Publication No. 03-103-139

EVALUATION OF CONSTRUCTED WETLANDS ON PHOSPHATE MINED LANDS IN FLORIDA
VOLUME II

Hydrology, Soils, Water Quality, & Aquatic Fauna

Prepared By
University of Florida
K. L. Erwin Consulting Ecologists
Florida Audubon Society
Missimer International
The Nature Conservancy

under a grant sponsored by

FIPR
Florida Institute of Phosphate Research

November 1997

The Florida Institute of Phosphate Research was created in 1978 by the Florida Legislature (Chapter 378.101, Florida Statutes) and empowered to conduct research supportive to the responsible development of the state's phosphate resources. The Institute has targeted areas of research responsibility. These are: reclamation alternatives in mining and processing, including wetlands reclamation, phosphogypsum storage areas and phosphatic clay containment areas; methods for more efficient, economical and environmentally balanced phosphate recovery and processing; disposal and utilization of phosphatic clay; and environmental effects involving the health and welfare of the people, including those effects related to radiation and water consumption.

FIPR is located in Polk County, in the heart of the central Florida phosphate district. The Institute seeks to serve as an information center on phosphate-related topics and welcomes information requests made in person, by mail, or by telephone.

Research Staff

Executive Director
Paul R. Clifford

Research Directors

G. Michael Lloyd Jr.	**-Chemical Processing**
Jinrong P. Zhang	**-Mining & Beneficiation**
Steven G. Richardson	**-Reclamation**
Gordon D. Nifong	**-Environmental Services**

Florida Institute of Phosphate Research
1855 West Main Street
Bartow, Florida 33830
(863) 534-7160
Fax:(863) 534-7165
http://www.fipr.state.fl.us

EVALUATION OF CONSTRUCTED WETLANDS ON PHOSPHATE MINED LANDS IN FLORIDA

VOLUME II

HYDROLOGY
SOILS
WATER QUALITY
AQUATIC FAUNA

Edited by
K.L. ERWIN, S. J. DOHERTY, M.T. BROWN, and G.R. BEST

Summarizing Research Conducted
from
June, 1993 to May, 1995

By:

G.R. Best, M.T. Brown, T.L. Crisman
Univ. of Florida, Dept. Env. Eng. Sci. & Center for Wetlands
K.L. Erwin
Kevin L. Erwin Consulting Ecologists
D.A. Graetz, K.R. Reddy
Univ. of Florida, Dept. of Soil and Water Sciences
H. Kale and P. Pritchard
Florida Audubon Society
T.M. Missimer, C.W. Walker, A. Owosina
Missimer International
M.J. Deuver
The Nature Conservancy

FINAL REPORT
FIPR PROJECT 92-03-103

Prepared for

Florida Institute of Phosphate Research
1855 West Main Street
Bartow, Florida 33830

Contract Manager: Steven G. Richardson

November, 1997

DISCLAIMER

PERSPECTIVE

EVALUATION OF CONSTRUCTED WETLANDS ON PHOSPHATE MINED LANDS IN FLORIDA

Construction of wetlands to replace natural wetlands damaged or destroyed by mining activities has been required by state law since 1975. The degree of success in replacing those mined wetlands has been debated for many years. In an effort to shed some light on the subject, representatives of the phosphate industry approached FIPR to conduct an evaluation of constructed wetlands. By late 1991 an *ad hoc* committee, including representatives from government, industry, environmental organizations and the scientific community, was formed to develop the project. In 1993, a multidisciplinary team of research scientists received a grant from FIPR to evaluate wetland construction on phosphate mined lands in Florida. The general approach was to assemble the data available from various reports and company or agency files and to observe as many constructed wetland sites as possible. A limited amount of descriptive data was also taken during the site visits. A Wetlands Research Advisory Committee (WRAC) was formed to provide critical review of the project, and the WRAC members' valuable input is here acknowledged.

The report is divided into three volumes. The first volume summarizes the conclusions and recommendations of the entire research team. The second volume contains the subgroup reports on Hydrology, Soils, Water Quality, and Aquatic Fauna. The third volume contains the subgroup reports on Vegetation, Wildlife, and Ecosystem and Landscape Organization.

The reader is referred to the following related projects and reports:

Brown, M.T. and R.E. Tighe (Eds.). 1991. Techniques and Guidelines for Reclamation of Phosphate Mined Lands. FIPR Publication No. 03-044-095.

Crisman, T.L., W.J. Streever, J.H. Kiefer and D.L. Evans. 1997. An Evaluation of Plant Community Structure, Fish and Benthic Meiofauna and Macrofauna as Success Criteria for Reclaimed Wetlands. Final Report FIPR Project 88-03-086.

Cowell, B.C. 1997. Meiofauna and Macrofauna in Six Headwater Streams of the Alafia River, Florida. FIPR Publication No. 03-101-130.

Richardson, S.G. and C.D. Johnson. 1998. Forested Wetland Restoration and Nuisance Plant Species Management on Phosphate Mined Lands in Florida. Proceedings of the 1998 National Meeting of the American Society for Surface Mining and Reclamation.

Steven G. Richardson
FIPR Reclamation Research Director

TABLE OF CONTENTS

SECTION 2

AN EVALUATION OF CONSTRUCTED WETLANDS ON PHOSPHATE MINED LANDS IN FLORIDA

HYDROLOGY

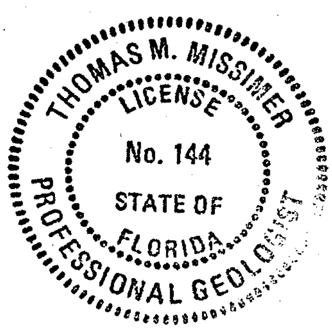
T. M. MISSIMER, C. W. WALKER, M. J. DUEVER AND A. OWOSINA

prepared for

Kevin L. Erwin Consulting Ecologist, Inc.
and
Florida Institute of Phosphate Research

by

Missimer International, Inc.
8 140 College Parkway, Suite 202
Fort Myers, FL 33919



Thomas M. Missimer, P.G.
Professional Geologist #144

2.1 EXECUTIVE SUMMARY

During the process of mining phosphate matrix the landscapes of the Florida phosphate mining districts are greatly altered in terms of both the surface environment and the subsurface hydrogeology. Upon the completion of mining, it is desirable to restore the surface environment into a viable, functional, and productive condition. One of the most significant factors controlling the viability of the surface environment is the hydrologic character. There is a unique interrelationship between the type of environment and the hydrology, which dictates the distribution and function of all types of wetland and upland ecosystems.

It is a specific goal of all reclamation efforts to restore wetland areas so as to meet the national goal of no net loss of wetland habitat. In order to successfully restore or to create wetlands it is necessary to thoroughly understand the hydrology of the watersheds in which the wetlands reside and the hydrology of specific wetland types. Without some baseline information on the watershed hydrology, it is not possible to develop a viable restoration plan for the mined watershed. One very important fact is that the water balance of the restored watershed will not necessarily function in a completely similar manner to the pre-mined watershed. This water balance is fundamental in the control of both surface-water and groundwater flows. The creation of wetland environments can only be successful if the hydrology at the location of the new wetland matches the required hydrologic regime of the specific wetland type desired.

Changes in the hydrogeologic framework of the shallow aquifer system tend to cause permanent changes to the water balance in each part of the created watershed. For example, about 40% of the created watersheds (average) have clay as a shallow substrate compared to a much smaller percentage in the natural landscape. The clay occurs either within former settling ponds or as mixed overburden. Therefore, the created wetlands must be located in proper relation to the new hydrologic regime. Restoration efforts attempting to locate wetlands at their former geographic positions alone are more likely to have a high percentage of failures. Because of changes to the watersheds, it may be necessary to locate wetland environments lower in the new watersheds and it will be necessary to increase the size of the land area surrounding isolated wetlands in order to compensate for the increased amount of clay in the new environment.

Prior to mining, the Florida phosphate districts contained about 11 different types of wetlands of which about 6 of these wetland types have been successfully created. This does not mean that wetland restoration efforts have failed, because over a period of time the created wetlands will evolve into the types most suited for their new hydrologic regime and position in the watershed. All wetland types evolve with time and sufficient time must be allowed before the restoration efforts can be evaluated.

Wetland creation efforts can be greatly improved by clearly assessing the hydrology of the restored watershed in terms of the geomorphology and water balance at different locations in the basin and in terms of the regulations applied to mine reclamation. It is necessary to establish a cooperative effort between the mining companies and the regulatory agencies to enhance the reclamation efforts by incorporating the hydrologic regime into both the mining plan and the proposed wetland locations after mining. Minor adjustments in the mining plan can increase the potential success rates of reclamation without adding significant costs. Cooperation of the regulatory agencies in providing flexibility in the location and evaluation of created wetlands with specific consideration of the new watershed hydrology would greatly increase the success rate for created wetlands.

2.2. CONTENTS

LIST OF FIGURES

LIST OF FIGURES - Continued:

LIST OF TABLES

2.3. INTRODUCTION

2.3.1. GOALS OF MINE RECLAMATION AND SUCCESS CRITERIA

In the process of mining phosphate matrix, it is necessary to significantly alter both the surface of the land and the corresponding shallow subsurface. The process of resculpting and revegetating the mined landscape back into some environmentally acceptable condition is the basic goal of mine reclamation. Currently, what is defined as "environmentally acceptable" is to mimic the former contours of the pre-mining landscape and to reestablish the environmental conditions at the land surface as close to the pre-mining condition as possible. It is also part of the goal to match or exceed the acreage and diversity of wetland communities. A part of the reclamation procedure is to build watersheds or stream basins to the approximate characteristics of the watersheds removed by mining. In the past, the channels of even large streams or rivers were moved in order to mine the phosphate, but in the modern mining era, this practice is no longer acceptable.

A major objective of the mining restoration process is to be able to gage the success of any mine reclamation project. In many cases the primary method of ascertaining the "success" of a project includes counts of the number of wetland trees that survive for some pre-established time period or assessment of the percentage of overstory canopy cover or the percentage of the understory herbaceous ground cover as related to some "reference" natural site. Despite considerable effort to reestablish the pre-mining wetland types and diversity, little success has been achieved in some areas while other projects appear to be successful to varying degrees. The newer created wetlands have not had sufficient time to develop and therefore the degree or success cannot presently be determined at this time.

A fundamental question to be assessed is "why do some wetland restoration programs fail to achieve an acceptable level of success despite the fact that the landscape has been contoured to match the pre-mining condition and wetland plants have been planted at the same general locations". In the mining process and during reclamation, the hydrogeology of the shallow aquifer system is altered to a large degree. The phosphate matrix removal, the geometry of the mining cuts, and the production of clay and sand byproducts all contribute to major changes in the hydraulic conductivity of the shallow aquifer system. It is the purpose of this report to document the effects of altering the hydrologic system on the success of wetlands restoration efforts.

2.3.2. THE ROLE OF HYDROLOGY IN WETLANDS CREATION

Wetland plant communities occupy niches in the natural system controlled primarily by the hydrology of the specific location. Without a sufficient supply of water over an appropriate part of the year, any given type of wetland could not develop or remain in a healthy condition. The hydrologic regimes of a wetland, including the timing each year and the depth and duration that the area is flooded or the soil is saturated, are the critical elements providing for growth of the plant community and control of fire. The flooded condition also allows wetland plants to survive potential competition from upland plant communities, which are not adapted to the soil types and flooded conditions within typical wetland sites.

The location of areas having the natural hydrologic regime necessary to allow the successful growth of wetland plants is solely dependent on the water balance of the location. The water balance at any location is controlled by the physical framework of the shallow aquifer system, the altitude and general topographic characteristics of the landscape, and the basinwide climatic conditions. Once wetland plant communities become established, they can actually modify the soil conditions by deposition of organic detritus over a period of many years to change the type of plant community with time or allow an increase in size of the feature. Wetlands and hydrology cannot be separated because they are fully and totally interrelated based on physical occurrence and continued success. However, it has been noted that hydrology is the most important variable that distinguishes wetlands from other ecosystems and wetlands from each other, there has been insufficient quantitative work to reveal why and how hydrology influences wetland type (Brinson, 1993).

2.4. OVERVIEW OF WETLANDS HYDROLOGY

2.4.1. GEOLOGIC FRAMEWORK, WATERSHED AND WETLAND HYDROLOGY

INTRODUCTION

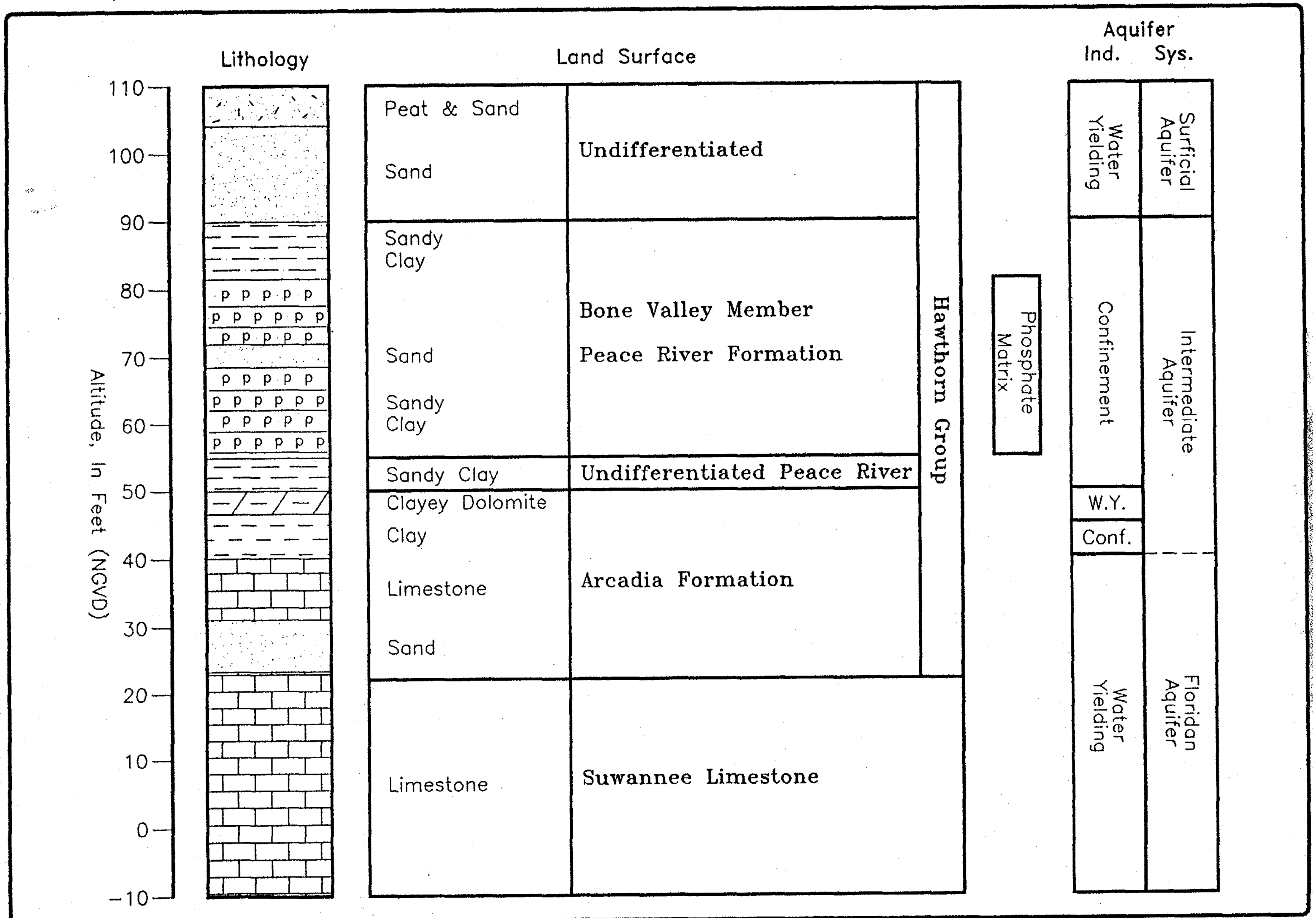
There are two principal areas of phosphate mining activity within the state of Florida. The most economically productive area occurs in the Central Florida Phosphate District and the less productive deposits are located in the Northern Florida Phosphate District. Each district has its own distinctive hydrogeologic characteristics but both phosphate deposits occur within the Miocene-age Hawthorn Group. In the Northern District the phosphate deposits are mined from the Statenville Formation which consists of interbedded sands, clays and dolostones. The Central District phosphate deposits occur within the Bone Valley Member of the Peace River Formation. This unit consists of pebble or larger size phosphate material and sand-sized phosphate grains in a matrix of clay and quartz sands.

The very phosphatic section of the Bone Valley Member (the phosphate ore matrix) grades upward into less phosphatic to non-phosphatic clayey sands. A reference core (Scott, 1988) drilled in Polk County (northern part of the Central Phosphate District) through the Hawthorn Group is displayed in Figure 2.4.1.1. Also shown in this figure are the aquifer systems with their more permeable and confining units. In this particular core, the phosphate matrix occurs approximately 40 feet below land surface and is about 25 feet thick. Both the depth to and thickness of the matrix zone vary considerably throughout the Central District.

The mined phosphate matrix in the Northern District occurs in the upper, less dolomitic portion of the Statenville Formation. A hydrogeologic column of this district is displayed in Figure 2.4.1.2. In comparing the lithologies of the Central and Northern Districts (Figure 2.4.1.1 and 2.4.1.2) phosphate bearing sections it can be seen that the Northern District contains considerably more clay than its Central District counterpart. This greater clay content results in much lower hydraulic conductivities of the materials and therefore provides a higher degree of confinement than is realized in the Central District. The higher clay content of the overburden in the Northern District also relates to greater clay to sand waste ratios generated in the benefication process than in the Central District, resulting in differing reclamation problems.

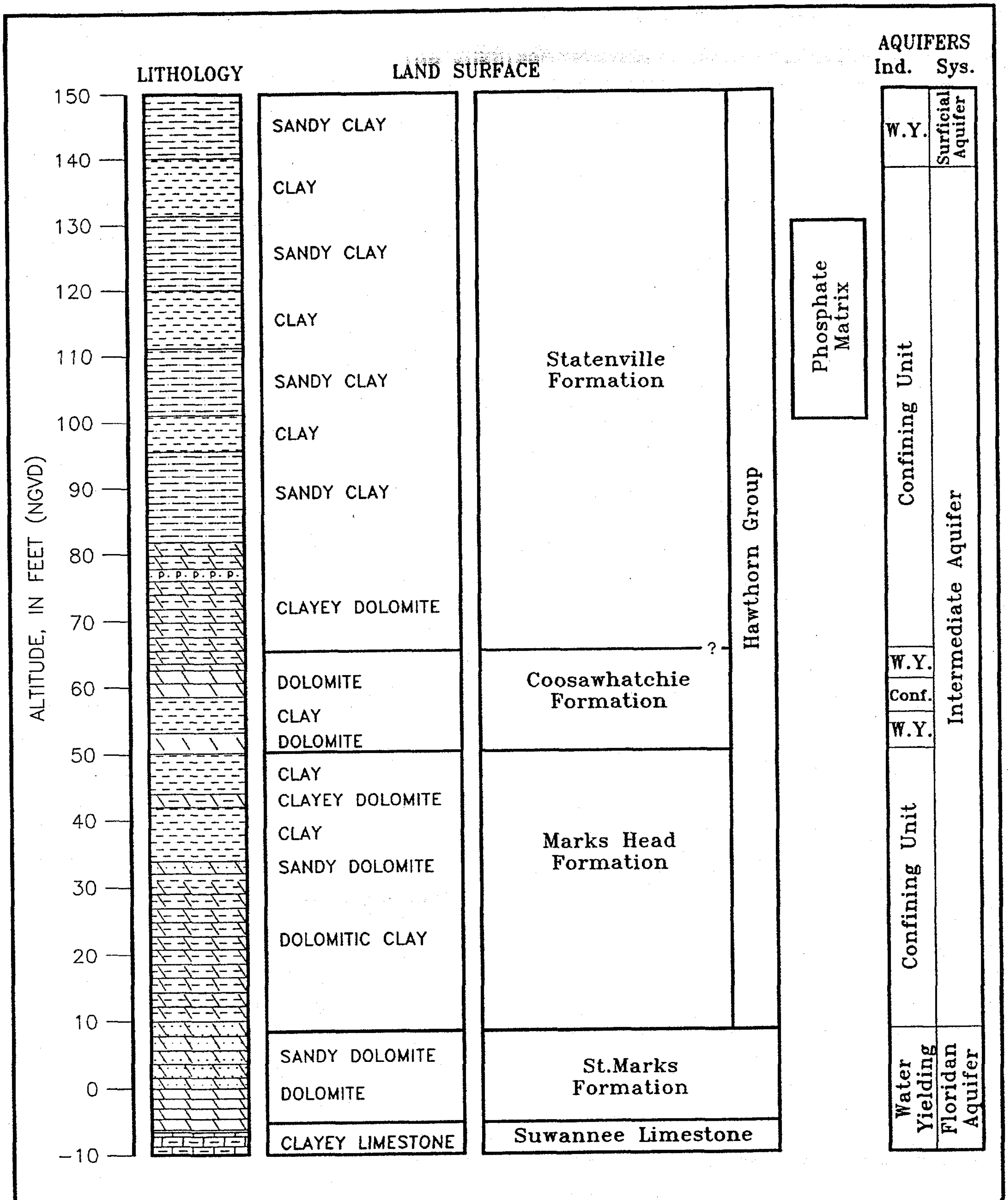
HYDROGEOLOGIC FRAMEWORK - NATURAL STATE

In both the Central and Northern Phosphate Districts, three principal hydrogeologic units are recognized as defined by the Ad Hoc Committee on Florida Hydrostratigraphy Unit Definition (1984). These units are the surficial aquifer system, the intermediate aquifer system and the Floridan aquifer system. Mining and reclamation activities normally involve only the upper two aquifer systems.



MISSIMER INTERNATIONAL	Pr Name: CENTRAL FLORIDA PHOSPHATE	Groundwater and Environmental Services
	Pr.No. FH4-8 DWG No. FH4-8A.DWG Date: 08/11/94 Rev.No. 3	

FIGURE 2.4.1.1 CENTRAL FLORIDA PHOSPHATE DISTRICT. HYDROGEOLOGIC COLUMN FROM CORE W-8879, GRIFFIN #2, POLK COUNTY (MODIFIED FROM SCOTT, 1988).



MISSIMER INTERNATIONAL

Pr Name: CENTRAL FLORIDA PHOSPHATE		
Pr No. FH4-8	Date: 08/11/94	Groundwater and Environmental Services
DWG No. FH4-8B.DWG	Rev.No. 3	

FIGURE 2.4.1.2. NORTHERN FLORIDA PHOSPHATE DISTRICT. HYDROGEOLOGIC COLUMN FROM CORE W-15121. BETTY #1. HAMILTON COUNTY (MODIFIED FROM SCOTT, 1988).

Surficial Aquifer System

In the Central District the surficial aquifer system is composed of undifferentiated sedimentary deposits of Quaternary age. These sediments are predominantly fine to medium sand, becoming more clayey and phosphatic with increasing depth (Hutchinson, 1978). This system ranges in thickness from a few feet to more than 50 feet. Depth to the water table ranges from above land surface to as deep as 20 or more feet below surface during dry periods and in higher areas. The position of the water table varies seasonally within any watershed. Uplands have generally greater seasonal water level fluctuations than do the lower wetlands and stream valleys. Water movement in the surficial aquifer system is from the higher recharge areas to discharge areas that are normally topographically low areas such as streams, lakes, and wetlands. The rate that the water flows through the surficial aquifer is dependent on the hydraulic properties of the comprising sediments and the gradient (slope) of the water table. Flow rates through the surficial aquifer underlying wetlands can be measured in feet per year as these rates are quite slow. Recharge to the surficial aquifer occurs from infiltration of rainfall and downward percolation to the water table. The recharge contributes to groundwater storage which in turn either recharges the underlying intermediate aquifer system or discharges in topographically low places.

The hydraulic properties of the surficial aquifer system in the Central District unmined areas have been evaluated (Hutchinson, 1978; Duerr et al, 1987; and Lewelling and Wylie, 1993). Transmissivities from two aquifer tests in the Central District gave values of 1,600 and 2,200 ft^2/d with specific yields of about 0.05 and 0.005, respectively. Transmissivity values at three unmined basin sites, ranged from 2.5 to 720 ft^2/d and averaged approximately 170 ft^2/d. Hydraulic conductivities of the surficial aquifer system in these unmined basins were estimated to be from less than 0.1 to 17.9 ft/d with an average value of 4.4 ft/d.

In the Northern Phosphate District the surficial aquifer system is composed of sands, sandy clays and clayey sands. This aquifer system is generally less than 15 feet thick but can be of much greater thickness locally. Water levels are usually at or near land surface except during very dry periods (Burnson, 1982). Recharge is from downward percolation from rainfall and discharge is vertically to the intermediate aquifer system or horizontally to swamps, lakes, and streams. Hydraulic properties of the surficial aquifer system in this district have not been precisely determined but it is estimated that hydraulic conductivities are less than in the Central District due to the finer grain nature of the comprising sediments.

Intermediate Aquifer System

The top of the intermediate aquifer system in the Central District corresponds to the top of the Bone Valley Member of the Peace River Formation. The base of this system lies within the Hawthorn Group Arcadia Formation. The sediments composing the intermediate aquifer system are a mixture of siliciclastics and limestones and dolomites. The upper portion of this system contains the phosphate matrix. Generally, the limestones and dolomites are water-bearing, while the fine siliciclastics serve as confining units. Overall, the intermediate aquifer system in this area can be considered to have fair to poor water yielding properties.

The aquifer system ranges from 125 to more than 400 feet thick, thickening from north to south in the Central District (Lewelling and Wylie, 1993). In the Lake Hamilton area, approximately 10 miles northeast of the Central District, the intermediate aquifer system is thought to be in direct connection with the underlying Floridan aquifer system (Hutchinson, 1983). This aquifer system is recharged by downward leakage from the surficial aquifer system and more directly through sinkholes and abandoned mine pits that breach the semiconfining units (Hutchinson, 1978), particularly in the southern portion of the Central District (Gilboy, 1988). Lewelling and Wylie (1993), determined that differences in the potentiometric surface between the dry season and the wet season are less than 8 feet, despite the aquifer system being a major source of water supply throughout much of DeSoto, Hardee, Highlands, Hillsborough, Manatee and Polk counties. Transmissivities of the intermediate aquifer system in the Central District are fairly low ranging from 160 to almost 800 ft^2/d, with storage coefficients of 0.001 to 0.0001 (Kelley, 1988).

The intermediate aquifer system in the Northern Phosphate District is composed of elastics and carbonates of the Hawthorn Group. The upper part of the system is the Statenville Formation which contains the phosphorites currently being mined in Hamilton County. Dolomites of the Coosawhatchie Formation, the middle portion of the aquifer system, yield water in some of the northern areas., Sands of the Statenville are thought to be fairly low water producers, but domestic wells tap this water source.

The Marks Head Formation, composed primarily of dolomitic clays, corresponds to the base of the intermediate aquifer system and is the confining unit for the Upper Floridan Aquifer. Recharge to the intermediate aquifer system is primarily from water leaking downward from the surficial aquifer and from direct surface water contribution where the upper intermediate aquifer has been breached by the mining process. Discharge from this system is both downward through leakage and laterally along the Cody Scarp (Burnson, 1982).

<u>Floridan Aquifer System</u>

Throughout most of its extent, the Floridan aquifer system is generally comprised of two general aquifer units, the Upper and Lower Floridan aquifers. These units are usually separated by less permeable dolostones and limestones, which act as the middle confining beds. In this study, only the Upper Floridan aquifer will be considered. Regional hydrogeologic units within the Upper Florida aquifer, in descending order, are: the Suwannee permeable zone, the lower Suwannee-Ocala semiconfining unit, the Ocala-Avon Park moderately permeable zone, and the Avon Park highly permeable zone.

In the Central Phosphate District part of the lower Arcadia Formation or the Suwannee permeable zone is the uppermost permeable unit in the Upper Floridan aquifer. Lying between 90 and 300 feet beneath land surface in this district, it is confined above by clayey elastics and carbonates of the Hawthorn Group, and below by low permeability limestones, of the lower Suwannee-Ocala semiconfining unit. The Upper Floridan thickens from about 1000 feet in the northern areas of the district to approximately 1400 feet in the southern areas (Kelley, 1988). Transmissivities of the Upper Floridan aquifer are known to be highly variable, both laterally and vertically within the different permeable units. This aquifer is the principal source of water for consumptive use in the Southern West-Central Florida Ground-Water Basin (Kelley, 1988). Recharge to the Upper Floridan aquifer occurs primarily in the northern, north-central and eastern portions of the district and discharge occurs along coastal and riverine systems.

The Upper Floridan aquifer in the Northern District coincides with the top of the St. Marks Formation. The depth to this formation is approximately 140 feet below land surface in the mining area and gradually gets deeper toward the east. The potentiometric surface of this aquifer is about 50 to 60 feet above the top of the aquifer. Transmissivities have been reported to be greater than 1000 ft^2/d in much of this district (Andrews, 1990).

SURFACE WATER HYDROLOGY

A description of the surface water hydrology for both the Central and Northern phosphate districts is presented in the FIPR Hydrologic Model documentation (1991). This information is presented in this document verbatim.

Central District

> There are numerous perennial and ephemeral swamps and basins of interior drainage in the low-lying areas, while in the ridge areas, sinkholes, lakes and closed basins are common. The major surface water drainage basins include the Peace River, Alafia River, Manatee River, Little Manatee River, and portions of the upper reaches of the Hillsborough River. Most of the river basins are considered poorly drained, have flat slopes, and are characterized by shallow channels with broad flood plains and sluggish flow during low flow periods (Hammet, 1985).
>
> Rainfall is the source of all fresh water, with rainfall amounts varying seasonally and annually with longer-term variations in rainfall, including droughts. The mean annual rainfall in Bartow, Florida, located at the center of the region, is 49.94 inches (Palmer, 1990). Approximately 60 percent of the rainfall occurs during the rainy season from May through October (SWFWMD, 1987). Some rainfall infiltrates into the soil and surficial aquifer where it eventually returns to the surface as streamflow or leaks into the deeper confined aquifers. Approximately 70 percent of the rainfall is estimated to be lost to evapotranspiration annually.

Northern District

> The major surface water basins in the Northern Florida District are the Alapaha and Suwannee Rivers. The Alapaha River flows through a mature karst terrain characterized by many sinkholes, stream sinks, and springs (Fernald and Patton, 1984). About 40 percent of the entire flow of the river is captured by several sinkholes in the streambed (Ceryak, 1977). After flowing about 19 miles

underground, the river emerges at two springs. The Suwannee River originates in Georgia and flows through the northern phosphate district, eventually draining about 10,000 square miles before discharging into the Gulf of Mexico.

Rainfall at Lake City averages 52.4 inches (Fernald, 1984), with approximately 50 percent of the annual total falling during the summer months (June through September). Summer rainfall is associated with local thunderstorms, and winter rains occur as a result of frontal systems moving though the district. Frontal rainfall events more commonly result in uniform rainfall distribution with longer durations than summer rainfall.

DISCUSSION

The geologic framework of the two phosphate mining districts greatly influences surface and groundwater features of the associated watersheds and the natural wetlands that occur within these watersheds. On a much smaller scale, the hydrology of individual wetlands are largely dependent on their type and distribution of geologic materials present and the 3-dimensional shape (geomorphology) of the watershed system at a point in time. Dynamic processes continually occur within any watershed and therefore the resultant biological, geological, and hydrological features are also in constant change. Therefore, wetland locations and type tend to naturally relocate and/or change character as they respond to changes in the hydrologic system over time.

It is understood that certain regions within a watershed contribute runoff to the storm hydrograph while other areas act as recharge or storage zones. Important factors to evaluate in determining whether an area contributes to runoff (or to the groundwater) include its physical position with respect to the natural channel, its soil properties and the storm characteristics (Hewlett, 1974). Valley bottoms are generally considered to be the areas that contribute to streamflow while higher elevations constitute recharge areas. The area in between the valley bottoms and the higher places, often referred to as the dynamic zone, may be either contributing or recharging, depending upon the storm size and temporal characteristics and antecedent soil water content and soil properties. In order for wetlands to exist in this dynamic zone, the area must be “contributing” to the surface water volume a good part of each year (sufficient hydroperiod).

2.4.2. THE WATER BALANCE AND WETLANDS HYDROLOGY

INTRODUCTION

All types of wetlands occur in nature because of the hydrologic conditions which allow the successful growth of specific plant communities. Although the subsurface geology and soil conditions are important in the initial establishment of a wetland environment, the fundamental factor influencing the longevity and health of any wetland environment is its hydrologic regime. The hydrologic regime of any given plant community influences the type and composition of plant species and a significant change in the hydroperiod normally causes a change in the composition of the community, succession of the community, or the failure of the community

(Ewel, 1991). Therefore, all of the hydrologic factors affecting the hydroperiod bear great significance to the continued success of a wetland community.

A fundamental question revolves around what are the hydrologic factors within the hydrologic cycle that are most important to the continued success of wetland environments. The water balance is governed by the simple principle that the balance between inflow and outflow factors causes a change in the quantity of water stored in any system, whether it be a wetland, a stream, or some part of the aquifer system lying beneath an upland environment. Depending on the part of the hydrologic system analyzed, there can be rather large changes in the water balance for any given set of hydrologic conditions. This is the fundamental reason why different types of wetland communities occur in different parts of the hydrologic system. The different parts of the hydrologic system are governed by the altitude of land surface, the hydraulic conductivity of the surficial aquifer system, and proximity to drainage features.

It is important to carefully review the water balance factors and relate these factors to the causation of wetland development. The simplest form of the water balance equation is:

$$\Delta S = \text{inflow} - \text{outflow} \quad (1)$$

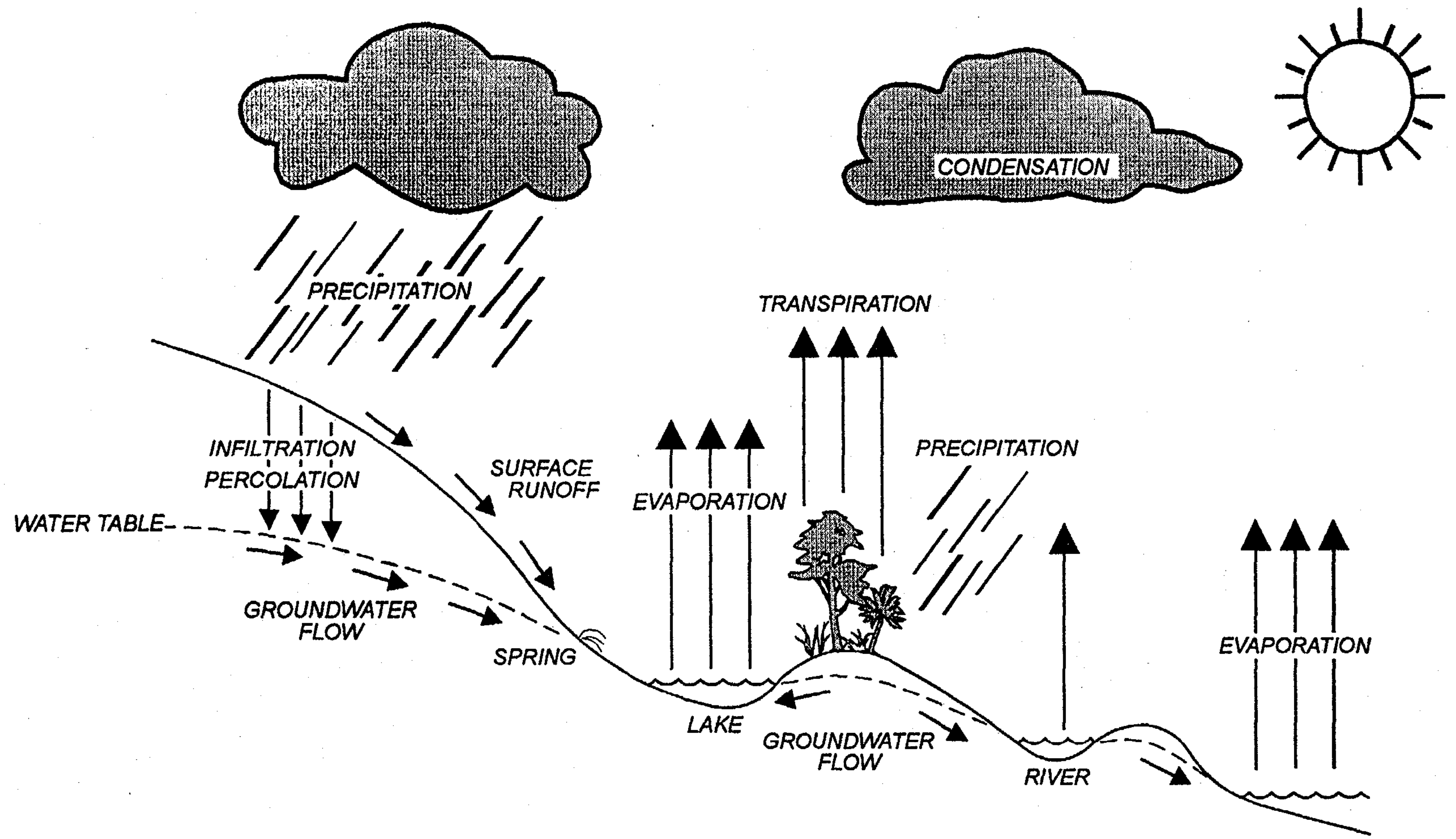
where, ΔS = the change in storage

Important natural inflow factors include rainfall, groundwater inflow (both horizontal and vertical), and surface-water inflow (overland and interflow components). Natural outflow factors include evaporation, transpiration, groundwater outflow (vertical and horizontal), and surface-water outflow. In many cases the activities of man significantly affect the natural water balance. The outflow can be affected by pumping and utilization of water from the aquifer system, by the enhancement or channelization of drainage, or by the alteration of the geology of a basin by mining or other activity. Inflow can be affected by irrigation systems or the location of surface water impoundments. The enhanced water balance equation that is most appropriately applied to wetland systems is:

$$\Delta S = \text{rainfall} + \text{groundwater inflow} + \text{surface-water inflow} - (\text{evapotranspiration} + \text{groundwater outflow} + \text{surface-water outflow})$$

THE WATER BALANCE FACTORS

A pictorial representation of the water budget or hydrologic cycle is given in most textbooks (Figure 2.4.2.1). Although the concepts involved are rather simple, the movement of water through the hydrologic cycle is complex with many subdivisions of the primary flow paths. In a basin, precipitation can infiltrate into the ground, it can be intercepted by plants and be lost from the system via evapotranspiration, or if the infiltration capacity of the soil is exceeded by



MISSIMER INTERNATIONAL	Pr.Name: FIPR - HYDROLOGY				Groundwater and Environmental Services
	Pr.No. FH4-8	DWG No. FH4-8H.CDR	Date: 08/05/94	Rev.No. 1	

FIGURE 2.4.2.1. GROUND WATER AND THE HYDROLOGICAL CYCLE

the rainfall rate, runoff can occur as overland flow (Figure 2.4.2.2). Even if some of the water does infiltrate into the unsaturated zone or even to the upper part of the saturated zone, this water may pass very quickly into the surface-water drainage system as interflow. If the water does pass into the saturated system to add recharge to the groundwater system, then the new water becomes part of a local or regional flow system. During periods of time when precipitation is low and interflow is not adding to streamflow, groundwater discharge into the stream or flowway provides baseflow. In the absence of recharge to the groundwater system, the discharge of groundwater into the surface-water system causes a depletion of storage in the water-table aquifer with a corresponding reduction in the discharge of the stream until the adjacent water table equals the altitude of the stream bottom causing stream discharge to be near zero or the stream becomes a "losing" stream in that area.

WATER BALANCE INFLOW FACTORS

Precipitation

Rainfall information for the study area can be obtained from both governmental and private weather stations. This information is most reliable during the winter months when frontal systems distribute the rainfall fairly evenly over large areas. However, the frequent heavy summer storms are extremely variable in their spatial distribution resulting in potentially poor site-specific rain data (Duever, 1988). A rainstorm of high intensity may produce high runoff but low intensity storms that did not exceed soil infiltration capacities may result in zero runoff. Storm durations usually have to be fairly significant so that watershed soil storage capacities are exceeded before runoff can occur. Rainfall amounts to the surface beneath a vegetation canopy can be significantly different from those in an adjacent area without a canopy (Duever, 1990). Interception of rainfall by vegetation surfaces collecting and retaining this water limits the amount of water available for runoff or soil infiltration. Factors which influence the amount of interception at any particular site include rainfall frequency, duration, and amount, type and morphology of the vegetation cover.

Groundwater Inflow

Groundwater inflow into a basin occurs in response to changes in hydraulic gradient, that is moving from a higher hydraulic head to a lower hydraulic head. This movement may be either horizontal or vertical, depending on the direction of the molecular and gravity forces. Groundwater inflow generally tends to be horizontal in direction and will follow paths of least resistance with the greatest volumes flowing through aquifer sections which have the highest permeability. An example of vertical groundwater inflow is when the potentiometric surface of an underlying aquifer is higher than that of the overlying aquifer and water leaks upwards through a semiconfining unit and contributes water to the upper aquifer. Another groundwater inflow process occurs where streams lose water to the groundwater reservoir (losing streams) in areas where the water table is well below the base of the stream.

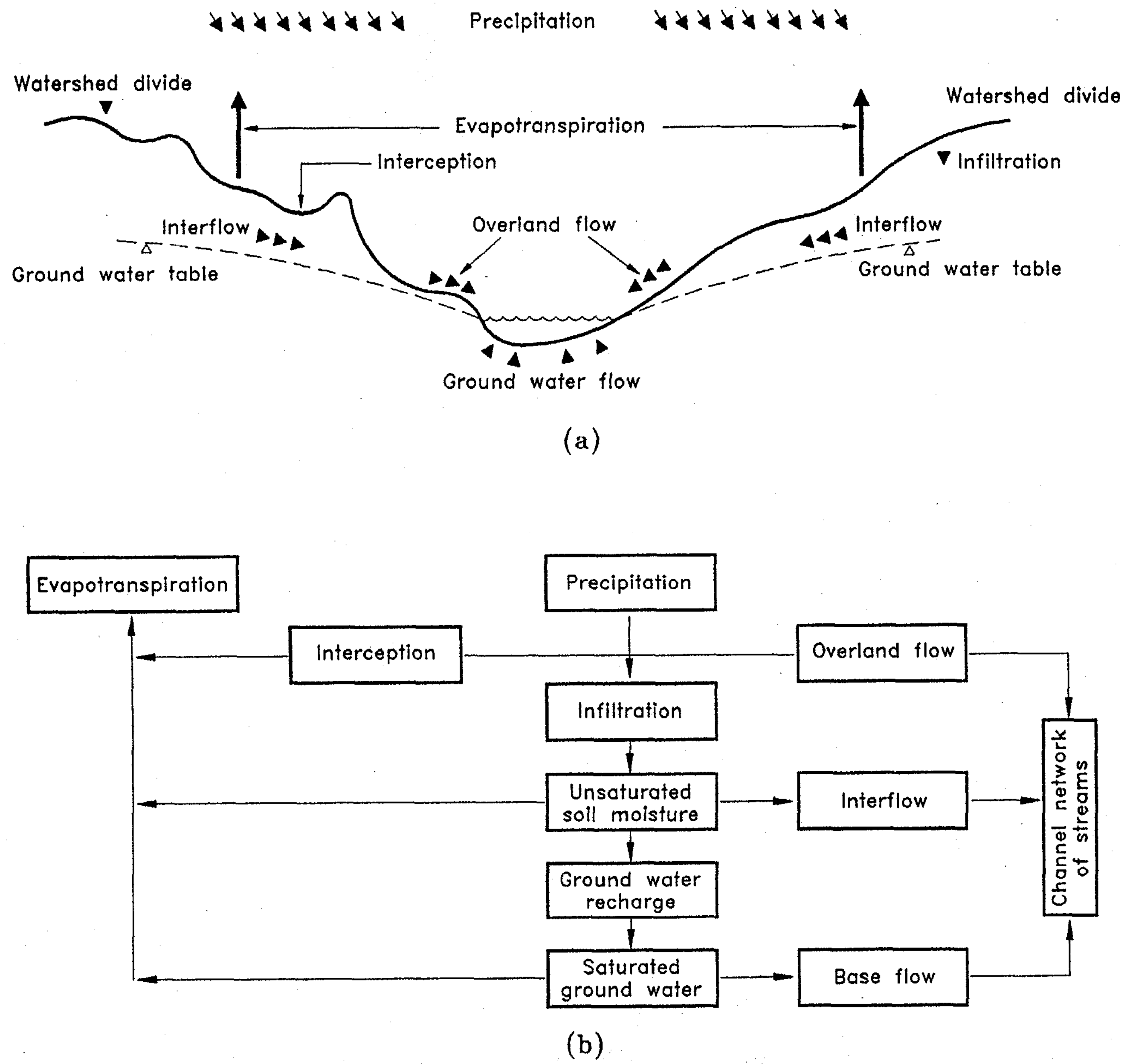


FIGURE 2.4.2.2. THE BASIN HYDROLOGIC CYCLE (AFTER DOMENICO AND SCHWARTZ, 1990).

Surface Water Inflow

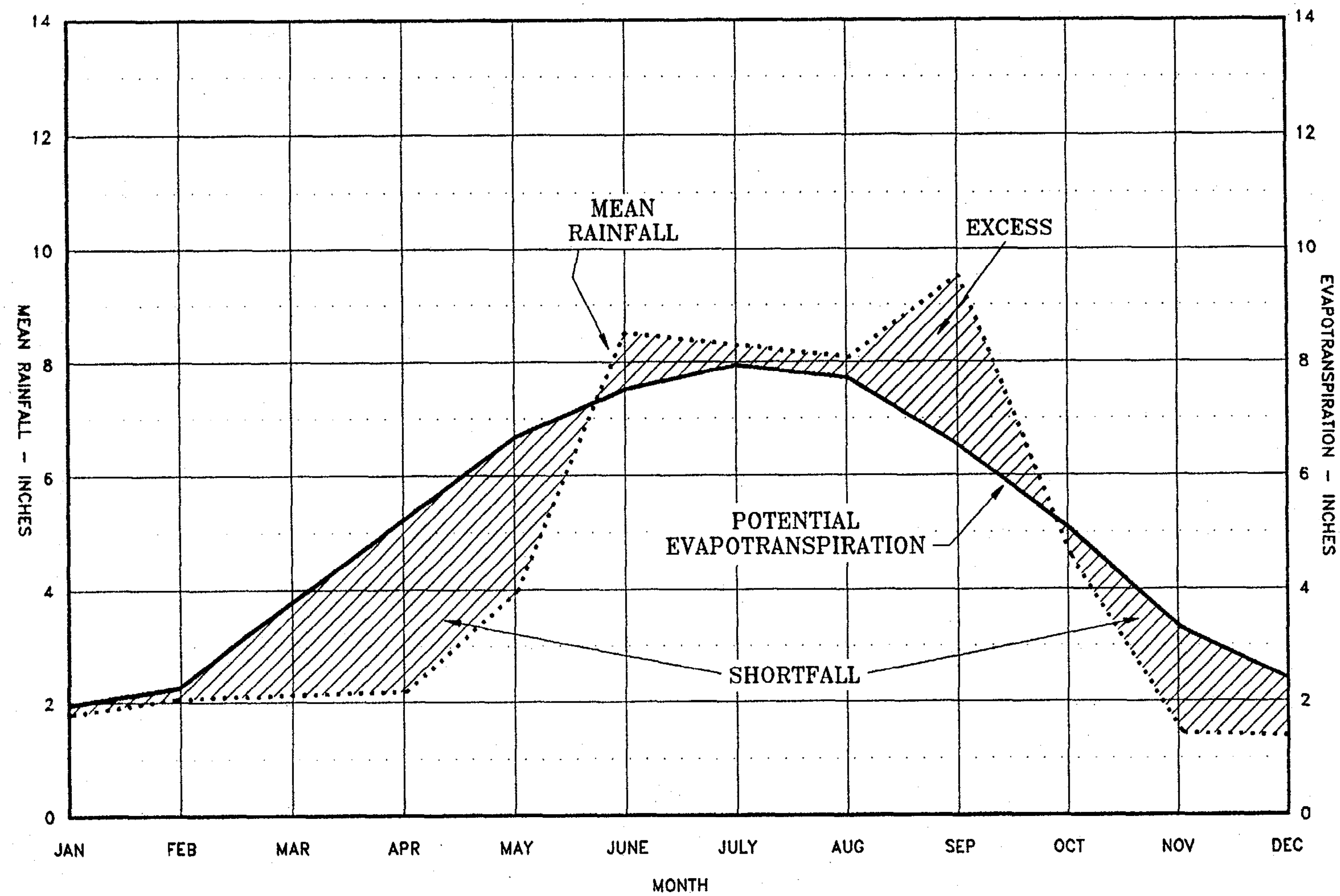
Surface water can enter a basin as channelized flow from a higher basin or as overland flow that travels over the soil surface to the nearest stream channel, or interflow to the surface via a short time in the groundwater system. Runoff is initiated when rain water occupies all available soil and vegetation surface storage and/or the infiltration rate of the soil is exceeded. Additional rainfall causes overland flow with the volume dependent on precipitation intensity, duration, and distribution; watershed topography; geology; soil type; vegetative cover characteristics; and antecedent soil moisture conditions (Branson and others, 1981). The interflow component is that part of precipitation which infiltrates into the soil to a less permeable layer, and as a result spreads out and flows laterally a short distance below the soil surface but above the water table to the nearest stream channel. Most surface-water inflow to streams in Florida is via interflow, because of high soil permeability (Wanaleista, 1988).

WATER BALANCE OUTFLOW FACTORS

Evaporation and Transpiration

Much of Florida's rainfall is lost to the processes of evaporation and plant transpiration, commonly referred to in combination as evapotranspiration (ET). Within any one particular wetland, ET may represent by far the largest water loss. Evapotranspiration at a particular site varies primarily as a function of microclimate (relative humidity, air and water temperature, wind velocity and duration, soil moisture content and type and density of vegetation (Duever, 1990). A related term is "potential evapotranspiration" (PET) which defines the water loss by ET which would occur if there is no deficiency of water in the soil for use by vegetation. The relationship between precipitation and PET is shown in Figure 2.4.2.3. From this figure it can be seen that only during the summer rainy season precipitation exceeds PET. An applicable discussion concerning PET and the hydrologic cycle (water balance) is given in Domenico and Schwartz (1990) and is present verbatim below:

> "In formulating some rules (laws) that govern the behavior of water in the hydrologic cycle, we first stipulate that the demands of potential evapotranspiration must be met (if at all possible) before water is permanently allocated to other parts of the cycle. Thus, when precipitation is equal to potential evapotranspiration, the surplus is theoretically zero, and all the rainfall for that period is available to satisfy the evaporation needs. During such time periods the actual evapotranspiration equals the potential evapotranspiration. This does not mean that infiltration cannot take place. It means simply that any infiltrated water will be available in the soil moisture for use by plants in the transpiration process. In addition, any time the rate of precipitation exceeds the rate of infiltration, there will be some water available for overland runoff so that this suggested balance of precipitation and potential evapotranspiration is not exactly true. At any rate, the surplus after all demands of potential evapotranspiration are met will be zero.



MISSIMER INTERNATIONAL INC.	Pr Name: FIPR - HYDROLOGY	Groundwater and Environmental Services
	Pr.No. FH4-8 DWG No. FH4-8C.DWG Date: 08/05/94 Rev.No. 2	

FIGURE 2.4.2.3. RELATIONSHIP BETWEEN PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION IN CENTRAL FLORIDA.

> When precipitation is less than potential evapotranspiration, all the precipitation is available to partially satisfy potential evapotranspiration. During such time periods, the actual evapotranspiration would appear to be less than the potential amount. Such is not the case, however, as the part of the demand not met by precipitation may be met by drawing on whatever moisture is in the soil zone. So here again the actual rate can equal the potential rate. If this situation continues over a prolonged period, the soil becomes depleted of its moisture and the actual rate of evapotranspiration will fall below the potential rate. Such periods are normally labeled droughts."

A study conducted in several watersheds in the Central Phosphate District showed that the average ET derived from water balance analyses was about 38 inches/year which is 90% of annual rainfall or 83% of PET (Reikerk and others, 1991). Another study in central Florida dealing with a freshwater marsh found that marsh ET was generally higher than measured pan evaporation during the summer months and lower than pan evaporation during winter months and the total annual ET of the marsh was approximately equal to annual rainfall (Dolan and others, 1984). This study measured the marshland ET by utilizing water table elevation records.

Groundwater Outflow

Groundwater outflow from a watershed can occur in response to hydrologic processes. The first and probably the most important process of groundwater loss is termed base flow in which groundwater in transient storage enters a stream channel or some other type of surface water feature. This groundwater outflow loss is generally determined from stream hydrographs. Streams that receive water from the groundwater reservoir by the base flow component are termed gaining streams. This occurs when the water table in the vicinity of the stream is above the base of the stream, usually in the lower reaches of the drainage system. Another process of groundwater outflow can be by downward leakage through a semiconfining layer into an aquifer with a lower potentiometric head.

Surface Water Outflow

Surface water outflow may leave a basin as channelized flow into a lower basin, a higher order stream channel or into a large body of water such as a lake or ocean. It may also exit a basin as overland flow with this process being quite rare. Surface water volume leaving a basin in a stream channel is measured at a gaging station located in the lowermost point in the watershed. Discharge data can then be displayed in the stream hydrographs.

THE WATER BALANCE IN CENTRAL FLORIDA STREAM BASINS

The balance of hydrologic factors influencing changes in storage varies at different geographic positions within any watershed or drainage basin. It is important to discuss the significance of the different components of the water balance at three different locations within a few different, naturally-occurring basin types, because many of the wetland communities to be discussed later occur within these general locations. Based on field observations and personal experience of the investigators, the drainage basins can be classified into the following types: 1) small basins with relativity high relief, containing upland forests or pastures with sandy soils and few wetlands, draining through relatively well-defined channels or flowways, 2) small basins with little relief and mixed sandy and organic/clayey soils, containing a mix of wetland and upland environments and draining through poorly-defined flowways, and 3) intermediate size basins containing multiple sub-basin types, with variable vegetative characteristics, and both well-defined channels and poorly-defined flowways coalescing into well defined channels in the lower part of the basin before entry into a major stream or river. The geographic locations within each basin subtype to be discussed are the upper basin, the middle basin, and the lower basin near the point of trunk discharge. The descriptions of the hydrologic functions within each basin type are also based on field observations and the professional experience of the authors.

Basin Type 1

Development of drainage basins with significant relief and reasonably well-defined channels or flowways occurs geographically in areas adjacent or near the central sand ridge areas. These basin types are characterized by sandy soils and rather high subsurface hydraulic conductivities. The water balance in the upper part of this basin type produces mostly upland environments, because the only significant inflow factor is rainfall and the outflow is predominantly groundwater outflow and evapotranspiration. Wetland development in the upper portion of these basins is not common.

