


Figure 3-8. Piezometric ground water levels at the demonstration site well array.

Table 3-2. Mean piezometric surface at shallow and deep wells in the demonstration site.

Date	Shallow	Deep	Difference
	ft.		
3/30/99	3.253	3.147	0.107
5/13/99	0.290	0.223	0.067
6/10/99	0.092	0.359	-0.267
7/29/99	-0.080	0.039	-0.119
9/18/99	3.381	3.176	0.205
11/4/99	0.310	0.283	0.027
Average			0.003

WATER QUALITY

Water quality in Tates Hell is generally very good. The area is largely undeveloped, the only significant potential source of water quality degradation being silviculture. No silvicultural activities were conducted on or adjacent to any of the study sites during the monitoring period. Water quality monitoring was conducted for the purpose of establishing baseline conditions, assessing the impacts of restoration activities, and providing background data to support biological observations.

Nutrient levels were very low at all sites throughout the study. Of 107 observations, 52 ammonium values, 55 nitrate-nitrite values, 74 total phosphorus values, and 82 ortho-phosphorus values were at or below laboratory practical quantification limits (PQLs), with most of these also lying below the minimum detection limit (MDL). (PQL is the level at which the analyte can be detected, but not accurately quantified; MDL is the level below which the analyte cannot be detected. The DEP laboratory reports estimated values for samples that lie below the PQL but above the MDL. For values at or below the MDL, the MDL is reported. Data were tabulated for this report exactly as reported by the laboratory.) Heavily left-censored data of this type violate the assumptions of normality and mean-independent variance that are required for traditional parametric statistical analysis. For this reason , the nonparametric Wilkoxon rank sum test (for comparisons between two groups) or Kruskal-Wallis rank sum test (for more than two groups) were used to determine statistical differences in these data (SAS Institute 1995). Analysis is still problematic because none of the many data points that lie below the MDL can be distinguished from one another regardless of whether parametric or nonparametric methods are employed. (While means and standard errors are shown in the water quality figures, standard errors are presented for descriptive purposes only, and are not applicable for discriminatory purposes.)

Previous work conducted in Tates Hell (NWFWMD 1999) found little or no difference between storm event and base flow conditions with respect to nutrient and suspended solids concentrations. To examine this issue at the current study sites, five of the 13 sampling events were timed to occur during or within two days following rainfall events of two inches or greater. For most nutrients, no significant differences were seen between storm and base flow concentrations. However, both ammonium and total suspended solids concentrations were significantly higher during base flow than during storm runoff events (Table 4-1). These results were consistent among demonstration, reference, and control sites. Ammonium produced by ammonification of organic nitrogen in the sediments and suspended solids produced by a number of possible processes apparently accumulate in the water column during low flow conditions, and are flushed out during rain events. Failure to observe elevated nutrient and suspended solids concentrations during storm events—as is commonly observed in streams—was likely due to the low hydraulic gradients, low water velocities, and predominance of natural groundcover in the study area.

For the purpose of comparing the demonstration, control, and reference sites before and after restoration, sampling stations in the demonstration site were divided into upper (S537 and S541) and lower (S533 and S534) sectors. This was not done for the control and reference sites because preliminary analysis indicated minimal differences between upstream and downstream water quality for these sites. Comparisons are presented in Figures 4-1 through 4-7. Due to the limited number of pre-restoration sampling events (two events for most sites, one event for the lower demonstration site) few statistically significant differences between pre- and post-restoration conditions were found.

Overall ammonium N concentrations averaged less than 0.05 mg/L. No statistically significant differences were observed between pre- and post-restoration samples. The reference site was slightly, but significantly lower in ammonium than the other sites. Nitrate-nitrite N concentrations averaged less than 0.02 mg/L, with no significant differences either among sites or between pre- and post restoration. Total Kjeldahl N averaged 0.8 mg/L, with the reference site significantly lower than the other sites.

Total organic carbon concentrations averaged 21 mg/L overall. The lower demonstration site was significantly higher in TOC than the other sites, while the reference site was significantly lower. No significant pre- post-restoration differences were observed.

Interpretation of total P and ortho-P data is particularly problematic due to the overwhelming number of observations at or below the PQL. No significant differences in total P could be detected either among sites or between pre- and post-restoration. Oddly, post–restoration ortho P was significantly higher than pre-restoration for all sites except the lower demonstration site. This difference is difficult to explain, but given the very low concentrations involved, it is believed that the effect may be spurious, or perhaps an artifact.