In the middle part of this basin type, the water balance at a given location is dependant on proximity to surface drainage features, the localized geology of the water-table aquifer, and the soil type. Within the floodplain of the flowways and adjacent areas, the predominant inflow factors are surface-water and groundwater inflow with rainfall being a less significant factor. The predominant outflow factor is surface-water outflow with a significant quantity of evapotranspiration loss. Further away from the channelized drainage features rainfall becomes the predominant inflow factor with groundwater being less significant and surface water inflow being rare. Outflow is predominantly by evapotranspiration with some groundwater outflow. Surface water outflow occurs only under extreme flood conditions. Wetland occurrence in this part of the basin is limited mostly to the flowway or channel floodplain unless there is a significant area containing low permeability soils or the water-table aquifer has a low hydraulic conductivity.

In the lower part of the basin within the floodplain and adjacent areas, the inflow factor of greatest significance in the water balance is surface-water inflow with only a minor component of rainfall and groundwater inflow. Outflow is predominantly surface-water discharge with evapotranspiration being significant. Usually in the lower part of the basin, the stream channels are not incised to a great depth and the horizontal gradients have a lower slope. These hydraulic factors lead to the development of a greater diversity of surficial environments with the occurrence of both uplands and wetlands. In the areas away from the flowways or channels, the predominant inflow factor is rainfall with contributions from groundwater and surface-water depending or the location or localized geology of the water-table aquifer. The predominant outflow factor can be either evapotranspiration or groundwater discharge depending on proximity to a drainage feature. The further away from a drainage feature the smaller the loss via groundwater discharge. A semi-quantitative analysis of the water balance for this type of basin is given in Table 2.4.2.1.

Basin Type 2

Most small stream basins in the Florida phosphate district are similar to the second general type of basin. The upper part of the basin is characterized by moderate relief, mixed soil types, poor to fair definition of flowways and channels, and moderate hydraulic conductivity within the water-table aquifer.

The diversity of hydrologic conditions in the upper part of the basin allows more water to be retained, which allows the growth of both upland and wetland plant communities. The water balance in the upper part of the basin causes a generally lower range of seasonal water table fluctuations compared to the first type of basin described. In areas above the flowways, the predominant inflow factor is precipitation. Outflow is predominantly by evapotranspiration and groundwater outflow. Overland flow and interflow can occur during exceptionally intense storm events. If any upland environments lie at a higher altitude, then some groundwater inflow does occur. Some limited development of wetlands with short-duration hydroperiods can occur in the upper basin. Within stream channels or flowways, the predominant inflow factor is surface-water inflow closely followed by precipitation and groundwater inflow. In each stream channel, the surface-water inflow component becomes more predominant going downstream. In the middle of the basin away from significantly incised channels, the predominant inflow factor in the upland environments is precipitation and in the wetland areas is groundwater. The groundwater component varies in importance based on the up-gradient land area draining into the area. The predominant outflow factor in the same areas is evapotranspiration with some outflow via groundwater from the upland areas and via surface-water discharge from wetland areas. The lower part of the basin tends to be flatter and generally wetter, which equalizes the importance of groundwater, surface-water and precipitation in areas away from channels. Since hydraulic gradients are generally low in this part of the basin, the predominant outflow factor is evapotranspiration with groundwater and surface-water discharge being secondary. A semi-quantitative analysis of the second type of basin is given in Table 2.4.2.2.

Basin Type 3

The third type of basin has a generally smaller slope of land surface and a variety of surficial environments occur with a mix of wetland and upland types in all parts of the basin. In the upper part of the basin, there are both sloped areas drained by low-gradient flow-ways and flat areas containing wetlands, which drain into each other and can produce wide slough-type flowways. In these areas the inflow factors can vary in importance with precipitation being the

TABLE 2.4.2.1 SEMI-QUANTITATIVE ANALYSIS OF THE WATER BALANCE FOR BASINS WITH SIGNIFICANT RELIEF AND HIGH PERMEABILITY SOILS (TYPE 1)

Basin Location	Upper Basin			Middle Basin			Lower Basin		
Environment	U	W	C	U	W	C	U	W	C
Balance Factor									
Inflow									
Precipitation	5	0	1	4	2	1	4	1	1
Groundwater	1	0	2	2	4	2	1	4	1
Surface-water	0	0	3	0	0	3	1	1	4
Outflow									
Evapotranspiration	2	0	2	4	4	2	4	3	1
Groundwater	3	0	0	2	1	0	2	1	0
Surface-water	1	0	4	0	1	4	0	2	5

Most Important = 6
Least Important = 1
Not Significant = 0

U = Upland
W = Wetland
C = Channel

TABLE 2.4.2.2 SEMI-QUANTITATIVE ANALYSIS OF THE WATER BALANCE FOR BASINS WITH MEDIUM RELIEF AND A DIVERSITY OF SOIL TYPES (TYPE 2)

Basin Location	Upper Basin			Middle Basin			Lower Basin		
Environment	U	W	C	U	W	C	U	W	C
Balance Factor									
Inflow									
Precipitation	5	4	2	4	2	1	3	1	1
Groundwater	1	2	1	2	4	1	2	4	0
Surface-water	0	0	3	0	0	4	1	1	5
Outflow									
Evapotranspiration	4	3	2	4	4	1	4	3	1
Groundwater	2	2	0	2	0	0	2	1	0
Surface-water	1	1	4	0	2	5	0	2	5

Most Important = 6
Least Important = 1
Not Significant = 0

U = Upland
W = Wetland
C = Channel

major contributor to inflow and both precipitation and groundwater inflows being important to the wetland features. Outflow is mostly via evapotranspiration in the flat areas and by a combination of surface-water and groundwater in the sloped areas. In the middle part of the basin within the flowways or low-slope channels, the most important inflow factors are surface-water and groundwater with direct precipitation inflow being of lesser significance. In the corresponding upland areas, precipitation and groundwater inflows are of greatest significance.

Outflow is by evapotranspiration and surface-water in the wetland areas and by groundwater and evapotranspiration in the upland areas. In the lower part of the basin, the area is generally flat and inflow is almost equally provided by precipitation, surface-water, and groundwater in areas away from channels or flowways. Within flowways the primary inflow factor is surface-water. Outflow is controlled primarily by evapotranspiration and surface water discharge. A semi-quantitative analysis of the mixed type of basin is given in Table 2.4.2.3.

There are some very fundamental principles which merit discussion before the effects of the water balance can be assessed for each wetland type. Wetlands occur at the base of a flow system, either a local or regional system. Wetlands are not recharge areas and in most cases groundwater and surface-water flow into wetland areas in order to maintain the hydroperiod. There may be a few, rather rare cases in which wetlands can transmit some water to upland environments during a short duration of time.

2.4.3. WATER LEVELS AND TOPOGRAPHY

The geologic framework and the balance of water inflows and outflows determine the range of fluctuations in water level. The geologic framework includes substrate lithology and soil characteristics, plus surface physiographic features such as drainage and topography.

This relationship between water level and land surface topography is especially critical when considering created wetland environments. Although this may seem an obvious concept, its importance cannot be over emphasized and therefore requires discussion in a treatise on wetland hydrology. In a natural wetland setting, fluctuations of water level typically occur within a relatively small range above and below the land surface so that topography and water level together create a suitable environment for wetland biota.

In an altered (mined) environment, the geologic framework is modified, the balance of water is likely altered, and topography is invariably changed. The design and construction of a viable wetland environment in such an altered setting must take into account all three components, one of which must be designed to the other two. That is, for a given subsurface geology and land surface topography, the hydrology must establish water levels near and periodically above land surface. Similarly, for a given geology and water balance, topography must be established where land surface intersects the water surface.

TABLE 2.4.2.3 SEMI-QUANTITATIVE ANALYSIS OF THE WATER BALANCE FOR BASINS WITH RELATIVELY FLAT RELIEF AND A DIVERSITY OF SOIL TYPES (TYPE 3)

Basin Location	Upper Basin			Middle Basin			Lower Basin		
Environment	U	W	C	U	W	C	U	W	C
Balance Factor									
Inflow									
Precipitation	4	2	4	4	2	0	3	1	1
Groundwater	1	3	2	2	4	2	2	4	0
Surface-water	1	1	0	0	0	4	1	1	5
Outflow									
Evapotranspiration	3	4	2	4	4	1	4	4	1
Groundwater	2	0	0	2	0	0	2	0	0
Surface-water	1	2	4	1	2	5	0	2	5

Most Important = 6
Least Important = 1
Not Significant = 0

U = Upland
W = Wetland
C = Channel

2.4.4. NATURAL WETLAND COMMUNITY TYPES

Various classification systems have been used in the process of inventorying and describing wetland types based solely on the preference of the biologist performing a given investigation. In order to communicate to a wide group of both biologists and hydrologists, the wetland classification used in this report conforms to the "Guide to the Natural Communities of Florida" (Florida Dept. of Natural Resources, 1990). A complete list of wetland types described in this classification is given in Table 2.4.4.1. Only certain types of wetlands described in this comprehensive classification actually occur within the phosphate mining districts. Of the 30 classified types of wetlands occurring in Florida, only 11 types were observed in the pre-mining landscape within the Florida phosphate mining districts (Table 2.4.4.2). Appendix 2.10.3 compares this classification scheme to others commonly used in Florida. The estimated hydroperiods and fire frequencies of the common wetland areas are given in Table 2.4.4.3. It is important to discuss the characteristics of these wetland types in terms of hydrology and other issues which affect occurrence and succession.

2.4.5. WETLAND TYPE AND VARIATIONS IN THE WATER BALANCE

Locations of wetland types within a given watershed or small basin along with the localized subsurface geology cause the variations in the water balance, which in turn cause the changes in the hydrology, Variations in wetland type have been documented on the basis of differences in hydroperiod (the length of time that soils are saturated during a year), fire frequency, and the accumulation of organic matter (Sharitz and Gibbons, 1982; Duever and others, 1984). Ewel (1992) states "the presence of saturated soils or standing water for at least part of the year is the dominant environmental control over the ecological characteristics of a swamp". The sole presence of water is not the primary factor affecting the predominance of wetland plants at a given location, but the reducing conditions within the soils creates an inverse relationship between the number of plant species and the hydroperiod (Ewel, 1992). The relationship between the length of the hydroperiod and the species richness of woody species is given in Figure 2.4.5.1 and length of the hydroperiod versus fire frequency is given in Figure 2.4.5.2. Duever and others (1984) related the hydroperiod to both the accumulation of peat and the frequency of fires to assess successional patterns (Figure 2.4.5.3).

The hydroperiod corresponding to each wetland type is similar to a large degree, but the exact composition of the vegetative assemblage varies with other factors, such as the thickness of organic accumulation in the soils. Since the hydrologic conditions vary greatly in each watershed or basin depending on the local hydrogeologic and geographic conditions, there is a correspondence between the hydroperiod required and the localized water balance in order for a given wetland environment to become established. As discussed in section 2.4.2, the water balance varies significantly within each watershed or basin depending on the type of watershed and the geographic location within the watershed. A given wetland type can occur at a variety of altitudes and positions within a region with no unique position within a watershed, but based solely on the localized hydroperiod created by variations in the water balance. However, certain

TABLE 2.4.4.1 NATURAL WETLAND COMMUNITIES OF FLORIDA (FLORIDA DEPT. OF NATURAL RESOURCES, 1990)

Palustrine
Wet Flatlands
Hydric hammock
Marl prairie
Wet flatwoods
Wet prairie
Seepage Wetlands
Baygall
Seepage slope
Floodplain Wetlands
Bottomland forest
Floodplain forest
Floodplain marsh
Floodplain swamp
Freshwater tidal swamp
Slough
Strand swamp
Swale
Basin Wetlands
Basin marsh
Basin swamp
Bog
Depression marsh
Dome swamp
Lacustrine
Clastic upland lake
Coastal dune lake

TABLE 2.4.4.1 NATURAL WETLAND COMMUNITIES OF FLORIDA (FLORIDA DEPT. OF NATURAL RESOURCES, 1990) - CONTINUED -

Coastal rockland lake
Flatwoods/prairie/marsh lake
River floodplain lake and swamp lake
Sandhill upland lake
Sinkhole lake
Riverine
Alluvial streams
Blackwater streams
Seepage streams
Spring-run streams

TABLE 2.4.4.2. COMMON WETLANDS IN PHOSPHATE MINING REGIONS OF FLORIDA*

General Type	FDNR[1]	FLCFC[2]	Other Synonyms
Palustrine			
Flatwoods or Wet Flatlands	Wet Flatwoods, Wet Prairie	310/Herbaceous, 411/Pine Flatwoods, 419/Other Pines, 428/Cabbage Palm, 622/Pond Pine, 624/Cypress-Pine-Cabbage Palm, 630/Wetland Forested Mixed, 641/Wet Prairies	Wet Flatwoods: hydric flatwoods, pine savanna, cabbage palm savanna, moist pine barrens Wet Prairie: sand marsh, savanna, pitcher plant prairie
Seepage Wetlands	Baygall	611/Bay Swamps, 614/Titi Swamps	seepage swamp, bayhead, bay swamp, sandhill bog
Floodplain Wetlands	Bottomland Forest, Floodplain Forest, Swale	615/Stream and Lake Swamps, 617/Mixed Wetland Hardwoods, 623/Atlantic White Cedar, 630/Wetland Forested Mixed, 641/Freshwater Marshes, 643/Wet Prairies	Bottom Land Forest: bottomland, river bottom, stream bottom, white cedar swamp Floodplain Forest: bottomland hardwoods, seasonally flooded basins or flats, second bottom, levees, point bars, terraces Swale: sloughs, river of grass, glades
Basin Wetlands	Basin Marsh, Depression Marsh, Dome Swamp, Basin Swamp	621/Cypress, 641/Freshwater Marshes, 643/Wet Prairies, 644/Emergent Aquatic Vegetation	Basin Marsh: prairie Depression Marsh: flatwoods pond, St. John's wort pond, pineland depression, ephemeral pond or marsh, flag pond, gator hole
Lacustrine			
Lake Lining Wetlands	Flatwoods, Prairie, Marsh Lakes	615/Stream and Lake Swamps, 641/Freshwater Marshes, 644/Emergent Aquatic Vegetation	flatwood pond, ephemeral pond, grass pond, St. John's wort pond, freshwater lake, pineland depression, swale and prairie pond

TABLE 2.4.4.2. COMMON WETLANDS IN PHOSPHATE MINING REGIONS OF FLORIDA -CONTINUED-

General Type	FDNR[1]	FLCFC[2]	Other Synonyms
Riverine			
Stream/River Lining Wetlands	Blackwater Stream, Seepage Stream	615/Stream and Lake Swamps	<u>Blackwater Stream</u>: black water river, black water creek <u>Seepage Stream</u>: steephead stream, clear brook, swift brook, hammock stream

*Since several wetland classification schemes are commonly used in Florida, the reader is provided with a wetland type cross reference for the natural communities listed in this table. This cross reference can be found in Appendix 2.10.3.

[1] Florida Department of Natural Resources, 1990, Guide to the natural communities of Florida: Fla. Dept. of Nat. Res., Tallahassee, FL, 111 p.

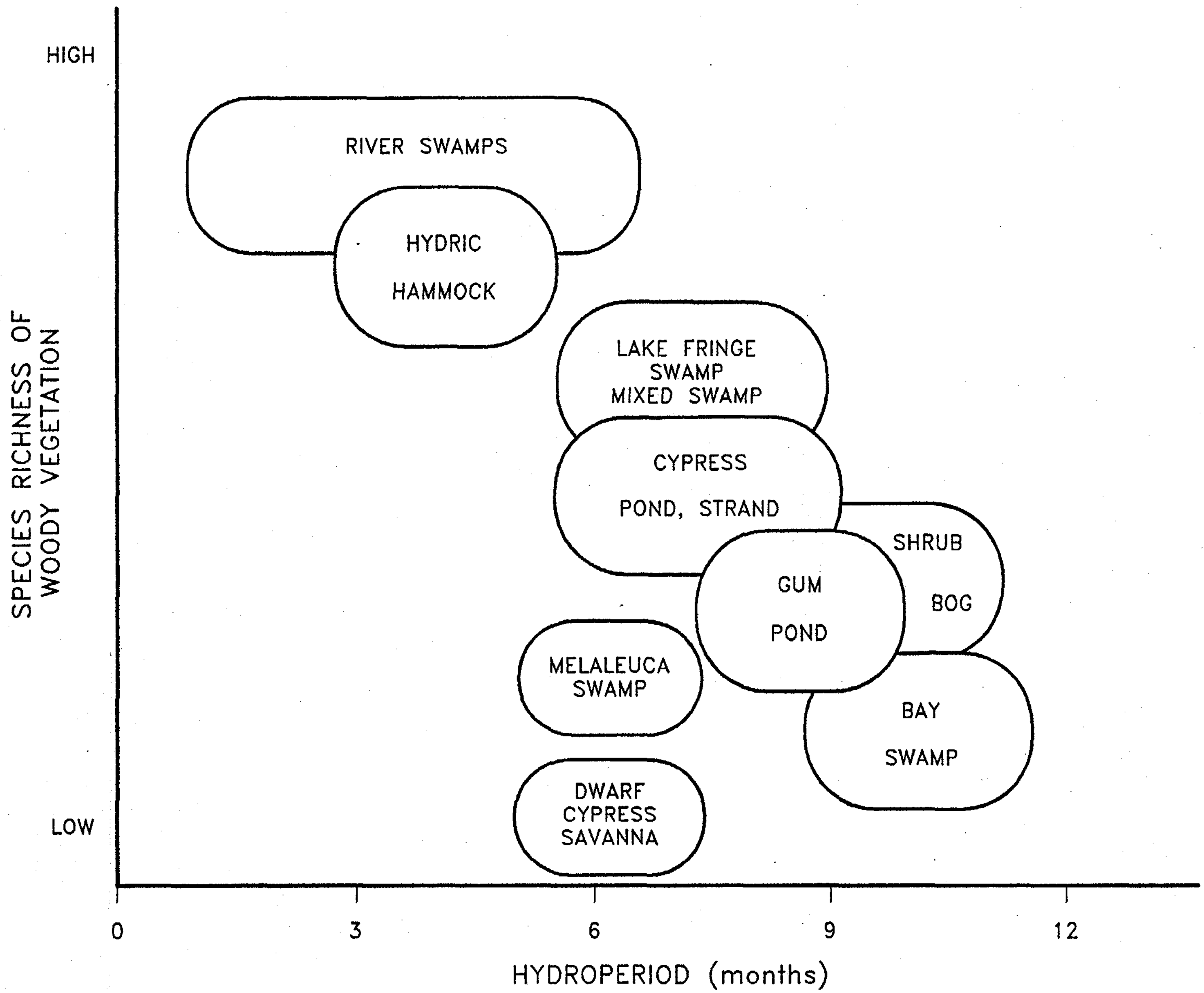
[2] Florida Department of Transportation. 1985. Florida Land Use, Cover and Forms Classification System.

TABLE 2.4.4.3 ESTIMATED HYDROPERIODS AND FIRE FREQUENCIES OF THE COMMON WETLAND TYPES

	Est. Hydroperiod[1] (days)	Fire Frequency[1] (years)
Palustrine		
Wet Flatlands		
Wet flatwoods	30+	3-10
Wet prairie	50-100	2-4
Seepage Wetlands		
Baygall	365	50-100
Floodplain Wetlands		
Bottomland forest	Only during floods	Rare
Floodplain forests	2-50% growing season	Rare
Swale	250	1-5
Basin Wetlands		
Basin marsh	200	1-10
Depression marsh	50-200	1-10
Lacustrine		
Flatwoods/prairie/marsh lakes[2]	365	-0-
Riverine		
Blackwater streams[2]	365	-0-
Seepage streams[2]	365	-0-

[1] from Fla. Dept. Nat. Res. (1990)

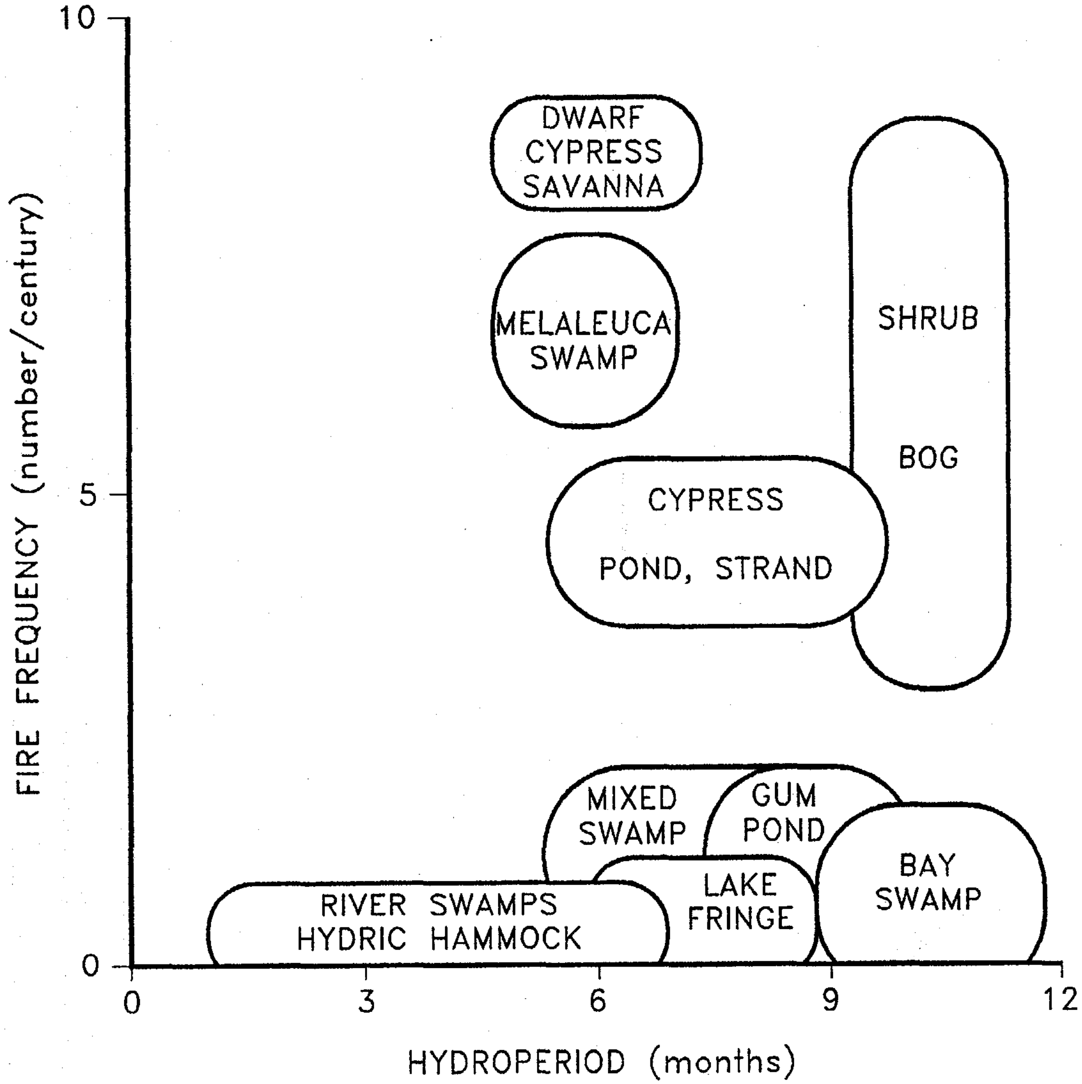
[2] estimated by authors



MISSIMER INTERNATIONAL

Pr Name: FIPR – HYDROLOGY	
Pr.No. FH4-8 DWG No. FH4-8G.DWG Date: 08/04/94 Rev.No. 1	Groundwater and Environmental Services

FIGURE 2.4.5.1. HYDROPERIOD LENGTH IN TIME vs. SPECIES RICHNESS (FROM EWEL, 1992).



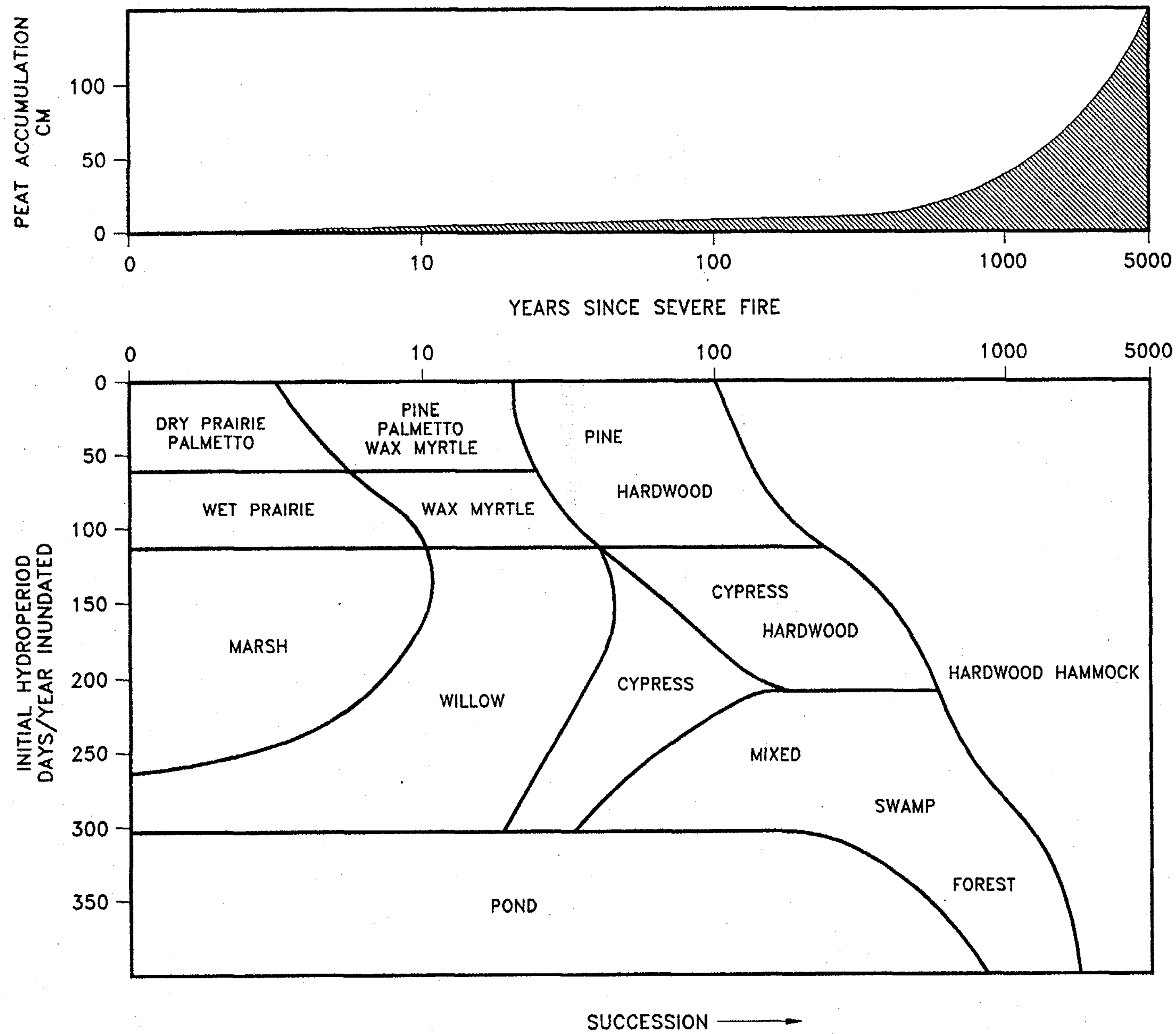
MISSIMER INTERNATIONAL, INC.

Pr Name: FIPR – HYDROLOGY

Pr.No. FH4-8 DWG No. FH4-8F.DWG Date: 08/04/94 Rev.No. 1

Groundwater and Environmental Services

FIGURE 2.4.5.2. HYDROPERIOD LENGTH IN TIME vs. FIRE FREQUENCY (FROM EWEL, 1992).



MISSIMER INTERNATIONAL INC.

Pr Name: FIPR – HYDROLOGY			
Pr.No. FH4-8	DWG No. FH4-8E.DWG	Date: 08/04/94	Rev.No. 1

Groundwater and Environmental Services

FIGURE 2.4.5.3. SUCCESSIONAL PATTERNS AS A FUNCTION OF HYDROPERIOD AND TIME SINCE SEVERE FIRE; PEAT ACCUMULATION AS A FUNCTION OF TIME (DUEVER, 1984).

wetland types tend to exist in specific topographical locations within a watershed, because of unique water balance factors. A summary of the importance of the factors in the water balance is given in Table 2.4.5.1. The information contained in the discussion of each wetland type was taken from the Florida Department of Natural Resources (1990), from field observations, and the experience of the investigations.

WET FLATWOODS

A common wetland type occurring throughout the phosphate district is the wet flatwoods. The wet flatwoods environment is characterized as an open-canopy forest of scattered pine trees or cabbage palms with either thick shrubby understory and very sparse ground cover, or a sparse understory and a dense ground cover. This environment occurs on relatively flat, poorly drained soil. Land surface is commonly inundated during wet periods for 30 days or greater in a given year. In some areas, a hardpan or clay underlies this environment, causing the rapid accumulation of surface-water during wet time periods and preventing deep root penetration to allow normal vegetative growth during dry periods. The result of this condition is that the vegetation is stressed during the wet season by flooding and in the dry season by the lack of water. The natural occurrence of fire in these areas is every 3 to 10 years.

There are some key variations in the hydroperiod that allow the occurrence of the wet flatwoods environment. The most important inflow factors are direct collection of precipitation and sometimes groundwater inflow. Because of the slightly more elevated, but still flat nature of this environment, surface-water inflow is not a significant part of the inflow with the exception of extremely wet periods when overland flow occurs. The most important outflow factor is evapotranspiration with some surface water outflow during very wet time periods. Groundwater outflow is minimal because the key factors in the development of this environment are the flat land surface, which produces very low hydraulic gradients and the low hydraulic conductivity of the soils and the underlying water-table aquifer. If groundwater outflow would be a significant outflow factor, then standing water would occur for short time periods and either a palmetto/pine flatwoods or some type of xeric environment would occur.

THE WET PRAIRIE ENVIRONMENT

A wet prairie is a treeless plain with a sparse to dense cover of grass or herbs. This environment is similar to the wet flatwoods in terms of the flat character of the land and the poorly drained soils. This environment has a hydroperiod of 50 to 100 days, but is subject to prolonged desiccation during each dry season.

Variations in the water balance to produce this type of environment are similar to the wet flatwoods and these environments commonly occur on adjacent lands. However, the slightly lower elevation of the wet prairie results in more overland flow than occurs in the wet flatwoods. In many cases the soils of the wet prairie contain a sufficient percentage of clay and organic detritus to produce a low hydraulic conductivity substrate, preventing rapid percolation of water

TABLE 2.4.5.1. SEMI-QUANTITATIVE ANALYSIS OF THE WATER BALANCE FOR VARIOUS WETLAND TYPES BASED ON FIELD OBSERVATIONS AND EXPERIENCE OF THE INVESTIGATORS

Water Balance Features	Wet Flatwoods	Wet Prairie	Baygall	Bottomland Forest	Floodplain Forests	Swale	Basin Marsh	Depression Marsh	Flatwoods/ Prairie/Marsh Lakes	Blackwater Streams	Seepage Streams
Inflow											
Precipitation	4	3	1	1	0	1	1	1	1	1	0
Groundwater	1	1	4	4	1	2	4	4	4	1	5
Surface-water	1	2	1	1	5	3	1	1	1	4	1
Outflow											
Evapotranspiration	5	4	5	3	2	2	4	4	5	0	0
Groundwater	0	1	1	2	0	0	1	1	1	1	1
Surface-water	1	1	0	1	4	4	1	1	0	5	5

Most Important = 6
Least Important = 1
Not Significant = 0

All add to 6

into the regional flow system of the surficial aquifer. Again, the slope of the land must be flat in order to maintain this type of environment. When these types of flat wetland environments are surrounded to some degree by higher altitude upland environments, the groundwater inflow component can become a significant inflow factor, prolonging the hydroperiod. Because of the general dry season desiccation of these systems, some capillary water must reach the roots of some plants in order to maintain them over a long time period. Without some clay in the substrate, the capillarity would be insufficient to allow the necessary quantity of water to enter the system. Based on the available data, although these systems contain a clayey substrate, the water table is not perched to any significant degree.

BAYGALL WETLANDS

Baygall wetlands are commonly referred to as seepage swamps. They are densely forested, peat-filled depressions commonly occurring at the base of sand slopes. The very existence of baygalls is dependant on the groundwater inflow component of the water balance. These environments rarely dry out and an intense fire could permanently alter the environment to a wet flatwoods or other type of wetland. Because the baygall environment is so dependant on groundwater inflow, any major alteration of the hydrogeologic framework of the aquifer that affects the flow system will allow it to become subject to fire damage or it will cause succession to another environment.

The baygall environment is similar to a mini-basin with the primary inflow being groundwater during virtually all times of the year and direct rainfall and surface water during limited times. The predominant outflow from a baygall is evapotranspiration. If the seepage outflow exceeds the storage capacity of the depression, some surface-water outflow will occur.

BOTTOMLAND FOREST

The bottomland forest environment occurs on low-lying flatlands bordering streams with distinctive banks where water rarely overflows to inundate the forest. They also occur in low spots in basins and depressions that are not often flooded. They are characterized by a closed-canopy of tall straight trees with an understory of dense shrubs and little ground cover or an open understory and a ground cover of ferns, herbs, and grasses. The soils underlying the environment are a mixture of clay and organics. Bottomland forests are very similar to floodplain forests and or hydric hammocks.

Since bottomland forests are rarely flooded, the inflow factors in the water balance are a combination of groundwater inflow from the upgradient adjacent portions of the water-table aquifer, direct rainfall, and some surface water. In the case of the bottomland forest, the composition of the soil is critical, because water must be drawn from the underlying saturated soils associated with the stream via capillary movement. If the soils were sandy with a high hydraulic conductivity, the capillary raise would be insufficient to allow movement of water to supply the forest or the forest would be constrained to the immediate area adjacent to the stream bank. Indirectly, the surface water inflow of the stream must be maintained at some rate to maintain the environment. If a major part of the stream basin or watershed is altered, seasonal stream discharge rates could be changed sufficiently to alter the hydroperiod of the bottomland forest and cause some type of change in community type.

FLOODPLAIN FORESTS

Floodplain forests occur on various mixtures of sand, organic, and alluvial soils at some elevation above the stream bottom, sufficiently low enough to allow some seasonal flooding. These forests occur on drier soils on levees, ridges, and terraces. With respect to the hydroperiod, floodplain forests are inundated between 2 and 50 percent of the growing season from April through August. They are rarely flooded in the dry season.

Maintenance of the hydroperiod is the critical factor in the propagation and continued success of this environment. The primary factor influencing the hydroperiod is the surface-water inflow from the upstream basin. The seasonal delivery of water through the channel is greatly influenced by the hydrogeology of the basin. If the basin characteristics are greatly altered, the flow regime of the stream could cause a shortened period of flooding during the wet season and a longer period of desiccation during the dry season both of which would be stressful to the floodplain forest. The critical outflow factor from this environment is surface-water discharge with considerable evapotranspiration loss.

SWALE

The swale environment is a marsh located in a broad channel with flowing water. Vegetation in this environment consists of emergent grasses, sedges, and herbs up to 10 feet tall. Soils in the swale are peats or sands. The hydroperiod is about 250 days of flooding by sheet flow over each year. If the peat soils are removed by fire or the acts of man, the environment can convert to a slough, loosing the typical herbaceous vegetation associated with the swale.

Hydroperiod of the swale environment is again maintained by the upstream basin, but also by the adjacent uplands. A major component of the sheet flow is from upstream surface-water inflow. However, groundwater inflow from the immediate margins of the swale can be a very important component of the inflow. Baseflow into the system is provided totally by groundwater inflow to the “channel”. In summary, the primary inflow factors are surface water and groundwater and the primary outflow factors are surface water and evapotranspiration.

BASIN MARSH

A basin marsh is one of several types of basin wetlands, which are shallow closed basins with a high water outlet. These wetlands are characterized as herbaceous or shrubby wetlands located in large, irregular-shaped basins. They develop in former depressions or lakes commonly associated with karst features. The hydroperiod is about 200 days. Soils are usually acidic peats. These features rarely are perched above the natural water table. If the water table is below the wetland bottom, when a rainfall event occurs, there is a lag time before water moves vertically through the marsh sediments to the water table. This lag time is usually on the order of days.

All basin type wetlands share some common characteristic in terms of the relationship between the hydroperiod and the water balance. The primary inflow factor is groundwater from the surrounding upland basin. Obviously, there is some direct rainfall inflow and during extreme storm events surface water may enter the wetland. The groundwater inflow component can be subdivided into interflow during extremely wet periods and normal aquifer flow during most of the year. Without the groundwater inflow component, the basin wetland environment would be some type of wet flatwoods or even an upland environment. The predominant outflow factor is evapotranspiration with some surface water outflow during extremely wet periods. Depending on the location of the basin marsh, groundwater outflow can also be a significant outflow factor, but in most cases the hydraulic gradient within the water-table aquifer is radially directed inward toward the center of the wetland. In certain cases, the dry season hydraulic gradient can assume the general direction of the regional flow system and some water can leave the area of the wetland via horizontal flow.

DEPRESSION MARSH

Depression marshes are shallow, rounded depressions in a sand substrate with herbaceous vegetation in concentric bands following the contours of the feature. These wetlands are similar to basin marshes, but they are generally smaller, and can be classified as isolated wetlands. The round nature of most depression marshes is attributed to karst features that have infilled, such as sinkholes. Hydroperiods range between 50 days or less to more than 200 days per year (FDNR 1990 Guide to Nat. Comm.).

The large variation in the hydroperiods of depression marshes can be attributed directly to the size of the surrounding upland drainage through which groundwater feeds the feature. Again, the primary inflow factor that maintains this type of wetland is groundwater inflow. When the storage in the surrounding basin becomes depleted as groundwater discharges into the depression marsh, the water level in the marsh recedes until the marsh becomes dry. Some precipitation enters these wetlands directly and in extreme storm events some flooding can occur. Outflow is predominantly via evapotranspiration, particularly during the wet season. During the dry season, outflow occurs by some evapotranspiration and by groundwater, if the direction of the hydraulic gradient changes from radial inflow to a single direction.

FLATWOODS/PRAIRIE/MARSH LAKES

These lakes are similar to the depression marsh and can only be separated by the greater water depth in the center of the feature. They are circular in shape with concentric bands of vegetation and an open water body in the middle with or without floating vegetation. The open water is specifically called the marsh lake. The soils in this feature are generally sands with some peat and occasional clay lens.

Overall, the water balance for marsh lakes is similar to or the same as for depression marshes, which commonly surround the marsh lakes. The primary source of water to maintain these features is groundwater from the surrounding upland areas. The groundwater may enter the lake via horizontal flow or by interflow (technically a component of the surface water flow). Surface water runoff from the surrounding basin may be a significant inflow component when the precipitation rate exceeds the infiltration capacity of the upland soils. Outflow from these lakes is primarily caused by evapotranspiration. When the central pond is covered by floating aquatic vegetation the evapotranspiration loss rate is significantly greater. During very wet periods or during major storm events, surface water discharge can occur. Groundwater outflow is not a significant factor during the wet season, but can occur during the dry season under some special circumstances.

BLACKWATER STREAMS

Blackwater streams are defined as perennial or seasonal streams originating in sandy lowlands. Within the lowland areas large areas of wetlands occur with associated organic or peaty soils. These wetlands serve as small reservoirs by collecting precipitation and conducting the water into the stream. Blackwater streams commonly have an acidic pH and contain significant concentrations of tannic acid, giving the water a brownish-tan color. These streams commonly have high, steep banks and while there is considerable seasonal fluctuation in water level, they have a minimal floodplain. The sandy bottomed streams do not contain a significant sediment load due to minimal velocity, thus inhibiting the building of natural levees, which are generally not present. Because of the well-defined channels, overbank flooding does not occur on a routine basis.

The water balance of a blackwater stream varies depending on location within the watershed or basin. Near the headwaters of the stream, the collection of water from the wetlands to form the stream is precipitation dependant with a component of groundwater inflow. In the downstream areas toward the lower part of the basin, the inflow to the stream is primarily by surface water or flow through the channel to the area of observation. Some seepage through the banks contributes some groundwater inflow. The base flow of this type of stream, as in the case of most natural drainage features, occurs through groundwater discharge into the stream channel or into the bordering wetland areas. The primary outflow factor is downstream discharge of water through the channel, with a component of evapotranspiration. In a rare case, a blackwater stream within a large-sized basin may contribute to the groundwater system in the lower reach of the stream.

SEEPAGE STREAMS

Seepage streams are defined as perennial or intermittent seasonal water courses originating from groundwater percolating through the associated upland areas. These streams are often covered with a dense overstory of broad-leaved hardwoods. In order for a seepage stream to form, there must be sufficient relief and an adequate-sized upland area. The water-table aquifer within the upland area must have sufficient hydraulic conductivity to be able to transmit a significant amount of water to the stream.

Seepage streams are totally dependant on groundwater inflow for initial formation and for long-term maintenance. Any changes to the geology of the drainage basin or the hydraulic conductivity of the bordering water-table aquifer may preclude the viability of this stream type. In terms of the water balance, the major inflow factor in the upper part of the watershed is groundwater. Lower in the watershed, both groundwater and surface-water inflow contribute to flow. The predominant outflow factor is surface-water discharge through the channel and some evapotranspiration loss from the vegetation. This type of stream classification, from a strict geomorphic viewpoint has little basis in science, because the base flow of all perennial streams comes from groundwater. Also, when viewing a stream from the upper part of a basin to the lower basin, the stream classification may change as both the landscape topography and the geology of the water-table aquifer vary.

2.4.6. LOCATIONS OF VARIOUS WETLAND TYPES IN A BASIN

Based on the description of the natural wetland types that occur in the phosphate mining districts and on the general hydrologic characteristics of each wetland type, it is generally observed that each specific wetland types will occupy different parts of a given watershed (Table 2.4.6.1). For discussion of the location of wetlands, the different wetland types can be grouped into three broad categories which are: isolated or basin wetlands, planar wetlands, and riverine wetlands.

Basin Wetlands

All types of basin wetlands are greatly dependant on the contribution of water from the surrounding lands in order to maintain the necessary hydroperiod. Therefore, it is rare to find these types of wetlands near the top of a watershed, because the water levels in this area are the highest in altitude and lowest in depth below land surface compared to any part of the watershed, and because the contribution of groundwater and runoff is insufficient. Therefore, in the investigator's opinion, they must be located in the middle or lower part of the watershed. No basin wetlands will occur in basin type 1 in the upper or middle area (Section 2.4.2), but they can form in the middle to lower sections of basin types 2 and 3. There are some exceptions to this concept, specifically with regard to wetland development adjacent to sinkholes, which can develop at any location in a basin. If a sinkhole did develop in the upper part of a basin and there is an insufficient quantity of water entering the feature, a wetland environment may not develop. Another major factor in the development and maintenance of a basin wetland is the localized hydrogeology. If the water-table aquifer underlying the upland areas contributing water to the wetland has a low hydraulic conductivity, then the transfer rate of water from the aquifer to the wetland may be insufficient to maintain or allow the development of the wetland. Also, if the aquifer contains a significant quantity of clay at a shallow depth, the wet season runoff may be increased causing less water to be available for recharge. The reduced quantity of water in storage would decrease the length of time that groundwater inflow would maintain the wetland condition. In the case of the baygall wetland, groundwater inflow is the predominant inflow factor and the location of the environment must be at the toe of a slope with a considerable area of water-table aquifer above it. Therefore, the location of a basin or isolated wetland is based

TABLE 2.4.6.1 BASIN TYPES AND COMMON OCCURRENCE OF WETLAND TYPES FROM FIELD OBSERVATIONS AND EXPERIENCE OF THE INVESTIGATORS

Features	High Relief & Permeability			Medium Relief & Diverse Soils			No Relief & Diverse Soils		
Basin:	Type 1			Type 2			Type 3		
Location:	U	M	L	U	M	L	U	M	L
Wetland Type									
Wet Flatwoods	N	R	C	R	R	C	R	C	C
Wet Prairie	N	R	C	R	R	C	R	C	C
Baygall	N	C	C	N	C	C	N	C	C
Bottomland Forest	N	R	C	N	R	C	N	C	C
Floodplain Forest	N	R	C	N	R	C	N	C	C
Swale	N	R	R	N	R	C	R	C	C
Basin Marsh	N	R	C	R	C	C	R	C	C
Depression Marsh	N	R	C	R	C	C	R	C	C
Flatwood/Prairie/Marsh Lakes	N	R	C	N	C	C	N	C	C
Blackwater Streams	N	N	N	N	N	R	N	R	C
Seepage Streams	N	N	R	N	R	C	R	C	C

N = Does Not Occur
R = Rare
C = Common

U = Upper
M = Middle
L = Lower

on both altitude within a watershed, the watershed or basin type (geometry), and the local water-table aquifer hydraulic characteristics.

Planar Wetlands

The category of planar wetlands includes the wet flatwoods and other broad areas where water accumulates. These type of wetland features can develop wherever the soil and underlying substrate have a low hydraulic conductivity sufficient to allow seasonal ponding of water. In parts of the phosphate district, there are broad flat areas that occur near the top of a watershed (type 3) and in other areas, the flatlands occur near the base of the watershed. If a broad flat area provides a sufficient area of catchment to gather precipitation, one of the planar wetlands could develop. In this case, the most important factor may be the hydraulic conductivity of the substrate. At or near the top of the watershed, the hydroperiod of the wetland type would be solely dependant on the balance between precipitation and evapotranspiration. These higher wetlands would tend to have shorter hydroperiods compared to planar wetlands located in the lower part of a watershed. In conclusion, the location of planar type of wetlands is dependant to a large degree on the local landscape topography, the hydraulic properties of the substrate, and the water balance controlling the localized hydroperiod.

Riverine Wetlands

The riverine wetlands are greatly dependant on the net hydraulic characteristics of the watershed including slope, surface-water runoff, and the hydraulic conductivity of the aquifer system. Development of these wetland types is dependant on the geometry of the stream channel, the seasonal duration of flow through the channel, and the flood frequency. As described in the previous section, the bottomland forest cannot tolerate prolonged flooding or frequent flooding. Therefore, the riverine wetland types associated with distinct channels usually develop in the middle and lower portions of a watershed, consummate with the flow characteristics of the stream. Unchannelized riverine wetland systems, such as swales, can develop higher in the watershed, particularly if there are sufficient areas of surrounding uplands to produce a base flow for the swale. The alteration of a watershed can lead to substantial changes in the locations of riverine wetlands, particularly in lower basin areas. The exact location of riverine wetlands within a watershed is dependant on both the channel geometry and the flow duration within the channel, which is dependant on the water balance in the upstream part of the watershed.

2.4.7. SUMMARY

The occurrence of wetlands in nature is not based on random distribution, but is a function of the hydroperiod. Hydroperiod is the amount of time in a given year that some area or vegetative assemblage is inundated or saturated with water. The hydroperiod of any location in a watershed is a function of the water balance occurring at the corresponding location. The balance between inflow and outflow factors is greatly affected by the geographic position within a watershed, the altitude, and the hydraulic characteristics of the shallow aquifer system, particularly the hydraulic conductivity, the porosity, and the hydraulic gradient. Aquifer hydraulic parameters are controlled to a large degree by the geology within the aquifer.

There are about eleven types of naturally-occurring wetland communities located in the Florida phosphate mining district. Each of these wetland types occurs within a unique environment controlled by the hydrogeology and the hydrologic regime. The specific location of many wetland types does not occur at a unique altitude or position within a watershed, but the location is controlled by the set of properties necessary to produce the environment. If a drainage basin or watershed is altered, the water balance may be altered sufficiently to cause a change in the type of wetland environment that may occupy a given geographic location. This is particularly relevant to the isolated or basin wetlands. Riverine wetland types are associated with channels or flowways, which must have a specific set of flow conditions in order to maintain the environments.

In conclusion, the natural occurrence of wetlands is directly related to a unique set of hydrologic conditions produced by the hydrogeology of the shallow aquifer system, the soil types, the altitude of the location within a watershed, the physical contours of the land surface, and local climatic conditions.

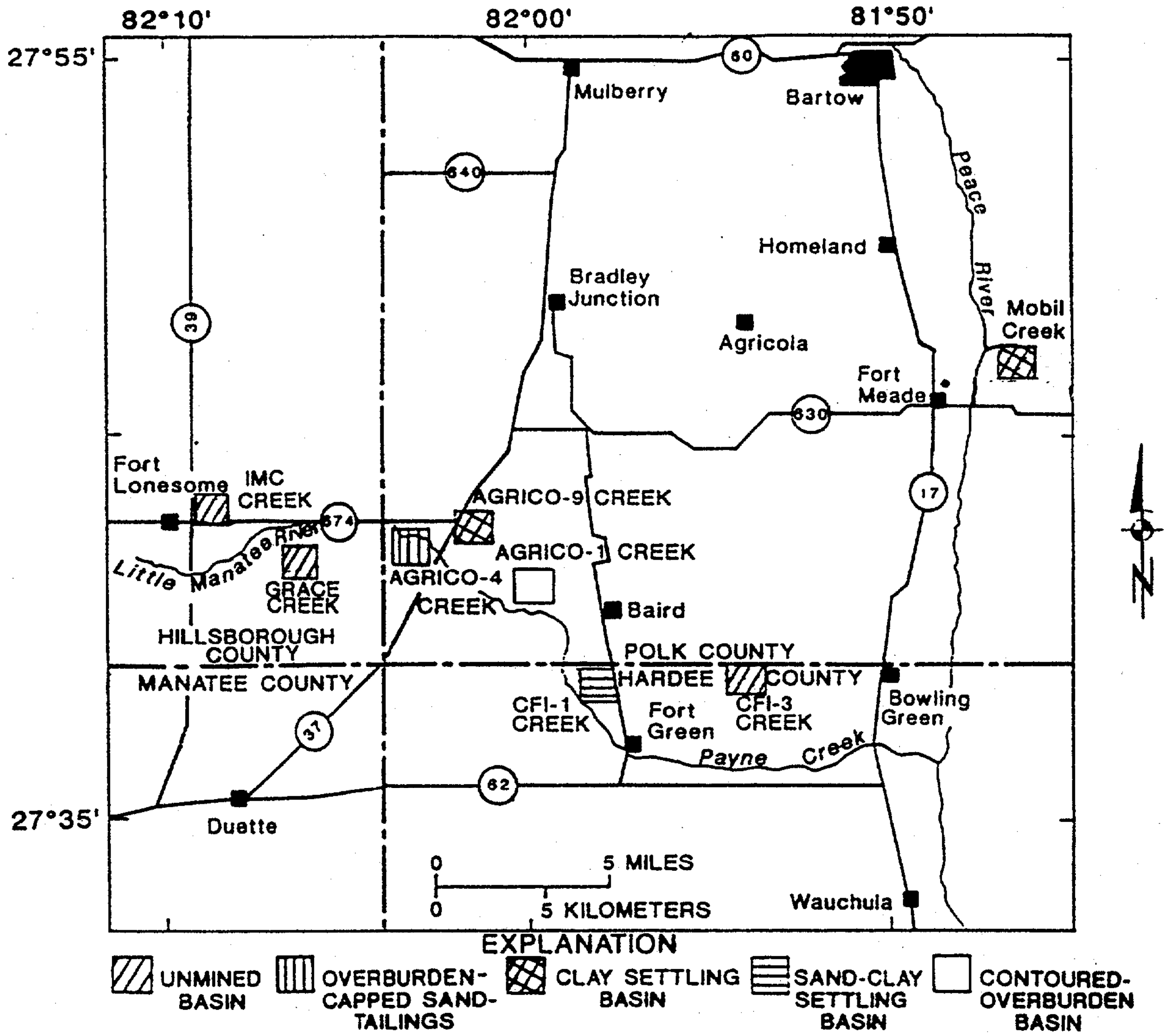
2.5 HYDROLOGY OF CREATED WETLANDS IN THE FLORIDA PHOSPHATE DISTRICTS

2.5.1. METHODS OF STUDY

There are over 170 wetland creation/mitigation projects being conducted by 7 phosphate mining companies. Most of these projects are located in the Central Phosphate District with the remainder being located in the Northern District. Available hydrologic information ranges from fair to none on a site to site basis and its quality seems to follow this same trend. In no case is there an adequate set of hydrologic data to make a complete systematic analysis of the water balance for a given wetland site. Sources of data include regulatory monitoring reporting, governmental research agencies (Florida Institute of Phosphate Research, Florida Geological Survey, U.S. Geological Survey and State Water Management Districts), mining company records and private research and consulting organizations. A recent research project compared the hydrology of unmined and reclaimed basins within the Central Florida Phosphate District (Lewelling and Wylie, 1993). This report provides valuable research information on this topic. The locations of their study basins are shown in Figure 2.5.1.1. Other valuable recent hydrologic investigations pertinent to this study include a report entitled “Creation and Restoration of Wetlands: Some Design Considerations for Ecological Engineering” (Mitsch and Clark, 1992), and a report by Riekerk, Kovhnak and Brown (1991) entitled “The Hydrology of Reclaimed Phosphate-Mined Wetlands”. Informative Florida wetland papers have been authored by a number of scientists and are utilized in this study. Unfortunately, there is no “central clearing house” which catalogs and stores all this hydrologic information under one roof, although FIPR makes the best attempt at doing this.

Pre-mining hydrologic data is almost non-existent for the earlier mined sites. The best sources of information can be found in regional hydrologic studies conducted prior to mining an area and by studying the older topographic maps and air photos. Lands now being mined or to be mined in the near future have a much better pre-mining hydrology data base inventory.

Created wetlands design at any particular site is significantly influenced by federal and state regulatory criteria, standards and mandates. Also of consideration in the design of a created wetlands site is the application of knowledge of natural wetland hydrologic characteristics and processes. The permitted designs attempt to regulate water inflows, outflows and storage patterns at each site. These flow and storage patterns may or may not be the optimum hydrologic characteristics, based on the particular substrate, surficial aquifer parameters, ground surface contours and other important attributes, to design a successful wetland. Only after a fairly long period of time has elapsed since the completion of the created wetland, can one evaluate if the design criteria were truly adequate.



MISSIMER INTERNATIONAL	Pr Name: FIPR – HYDROLOGY	Groundwater and Environmental Services
	Pr No. FH4-8 Date: 1/12/95	
	DWG No. Rev.No. 1	

FIGURE 2.5.1.1. LOCATIONS OF U.S.G.S. CENTRAL FLORIDA STUDY BASINS. MODIFIED FROM LEWELLING AND WYLIE (1993).

2.5.2. CREATED WETLAND DESIGN CONSIDERATIONS

It is suggested here that certain basic information concerning the pre-mining landscape and hydrogeology, the mining plan, the post mining landscape, regulatory permitting and the desired end product all be considered in the design phase. The application of this basic information to the final reclamation plan should provide the best opportunity for a successful project. A discussion of this required basic information is presented.

PRE-MINING SITE CHARACTERIZATION

The regional hydrogeologic framework of the two phosphate mining districts is presented in Section 2.4.1. This information should first be examined to understand how the site fits into this regional framework. Climatic data over the entire period of record needs to be evaluated. These data can be obtained from selected NOAA weather stations and other sites where high quality weather measurements are being made in the region.

The geomorphic features of the proposed mining area and the surrounding land should be thoroughly documented. This includes topography, drainage patterns and definition of watershed boundaries. The various landforms, such as upland flatwoods, stream flood plains, lakes, wetlands and hillslopes and their associated vegetation patterns that occur throughout the pre-mining landscape should be examined. The soils and surface materials that support those various landforms should be evaluated in terms of biological associations, areal distribution and hydrologic properties.

The hydrogeologic framework of the proposed mining area and those lands adjacent to this area must be carefully characterized. How the water balance of each watershed which will be altered in the mining process should be determined. The various hydrogeologic parameters that need to be considered in water balance analyses are discussed in Section 2.4.2. The stratigraphy of the site, at least down to the maximum mining depth, can be studied from the existing mining exploratory borehole information. Definition of the surficial and intermediate aquifer systems which will be altered in the mining process should be studied. This includes water levels, water level fluctuations, hydraulic properties and the potentiometric head relationships between the two aquifer systems. Obtaining these data may require the installation of several piezometers open exclusively to each aquifer system.

The pre-mining study should conclude with a system analysis approach of the features, processes and materials which collectively created the landscape as it exists today. This knowledge can then be used in the mining program and reclamation plans in order to optimize the chances of achieving the stated project goals.

THE MINING PLAN

Similar mining techniques are utilized in both the Central and Northern Phosphate Districts. This basically involves the removal of all vegetation followed by the construction of a trench around the perimeter of the planned mine site and/or the drilling of dewatering wells to dewater the surficial aquifer system. The overburden, ranging in thickness from 20 to 60 feet is removed in layers by draglines and cast into a previously mined cut. The phosphate ore matrix, ranging in thickness of 5 to 10 or more feet is then removed. At the end of mining the site, a series of linear lakes and overburden spoil piles remain. The width of these lakes and spoil piles average between 120 to 150 feet and their lengths vary with the size of the particular mine site and therefore can be 5000 feet or more in length. Lake depths vary with the thickness of overburden and original ore matrix.

The hydrologic features resulting from the mining process most closely related to the hydrology of the future reclamation site should be considered. The potential breaching, removal or partial removal of the confining layer between the surficial aquifer and the intermediate aquifer systems may result from the mining process (see Section 2.6.1 for a more detailed discussion of this topic). This disruption of the confining layer could affect the water balance relationships, affecting the created watersheds. For example, downward recharge to the intermediate aquifer from the surficial aquifer may be so rapid that desired water levels in the surficial aquifer cannot be maintained. The direction of mining relative to natural and/or created drainage patterns may have hydrologic importance. As previously noted, mining results in linear features which can either retard or enhance subsurface seepage velocities and may even influence flow direction within the reclamation framework.

These features, directly related to the mining activity, can be evaluated prior to mining the site by analyzing the baseline data obtained during the pre-mining study. The effects of removing the confining layer between the two aquifers can be estimated by knowing the natural hydraulic head differences between the two aquifers. Minor modification of the mining plan may be required to account for these effects in order to reduce the potential for later problems in the created landscape. Likewise, mining orientation could be chosen to optimize groundwater movement within the constructed landscape based on the baseline information.

POST MINING LANDSCAPE

This discussion concerns the methods used in the final phase of the mining process. Briefly described are the four mined area types based on the type of material that is used to backfill the mine site and provides the basic framework for the final created landscape. A fifth type is further discussed that does not involve the filling of the mined area. The five types, of features requiring reclamation are: phosphate clay settling areas, sand tailings, contoured overburden, sand-clay mix and land and lake areas. Each of these features affects the hydrology and therefore water balance within the created landscape, in different ways.

<u>Phosphate Clay Settling Areas</u>

Benefication of the phosphate matrix produces three products: phosphate ore, clay waste and sand waste. The largest volume of byproduct is the phosphate clay waste. Therefore, the most common method of reclaiming mined land is by backfilling the mined site with the clay waste

(Lewelling and Wylie, 1993). First large earth dikes are constructed around the perimeter of the mined site, typically about 500 acres in area. These dikes may be 20 to 40 feet or more above the natural grade and are generally composed of sand tailings and/or mined overburden. The clay waste is pumped into the diked area as a slurry at about 3-percent solids from the benefication plant. At the other side of the site is a constructed spillway which allows the excess water to return to the process water canal. Freeboard between the top of the dike and the clay slurry cannot be less than 5 feet by law. Under ideal conditions, several of the clay settling sites are available for clay disposal. This situation allows alternating disposal between the sites and thereby providing more time for clay settling and consolidation in each case (Selwyn Presnell, verbal communication). It takes approximately 3 or more years to fill a site, depending on the number of sites available for disposal.

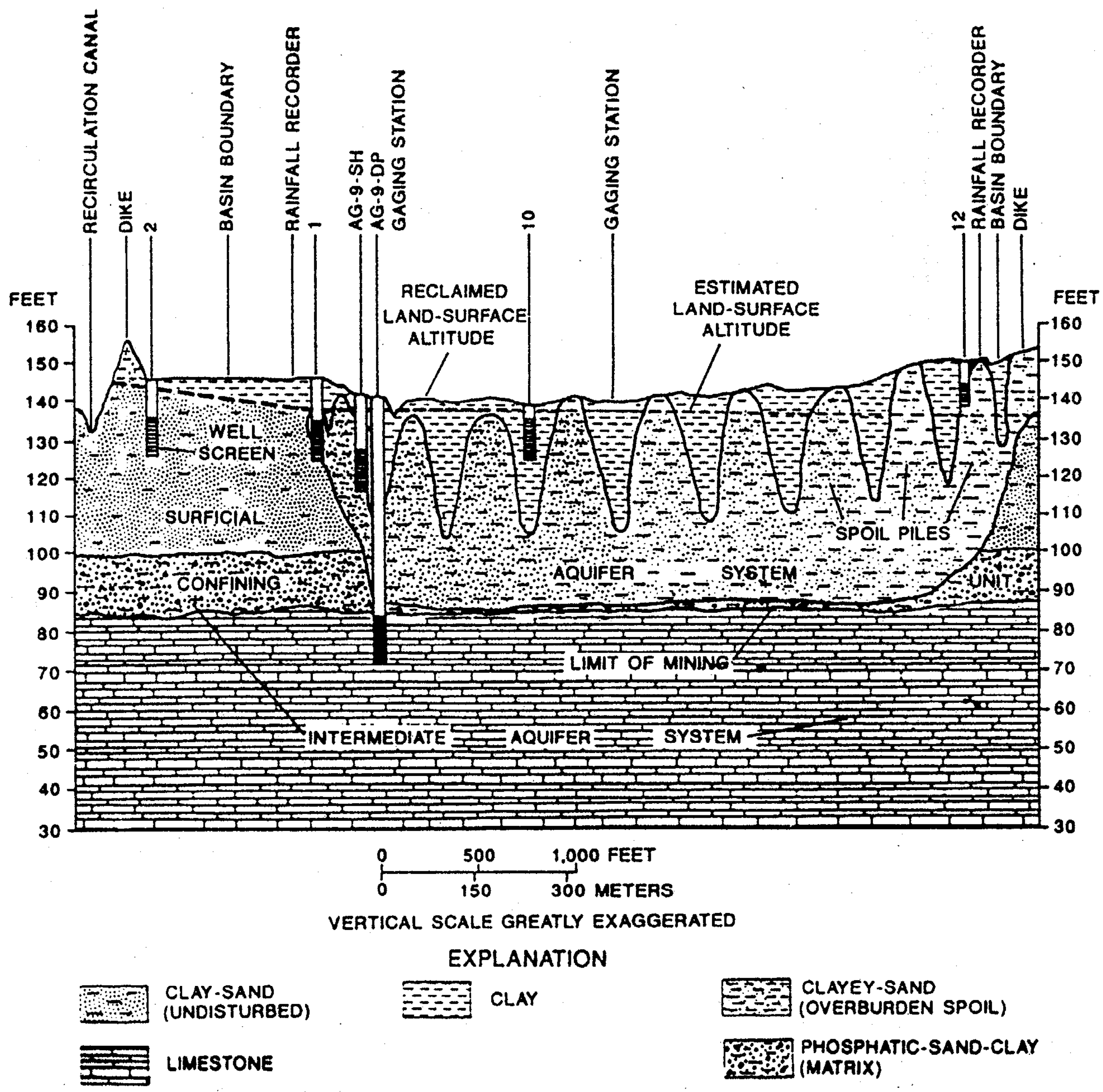
After the mining area is completely backfilled with the clay waste, as much water as possible is decanted from the area. Within a few months, the slurry looses water to about 18 to 22 percent solids, however, one still cannot walk on the material. After about 5 years a solid crust forms on the surface allowing support for a farm tractor. To speed up the reclamation process, a perimeter ditch is constructed inside the dike for further dewatering of the slurry. Low areas on the crust surface are then connected to the perimeter ditch and drained. According to Lewelling and Wylie (1993) the clay slurry must consolidate to at least 33 percent to occupy the same volume it occupied prior to mining. The consolidation process continues for years and the entire surface may subside 10 or more feet during this time. The existing overburden piles can form topographic highs as the surrounding clays consolidate. Some of the clay settling areas that have consolidated to a point where the surface is below natural grade and near the water table form shallow lakes and/or wetlands with clay bottoms. An example of a phosphate clay settling reclaimed mined site is displayed in Figure 2.5.2.1.

Overburden-Capped Sand-Tailings Areas

Sand, as previously stated, is another byproduct of the matrix benefication process. This material, on a dry weight basis, is the major waste byproduct produced. The sand tailings are pumped as a slurry from the benefication plant to the mined pits to serve as backfill material. When the pits are filled almost to the desired level, the adjacent overburden spoil piles are pushed over onto the sand tailings. A hydrogeologic section showing this type of mine reclamation is illustrated in Figure 2.5.2.2.

Contoured Overburden Areas

A third method, known as contoured overburden backfilling, is usually done when the overburden thickness is greater than three times the phosphate matrix thickness. The reworked overburden has nearly the same volume as the mining void so that the overburden spoil piles are simply pushed into the adjacent mine pits and are contoured to final grade. Because of a somewhat decreased net volume of material, these areas generally drain internally (Lewelling and Wylie, 1993). This type of mining landscape is more common in areas where the mining is fairly deep

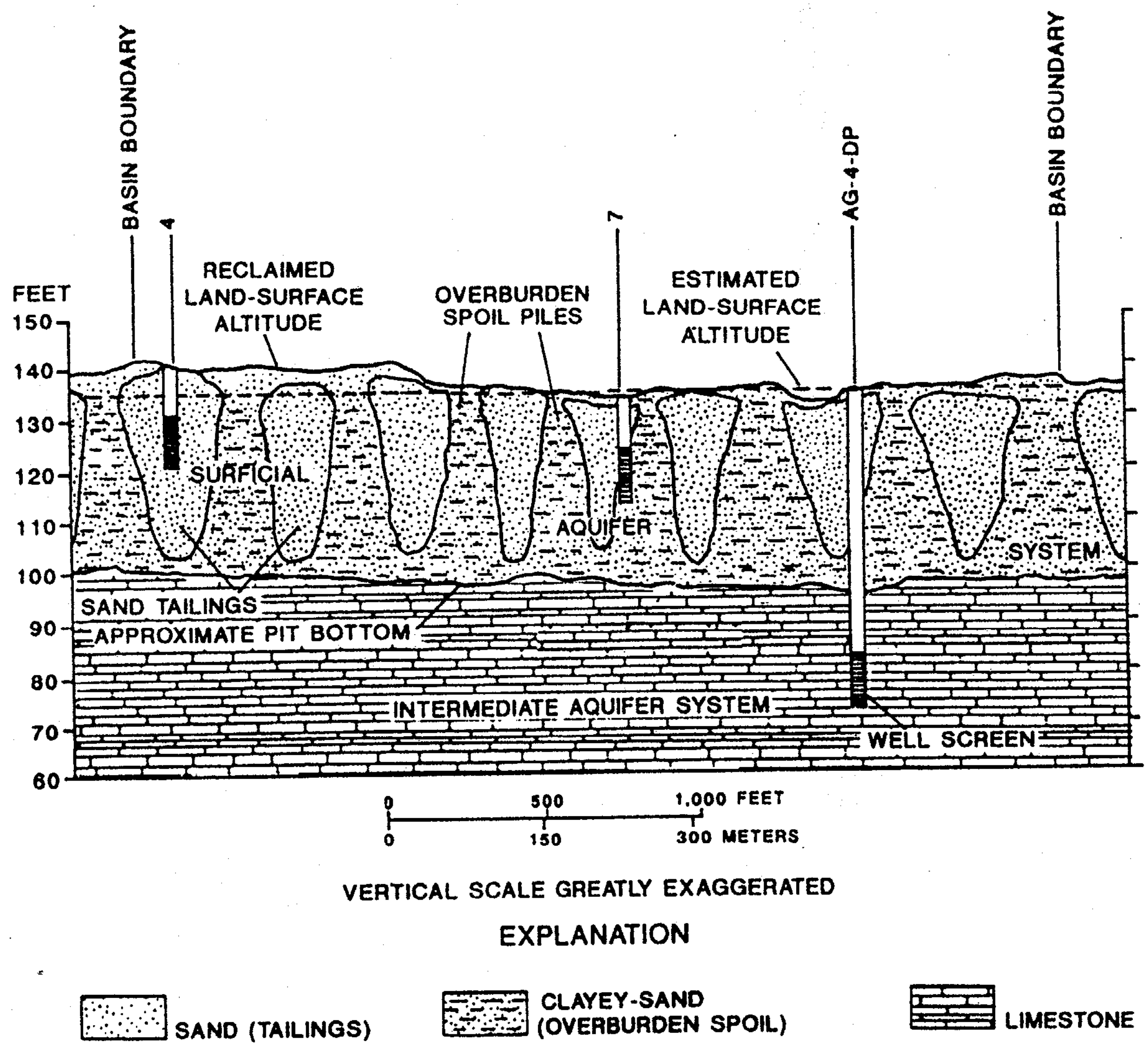


MISSIMER INTERNATIONAL INC.

Pr Name: FIPR – HYDROLOGY		
Pr.No. FH4–8	DWG No. CUTPASTE.DWG	Date: 08/04/94 Rev.No. 1

Groundwater and Environmental Services

FIGURE 2.5.2.1. HYDROGEOLOGIC SECTION AT AGRICO-9 CREEK CLAY-SETTLING BASIN (AFTER LEWELLING AND WYLIE, 1993).



MISSIMER INTERNATIONAL Inc.	Pr Name: FIPR – HYDROLOGY	Groundwater and Environmental Services
	Pr.No. FH4–8 DWG No. CUTPASTE.DWG Date: 08/04/94 Rev.No. 1	

FIGURE 2.5.2.2. HYDROGEOLOGIC SECTION AT AGRICO-4 CREEK OVERBURDEN-CAPPED SANDTAILING BASIN (AFTER LEWELLING AND WYLIE, 1993).

thus requiring considerable earthwork. An example of a contoured overburden site is given in Figure 2.5.2.3.

Sand-Clay Settling Areas

A fourth type of waste disposal is to backfill mined areas with a mixture of the sand and clay waste from the benefication process. The ratio of sand to clay is determined by the overall sand to clay material balance of the ore processing at any given time, but usually is approximately 2:1, respectively. It has been stated that this mixture is easier to work with (Keen and Sampson, 1983) and that these mined landscape areas are hydrologically and topographically similar to, and may achieve similar results as a clay settling disposal area (FIPR/FHM doc., 1991). A hydrogeologic section showing this type of mine reclamation is displayed in Figure 2.5.2.4.

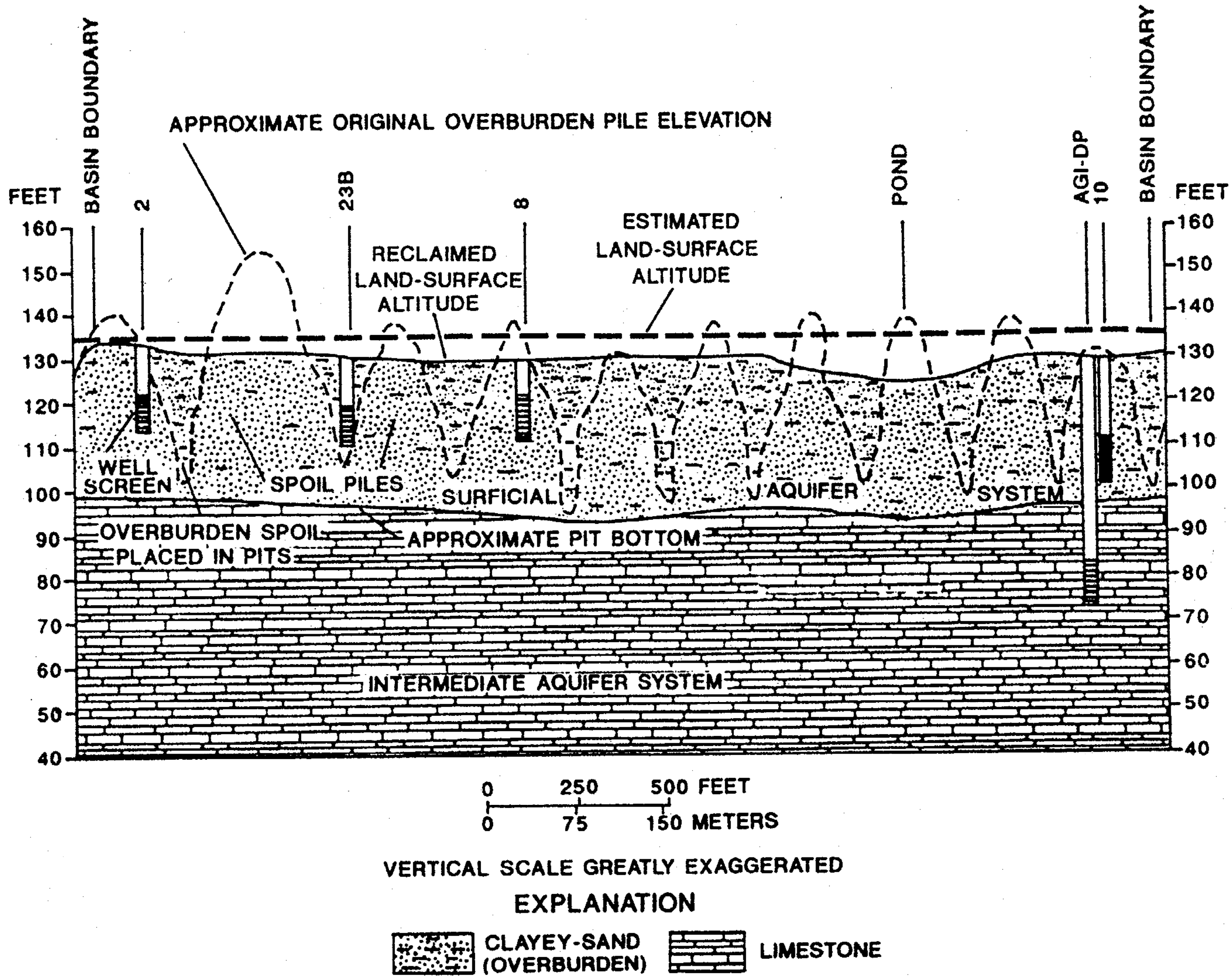
Land and Lake Areas

The last mining technique results in a system of linear water-filled mine cuts and adjacent spoil piles. The overburden spoil piles are graded to be fairly flat in the central portion with slopes no steeper than 4:l along the lake edge down to a depth of 6 feet. Beyond this depth, slopes are much steeper and lake depths are 30 to 40 feet deep. This type of landscape has very limited opportunity for extensive wetlands creation since there is only a narrow littoral zone.

RECLAMATION PERMITTING

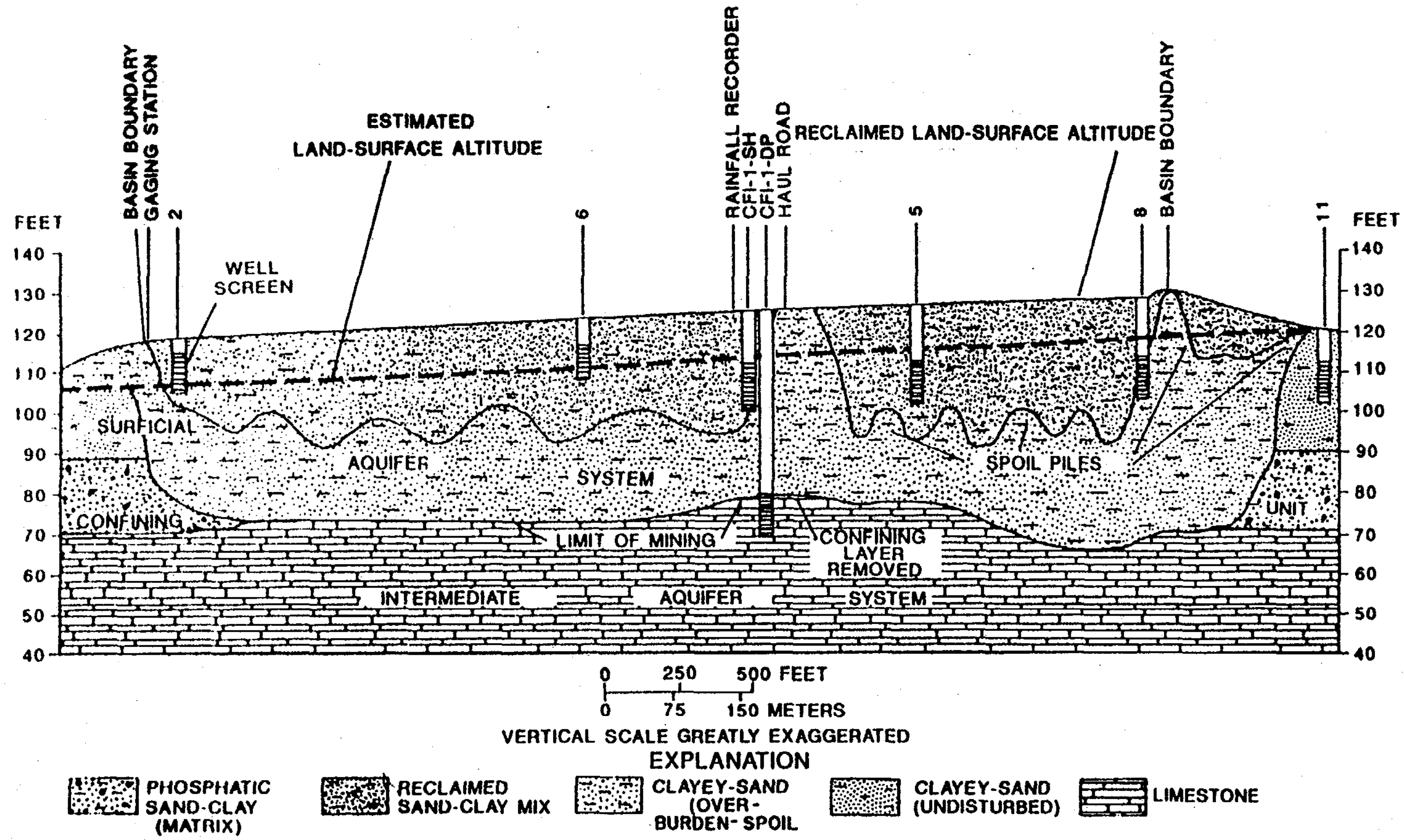
The reclamation of mined areas is regulated by federal, state and sometimes local laws. Created landscape design criteria have varied widely and typically evolve through the permitting process. In the past, four or more different permits were required from at least three different agencies, each with different rules, restrictions and mitigation requirements. Currently, the authority to regulate mandatory reclamation at the state level is the Department of Environmental Protection (FDEP). An attempt is being made by the FDEP, water management districts and the Army Corps of Engineers to develop a one-stop permit for mine reclamation activities. This new permitting process began July 1, 1994 and is expected to take several years to fully implement. It is hoped that the one-stop wetlands permit should eliminate many of the previously encountered problems,

From a hydrologic point of view, there may be conflicts between the permitted wetland creation design and what actually will be successful under the altered conditions. For example, one permitted design concept is to try to replicate in the created landscape those same features that were present prior to mining. The problems with this concept are that the created parcel has a completely new water budget: groundwater levels are different due to the altered aquifers and changes in land contours and elevations; different evapotranspiration rates develop in response to changes in soil matrix, drainage condition and vegetation types; and surface water inflows and outflows are completely altered from the original state. All of these new variables make the reproduction of the old landscape a most difficult, if not impossible, task to accomplish.



MISSIMER INTERNATIONAL Inc.	Pr Name: FIPR – HYDROLOGY Pr.No: FH4-8 DWG No. CUTPASTE.DWG Date: 08/04/94 Rev.No. 1	Groundwater and Environmental Services

FIGURE 2.5.2.3. HYDROGEOLOGIC SECTION AT AGRICO-1 CREEK CONTOURED-OVERBURDEN BASIN (AFTER LEWELLING AND WYLIE, 1993).



MISSIMER INTERNATIONAL Inc.

Pr Name: FIPR – HYDROLOGY		
Pr.No. FH4-8	DWG No. CUTPASTE.DWG	Date: 08/04/94 Rev.No. 1

Groundwater and Environmental Services

FIGURE 2.5.2.4. HYDROGEOLOGIC SECTION AT CFI-1 CREEK SAND-CLAY SETTLING BASIN (AFTER LEWELLING AND WYLIE, 1993).

Created wetlands permit stipulations generally include some type of monitoring program to evaluate vegetational restoration. For mitigation purposes, wetland success criteria are outlined in the FDEP permit. These criteria are usually based on vegetation type, percent of area covered by plants, trees per acre, etc. - all related to some undisturbed control (reference) wetland in the same area. However, as previously stated, hydrologic conditions at the created site are quite different than those conditions at natural sites. Since the hydrologic conditions are different, there is the possibility that similar vegetation type, density and distribution of the control wetland cannot be successfully duplicated at the created site. However, the use of the control wetland has advantages also. The created wetland may be a different wetland than was the original, but it would be similar to some type of wetland that occurs naturally in the area.

Discussion

Perhaps a more like-kind comparative approach to wetland success could be used in addition to the comparison to some "control" wetland. In this option, newly created wetlands would be compared to established created wetlands (those deemed successful) with similar mine reclamation histories. Success criteria for each mine landscape type (clay settling area, sand tailings, etc.) could be developed by mutual agreement between mine operators, research groups, and regulatory people. Newly created wetlands could be compared to created reference wetlands with similar hydrologic characteristics and at the same time compared to natural reference wetlands in the same area. It has also been suggested (Tim King, written communication, 1994) that the control wetland should be a reclaimed native site rather than a reclaimed mine site for a like-kind comparative approach. The authors believe this could be a valuable approach in determining success criteria.

CREATED WETLANDS DESIGN CONSIDERATIONS

It has been stated "Simple systems tend to be self-regulating and self-maintaining" (Boule, 1988). In other words, the wetland design should be kept simple which normally requires considerable effort into the act of designing these wetlands. The following are some suggested, design considerations:

1. Design the created wetlands in accordance with the reclaimed hydrogeologic framework. Understand the new water balance of the new watershed and incorporate this information into the final design plan.

2. Design the created watershed to utilize natural energies and hydrologic processes associated with the water balance.

3. Design the system with the landscape, not against it. Floods and droughts are to be expected, not feared. Outbreak of plant diseases or invasion of exotic species are often symptomatic of other stresses and may indicate faulty design rather than ecosystem failure (Mitsch and Cronk, 1992).

4. Take into account the surrounding land use and the future plans for the land. Future land use plans, such as new mining activities and accompanying dewatering of the surficial aquifer or the creation of a new clay settling pond with accompanying groundwater mounding and more rapid runoff, can have significant results in the created wetland.

5. Give the system time. Wetlands are not functional overnight and several years may elapse before nutrient retention, soil formation or wildlife habitat are even beginning to develop. Strategies that try to short-circuit ecological succession or over-manage it are often doomed to failure (Mitsch and Cronk, 1992).

6. Design the system for function, not form. If initial plantings and animal introductions fail, but the overall function of the wetland, based on the initial objectives, is intact, then the wetland has not failed. Expect the unexpected (Mitsch and Cronk, 1992).

2.5.3. CREATED WETLAND COMMUNITY TYPES

A very limited number of wetland community types have been created in the reclaimed phosphate mining areas. Of the eleven common wetland plant communities present in the phosphate mining districts, only about six types have been generally recreated (Table 2.5.3.1). It should be noted that the wetland classification used in this report is generic to a large degree and other subtypes of the primary described wetland types may be present. Therefore, wetland plant specialists may believe that a larger number of wetland types have been restored, but the authors conclude that a more detailed classification would serve no positive purpose to the hydrology discussions.

2.5.4. FIPR HYDROLOGIC MODEL

DISCUSSION

The FIPR Hydrologic Model (FHM) represents an integrated modeling environment that combines GIS, surface and groundwater flow models. The GIS package (Spatial Analysis System, SPANS, Tydac Technologies, Inc.) is used for spatial analysis of data and for preprocessing data for both the surface water model (Hydrological Simulation Program, HSPF, U.S. EPA) and the groundwater model (MODFLOW, USGS). The application of GIS to surface and groundwater models in an integrated modeling environment represents the current trend. Recent work by Richards and others (1993) and Roaza and others (1993) show the application of this approach to groundwater flow modeling in North Florida.

There are several advantages to the integrated approach employed in the FHM. The use of GIS for data pre- and post-processing results in considerable savings in model development time. Also a consistent set of input data is generated depending on the grid spacing or sub-basin areas since the same GIS overlays are used. Generation of output in graphical form is also expedited.

TABLE 2.5.3.1. NATURAL WETLAND VS. CREATED WETLAND TYPES IN THE PHOSPHATE MINING DISTRICTS

	Natural	Created
Palustrine		
Wet Flatlands		
Wet flatwoods	X	
Wet prairie	X	X
Seepage Wetlands		
Baygall	X	X
Floodplain Wetlands		
Bottomland forest	X	
Floodplain forests	X	X
Swale	X	X
Basin Wetlands		
Basin marsh	X	
Depression marsh	X	X
Lacustrine		
Flatwoods/prairie/marsh lakes	X	
Riverine		
Blackwater streams	X	
Seepage streams	X	X

2.5.5. SUMMARY

It is quite clear that little hydrogeologic information is available on the premining landscape beneath the Florida Phosphate Districts. Despite the fact that a very large financial investment has been made by the mining companies and the state of Florida to develop a detailed plan for mining reclamation, varying degrees of success have been achieved to date in the process of creating wetlands. Only about six of the eleven naturally-occurring wetland types have been successfully created. It is concluded that the primary causes of created wetland problems is the hydrology of the wetlands. If the pre-mining watershed hydrology was known, it would be possible to locate created wetlands in more hydrogeologically appropriate settings, which would greatly increase the probability of success.

During the mining process, the hydrogeology of the shallow aquifer system is significantly altered. Watershed hydraulic characteristics have been changed, causing changes in the water balance in nearly every point in the created system. Despite the use of such tools as the FIPR model, the reclamation plans have been reviewed by regulatory agencies with rigid guidelines predicated on mimicking the pre-existing natural system. It is not possible, nor is it logical, to place wetland environments in the same geographic position, when the water balance has been altered. It is necessary to match the created wetland environments with the post-mining hydrologic system not the pre-mining condition.

2.6 HYDROLOGIC FACTORS IN THE CREATION OF WETLANDS

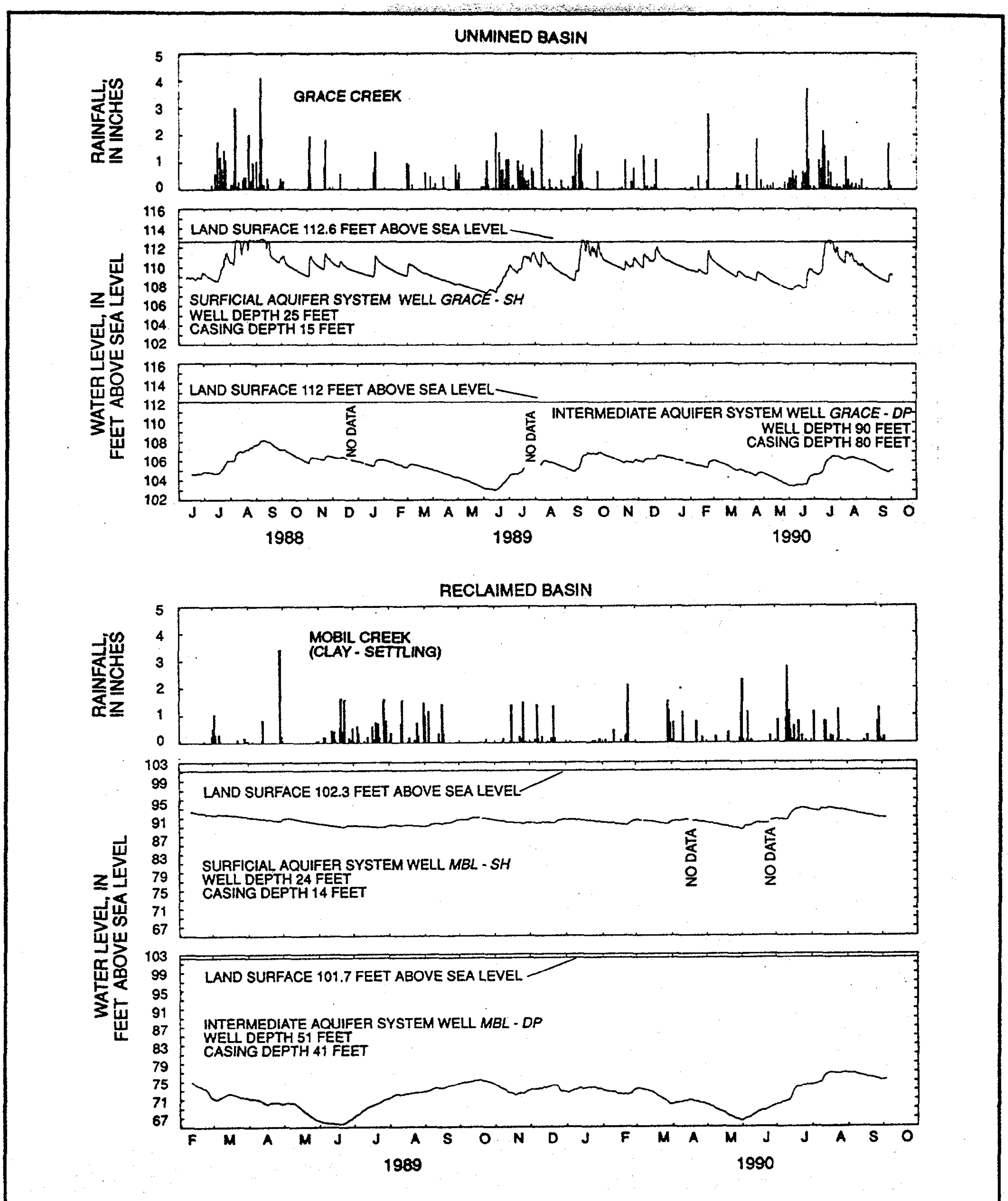
2.6.1. ALTERATION OF THE GEOLOGIC FRAMEWORK OF THE WATER TABLE AND INTERMEDIATE AQUIFERS

The hydrogeologic framework of the natural setting, as described in Section 2.4.1., is severely altered during the mining and reclamation processes. These changes create new and different water balance factors from those that are presented in Section 2.4.2. This discussion outlines the various notable differences and similarities of properties in the water-table and intermediate aquifers under pre-mining and post-reclamation conditions.

WATER-TABLE AQUIFER

The undifferentiated sedimentary deposits that form the water-table aquifer are removed to uncover the phosphate ore matrix as mining proceeds. The overburden material is cast into an adjoining previously mined area. This and additional material from the ore benefications process is then frequently brought back to the mined site and used to fill the remaining void to a desired elevation. The end product of this activity is the newly formed framework of the new water-table aquifer.

A comparison of three unmined basins with five reclaimed basins showed that similar water-level fluctuations in the water-table aquifers were noted in all eight basins but the response of water levels to rainfall and seasonal trends in water levels varied among basins (Lewelling and Wylie, 1993) with the reclaimed basins generally showing an attenuated response to rainfall recharge. Figure 2.6.1.1. illustrates the water-table aquifer response to rainfall in one unmined basin (Grace Creek) and in a mined clay-settling basin (Mobil Creek). This subdued rainfall response may result from the fact that surface soil bulk density tends to be increased while subsoil bulk density decreases after reclamation (Gee and others, 1978). The changes in bulk soil density, in turn decrease infiltration (soil compaction) and increase groundwater storage capacity (Riekerk and others, 1991). The clay-settling areas respond more slowly to rainfall recharge. This is attributed to the low permeable clay restricting the downward infiltration of water (Lewelling and Wylie, 1993). Another study of a clay settling area showed a similar slow water level response to rainfall recharge but the authors related this to the low air content entrapped in the normally wet clays (Riekerk and others, 1991). Both the clay settling and sand-clay settling basins had the largest average depths to water below land surface probably resulting from their elevated land surface, the low permeability of the material matrix and possibly from the flow of water downward into the hydraulically connected (breached confinement) intermediate aquifer (Lewelling and Wylie, 1993). These authors further conclude that in the low permeability basins, groundwater levels do not fluctuate in response to variations in stream flow. This indicates to Lewelling and Wylie that the surface-water and groundwater systems have little hydraulic connection in the basins. It was noted that groundwater level fluctuations in the overburden-capped sand-tailing basin most closely resembled surficial aquifer water level fluctuations in unmined basins. However, water level response to rainfall recharge was still slower than in the



MISSIMER INTERNATIONAL

Pr Name: FIPR – HYDROLOGY		Groundwater and Environmental Services
Pr No. FH4-8	Date: 1/12/95	
DWG No.	Rev.No. 1	

FIGURE 2.6.1.1. AQUIFER RESPONSE TO RAINFALL IN AN UNMINED BASIN AND IN A CLAY-SETTLING BASIN. MODIFIED FROM LEWELLING AND WYLIE (1993).

unmined basin. Water levels in the contoured-overburden basin fluctuated less in response to seasonal rainfall variations than water levels in the overburden-capped sand-tailings basin.

Hydraulic conductivity of the newly created surficial aquifer was measured in 5 reclaimed basins by slug recovery testing (Lewelling and Wylie, 1993). This method involves displacing a known volume of water in a well and measuring the responding rate of change in water level. Two clay settling basins have calculated hydraulic conductivity ranging from less than 0.01 ft/d to as high as 1.2 ft/d with both basins averaging about 0.5 ft/d. Somewhat surprising is that the contoured overburden basin has a lower average conductivity value (0.35 ft/d) than the clay-settling basin. Also puzzling are the relatively high hydraulic conductivities of the sand-clay settling basin which range from 1.2 to 11 ft/d and average 5.6 ft/d. Not surprising, the sand-tailings basin had the. highest conductivity, averaging 33.1 ft/d. It is believed that these apparent anomalous hydraulic conductivity values reflect varying degrees of compaction and consolidation within the hydrogeologic frameworks and the heterogeneous materials used to backfill these individual basins. Another possible explanation for these anomalous conductivity values could be the presence of deep desiccation cracks in the clay or sand clay mix.

Also related to the alteration of the geologic framework by the mining and reclamation procedures is the relationship between the water-table aquifer and the overlying unsaturated zone. Each reclamation type results in different substrate characteristics. For example, reclaimed basins backfilled with sand-tailings may present problems unique to this type of basin.

In addition to the highly permeable nature of the sand-tailings, resulting in rapid infiltration, is the fact that this texture cannot maintain moisture during normal dry or drought periods. In contrast, naturally occurring deep organic soils have the ability to provide moisture to plant roots because of their high capillarity during dry and drought times.

Capillarity is the physical phenomenon where water molecules at the water table are subject to an upward attraction due to surface tension of the air-water interface and the molecular attraction of the liquid and solid phases. The vertical distance the water will rise above the water table is a function of soil texture. For example, the capillary height for a coarse sand is approximately 3 centimeters while the height for clay is about 3 meters. This large difference in capillary height can be an important variable in determining if this water is available for plant survival.

The sand-tailings commonly used for substrate in the created wetlands are usually free of fine-grained materials and therefore would have minimum capillary water height. This could be a problem during dry periods when plant roots are unable to extend downward far enough to intercept the capillary water.

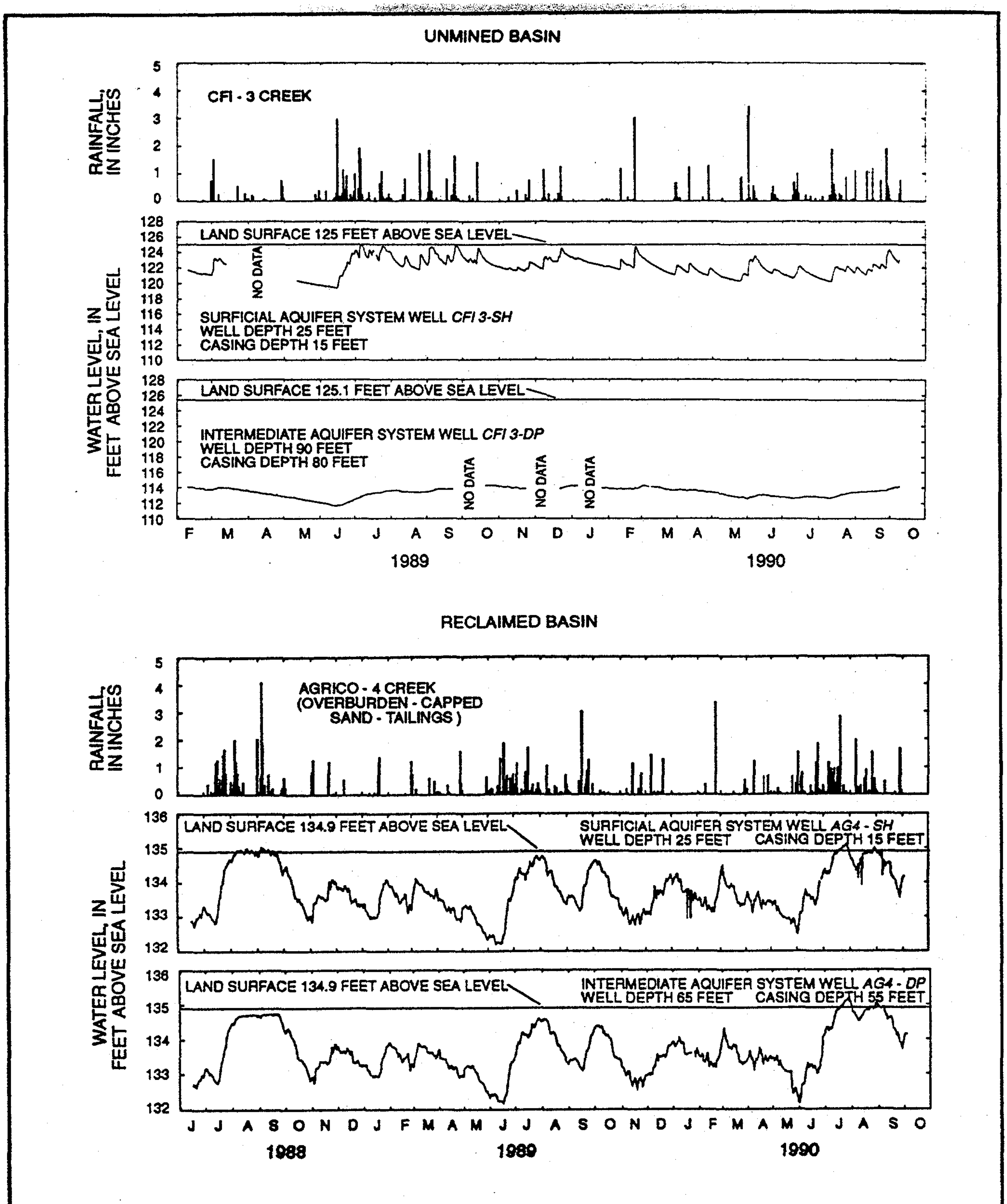
The commonly encountered wet prairie type wetland created in previously mined areas may be particularly sensitive to periodic changes in available water as flooding is the most important sustaining parameter. These wet prairies are relatively flat and generally have a shorter hydroperiod than other wetlands and are subject to regular and prolonged desiccation during the dry season (FNAI and FDNR, 1990). A sandy substrate would most likely reduce the hydroperiod and not allow the capillary water to move upward sufficiently high enough to provide water to the plants during the dry season resulting in vegetation losses. It is believed that seepage wetlands may not be as dependent on capillary water as are the wet flatlands. Floodplain wetlands may or may not be directly dependent on capillary water during dry seasons with this dependency related primarily to other hydrologic and site location parameters.

A study of freshwater marsh creation in the Southeast found that substrate type was not usually critical for a successful project, but can affect the hydrology if it is too porous or poorly drained (Erwin, 1989). This investigation further noted that marsh construction could generally be completed with satisfactory results if other critical aspects of the project plan, such as hydrology and construction practices were properly planned. However, this statement did not address reclaimed phosphate mined lands in particular which often encounter extreme variations in substrate textures.

INTERMEDIATE AQUIFER

The intermediate aquifer system in the Central Phosphate District is semiconfined from the overlying water-table aquifer by a layer of mixed phosphate, sand, and clay (ore matrix). This semiconfining layer is sometimes removed, in part or completely, during the mining process. Physical disruption of the intermediate aquifer normally does not occur below this confining layer. Figures 2.5.2.1 through 2.5.2.4 presented in the proceeding section, show the relationships between the two upper aquifer systems, the semiconfining unit that separatesthe two systems, the mining technique and the basin reclamation method.

A study in three unmined basins revealed that hydrographs for the intermediate aquifer wells had seasonal water level trends similar to the water-table aquifer wells, but did not show the rapid water level increases in response to rainfall recharge as the upper aquifer hydrographs showed (Lewelling and Wylie, 1993). The difference in potentiometric heads between the two aquifers ranged between 4 to 10 feet indicating an effective confining layer separates the two aquifers. This same study showed that in one clay settling basin, the confining unit was removed in the mining process but was replaced by a thick layer of clay waste which re-established the separation between the two aquifers. In three other mined basins (sand-clay settling, sand-tailings and contoured overburden) wells tapping both the water table and intermediate aquifers had water levels generally within 1 foot of each other indicating the confining unit had been breached and that both aquifers are functioning as one unconfined aquifer in these basins. Examples showing the relationship between aquifer “connectivity” in an unmined basin (CF1-3 Creek) and an overburden covered sand-tailing filled basin (Agrico 4 Creek) are shown in Figure 2.6.1.2.



MISSIMER INTERNATIONAL

Pr Name: FIPR – HYDROLOGY		
Pr No. FH4-8	Date: 1/12/95	
DWG No.	Rev.No. 1	

Groundwater and Environmental Services

FIGURE 2.6.1.2. RELATIONSHIP BETWEEN THE WATER-TABLE AQUIFER AND INTERMEDIATE AQUIFER IN AN UNMINED BASIN AND IN A MINED BASIN BACKFILLED WITH SAND TAILINGS. MODIFIED FROM LEWELLING AND WYLIE (1993).

2.6.2. ALTERATION IN TOPOGRAPHY AND RELATION TO WATERSHED WATER LEVEL CHANGES

As a general practice, topographic changes between a pre-mined basin and the reclaimed basin are kept to a minimum. Clay and sand-clay settling basins are typically topographically higher than their original counterparts because of the need for the constructed high dike around the perimeter of these type of reclamation basins (see Sec. 2.5.2 for related discussion). Contoured-overburden basins are usually at a lower elevation than before mining because no new material is brought in to replace the volume lost by removing the ore matrix. Overburden-capped sand-tailing basin types are normally fairly close to pre-mining land surface altitudes. Land and lakes type reclaimed areas have the greatest differences in pre-mining and post-mining topography.

Contouring of the reclaimed basin provides opportunities to develop slope and slope length, detention storage areas and channelized stream drainage patterns. Riekerk and others (1991) believe that reclamation procedures control to some degree groundwater flow, runoff volume and flow-duration, and erosion with attendant sediment production. However, differential settling of the land surface created by consolidation and dehydration over long periods of time can present problems, particularly in clay and sand-clay settling basins. Water levels, both groundwater and surface-water, will reflect the watershed water storage components of the new basin as the local flow system develops a new dynamic equilibrium condition.

2.6.3. CHANGES IN THE WATER BALANCE IN AQUIFERS

Modification of the hydrogeologic framework by mining and reclamation of a basin results in a whole new set of aquifer flow patterns. Groundwater inflow and outflow factors in natural watersheds are discussed in Section 2.4.2.

The clay and sand-clay settling basin types have the greatest degree of aquifer inflow and outflow water balance differences when compared to unmined basins. Probably the most critical factor related to these types of basins is the fact that they are constructed above the natural grade. Groundwater in unmined basins generally discharges from the water-table aquifer into streams as the base flow component. However, because of the elevated nature of the clay and sand-clay settling basins, groundwater does not usually discharge into the local streams within the reclaimed watershed because the water-table is generally below the stream channel. Groundwater outflow in these elevated basins may occur as lateral seepage through dikes if they were built from the more permeable waste materials.

A groundwater flow study of a clay settling basin (Riekerk and others, 1991) evaluated flow velocities through the impoundment dikes. The created watersheds are located on the west side of the Peace River near Fort Meade. The Peace River side dikes were constructed with clay and loam and allowed little seepage toward the river. The western dike of the watershed was built of sand-tailings and the southern dike was constructed of sand over clay. The greatest groundwater velocity and therefore outflow contribution was in the northwestern section of the area suggesting the dikes are a major groundwater control mechanism. The sand over clay dike would allow significant groundwater flows into an adjacent wetland area only after exceeding a threshold water table level during very wet conditions. Other more permeable types of reclaimed areas adjacent or near to the elevated settling basins would most likely realize positive net groundwater flows due to the mounding of the water table in these elevated settling areas.

Groundwater outflow from the surficial aquifer system to the intermediate aquifer system is enhanced when the confinement between the two systems is removed in the mining process. This is particularly important in the sand-tailings reclaimed basin type which results in highly permeable material in direct contact with the intermediate aquifer. In this situation the local flow system would have a lower than normal water table elevation and downward leakage would most likely exceed the baseflow component when viewed on a basin wide system approach. These factors may not be true in the lowermost reaches of the sand-tailings watershed where water levels could be higher than under natural conditions and base flow is a major water balance outflow factor.

2.6.4. CHANGES IN THE WATER BALANCE OF STREAMS AND FLOWWAYS

The balance of hydrologic factors influencing changes in stream and flowway storage components of natural basins are discussed in Section 2.4.2. All of these hydrologic factors are altered, to varying degrees, during the mining and reclamation procedures. Lewelling and Wylie (1993) state that the naturally occurring, well defined drainage patterns of the pre-mining site are often replaced by swales and/or other poorly defined drainage features as reclamation proceeds. They indicate that the natural soils were well sorted and allowed infiltration of rainfall whereas the reclaimed basin commonly is composed of a less permeable substrate resulting in more overland runoff and less infiltration.

Runoff in comparison to associated rainfall has been said to be a useful measure of the hydrological character of a watershed. Low ratios suggest high infiltration and/or ET. High ratios suggest little infiltration or very high net groundwater flows and little storage capacity (Riekerk and others, 1991). A natural pine flatwoods site in north central Florida in Bradford County had an average runoff/rainfall ratio of 0.26. The average ratio for three unmined basins in the central district was approximately 0.20, with individual values ranging between 0.03 and 0.46 (data from several storm events). Two clay settling basins had a combined runoff/rainfall average of 0.21 from 4 rainfall events. Singularly the two clay settling basins each have ratios of 0.40 and 0.11 with one basin having the clay waste only partially consolidated and the second basin being older and more consolidated. One sand-clay settling basin had a measured runoff/rainfall ratio of 0.97; a contoured-overburden basin with four data sets had an average of 0.49; and an overburden-capped sand-tailing basin with two values of 0.30 and 0.91 which averages to 0.60. These average runoff/rainfall ratios must only be considered as generalizations since storm intensity and duration and antecedent soil moisture are not factored in. In the four types of reclaimed basins, the largest runoff/rainfall ratios were the result of intense rainfall near the end of the summer rainy season when the soil was saturated (Lewelling and Wylie, 1993).

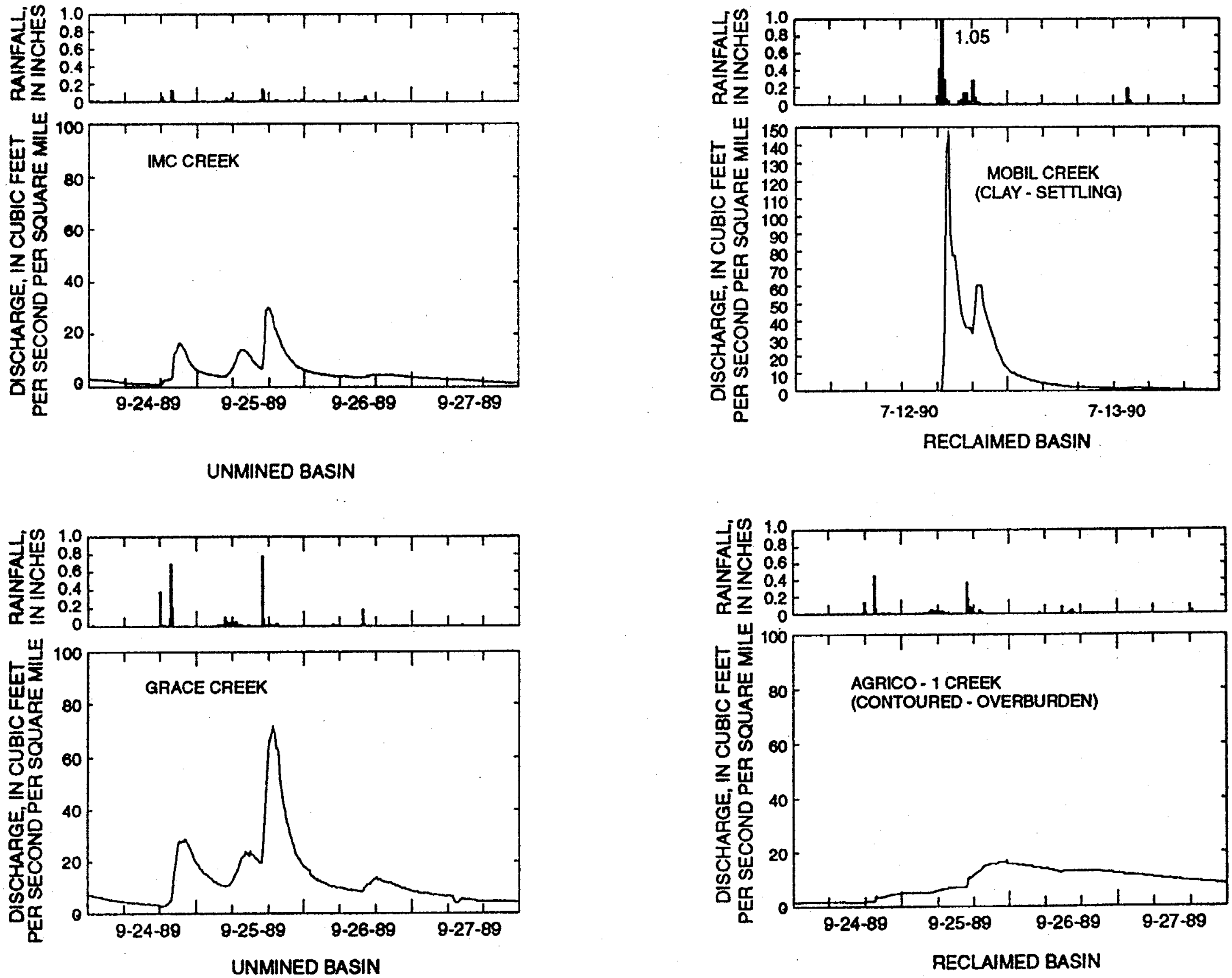
The largest ratios during any given storm event were related to basins with the finer material substrates.