Total suspended solid concentrations were significantly higher in the upper demonstration site than in other sites. Suspended solids in natural wetlands tend to be largely autocthonous (generated in situ), and the dynamics of solids generation and suspension in wetlands is very complex. None of the suspended solids concentrations observed in this study are unusual, and no explanation is offered for the observed site effect.

The observed higher TKN and TOC values in the lower demonstration site than in the upper demonstration site suggest that the demonstration site functions as a source for these two elements. This is not uncommon in predominantly ombrotrophic wetlands such as Tates Hell. Nitrogen and carbon fixed in the rainfall-fed headwaters of these systems are exported downstream. The control and reference sites did not exhibit this effect. In the case of the control site, this is due to the close proximity of the upstream and downstream stations. The situation for the reference site is less clear. The lack of difference between upstream and downstream stations may be related to the relatively undisturbed nature of the reference site, or possibly to the flow configuration. The downstream end of the demonstration site receives water from a relatively linear system of wetlands, with long, extensive areas of sheet flow that allow for accumulation of

organic carbon and nitrogen in the water. The watershed configuration of the reference watershed is more palmate than linear; that is, a number of small, independent sub-basins each discharges into a common collecting waterway. The longer travel/residence time in the linear system further promotes carbon and nitrogen accumulation.

Nitrogen, phosphorus, and suspended solids concentrations observed in this study are typical for oligotrophic wetlands, and are comparable to those found in natural areas of the Everglades (Kadlec and Knight 1995). As noted earlier, no silvicultural activities took place in or adjacent to any of the study sites during the study period. However, incidental sampling was conducted during the study period at a silviculturally-impacted site approximately 10 miles southeast of the demonstration site. This sampling site was downstream of privately-owned property on which extensive silvicultural land-preparation and "ditch maintenance" activities had been occurring. Samples ranged as high as 1.5 mg/L ammonium N, 3.8 mg/L TKN, and 0.26 mg/L total P. This is a stark contrast to concentrations found at the main study sites, and represents severe water quality degradation, which is undoubtedly of considerable ecological significance. Studies indicate that forestry in North Florida can have a minimal impact on water quality if state BMP guidelines are observed (Frydenborg 1997). It is clear both from casual observation and from water quality impacts that adequate BMPs were not being practiced at this location.

Dissolved oxygen and pH measurements were taken in conjunction with biological sampling at three stations in the upper demonstration site and one each in the control and reference sites. Measurements were taken in wetlands and at top and bottom depths of demonstration and control site ditches. Due to logistic problems and dry conditions, no pre-restoration oxygen or pH monitoring was conducted in the control or reference wetlands, and only two pre-restoration monitoring events were conducted in the ditch sites. Little systematic variation was observed for either parameter (Figures 4-8 and 4-9), except for the expectably lower DO readings at the ditch bottoms. Both DO and pH values were typical for wetlands of this type.

Table 4-1. Mean nutrient and suspended solids concentrations under base flow and storm runoff conditions.

Parameter	Base Flow	Storm Runoff
	----------mg/L----------	
Ammonium N	0.066*	0.017*
Nitrate-Nitrite N	0.017	0.019
Total Kjeldahl N	0.92	0.79
Total Organic Carbon	21.5	22.2
Total Phosphorus	0.023	0.017
Ortho-phosphorus	0.011	0.006
Total Suspended Solids	11.74*	4.73*

*Base flow and storm values significantly different (p=0.05).

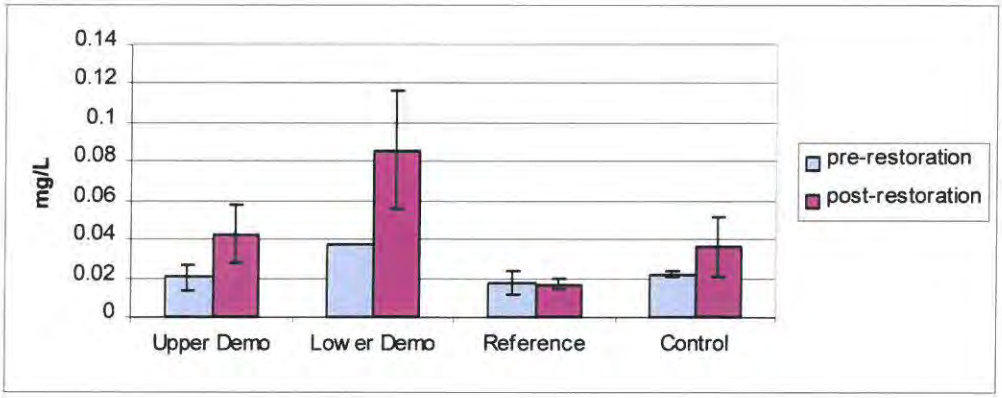


Figure 4-1. Mean ammonium nitrogen concentrations in demonstration, control, and reference sites before and after restoration.