Stream discharge in runoff per square mile averaged somewhat higher in the reclaimed basins during intense, short duration thunderstorms but were similar at both the unmined and reclaimed basins during low intensity, long-duration frontal storms (Lewelling and Wylie, 1993). This similarity in streamflows for a given rainfall event is also related to the abnormal storage provided by most clay basins. If the real ratio was calculated with both streamflow and retention areas, the new runoff/rainfall ratio would be much smaller. The highest runoff per square mile of any of the study basins was recorded at a mature clay-settling reclaimed basin. Except for this clay-settling basin, streamflows usually responded more slowly to rainfall at the reclaimed basins than at the unmined basins due to depression surface storage and less developed drainage patterns in the reclaimed sites (Lewelling and Wylie, 1993). Stream hydrographs from two unmined basins, one clay settling basin and one contoured overburden basin are shown in Figure 2.6.5.1. All four hydrographs were recorded during thunderstorm events. This attenuation feature has a net positive effect on the basin water balance equation by storing more water during and after rainfall events when compared to unmined basins and the one clay-settling basin.

2.6.5. ESTABLISHMENT OF UNNATURAL CORRIDORS OF ENHANCED HYDRAULIC CONDUCTIVITY

The basic mining method to recover the phosphate ore matrix is to remove 20 to 50 feet of the sand and clay overburden; cast this material into an adjacent mined area and then remove the phosphate ore, leaving a series of linear lakes and overburden spoil piles. As previously discussed, the undisturbed matrix forms a semiconfining bed between the surficial aquifer system and the underlying intermediate aquifer system. Removal of the ore matrix results in at minimum an increase of leakage between the two systems and at maximum a direct contact relationship between the aquifers. The hydrologic impacts of this new relationship on the reclaimed basins has been outlined in Section 2.6.1. This discussion concerns these impacts to smaller areas (wetlands, streams, uplands, etc.) rather than on a basinwide scale.

Individual areas within a reclaimed basin may be underlain by a linear-shaped spoil pile, underlain by a linear backfilled trench consisting of sand-tailings covered by a thin mantle of overburden material, or a clay or sand-clay mixture which can be as great as 40 to 50 feet thick overlying the spoil pile ridges and trenches produced in the mining process. The clay and sand-clay settling basins are constructed above natural grade and have a more homogeneous vertical and horizontal material component than the other reclaimed basin types. However, even these basins are texturally graded where the coarser material is at the pipe outfall and becomes finer toward the drainage control structure. All of these features result in major hydrogeologic variations from area to area within any one basin and also with depth at any one point in the basin. These spatial hydrologic variations create a very complex water balance system within any reclaimed basin. Because of this complexity, it is most difficult if not impossible to absolutely predict the inflow, outflow, and storage components of any given area within the created



MISSIMER INTERNATIONAL INC.	Pr Name: FIPR – HYDROLOGY		Groundwater and Environmental Services
	Pr.No. FH4-8 DWG No.	Date: 1/12/95 Rev.No. 1	

FIGURE 2.6.5.1. STREAM HYDROGRAPHS FOR TWO UNMINED BASINS AND TWO RECLAIMED BASINS. MODIFIED FROM LEWELLING AND WYLIE (1993).

watershed. However, general trends in these components can be reasonably predicted if based on the mining plan, and other available knowledge and experience.

Backfilling with the sand-tailings and breaching of the confinement between the surficial and intermediate aquifer systems can result in unnatural corridors of enhanced hydraulic conductivity within the created hydrogeologic framework. The enhanced conductivity will alter the water balance and establish a new dynamic equilibrium for the associated area. It is expected that some areas within the created watershed will have increased outflow conditions resulting in a net loss of transient storage. This loss could occur as groundwater outflow through the enhanced hydraulic conductivity corridors due to increased downward leakance and/or by an increase in groundwater discharge to nearby streams. Water levels in these areas may be quite different from those levels which would exist without the higher conductivity corridors. The orientation of the mine trenches may have a direct effect on the direction of the flow system and the rates of outflow and inflow water balance components of the system.

2.6.6. SUMMARY

Various hydrologic factors that result from the phosphate mining and reclamation of the mined basin have been identified. It can be observed that the mining method and reclamation type play an important role in determining the water balance components of a newly created watershed. The constructed water-table aquifer can be composed of several material types or as mixtures of these materials and commonly occurring composition changes in both lateral and vertical directions. The confinement between the water-table aquifer and the intermediate aquifer is often breached and sometimes completely removed during the mining process which results in hydraulic changes to both aquifer systems.

The reclaimed basins have different topography and elevations than the pre-mining site had. Drainage patterns are generally not well developed and numerous small depression storage sites can exist on the created landscapes. Infiltration capacity of the new substrate may be much greater or much less than the natural soils. Recharge - discharge relationships of the created sites are different from the pre-mining basin relationships. Corridors of enhanced or reduced hydraulic conductivity are often the result of mining and reclamation procedures.

All of these changes in morphology, hydrology, soil and geologic parameters and processes due to mining may create new and different water outflow, inflow, and storage characteristics within the reclaimed basin. The new water-balance characteristics may result in such changes as; proportions, locations and characteristics of any given ecosystem, whether it be upland, stream or wetland, which can exist within the created watershed. A reasonable understanding of the new water-balance characteristics is required to properly locate and determine the type of any particular ecological environment suitable to the area.

2.7. VIABILITY OF CREATED WETLAND TYPES IN CONSIDERATION OF THE ALTERED HYDROLOGY AND THE CREATED WATERSHED

2.7.1. INTRODUCTION

If the six basic types of created wetlands are grouped according to the factors most important to each type in the water balance, the depression marsh, seepage streams and baygall environments are most dependant on groundwater inflows, the floodplain forests and swale environments are most dependant on surface-water inflows, and the wet prairie is most dependant on precipitation. It is important to generally describe each of these wetland types in terms of where they have been located within the created watersheds and what levels of successful recreation have been observed. With regard to outflows in wet prairies, baygalls, and depression marshes, water is lost primarily to ET, while in swale, floodplain forests and seepage streams, water is lost primarily to surface flows.

2.7.2. CREATION OF ISOLATED WETLANDS

Based on the overview of the relationship between the natural water balance and the wetland type as presented in section 2.4.5, the depression marsh is considered to be an isolated wetland with the maintenance of the wetland being dependant on the surrounding drainage basin and the geology of the substrate. In order to maintain the hydroperiod of a depression marsh, the area of the surrounding uplands must be of sufficient size to allow continuous groundwater inflow into the environment when precipitation is insufficient to maintain the necessary moisture. It has been suggested that at minimum the upland area needs to be twice as large as the wetland area (John Kizler, Per. Communication). Some depression marshes have been developed upon the former clay settling areas, which provide a substrate with a low permeability, which is good for maintaining water ponded at land surface when there is adequate precipitation. However, many of the clay settling areas lie at relatively high elevations in the small watersheds, with a minimal area of high uplands to feed water into the created depression marsh. In each case where the area of the surrounding drainage is too small, the depression marsh has a shortened hydroperiod limited to the time of highest precipitation during the wet season. In some cases the surrounding upland basin has an adequate size, but the hydrogeology is not compatible with the slow release of water into the depression marsh. This produces two deleterious effects: 1) severe desiccation of the wetland substrate during the dry season, and 2) inadequate inflow rates during the early and later part of the wet season. The deep desiccation of the substrate can cause the death of many wetland plant species and replacement with only a few species or replacement with exotic plants.

Another major problem observed with the construction of isolated wetlands, is the placement of the created wetlands in the proper position in a basin, but the altered substrate does not allow maintenance of the hydroperiod. The problem of backfilling the mining trenches, as discussed in sections 2.4 and 2.6, produces a new fabric for the subsurface flow of water, which can increase the rate of flow to discharge points and lower the position of the water table more rapidly than occurred in the natural condition. An example of the problem is given in Figure 2.7.2.1, in which a clayey sand was replaced with sand. This sand material had a significantly higher hydraulic conductivity, which reduced the hydroperiod of the created wetland, despite the placement of the created wetland in the same geographic position within the watershed.

Similar types of problems occur with the creation of the baygall environment, which is seepage dependant. A baygall environment occurs in a depression near the toe of a slope. Under natural conditions, the horizontal flow of water discharging at a given location controls the hydroperiod and viability of this environment. This flow pattern is commonly controlled by the hydraulic conductivity of the aquifer to the point of discharge and in some cases there is a clayey layer, which inhibits vertical flow and directs the water to the point of discharge. When the watershed is created, it is not possible to reconstruct the internal structure of the shallow aquifer, especially the minor features such as a thin clay layer. Therefore, the creation of the baygall environment is even more sensitive to changes in the distribution of aquifer hydraulic conductivity than in the case of the wet prairie.

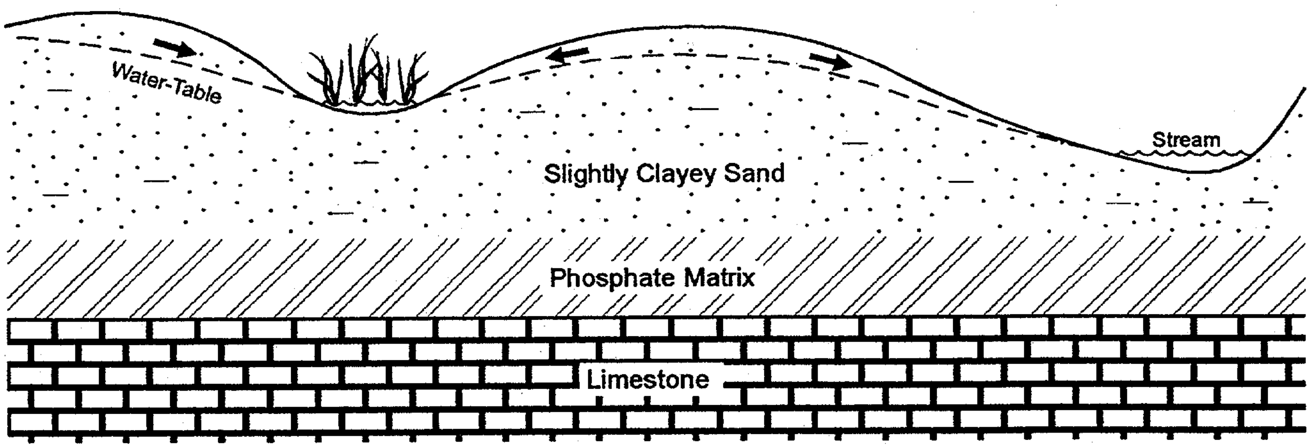
Based on the field inspections given in the appendix, some created isolated wetlands appear to be functioning in a completely viable manner, whereas others have significant problems. It must be noted that a large number of sites in this study are very young and therefore it is difficult to evaluate whether they have been successfully created. Some isolated wetlands located atop the former clay settling areas tend to be slightly more viable, especially when they have a sufficient area of upland basin to supply them with groundwater and surface-water runoff. In the case of creating an isolated wetland or pond, the primary design consideration should be the hydrogeology of the site and lesser dependence on the geographic position in the watershed. It is not possible to reconstruct the former features of any watershed in terms of the geographic positions of the upland and wetland environments, once the shallow aquifer system has been greatly altered. The sites for creation of isolated wetlands must match the site-specific requirements for maintenance of the water balance to produce the proper hydroperiod and water levels. This means that the location of isolated wetland environments in created watersheds will not occur in the preexisting pattern.

2.7.3. CREATION OF FLOODPLAIN WETLANDS

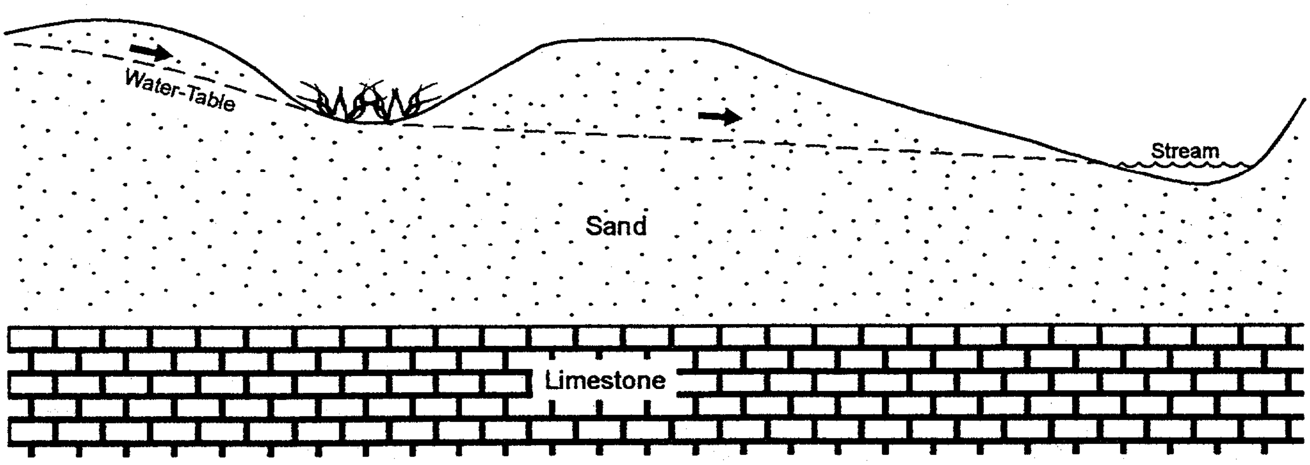
Two types of floodplain wetlands have been created in the phosphate mining district. These wetland types are the swale and the floodplain forest. Detailed descriptions of the plant communities and hydrology of these naturally occurring wetland environments is given in sections 2.4.4 and 2.4.5.

The successful creation of any type of wetland environment associated with a stream or river channel is greatly dependant on the restoration of the stream watershed above the altitude of the wetland creation location. If it is assumed that the location of the created wetland will be at the same geographic location as the pre-existing wetland in the landscape before mining, then the flow regime in the stream must have similar characteristics. This means specifically that the flow

Natural Isolated Wetland



Created Isolated Wetland



MISSIMER INTERNATIONAL

Pr.Name: FIPR - HYDROLOGY

Pr.No. FH4-8 Date: 8/11/94

DWG No. FH4-8I.CDR Rev.No. 3

Groundwater and Environmental Services

FIGURE 2.7.2.1. ALTERED SUBSURFACE FLOWS CAUSED BY REPLACEMENT OF CLAYEY SAND WITH SAND.

duration curve for the stream must be equivalent for a storm event, pre- and post-mining, and the normal seasonal flow durations must be equivalent. The reason that the floodplain wetlands established at specific locations in the past was fully dependant on the flow characteristics of the stream, the stream profile (cross-section), and the configuration of the floodplain, particularly in the case of the floodplain forest. In order to restore a stream to its pre-mining natural condition, it would be necessary to have approximately the same drainage basin size, approximately the same slopes of the land surface into the stream, approximately the same hydraulic slope of the stream bed, a similar distribution of soil types, and a similar subsurface geology in order to simulate natural base flow discharges. It is quite clear that in the mining process the hydrology of both the shallow aquifer system and the watersheds are greatly altered (section 2.6). Despite use of even the best and most advanced reclamation techniques, it is not possible to reconstruct a watershed exactly as it previously occurred in nature. Therefore, the creation of floodplain wetlands in their past geographic locations is fraught with great difficulties, making the successful propagation of the wetlands environments in these locations doubtful at best.

The bottomland forest is perhaps more difficult to create successfully than the floodplain forest. The reasons that the bottomland forest are difficult to create is two-fold. First, it is virtually impossible to recreate the natural hydrologic characteristics of a stream. If the stream tends to flood more frequently then the bottomland forest is stressed. If the seasonal flow characteristics of the stream are changed significantly, the stream may have no flow during part or all of the dry season, which does not yield sufficient moisture to the bottomland forests via capillarity. Second, the bottomland forests are dependant to some degree on the inflow of groundwater from the adjacent uplands environments. Depending on the character of the adjacent soils and on what orientation was used to mine the phosphate, the flow of groundwater must be sufficient to maintain the forest. Bottomland forests observed to be in rather poor condition appeared in some cases to be starved for water and in others to be stressed by too frequent flooding. In a few cases, poor performance of the bottomland forest appears to be related to a change in the geographic size of the upper watershed and therefore the amount of water reaching the wetland.

The occurrence and conditions of floodplain forests is more closely related to the water balance of the stream channel and watershed. The primary inflow factor is flow through the channel from higher parts of the basin. This type of environment has been more successfully created because as long as there is perennial flow in the stream channels, there is a sufficient supply of water to allow successful growth of the forest. One of the primary factors that can cause too much wet season loss of water from the watershed is when the percentage of clay settling areas is too high for the size of the basin. The more rapid runoff, inhibited infiltration and reduced quantity of groundwater storage collectively reduce base flow during the dry season and can cause the floodplain forest to be less successful, particularly in the upper part of the watershed.

2.7.4. CREATION OF FLOWWAY WETLANDS

One of the types of flowway wetlands created is the swale environment, which is a wide wetland belt that functions as a broad, shallow, low gradient stream. In some cases the channel is well-defined with a "V" type of channel geometry and in other cases the channels are not as well defined and the wetland takes on the appearance of a wetland slough (inundated with flowing water except during extreme droughts). The floodplain is very wide adjacent to the stream in order to accommodate these wetland areas.

Both successful and unsuccessful swale wetlands were observed in the field. Since the swale wetland environment lies in a low gradient, rather flat area, the key factor affecting the hydrology is the size of the basin feeding water into the swale. Both surface-water runoff, interflow and groundwater inflow provide the necessary water supply to the swale. The most successful swale environments lie in broad "valleys" surrounded by uplands and in certain cases by large clay settling areas. These swales are characterized by emergent grasses, sedges, and herbs which may be up to ten feet tall. A sufficient supply of water is directed into the swales and the natural hydroperiod is maintained. The area is sufficiently wet to discourage fire destruction of the plant assemblage. In the cases of poor swale environments, the drainage basins feeding the swales were too small or water depth was too deep, resulting in failed plant growth and/or perhaps the lack of woody species. Often the basin reclamation was incomplete and the distribution of upland soils was not consummate with providing an appropriate water supply on a seasonal basis.

2.7.5. CREATION OF LAKE LITTORAL ZONE WETLANDS

In the natural system, the occurrence of wetlands lying in the littoral zone or the shelf area surrounding a lake is dependant on the natural fluctuation of the lake stage, which is affected by components of the water balance. The presence of lakes in the watershed is a function of the substrate hydraulic conductivity, the depth of the depression, the size of the basin feeding water to the lake, and the characteristics of the shallow aquifer in the basin. Lakes can be created in a variety of locations within a watershed, but in general the higher in the watershed the lake occurs, the larger the ranges in seasonal stage fluctuations. Although it is possible to create lakes in the upper parts of basins, it is necessary to place the lake within a clay substrate, which would significantly obstruct the outflow of water from the lake bottom. Naturally occurring lakes tend to be located lower in the watershed, where the water balance of the lake is maintained by inflows from the drainage basin. Lake littoral wetlands can be successful only if the lake stage fluctuations are relatively small and the slope area containing the wetland plants around the lake remains flooded for extended time periods. If the area becomes dry for long time periods, upland plant species 'can become established and displace the wetland plants. Where wetlands plants have been placed on these sites, they seem to be doing well. However, the narrowness of this fringe in many cases does not really allow development of a wetland community. The hydrology of these wetlands is very similar to the isolated wetlands. If the basin feeding water to the lake is too small or the hydraulic characteristics have been altered to a large degree, then the lake stage fluctuations will be too large and the success of the littoral zone wetlands will be poor. The restoration of a lake in the exact geographic position as it occurred in the pre-mining landscape is quite difficult, especially if there is a requirement to have littoral wetlands fringing the lake.

2.7.6. DISCUSSION

Based on field observations, knowledge of basin surface-water and groundwater hydrology, and the natural water balance of various wetland communities, the fundamental factor relating to the success of each wetland type is the water balance and how it affects the hydroperiod. In each case observed in the field, when a wetland appeared to be not functioning in a successful condition, a problem with the hydrology could be suggested. The largest single problem seems to be related to the concept that wetlands should be relocated to their pre-mining geographic locations, regardless of changes to the drainage basin or the hydrogeology. When the inflow of water necessary to maintain a wetland community cannot be achieved, it will either succeed to another wetland community type or it will become an upland or some other habitat. Careful consideration should be given to the locations of created wetlands in each new watershed to match the hydrologic conditions necessary for successful growth and maintenance. In many cases, wetland communities must be recreated lower in the watersheds compared to the natural condition, because of the changes in the hydrology of the basins. It also may be necessary to alter the channel configuration of some streams in order to slow the outflow of water and to allow wetland creation to be successful. The most successful wetlands observed were the large wetlands located near streams at the base of the basins, such as the Agrico's Morrow swamp wetland.

2.8. DISCUSSION AND RECOMMENDATIONS

2.8.1. DISCUSSION

It was once stated that some understanding of wetland hydrology is desirable to carry out a broad range of wetland management activities and is essential where activities are proposed which may alter natural hydrology or where a wetland is to be altered or restored (Kunsler, 1987). This concept should be expanded to state that it is essential to understand the watershed hydrology where a wetland is to be altered or restored. It is the hydrologic balance within the entire watershed, which determines if and where wetlands can survive.

Successful propagation and maintenance of wetland plant communities is quite dependant on the hydrologic regime over both the initial growth stage and through the life history of the environment. In turn, the hydrologic regime is created by the changes of the inflow and outflow parameters within the natural water balance. It is not reasonable to assume that wetland plant communities can be successfully created in a new landscape without knowledge of the system hydrology, the water balance, or the expected hydrologic regime. It is important to obtain an adequate base of hydrogeologic information on the water balance within natural watersheds prior to mining. This information includes geomorphic features, local groundwater flow directions, depth to and thickness of the confinement between the water-table and intermediate aquifers and an estimate of the inflow and outflow quantities of the basin. These data can then be used to adjust the mining plan (if deemed necessary) and be incorporated into the general reclamation plan. This procedure attempts to take into account the regional hydrogeologic regime and how it will relate to the newly created watershed and its individual habitats.

A preliminary investigation of the watershed hydrogeology in both natural and reclaimed basins was conducted by the U. S. Geological Survey (Lewelling and Wylie, 1993), but the scope of the investigation was insufficient to quantify all of the necessary parameters. Additional, detailed investigations should be conducted with specific goals related to prediction of the hydrologic regime in portions of the landscapes created after mining. This would require in-depth investigation of both natural and restored watersheds.

Based on the field observations, the limited hydrogeologic studies conducted, and the theoretical considerations, it is quite clear that created watersheds cannot be constructed to match the characteristics of the pre-mined landscape. The very act of removing the phosphate matrix and the separation of the clay component together tend to alter the geology and hydrology of the landscape in a permanent fashion. The alteration of the natural hydrogeology does not mean that restoration of the mined landscape cannot be successfully accomplished, but the concept of matching the pre-mined landscape with a created environment “overlay”, duplicating the distribution and geographic positions of the natural landscape, should be abandoned. The created watershed hydrology must be used to guide in the restoration efforts. This means the created wetlands and other environments must be located in the appropriate parts of the watershed, using a logical approach based on science, not on fixed rules or politics.

There are a few minor changes in the mining process that could assist in the later restoration efforts. One of the most important post-mining problems has been the orientation of the mining trenches in certain watersheds. In areas mined adjacent to major stream or river channels, if the mining cuts would be oriented parallel to the axis of the stream, overdrainage in the adjacent areas would not be as problematical. Within any given watershed if the orientation of the mining cuts could be balanced to accomplish approximately the same rate of groundwater inflow to streams pre- and post-mining. If some detailed watershed hydrology studies would be accomplished in the future, it would be important to call a meeting of the mining engineers and the hydrologists to review mining practices to make other minor adjustments in order to simplify the restoration process and perhaps save costs in unsuccessful restoration efforts.

A major question that has been raised involves what types of wetland environments cannot be created. Most types of natural wetland communities can be created with success, if the water balance and hydroperiod requirements are met. However, there are certain wetland types that occur in rather unique niches based on the occurrence of very minor features within the hydrogeologic framework. For example, if a minor clay unit is present in a sandy sediment sequence within a sloped area, it may cause water to flow along it to some type of seep feature. The small seep feature may be the location of some wetland environment, usually of small or limited size. Creation of these wetlands types have been experimented with but may not be feasible in the restoration process. The logical approach to take involves a pre-mining analysis of the existing wetland types, their size, and an assessment of why they occur in a particular location. If the wetland type is dependant on a minor feature within the watershed, then no attempt should be made to create that particular environment. These kinds of features should be given the highest priority for being preserved as a natural feature and incorporated into the surrounding post-mining landscape.

Based on the mining techniques and the realities of phosphate extraction, the restored shallow aquifer system will tend to have an enhanced runoff percentage and less water will be available in the water-table aquifer to provide base flow to streams during dry periods. These changes tend to make the upper parts of watersheds less desirable for creation of wetland environments. Depending on the size of the watershed, even the middle part of some watersheds will tend to be poor areas to locate certain wetland types. As a general conclusion, wetland creation efforts will be more successful lower in the created watersheds compared to the natural watersheds, because of limited upland areas in the created watersheds. Again, a logical assessment of the changes to the hydrogeology of the watershed, perhaps even using an improved version of the FIPR model, can be used to estimate the best areas to restore wetlands.

2.8.2. RECOMMENDATIONS

1. Cease the practice of locating wetlands based on their geographic position in the pre-mining landscape and base the created wetlands locations on the hydrology of the created watershed.

2. Establish a systematic program of acquiring basic pre-mining hydrogeologic data on the watersheds to be mined with the specific purpose of using the data to create a viable reclamation plan.

3. Coordinate the mining methods with the reclamation plan to minimize unnecessary alterations to watershed flow characteristics. This is not a recommendation to change the mining methods, but to simply orient mining cuts parallel rather than perpendicular to major drainage features and have an equal number of mining cuts parallel and perpendicular to minor drainage features.

4. Create wetlands lower in the watersheds to compensate for some reduction in land surface altitude and the resultant changes in the hydrogeology. This should increase the success rate for many wetland types. Some small wetlands with short hydroperiods should be created higher in the basins to allow flooding variation for wildlife, but these environments may not be viable in the long-term.

5. In the creation of isolated wetland types, there should be at least five times the land area size for the surrounding uplands compared to the intended size of the wetland. The increase in the clayey soil type at land surface, 35 to 45% of landscape being clay storage impoundments, causes the need for more storage area to slowly release water to the isolated areas.

6. Continue to upgrade and improve the FIPR model in order to make it a more useful tool in assisting in the design of created watersheds.

7. Limit wetland creation to types of wetlands that do not rely on subtle changes in the geology, such as minor seepage wetland types.

8. Allow time between final contouring and wetland construction. Considerable knowledge on the function of a created basin can be obtained by the simple observation of water levels and ponding within the basin during the year after basin creation. The soil can be stabilized with a temporary ground cover before the final planting of wetland plants to help assess the new hydrologic regime.

9. Create wet prairie type wetlands in terraced flat areas in clay tailings impoundments, excavated to a lower altitude than most of the feature.

10. Design the created wetlands to utilize natural energies and hydrologic processes associated with the water balance.

11. Be careful not to create wetlands prior to reclamation of a majority of the upstream watershed, because if hydrologic conditions are changed, the effort will be less successful.

2.9 REFERENCES

Andrews, W. J., 1990, Transmissivity and well yields of the Upper Floridan Aquifer in Florida, Fla. Geol. Sur., ISSN0085-0624.

Best, G. R., and K. L. Erwin, 1984, Effects of hydroperiod on survival and growth of tree seedlings in a phosphate surface-mined reclaimed wetland. Symp. of Sur. Mining, Hydro., Sed., and Recl., Lexington, pp 221-225.

Brinson, M. M., 1993, A hydrogeomorphic classification of wetlands. Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS: 79p.

Brown, S., 1981, A comparison of the structure, primary productivity, and transpiration of cypress ecosystems in Florida: Ecol. Monogr., v. 51, p. 403-427.

Burnson, T., 1982, Hydrologic overview of Suwannee River Water Management District. Suwannee River Water Management Dist. Tech. Report 822-3.

Caiazza, Nicholas, 1988, Ecological Functions of a Created Freshwater Tidal Wetland. Transp. Res. Rec.; 1224: 34-39.

Carter, V., 1990, Importance of hydrologic data for interpreting wetland maps and assessing wetland loss and mitigation. U.S. Fish and Wildlife Service Biological Report 90(18): 79-86.

Ceryak, R., 1977, Alapaha River Basin, Suwannee River Water Management District, Circ. 5.

Coats, R. M., Swanson, and P. Williams, 1989, Hydrologic analysis for coastal wetland restoration. Environmental Management 13 (6): 715-728.

Cole, C. A., and E. F. Lefebvre, 1991, Soil and water characteristics of a young surface mine wetland. Environmental Management 15(3): 403-410.

Cole, C. A., 1988, Wetland Ecosystem Development on a Reclaimed Surface Coal Mine in Southern Illinois. Ph.D. dissertation, South Ill University (Carbondale); 307p.

Coultas, C. L., and M. J. Duever, 1984, Soils of cypress swamps. In K. C. Ewe1 and H. T. Odum, eds. Cypress swamps. Gainesville: University of Florida Press. p. 51-59. [Scientific Paper]

Dolan, T. J., A. H. Hermann, S. E. Bayley and J. Zoltek, Jr., 1984, Evapotranspiration of a Florida, USA freshwater wetland. J. Hydrology (Amsterdam) 74(3-4): 355-372.

Domenico, P. A., and F. W. Schwartz, 1990, Physical and chemical hydrogeology. John Wiley and Sons. 824 p.

Duerr, A. D., J. D. Hurnn, B. R. Lewelling, and J. T. Trommer, 1987, Geohydrology and 1985 water withdrawals of the aquifer systems in Southwest Florida, with emphasis on the intermediate aquifer system: U. S. Geol. Survey Water-Resources Invest. 87-4259, 115 p.

Duever, M. J., J. E. Carlson, and L. A. Riopelle, 1974, Water budgets and comparative study of virgin Corkscrew Swamp. In H. T. Odum, K. C. Ewel, J. W. Ordway, M. K. Johnston and W. J. Mitsch, eds. Cypress wetlands for water management, recycling and conservation. 1st Annual report to National Science Foundation and Rockefeller Foundation. Gainesville: Center for Wetlands, University of Florida. p. 595-634. [Report]

Duever, M. J., J. E. Carlson, and L. A. Riopelle, 1975, Ecosystem analyses at Corkscrew Swamp. In H. T. Odum, K. C. Ewel, J. W. Ordway, and M. K. Johnston, eds. Cypress wetlands for water management, recycling and conservation. 2nd Annual Report to National Science Foundation and Rockefeller Foundation. Gainesville: Center for Wetlands, University of Florida. p. 627-725. [Report]

Duever, M. J., 1980, A comparison of surface and bottom discharge effects on a small reservoir. In Proceedings of the Symposium on Surface Water Impoundments; June 2-5; Minneapolis. p. 865-874. [Scientific Paper]

Duever, M. J., 1980, Surface water hydrology of an important cypress strand, Corkscrew Swamp Sanctuary. In P. J. Gleason, ed. Water, oil, and the geology of Collier, Lee, and Hendry counties. Miami, Florida: Miami Geological Society. p. 74-78. [Report]

Duever, M. J., 1982, Hydrology-plant community relationships in the Okeefenokee Swamp. Florida Scientist 45: 171- 176. [Scientific Paper]

Duever, M. J., 1982, Tropical peatland hydrology. Presentation at Tropical Peatlands Workshop. Indianapolis: June 1-2. Naples, Florida: Ecosystem Research Unit, National Audubon Society, 4 pp. [Report]

Duever, M. J., 1984, Environmental factors controlling plant communities of the Big Cypress Swamp. In P. J. Gleason, ed. Environments of South Florida present and past. Coral Gables, Florida: Miami Geological Society. p. 127-137. [Scientific Paper]

Duever, M. J., J. E. Carlson, and L. A. Riopelle, 1984, Corkscrew Swamp: A virgin cypress strand. In K. C. Ewe1 and H. T. Odum, eds. Cypress swamps. Gainesville: University of Florida Press. p. 334-348. [Scientific Paper]

Duever, M.. J., J. F. Meeder, and L. C. Duever, 1984, Ecosystems of the Big Cypress Swamp In K. C. Ewe1 and H. T. Odum, eds., Cypress Swamps: Univ. Presses of Florida, Gainesville, p. 294-303.

Duever, M. J., 1988, Surface hydrology and plant communities of Corkscrew Swamp. In D. A. Wilcox, ed. Interdisciplinary approaches to freshwater wetland research. East Lansing: Michigan State University Press. p. 97-118. [Scientific Paper]

Duever, M. J., J. M., McCollom, and L. Neuman, 1988, Plant Community Boundaries and Water Levels at Lake Hatchineha, Florida. In J. A. Kusler and G. Brooks, eds. Proceedings of the National Wetland Symposium: Wetland Hydrology, September 16-18, 1987, Berne, NY: Association of State Wetland Managers. p. 67-72. [Scientific Paper]

Duever, M. J., 1990, Hydrology. In B. C. Patten, ed. Wetlands and shallow continental water bodies, Volume 1. The Hague, Netherlands: SPB Academic Publishing. p. 61-89. [Scientific Paper]

Duever, M. J., 1990, The Long Term viability of Restored Wetlands. In M. K. Loftin, L. A. Toth, and J. T. B. Obeysekera, eds. Kissimmee River Restoration Symposium Proceedings. October, 1988. West Palm Beach, Florida: South Florida Water Management District, pp 279-289. [Scientific Paper]

Duever, M. J., 1993, Environmental control of wetland plant communities. In Hydraulic Engineering '93. Volume 1. New York, New York: American Society of Civil Engineers. pp. 293-298. [Scientific Paper]

Duever, M. J. and J. M. McCollom, 1993, Transects and well sites to monitor restoration of four wetlands at the Disney Wilderness Preserve. Report to the Nature Conservancy. Naples, Florida: Ecosystem Research Unit, National Audubon Society. 33 pp. [Report]

Erwin, Kevin L., 1989, Freshwater marsh creation and restoration in the southeast. MISC: EPA/600/3-89/038a1989.

Erwin, Kevin L., G. R. Best, W. J. Dunn and P. M. Wallace. Marsh and forested wetland reclamation of a central Florida phosphate mine. Wetlands, J. Society Wetland Scientists. 4:87-103.

Erwin, Kevin L., and G. R. Best, 1985, Marsh community development in a central Florida phosphate surface mined reclaimed wetland. SOURCE: Wetlands, J. Society Wetland Scientists, MISC: 4:87-103.

Erwin, Kevin L., 1987, The implications of hydrology and landscape ecology on the maintenance of freshwater wetland ecosystems in Florida. National Wetlands Symposium Proceedings, Chicago, pp. 327-329.

Erwin, Kevin L. and F. D. Bartleson, 1985, water quality in ground and surface waters within and adjacent to created wetlands is evaluated. Proceedings of the 12th Annual Conference on Wetlands Restoration and Creation, In F. J. Webb, Jr. (ed.) pp. 84-95.

Ewel, K. C., 1985, Effects of harvesting cypress swamps on water quality and quantity: Univ. Fla. Water Res. Cent. Publ. No. 87.

Ewel, K. C., 1991, Swamps, in R. L. Myers and J. J. Ewel, Ecosystems of Florida: Univ. of Central Florida Press, Orlando, p. 281-323.

Fernald, E. A., and D. J. Patton (ed.), 1984, Water resources atlas of Florida. Florida State University, Tallahassee.

Florida Department of Natural Resources, 1990, Guide to the natural communities of Florida: Fla. Dept. of Nat. Res., Tallahassee, FL, 111 p.

Florida Institute of Phosphate Research, 1991, FIPR Hydrologic Model, Bartow.

Gee, G. W., A. Bauer, and R. S. Decker, 1978, Physical analyses of overburden materials and mine land soils. In Reclamation of Drastically Disturbed Lands, Am. Soc. Aagron., Madison, WI, p. 665-686.

Gilboy, A. E. et al., 1988, Groundwater resources availability inventory: Polk County, Florida. Southwest Florida Water Management District.

Hammett, K. M., 1985, Low flow frequency analysis for streams in west-central Florida. U.S. Geol. Survey Water Resources Invest. 84-4299.

Hensel, B. R., and M. V. Miller, 1991, Effects of wetlands creation on groundwater flow. J. Hydrology (Amsterdam) 126 (3-4): 293-314).

Hewlett, J. D., G. B. Cunningham, and C. A. Troendle, 1977, Predicting storm-flow and peak flow from small basins in humid areas by the R-Index method. Am. Water Resources Bull. 13, p. 231-253.

Hollands, G. G., 1987, Assessing the relationship of groundwater and wetlands. In Wetland Hydrology, National Wetlands Symposium Proceedings, Chicago, pp.. 240-242.

Hutchinson, C. B., 1978, Appraisal of shallow groundwater resources and management alternatives in the upper Peace and eastern Alafia River basins, Florida. U. S. Geol. Survey Water Resources Invest. 77-124, 57 p.

Keen, P. W., and J. G. Sampson, 1983, The sand/clay mix technique: A method of clay disposal and reclamation options. In Symposium on Reclamation and the Phosphate Industry, Clearwater Beach, p. 59-84.

Kelley, G. M., et al., 1988, Groundwater resource inventory: Hillsborough County, Florida. Southwest Florida Water Management District, 203 p.

Kusler, J., 1987, Hydrology: An introduction for wetland managers. In Wetland Hydrology, National Wetlands Symposium Proceedings, Chicago, pp. 4-24.

Lewelling, B. R. and R. W. Wylie, 1993, Hydrology and water quality of unmined and reclaimed basins in phosphate mining areas west central Florida. Report 93-4002. U.S. Geological Survey Water-Resources Investigations.

Mitsch, W. J. and J. K. Cronk, 1992, Creation and Restoration of Wetlands: Some design considerations for ecological engineering. In R. Lal and B. A. Stewart, eds.: Advances in Soil Science, V17, Soil Restoration.

Palmer, Z., 1990, Cumulative rainfall: Surplus/deficit analysis. Water Resources Division of Polk County, Bartow, Florida.

Reed, S. C., and others, 1993, Subsurface flow constructed wetlands for wastewater treatment. USEPA 832-R-93-008.

Reid, Frederic A. 1985, Wetland Invertebrates in Relation to Hydrology and Water Chemistry. U.S. Forestry Service General Technology Rep., NC-100 p. 72-79. 1985 WR 198.

Reuter, J. E., T. Djohan and C. R. Goldman, 1992, The use of wetlands for nutrient removal from surface runoff in a cold climate wetland at Lake Tahoe. J. Environmental Management 36(1): 35-53.

Richards, C. J., H. Roaza, and R. M. Roaza, 1993, Integrating geographic information systems and MODFLOW for groundwater resource assessments. Water Resources Bulletin, Vo. 29, No. 5, pp. 847-853.

Riekerk, L., V. Korhnak and M. T. Brown, 1991, The hydrology of reclaimed phosphate-mined wetlands. In Techniques and guidelines for reclamation of phosphate mine lands. FIPR Pub. No 03-044-095, pp. 7-i - 7-42.

Roaza, H., R. M. Roaza, and J. R. Wagner, Integrating geographic information systems in groundwater applications using numerical modelling techniques. Water Resources Bulletin, Vol. 29, No. 6, pp. 981-988.

Schlesinger, W. H., and Chabot, B. F., 1977, The use of water and minerals by evergreen and deciduous shrubs in the Okeefenokee Swamp: Bot. Gaz., p. 490-497.

Scott, T. M., 1988, The lithostratigraphy of the Hawthorn Group (Miocene) of Florida. Fla. Geol. Survey Bul. No. 59, 148 p.

Sharitz, R. R., and J. W. Gibbons, 1982, The ecology of southeastern shrub bogs (Pocosins) and Carolina Bays: A community profile: U.S. Fish and Wildlife Scrv. Off. Biol. Serv. (Tech. Rep.) FWS/OBS 82-04.

Spangler, D. P., 1979, Hydrogeologic variability of four wetland sites in north central Florida: In D. P. Cole, ed. Proceedings of the sixth annual conference on wetlands restoration and creation. Hillsborough Community College, Tampa, Florida pp. 27-28.

Suso, J. and M. R. Liamas, 1993, Influence of groundwater development on the Donana National Park Ecosystems Spain. J. Hydrology (Amsterdam) 141 (1-4): 239-269.

Tighe, R. E., and M. T. Brown, 1991, Hydrology of native Florida ecosystems. In Techniques and guidelines for reclamation of phosphate mined lands. FIPR Pub. No. 03-044-095, pp 6-l - 6-34.

Uebelhoer, G., 1979, Problems associated with the successful recreation of wetlands in mined areas of DeSoto and Manatee counties, Florida. In D.P. Cole, ed. Proceedings of the sixth annual conference on wetlands restoration and creation. Hillsborough Community College, Tampa, Florida pp. 102-126.

Winchester, B. H., J. S. Bays, and J. C. Higman, 1987, Inundation characteristics of wet prairie and marsh wetlands in southwestern Florida. In Wetlands Hydrology National Wetlands Symposium Proceedings, Chicago, pp 243-252.

2.10 APPENDICES

2.10.1 ANALYSIS OF INDIVIDUAL WETLAND SITES BY M. J. DUEVER

AGRICO

Introduction

We visited 26 wetland sites at Agrico on 29 June - 1 July 1993. These included six unmined sites; three not directly affected by mining (AG23, AG24, AG25) and three that are managed to protect them from mining of lands immediately surrounding them (FG-PC-2?, FG-SP-5?, PC-PC-2?). Another is a narrow wetland fringe around a lake, which is being used as a part of a power plant cooling system (PC-PC-2?). All of the other wetlands are on mined sites that had been restored to varying degrees. Important factors that influenced the degree of restoration were related to: 1) sites mined prior to current requirements for restoration (AG18, AG20); 2) clay settling areas that did not require wetland restoration (AG12); 3) volunteer wetlands (FG-SP-4?); and 4) time since completion of site restoration, such as recently constructed sites (AG6, AG7, AG13, AG14, AG16, AG17, AG22, AG26). There are six Agrico sites (AGl, AG3, AG4, AG5, AG10, FG-sP-9?) where major efforts had been made to create wetland communities that are now between 5 and 11 years old.

Of the 26 wetlands visited, there are only four sites for which water level data are available. These include three that were 2 (AG7), 7 (AG1), and 11 (AG10) years old at the time of our site visit. In addition, water levels have been monitored as part of a study of tree survival and growth (Rushton?) on a clay settling area (AG12). Reclamation had just been completed on one other site (AG16), so no data are available. The United States Geological Survey conducted hydrologic studies of the watershed of three sites, including AG1, AG4, and AG9 (Lewelling and Wylie 1993).

Analvsis of Individual Sites

AG24 is a bay forest and AG25 is a marsh. Both are unmined sites and appear to be in reasonably good condition, suggesting a relatively undisturbed hydrologic regime.

FG-PC-2? is one of the sites whose water levels had been actively managed to protect the biota from mining impacts on adjacent lands, and it appears to have been successfully protected. It is one of the few natural cypress forests seen on phosphate company lands in central Florida. However, a preservation area in PC-PC-2? is visibly impacted, apparently due to temporarily excessive water levels that killed or damaged many trees on the site. Despite these impacts, much of the vegetation survived and the substrate is still intact, As a result, this site can be expected to recover its original structure, composition, and productivity much more rapidly than adjacent mined and reclaimed wetlands. This, of course, assumes that the post-mining hydrologic regime approximates pre-mining conditions. Unfortunately, no pre-mining data exist upon which to base this judgement, so we will only be able to judge success of the preservation effort on the basis of long-term vegetative recovery.

The power plant cooling lake (PC-PC-2?) has a narrow herbaceous wetland fringe that is probably fairly stable because of the constant availability of water and its narrow range of fluctuation. Wetland shrubs and trees will probably invade this fringe eventually. Among the mined sites, AG18 and AG20 are lakes with remnant overburden ridges. Wetlands exist as a narrow fringe along the lake edges, and again are probably stable. The wetland vegetation is primarily herbaceous, with numerous planted trees.

AG12 is a clay settling area with shallowly inundated portions dominated by willows and some smaller deeper area of open water. This site is listed as being 12 years old, and has been planted with some wetland trees that appear to be doing well. Depending on how factors influencing the hydrology of the settling area are managed, and given time and adequate seed sources, these shrubby wetlands could develop into reasonably healthy swamp forests.

FG-SP-4? is a young riparian shrub forest that developed in an unplanned flowway on a reclaimed site. Given time and an adequate seed source or planting of wetland trees, this should develop into a narrow riparian forest. Alternately, a high fire frequency in the surrounding area could eliminate woody vegetation and convert the site into a marsh community.

The youth of sites AG6, AG7, AG13, AG14, AG16, AG17, AG22, and AG26 precludes any conclusions about the success of their hydrologic restoration. However, AG26, a small seepage bayhead marsh complex situated at the base of a constructed sandhill did appear to be working as planned. AG14 and AG22, both marsh communities, seemed reasonably healthy and vigorous given their relative youth. While still very young, there is water level information available for AG7.

The following are older sites where major efforts were made to create wetlands on mined lands: All have a forested wetland component at this time. In the absence of a prescribed burning regime, it is likely that woody vegetation will come to dominate all of these sites as a result of natural successional processes.

FG-SP-19 is a vigorous marsh with some willow along its upland edge.

AG5 is a small but vigorous marsh that has been invaded by willow along most of its periphery.

The AG4 wetland appears to have a young, but vigorous wetland forest.

AG1, AG3, and AG10 are all lake-marsh-swamp complexes. The latter supports a particularly healthy wetland between aquatic and upland portions of this reclamation site. Water level data are available for two of these sites, AG1 and AG10.

Conclusions

With few exceptions there are no hydrologic data upon which to base conclusions as to whether a natural wetland hydrologic regime exists on the majority of the Agrico wetland sites. Thus, conclusions must be based largely on vegetation present on reclaimed sites at the time of our visit. On the older sites, condition of wetland vegetation suggested that a wetland hydrologic regime currently exists. In addition, there is a small volunteer riparian wetland that appears to be doing well. The clay settling areas seemed to have some functional wetlands whose long-term diversity may be limited primarily by available seed sources, and whose viability will be influenced primarily by how the site is managed. Although, it is difficult to say much about the younger wetlands, several of them are exhibiting some characteristics of viable wetlands. Finally, one of two forested wetland preservation sites had been impacted by an altered hydrology during mining of surrounding lands. If the hydrology of this site has been successfully restored, this damaged forest can be expected to recover its former character much more rapidly than could a newly created site. However, the prognosis for recovery of this forest is currently uncertain, due to the short time since reclamation of adjacent lands. Thus, on these mined and reclaimed landscapes, it appears that wetland hydrologic regimes are being successfully recreated.

CF INDUSTRIES

Introduction

A total of 9 sites were visited on the CF Industries property on 11-12 August 1993. These included three unmined (and unnamed) sites, two of which are still functioning wetlands. Two sites are still in the process of being reclaimed (R6, R8). Two reclaimed wetland sites are from 4-8 years old (CF5, CF7), while one other had just been planted (CF8). Portions of another site could not be adequately drained for planned agricultural production and developed into a volunteer wetland (CF1), which was 7 years old at the time of our visit.

Hydrology information is available for three (CF1, CF5, CF8) of the 9 sites visited.

Analysis of Individual Sites

One of the unmined sites is a portion of Hickey Creek, which flows through what still appears to be a healthy floodplain forest. Another site, at some distance from any mined land, is a small marsh with a dense herbaceous cover and organic soils. The third site is the original channel of Hickey Creek where it enters the CF Industries property from the north. A small area of floodplain forest is still intact, although stream flows had been diverted at some time in the past.

Trees in the 7 year old volunteer wetland (SP1) appear to be doing well, and can be expected to develop into a swamp forest eventually.

Nothing can be concluded about the hydrology of the young wetlands (R6, R8, CF8) at this time.

The remaining two wetlands (CF5, CF7) are portions of a contiguous Hickey Branch system, which could eventually develop into a narrow riparian forest. At the time of our site visit, sampling trees within a dense herbaceous ground cover dominated the floodplain adjacent to the creek, and the herbaceous vegetation also dominated portions of the creek. Several marshes have been created in CF7, and appear to be healthy. Although there is considerable hydrologic data from a grid of eleven piezometers on this system, there does not appear to be any data on above-ground water levels in the creek or wetlands. At no time during the more than three years of record did water levels rise above the ground surface at any of the piezometers. This makes it difficult to say anything about hydroperiods or water depths within the creek or wetland communities.

OCCIDENTAL CHEMICAL

Introduction

We visited 19 wetland sites at Occidental Chemical on 8-9 September 1993. These included three natural wetlands (OX2, Cabbage Head Swamp, Bee Haven Swamp), a clay settling area that is not yet filled (SA-12) and another that is being dewatered (SA-10), a ditch across unmined land to reconnect a stream channel (Four Mile Branch replacement), a constructed stream across unmined land (OX11), and a series of constructed swamps, four with (OX5, OX8, OX9, OX10) and eight without (OX1, OX3, OX6, OX7, OX13, OX14, OX15, OX16) associated ponds or lakes. The constructed swamps range in age from 1-11 years, but only three are more than 4 years old. There are several volunteer wetlands on the OX5 site that we did not visit.

Hydrologic data are available from six of the 19 sites visited. These include piezometer data on a natural forested wetland (OX2) and two reclaimed forested wetlands, one 7 years old (OX5) and the other 2 years old (OX7). Monthly surface and groundwater data are available for a 6 year old lake-forested wetland complex (OX9), and for a recently constructed stream channel (OX11). There are data on water level fluctuations in Purvis Lake, along which an 11 year old wetland (OX6) was constructed.

Analysis of Individual Sites

OX2 and Cabbage Head Swamp are unmined forested wetlands that appear to be reasonably healthy. Piezometer data indicated a water-table drawdown that extended 1000 feet into OX2 from a perimeter ditch between the natural wetland and an adjacent mine. We did not see any obvious effects of the drawdown, although we did not visit the portion of the site closest to the perimeter ditch. There did not appear to be any adverse effects on Cabbage Head Swamp as a result of digging a ditch (Four Mile Branch replacement) to carry outflows from the swamp.

OX17, a clay settling area, is still being dewatered. Although some trees have been planted, the final topography, and hence its hydrology, have yet to be established.

OX11 is a 4 year old stream channel constructed on unmined land. Prior to reclamation, the original stream had been channelized. Given its youth since reclamation, it still has this general appearance. The current stream gradient is fairly steep in places, particularly just upstream of where it passes under C-135. Two continuous surface water level recorders and a groundwater station have monitored its hydrology.

The remaining sites are all reclaimed forested wetlands, ranging in age from 1-11 years. It is difficult to assess the hydrologic condition of sites younger than 4 years. Only OX7, a 2 year old site, has piezometers to monitor water levels. OX1 and OX3 appear to be drier than is appropriate for a healthy wetland, and mortality of planted trees is high. OX7 also appears to have a high mortality of planted trees. On the other hand, trees planted in OX14 appear to be growing well.

There are three older forested wetland sites, all of which have some hydrologic data. OX5 was constructed as a swamp with associated small areas of marsh and shallow open water. The 4:l upland: wetland ratio resulted in development of several volunteer wetlands. OX6 is a forested wetland constructed along a portion of the littoral zone of deep lake. The wetland ground elevation is at 119 feet, while the lake level normally fluctuates from 118-120 feet and occasionally reaches 122 feet. The “Demonstration Area” of OX9 occupies an overflow slough from a lake. Water levels in the wetland are maintained at an approximate 1 - 1.5 feet maximum depth by a culvert where the water leaves the slough. Tree growth appears good at all three sites.

MOBIL MINING AND MINERALS

Introduction

We visited 32 wetland sites at Mobil on 11-12 October 1993. These included five unmined sites; three not directly affected by mining (MO6, MO20, near BF82 (1B) and two that were managed to protect them from mining on lands surrounding them (FM87 (4) forest, Reserve Forest). No reclamation occurred on one site (MO1 3) that was mined and subsequently abandoned 40 years ago. All of the other wetlands were on mined sites that have been reclaimed to varying degrees. Three sites are clay settling areas that are 1 (MO12), 5 (MO37), and 6 (MO15) years old. The remaining reclaimed sites varied in age from 0-13 years old.

Only one of all of the sites visited (MO30) was reported to have hydrologic data, which had been collected both before and after mining.

Analvsis of Individual Sites

MO6 was a natural mesic forest along the North Prong of the Alafia River, to which wetland trees have been added to enhance the wetland character of the site. MO20 includes Rocky Branch and its associated forested floodplain, which has been used as a reference wetland for other restoration sites. These and a third forest near MO30 all appeared to be reasonably intact forests.

The two preserved forests involved relatively small areas in much larger mined landscapes. Trees in the preserved three acre forest in MO11 had been severely stressed as evidenced by a very open forest canopy, due to loss of some trees and thinning of foliage on the remaining trees. There was substantial amounts of silt around the bases of these trees, which could have been part of the problem. Despite the impacted character of this forest, if site hydrology is adequately restored, it should recover its original condition much more quickly than will surrounding mined and reclaimed wetlands. The Reserve Forest was kept wet while the area around it was mined. It appeared to be in good condition at the time of our visit.

The old abandoned mine (MO13), with its erratic topography represents a unique environment with a unique hydrology that did not exist in the region before mining. The topography ranges from relatively deep water sites to the tops of ridges high above the water table. The steep slopes are quite different from the shallow slopes normally associated with Florida wetlands. These characteristics result in narrow fringing wetlands along deeper troughs between the ridges and sparsely vegetated wetlands in shallower troughs due to the closed canopy created by the dense forest on adjacent ridges. Some wetland trees may contribute to this closed canopy, but isolation from seed sources would limit their occurrence on these sites. Given the 40 years since this site was abandoned, these communities appear to be relatively stable. Hydrologically, these types of sites probably increase water storage on the landscape because of the increased area of aquatic habitat, which in turn tends to increase the stability of water flows to downstream wetlands and streams.