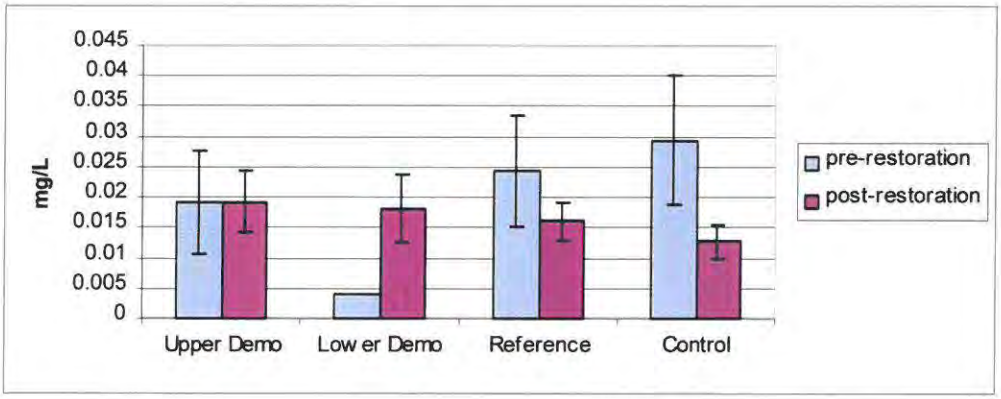


Figure 4-2. Mean nitrate-nitrite nitrogen concentrations in demonstration, control, and reference sites before and after restoration.

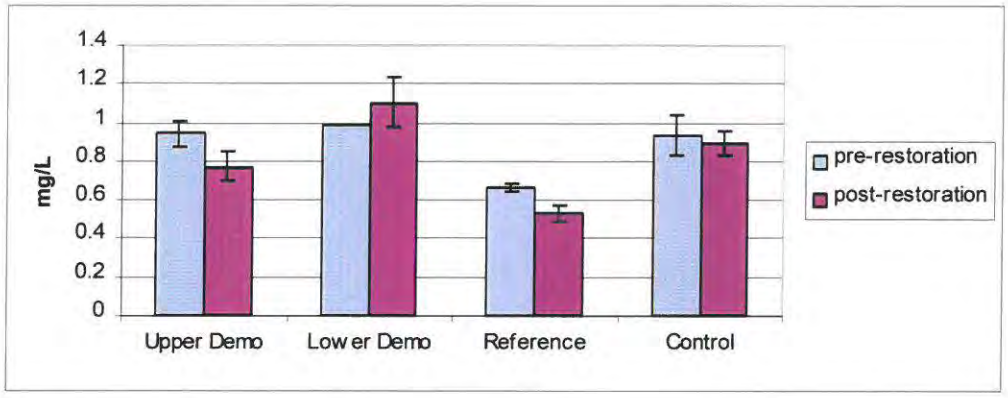


Figure 4-3. Mean total Kjeldahl nitrogen concentrations in demonstration, control, and reference sites before and after restoration.

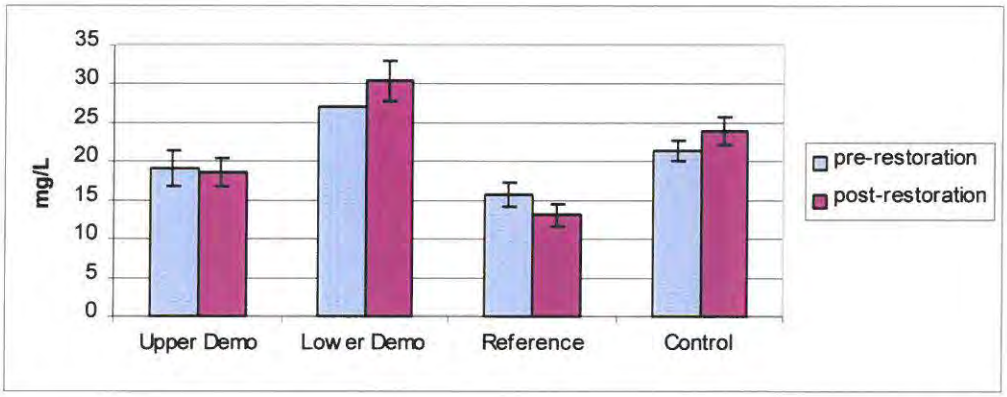


Figure 4-4. Mean total organic carbon concentrations in demonstration, control, and reference sites before and after restoration.