We inspected two clay settling areas that had been reclaimed. One that had been completed within the last year (MO12) involved interconnecting a number of subsidence depressions, revegetating them, and installing a control structure at the site's outlet to maintain water levels within the wetlands. This site supported predominantly dense marsh vegetation at the time of our visit, and its youth precluded drawing any conclusions about its hydrology. Trees had been planted in MO15 six years before our visit, but water flows to the stream running through the site had only been restored for a few weeks at that time, after having been diverted for almost 50 years. The floodplain vegetation is a dense shrubby thicket.

The remaining sites are all reclaimed wetlands, which vary in age from 0-13 years. It is difficult to say much about most of the 0-2 year old sites (MOl, MO5, MO8, MO11, MO16, MO18, MO21, MO35, MO38), since there are no hydrology data for them and the wetland vegetation had not yet had much opportunity to respond to multi-year environmental conditions. MO1 had some standing water at the time of our visit, but it is currently plugged on its upstream and downstream ends to allow the channel to stabilize before receiving full flows. MO18, a 2 year old site, does appear to be exhibiting hydrologic characteristics of a stream floodplain. MO5, a less than 1 year old site, includes a seepage slope wetland, a wetland depression, and an outflow stream, for all of which the hydrology seems to be functioning appropriately. MO16 was designed to be a marsh and forested wetland, but appears to be primarily open water with some deep marsh. Over the long term (decades-centuries) organic soils could build up and the site could succeed to a herbaceous and/or forested wetland. MO35 is apparently receiving seepage from a new adjacent clay settling area, which keeps it wet enough to support wetland vegetation. Whether this water supply will continue to support the wetland when the clay settling area is filled and dewatered is unknown at this time.

The oldest reclaimed site (MO14) is 13 years old. Flows from Rocky Branch had been diverted into this flowway for approximately 50 years, and had just been returned to Rocky Branch a few weeks before our visit. The flowway appears to be reasonably functional, although its channel characteristics will probably change somewhat over the next few years in response to the newly reduced flow regime. MO32 is a well developed 12 year old wetland with an interior marsh bordered by a forested wetland. MO34 is also 12 years old. It was designed as a forested wetland, but is dominated by what appears to be a healthy deep marsh.

The remaining reclaimed wetlands are 3-9 years old. Again, it was difficult to describe the degree of successful hydrologic restoration on most of these sites (MO2, MO3, MO4, MO9, MO17, MO19, MO30, MO36). Except for one site (MO30), there are no available hydrology data. And while there are sapling trees present on these sites, they are intermixed with dense shrubs and herbaceous vegetation so that it is often difficult to see them or even the stream channel. The 3 year old outlet channel for MO10 has a dense thicket of floodplain vegetation that completely covers the stream, although there was good flow in the floodplain at the time of our visit. One site that did appear to be doing well is MO9, with many healthy trees and a distinct stream channel. MO33 is a deep lake with only a very narrow wetland fringe along its edge. MO2 is a stream constructed with a narrow floodplain and on a relatively steep gradient. It had severe erosion problems, which required rip-rap and a sediment trap. At the time of our visit it looked more like a channelized canal than a natural stream.

Conclusions

The reclaimed marshes and older reclaimed forested sites appear to be developing characteristics of natural wetlands, and can be expected to be viable over the long term. With a few exceptions, most of the other sites also seem to have the potential for developing into viable wetlands. However, with the almost complete absence of hydrologic data and the early stage of plant community development on forested wetland sites up to about 10 years after reclamation, it is virtually impossible to say with confidence that they have been successfully restored. It is interesting that the ages when it is most difficult to judge the condition of a forested wetland site are when they are about 3-10 years old. Before that time period, it is easier to see the characteristics of the stream channel, although one could not say much about the vegetation. After that time period, the vegetation becomes more open and again the channel is visible. In addition, the trees are grown large enough that one could get a better sense of the character of the developing forest.

Many of these wetlands are associated with stream channels. Floodplain wetlands appear to be much easier to reestablish than isolated wetlands, primarily because of regular availability of aboveground water. The primary design decisions are channel gradients and widths and floodplain contours in the context of the characteristics of the overall watershed. Thus, even the surfaces of clay settling areas can be sculpted to function as floodplains with their associated wetland communities. The main difficulty with creating isolated wetlands is largely a function of designing wetland topography in relation to the seasonal fluctuations of the water table. Since wetland inundation occurs over a range of only a few feet, the subtlety of this relationship can be very difficult to predict on a newly created land surface and soil profile.

The old abandoned mine site has a well developed forest growing on a sharply undulating ground surface. The topography ranges from the bottom of deep water sites to the tops of ridges high above the water table. Wetland habitats occupy the shallower troughs or occur as narrow bands along the edges of the ridges. This site represents a unique ecosystem with a unique hydrology that did not exist in the region before mining. This unique hydrology can be expected to influence hydrology of wetlands and streams on surrounding lands.

The floodplain forests preserved at several of the mined sites have persisted through mining and reclamation activities on these sites. One was in reasonably good condition, and the other,- while somewhat degraded, will have a much shorter timetable for recovery than do wetlands on surrounding mined lands.

CARGILL

Introduction

We visited 14 wetland sites at Cargill on 19 January 1994. These included two unmined sites; one not directly affected by mining (Unmined marsh) and one that is managed to protect it from mining on surrounding lands (Unmined forest). No reclamation occurred on one site (CAR11) that was mined and subsequently abandoned about 80 years ago. All of the other wetlands are on mined sites that have been reclaimed 0.5-4 years prior to our site visit.

Water level data are not required for the majority of these sites, although weekly staff gauge measurements have been taken at a number of them.

Analysis of Individual Sites

The unmined marsh was viewed in the vicinity of CAR8 and CAR6. It is a deep marsh community with numerous scattered shrubs. Although virtually surrounded by mining activity, it still appears to be reasonably healthy.

The unmined forest, which is adjacent to CAR5, has been severely stressed. Many of the trees had been killed, and those remaining are in poor condition. The most likely cause of the impacts was mining adjacent to the site that either cut off groundwater inflows from uplands to the east or simply lowered water levels in the general area. As with other preserved sites, if pre-mining hydrology is restored, it is likely that this site will recover its pre-disturbance condition much sooner than will the surrounding reclaimed wetlands. However, there does not appear to be any pre-mining hydrology data for this area, so we can only wait and see how the vegetation responds to the hydrologic regime of the current reclaimed environment.

CAR11 was mined in 1914 and subsequently abandoned. Topography is primarily low ridges and shallow intervening depressions. The gradients between the ridges are not as steep as in some other more recently mined and abandoned sites we visited. The wetlands we saw are small and shallow. They have little rooted vegetation, probably because of shading from the dense canopy of trees growing on the adjacent ridges. Their small size provides little surface water storage that would affect the hydrology of surrounding lands.

All of the remaining reclaimed sites were designed with a forested wetland as one component of the reclamation. However, given their youth and the usually dense herbaceous vegetation in which they are growing, it was difficult to say much about the success of these forests. CAR1 and CAR4 are both primarily deep lakes with fringing wetlands, which should be fairly stable over the long term. The marshes on these sites all appear to be functioning wetlands, given the variability of time and circumstances since reclamation was completed. CAR2 is less than a year old and was only sparsely vegetated at the time of our visit. A severe windstorm, which occurred shortly after the initial wetland herbaceous planting on CAR9, ripped up most of the seedlings and resulted in a wetland dominated by open water and dense patches of cattails. The site was scheduled for replanting shortly after our site visit. The other 2-4 year old sites (CARS, CAR7, CAR8, CAR10) appear to be functioning reasonably well.

A significant feature of a number of the original wetlands seen on this site visit is the presence of deep organic soils. In my experience, unique biotic communities exist on these deep organic soils and are intimately tied to them. These communities typically support a unique species composition in an area, and the productivity and structural characteristics of these species are directly related to organic soil depth. The organic soils, with their high capillarity, result in greater moister availability during dry periods. This increased moisture can be of direct importance to the biota, particularly during severe droughts, and of indirect importance in stopping or at least moderating the severity of fires that occur in these areas. The original communities on these sites occurred on organic soils up to 15 feet in depth. While it is difficult to say that 15 feet of organic soil would be required to reestablish these communities, I expect that depths in excess of 6 feet are necessary.

US AGRI-CHEMICAL

Introduction

We visited 11 wetland sites at US Agri-Chemicals Corp. on 21 January 1994. Two unmined sites visited are on McCollough Creek (1, 2). A disturbed but unmined site is a seven year old dragline crossing (USAC6). Another site is an old abandoned mine. All of the remaining mined sites (USAC1-5), USAC7-8) are 0-6 year old lakes with some wetlands within them or along their edges.

Some hydrologic data had been collected at irregular intervals on the above sites, but none are available in a usable form.

Analysis of Individual Sites

In 1970 one unmined site along McCollough Creek (1) had been pasture with a few scattered larger trees left for shade. At the time of our visit, a dense floodplain forest of small trees and shrubs had grown up along the small creek. At another location (2), all of these trees had been recently killed, and the site is now dominated by a dense thicket of small shrubs and herbaceous vegetation.

Where we visited the old abandoned mine, there are deep, relatively large open bodies of water with intervening heavily forested ridges. There is little wetland vegetation due to a narrow zone of fluctuation along the steep slopes and shading of shorelines by trees on adjacent ridges. Water storage in the deeper depressions may have modified the hydrology of surrounding areas by reducing surface water outflows during wet periods and increasing the duration of groundwater flows in drier periods.

The land surface at the seven year old dragline crossing (USAC6) was restored at too high an elevation and will have to be lowered to reestablish hydrologic conditions suitable for the original forested floodplain community.

Among the 0-6 year old reclaimed sites (USAC1-5, USAC7-8), there is little wetland vegetation visible other than cattails in shallow areas within and along the edges of lakes. The constant availability of water at fairly predictable elevations probably makes it easier to design viable fringing wetlands around lakes (or redesign them if those originally created are not working) than to construct isolated or floodplain wetlands. However, fringing wetlands, even if wide, were not a significant feature in the area before mining. They provide a very different environment, both hydrologically and biologically, than are found in the original isolated or floodplain wetlands. In addition, the large volume of water storage in these lakes has probably significantly reduced surface water flows to surrounding lands during wet periods and significantly lengthened the duration of groundwater flows during dry periods.

IMC FERTILIZER

Introduction

We visited 22 wetland sites at IMC on 8 and 10 February, 1994. These included two dragline stream crossings that were not mined. All of the other wetlands are on mined sites that had been reclaimed for 0-16 years prior to our site visit.

Water level data are not required for the majority of these sites, although some data were taken at a few sites.

Analysis of Individual Sites

The two dragline crossings are five (IMC1) and nine (IMC3) years old, and appeared to be recovering well.

For most of the reclaimed sites less than four years old (IMC2, IMC4, IMC6, IMC8-13, IMC37, IMC41), it was difficult to draw conclusions as to the hydrologic success of the reclamation effort. This is a function of a lack of hydrologic data on most sites and their early stage of vegetative development, particularly for those sites designed as forested wetlands. However, the vegetation is sufficiently dense on most so that it is difficult to see the ground surface topography or water levels on these sites. The one site that had been reclaimed for less than a year still has little vegetative cover, and the topography and water levels at the time of our visit appeared to be suitable for establishment of a viable wetland. IMC9 was apparently constructed so that elevations on most of the site are either too high or too low to support wetland vegetation.

IMC14 is a four year old site that has the appearance of a healthy marsh, although it was originally designed as a combination herbaceous-forested wetland. Similarly, IMC21 and IMC40, which are five and six years old, respectively, have the appearance of healthy marsh-lake sites, but were originally designed with a forested component as well. On the other hand, IMC5 and IMC19, which are nine and ten years old respectively, appear to have reasonably well developed wetland forests.

There are also a number of sites that appear to be coming along as wetlands, but not as well developed as those described above, particularly considering the time since reclamation (8-16 years). IMC42 is a thirteen year old lake-wetland site, while IMC7, IMC24, IMC38, which are ten, eight, and sixteen years old, respectively, were all designed as wetland forests. In general, the wetland trees do not appear to dominate these sites to the degree I would have expected in a healthy wetland environment.

AGRICO							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
PCSP1	AG1	7	reclaimed	???	MARSH/FOREST	water level recorder-NR	6/93
FG84(5)	AG3	6	reclaimed	seepage wetland from lake	LAKE/Forest/marsh	none-NR	6/93
8.4 acre	AG4	8	reclaimed	swamp	forest	USGS study-NR	6/93
FGSP-4		?	volunteer	shrub/stream	---	none	6/93
FG84(1)	AG5	5	reclaimed	marsh/shrub	marsh	none-NR	6/93
PC drag	AG6	1	reclaimed	???	forest	none-NR	6/93
FGPC1	AG7	2	reclaimed	lakes/seepage swamp	LAKE/FOREST	water levels - computerized	6/93
FGPC-2		--	preserved	cypress dome	---	none	6/93
FG13	AG10	11	reclaimed	pond/marsh/swamp/upland	FOREST	water levels/rainfall-NR	6/93
FGSP-5?		--	preserved	hardwood swamp	---	none	6/93
FGSP8	AG11	?	???	???	---	none	6/93
FGSP9	AG12	12	clay settl.	pond/swamp/shrub	shrub	Betty Rushton study	6/93
FGSP-19		5	reclaimed	marsh	---	none	6/93
FGGSB3-1	AG13	0	reclaimed	marsh/swamp	MARSH/Forest	none-NR	6/93
FG84(7)	AG14	1	reclaimed	marsh (open)	MARSH	none-NR	6/93
PresDrain	AG15	?	reclaimed	???	forest	none-NR	6/93
PCPC2 west	AG16	0.5	reclaimed	???	Forest	not yet	6/93
Preservation Area (PCPC2)		--	preserved	impacted wetland forest	Forest	none	6/93
Power Plant lake (PCPC2)		--	industrial	power plant lake	LAKE/marsh	none	6/93

c:...\work\FH4-008.tb1

AGRICO							
Project	**ID**	**Age**	**Wetland History**	**Wetland Habitat - MJD**	**HABITAT - K. ERWIN**	**HYDROLOGY DATA**	**VISIT**
PCPC2 east	AG17	0.5	reclaimed	???	Marsh/Forest	none	6/93
Sec28FG	AG18	~9	reclaimed	pre-reg. lake/forested edge	---	none	6/93
Sec28FG	AG19	--	???	---	---	---	6/93
PC-17	AG20	~15	mined	pre-reg. lake/forested edge	---	none	6/93
FG-HC-1	AG22	1	reclaimed	marsh	---	none	6/93
NatMar20	AG23	--	natural	marsh	---	none	6/93
NatBay	AG24	--	natural	bayhead (flowway?)	---	none	6/93
NatBayS	AG25	--	natural	marsh	---	none	6/93
PC-SP-14	AG26	0.5	reclaimed	seepage bayhead/marsh/sandhill	---	none	6/93
RM19A	AG27	--	???	---	---	---	???
RM19C	AG28	--	???	---	---	---	???
RM19D	AG29	--	???	---	---	---	???
RM20A	AG30	--	???	---	---	---	???
RM20B	AG31	--	???	---	---	---	???
RM29B	AG32	--	???	---	---	---	???

c:...\work\FH4-008.tb1

OCCIDENTAL CHEMICAL							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
SRSP1	OX1	2	reclaimed	swamp (dry?)	FOREST	none-NR	9/93
MBayNat	OX2	--	natural	bayhead	---	yes-NR	9/93
SR-82(3)A	OX3	3	reclaimed	swamp (dry?)	FOREST	none-NR	9/93
SA-12		0	clay settl.	pond/marsh	---	none-NR	9/93
SRSP(4)	OX5	7	reclaimed	swamp/pond	Forest/Marsh	yes-NR	9/93
SR8	OX6	11	reclaimed	swamp	LAKE/Forest	yes?	9/93
Four Mile Branch replacement		?	not mined	shallow ditch	---	none-NR	9/93
Cabbage Head Swamp		--	natural	swamp forest	FOREST	none-NR	9/93
SR8715	OX7	2	reclaimed	swamp	FOREST	yes-NR	9/93
SR8816	OX8	1	reclaimed	isolated swamps/swales/lake	Forest/Lake	none-NR	9/93
GREEN (SR 83-2)	OX9	6	reclaimed	swamp/lake	FOREST/Lake	yes-NR	9/93
SR82(2)	OX10	4	reclaimed	swamp/lake	Lake/Forest	none-NR	9/93
RCchannel	OX11	4	reclaimed	narrow floodplain	Stream	yes	9/93
SA1	OX12	10	clay settl.	???	Forest	none-NR	--
SC85(5)	OX13	1	reclaimed	swamp	Forest	none-NR	9/93
SC85(2)	OX14	4	reclaimed	swamp	Forest	none-NR	9/93
SC86(1)	OX15	2	reclaimed	swamp	Forest	none-NR	9/93
SC-85(6)	OX16	4	reclaimed	???	Forest	none	9/93
Bee Haven Swamp		--	natural	mixed pine-hardwood	---	none	9/93
SR-4, SA#10	OX17	??	clay settl.	grassy with trees	FOREST	none	9/93
SR82(2)?		??	reclaimed	lake	---	--	9/93

MOBIL							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
VARN	MO-15	6	clay settl.	stream with shrub-dam. floodplain	Forest/marsh/lake	none-NR	10/93
Candies	MO16	2	reclaimed	open water/marsh	marsh/forest	none-NR	10/93
FM83(3)	MO17	5	reclaimed	herbaceous stream and floodplain	Forest/marsh	none-NR	10/93
FM87(1)	MO18	2	reclaimed	stream with herbaceous floodplain	Stream/Forest	none-NR	10/93
FM22A	MO19	9	reclaimed	stream with forested floodplain	Forest	none-NR	10/93
RKYREF	MO20	--	natural	STREAM/FOREST	---	none-NR	10/93
PRDrag	MO21	1	reclaimed	???	forest	none-NR	10/93
3WCUT	MO22	44	abandoned	???	FOREST	none-NR	---
HOMELAND	MO23	20	clay settl.	???	Forest	none-NR	---
Min.Jones	MO24	2	reclaimed	???	Lake/forest	none-NR	---
FMPR1	MO25	1	reclaimed	???	Forest/Lake	none-NR	---
FMSP4	MO27	1	reclaimed	???	Lake/Forest/Marsh	none-NR	---
TFWEST	MO28	2	reclaimed	???	forest	none-NR	---
SFM1	MO29	1.5	reclaimed	???	Marsh	none-NR	---
BF82(1B)	MO30	7	reclaimed	forested floodplain	forest	yes-NR	10/93
near BF82(1B)		--	natural	hardwood forest	FOREST	none-NR	10/93
BF1	MO31	12	reclaimed	???	Forest/lake	none-NR	10/93
BF2	MO32	>11	reclaimed	forested wetland/marsh	Forest	none-NR	10/93
BF4	MO33	>8	reclaimed	lake(tree/herbaceous fringe)	Lake	none-NR	10/93

c:...\work\FH4-008.tb4

MOBIL							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
BF5	MO34	12	reclaimed	marsh	Forest	none-NR	10/93
BFSP(8)	MO35	1	reclaimed	marsh	Forest	none-NR	10/93
BFSP(9)-1	MO36	7	reclaimed	???	Marsh	none-NR	10/93
Reserve Forest		--	preserved	forested wetland	FOREST	none-NR	10/93
2/M-5	MO37	5	clay settl.	???	forest?	none-NR	10/93
BFSP(9)-2	MO38	0	reclaimed	marsh	Marsh	none-NR	10/93

CARGILL							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
HP4-1	CAR1	3	reclaimed	???	LAKE/Forest	none-NR	1/94
HP4-2	CAR2	0.5	reclaimed	marsh	MARSH/Forest	none-NR	1/94
HP6-1	CAR3	0.5	reclaimed	marsh	Marsh/Forest	yes	1/94
HP1	CAR4	4	reclaimed	wetland fringe along lakes	LAKE/Marsh/Forest	none-NR	1/94
HP5-1	CAR5	4	reclaimed	marsh with shrubs	Marsh/Forest/lake	none-NR	1/94
HP5-2A	CAR6	4	reclaimed	???	MARSH/Forest/lake	none-NR	1/94
HP5-2B	CAR7	3	reclaimed	marsh	MARSH/Forest/lake	none-NR	1/94
HP5-3	CAR8	2	reclaimed	marsh	MARSH/Forest/lake	none-NR	1/94
HP3-4	CAR9	4	reclaimed	open water/marsh	MARSH/Forest	none-NR	1/94
HP3-5	CAR10	3	reclaimed	marsh	FOREST/Marsh	none-NR	1/94
HP3-7	CAR11	80	abandoned	forest	lake	none-NR	1/94
HPSP(2)A	CAR12	9	reclaimed	???	MARSH	yes-NR	1/94
Unmined marsh		--	natural	marsh	---	none-NR	1/94
Unmined forest		--	preserved	forest	---	none-NR	1/94
FMWC1	CAR13	5	reclaimed	???	Lake/marsh	none-NR	---
FMOLD	CAR14	45	abandoned	???	FOREST	none-NR	---
FMPR1	CAR15	9	reclaimed	???	Lake/Marsh/forest	none-NR	---
FMPR2	CAR16	6	reclaimed	???	Lake/Forest/Marsh	none-NR	---
FMSP10	CAR17	9	reclaimed	???	Lake/forest/marsh	none-NR	---

c:...\work\FH4-008.tb5

CARGILL							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
FMSP11	CAR18	9	reclaimed	???	Lake/marsh/forest	none-NR	---
FMSP12	CAR19	8	reclaimed	???	STREAM/Forest/Lake/ marsh	none	---
FMLP1	CAR20	1	reclaimed	???	Forest/Lake/marsh	none	---
FMLP1REF	CAR21	--	natural	???	---	none-NR	---
FMLP4	CAR22	3	reclaimed	???	LAKE/Marsh	none-NR	---
FMLP2	CAR23	3	reclaimed	???	Lake/Marsh/forest	none	---
FMSPO2	CAR24	9	reclaimed	???	Forest/lake/marsh	none-NR	---
FMSPO4	CAR25	10	reclaimed	???	Lake/marsh/forest	none-NR	---
FMSPO8	CAR26	10	reclaimed	???	forest/lake	none-NR	---

c:...\work\FH4-008.tb5

US AGRI-CHEMICAL							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
SP(2A)	USAC1	0	reclaimed	lake with wetland fringe	MARSH/Lake/forest	none-NR	1/94
SP(5A)	USAC2	0	reclaimed?	lake with wetland fringe	marsh?	none-NR	1/94
SP(4)	USAC3	0	reclaimed?	lake with wetland fringe	marsh?/forest?	none-NR	1/94
84(1A)	USAC4	??	reclaimed	lake with wetland fringe	Lake/Forest	none-NR	1/94
84(2B)	USAC5	??	reclaimed?	lake with wetland fringe	forest?	none-NR	1/94
DR Cross	USAC8	7	reclaimed	???	forest/marsh	none-NR	1/94
86(2B)	USAC7	6	reclaimed	lake with wetland fringe	Lake/forest	none-NR	1/94
86(4B)	USAC8	5	reclaimed	lake with wetland fringe	Lake/forest/marsh	none-NR	1/94
SP6A	USAC9	3	clay settl.	???	MARSH/Forest	none-NR	---
SP8	USAC10	3	reclaimed	???	Marsh/Forest	none-NR	---
SP(11)8	USAC11	??	reclaimed	???	Marsh/Forest	---	---
84-3A	USAC12	??	---	???	---	---	---
R-3	USAC13	??	---	???	---	---	---
S1	USAC14	??	---	???	---	---	---
87-4	USAC15	4	reclaimed	???	lake/forest	---	---
McCollough Creek(1)		--	unmined	floodplain forest	---	---	1/94
McCollough Creek(2)		--	unmined	floodplain forest	---	---	1/94
Old mine		??	abandoned	lake/forest	---	---	1/94

c:...\work\FH4-008.tb6

IMC FERTILIZER							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
Cemetery	IMC1	5	dragline cross.	forest	forest	none-NR	2/94
Lizard	IMC2	0	reclaimed	forest	forest	yes7-NR	2/94
McMulen	IMC3	9	dragline cross.	forest	forest	none-NR	2/94
Jarnerson	IMC4	1	reclaimed	herbaceous	forest	none-NR	2/94
Hall	IMC5	9	reclaimed	forest	marsh/forest	none-NR	2/94
Miles Gr.	IMC6	2	reclaimed	marsh/lake	Forest/Lake/Marsh	yes	2/94
Dogleg	IMC7	10	reclaimed	herbaceous/forest	Forest	none-NR	2/94
E. Lake	IMC8	1	reclaimed	herbaceous	FOREST/Marsh	none-NR	2/94
Tadpole	IMC9	2	reclaimed	herbaceous	marsh/forest	none-NR	2/94
E.oldFG	IMC10	1	reclaimed	forest/lake	Forest	none-NR	2/94
N CR830	IMC11	1	reclaimed	marsh/lake	Marsh	none-NR	2/94
S CR630	IMC12	2	reclaimed	marsh/lake	Marsh/Lake/forest	none-NR	2/94
V SR37	IMC13	2	reclaimed	lake/forest	Lake/forest	---	2/94
FCOsec15	IMC14	4	reclaimed	marsh	forest/marsh	yes	2/94
FCOsec1	IMC15	1	reclaimed	???	Marsh/Forest	none-NR	---
HorseCr.	IMC16	9	reclaimed	???	Marsh	none-NR	---
S K6	IMC17	10	reclaimed	???	Lake/forest	none-NR	---
Lake Br.	IMC18		reclaimed	???	forest	---	---
W K6	IMC19	10	reclaimed	forest	Forest/marsh/lake	none-NR	2/94
S.Mizelle	IMC20	7	reclaimed	???	forest/marsh/lake	none-NR	2/94
UnitH	IMC21	5	reclaimed	marsh/lake	Marsh/Forest/lake	yes-NR	2/94

c:...\work\FH4-008.tb7

IMC FERTILIZER							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
Achin5/6	IMC22	5	reclaimed	???	Marsh/Lake/forest	none-NR	---
Achan	IMC23	5	reclaimed	???	LAKE/MARSH/Forest	none-NR	---
Bird Br.	IMC24	8	reclaimed	forest	forest	none-NR	2/94
Myers L.	IMC25	5	reclaimed	???	marsh/forest/lake	none-NR	---
S.Pebb.	IMC26	1	reclaimed	???	forest/marsh	none-NR	---
Svc12	IMC27	4	reclaimed	???	LAKE/Marsh/Forest	none-NR	---
Ssc7/12	IMC28	4	reclaimed	???	STREAM/Marsh/Forest	yes	---
Sec6	IMC29	1	reclaimed	???	forest/marsh	none-NR	---
SWPhos	IMC30	0	reclaimed	???	Marsh/lake	none-NR	---
Cateye	IMC31	7	reclaimed	???	lake/forest/marsh	none-NR	---
N2area	IMC32	0.5	reclaimed	???	marsh/forest	none-NR	---
SWbranch	IMC33	9	reclaimed	???	Lake/Marsh/Forest	none-NR	---
Self30	IMC34	30	abandoned	???	Forest	none-NR	---
S. Tiger	IMC35	10	reclaimed	???	LAKE/FOREST/Marsh	none-NR	---
H9oss	IMC36	25	clay sett.	???	Forest	none-NR	---
N Par B	IMC37	3	reclaimed	forest/marsh/lake	Forest/Lake/Marsh	yes-NR	2/94
ParcelB	IMC38	16	reclaimed	forest	Forest	none-NR	2/94
W CS11	IMC39	5	reclaimed	???	Marsh/Forest/Lake	yes-NR	---
WCS11FL1	IMC40	6	reclaimed	lake/marsh	Forest/Marsh/Lake	yes-NR	2/94
WCS11FL2	IMC41	7	reclaimed	???	forest/marsh/lake	yes-NR	2/94
N640 11	IMC42	13	reclaimed	forest/lake	forest/marsh/lake	none-NR	2/94

c:...\work\FH4-008.tb7

IMC FERTILIZER							
Project	ID	Age	Wetland History	Wetland Habitat - MJD	HABITAT - K. ERWIN	HYDROLOGY DATA	VISIT
E CS11	IMC43	3	reclaimed	lake/marsh	Lake/Forest/marsh	none-NR	---
SandExud	IMC44	2	reclaimed	???	Lake/Marsh/Forest	none-NR	---
Fortner	IMC45	15	reclaimed	???	Lake/forest	none-NR	---
SWCS8	IMC46	3	reclaimed	???	lake/marsh/forest	---	---
SEC6HP2	IMC47	6	reclaimed	???	LAKE/MARSH/FOREST	---	---

c:...\work\FH4-008.tb7

2.10.2 COMMENTS RELATED TO FIELD OBSERVATIONS (BY M. J. DUEVER)

METHODS

Methods used on the field trips were primarily observational. We stopped at most sites and normally walked into the wetland community to examine water depths, substrate characteristics, and plant communities. I also photographed each site. Discussions were held between industry staff leading the trips, which focused on the history of the site and particularly on any data on site construction, watershed characteristics, and monitoring that might have been done on the site.

RESULTS

* While we visited many sites, a large number of them were very new, and thus were in the early stages of developing into functioning systems. This made it very difficult to come to any conclusions as to whether they had been "successfully restored".

* A wide variety of community types had been created:
  - land and lakes with relatively small percentages of wetlands
  - shallow depressional marsh wetlands
  - shallow depressional forested wetlands
  - streams and associated forested floodplains
  - deep organic soil marsh communities
  - deep organic soil bayheads

* The land and lake systems should have the least hydrologic fluctuation because of the volumes of water contained in the lakes.

* The depressional marsh and forested wetlands are the most difficult to create because they exist over a very narrow range of water level fluctuation and getting the topography "right" to provide an appropriate hydrologic regime has proven to be one of the most difficult challenges in creating these wetlands. If water levels are too "deep", open water develops. If they are too "shallow", upland communities develop. In many ways, it would be ideal to create the topography and let it "run" for a few years before planting vegetation. Then based on observed hydrology, in the light of climatic conditions during the period, the topography could be modified as necessary, and vegetation planted where there is a relatively high certainty of achieving success. The problem with this is that undesirable vegetation would probably come in on its own and be very difficult to displace with more desirable vegetation by the time the site contours have been finalized.

* Other community types that would be difficult to replace would be deep organic soil communities, such as deep marshes and bayheads. The main reasons for the difficulty are apparently finding sufficient quantities of organic soil and then being able to work on these sites to plant and manage them. However, the deep organic soils are a crucial factor in the survival

of these communities. The accumulation of organic soil provides a relatively high site for them to develop on so that water depths and hydroperiods are suitable. During droughts the deep organic soils maintain contact with a declining water table, which creates a more moist substrate to protect the root systems of marsh communities from fires, and a more moist microclimate that helps protect the aboveground portions of forested communities from fire.

* Another mechanism for developing organic soils would be to merely create sites that would be flooded too deeply for the establishment of emergent vegetation, and let them fill in with organics. This would be a very long-term process (decades at least). Would clean compost be a mechanism for expediting this process?

* Stream floodplains may represent the simplest wetland types to reestablish. Probably the most complicating factor would be dealing with erosion in areas with steeper slopes. However, with a wide enough floodplain for the water to spread out over, higher flows can be sufficiently dispersed so that erosion can be controlled. Where a situation did not allow a wide floodplain, rip-rapping of the channel was planned to minimize erosion.

* Streams were created in some cases as a broad shallow floodplain in which the stream would carve its own channel, while in other situations a winding channel was dug in the floodplain.

* While old abandoned mined lands may be interesting, largely because they are so different from natural Florida communities, I have seen little data that would justify their protection from reclamation activities where this might fit into an overall site restoration effort.

* A “watershed size to wetland acreage” ratio of between 2 and 3 has been used in the design of depressional wetlands. It seems that a lower ratio reduces the proportion of wetland acres created while a higher ratio increases the proportion of wetland acres.

* Since soil permeability is a significant factor in the movement of water, it can be used in a variety of ways to create a suitable wetland hydrology.

* Soils in clay settling areas have a very low permeability. As a result, water can be ponded on its surface for extended periods of time, creating wetlands with very short hydroperiods. Where there is a sufficient watershed upstream of a site, longer hydroperiods can be maintained, and depending on the depth of the depression, organic soils may begin to accumulate. The relative impermeability of these soils will also lead to more rapid and less sustained runoff, so that downstream wetlands could have relatively deep flooding, but short hydroperiods.

* At the opposite extreme, sand-tailings are a very permeable substrate. In these situations, water is not ponded on the surface and rapidly infiltrates into the ground. Thus, water levels in streams and wetlands on these sites would fluctuate much more gradually. There would be lower highs and higher lows as the groundwater seeps into these water bodies over longer periods of time. This slow, steady groundwater seepage is a significant factor in the location of many bayheads, and the formation of organic soils important to the sustenance of some communities.

* In hydrologic terms, dragline stream crossings represent a relative minor type of impact compared to the mined sites. The small area involved, the fact that soils (other than deep organics?) are not removed, and topography is restored within a matter of days (weeks) all result in only minor, short-term hydrologic impacts.

* Mixes of substrates, both in terms of actual mixing of different substrates and in the location of certain substrate types within a landscape have been used to control water levels within wetlands. The former can control seepage rates along a specific portion of a wetland edge, while the latter function as dams or dikes to maintain a desired maximum water depth.

* Active mining or storing mining wastes near wetlands being restored can significantly effect the expected outcome of the restoration effort by producing a shifting hydrologic regime. These shifts can be a result of modifications in local groundwater flows or changes in watershed characteristics that affect surface flows.

* Mining was not allowed on some small isolated parcels, while the entire area surrounding them was mined. The sites we visited showed variable protection success. Several appeared to have fared quite well, while others showed major impacts in their forest canopies. In one case, water levels had been supplemented during mining, but apparently had gotten too deep for awhile. In another, a site that appeared to have been located on a seepage slope, was impacted when the area upslope from it was mined. While the impacted sites may not have been completely protected and may take many years to achieve their original condition once the surrounding landscape has been restored, the continued presence of undisturbed substrates and seed source for most of the original flora should greatly accelerate this process as compared to sites that have been mined and restored.

* There is very little hydrologic data for restored wetlands on phosphate mined lands. Part of this is due to the youth of many of the sites, or to the fact that it may not really be needed for some sites, such as dragline stream crossings. For many sites only water depths at the time of vegetation sampling have been taken. When there is standing water, this is useful in relating vegetation observed to relative elevation in different portions of that wetland. Much of what hydrologic data are available are generally not in a readily accessible form, and do not appear to have been analyzed other than to list the values.

* There is even less hydrologic data for natural wetland communities.

2.10.3 FLORIDA WETLAND CLASSIFICATION SCHEMES - CROSS REFERENCE

The below listed cross reference of commonly used Florida wetland classification schemes has been taken directly from the "Guide to the Natural Communities of Florida" (FNAI and DNR, 1990). Only those wetland types commonly occurring within the Florida Phosphate Districts have been included here.

The levels of hierarchy are:

NATURAL COMMUNITY CATEGORIES - defined by hydrology and vegetation

NATURAL COMMUNITY GROUPS - defined by landform, substrate, and vegetation

Natural Community Type - defined by landform and substrate; soil moisture condition; climate; fire; and characteristic vegetation.

The vegetation classifications used in the comparison are:

Kuchler = A. W. Kuchler. 1964. Potential Natural Vegetation of the Conterminous United States. American Geographical Society Special Publication No. 36. (Map and accompanying manual)

Davis = J. H. Davis. 1967. General Map of Natural Vegetation of Florida. Institute of Food and Agricultural Sciences, University of Florida.

SCS = Soil Conservation Service. No date. 26 Ecological Communities of Florida. (Map and accompanying manual)

Myers = R. L. Myers. 1988. Florida's Physical Setting and Florida's Vegetation. Unpublished manuscript.

SAF = F. H. Eyre, Editor. 1980. Forest Cover Types of the United States and Canada. Society of American Foresters, Washington, D. C.

FLCFC = Florida Department of Transportation. 1985. Florida Land Use, Cover and Forms Classification System. (FLUCCS)

PALUSTRINE - Wetlands dominated by plants adapted to anaerobic substrate conditions imposed by substrate saturation or inundation during 10% or more of the growing season. Includes nontidal wetlands; tidal wetlands with ocean derived salinities less than 0.5 ppt and dominance by salt-intolerant species; small (less than 8 ha), shallow (less than 2 m deep at low water) water bodies without wave-formed or bedrock shoreline; and inland brackish or saline wetlands.

WET FLATLANDS - flat, poorly drained sand, marl or limestone substrates.

Wet Flatwoods - flatland with sand substrate; seasonally inundated; subtropical or temperate; frequent fire; vegetation characterized by slash or pond pine and/or cabbage palm with mixed grasses and herbs.

Kuchler	112/Southern Mixed Forest
Davis	2/Pine Flatwoods
SCS	6/South Florida Flatwoods
	7/North Florida Flatwoods
	8/Cabbage Palm Flatwoods
Myers	Flatwoods - wet flatwoods and seepage savannas
SAF	74/Cabbage Palmetto
	84/Slash Pine
	85/Slash Pine - Hardwood
	98/Pond Pine
FLCFC	411/Pine Flatwoods
	419/Other Pines
	428/Cabbage Palm
	622/Pond Pine
	624/Cypress - Pine - Cabbage Palm
	630/Wetland Forested Mixed

other synonyms - hydric flatwoods, pine savanna, cabbage palm savanna, moist pine barrens

Wet Prairie - flatland with sand substrate; seasonally inundated; subtropical or temperate; annual or frequent fire; maidencane, beakrush, spikerush, wiregrass, pitcher plants, St. John's wort, mixed herbs.

Kuchler	112/Southern Mixed Forest
Davis	13/Grasslands of Prairie Type
	2/Pine Flatwoods
SCS	6/South Florida Flatwoods
	7/North Florida Flatwoods
	23/Pitcher plant bog
	26/Slough
Myers	Freshwater Marshes - wet prairies
SAF	N/A
FLCFC	310/Herbaceous
	641/Wet Prairies

other synonyms - sand marsh, savanna, pitcher plant prairie

SEEPAGE WETLANDS - sloped or flat sands or peat with high moisture levels maintained by downslope seepage.

Baygall - wetland with peat substrate at base of slope; maintained by downslope seepage, usually saturated and occasionally inundated; subtropical or temperate; rare or no fire; bays and/or dahoon holly and/or red maple and/or mixed hardwoods.

Kuchler	112/Southern Mixed Forest
Davis	2/Pine Flatwoods
	8/Swamp Forests, mostly of Hardwoods
SCS	12/Wetland Hardwood Hammocks
	22/Shrub Bog
Myers	Freshwater Swamp Forests - titi swamps, bayheads
SAF	85/Slash Pine - Hardwood
	104/Sweetbay - Swamp Tupelo - Redbay
FLCFC	611/Bay Swamps
	614/Titi Swamps

other synonyms - seepage swamp, bayhead, bay swamp, sandhill bog

FLOODPLAIN WETLANDS - flat, alluvial sand or peat substrates associated with riverine Natural Communities and subjected to flooding but not permanent inundation.

Bottomland Forest - flatland with sand/clay/organic substrate; occasionally inundated; temperate; rare or no fire; water oak, red maple, beech, magnolia, tulip tree, sweetgum, bays, cabbage palm, and mixed hardwoods.

Kuchler	113/Southern Floodplain Forest
Davis	8/Swamp Forests, mostly of Hardwoods
SCS	21/Swamp Hardwoods
	20/Bottomland Hardwoods
Myers	Freshwater Swamp Forests - floodplain forests
SAF	61/River birch - Sycamore
	74/Cabbage Palmetto
	82/Loblolly Pine - Hardwood
	88/Willow Oak - Water Oak - Diamondleaf Oak
	92/Sweetgum - Willow Oak
	97/Atlantic White Cedar
FLCFC	615/Stream and Lake Swamps (Bottomland)
	617/Mixed Wetland Hardwoods
	623/Atlantic White Cedar
	630/Wetland Forested Mixed

other synonyms - bottomland, river bottom, stream bottom, white cedar swamp

Floodplain Forest - floodplain with alluvial substrate or sand, silt, clay or organic soil; seasonally inundated; temperate; rare or no fire; diamondleaf oak, overcup oak, water oak, swamp chestnut oak, blue palmetto, cane, and mixed hardwoods.

Kuchler	113/Southern Floodplain Forest
Davis	8/Swamp Forests, mostly of Hardwoods
SCS	20/Bottomland Hardwoods
	21/Swamp Hardwoods
Myers	Freshwater Swamp Forests - floodplain forests
SAF	61/River Birch - Sycamore
	88/Willow Oak - Water Oak - Diamondleaf Oak
	91/Swamp Chestnut Oak - Cherrybark Oak
	92/Sweetgum - Willow Oak
FLCFC	615/Stream and Lake Swamps (Bottomland)
	617/Mixed Wetland Hardwoods
	630/Wetland Forested Mixed

other synonyms - bottomland hardwoods, seasonally flooded basins or flats, oak-gum-cypress, elm-ash-cottonwoods, NWTC Zones III - V, second bottom, levees, point bars, terraces

Swale - broad, shallow channel with sand/peat substrate; seasonally inundated; flowing water; subtropical or temperate; frequent or occasional fire; sawgrass, maidencane, pickerelweed, and/or mixed emergents.

Kuchler	92/Everglades
Davis	16a/Everglades Saw Grass Marshes
	16b/Everglades Region Marshes, Sloughs, Wet Prairies, and Tree Islands
SCS	24/Sawgrass Marsh
Myers	Freshwater Marshes - swale
SAF	N/A
FLCFC	641/Freshwater Marshes
	643/Wet Prairies?

other synonyms - sloughs, river of grass, glades

BASIN WETLANDS - shallow, closed basin with outlet usually only in time of high water; peat or sand substrate, usually inundated; wetland woody and/or herbaceous vegetation.

Basin Marsh - large basin with peat substrate; seasonally inundated; temperate or subtropical; frequent fire; sawgrass and/or cattail and/or buttonbush and/or mixed emergents.

Kuchler	80/Marl Everglades

	112/Southern Mixed Forest
Davis	13/Grasslands of Prairie Type
	16/Fresh Water Marshes
SCS	25/Freshwater Marshes and Ponds
Myers	Freshwater Marshes - basin or depression marshes
SAF	N/A
FLCFC	641/Freshwater Marshes
	643/Wet Prairies
	644/Emergent Aquatic Vegetation

other synonyms - prairie

Depression Marsh - small rounded depression in sand substrate with peat accumulating toward center; seasonally inundated; still water; subtropical or temperate; frequent or occasional fire; maidencane, fire flag, pickerelweed, and mixed emergents, may be in concentric bands.

Kuchler	112/Southern Mixed Forest
Davis	13/Grasslands of Prairie Type
SCS	25/Freshwater Marsh and Ponds
Myers	Freshwater Marshes - basin or depression marshes
SAF	N/A
FLCFC	641/Freshwater Marshes
	644/Emergent Aquatic Vegetation

other synonyms - flatwoods pond, St. John's wort pond, pineland depression, ephemeral pond or marsh, flag pond, gator hole

The following natural wetland communities are not listed in the "Guides" cross reference appendix. However, common synonyms for each of the remaining three wetland types are presented below:

LACUSTRINE - Lake environments in which water inundates the area continuously except for periods of extreme drought.

Flatwoods/Prairie/Marsh Lakes - Synonyms: Flatwoods pond, ephemeral pond, grass pond, St. John's wort pond, freshwater lake, pineland depression, swale and prairie pond.

RIVERINE - Characterized as perennial or intermittent seasonal water courses.

Blackwater Stream - Synonyms: Black water river and black water creek.

Seepage Stream - Synonyms: Steephead stream, clear brook, swift brook and hammock stream.

SECTION 3 - SOILS

By
D.A. Graetz, Principal Investigator, and K.R. Reddy, Co-principal Investigator

With
V.D. Nair and O.G. Olila

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 3 - SOILS

EXECUTIVE SUMMARY

Soils of constructed wetlands provide the substrate for aquatic flora and fauna to establish themselves and to flourish in a manner similar to natural wetlands. The objectives of this study were to: review and analyze existing information on soils of phosphate-reclaimed wetlands; conduct a synoptic soil sampling of phosphate-reclaimed wetlands and determine physical and chemical characteristics; and identify soil-related criteria to evaluate successful progression of constructed wetlands.

Characteristics of reclaimed uplands, overburden material, and phosphatic clays from waste clay impoundments have been extensively evaluated in existing reports. Physiographic characteristics, avifuanal population, landscape organization, vegetation, and hydrology were the most common types of available information. However, we found only limited information on soil/sediment characteristics and physico-chemical properties in existing reports on evaluation of phosphate-mined reclaimed wetlands. The common soil parameter determined in earlier studies was the organic matter content which is often regarded as an important milestone parameter. Nutrient content, compaction, and bulk density were seldom addressed.

A wide variety of reconstructed wetlands in phosphate-mined areas were visited to evaluate the overall progression of these wetlands to wetlands similar to native wetlands in the area. Soil profile development of the reconstructed wetlands was visually evaluated at each site. Soil samples (184 total) were taken at selected sites to determine criteria which may be used to determine soil development in constructed wetland. Several sites were revisited for more-detailed soil sampling.

Criteria selected for evaluation included soil compaction, bulk density, organic matter (carbon) and nitrogen content, C:N ratio, available and total nutrient content, and cation-exchange capacity. Organic matter accumulation, one of the indicators of a productive wetland, increased across transects going from uplands toward the center of the wetlands and with wetland age. Native wetlands generally had significantly greater organic matter accumulation both in the litter and mineral soil surface. This is to be expected since native wetlands were in existence for a very long time. More importantly to the evaluation of constructed wetlands, nearly all showed evidence of organic matter accumulation, albeit, at varying rates. The C:N ratio of the soil organic matter decreased with wetland age and approached values commonly found in wetland soils (20-25). This indicates that not only is the amount of organic matter increasing in the created wetlands but the quality of the organic matter is similar to that of a native wetland. The improvement in quality of organic matter was also indicated by its increased cation exchange capacity with age.

Bulk densities of the initial substrate material after placement in the constructed wetlands was often quite high due to the lack of organic matter and the compaction of heavy machinery. Incorporation of “muck” within the surface soil and/or deep tillage of the surface soil subsequent to land leveling activities could ameliorate this problem Bulk density decreased with increasing organic matter content in the created wetland soils. Areas that had lower bulk density and higher organic matter content also appeared to support better vegetative growth.

The pH of the recreated wetland soils was near neutral (pH 6.0-7.4) to slightly alkaline (pH 7.5-8.0) reflecting the high pH of the initial substrate material. Many native wetlands have an acidic pH due to the input of rain-fed runoff and organic acid production during the decomposition of organic matter within the wetland. The reconstructed wetland soils showed evidence that high pH of the initial substrate materials was decreasing, particularly in the surface horizons and in the older wetlands.

Penetrometer measurements may be used as a in situ evaluation of overall soil compaction and an indication of compact layers within the soil horizon. The real value of the penetrometer may be to evaluate the degree of compaction during the wetland construction phase rather than changes in compaction with wetland progression. Preliminary soil penetrometer results suggest that penetrometer readings will be a useful parameter for relating compaction to vegetative growth in existing created wetlands.

Overall, the recreated wetland soils are developing into "typical" wetland soils based on parameters such organic matter content and quality, bulk density, pH, and nutrient content. We believe the early rate of development could be increased by at least three practices at the time of wetland construction, ie., minimizing compaction, incorporation of organic matter and fertilization. Additions of controlled amounts of composted materials such as biosolids would provide the latter two requirements. Also, the rate of wetland development appears to be closely related to the hydrology of the created wetland. The design of created wetlands should be based on hydrologic conditions of the created landscape and not on parameters based on the previously existing wetland.

Soil sampling in this project was done on a synoptic basis at a variety of wetland sites. Definite conclusions regarding correlation of soil parameters with wetland progression should not been made due to the lack of systematic and detailed sampling. A systematic evaluation of wetland progression should be done by careful selection of sites and sampling locations within sites to correlate vegetative growth and stand establishment with soil parameters.

SECTION 3 - SOILS

INTRODUCTION

Soils of constructed wetlands provide the substrate for aquatic flora and fauna to establish themselves and to flourish in a manner similar to natural wetlands. Soils of wetlands constructed in previously-mined areas differ in several major ways from soils in natural wetlands. Information on several soil parameters was addressed in order to establish soils-related criteria needed to evaluate the successful progression of constructed wetlands. Differences in these soils-related criteria, such as compaction, nutrient status in soil and vegetation, and soil organic matter accumulation were used as criteria for evaluating the potential success of constructed wetlands.

Constructed wetlands require a period of time, depending on their basic design and purpose, to become functional. For example, it may take several years before established vegetation, a developed soil, and an optimum wildlife enhancement can be attained. Given the proper hydrology and appropriate hydroperiod, a wetland can establish a good vegetative stand during the first season of growth but the soils may not exhibit the same degree of stabilization until after two seasons (Mitsch and Gosselink, 1993). In some cases, start-up periods for the establishment of plants may take two or three years whereas an adequate litter-soil compartment may take another two or three years thereafter (Kadlec, 1989). Soil development is a long, slow process and is a function of climate, topography and relief parent material, biotic factors (production rate, root binding, herbivory, peat accretion), and time.

To support rooted vegetation, substrates of constructed wetlands must possess the following characteristics: (i) adequate depth of permeable, light-textured surface, (ii) presence of organic matter (optimum of about 4-5% OM for wetland rice, depending on the rate of N fertilization (Neue, 1985)), (iii) presence of an impermeable subsurface to prevent downward percolation, and (iv) sufficient nutrient holding capacity. Clay material may be a favorable substrate for surface flow wetlands since it prevents percolation of water to the groundwater; however, clays limit root and rhizome penetration and introduce limited permeability to water for plant roots. Sandy soils, on the other hand, could serve as a good anchor for plants and allow water to reach the plant roots readily but they are generally poor in nutrients and have low nutrient retention capacities (Allen et al., 1989). Hence, a good mixture close to a loamy soil with considerable amounts of organic matter should be preferable.

Development of a wetland soil is closely associated with the changes brought about by the plant community. The soils begin to accumulate organic matter from dying flora or plants. Changes in organic matter content could be slow at first due to the initially limited source of organic C, most likely single-celled planktons. The rate of organic matter deposition increases as the soils start to support rooted aquatic plants. By this time the soils exhibit some distinct biogeochemical properties i.e., presence of aerobic microzone, a reduced layer, mottle formation in Fe-rich mineral soils, presence of oxidized rhizosphere, narrow C:N ratio, and fauna1 perturbations. A developed wetland soil may be characterized by, among other factors, the following morphometric and biogeochemical characteristics: (i) presence of oxidized and reduced regions and gleying (Stoops and Eswaran, 1985), (ii) net productivity and organic matter accumulation, and (iii) presence of oxidized rhizosphere that results from the capacity of many hydrophytes to transport oxygen through the above-ground stems and leaves to below ground roots (Armstrong, 1964; Mendelssohn et al., 1981; Raskin and Kende, 1985; Reddy and Moorehead, 1988). The soils continue to accumulate organic matter and eventually, develop a peat mat especially if the hydroperiod favors emergent vegetation. The rates of biogeochemical processes in a wetland is determined by soil characteristics, vegetation, and its diverse hydrologic conditions. These processes influence the chemical forms and availability of nutrients, spatial movement of materials within wetlands and the surrounding ecosystems.

The objectives of this study were as follows:

1. to review and analyze the existing information on soils of phosphate-reclaimed wetlands,
2. to collect, synthesize, and evaluate information on soils of phosphate-reclaimed wetlands based on synoptic sampling, and
3. to identify soil-related parameters needed to evaluate successful progression of phosphate-reclaimed wetlands.

OVERVIEW OF WETLAND SOILS

PROCESSES IN WETLAND SOILS

A constructed wetland is defined as a designed and man-made complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for human use (e.g., sports, recreation, water quality improvement, etc.). Wetlands act as storage for storm- and floodwater, serve important biological functions, and support vegetative structure and diversity. Some of the substrates used in creating a wetland in phosphate-mined areas include overburden, sand tailings and/or clay that provide both mechanical support and growth media for plants. Since creation of a wetland involves inundation of substrate or soil, it is important to understand the physicochemical and electrochemical changes in the substrate as it undergoes flooding or submergence.

When the soil is submerged, the gas exchange between soil and air is drastically decreased. Oxygen and other atmospheric gases enter the submerged soil by molecular diffusion which is 10,000 times slower in water- than in gas-filled pores (Kristensen, 1960; Greenwood, 1961). Within a few hours of soil submergence, microorganisms use up the molecular oxygen present in water or in soil pores. A series of redox reactions, almost entirely mediated by facultative and obligate anaerobes, then occurs. These reactions require the presence of facultative or anaerobic bacteria, a carbon or energy source (simple sugars and other soluble organic substrates), and electron acceptors (O_2, NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}) (Fig. 1). The kinetics and intensity of reduction and the accumulation of reduced products in wetland soils are determined by the nature and composition of the soil substrate. Soils rich in Fe, for example, are more redox-sensitive than the soil systems dominated by $CaCO_3$.

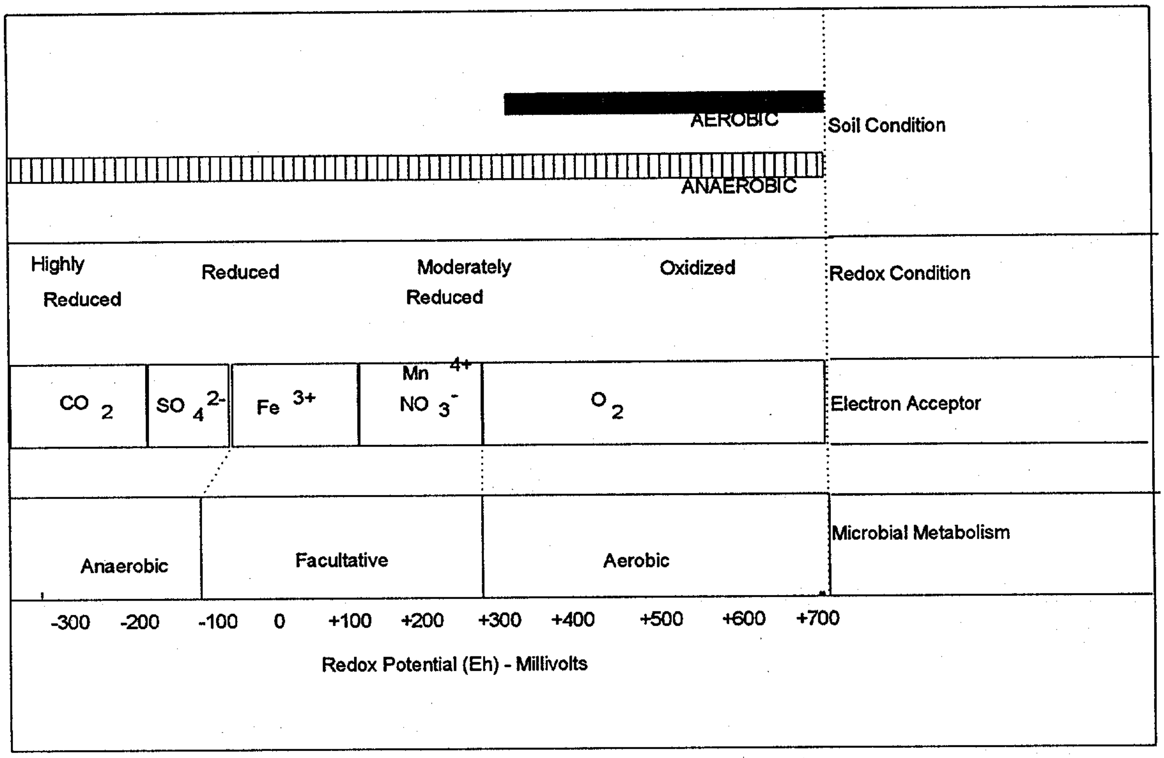


Figure 1. Electrochemical and microbial changes in submerged and flooded wetland soils (Ivanoff, 1993).

Plants growing in wetland soils have unique features in adapting to the anaerobic environment: (i) transport of molecular oxygen from the aerial parts through the stem and to the roots (Armstrong, 1964), and (ii) anaerobic respiration. These mechanisms enable wetland plants to ward off toxic reduction products, accumulate nutrients, and survive in an oxygen-free medium (Armstrong, 1964; 1967). Oxidation of the rhizosphere serves as a protective mechanism in preventing high concentrations of reduced substances from coming in contact with the root surface. Oxygen diffusing from the root Surface to the adjacent soil layer also enhances the development of a predominantly aerobic microflora in the rhizosphere.

Accumulation and/or decomposition of organic matter in wetland soils is a function of pH, C:N ratio of plant residue, available nutrients in the soil, and other soil conditions such as particle size distribution and structure. Organic matter decomposition in an aerobic system is caused by general-purpose heterotrophic bacteria and fungi whereas that in an anaerobic system is mediated by a less efficient and more restricted microflora which may not require molecular oxygen for respiration. Some of the characteristic features of anaerobic decomposition of organic matter by bacteria are: (i) incomplete decomposition of carbohydrates into methane, organic acids, hydrogen, and carbon dioxide, (ii) low-energy fermentation, resulting in the synthesis of fewer microbial cells per unit of organic carbon decomposed, and (iii) low N requirement for anaerobic metabolism Since anaerobic bacteria function at a much lower energy level than aerobic organisms, both decomposition and assimilation are much slower in submerged soils than in aerobic soils. Hence, accumulation of plant residues is expected in marshes and underwater sediments.

Flooding increases solubility, and therefore plant availability, of phosphorus (P), iron (Fe), and manganese (Mn). Among the plant macronutrients, however, nitrogen (N) is most markedly affected by submergence. The biological, chemical, and physical processes involved in N transformation and N loss from flooded soils and sediments include: (i) mineralization of organic N, (ii) nitrification of **NH_4-N,** (iii) **NH_3** volatilization, and (iv) denitrification. The ultimate **NH_4-N** formation is controlled by ammonification and immobilization balance in anaerobic systems, which can be interpreted using the C:N ratio of decomposable plant residue. Williams et al. (1968) found that the minimum N content required for the net release of **NH_4-N** from rice straw decomposition in flooded soils was about 0.5% N compared to about 1.7% N for aerobic systems. If the rice straw is assumed to have a total C content of 400 g kg^{-1}, the critical C:N ratio for the net release of **NH_4-N** into solution is about SO. Under aerobic systems, mineralization and immobilization processes are balanced at a C:N ratio of approximately 23 (Williams et al., 1968). Hence, **NH_4-N** release may be higher under anaerobic than aerobic conditions during decomposition of a plant material with a wide C:N ratio. The efficiency of nutrient utilization in wetlands, therefore, is a function of the biochemical as well as the physicochemical processes in wetland soil-plant system

EVALUATION OF EXISTING DATA

We conducted a comprehensive review of literature based on reports and other publications compiled by Kevin L. Erwin Consulting Ecologist, Inc., Fort Myers, Florida, and the Center for Wetlands, University of Florida. The common soil parameter found in many reports is organic matter content which is regarded as an important parameter in Milestone reports particularly in the Occidental Chemical Corporation (Environmental Services and Permitting, 1993). Milestone achievements for organic matter (OM) in these wetland areas were compared at 0.5% OM for milestones I and II and 1.0% OM for milestone III. Organic litter accumulation was used as a criterion in evaluating success, in addition to water quality, plant cover, and wildlife diversity.

More soil and sediment data exist for isolated wetland areas: IMC's Parcel B, Agrico's Morrow Swamp, CF Industries, and Mobil Pasture Pond (Center for Wetlands, University of Florida, 1991). Brown and Tighe (1991) found that organic matter and available nutrients (Ca, Mg, Zn, Cu, and Na) for IMC, Mobil, and Occidental Chemical wetland sites varied widely among plant communities and wetland areas. The authors reported that reclaimed wetlands have higher P, Ca, Fe, and Mn concentrations in soil than the native wetland communities.

Unreclaimed, mined areas were found to accumulate organic matter (Wallace and Best, 1983), with old sites (43 to 60 years) having higher organic matter content than young (0 to 17 years) sites. The authors noted the majority of organic matter in the intermediate particle size fractions, suggesting that organic matter storage occurred in relatively small refractory particulate fractions.

Nutrient availability and successional sequences for wetland restoration of clay settling ponds were evaluated by Rushton (1990). Among the nutrients analyzed (P, K, Ca, Mg), K was found to be the only macronutrient in short supply. The clay slimes, characterized as Ca-Mg-CO_3-SO_4 dominated systems, have high P content and buffering capacity (Bromwell Engineering, Inc., 1982). It was recommended that additional research about nutrients, nurse crops, soil amendments and time of planting be conducted at a larger scale (Rushton, 1990).

Some soils data were available for Hookers Prairie provided by the Cargill Fertilizers, Inc. (personal communication, 1994). The data showed a similarly low level of available K (1-27 mg L^{-1} using Mehlich III). These soils, which had high available P, Ca, and Mg, had organic matter contents ranging from 0.3 to 3.5%. Also included were available micronutrients (Zn, Cu, and Mn) but there was no information on bulk density, N, and CEC.

Existing reports also include selected chemical (organic matter content, pH, plant available nutrients) and physical (clay content, water holding capacity) properties of upland soils. Characteristics of reclaimed uplands, overburden material, and natural soils have been reported for agricultural uses (Environmental Services and Permitting, Inc., 1985) with limited information of created wetlands. It has been established , for example, that surface soils have greater organic content (OC) and extractable Mg and K than the subsurface soils (Gensheimer, 1985).

Based on our literature review, a number of project reports and communications are replete with information on physiographic characteristics (Environmental Services and Permitting, 1985), avifaunal population (Kale, II, 1992), landscape organization (Brown and Tighe, 1991), and vegetation and hydrology (Best and Erwin, 1984). The physico-chemical properties of phosphatic clays from waste clay impoundments (“settling areas”) and fresh clay slurries from beneficiation plants were studied extensively by the Bromwell Engineering, Inc. (1982). Existing reports, however, showed limited information on soil/sediment characteristics of the native and created wetlands visited, their physico-chemical properties such as bulk density and compaction, total or available nutrients, and cation exchange capacity (CEC).

SOILS OF CREATED WETLANDS IN THE FLORIDA PHOSPHATE DISTRICT

METHODS

FIELD SAMPLING

Soils were visually evaluated by taking 30-cm cores of soil during all site visits and observing pertinent soil characteristics such as compaction, organic matter accumulation and texture. Field notes were taken for later selection of sampling sites for more intensive sampling. Subsequently, intensive field sampling was conducted at several Agrico sites and synoptic sampling was conducted in February 1994 on many of the IMC central Florida sites (Appendix 3-I). Soil samples were also collected from the Occidental Chemical Sites (north Florida) in June 1994. A description of soil profiles collected from central and north Florida sites is given in Appendix Tables A3-1.1 and A3-1.2, respectively.

Intact soil cores (ranging from 20 to 30 cm depth) were taken from selected wetlands in south Florida. Each core was sectioned into: (i) Ao ($\leq$ 10 cm depth) = organic/mineral layer with significant root mass, (ii) A1 = an intermediate 5-cm organic/mineral layer with "humus-type" material below Ao, (iii) B = an illuvial layer (when present), and (iv) C = the remaining subsoil. Organic litter accumulation was designated as "O". Layer designations for the soil profiles are shown in Fig. 2. The depth of the topsoil was visually determined based on organic matter accumulation and soil profile development. For north Florida sites, samples were collected from only two layers: (i) Surface organic and (ii) subsurface layers. Since the organic layer was often small, composite samples were collected to ensure sufficient amounts of soil for laboratory analyses. Separate samples of organic litter were taken in wetland areas where substantial accumulation of partially-decomposed plant materials was observed. The samples were placed in plastic bags, placed in a cooler, and taken to the Wetland Soils Laboratory, Soil and Water Science Department, University of Florida in Gainesville.

SOIL ANALYSES

The total weight and volume of each soil sample was recorded. The samples were then dried at 50°C to a constant weight, pulverized, and passed through a 2-mm sieve, and analyzed for the following parameters:

Moisture Content -- A subsample from each of the soil samples was oven dried at 105° C for a minimum of 24 hours. Moisture contents of both the original and partially-dried (50°C) soil samples were obtained to enable calculation of bulk density of the samples.

Bulk Density -- The wet weight and volume of the soil samples were recorded as soon as the samples were brought to the laboratory. The dry weight of the soil samples were calculated from the moisture content. The bulk density for all the soil samples were then calculated based on the dry (oven-dried, 105° C) weight.

Soil pH -- Soil samples were equilibrated with deionized water (1:2 soil:water) for one week (to simulate conditions in the wetland) and pH of the samples were determined.

Total C and N --Total C and N was measured using a Carlo Erba CNS Analyzer. The C and N in the soil samples were combusted at elevated temperatures (1020°C) and the percentage of the elements calculated.

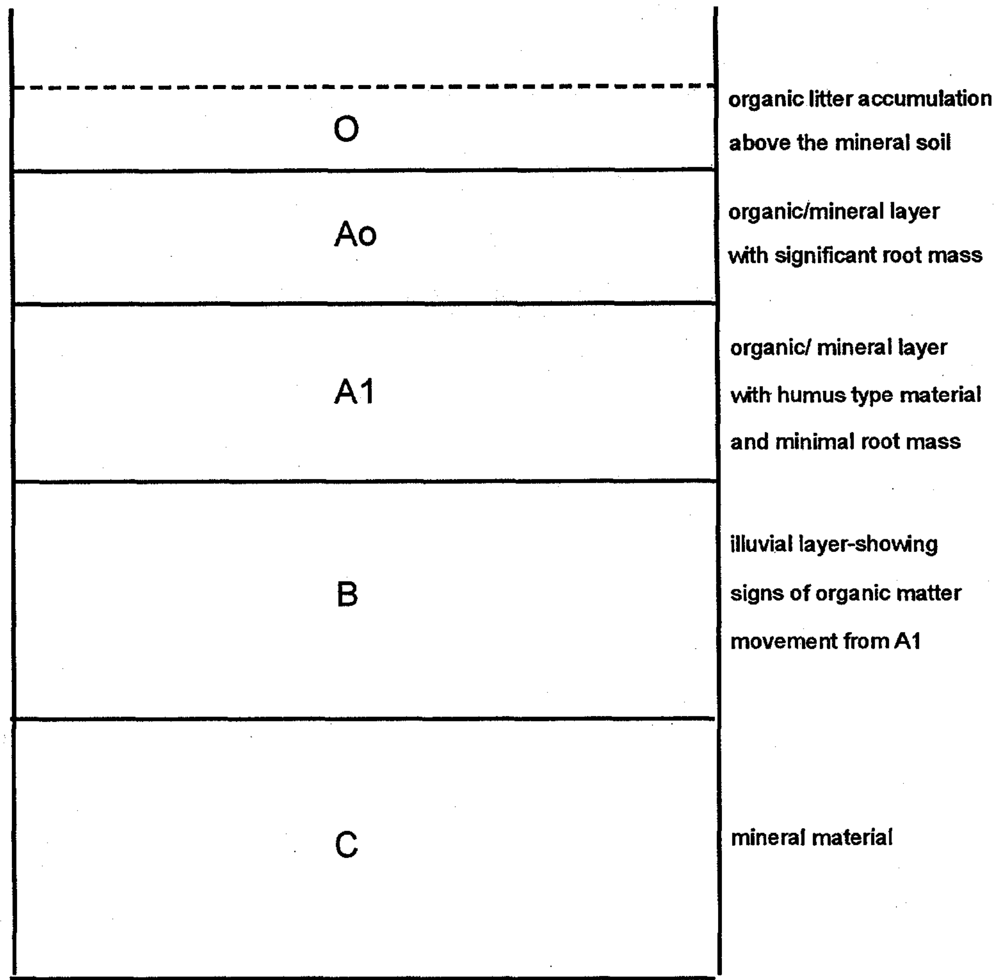


Figure 2. Layer designation for a soil profile. "A" designation indicates combined Ao and A1 where it was not possible to clearly separate the layers. (Note: All layers may not be present for some soils).

Available Nutrients -- Available P, K, Ca, Mg, Zn, Mn, Cu, and Fe were extracted using the Mehlich III procedure (Mehlich, 1984). The extracting solution was ammonium nitrate in an ammonium fluoride/EDTA mixture and the resulting mixture acidified with an acetic acid/nitric acid solution to maintain a pH of 2.5. The extracts were sent to the University of Florida Analytical Research Laboratory for analyses of the said elements using an inductively coupled argon plasma (ICAP) emission spectrometer.

Total Nutrients - One gram soil sample was ashed in a muffle furnace at 550° C (Anderson, 1974), dissolved in 20 mL of 6 M HCl, and made up to 50-mL volume with deionized water. The solution was analyzed for P, K, Ca, Mg, Zn, Mn, Cu, and Fe using an inductively coupled Agon plasma emission spectrometer.

Cation Exchange Capacity -- Cation exchange capacity was determined on surface soils only. The cation exchange sites of the soil were saturated with Na by equilibrating a subsample with 0.4 M NaOAc-0.1 M NaCl solution (pH 8.2) in 60% ethanol. The Na-saturated soil was then extracted with 0.5 M **$MgNO_3$** solution (Rhoades, 1982) to determine total exchangeable Na. Total Na in the extract, which represents cation exchange capacity of the soil, was analyzed using an atomic absorption spectrophotometer. Chloride in the extract was also determined using a chloridometer for correction (Rhoads, 1982).

Penetrometer Measurements -- Soil compaction was assessed for all north Florida sites using a recording penetrometer (DELMI Machine and Instrument Co., 123 Shafter Ave., Schafter, CA 93263) with a penetrating point consisting of a 30-degree circular cone and a base area of 1.29 cm^2 (Vazquez, et al., 1989).

RESULTS AND DISCUSSION

Selected physico-chemical properties of the soils are given in Appendix Tables A3-2.1 (central Florida) and A3-2.2 (north Florida). A visual description of the surface 30 cm of soil from each sampling site was noted to provide an indication of the extent of organic matter accumulation since the inception of the wetland. Two types of organic matter accumulation were observed. In some cases, an actual litter layer above the soil surface was observed. In other cases, no litter layer was observed, but a definite increase of organic matter content in the soil surface had occurred. The litter layer occurred primarily where herbaceous-type vegetation was present, particularly cattails. Accumulation of organic matter in the mineral soil is due to the presence of fine roots and also to some microfaunal mixing between the litter layer and mineral soil. Wetlands which were at least 5 years old showed this definite increase in organic matter content in either the litter layer and/or the soil mineral layer. Extent of organic matter accumulation in the younger wetlands varied considerably, but nearly all showed some evidence of organic matter accumulation.

Native wetlands generally had significantly deeper organic matter accumulation both in the litter and mineral soil surface. This should not be unexpected due to the very long time the native wetlands were in existence. More importantly to the evaluation of constructed wetlands, nearly all showed evidence of organic matter accumulation, albeit, at varying rates.

Bulk densities of wetland soils varied widely, ranging from 0.2 to 2.7 g cm^{-3} (Appendix Tables A3-2.1&2.2). Bulk densities of the initial substrate material after placement in the constructed wetlands was often quite high due to the lack of organic matter and the compaction of heavy machinery. However, as illustrated later, bulk density of the soil tends to improve, i.e., decrease with increasing amount of organic matter.

The pH of many of the wetland soils was near neutral (pH 6.0-7.4) to slightly alkaline (pH 7.5-8.0) reflecting the high pH of the initial substrate material. In the southeast U.S., many wetlands have an acidic pH due to the input of rant-fed runoff and organic acid production during the decomposition of organic matter within the wetland. For example, acidic soils were observed in many of the native wetland soils such as McCallum Bay where pH values ranged from 3.79 to 4.49 (Appendix Table A3-2.2). Not all wetland soils have an acidic pH, however. The pH of many alluvial wetlands is near neutral due to the influence of river flooding and river water with high Ca contents. The native soils from Parcel B Peace River floodplain (pH 8.0-8.4) reflect this type of scenario. The reconstructed wetland soils showed evidence that high pH of the initial substrate materials was decreasing, particularly in the surface horizons and in the older wetlands. Wetland soils in Fort Lonesome, Haynsworth, K6, and in some sites of Four Corners and Noralyn/Phosphoria were moderately acidic pH 5.0-5.9). Soils in north Florida were generally more acid ($pH<7$) than those in central Florida due to the more acidic nature of the initial substrate material.

Many of the wetland soils had near neutral (pH 6.0-7.4) to slightly alkaline (pH 7.5-8.0) pH Wetland soils in Fort Lonesome, Haynsworth, K6, and in some sites of Four Corners and Noralyn/Phosphoria mines, however, were moderately acidic (pH 5.0-5.9). The pristine soils from Parcel B Peace River Floodplain had pH 8.0 to 8.37 (Appendix Table A3-2.1). Soils in north Florida were generally more acidic ($pH \leq 7.0$) than those in central Florida. Highly acidic soils were found in McCallum Bay area (native soils) where pH values ranged from 3.7.9 to 4.49 (Appendix Table A3-2.2).

To establish the soils-related criteria for successful progression of constructed wetlands, soil samples were taken along transects of selected sites. Soil samples were also taken from within a wetland site that showed substantial differences in plant growth and survival. Accumulation of organic matter is an indication of a productive wetland. An illustration of organic matter accumulation across a transect from an upland to a wetland area from Morrow Swamp West is given in Fig. 3. Assuming (likely) that no significant organic matter accumulation occurred in the upland area during the past thirteen years the wetland has been in existence, accumulation rate of organic C (Ao and A1 layers) was 320 g m^{-2} yr^{-1}. This rate is comparable to that of the marshes (200-300 g C m^{-2} yr^{-1}) in Louisiana (Hatton et al., 1982) and the Water Conservation Areas of the Everglades (86 to 387 g C m^{-2} yr^{-1}, Reddy et al, 1993).

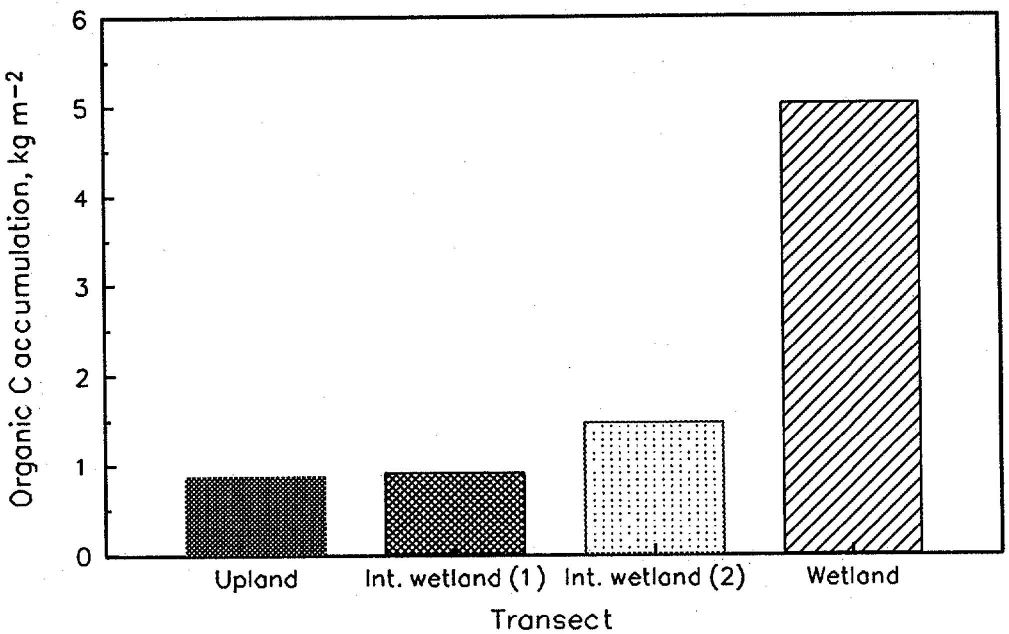


Figure 3. **Organic C accumulation across a transect (locations 127-193 to 127-199, Table A3-1.1) from Morrow Swamp West, Fort Green Mines.**

Organic matter is essential in improving structure and nutrient status of the soil. Based on the data obtained from all wetland sites visited, bulk density of the soils decreased logarithmically with increasing total C (Fig. 4). Total C reported in our current data had >95% organic C. Organic matter may be computed from organic C data using a multiplication factor of 1.724 (i.e., based on the assumption that organic C constitutes 58% of organic matter). Figure 4 shows that soils with **≤2.5%** total C were more compact (bulk densities >1.3 g cm^{-3}) than soils with **≥2.5%** total C.

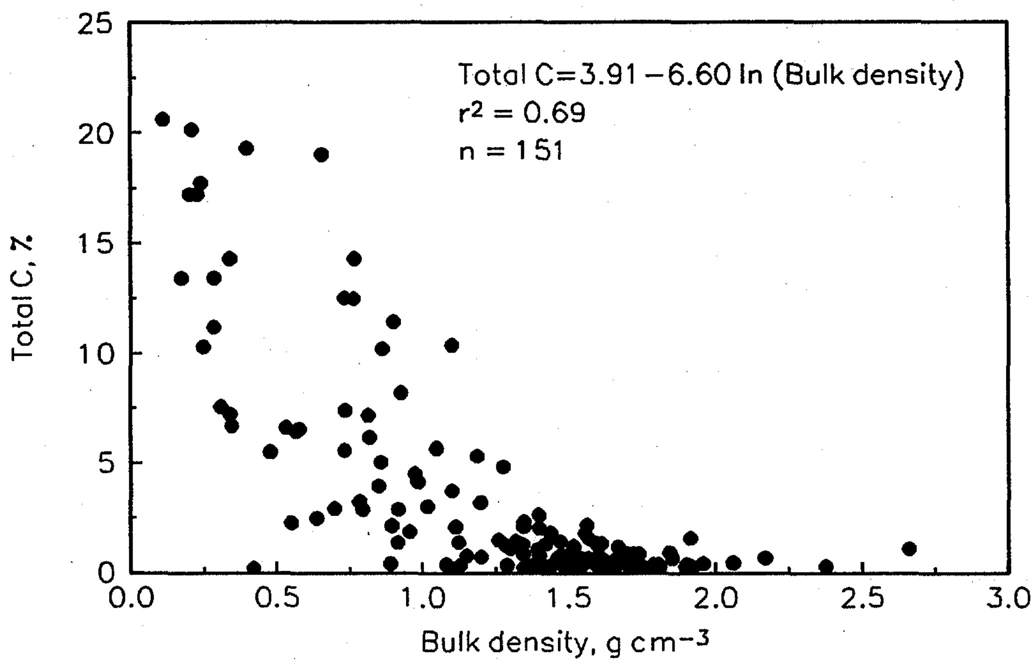


Figure 4. **Relationship between total C and bulk density for all central Florida sites sampled.**

The function of organic matter in improving soil nutrient status is evident in Fig.5 which shows a linear relationship between total C and total N. This observation is of particular importance in productive wetlands. Both C and N progressively increased from upland to wetland along an upland-wetland transect in the Morrow Swamp West (Fig. 6)

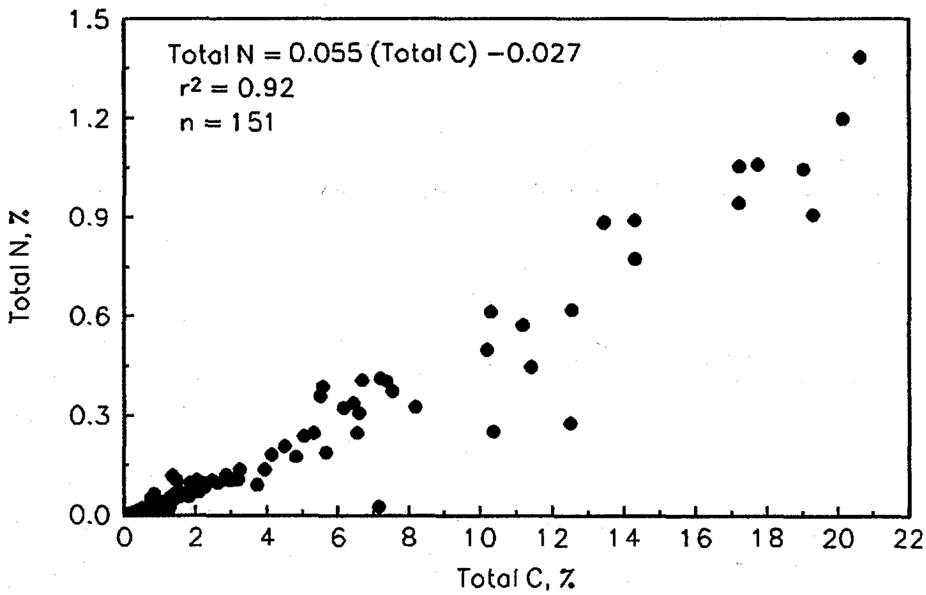
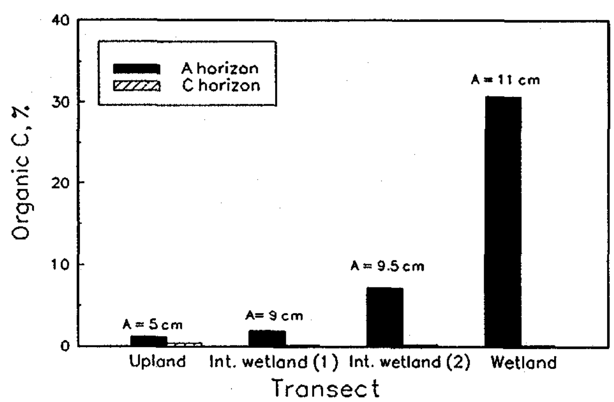


Figure 5. Relationship between total C and total N for all central Florida sites sampled.



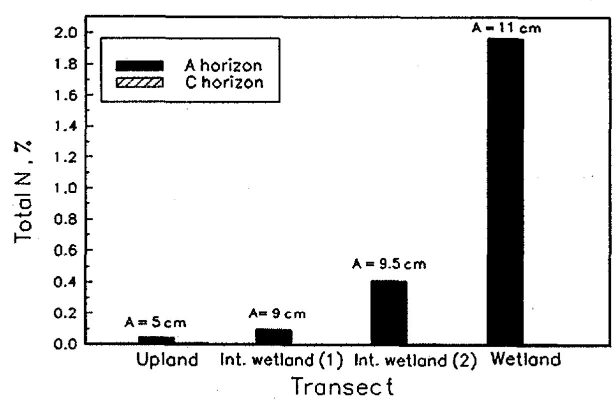


Figure 6. Total C and N contents in the surface (sum of concentrations of Ao, A1, etc.) and subsurface (C layer) across a transect of Morrow Swamp West.

Available nutrients such as Fe, Cu, and Zn (Fig. 7) and K, Ca, Mg (Fig. 8) in Surface soil (A horizons) also increased along the same transect. The concentration of available Mn did not show a similar trend but was highest in the intermediate wetland (Fig. 7). Available P in surface soils, which ranged from about 350 to 450 mg P kg^{-1}, showed considerable difference along the transect (Fig. 8). Accumulation of C and N in wetlands is well demonstrated in Transect T7 of Morrow Swamp East, Fort Green mines (Fig. 9). Total C content of surface soil in the upland area was about 3% whereas those of the moist (0 feet, reference point) and wet areas (100 and 200 feet distances) were between 14 to 20%. A similar trend was observed for total N contents. Due to high organic matter content, the Ao (surface) layer of the wetland had lower bulk density (Fig. 9) but had higher cation exchange capacities (CEC) than the upland.

During the field visits, it was observed that some areas in Agrico Swamp East (Transect T6) and South Pebbledale wetlands had uneven plant growth and survival rates. Soil cores taken from both and the good- and poor-growth areas of each site did not show considerable differences in bulk density and available Ca, Mg, K, P, Cu, Mn, and Zn (Appendix Table A3-3.1). Based on results of soil chemical analyses, the soil properties that separate the “good soil” from the “poor soil” in each wetland were: (i) total C and total N contents (Figs. 10 and 11) and (ii) degree of soil development (depth of Ao and A1 horizons). The south Pebbledale section which showed good plant growth (Fig. 10) appeared to have a developed soil profile (based on root development and organic matter content) within the 0-8 cm depth whereas the section with poor plant growth showed soil development to a depth of 4.5 cm (Appendix Table A3-2.1). In addition, the section with poor stand had no detectable total N below 1.5 cm (Ao) depth (Fig. 10).

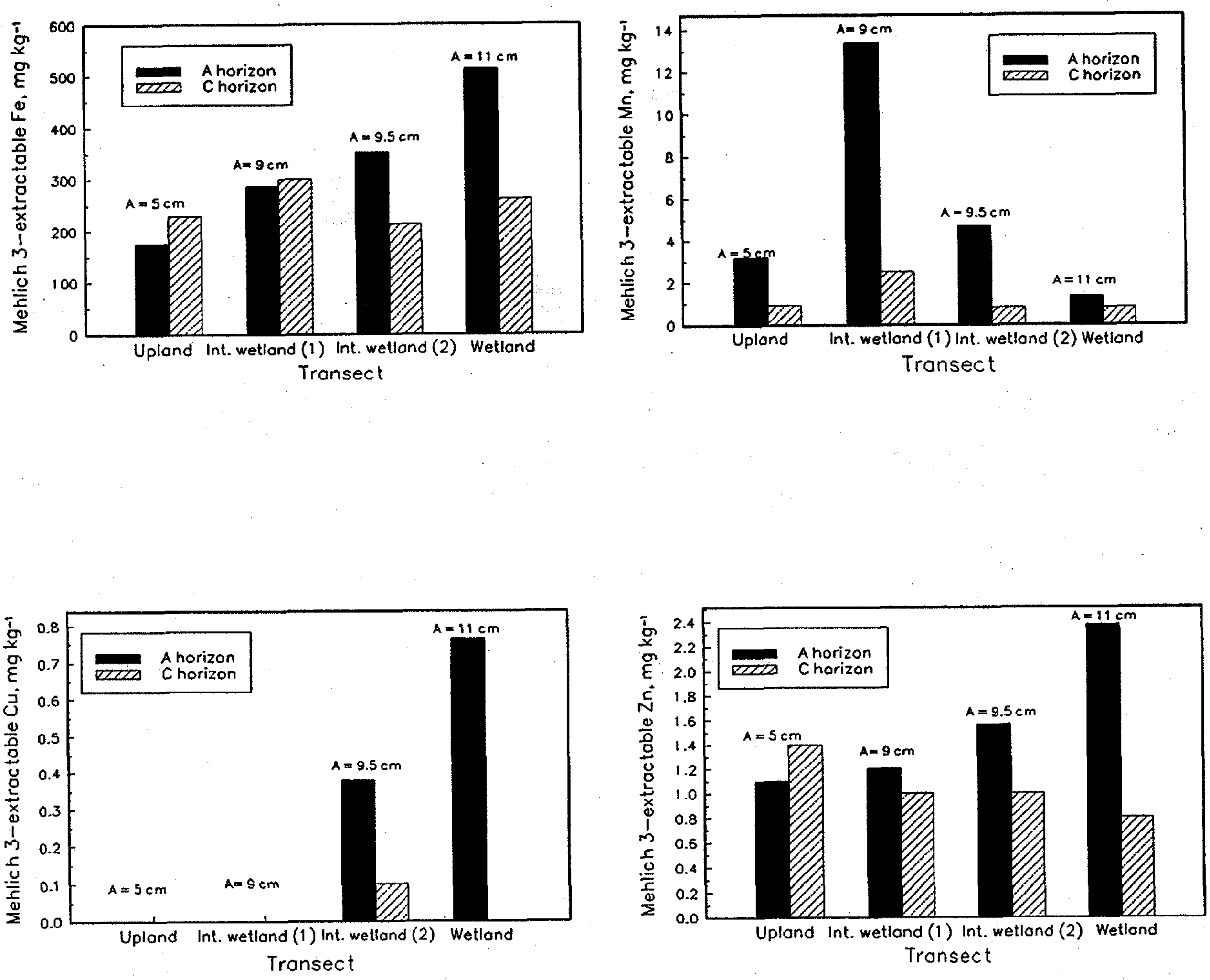


Figure 7. Concentrations of available Fe, Mn, Cu and Zn in the surface (sum of concentrations of Ao, A1, etc.) and subsurface (C layer) across a transect of Morrow Swamp West.

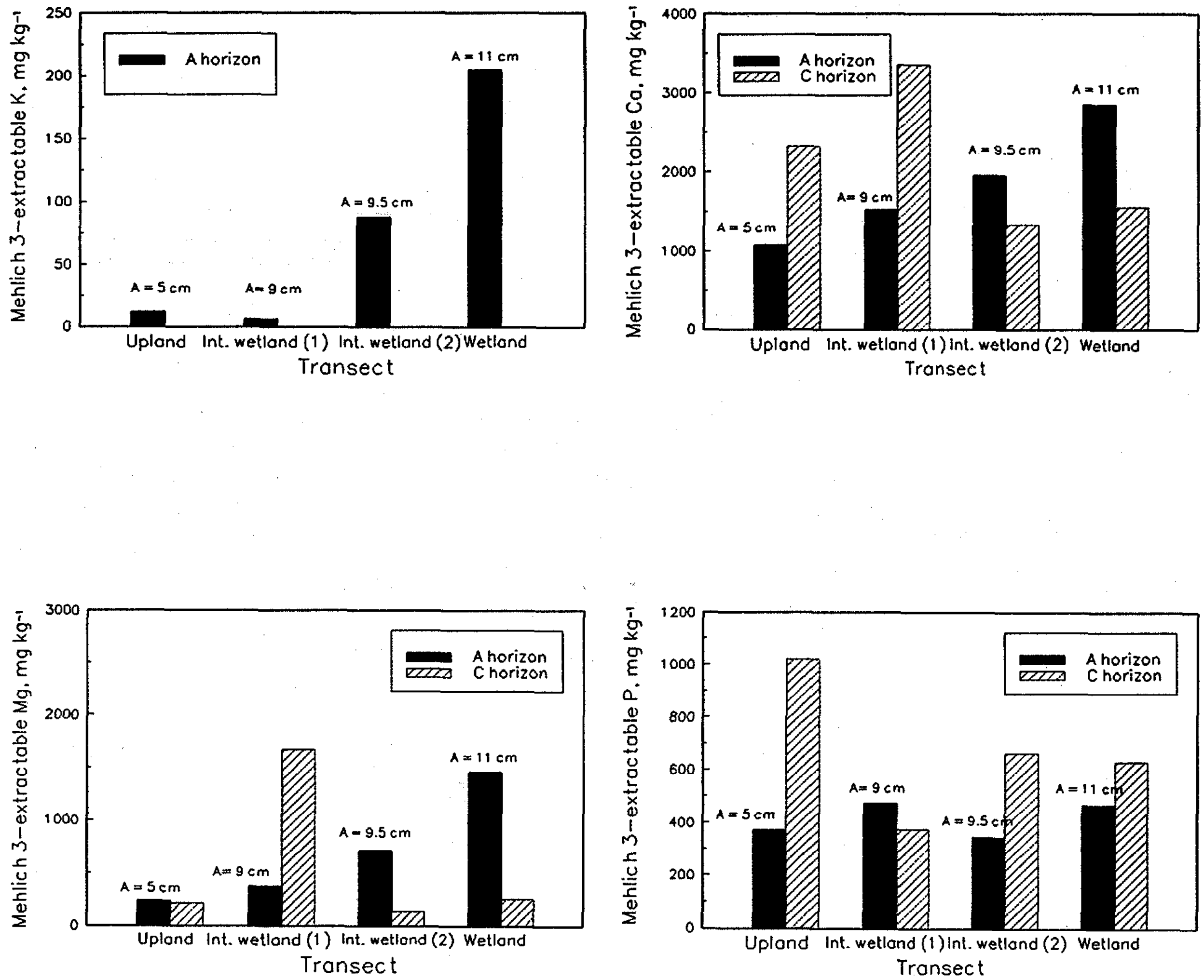


Figure 8. Concentrations of available K, Ca, Mg and P in the surface (sum of concentrations of Ao, A1, etc.) and subsurface (C layer) across a transect of Morrow Swamp West.

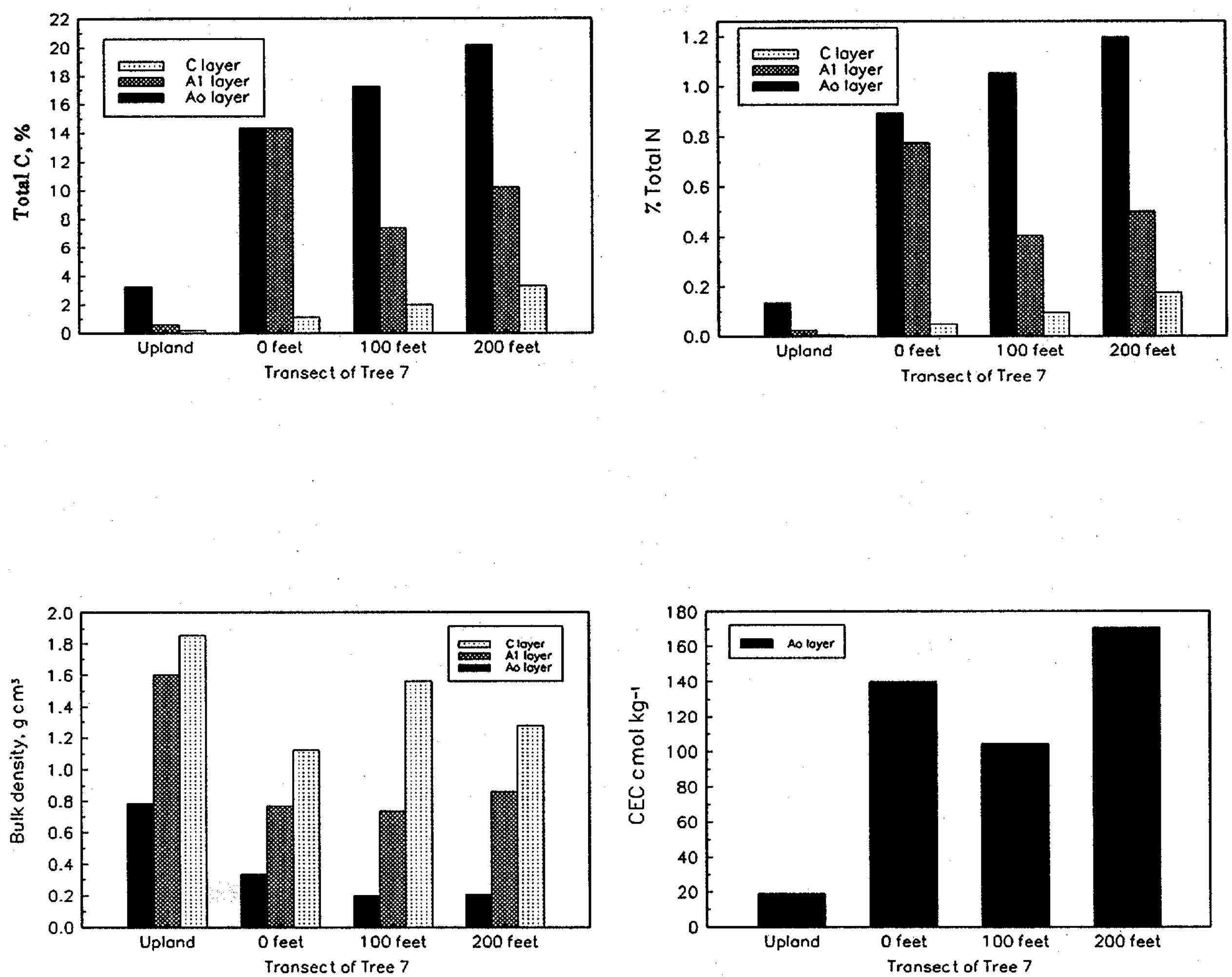
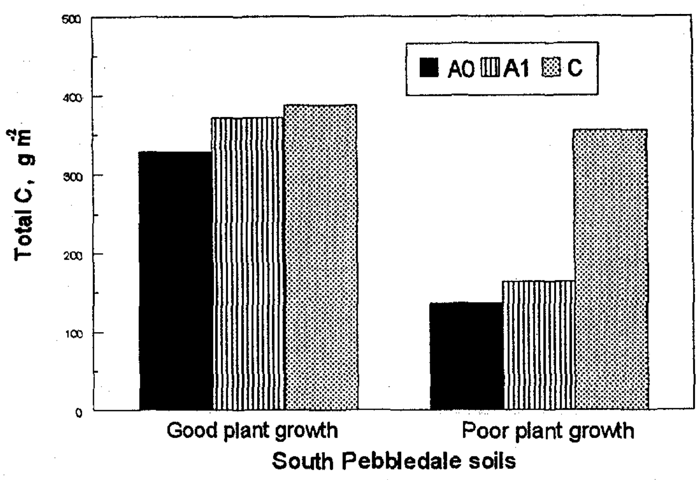


Figure 9. **Comparison of soil parameters (Total C and N contents, bulk density and CEC) across a transect of Tree 7.**



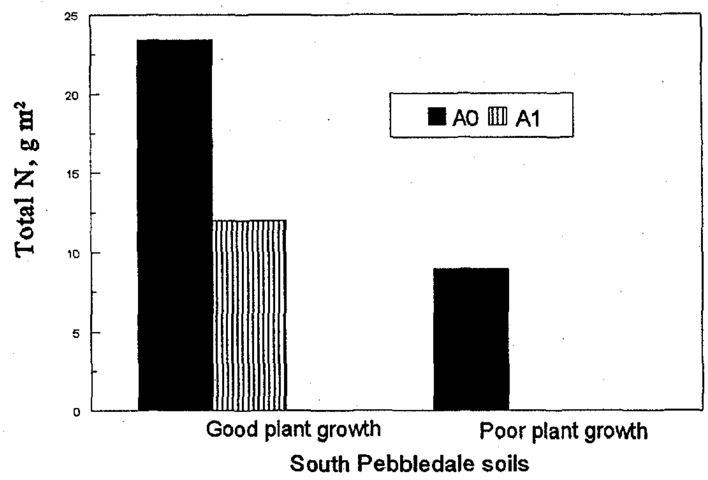


Figure 10. Comparison of C and N contents of South Pebbledale soils to explain poor and good plant growth.

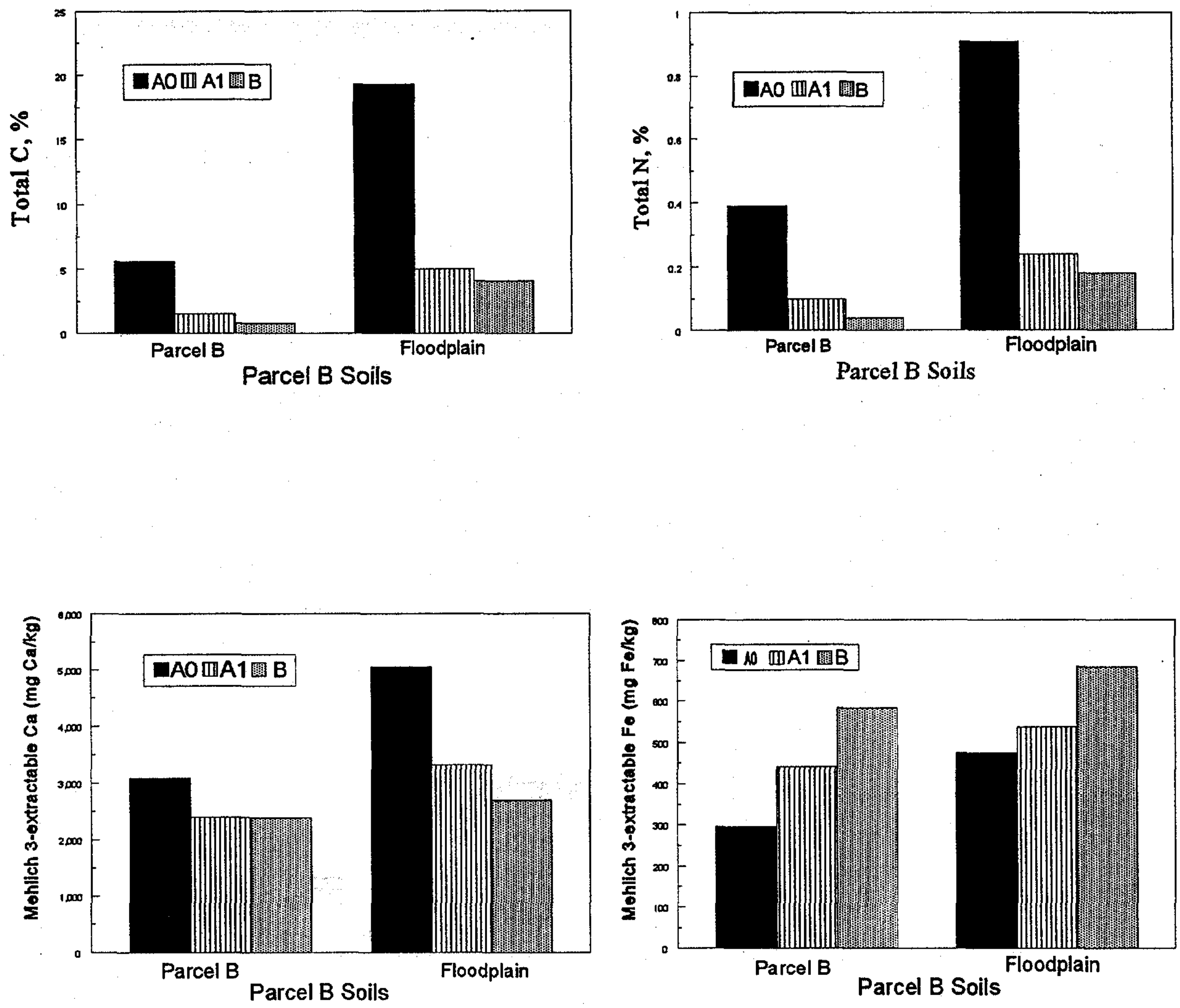


Figure 11.. Comparison of soil parameters (C and N contents, and Mehlich 3-extractable Ca and Fe for soils for Parcel B and its floodplain (native area)).

Soil cores from Parcel B site were studied to compare the chemical characteristics of soils in "constructed" versus "native" wetlands. Total C content for the pristine wetland of Peace River Floodplain was about four times higher than that of the Parcel B, a 15-year old reconstructed wetland (Fig. 11). The native wetland had two times more total N than the created wetland (Fig. 11). The two wetlands were found to have similar concentrations of available nutrients (P, K, Cu, Mn, Zn) except for Ca and Mg which were considerably higher in the floodplain (Fig. 11). Nutrient stability and equilibrium is apparent in the native wetland, based on C:N ratio. The floodplain maintains a C:N ratio between 20 to 23 (Fig. 12), indicating a well balanced system with respect to mineralization and immobilization processes (Williams et al., 1968). The B horizon of constructed wetland (Parcel B) had a C:N ratio of 23 (Fig. 12), suggesting a developed horizon approaching that of the native wetland condition. The surface soil (Ao and A1 horizons) of the reconstructed wetland had narrow C:N ratios (about 10 to 13) which may favor N mineralization, and hence nutrient availability. Some precaution, however, must be exercised in using C:N ratio as one of the characteristic equilibrium values for soils (Alexander, 1977). The C:N ratio, for example is meaningless in wetlands where substrates or soils have extremely low N (>0.01% total N) and total C. The use of C:N ratio in evaluating progression of constructed wetlands requires due consideration of other indicators and parameters such as organic matter content and accumulation, soil development, and established vegetation. The floodplain maintains a C:N ratio between 20 to 23 (Fig. 12), suggesting a well balanced system with respect to mineralization and immobilization processes (Williams et al., 1968). The created wetland (Parcel B, Fig. 12) had a C:N ratio of 23 in the B horizon, an indication of a developed horizon approaching that of the native wetland condition. The surface soil (Ao and A1 horizons) of the reconstructed wetland had narrow ratios (about 10 to 13) which may favor N mineralization, and hence nutrient availability.

EFFECT OF AGE ON WETLAND SOIL CHARACTERISTICS

Five wetlands of different ages (East Old Fort Green Road - 1 yr, Miles Grove - 2 yr, Section 12 - 4 yr, Tiger Bay - 10 yr and Parcel B - 16 yr) with the same general background, i.e., overburden matrix without mucking, were selected to evaluate changes in soil properties as a wetland becomes progressively more established. Bulk density of the surface layer decreased with age (Fig. 13). This trend was also observed in the subsurface layer but to a lesser extent. Bulk density values ranged from 1.5 g cm^{-3} in the early stages of development to 0.75 to 1.0 g cm^{-3} after about 4 years. This decreasing bulk density reflects the increasing amount of organic C accumulating in the soil (Fig. 13). Organic C, which is a measure of organic matter, increased from <0.5% in a new wetland to nearly 6% in a 16 yr old wetland. Nitrogen concentration also increased with time but at a faster rate than carbon concentration. This is reflected in the C:N ratio which is an indication of organic matter decomposition and stabilization. Wetland plants typically have a C:N ratio of >50. As the plant matter decays in the soil, CO_2 is evolved while N is retained. This results in a decreasing C:N ratio and suggests an increasing stabilization of the soil organic matter. Typical C:N ratios for stabilized soil organic matter are in the range of 15 to 25. We see a progressive decrease in C:N ratio of soil organic matter with increasing age. Thus, overall, we observed both an increase in the amount of organic matter accumulating and a decrease in the C:N ratio indicating that the wetlands are functioning as anticipated with regard to these parameters.

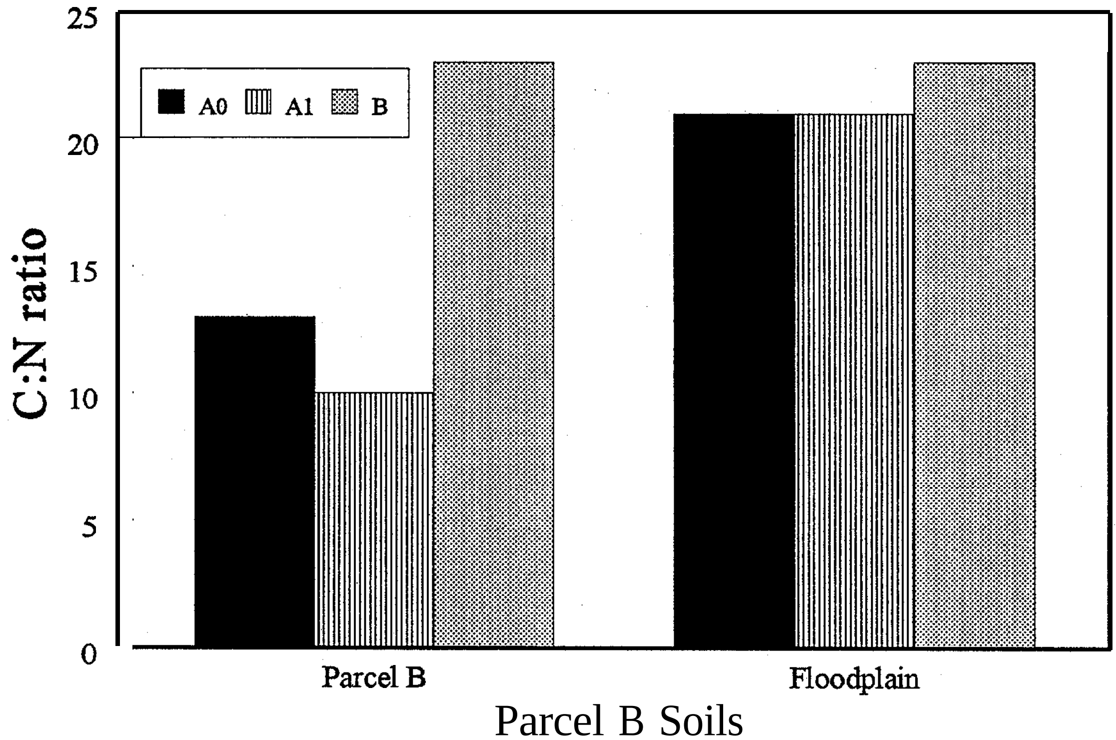


Figure 12. Comparison of C:N ratios of Parcel B and its floodplain (native area).