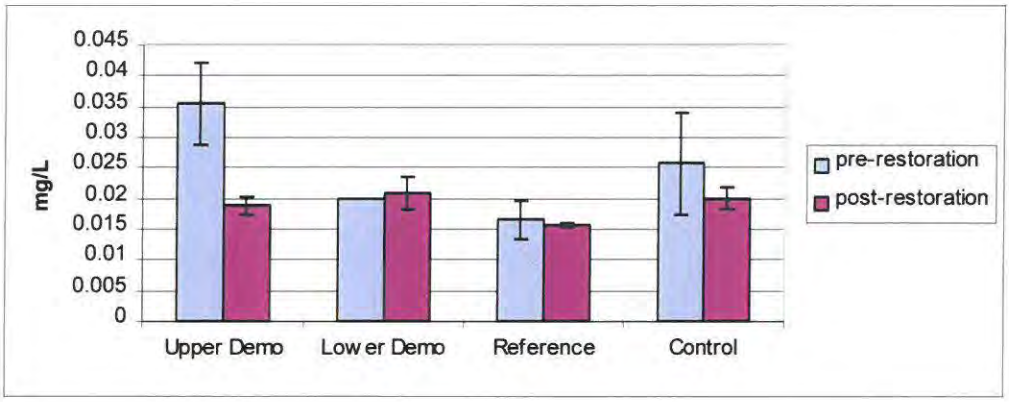


Figure 4-5. Mean total phosphorus concentrations in demonstration, control, and reference sites before and after restoration.

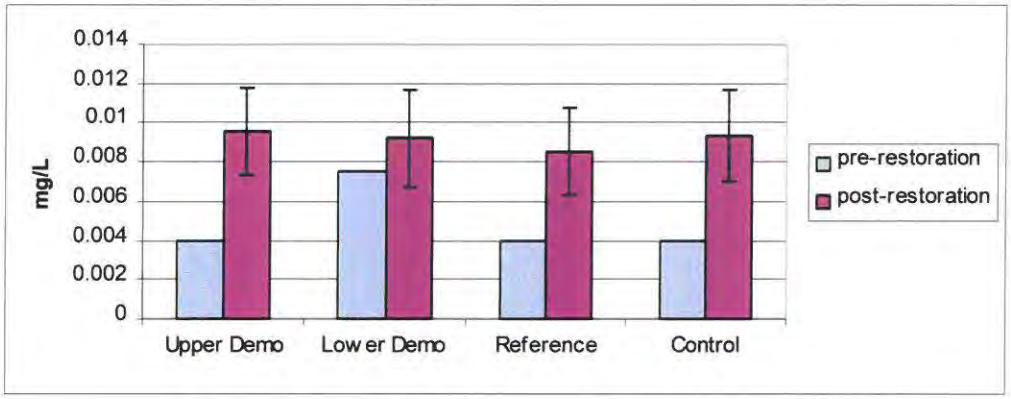


Figure 4-6. Mean ortho-phosphorus concentrations in demonstration, control, and reference sites before and after restoration.

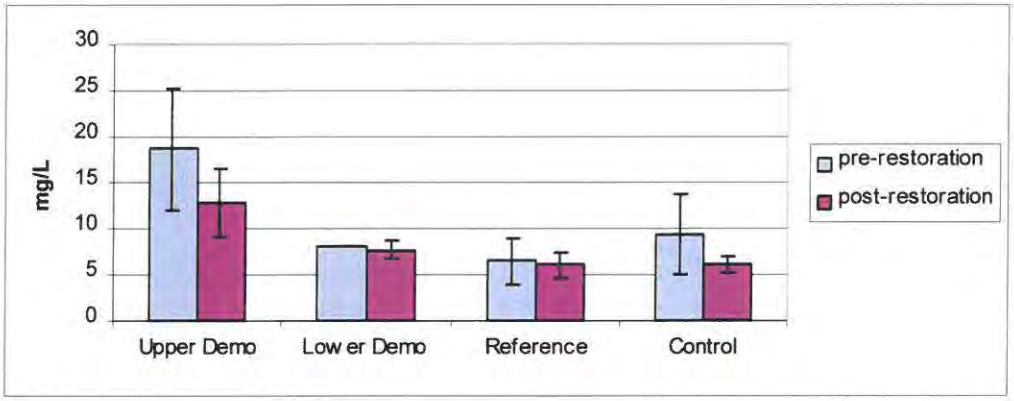


Figure 4-7. Mean total suspended solids concentrations in demonstration, control, and reference sites before and after restoration.