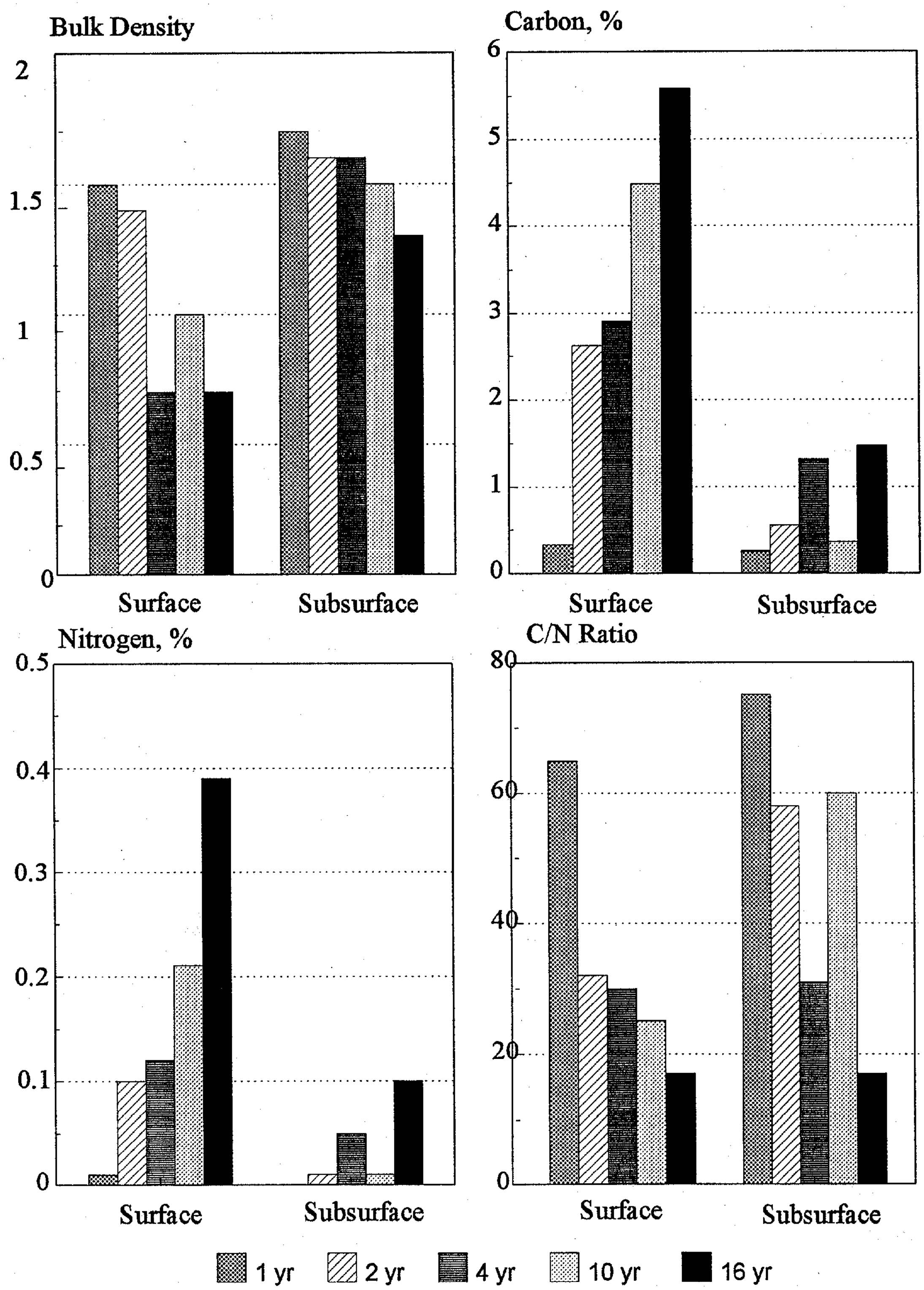


Figure 13. Trends in bulk density, carbon and nitrogen concentration, and C:N ratio of wetlands ranging from one year to 16 years of age.

A similar trend was observed in a transect going from an upland location toward the center of a wetland Such a transect for East Old Fort Green Road wetland at Haynsworth Mine (Fig. 14) was characterized to confirm this trend. This is a two-year old wetland on overburden without mucking. A definite increasing trend in organic matter accumulation was observed, particularly in the surface layer, going from the upland toward the center of the wetland. This trend was not as clearly reflected by the bulk density, but bulk density would not be expected to measurably decrease in such a short time. Nitrogen concentration changes were also too small to measure. An accumulation of nutrients other than N, toward the center of the wetland, was observed as illustrated by Ca and Fe concentrations. This accumulation likely reflects nutrient loading from the surrounding watershed.

EFFECT OF MUCKING ON WETLAND SOIL CHARACTERISTICS

In the re-establishment process, a muck base is sometimes added to the surface of the wetland. The purpose of this muck addition is to provide a seed bank to enhance establishment of wetland vegetation. Mucking may also enhance the early productivity of the wetland due to it's nutrient content and effect on water-holding capacity. Figure 15 shows bulk density, carbon and nitrogen concentration, and C:N ratio of three unmucked wetlands ranging from 5 to 16 years of age (Unit 4 - 5 yr, McMullen - 9 yr and Parcel B - 16 yr) and two mucked wetlands of two (Tadpole) and four (Section 12) years of age. As shown previously (Fig. 13), C and N concentrations generally increase with age, and C:N ratio decreases. Although it is difficult to make a rigorous comparison of mucking effects with these small sample numbers, it appears that mucking increases the rate of wetland establishment as measured by soil properties. However, it is difficult to separate the effects of simply added muck from the potential enhanced productivity caused by mucking.

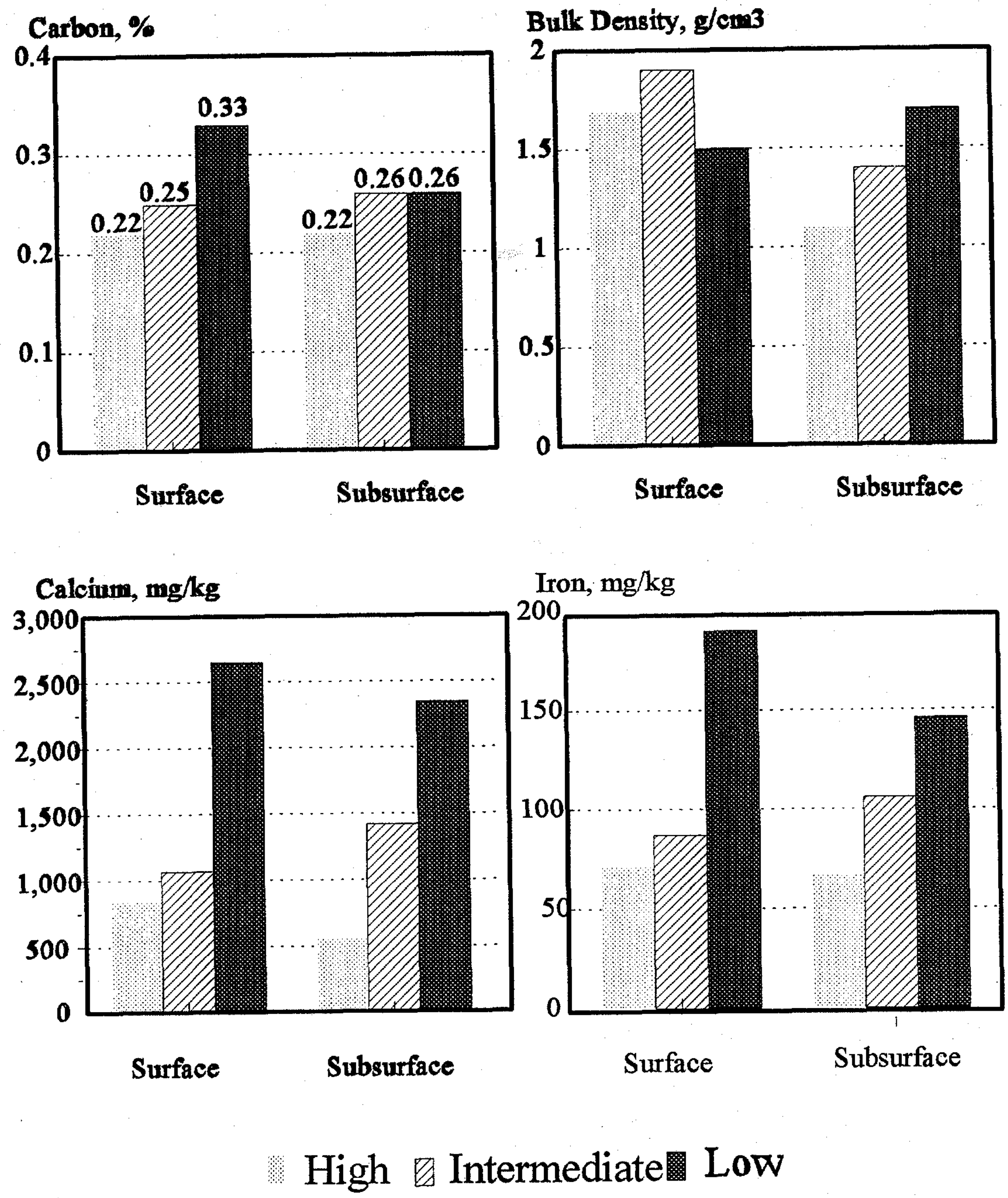


Figure 14. Trends in bulk density and C, Ca, and Fe concentrations in a transect at East Old Fort Green Road wetland. High, intermediate and low represent upland, wetland edge, and within the wetland, respectively.

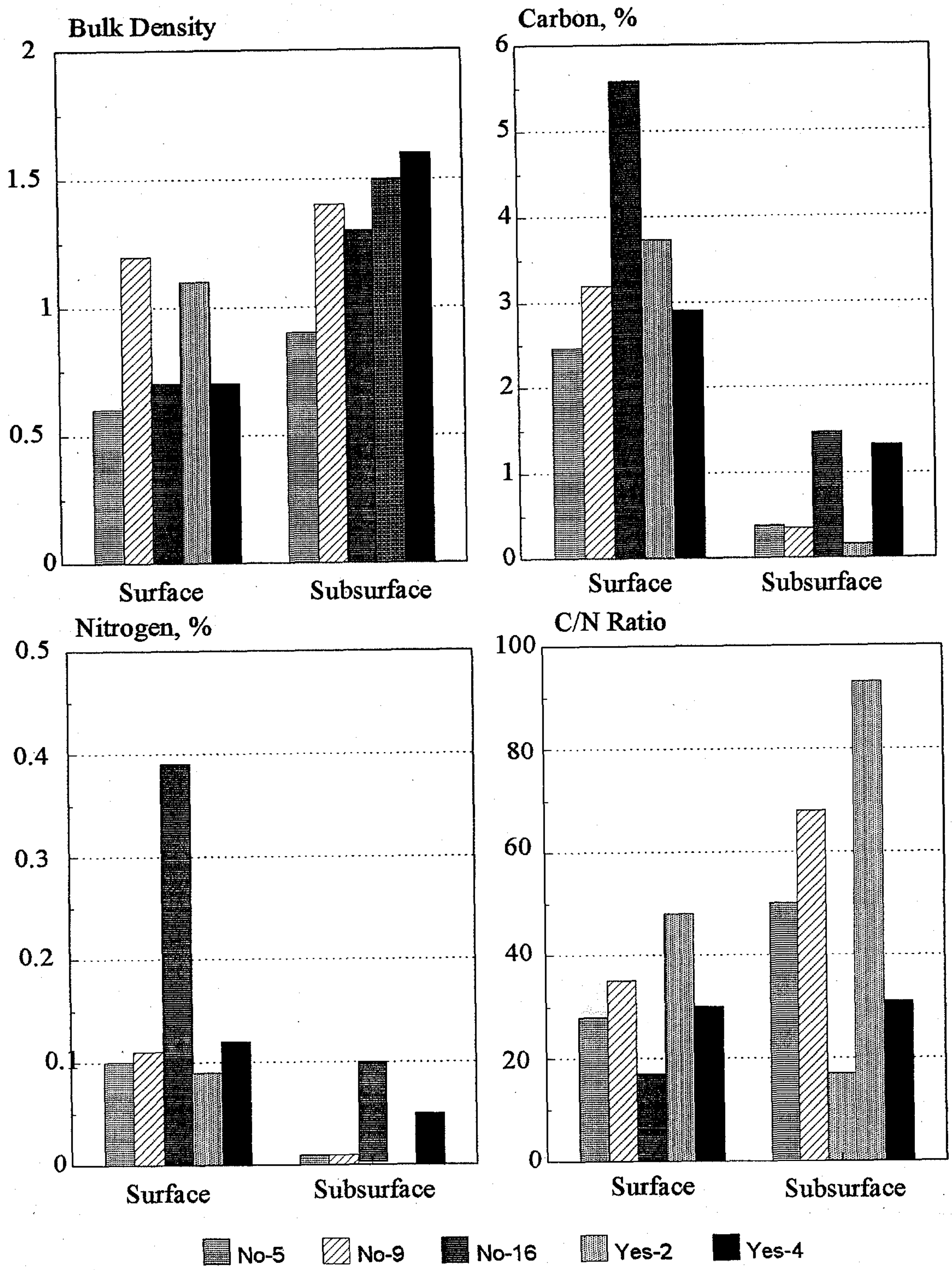


Figure 15. Effect of mucking on selected soil parameters. "No" and "yes" indicate no mucking and mucking, respectively. Numbers represent wetland age.

CONSTRUCTED AND NATURAL WETLANDS IN NORTH FLORIDA

Comparison of surface soils of constructed and natural wetlands in the north Florida region indicates that the total C, total N, and CEC of constructed wetlands were significantly lower than those in an adjacent natural wetland (Table 3-1). Mean values of total C for the natural wetland are approximately 30 times the mean value of total C for constructed wetlands while mean CEC values for the natural wetlands are about 14 times that for the constructed wetlands. Since elevated values in these parameters are indicators of wetland progression, it appears that these one- and three- year old constructed wetlands have not as yet made significant progression toward becoming a productive wetland. Disturbances to the native soil have resulted in higher pH (>5.50) in the soils of constructed wetlands compared to that of the natural wetlands (pH <4.50). Increases in pH of constructed wetlands may be attributed to increases in available Ca (Table 3-2) and total Ca (Appendix A3 - 4.2). Some increases in available P and Fe are also noted in the constructed wetlands.

Table 3-1. Comparison of pH, % total C and N, and CEC in surface soils of two constructed wetlands with a natural wetland soil in north Florida. There were two locations within each constructed wetland and three locations within the natural wetland.

Depth (cm)	pH	% Total C	% Total N	C:N ratio	CEC,cmol kg^{-1}
Natural wetland - McCallum Bay					
0-15	4.24	19.9	1.0	20	107
0-8	4.49	35.1	1.6	23	167
0-8	3.79	38.1	1.2	33	161
Constructed wetland - McCallum Bay (3 years)					
0-3	5.67	2.2	0.1	29	10
0-3	6.00	0.7	<0.03	28	0
Constructed wetland - Little O (1 year)					
0-9	5.50	0.5	<0.02	31	2
0-3	6.30	0.9	0.05	18	12
0-4	5.80	0.5	<0.02	24	28

Table 3-2. **Comparison of available nutrients in surface soils of constructed wetlands with a natural wetland soil in north Florida.**

Depth (cm)	P	Ca	Mg	K	Zn	Cu	Mn	Fe
				mg kg^{-1}				
Natural wetland - McCallum Bay								
0-15	56	57	33	41	1.1	0.0	0.6	17
0-8	39	208	77	66	1.3	0.0	1.8	27
0-8	41	193	136	93	6.3	0.0	2.4	77
Constructed wetland - McCallum Bay (3 years)								
0-3	148	596	115	31	0.5	0.0	1.4	60
0-3	196	512	62	14	0.3	0.0	1.1	49
Constructed wetland - Little O (1 year)								
0-9	149	373	40	11	0.4	0.0	0.3	60
0-3	122	584	94	29	0.7	0.0	1.2	73
0-4	189	528	69	24	0.6	0.0	1.0	96

Variation in Soil Properties along: a Transect at the Occidental Site in North Florida

Soil parameters, such as CEC and total C and N percentages (Table 3-3) that are indicators of wetland progression, appear to increase along a transect from the uplands to the wetlands. Surface C content increases from 3.1% at the upland to 8.6% at a distance of 150 ft into the wetland, while the N content increases from 0.18% to 0.46% at a distance of 150 ft into the wetland. An increase of CEC values from 9 $cmol^{-1}$ kg^{-1} at the uplands to 63 $cmol^{-1}$ kg^{-1} 150 ft into the wetlands further suggests that vegetation should normally be better supported as we move into the wetlands from the uplands. However, we found poorer vegetation at location A3 compared to the vegetation at location A2 (3-3). Although we cannot attribute the differences in vegetative growth to any one parameter, the bulk density of the subsurface soils is higher at A3 (1.6 g cm^{-1}) than at A2 (1.2 g cm^{-1}). Soil compaction (from penetrometer studies) and vegetative growth will be discussed later.

Table 3-3. Changes in soil properties along a transect from the uplands to wetlands at the Occidental site sampled.

Location	Hz	Depth (cm)	Bulk Density (g cm^{-3})	CEC ($cmol^{+}$ kg^{-1})	pH	%C	%N	C:N
Upland (A5)	1	0-4	NA¶	9	5.19	3.1	0.18	18
	2	4-18	1.5		5.21	0.5	0.02	21
50 ft (A1)	1	0-3	NA	16	5.54	4.7	0.19	25
	2	3-18	1.8		6.80	0.5	0.02	23
80 ft (A2)	1	0-3	NA	27	5.88	6.0	0.25	25
	2	3-23	1.2		7.02	0.4	0.02	20
150 ft (A3)	1	0-3	NA	63	6.60	8.6	0.46	19
	2	3-15	1.6		6.39	0.4	0.01	31
Open water	1	0-4	NA	51	6.65	8.6	0.48	18
area (A4)	2	4-13	2.3		6.99	0.5	0.02	23

¶ NA - Not Available

Variation of C:N Ratio with Age of Wetlands

A progressive decrease in C:N ratio with age was noted earlier (Fig. 13) for selected soil samples in the central Florida sites. Figure 16 (horizontal lines in the figure indicate typical C:N ratios for stabilized soil organic matter) shows C:N ratios for north and central Florida sites. Some soils with extremely low N content (<0.01%) were not included as this would result in a significant error in the calculation of C:N ratios. Although there is a tendency for C:N ratios to decrease with age and approach values close to those of native (natural) wetlands, some mucked areas do not seem to follow this pattern. Consequently, a few areas with similar soil characteristics (i.e. overburden soils without mucking from central Florida), were selected to study C:N variation with time (Fig. 17).

The C:N ratios for overburden soils without mucking (surface horizon only) appear to approach values for stabilized soil organic matter about five years after construction of the wetland. However, this observation is based on C:N ratios for a limited number of samples and should not be taken as a definite conclusion at this time.

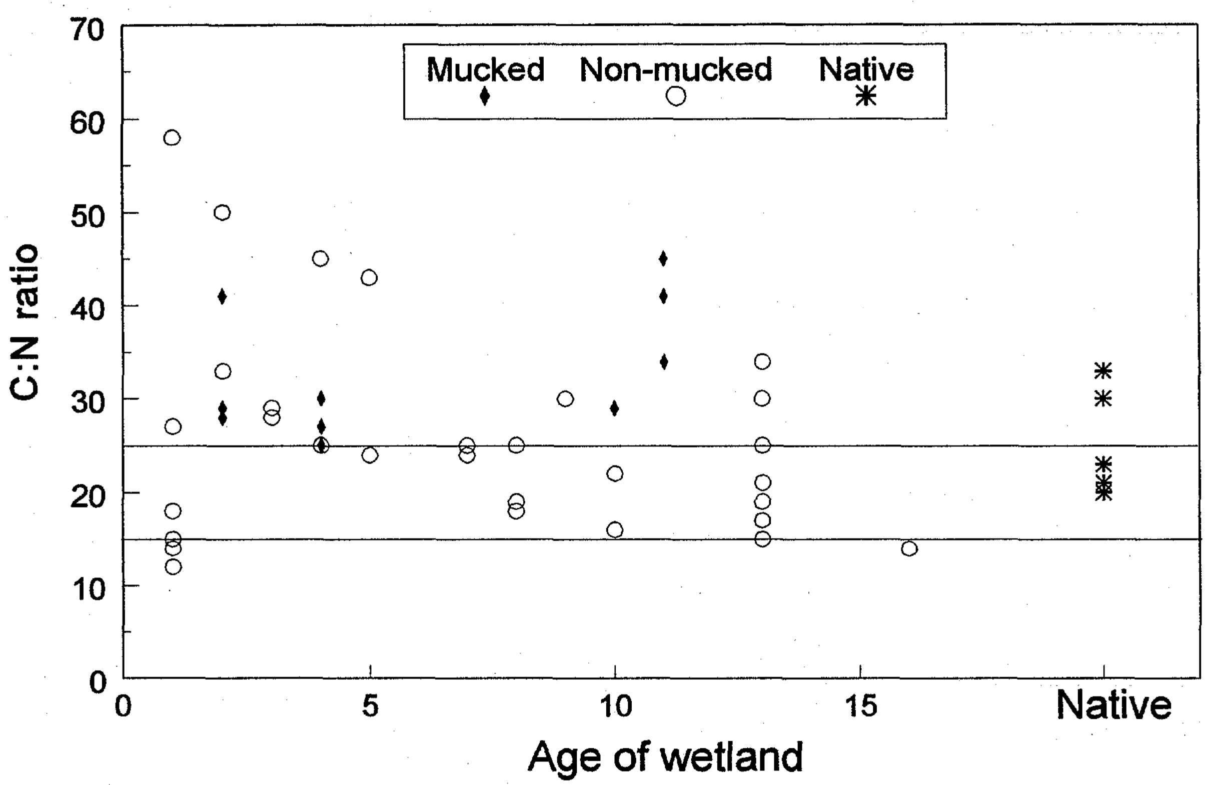


Figure 16. Variation in C:N ratio with age of wetland (wetlands from central and north Florida included).

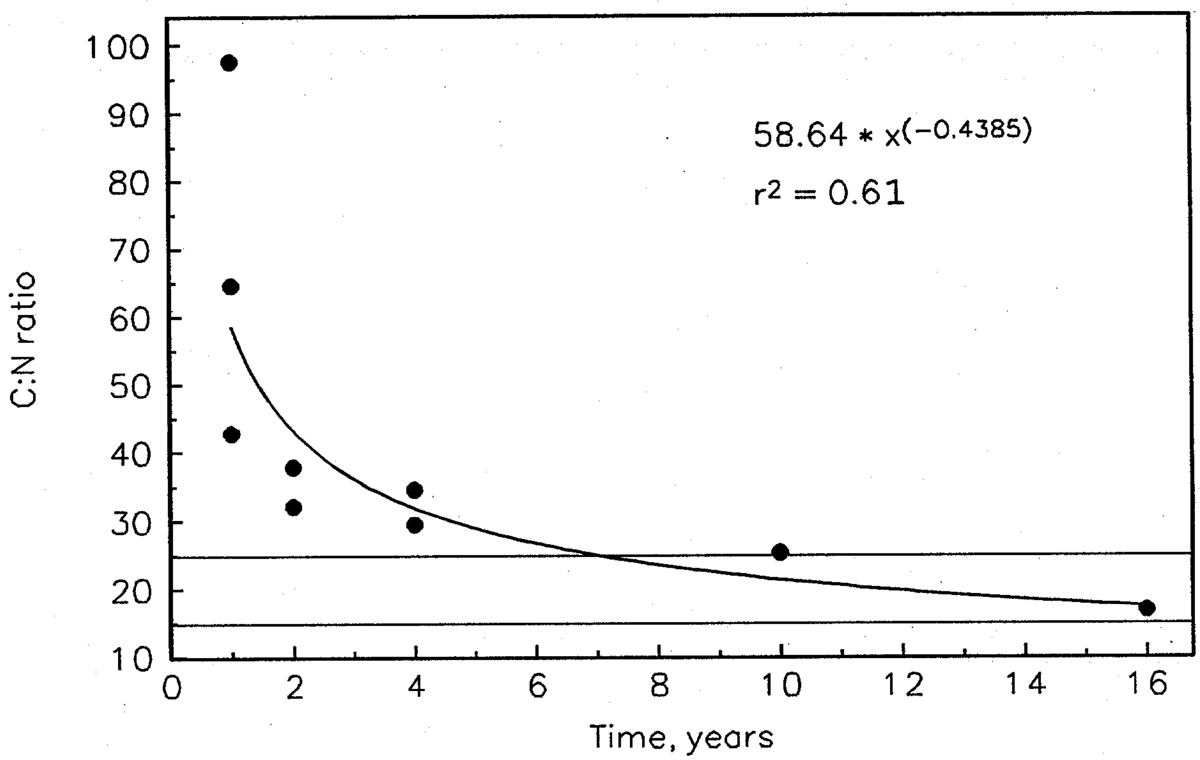


Figure 17. Variation in C:N ratio with age of selected wetlands in central Florida.

PENETROMETER READINGS AND SOIL COMPACTION

The penetrometer is a tool for measuring forces required to penetrate a soil (Cockroft et al., 1969). Its readings (usually expressed in bars or equally, in kg cm^{-2}) is a measure of soil strength or resistance to probe penetration. High soil strength and mechanical resistance can be found in compact soils or substrates, overburden materials (Bradford et. al., 1971), cemented or indurated horizons (Lutz, 1952), and hardpans (Krusekopf, 1942; Blanchar et al., 1978). Soil overburden pressure has been found to significantly affect root distribution pattern and decrease root elongation by 10 to 30% (Bradford et. al., 1971).

Soil strength and mechanical resistance have been related to soil bulk density, compaction and root penetration (Taylor et al., 1966; Barley et. al., 1965). Blanchar et al. (1978) found that pea root growth in a B2 horizon (Hobson soil) and a fragipan soil was greatly restricted as probe resistance increased from 10 to 20 bars; the authors reported that root growth stopped past 20 bars. Similar observations were reported by Taylor et al. (1966) who found in soils varying in texture (loamy fine sand to loam) that cotton root elongation nearly ceased as probe resistance approached 20 bars. Others have shown that pea root elongation in a clay soil essentially ceased at penetrometer readings >30 bars (Gerard et al., 1972). Based on literature information, we may consider a penetrometer reading of 20 bars (or kg cm^{-2}) as a critical value for root penetration and/or elongation in agricultural soils. However, we do not know if this would be an appropriate value for herbaceous and forested wetland soils.

Penetrometer readings recorded at the north Florida sites are given in Figs. 18 (for Occidental site) and 19 (for McCallum Bay, Little 0 and a native wetland). Readings for each location within a site is a mean of three measurements taken within a radius of two meters. At 20-cm depth, the upland soil showed higher mechanical resistance to probe penetration than the wet soils (Fig. 18). Soil strength or compaction in wet areas (A1, A2, A3, and A4) varied considerably at depths ≥40 cm, having penetrometer readings between 20 to 45 kg cm^{-2}. Native areas and McCallum Bay soils (3-year old wetland) had penetrometer readings < 20 kg cm^{-2} at depths ≤50 cm (Fig. 19). Little O wetland, a newly constructed wetland, was highly compacted at the 20-cm

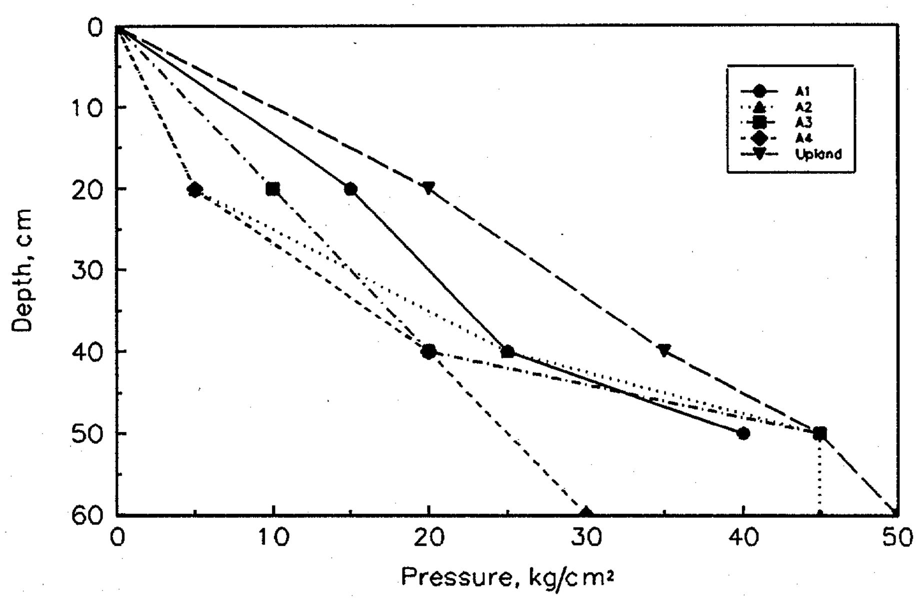


Figure 18. Changes in pressure with depth along a transect at the Occidental site. A1, A2, A3, etc. refer to locations increasing with distance into the wetland (see Table 3).

depth, yielding a penetrometer reading > 20 kg cm^{-2} considered critical to root penetration (Taylor et. al., 1966; Blanchar et al., 1978). At the time of sampling, Little O had sparse vegetation compared to the older wetlands.

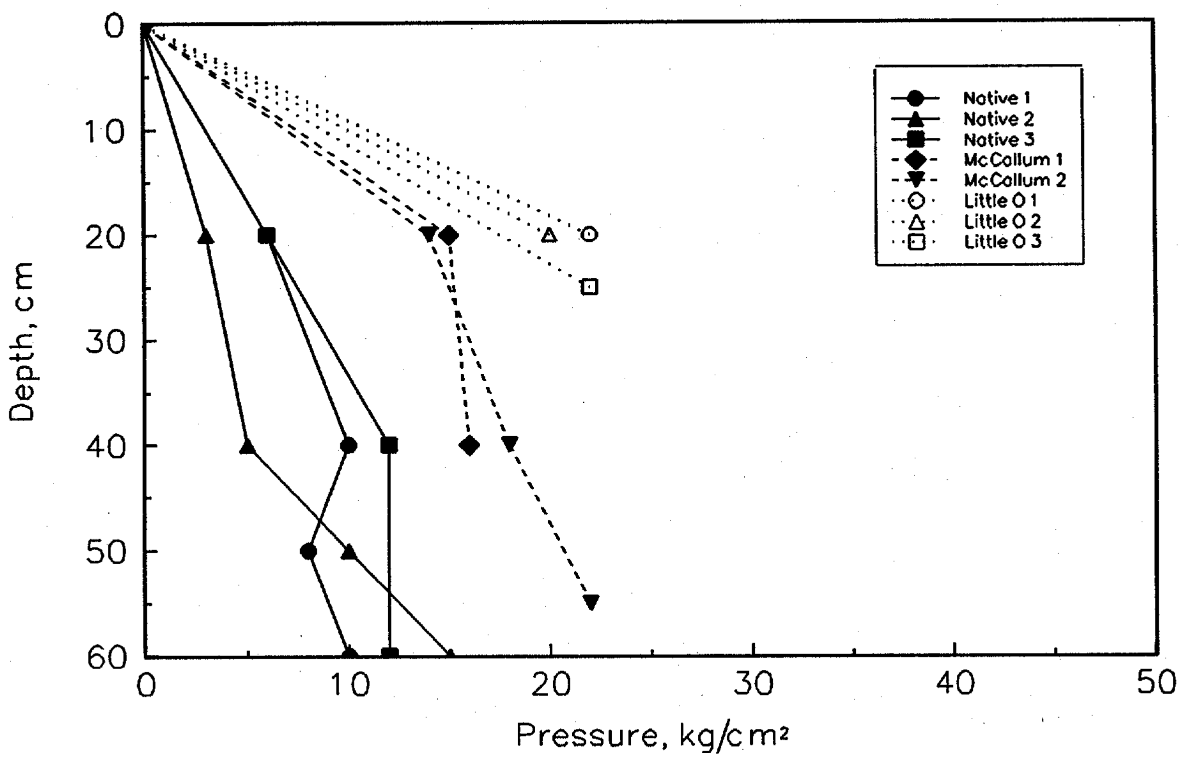


Figure 19. **Changes in pressure with depth at natural and constructed (McCallum Bay and Little O) wetlands.**

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Characteristics of reclaimed uplands, overburden material, and phosphatic clays from waste clay impoundments have been evaluated in existing reports. However, we found only limited information on soil/sediment characteristics and physico-chemical properties in existing reports on evaluation of phosphate-mined reclaimed wetlands. The common soil parameter found was the organic matter content which is often regarded as an important Milestone parameter. Nutrient content, compaction, and bulk density were seldom addressed. Physiographic characteristics, avifuanal population, landscape organization, and vegetation and hydrology were the most common types of available information.

2. Organic matter accumulation, one of the indicators of a productive wetland, increased with wetland age and across transects going from uplands toward the center of the wetlands. Most constructed wetlands showed a definite increase in organic matter content in either the litter

layer and/or the soil mineral layer. Extent of organic matter accumulation in the younger wetlands varied considerably, but nearly all showed some evidence of organic matter accumulation. Native wetlands generally had greater organic matter accumulation both in the litter and mineral soil surface. This is to be expected since native wetlands were in existence for a very long time. More importantly to the evaluation of constructed wetlands, nearly all showed evidence of organic matter accumulation, albeit, at varying rates.

3. The C:N ratio of the soil organic matter decreased with wetland age and approached values commonly found in wetland soils (20-25). This indicates that not only is the amount of organic matter increasing in the constructed wetlands but the quality of the organic matter is moving closer to that of a native wetland. The improvement in quality of organic matter was also indicated by its increased cation exchange capacity with age.

4. Bulk densities of the initial substrate material after placement in the constructed wetlands was often quite high due to the lack of organic matter and soil compaction due to the operation of heavy machinery. Incorporation of organic amendments and/or deep tillage subsequent to land leveling activities could ameliorate this problem Bulk density decreased with increasing organic matter content in the created wetland soils. Areas that had lower bulk density and higher organic matter content also appeared to support better vegetative growth.

5. The pH of the created wetland soils was near neutral (pH 6.0-7.4) to slightly alkaline (pH 7.5 8.0) reflecting the high pH of the initial substrate material. Many native wetlands have an acidic pH due to the input of rain-fed runoff and organic acid production during the decomposition of organic matter within the wetland. The created wetland soils showed evidence that high pH of the initial substrate materials was decreasing, particularly in the surface horizons and in the older wetlands.

6. Penetrometer measurements may be used as an in situ evaluation of overall soil compaction and an indication of compact layers within the soil horizon. Measurements showed distinct differences between native and created wetlands. The real value of the penetrometer may be to evaluate the degree of compaction during the wetland construction phase rather than changes in compaction with wetland progression. Preliminary soil penetrometer results suggest that penetrometer readings will be a useful parameter for relating compaction to vegetative growth in existing created wetlands.

7. Based on this synoptic survey, the recreated wetland soils surveyed are developing into "typical" wetland soils based on parameters such organic matter content and quality, bulk density, pH, and nutrient content.

8. Soil-related criteria needed to adequately evaluate wetland performance and soil profile development should include: compaction, organic matter content, C:N ratio, available nutrients, and CEC.

RECOMMENDATIONS

1. We believe that rate of development of a constructed wetland could be enhanced by at least three practices at the time of wetland construction, i.e., minimizing compaction, incorporation of organic matter and fertilization. Additions of controlled amounts of composted materials such as biosolids would provide the latter two requirements.

2. The rate of wetland development appears to be closely associated with hydrology. The wetter areas accumulated more organic matter and nutrients than de drier areas and thus approach maturity faster. The design of constructed wetlands should be based on hydrologic conditions of the created landscape and not on parameters based on the previously existing wetland.

INFORMATION GAPS AND RESEARCH NEEDS

1. Soil sampling in this project was done on a synoptic basis on a variety of wetland sites. Definite conclusions correlating soilparameters with wetland progression should not be made due to the lack of systematic and detailed sampling.

   Therefore, a systematic evaluation of wetland progression should be done by careful selection of sites and sampling locations within sites to correlate vegetative growth and stand establishment with:

   - Compaction (penetrometer measurements), bulk density and organic matter content.
   - Substrate type (overburden, sand tailings, clay, or mixtures thereof)
   - Mucking vs. no mucking.

2. Vegetation nutrient concentrations need to be correlated with soil parameters to establish recommendations for soil-amendments (organic and inorganic) and on substrate composition during wetland construction.

3. Wetland construction practices such as compaction reduction, possibly by tillage, incorporation of organic matter such as natural muck and various types of composts and a starter application of fertilizer should be evaluated. We believe these practices could lead to significant improvements in constructed wetland establishment and speed the initial progression of wetland development.

LITERATURE CITED AND RELATED REFERENCES

Allen, H. H., G. J. Pierce, and R Van Wormer. 1989. Considerations and techniques for vegetation establishment in constructed wetlands. *In* D. A. Hammer (ed.) Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, MI. pp 405-416.

Anderson, J. M. 1974. An ignition method for determination of total phosphorus in lake sediments. Water Res. 10:329-33.

Armstrong, W. 1964. Oxygen diffusion from the roots of some British bog plants. Nature (London):204:801.

Armstrong, W. 1967. The oxidizing activity of roots in waterlogged soils. Physiol. Plant 20:920.

Barley, K. P., D. A. Farrell, and E. L. Greacen. 1965. The influence of soil strength on the penetration of a loam by plant roots. Aust. J. Soil Res. 3:69-79.

Best, R G., and K. L. Erwin. 1984. Effects of hydroperiod on survival and growth of tree seedlings in a phosphate surface-mined reclaimed wetland. Symposium on surface mining, hydrology, sedimentology, and reclamation. University of Kentucky, Lexington, Kentucky.

Blanchar, R. W., C. R. Edmonds, and J. M. Bradford. 1978. Root growth in cores formed from fragipan and B2 horizons of Hobson soil. Soil Sci. Soc. Am. J. 42:437-440.

Bradford, J. M., and D. A. Farrel, and W. E. Larson. 1971. Effect of the soil overburden pressure on penetration of fine metal probes. Soil Sci. Soc. Am. Proc. 35:12-15.

Bromwell Engineering, Inc. 1982. Physico-chemical Properties of Florida Phosphatic Clays. Final Report to the Florida Institute of Phosphate Research, Contract No. 80-02-003. Bartow, FL.

Brown M. T., and R E. Tighe. 1991. Techniques and guidelines for the reclamation of phosphate mined lands. Publication # 03-044-095. Prepared for Florida Institute of Phosphate Research, Bartow, FL

Center for Wetlands, University of Florida. 1991. Evaluation of alternatives for restoration of soil and vegetation on phosphate clay settling ponds. Publication # 03-076-094. Prepared for the Florida Institute of Phosphate Research, Bartow, Fl.

Cockroft, B., K. P. Barley, and E. L. Greacen. 1969. The penetration of clay by fine probes and root tips. Aust. J. Soil Res. 7:333-348.

Environmental Services and Permitting, Inc., 1985. Technical Background Document: Environmental Evaluation of existing and proposed mining operations. Vol. II. Prepared for Occidental Chemical Agricultural Products, Inc., Hamilton County, Fl.

Environmental Services and Permitting, Inc., 1993. Preliminary milestone report for wetland reclamation success monitoring at Occidental 1992 monitoring. Submitted to Occidental Chemical Corporation, White Springs, Fl.

Gerard, C. J., H. C. Mehta, and E. Hinojosa. 1972. Root growth in a clay soil. Soil Sci. 114:37-49.

Greenwood, D. J. 1961. The effect of oxygen concentration on the decomposition of organic material in soil. Plant Soil 14:360-376.

Hatton, R.S., W.H. Patrick, Jr., and RD. DeLaune. 1982. Sedimentation, nutrient accumulation, and early digenesis in Louisiana Barataria Basin coastal marshes. p. 255-267. In V.S. Kennedy (ed.) Esturine comparisons. Academic Press, New York.

Kadlec, R. H. 1989. Hydrologic factors in wetland water treatment. *In* D. A. Hammer (ed.) Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, Ml. pp 21-40.

Kale, II, H. W. 1992. A two-year study of the avifauna of reclaimed and unreclaimed mined lands of IMC Fertilizer, Inc., Polk County, Fl. Final Report prepared for IMC Fertilizer, Inc., Bartow, Fl.

Kristensen, K. J., and H Enoch 1964. Trans. Int. Congr. Soil Sci. 8th ed 1964. Vol. 2, pp 159-170.

Lutz, J. F. 1952. Mechanical impedance and plant growth. *In.* B. T. Shaw (ed.). Soil Physical Conditions and Plant Growth. Am. Soc. Agron. Monographs. Vol. 2. Academic Press, New York.

Krusekopf, H. H. 1942. The hardpan soil of the Ozark region. Soil Sci. Soc. Am. Proc. 7:434-436.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. in Soil Sci. Plant Anal., 15(12), 1409-1416.

Mendelssohn, I. A., K. L. McKee, and W. H. Patrick, Jr. 1981. Oxygen deficiency in *Spartina alterniflora* roots: Metabolic Adaptation to anoxia. Science 214:439-441.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, NY. 722 pp.

Moorehead, K. K, and K R Reddy. 1988. Oxygen transport through selected aquatic macrophytes. J. Environ. Qual. 17: 138-142.

Neue, H. U. 1985. Organic matter dynamics in wetland soils. *In* IRRI, 1985. Wetland Soils: Characterization, Classification, and Utilization. Proceedings of a workshop on March 26 to April 5, 1985. IRRI, Los Banos, Laguna, Philippines. pp. 109-122.

Raskin, I., and H. Kende. 1985. Mechanism of aeration in rice. Science 228:327-329.

Reddy, KR, R D. DeLaune, W.F. DeBusk and M.S. Koch. 1993. Long-term nutrient accumulation rates in the Everglades. Soil Sci. Soc. Am. J. 57: 1148-1155.

Rhoades, J.D. 1982. Cation Exchange Capacity. *In* Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties-Agronomy Monograph no. 9 (2nd Edition).

Rushton, B. T. 1990. Seedlings for enhancing wetland succession. pp. 123-176. *In* H. T. Odum, G. R Best, M. A. Miller, B. T. Rushton, R Wolfe, C. Bersok, and J. Feiertag. Accelerating Natural Processes for Wetland Restoration after Phosphate Mining. Final Report to the Florida Institute of Phosphate Research. Bartow, FL. FIPR Contract No. 83-03-041R Center for Wetlands, Phelps Laboratory, University of Florida, Gainesville.

Stoops, G., and H. Eswaran. 1985. Morphological characteristics of wet soils. *In* IRRI, 1985. Wetland Soils: Characterization, Classification, and Utilization. Proceedings of a workshop on March 26 to April 5, 1985. IRRI, Los Banos, Laguna, Philippines. pp. 177-189.

Taylor, H. M., G. M. Roberson, and J. J. Parker, Jr. 1966. Soil strength-root penetration relations for medium to coarse textured soil materials. Soil Sci. 102:18-22.

Vazquez, L., D.L. Myhre, RN. Gallaher, E.A. Hanlon and KM. Portier. 1989. Soil compaction associated with tillage treatments for soybean. Soil Tillage Res., 13:35-45.

Wallace, P. M., and G. R Best. 1983. Enhancing Ecological Succession: 6. Succesion of vegetation, soils, and micorrhizal fungi following strip mining for phosphate. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. University of Kentucky, Lexington, Kentucky. November 27-December 2, 1983.

Williams, W. W., D. S. Mikkelsen, K E. Muller, and J. E. Ruckman. Nitrogen immobilization by rice straw incorporated in lowland rice production. Plant Soil 28:49.

APPENDIX 3-I

Field Notes for Present Sampling Sites

Site 1: Cemetery Branch; old dragline crossing; only dragline crossing, no mining activity; unmined but reclaimed; muck removed and then replaced; could use as a comparison between mined and unmined; 1988.
Site 2: Lizard Branch; recently lowered elevation, newly mucked; appears to be high bulk density; 3 soil samples taken;
Site 3: Dogleg Branch; has been sodded; sampled at stake 19Q right where drainage ditch enters newly constructed area;
Site 4: McMullen Branch dragline walkpath; Soil sample taken in valley not affected by dragline crossing in floodplain; Sample to represent native (forested) area.
Site 5: Jamerson Junior; recently redone; pushed in sides to raise bottom; took one soil sample; See Andy Clewel report.
Site 6: Hall Branch; didn't have time to sample;
Site 7: East Lake Branch; Lakes and fringes; Alligator enroute to next site; slash pine planted in 1993; area across the road may be a good native wetland.
Site 8: Tadpole; 2-3 years old, mucked; hydrology problems; Sampled at south end right at edge of wetland;
Site 9: East of old Fort Green Road; planted last year; source of new soil; Not on map; three soil samples taken; flooded one foot;
Site 10: N. CR 630; Sampled at edge of water and upland.
Site 11: South CR 630; dry and wet samples taken; wet at edge of water; dry halfway up slope;
Site 12: West of SR Basically a lake with small wetland on east side; No samples taken. East of river to be mined yet.
Site 13: Four Comers Section 15; Mitigation wetland; samples taken.
Site 14: Miles Grove; Reclamation just starting; Shaped like a time-clock; Sampled in west and east lobe, 6 inches water in west lobe; only moist in east lobe.
Site 15: Miles Grove Lake; 1-2 years old; marsh on south? side; Sampled dry area (part of the marsh) near PVC stake and at edge of water;
Site 16: FCO Sec 1; two samples taken. Two acres forested.
Site 17: Horse Creek; Herbaceous wetland constructed by Grace 1984-85; Most of wetland is dry due to high soil elevation. No soil sample taken due to distance to wet area. Meant to be 170 acres, closer to 45 acres.
Site 18: Section 12; Hal Scott Conservation area. Samples (two) taken at tower site; Herbaceous vegetation.
Site 19: Section 7/12; Stream and small flood plain; sampled in flood plain near power pole. Herbaceous vegetation. Cattail, bulrush.
Site 20: South Pebbledale; sand substrate; Three cores taken; 1) in water; 2) good growth area; 3) poor growth area. Mitigation area.
Site 21: Section 6; Going to be redone because not functioning properly; No samples. Cattail wetland.
Site 22: Cat Eye; Sample taken about 30 ft from water (lake) edge.
Site 23: N-2 area; No sample;

Site 24: Sweetwater Branch; Next to Gyp Pile. One sample, three increments. Area has been mucked. Feed by sandhill upland.

Site 25: Land and Lakes Area; Natural reclamation. Mined in early 1970's. No sample.

Site 26: South Tiger Bay; Sample taken near edge of water; character of sediment further into wetland unknown. Check with GRB regarding previous research here. Site is next to a clay settling pond which is going to be used by Florida Power for a new plant. S. Tiger Bay.

Site 27: H-9 Clay settling area (Homeland-9); Betty Rushton did work here. One sample taken here near edge.

Site 28: Parcel B; Planted January 1979. one sample taken in flood plain area; split into 0-2, 2-9, and 9-24cm. Present Best study site. Peace River flood plain sample also taken at this location. 0-6, 6-16, 16-30.

Site 29: Near Parcel B at POPOFF area; too stony to get soil sample.

Site 30: West of CS-11 floodplain (82-11); Actually not 82-1; see map. primarily cattail. Two samples taken; 6cm layer of cattail litter, 6 cm of clay.

Site 3 1: West of CS-11 Floodplain; SP-1; Cattail littoral fringe; 15 cm layer of organic litter sampled separately by hand. Core: 0-11 loose clay; 11-26 hard clay.

Site 32: North of 640 Floodplain, CS-19; Two samples taken: (A) in Willow site - 0-7, 7-12, 12-28; (B) in cattail site, appeared to be a lot of erosional deposition. Went over boots in loose mud.

Site 33: East of CS-11; Kingsford Mine

Site 34: Bird Branch; Sampled at edge of creek; Took organic litter layer by hand; Core 0-7 and 7-27. Sample taken in cattail area. Sampled at edge of creek.

Site 35: Unit H at boardwalk; Near Lake Wales Plant; Basically a long lake. Sample taken by Best near boardwalk about 40 ft from edge of water near Pontidera floating mat. 0-6,6-15, 15-25. Sign at Lakes Wales Plant said Pitman/Moore Feed Ingredients.

Site 36: South Mizelle Creek; one sample taken at edge of lake, two depths, organic plus sand. "Native" area between lake and fertilizer plant may be a good site for native samples.

Site 37: West of K-6; One core taken in native stream flood plain near lake. Stream cut into soil about 3-4 ft. 0-5.5, 5.5-15.5, 15.5-26 cm

Site 38: Paynes Creek reclamation area; presently being reclaimed; considerable earth moving activity. Several small wetland areas being mucked. Five core samples taken by Graetz and Best. See AGRICO handout for PC-PC-2. Cores were taken in "640" nonforested wetland area which contained muck (each core consisted of muck layer and underlying overburden material. Cores taken in "630" areas (mixed forest wetland) contained no muck; cores consisted of two increments of overburden material. See AGRICO report for map and sample locations.

Table A3-1.1. Visual description of soil profiles collected from the various central Florida sites. Layer designations are as follows: O1=organic litter accumulation, above the mineral soil, Ao-organic/mineral layer with significant root mass, A1-organic/mineral layer with "humus-type" material and minimal, root mass, B-illuvial layer, C-mineral material.

Lab #	Location	Layer designation	Visual description	Depth cm From - To
Sampling-Feb. 3, 1994				
FORT GREEN				
Morrow Swamp West				
101	90-191	Ao	Surface layer, fine roots, dark	0 - 3.5
102		A1	Dark/light grey mixture, few roots	3.5 - 8.5
103		C	Light/dark grey	8.5 - 30
104	90-193	O1	Litter - roots, plant debris	
105		A1	Surface layer - few roots, medium grey	0 - 5
106		C	Subsurface - dark grey with brown	5 - 18
107		A1-1	Surface - roots, partially decomp. plant	0 - 6
108		C-1	Subsurface - light grey	6 - 16
109	92-194	Ao	Surface - fine to medium roots, leaves,	0 - 3.5
110		A1	Subsurface - few roots, medium/lt. grey	3.5 - 8.5
111		C	Light grey/brown	8.5 - 31
112	92-196	O1	Organic litter	
113		Ao	Surface - fine roots, dark/light grey	0 - 4.5
114		A1	Subsurface - very lt. grey, fine roots	4.5 - 9.5
115		C	Mixture of light and dark grey	9.5 - 25.5

Lab #	Location	Layer designation	Visual description	Depth cm From	To
116	127-193	A1	Roots, decomposed plant material, light	0 -	5
117		C	Subsurface - light grey	5 -	25
118	127-195	Ao	Surface - plenty of fine roots, grey	0 -	4
119		A1	Subsurface - v. lt. grey with some mottles	4 -	9
120		C	Lots of mottles, lt. brown, clayey	9 -	29
121	127-197	Ao	Surface - fine roots, medium grey	0 -	4.5
122		A1	Subsurface - light grey with few roots	4.5 -	9.5
123		C	Light grey with very few lt. br. mottles	9.5 -	29
124	127-199	O	Organic litter	0 -	6
125		A1	Surface - lt. grey, fine roots, very wet	0 -	5
126		C	Light grey	5 -	25
Agrico Swamp East					
127	T6-0	*X1*	*clay leakage*. lt.grey with fine roots	0 -	3.5
128		A1	Muck - dark, fine roots	3.5 -	17
129		C	Light grey, brown mottles	17 -	29
130	T6-150	Ao	Dark- fine roots	0 -	5
131		A1	Muck - few lt. brown mottles	5 -	16
132		C	Very lt. grey, abundance of brown mottle	16 -	30
133	T6-300	Ao	Dark, fine roots	5.5 -	0
134		A1	Muck - dark, few lt. br. mottles	0 -	13.5
135		C	Light grey	13.5 -	19
136	T7-(-300)	Ao	Fine roots, light grey	0 -	3.5
137		A1	Lt. grey, few fine roots, lt. br. mottle	3.5 -	17
138		C	Dark grey, lt. brown mottles	17 -	30

Lab #	Location	Layer designation	Visual description	Depth cm From - To
139	T7-0	Ao	Dark grey, fine roots	0 - 6
140		A1	Muck - lt. brown mottles	6 - 20
141		C	Mixture of dark/ lt. grey, some mottles	20 - 31
142	T7-100	Ao	Fine roots, light grey	0 - 6
143		A1	Muck	6 - 13.5
144		C	Dark/light grey	13.5 - 30
145	T7-200	Ao	Fine roots	0 - 6.5
146		A1	Muck -- fine roots	6.5 - 22.5
147		C	Dark/ light grey	22.5 - 31

Sampling-Feb. 8 & 9, 1994

FORT LONESOME

Lab #	Location	Layer designation	Visual description	Depth cm From - To
148	Dogleg Branch	A	Muck - fine roots, dark	0 - 8
149		B	Dark, few fine roots	8 - 11
150	Lizard Branch	A1	Muck (wet) - dark	0 - 18
151		C	Light brown	18 - 26
152		A	New muck - dark	0 - 12
153		B	Mixture of light/ dark grey	12 - 18
154		A	Non-top soil - v. lt. grey with few root	0 - 2.5
155		C	Very light brown	2.5 - 18
156	Mc Mullen	A	Muck - dark	0 - 14
157		B	Muck - mixture of light/ dark grey	14 - 31

Lab #	Location	Layer designation	Visual description	Depth cm From	To
158	Jamerson Branch	A	Fine roots, plant material, lt. grey	0 -	3
159		B	Light grey	3 -	20
160		A	Muck - dark	0 -	11
161		B	Mixture of muck and sand	11 -	18
162	Miles Grove	A	Muck - fine roots, dark	0 -	12
163	Southeast	B	Light brown	12 -	24
164		A	Grey	0 -	10
165		C	Grey with mottles	10 -	20
166	Miles Grove	A	Grey with mottles	0 -	8
167	Northwest	C	Light grey with mottles	8 -	20
168		A	Muck - fine roots, dark	0 -	14
169		B	Muck - dark	14 -	28
HAYNSWORTH					
170	Tadpole	A	Muck - dark grey	0 -	13.5
171		C	Light brown	13.5 -	25.5
172	East Old Fort	A	Light grey	0 -	10
173	Green Road	C	Light grey with brown mottles	10 -	20
174		A	Light grey	0 -	10
175		C	Light grey	10 -	22
176		A	Light grey	0 -	10
177		C	Light grey	10 -	22

Lab #	Location	Layer designation	Visual description	Depth cm From - To
178	North County	A	Light grey with fine roots	0 - 10
179	Road 630	B	Light grey	10 - 20
180		Ao	Grey with fine roots	0 - 3
181		C	Light grey	3 - 20
182	South County	A	Dark grey, fine roots	0 - 5
183	Road 630	C	Light grey	5 - 20
184		A	Light grey	0 - 10
185		B	Light grey	10 - 20
FOUR CORNERS				
186	FCO Sec. 15	A	Light brown, fine roots	0 - 9
187		B	Light brown	9 - 17
188		A	Light brown	0 - 6
189		B	Light brown	6 - 20
190	FCO Sec 1	A	Dark grey	0 - 4
191		C	Light grey	4 - 11.5
192		A	Dark grey with fine roots	0 - 3.5
193		C	Light grey	3.5 - 12.5
NORALYN/PHOSPHORIA				
194	Section 12	A	Muck - dark grey	0 - 10
195	(N. Hooker's Prairies)	B	Muck - dark grey	10 - 20

Lab #	Location	Layer designation	Visual description	Depth cm From	To
196		A	Muck - dark grey with fine roots	0 -	3
197		B1	Muck - dark grey	3 -	13
198		B2	Muck - dark grey	13 -	23
199	Section 7/12	A	Muck - dark grey	0 -	18
200		B	Muck - light brown	18 -	25
201	South	A	Green algae	0 -	2
202	Pebbledale Sec. 6	C	Lt. grey	2 -	15
203		Ao	Few green algae	0 -	3
204		A1	Fine roots, lt. grey	3 -	11
205		C	Light grey	11 -	23
206		Ao	Some algae	0 -	1.5
207		A1	Few roots, light grey	1.5 -	6
208		C	Light grey with yellow/ brown mottles	6 -	23
209	East Farm-	A	Fine roots, dark grey	0 -	6
210	land Cateye	B	Light grey/light brown	6 -	21
211	Sweetwater	Ao	Light grey with roots	0 -	3
212	Branch	A1	Light grey with yellowish mottles	3 -	14
213		B	Light grey with lots of yellow mottles	14 -	23
214	South Tiger	Ao	Light grey, abundant fine roots	0 -	6
215	Bay	A1	Light grey	6 -	18
216		B	Light grey with yellow/brown color	18 -	25

Lab #	Location	Layer designation	Visual description	Depth cm From - To
CLEAR SPRINGS				
217		O1	Organic litter	
218		A	Mineral - lt. grey with yellow/gr. mottl	0 - 11
219		B	Abundance of mottles	11 - 21
Sampling-Feb. 10, 1994				
PAYNES CREEK				
220	1	A	Mucked - dark grey, mottled, fine roots	0 - 11
221		C	Wetland-new, light grey	11 - 26
222	2	C1	Forested - not mucked, light grey	0 - 10
223		C2	Wetland - lt. grey	10 - 27
224	3	A	mucked - Black with few lt. grey patches	0 - 9
225		C	Wetland-new, light grey	9 - 26
226	4	C1	Forested - not mucked, lt. grey brown	0 - 13
227		C2	Wetland - Lt. grey brown	13 - 28
228	5	A	Mucked - dark	0 - 11
229		C	Wetland-new, light brown	11 - 28
PARCEL B				
230		Ao	Surface	0 - 2
231		A1	Clayey	2 - 9
232		B	Grey mottled clay	9 - 24

Lab #	Location	Layer designation	Visual description	Depth cm From - To
PARCEL B (Peace River Flood Plain)				
233		Ao	Highly organic - black	0 - 6
234		A1	Highly organic - black	6 - 16
235		B	Highly organic - black	16 - 30
CS-19				
236		Ao	Surface	0 - 7
237		A1	Subsurface	7 - 12
238		C	Clayey, lt. grey	12 - 28
239		Ao	Cattail litter	0 - 6
240		A1	Subsurface	6 - 11.5
241		B	Dark grey mineral	11.5 - 19.5
242		C	Grey/brown mottled mineral	19.5 - 29
SP1				
243		O	Litter	
244		A	Grey - mineral	0 - 11
245		C	Mottled clay (yellow/grey)	11 - 25
BIRD PARCEL				
246		O	Litter - cattail	
247		A	Dark grey	0 - 7
248		C	Light grey clay	7 - 27

Lab #	Location	Layer designation	Visual description	Depth cm From	To
MIZELLE CREEK					
249		A	Dark grey	0 -	8
250		C	Mineral (grey)	8 -	30
k6-NATIVE					
251		A1	Sandy surface	0 -	5.5
252		A2	Dark subsurface	5.5 -	15.5
253		B	Lighter color - grey	15.5 -	26
UNIT H					
254		Ao	Litter - black	0 -	6
255		A1	Dark grey mineral	6 -	15
256		C	Light grey, some grey mottles	15 -	25
82-1					
257		Ao	Organic - black	6	
258		A1	Grey	6	

Table A3-1.2 Visual description of soil profiles collected from the various north Florida sites. Layer designations are as follows: 1-surface (organic); 2-subsurface (inorganic).