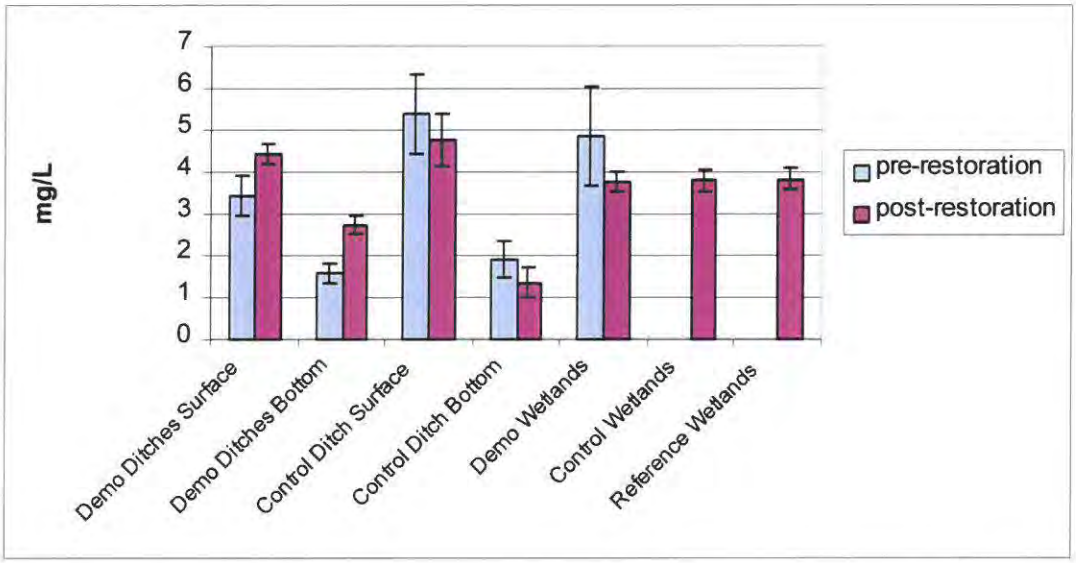


Figure 4-8. Mean dissolved oxygen concentrations in demonstration, control, and reference sites before and after restoration.

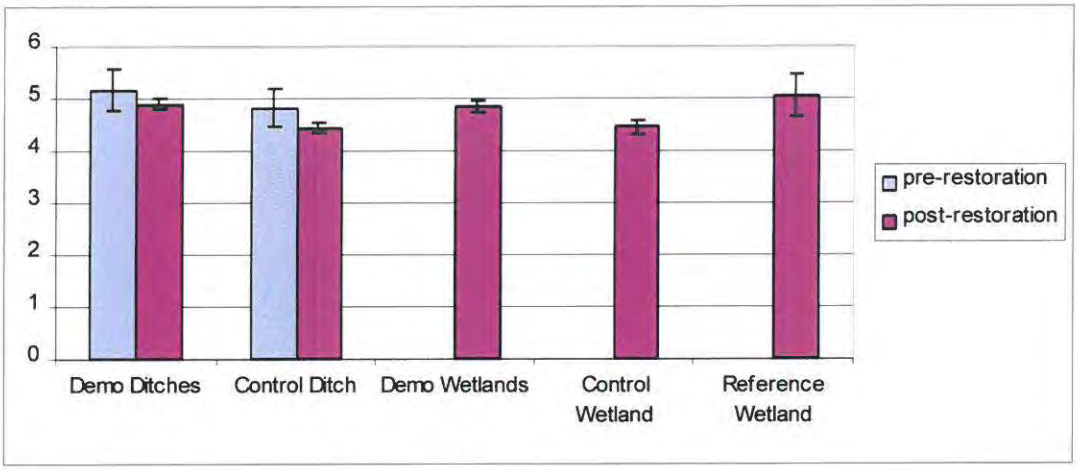


Figure 4-9. Mean pH in demonstration, control, and reference sites before and after restoration.