Lab #	Location	Layer designation	Visual description	Depth cm From	To
OCCIDENTAL CHEMICAL CORPORATION					
OCC-SR-SP(4)					
259	A1-50 ft from	1 surface	organic, black with sand and some leaves	0 -	3
260	trail beginning	2 subsurface	sandy, dark grey with lt. grey to brown mottles-moist area	3 -	18
261	A2-80 ft from	1 surface	organic debris on sand, some leaves,	0 -	3
262	trail beginning (slightly off trail)	2 subsurface	sandy, grey, fine roots; heavier tree growth than A1; moist area	3 -	23
263	A3-150 ft from	1 surface	organic, abundant roots, sandy	0 -	3
264	trail beginning	2 subsurface	light grey with yellowish-brown mottles poorer vegetation; 1" water	3 -	15
265	A4-open water	1 surface	organic, abundant fine roots, sandy	0 -	4
266	pond	2 subsurface	grey with abundance of fine roots with lt. grey mottles; 4" water	4 -	13
267	A5-upland; dry	1 surface	grass roots, sandy	0 -	4
268		2 subsurface	light grey, medium to fine roots	4 -	18
McCALLUM BAY AREA - NATIVE AREA					
269	B1	1 surface	very dark, highly organic, fine roots,	0 -	15
270		2 subsurface	black	15 -	28
271	B2	1 surface	fine roots (same as 269), black	0 -	8
272		2 subsurface	black with fine/medium roots	8 -	30
273	B3	1 surface	native surface, partially decaying	0 -	8
274		2 subsurface	dark grey with light grey	8 -	31

Lab #	Location	Layer designation	Visual description	Depth cm From	To
McCALLUM	**BAY AREA OCCSR-82(3)A**				
275	C1-high area	1 surface	sandy, with some algae, light grey	0 -	3
276	fairly dry	2 subsurface	very light grey, few roots	3 -	23
277	C2-fairly dry	1 surface	very light grey, sandy with algae,	0 -	3
278		2 subsurface	very light grey, few roots, few lt.	3 -	23
LITTLE O - NEW PROJECT					
279	D1-upland (dry)	1 surface	upland, light brown, sandy, few	0 -	9
280		2 subsurface	dark grey with lt. brown mottles	9 -	18
281	D2-20 ft to wet	1 surface	sandy, light grey, fine roots, algae	0 -	3
282	edge; dry	2 subsurface	light grey, with light brown and light grey mottles	3 -	17
283	D3-225 ft from	1 surface	brownish grey, fine roots, sandy	0 -	4
284	upland - moist	2 subsurface	grey, yellowish-brown mottles	4 -	19

Table A3-2.1. Moisture content (MC, wet basis), bulk density (BD), pH, total C and total N for samples collected from the central Florida sites. Layer designations are as follows: O1-organic litter accumulation, above the mineral soil, Ao-organic/mineral layer with significant root mass, A1-organic/mineral layer with "humus-type" material and minimal root mass, B-illuvial layer, C-mineral material.

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
FORT GREEN								
Morrow Swamp West								
101	90-191	Ao	3.5	46	0.5	6.53	6.60	0.31
102		A1	5.0	20	1.5	6.31	1.21	0.04
103		C	21.5	17	1.5	5.77	0.67	0.01
104	90-193	O1		86			31.26	2.06
105		A1	5.0	27	1.4	7.13	1.29	2.05
106		C	13.0	17	1.6	7.51	0.62	0.01
107		A1-1	6.0	74	0.2	7.70	10.29	0.61
108		C-1	10.0	22	1.2	7.75	0.71	0.01
109	92-194	Ao	3.5	27	0.6	7.30	6.53	0.25
110		A1	5.0	13	1.4	7.05	1.06	0.04
111		C	22.5	24	1.5	7.33	0.27	0.00
112	92-196	O1		85			31.26	2.33
113		Ao	4.5	57	0.5	7.18	5.50	0.36
114		A1	5.0	17	1.8	7.14	0.36	0.01
115		C	16.0	15	1.9	5.60	0.28	0.00
116	127-193	A1	5.0	22	1.5	7.26	1.15	0.04
117		C	20.0	12	1.9	6.88	0.36	0.01
118	127-195	Ao	4.0	36	1.0	7.75	1.85	0.10
119		A1	5.0	20	1.3	7.66	0.32	0.01
120		C	20.0	16	1.7	7.68	0.61	0.00
121	127-197	Ao	4.5	67	0.3	7.77	7.20	0.41
122		A1	5.0	17	1.5	7.75	0.50	0.02
123		C	19.5	16	1.5	7.64	0.28	0.01
124	127-199	O	6.0	90	0.3		30.72	1.97
125		A1	5.0	29	1.6	7.71	0.51	0.02
126		C	20.0	15	1.7	7.62	0.29	0.01

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm⁻³	pH	Total C %	Total N %
Agrico Swamp East								
127	T6-0	Ao	3.5	64	0.6	7.87	6.43	0.34
128		A1	13.5	44	0.7	7.20	12.53	0.62
129		C	12.0	14	1.5	7.96	1.41	0.06
130	T6-150	Ao	5.0	76	0.2	7.72	17.22	0.94
131		A1	11.0	35	1.2	7.92	5.31	0.25
132		C	14.0	15	1.7	7.93	0.83	0.01
133	T6-300	Ao	-5.5	77		6.75	25.97	1.45
134		A1	13.5	52	0.7	6.93	19.03	1.05
135		C	5.5	26	1.1	7.96	2.07	0.08
136	T7-(-300)	Ao	3.5	42	0.8	7.54	3.24	0.14
137		A1	13.5	15	1.6	7.55	0.77	0.02
138		C	13.0	13	1.9	7.69	0.64	0.01
139	T7-0	Ao	6.0	73	0.3	7.22	14.31	0.89
140		A1	14.0	51	0.8	7.46	14.31	0.78
141		C	11.0	20	1.1	7.77	1.38	0.05
142	T7-100	Ao	6.0	80	0.2	7.37	17.22	1.05
143		A1	7.5	48	0.7	7.00	7.38	0.41
144		C	16.5	19	1.6	7.99	2.17	0.10
145	T7-200	Ao	6.5	74	0.2	7.18	20.16	1.20
146		A1	16.0	40	0.9	7.77	10.20	0.50
147		C	8.5	23	1.3	7.90	4.82	0.18
FORT LONESOME								
148	Dogleg Branch	A	8.0	42	0.8	6.69	3.94	0.14
149		B	3.0	26	1.9	6.50	1.56	0.06
150	Lizard Branch	A1	18.0	41	0.8	6.79	12.50	0.28
151		C	8.0	12	1.1	6.74	0.36	0.01
152		A	12.0	22	1.1	4.33	10.37	0.25
153		B	6.0	11	1.5	6.32	0.42	0.01
154		A	2.5	24	2.7	7.35	1.08	0.03
155		C	15.5	18	1.4	7.10	0.28	0.01
156	Mc Mullen	A	14.0	29	1.2	5.21	3.19	0.11
157		B	17.0	18	1.4	5.87	0.35	0.01

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
158	Jamerson Branch	A	3.0	19	2.2	3.51	0.66	0.02
159		B	17.0	15	1.5	5.40	0.46	0.01
160		A	11.0	29	1.3	5.56	1.19	0.03
161		B	7.0	20	1.5	5.93	0.55	0.01
162	Miles Grove	A	12.0	24	1.4	7.19	2.62	0.10
163	Southeast	B	12.0	14	1.6	5.49	0.55	0.01
164		A	10.0	20	1.6	7.17	0.59	0.02
165		C	10.0	13	2.0	6.34	0.41	0.01
166	Miles Grove	A	8.0	14	1.6	6.28	0.50	0.01
167	Northwest	C	12.0	14	1.8	6.48	0.24	0.00
168		A	14.0	37	1.0	6.17	3.01	0.10
169		B	14.0	19	1.3	5.96	2.09	0.07
HAYNSWORTH								
170	Tadpole	A	13.5	32	1.1	7.02	3.73	0.09
171		C	12.0	18	1.5	6.79	0.16	0.00
172	East Old Fort	A	10.0	19	1.5	6.09	0.33	0.01
173	Green Road	C	10.0	16	1.7	6.24	0.26	0.00
174		A	10.0	18	1.9	6.20	0.25	0.00
175		C	12.0	13	1.4	6.07	0.26	0.00
176		A	10.0	18	1.7	5.77	0.22	0.01
177		C	12.0	11	1.1	5.82	0.22	0.00
178	North County	A	10.0	22	1.4	5.87	0.38	0.01
179	Road 630	B	10.0	19	1.5	5.75	0.32	0.01
180		Ao	3.0	20	0.9	5.62	2.87	0.11
181		C	17.0	8	1.6	5.65	0.32	0.01
182	South County	A	5.0	22	1.8	5.43	0.88	0.02
183	Road 630	C	15.0	14	1.7	6.02	0.45	0.01
184		A	10.0	5	1.7	5.79	0.55	0.01
185		B	10.0	7	1.7	5.61	0.83	0.01
FOUR CORNERS								
186	FCO Sec. 15	A	9.0	18	1.4	5.27	0.32	0.01
187		B	8.0	14	2.1	5.14	0.42	0.01

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
188		A	6.0	19	1.7	4.75	0.86	0.04
189		B	14.0	15	1.7	4.60	0.61	0.01
190	FCO Sec 1	A	10.2	47	0.8	6.67	8.75	0.00
191		C	19.0	16	1.4	7.39	0.23	0.00
192		A	8.9	47	0.9	6.45	2.12	0.07
193		C	22.9	17	1.3	7.51	0.22	0.00
NORALYN/PHOSPHORIA								
194	Section 12	A	10.0	23	1.3	6.46	1.43	0.05
195	(N. Hooker's Prairies)	B	10.0	18	1.7	6.29	1.17	0.04
196		A	3.0	50	0.7	6.67	2.91	0.12
197		B1	10.0	19	1.6	6.34	1.32	0.05
198		B2	10.0	19	1.6	6.05	1.32	0.04
199	Section 7/12	A	18.0	23	1.6	6.20	1.80	0.07
200		B	7.0	19	1.5	6.32	0.79	0.02
201	South	A	2.0	46	0.9	8.18	1.36	0.12
202	Pebbledale Sec. 6	C	13.0	18	1.1	7.30	0.22	0.00
203		Ao	3.0	31	1.3	7.47	0.84	0.06
204		A1	8.0	19	1.5	7.27	0.31	0.01
205		C	12.0	18	1.7	7.02	0.19	0.00
206		Ao	1.5	31	1.2	7.27	0.76	0.05
207		A1	4.5	19	1.1	6.84	0.33	0.00
208		C	17.0	17	1.9	5.52	0.11	0.00
209	East Farm-	A	6.0	36	0.9	4.41	8.19	0.33
210	land Cateye	B	15.0	17	1.7	4.58	0.59	0.02
211	Sweetwater	Ao	3.0	47	0.8	5.75	2.86	0.12
212	Branch	A1	11.0	21	1.5	6.02	0.64	0.01
213		B	9.0	12	1.6	5.73	0.55	0.01
214	South Tiger	Ao	6.0	45	1.0	6.14	4.49	0.21
215	Bay	A1	12.0	18	1.5	7.09	0.36	0.01
216		B	7.0	16	1.8	6.80	0.34	0.01
CLEAR SPRINGS								
217		O1		90			30.53	1.78
218		A	11.0	60	0.3	6.81	6.68	0.41
219		B	10.0	54	0.5	7.52	2.26	0.08

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
PAYNES CREEK								
220	2	A	11.0	17	1.3	7.56	2.30	0.09
221		C	15.0	12	1.5	7.69	0.32	0.00
222	2	C1	10.0	13	1.7	7.67	0.19	0.00
223		C2	17.0	15	1.5	7.59	0.14	0.00
224	3	A	9.0	22	1.4	6.98	2.03	0.10
225		C	17.0	17	1.6	7.73	0.21	0.00
226	4	C1	13.0	78	0.4	6.14	0.18	0.00
227		C2	15.0	13	1.7	6.07	0.30	0.01
228	5	A	11.0	17	1.6	7.04	1.53	0.07
229		C	17.0	12	1.8	5.92	0.10	0.00
PARCEL B								
230		Ao	2.0	36	0.7	5.94	5.58	0.39
231		A1	7.0	22	1.3	5.55	1.47	0.10
232		B	15.0	16	1.5	5.96	0.77	0.04
PARCEL B (Peace River Flood Plain)								
233		AO	6.0	57	0.4	6.15	19.31	0.91
234		A1	10.0	39	0.9	6.30	5.04	0.24
235		B	14.0	31	1.0	6.17	4.14	0.18
CS-19								
236		Ao	7.0	83	0.2	8.37	17.74	1.06
237		A1	5.0	72	0.3	8.00	11.19	0.57
238		C	16.0	42	0.8	8.15	7.15	0.03
239		Ao	6.0	91	0.1		20.64	1.39
240		A1	5.5	85	0.2	7.96	13.43	0.88
241		B	8.0	70	0.3	7.41	7.54	0.38
242		C	9.5	25	1.6	7.58	0.49	0.01
SP1								
243		O		78			31.93	1.93
244		A	11.0	31	1.3	7.32	1.09	0.02
245		C	14.0	29	1.3	7.52	1.24	0.01

Lab # Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
BIRD PARCEL							
246	O		82			35.30	2.16
247	A	7.0	78	0.3		13.45	0.89
248	C	20.0	16	1.8	7.64	0.27	0.00
MIZELLE CREEK							
249	A	8.0	62	0.8	7.29	6.16	0.32
250	C	22.0	6	1.7	7.00	0.31	0.01
k6-NATIVE							
251	A1	5.5	12	1.4	5.52	1.81	0.06
252	A2	10.0	32	1.0	5.71	5.67	0.19
253	B	10.5	18	1.3	5.30	1.28	0.02
UNIT H							
254	Ao	6.0	62	0.6	7.62	2.46	0.10
255	A1	9.0	20	0.9	6.41	0.38	0.01
256	C	10.0	13	2.4	6.30	0.26	0.01
82-1							
257	Ao	6.0	54	0.9	6.75	11.43	0.45
258	A1	6.0	42	1.4	6.45	0.78	0.02

Table A3-2.2. Moisture content (MC, wet basis), bulk density (BD), pH, total C and total N for samples collected from the north Florida sites. Layer designations are as follows: 1-surface (organic); 2-subsurface (inorganic).

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
OCCIDENTAL CHEMICAL CORPORATION								
OCC-SR-SP(4)								
259	A1	1	3	NA	NA	5.54	4.70	0.19
260		2	15	12	1.8	6.80	0.47	0.02
261	A2	1	3	NA	NA	5.88	6.05	0.25
262		2	20	12	1.2	7.02	0.43	0.02
263	A3	1	3	NA	NA	6.60	8.60	0.46
264		2	12	18	1.6	6.39	0.43	0.01
265	A4	1	4	NA	NA	6.65	8.57	0.48
266		2	9	13	2.3	6.99	0.47	0.02
267	A5	1	4	NA	NA	5.19	3.10	0.17
268		2	14	11	1.5	5.21	0.50	0.02
McCALLUM BAY AREA - NATURAL AREA								
269	B1	1	15	NA	NA	4.24	19.86	1.00
270		2	13	37	0.9	4.24	6.29	0.34
271	B2	1	8	NA	NA	4.49	35.12	1.56
272		2	23	36	0.8	4.28	6.31	0.44
273	B3	1	8	NA	NA	3.79	38.07	1.15
274		2	23	18	1.2	4.02	4.18	0.12
McCALLUM BAY AREA OCCSR-82(3)A								
275	C1	1	3	NA	NA	5.67	2.24	0.08
276		2	20	14	1.3	6.10	0.31	0.01
277	C2	1	3	NA	NA	6.00	0.69	0.03
278		2	20	13	1.3	6.06	0.27	0.01
LITTLE O - NEW PROJECT								
279	D1	1	9	NA	NA	5.46	0.46	0.02
280		2	9	9	2.0	5.28	0.28	0.03

Lab #	Site	Layer designation	Depth cm	MC %	BD g cm^{-3}	pH	Total C %	Total N %
281	D2	1	3	NA	NA	6.25	0.89	0.05
282		2	14	12	1.4	5.57	0.37	0.02
283	D3	1	4	NA	NA	5.75	0.46	0.02
284		2	15	13	1.3	5.66	0.21	0.01

NA - Not Available (All surface soils were composite samples)

Table A3-3.1 Mehlich III extractable nutrients P, Ca, Mg, K, Zn, Cu, Mn and Fe concentrations for samples collected from the various central Florida sites. Layer designations are as follows: O1-organic litter accumulation, above the mineral soil, Ao-organic/mineral layer with significant root mass, A1-organic/mineral layer with "humus-type" material and minimal root mass, B-illuvial layer, C-mineral material.

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
FORT GREEN										
Morrow Swamp West										
101	90-191	Ao	517	1740	1010	34	1.5	0.2	2.5	343
102		A1	1260	2140	215	0	1.2	0.0	0.9	151
103		C	2160	2520	23	0	1.1	0.0	0.9	130
104	90-193	O1	466	5440	2620	200	3.9	1.2	2.3	369
105		A1	1270	2250	321	0	1.0	0.0	1.0	74
106		C	1790	2530	394	0	1.3	0.0	1.2	52
107		A1-1	555	3210	1130	51	2.6	0.4	1.4	121
108		C-1	1310	3200	752	0	1.9	0.0	2.4	100
109	92-194	Ao	459	2580	1230	37	2.0	0.2	7.3	88
110		A1	818	1310	379	1	1.0	0.0	1.6	69
111		C	777	852	174	0	0.9	0.0	0.5	52
112	92-196	O1	240	6890	2270	229	2.1	0.0	20.2	1430
113		Ao	374	2700	623	36	1.3	0.1	13.8	1160
114		A1	1110	2280	228	0	1.2	0.0	2.3	123
115		C	1040	2060	156	0	1.0	0.0	1.2	117
116	127-193	A1	371	1080	230	12	1.1	0.0	3.2	176
117		C	1020	2320	207	0	1.4	0.0	0.9	229
118	127-195	Ao	304	1380	321	14	1.2	0.0	26.9	314
119		A1	609	1630	401	0	1.2	0.0	2.6	266
120		C	373	3360	1670	0	1.0	0.0	2.5	301
121	127-197	Ao	189	2570	1140	186	2.3	0.8	8.8	541
122		A1	482	1400	317	0	0.9	0.0	1.0	183
123		C	663	1330	131	0	1.0	0.1	0.8	214
124	127-199	O	262	3630	2400	376	3.6	1.4	1.6	789
125		A1	710	1920	319	0	0.9	0.0	1.0	184
126		C	629	1550	249	0	0.8	0.0	0.8	263

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
Agrico Swamp East										
127	T6-0	Ao	845	4610	1290	108	2.8	0.8	6.6	820
128		A1	160	4200	1280	10	1.8	0.4	8.0	718
129		C	341	3590	655	5	1.2	0.0	7.6	237
130	T6-150	Ao	432	7640	2180	164	4.3	1.2	10.4	996
131		A1	123	2670	761	0	0.6	0.0	6.4	390
132		C	781	10500	1380	15	0.7	0.0	14.6	230
133	T6-300	Ao	236	6700	2340	77	2.3	0.2	12.0	843
134		A1	94	4530	1670	6	0.8	0.0	7.9	794
135		C	341	8760	1560	18	0.6	0.0	15.0	367
136	T7-(-300)	Ao	824	3120	673	76	2.7	0.5	6.8	492
137		A1	1020	2870	552	4	1.1	0.1	2.8	279
138		C	1310	3280	684	25	2.3	1.0	4.6	230
139	T7-0	Ao	455	6470	2020	111	4.0	0.8	9.5	869
140		A1	98	4170	1580	4	1.3	0.1	7.8	765
141		C	531	3230	695	4	1.1	0.1	5.5	338
142	T7-100	Ao	420	5710	1710	120	3.2	0.3	8.0	669
143		A1	143	3840	1100	10	0.9	0.0	6.5	607
144		C	357	3130	722	3	3.9	0.0	6.1	310
145	T7-200	Ao	241	5690	1650	97	2.3	0.5	12.4	937
146		A1	101	4120	1520	7	0.8	0.0	10.2	706
147		C	260	4200	2130	2	0.8	0.0	12.6	436
FORT LONESOME										
148	Dogleg Branch	A	1080	1920	480	8	1.6	0.3	2.9	572
149		B	1240	1240	321	6	1.1	0.2	2.3	682
150	Lizard Branch	A1	565	1290	245	72	1.9	0.0	2.8	245
151		C	1600	1480	260	26	1.9	0.2	8.1	400
152		A	452	1200	231	60	1.5	0.0	3.1	196
153		B	1320	876	198	8	1.0	0.1	8.5	401
154		A	1700	2140	406	83	3.1	0.6	12.7	473
155		C	1750	2270	389	13	2.4	0.4	11.7	476
156	Mc Mullen	A	76	698	172	8	1.8	0.0	2.1	212
157		B	35	125	22	0	1.0	0.0	0.2	15

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
158	Jamerson Branch	A	436	211	77	10	1.2	0.0	3.5	645
159		B	431	203	41	13	18.7	0.1	4.1	524
160		A	719	734	157	12	2.6	0.5	13.9	586
161		B	516	394	99	0	1.4	0.0	3.0	269
162	Miles Grove	A	358	796	220	13	2.2	0.7	3.4	189
163	Southeast	B	1340	315	29	6	1.0	0.0	0.6	33
164		A	1120	740	106	12	1.2	0.4	1.5	94
165		C	804	312	65	8	2.2	0.2	1.2	85
166	Miles Grove	A	1210	929	56	16	1.4	0.4	1.7	103
167	Northwest	C	1270	1310	54	4	1.6	0.2	1.2	135
168		A	821	1620	398	32	15.1	4.0	11.5	587
169		B	315	639	101	0	5.1	3.9	6.4	301
HAYNSWORTH										
170	Tadpole	A	2320	4120	757	11	15.4	2.2	10.8	966
171		C	766	910	59	0	1.5	0.0	0.9	121
172	East Old Fort	A	1670	2650	86	17	1.9	0.4	1.1	190
173	Green Road	C	1580	2350	56	12	1.5	0.3	0.7	146
174		A	899	1070	41	5	1.4	0.0	0.9	87
175		C	1110	1420	68	3	1.4	0.0	1.3	106
176		A	1090	843	30	8	1.1	0.0	0.6	72
177		C	847	567	24	0	0.9	0.0	0.4	67
178	North County	A	1360	2080	160	27	1.8	0.4	1.0	303
179	Road 630	B	1250	1460	87	8	1.3	0.1	0.6	159
180		Ao	1030	1880	221	80	3.4	0.3	2.8	202
181		C	1330	1310	43	12	1.3	0.2	0.5	119
182	South County	A	999	1690	107	6	3.5	0.2	2.2	275
183	Road 630	C	953	1520	88	4	1.6	0.1	2.3	158
184		A	764	1050	75	11	1.4	0.0	1.7	117
185		B	739	1220	71	1	1.1	0.0	1.1	101
FOUR CORNERS										
186	FCO Sec. 15	A	192	101	8	0	0.5	0.0	0.1	216
187		B	950	97	16	0	0.8	0.0	0.2	919

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
188		A	70	110	15	2	0.7	0.0	0.2	110
189		B	96	31	3	0	0.6	0.0	0.1	54
190	FCO Sec 1	A	354	2160	608	36	3.8	0.4	3.6	721
191		C	650	1040	149	0	0.9	0.0	1.6	80
192		A	382	1960	482	41	4.8	0.4	2.6	756
193		C	589	907	115	0	0.9	0.0	1.3	72
NORALYN/PHOSPHORIA										
194	Section 12	A	341	1250	229	2	1.0	0.0	1.4	226
195	(N. Hooker's	B	391	1190	230	0	0.9	0.0	2.0	263
196	Prairies)	A	288	1420	346	20	1.6	0.1	3.2	260
197		B1	183	1030	236	4	0.6	0.0	2.6	261
198		B2	204	1040	222	3	0.7	0.1	2.7	160
199	Section 7/12	A	177	1430	397	6	0.9	0.2	0.9	378
200		B	252	884	180	3	1.2	0.0	0.6	242
201	South	A	233	818	470	28	1.2	0.1	2.6	82
202	Pebbledale Sec. 6	C	337	700	40	0	1.0	0.0	0.9	35
203		Ao	244	786	465	9	1.5	0.1	2.8	72
204		A1	337	635	49	0	1.1	0.0	0.7	29
205		C	190	357	29	0	1.0	0.0	0.4	19
206		Ao	334	873	302	16	1.4	0.1	1.5	80
207		A1	332	726	94	2	1.1	0.0	0.9	68
208		C	848	826	149	6	3.4	5.2	0.3	39
209	East Farm-	A	455	911	163	53	2.3	1.0	1.6	407
210	land Cateye	B	760	829	67	12	0.9	0.0	0.6	85
211	Sweetwater	Ao	554	1880	352	23	2.5	0.5	2.6	256
212	Branch	A1	806	1690	186	5	1.7	0.4	1.6	391
213		B	772	1560	101	9	1.3	0.3	1.3	258
214	South Tiger	Ao	337	1860	675	43	1.2	0.4	1.8	436
215	Bay	A1	509	1180	201	8	0.7	0.1	1.0	354
216		B	812	1730	307	21	0.9	0.2	1.4	635
CLEAR SPRINGS										
217		O1	211	5530	2410	222	11.5	0.6	21.9	678
218		A	512	4480	1640	113	10.2	1.5	21.3	693
219		B	559	4400	1630	75	7.9	2.3	24.3	658

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg⁻¹							
PAYNES CREEK										
220	1	A	116	1650	484	18	0.9	0.2	2.2	430
221		C	496	1180	55	0	1.1	0.0	1.5	45
222	2	C1	386	937	35	0	1.3	0.0	1.0	37
223		C2	225	554	29	0	0.6	0.0	0.8	27
224	3	A	100	1310	368	20	0.9	0.1	1.8	317
225		C	317	817	52	0	0.6	0.0	0.7	26
226	4	C1	573	1150	91	7	0.6	0.2	0.7	174
227		C2	943	1840	123	10	0.5	0.3	1.3	259
228	5	A	144	1750	363	17	0.7	0.2	1.8	410
229		C	220	307	68	10	1.5	0.1	0.2	239
PARCEL B										
230		AO	239	3090	647	243	11.6	1.2	17.4	296
231		A1	414	2400	459	112	4.5	0.7	13.2	441
232		B	560	2380	438	65	2.3	0.4	7.5	583
PARCEL B (Peace River Flood Plain)										
233		AO	213	5060	787	246	21.2	1.7	18.2	475
234		A1	543	3320	461	70	12.6	1.6	8.3	538
235		C	895	2700	341	30	9.7	0.9	7.2	685
CS-19										
236		AO	162	6440	3140	141	8.0	0.8	159.0	605
237		A1	222	5120	2670	72	5.0	0.6	66.8	603
238		C	331	8040	4960	18	7.8	3.7	21.6	212
239		AO	201	5270	2600	252	9.7	0.3	86.4	662
240		A1	294	5030	2070	89	7.3	0.1	101.0	712
241		B	395	3460	1700	45	3.2	0.3	50.2	652
242		C	497	1980	1080	25	1.2	0.2	7.6	564
SP1										
243		O	182	5370	2640	717	5.0	1.0	6.8	482
244		A	574	1800	664	20	1.6	0.4	3.1	444
245		C	456	1970	930	18	2.3	0.7	4.8	433

Lab # Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
		mg kg^{-1}							
BIRD PARCEL									
246	O	259	7130	2280	391	8.5	1.7	40.1	299
247	A	194	3040	1010	222	2.0	0.8	33.2	386
248	C	485	1140	202	15	1.2	0.8	3.0	150
MIZELLE CREEK									
249	A	194	839	200	60	1.4	0.1	4.8	323
250	C	346	714	90	4	1.1	0.1	1.8	71
k6-NATIVE									
251	A1	328	710	71	7	1.2	0.3	5.0	163
252	A2	396	2010	291	21	2.2	0.6	4.9	280
253	B	129	311	30	4	0.9	0.1	0.2	71
UNIT H									
254	AO	332	1080	446	265	1.6	0.7	1.7	93
255	A1	392	688	131	9	1.2	0.5	0.6	46
256	C	570	950	109	9	2.2	0.5	0.8	57
82-1									
257	AO	633	2220	840	71	2.1	0.5	6.7	538
258	A1	1280	1760	384	18	1.2	0.2	3.5	438

Table A3-3.2 Mehlich III extractable nutrients P, Ca, Mg, K, Zn, Cu, Mn and Fe concentrations for samples collected from the various north Florida sites. Layer designations are as follows: 1-surface (organic); 2-subsurface (inorganic).

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
OCC-SR-SP(4)										
259	A1-50 ft from	1	63	616	180	23	1.1	0.0	4.0	58
260	trail beginning	2	158	652	178	8	0.4	0.0	0.8	90
261	A2-80 ft from	1	72	564	173	16	1.0	0.0	4.3	60
262	trail beginning	2	130	548	171	6	0.6	0.0	0.8	83
263	A3-150 ft from	1	59	784	286	54	1.0	0.0	6.1	100
264	trail beginning	2	146	233	58	4	0.4	0.0	0.2	154
265	A4-open water	1	68	1180	500	56	1.0	0.0	5.9	115
266	pond	2	169	568	188	9	0.6	0.0	0.9	82
267	A5-upland; dry	1	106	404	87	32	0.9	0.0	3.2	58
268		2	154	269	42	8	0.4	0.0	0.2	56
McCALLUM BAY AREA - NATURAL AREA										
269	B1	1	56	57	33	41	1.1	0.0	0.6	17
270		2	32	25	6	6	0.6	0.0	0.2	16
271	B2	1	39	208	77	66	1.3	0.0	1.8	27
272		2	34	41	10	4	0.7	0.0	0.2	18
273	B3	1	41	193	136	93	6.3	0.0	2.4	77
274		2	12	10	5	4	1.1	0.0	0.1	23
McCALLUM BAY AREA OCCSR-82(3)A										
275	C1-high area	1	148	596	115	31	0.5	0.0	1.4	60
276	fairly dry	2	216	712	105	10	0.4	0.0	0.5	66
277	C2-fairly dry	1	196	512	62	14	0.3	0.0	1.1	49
278		2	225	568	58	7	0.4	0.0	0.6	54

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
LITTLE O - NEW PROJECT										
279	D1-upland (dry)	1	149	373	40	11	0.4	0.0	0.3	60
280		2	106	488	100	13	0.5	0.0	0.3	85
281	D2-20 ft to wet	1	122	584	94	29	0.7	0.0	1.2	73
282	edge; dry	2	150	528	78	12	0.4	0.0	0.7	117
283	D3-225 ft from	1	189	528	69	24	0.6	0.0	1.0	96
284	upland - moist (slight depression)	2	195	548	54	14	0.6	0.0	0.6	62

Table A3-4.1 Total P, Ca, Mg, K, Zn, Cu, Mn and Fe for samples collected from the central Florida sites. Layer designations are as follows: O1-organic litter accumulation, above the mineral soil, Ao-organic/mineral layer with significant root mass, A1-organic/mineral layer with "humus-type" material and minimal root mass, B-illuvial layer, C-mineral material.

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
FORT GREEN										
Morrow Swamp West										
101	90-191	Ao	2610	4160	870	140	74	3.0	4.5	965
102		A1	3620	5450	405	115	40	1.0	4.5	970
103		C	5750	4935	170	135	74	1.5	3.5	985
104	90-193	O1	5550	14150	3120	405	81	4.5	12.0	1505
105		A1	5050	7250	505	140	70	1.5	5.5	895
106		C	7500	11950	920	170	70	1.5	8.0	1010
107		A1-1	6200	12150	1290	250	79	2.5	8.5	1110
108		C-1	9500	20850	1800	220	72	2.0	13.0	1190
109	92-194	Ao	4490	6600	1000	150	75	1.5	8.5	795
110		A1	8100	15450	500	135	69	1.5	6.0	775
111		C	5150	3480	360	150	71	1.5	3.5	920
112	92-196	O1	5200	13200	2155	370	79	5.5	34.0	7350
113		Ao	4385	6500	680	140	73	2.0	17.5	2490
114		A1	8550	10300	525	210	75	2.0	8.5	1760
115		C	8800	16050	400	240	75	2.0	11.0	1845
116	127-193	A1	4965	9350	405	255	83	2.0	9.5	1415
117		C	4340	7000	380	255	78	1.5	5.0	1255
118	127-195	Ao	5250	12000	495	140	9	2.0	32.0	2100
119		A1	7300	10300	745	250	74	2.0	9.5	4480
120		C	7000	16900	6400	330	77	2.0	12.5	3070
121	127-197	Ao	5100	9650	1005	365	77	2.5	12.5	1545
122		A1	3880	6250	540	155	74	1.5	5.0	2220
123		C	5100	7000	370	200	80	2.0	6.5	1700
124	127-199	O	2955	13200	3600	570	78	5.0	11.0	2375
125		A1	8350	20400	720	155	73	1.5	9.0	1880
126		C	4595	10400	715	135	74	1.0	6.5	1600

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
Agrico Swamp East										
127	T6-0	Ao	22950	27700	2405	1220	84	6.5	22.5	7300
128		A1	7700	20300	1670	250	68	4.0	18.5	3070
129		C	8450	10800	950	300	76	2.0	11.0	2315
130	T6-150	Ao	17600	26400	3030	1015	79	6.5	25.0	6300
131		A1	7350	15850	1840	360	74	2.0	16.5	2460
132		C	19100	49450	4000	890	74	3.0	37.0	5550
133	T6-300	Ao	8850	20550	3320	605	74	5.5	23.5	4360
134		A1	4245	16550	2050	190	69	3.0	17.5	2420
135		C	17300	46950	3055	670	70	2.5	28.5	3015
136	T7-(-300)	Ao	7150	13700	840	340	53	1.5	11.0	1930
137		A1	9550	18450	1345	290	73	1.5	13.0	2140
138		C	24650	57000	1970	690	77	4.5	30.0	3045
139	T7-0	Ao	20150	30000	3180	1200	88	7.0	27.5	6700
140		A1	5150	18650	3810	320	74	3.5	18.0	2565
141		C	7700	18150	1170	220	19	1.5	13.5	1955
142	T7-100	Ao	16450	21850	2545	1005	32	6.0	21.5	5500
143		A1	6150	14850	1610	325	21	2.5	14.5	2380
144		C	8950	11000	1030	500	23	2.0	10.5	1970
145	T7-200	Ao	10100	19150	2185	635	25	4.5	23.0	4000
146		A1	7000	22200	3185	265	20	2.5	21.5	2465
147		C	5150	28200	10600	205	17	1.5	29.5	1575
FORT LONESOME										
148	Dogleg Branch	A	4150	3590	705	160	20	1.0	5.5	1275
149		B	5100	4770	805	405	21	1.5	7.5	2025
150	Lizard Branch	A1	3960	3730	325	200	20	2.0	5.0	820
151		C	13850	13900	690	565	25	2.5	17.0	2230
152		A	2400	2440	295	160	19	1.5	5.0	630
153		B	12800	4260	460	415	22	3.0	12.0	1680
154		A	14100	16300	1015	600	26	3.0	23.5	2345
155		C	14800	16250	910	540	27	2.5	22.0	2675
156	Mc Mullen	A	540	1095	245	60	17	0.5	3.5	530
157		B	130	230	35	30	30	0.5	0.5	41

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
158	Jamerson Branch	A	3075	970	375	270	23	1.5	8.0	1805
159		B	2170	745	375	245	22	1.5	8.0	1720
160		A	4455	1915	250	160	21	1.5	19.0	1310
161		B	2290	1420	260	180	19	1.0	5.5	825
162	Miles Grove	A	1100	1760	500	130	9	2.5	5.5	630
163	Southeast	B	3070	2290	370	300	23	1.0	3.5	910
164		A	3580	3545	600	220	23	1.5	5.0	760
165		C	3890	1195	300	205	22	2.0	3.5	935
166	Miles Grove	A	5300	2670	280	275	20	2.0	5.0	745
167	Northwest	C	3610	4250	260	205	21	1.5	5.0	690
168		A	12200	7250	1210	935	34	2.0	22.5	4670
169		B	1230	1005	210	120	24	2.0	7.5	670
HAYNSWORTH										
170	Tadpole	A	49150	147000	2075	950	56	8.5	64.5	4175
171		C	2455	2825	125	100	27	0.0	3.5	447
172	East Old Fort	A	15300	24000	695	480	26	3.0	8.5	1685
173	Green Road	C	11300	12450	425	435	24	2.0	5.5	1245
174		A	4620	8550	210	160	28	1.0	7.0	550
175		C	6100	12700	235	155	18	1.0	8.0	595
176		A	3135	3670	120	110	18	0.5	3.5	430
177		C	2555	2960	100	100	16	0.5	3.5	356
178	North County	A	11000	16950	680	520	119	2.5	9.5	2005
179	Road 630	B	5550	5200	280	245	20	1.5	3.5	870
180		Ao	7900	12800	640	510	25	2.0	9.0	1665
181		C	8700	13050	330	230	22	2.0	7.0	915
182	South County	A	13250	29950	520	255	26	1.5	18.0	1455
183	Road 630	C	20700	48600	580	320	26	2.5	34.0	2195
184		A	10150	24250	315	195	23	1.5	13.5	825
185		B	3260	6450	200	105	19	0.5	4.5	505
FOUR CORNERS										
186	FCO Sec. 15	A	680	1345	40	15	18	0.0	1.0	535
187		B	2230	310	110	35	19	1.5	2.5	10700

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
						mg kg^{-1}				
188		A	180	330	50	30	24	1.0	1.0	298
189		B	150	215	25	35	14	0.5	0.5	142
190	FCO Sec 1	A	7750	19300	1420	375	36	4.0	16.0	4020
191		C	8350	21700	405	145	18	1.0	10.5	467
192		A	5300	12100	840	310	24	2.5	9.0	2505
193		C	3920	10200	200	55	18	0.0	5.0	265
NORALYN/PHOSPHORIA										
194	Section 12	A	3455	7050	455	100	21	1.0	7.0	1520
195	(N. Hooker's Prairies)	B	3420	6900	435	95	20	1.0	6.5	1200
196		A	2480	5100	495	90	18	0.5	8.0	1100
197		B1	2500	4895	445	90	21	1.5	41.5	4300
198		B2	2845	6200	410	75	17	1.0	7.5	1165
199	Section 7/12	A	2525	4250	755	90	19	1.0	4.0	2020
200		B	4400	9250	395	90	17	1.0	7.0	1320
201	South	A	13800	34100	1120	285	27	1.5	20.5	1050
202	Pebbledale Sec. 6	C	6100	14800	125	65	25	0.5	9.5	397
203		Ao	7700	18300	680	135	20	0.5	12.5	590
204		A1	4705	10600	125	60	20	2.0	6.0	226
205		C	4680	10600	100	50	19	0.5	5.5	190
206		Ao	8950	19050	665	290	23	1.0	13.0	1175
207		A1	10500	23050	290	145	20	1.0	13.0	845
208		C	15700	6700	435	435	26	2.5	6.0	1750
209	East Farm-	A	1475	1970	250	160	20	3.0	4.5	1240
210	land Cateye	B	1655	1680	240	215	18	2.0	5.0	955
211	Sweetwater	Ao	19450	19900	1120	850	34	5.5	19.0	7000
212	Branch	A1	14600	19600	590	490	21	3.0	12.5	3995
213		B	14500	22900	540	380	41	3.5	21.5	5100
214	South Tiger	Ao	6750	11350	1160	390	20	1.5	10.0	3170
215	Bay	A1	7800	17900	520	195	18	1.0	11.5	4010
216		B	12100	20950	815	400	21	1.5	13.0	4240
CLEAR SPRINGS										
217		O1	30200	71000	5500	1095	82	13.0	75.0	10300
218		A	44200	147000	6650	1585	86	15.5	76.0	13400
219		B	51500	147000	7450	1730	94	17.0	90.0	16700

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
PAYNES CREEK										
220	1	A	4530	11900	1295	145	20	1.5	12.5	3410
221		C	9250	24100	265	110	8	1.0	11.5	660
222	2	A	7600	19600	205	90	7	0.5	9.5	488
223		C	5500	14300	150	75	7	0.5	8.0	411
224	3	A	2980	8250	765	95	7	1.5	8.0	2060
225		C	10850	28150	330	115	8	0.5	15.0	840
226	4	A	3500	3835	200	105	8	1.0	3.0	1075
227		C	10450	20650	465	260	6	1.0	7.0	1565
228	5	A	2755	5950	865	115	10	1.0	7.5	2490
229		C	3855	2725	225	145	7	2.0	2.5	1010
PARCEL B										
230		Ao	28750	58000	2905	680	8	7.5	58.5	8550
231		A1	31700	66500	2620	480	48	6.0	50.5	9250
232		B	32100	75000	2375	260	37	4.5	38.5	8000
PARCEL B (Peace River Flood Plain)										
233		Ao	10050	22900	1700	480	25	6.0	39.5	4580
234		A1	10000	19800	1425	310	43	5.0	22.0	4360
235		C	11050	21500	1380	330	33	6.0	20.0	4550
CS-19										
236		Ao	19400	55000	15850	725	52	10.5	530.0	15350
237		A1	24800	147000	28950	765	47	12.0	176.5	11600
238		C	36800	147000	50000	660	38	15.0	86.0	2160
239		Ao	15950	29100	6450	725	65	8.0	333.5	16050
240		A1	19950	32900	5950	615	53	8.0	242.5	16900
241		B	21450	54000	10050	440	29	6.0	95.5	10600
242		C	25250	61000	3525	250	23	3.5	27.0	9200
SP1										
243		O	7600	21300	6550	1030	30	4.5	25.5	5500
244		A	7100	17250	3160	1070	25	4.5	71.0	4135
245		C	21300	57000	7550	410	25	4.0	31.0	4680

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
						mg kg^{-1}				
BIRD PARCEL										
246		O	7000	17500	3195	1090	25	5.0	71.0	4055
247		A	9950	22000	1600	790	16	4.5	65.0	2640
248		C	8400	16250	595	395	13	3.0	16.0	1260
MIZELLE CREEK										
249		A	10250	25150	415	230	9	1.0	20.0	1170
250		C	7750	18200	280	180	8	1.0	14.0	640
k6-NATIVE										
251		A1	2390	2590	280	185	8	1.5	10.0	760
252		A2	5900	7200	945	480	11	2.5	18.0	2165
253		B	400	590	55	45	6	0.5	1.0	137
UNIT H										
254		Ao	2325	3530	425	305	9	1.0	4.5	705
255		A1	3095	3200	260	235	10	1.5	3.0	520
256		C	4080	5850	385	360	10	1.5	6.0	825
82-1										
257		Ao	19400	39700	2810	470	27	4.0	29.0	6950
258		A1	25300	48700	1600	310	25	3.5	20.0	5600

Table A3-4.2 Total P, Ca, Mg, K, Zn, Cu, Mn and Fe concentrations for samples collected from the various north Florida sites. Layer designations are as follows: 1-surface (organic); 2-subsurface (inorganic).

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
	OCC-SR-SP(4)									
259	A1-50 ft from	1	7750	19150	850	310	15	0.0	28.0	1960
260	trail beginning	2	11300	26700	985	410	13	0.0	23.0	2960
261	A2-80 ft from	1	6550	15600	865	310	16	0.0	31.0	2070
262	trail beginning (slightly off trail)	2	8850	19300	940	320	21	0.0	18.0	2670
263	A3-150 ft from	1	4045	6850	1535	740	17	0.0	36.5	3610
264	trail beginning	2	1680	2005	415	205	12	0.0	5.0	1705
265	A4-open water	1	11400	24450	1895	745	17	0.0	46.0	4135
266	pond	2	11500	24050	1050	425	15	0.0	21.0	2940
267	A5-upland; dry	1	1605	3115	660	365	13	0.0	24.5	1745
268		2	1470	1630	575	300	13	0.0	5.5	2515
	McCALLUM BAY AREA - NATURAL AREA									
269	B1	1	1085	290	380	290	9	2.5	6.0	750
270		2	595	185	340	210	7	1.0	4.0	735
271	B2	1	1035	1070	350	300	27	0.0	8.5	585
272		2	705	365	535	260	11	0.0	5.5	1070
273	B3	1	670	910	485	340	39	0.0	10.5	1030
274		2	90	85	80	50	7	0.0	1.0	203
	McCALLUM BAY AREA OCCSR-82(3)A									
275	C1-high area	1	16600	35200	1215	770	20	1.0	41.5	3135
276	fairly dry	2	17550	35300	1090	765	19	0.0	40.0	4285
277	C2-fairly dry	1	12050	26450	810	510	23	0.0	27.5	2260
278		2	15050	33700	875	565	17	0.0	32.0	2620
	LITTLE O - NEW PROJECT									
279	D1-upland (dry)	1	3095	7400	440	330	12	0.0	8.5	1445
280		2	1800	3665	750	380	25	0.0	7.0	2885
281	D2-20 ft to wet	1	5250	8700	805	705	26	0.0	15.0	2350
282	edge; dry	2	3505	8000	780	505	14	0.0	15.0	4535

Lab #	Site	Layer designation	P	Ca	Mg	K	Zn	Cu	Mn	Fe
			mg kg^{-1}							
283	D3-225 ft from	1	5250	8400	775	670	14	0.0	14.5	2740
284	upland - moist (slight depression)	2	9100	7100	670	700	17	0.0	11.0	2775

SECTION 4 - WATER QUALITY

By
Thomas L. Crisman, Principal Investigator

with
Gregory Bitter and Valma Jessamy

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 4 - WATER QUALITY

EXECUTIVE SUMMARY

The purpose of this section is to evaluate water chemistry trends of constructed wetlands and streams relative to natural systems of Florida. Data were compiled and synthesized from several sources to determine the success of reclamation projects. Site visits were made to over 164 reclaimed and natural streams and wetlands in the central and northern Florida phosphate mining regions. The main questions addressed relative to reclaimed wetlands and streams are:

- Does water chemistry in constructed wetlands and streams approximate that found in natural systems?
- If so, how long does it take to reach such conditions following construction?
- What are the interactions between reclaimed wetlands and streams that possibly affect water chemistry?

The current database consists of physical and chemical data from fifteen constructed wetlands. This is a very low percentage of the total number of constructed wetlands in Florida. Only one reclaimed stream and one stream which receives discharge from a constructed wetland have been monitored for water quality.

In addition to comparing trends relative to age among constructed sites, both wetland and stream databases were compared to comparable data from similar natural systems of central and northern Florida. Throughout the study, development of trends and conclusions has been hindered by the general paucity of the database for constructed wetlands and streams on phosphate mined lands. Water chemistry parameters included in the database for constructed wetlands and streams are those that are indicative of trophic state (eutrophication) and associated oxygen stress for aquatic biota.

SECTION 4 - WATER QUALITY

INTRODUCTION

Water chemistry data have been compiled from the monitoring reports for constructed and natural wetlands and streams in the Florida phosphate mining district. The purpose of this project is to determine if the available data are adequate to draw conclusions on whether or not constructed wetlands and streams can mimic natural Florida systems and how long it will take for this to be achieved.

CONSTRUCTED WETLANDS

Over 164 constructed and natural wetlands were visited in central and northern Florida phosphate mining districts during the course of this study. Water quality data from twelve constructed wetlands ranging in age from zero to eight years old were examined. A summary of the age and design type for each site and parameters sampled are provided in Table 4-1.

Most constructed wetlands have been contoured with sand tailings or capped with mulch from two main sources;

1) Wetlands to be mined for phosphate
2) Stock piles with overburden saved from pre-mining.

Dissolved oxygen pH, conductivity, total phosphorus, total nitrogen, and biological oxygen demand are the main parameters sampled. The monitoring reports cover the period 1983 to 1993 and average a maximum of six years for each site.

RECLAIMED STREAMS

Industry-wide, there are only a handful of stream relocation and reclamation projects that have been completed (Table 4-2). Four general stream types have been created on reclaimed sites,

(1) Channels which function as conduits for the efficient transport of water during high floods with trapezoidal shaped steep slopes
(2) Shallow vegetated swales
(3) Meandering channels in reforested or undisturbed forested floodplains
(4) Channels which have not been connected to existing stream drainage networks.

Presently, water quality data are available for only one reclaimed stream and one mine influenced stream Headwaters of these streams are often reclaimed wetlands, which also form part of the riparian corridor. In watersheds where mining activities are ongoing, the connection of reclaimed

TABLE 4-1 CONSTRUCTED WETLAND DATABASE

NAME	YEAR CONSTRUCTED	DESIGN	PARAMETERS MONITORED
AW	1982	Overburden and sand tailings; mulched from donor marsh; 60 hectares	pH, Conductivity, Phosphorus, Nitrogen Dissolved Oxygen, BOD
AE	1986	Hand planting and mulching; 83 hectares	pH, Conductivity, Phosphorus, Dissolved Oxygen
W8.4	1986	Hand planting and mulching; 3.3 hectares	pH, Conductivity, Phosphorus, Nitrogen Dissolved Oxygen, BOD
SA-1	1987	Capped with sand tailings; 4 hectares	pH, Conductivity Phosphorus
GA	1987	Overburden saved from pre-mining; 4 hectares	pH, Conductivity Phosphorus
NOWA	natural		pH, Conductivity Phosphorus, Nitrogen Dissolved Oxygen, BOD
P90	1989	Sand tailings; Planted 1990; 24.3 hectares	pH, Conductivity Phosphorus, Nitrogen Dissolved Oxygen
HP90	1990	Sand tailing and capped with mulch; 7.3 hectares	pH, Conductivity Phosphorus, Nitrogen Dissolved Oxygen
CS88	1989	Graded and planted; 3.6 hectares	pH, Conductivity Phosphorus, Nitrogen Dissolved Oxygen
CS86	1985	Planted 1987; 24.3 hectares	pH, Phosphorus Nitrogen, Dissolved Oxygen
CS84	1985	Mulched and planted; 2.4 hectares	pH, Phosphorus, Nitrogen, Dissolved Oxygen

Frequency: Samples were collected monthly
Replicates: Unknown
Method: Grab samples from open water areas

Table 4-2. MINE INFLUENCED AND RECLAIMED STREAMS DATABASE
*RES = Reclaimed Stream MIS = Mine influenced Stream

COUNTY	STREAM	AGE /YR	STATUS	PARAMETERS SAMPLED	SAMPLING TECHNIQUE
Polk	RES 1				
	Upper	2	Reclaimed	Vegetation	
	Lower	7	Reclaimed	Vegetation	
Polk	RES 2			Vegetation	
	Upper	3			
	Lower	7			
Polk	RES 3	14	Reclaimed	Vegetation	
Columbia	RES 4	4	Reclaimed (connected)	-Water quality -Macroinvertebrate -Fish -Flow -Weather conditions	 Core; Ponar; Qualitative -3 replicates Electric shock, multiple removal
Hardee	RES 5	6	Reclaimed (connected)	-Macroinvertebrate (pre and post mining)	Hester-Dendy multiple plates -4 weeks incubation
Hardee	RES 6	3	Reclaimed (connected ?)	-Macroinvertebrate	Core - 3.5 cm diameter; -10 cm - depth -3 replicates ; 0.25mm mesh
Polk	RES 7	4	Reclaimed	Macroinvertebrate	Core - 3.5 diameter -10 cm -depth
Polk	RES 8	10	Reclaimed (connected ?)	Vegetation	
Polk	RES 9	7	Reclaimed	Vegetation	
Polk	RES 10	6	Reclaimed	Vegetation	
Polk	RES 11	6	Reclaimed	Vegetation	
Polk	RES 12	5	Rclaimed	Vegetation	
Polk	RES 13	4	Reclaimed	Vegetation	
Polk	RES 14	4	Reclaimed	Vegetation	
Polk	MIS 1	83-89	Mine influenced	-Water quality -Macroinvertebrate -Surface water levels	 Hester -Dendy multiple plates -28 days incubation
Columbia-Suwannee	MIS 2	91-93	Mine influenced	-Water quality -Flow -Weather conditions	
Hardee	PRE 1	91	Pre-mining	-Macroinvertebrate	Hester-Dendy -28 days incubation -4 replicates

streams with downstream waters of the state has been delayed until large scale landscape restoration is completed.

OVERVIEW OF WATER QUALITY

WETLANDS

Few studies have been published that specifically address water quality of freshwater wetlands on phosphate mined lands. The notable exception is the work of Kiefer (1991) which examined age related trends in water chemistry and the development of bottom sediments for 22 constructed wetlands on phosphate mined lands of central Florida ranging in age from just constructed to eight years old. In addition to monitoring each site for one year, three wetlands were monitored for the first two or three years following construction. This study concluded that both water chemistry and sediment characteristics reach stability within four to five years following construction and that conditions are generally within the range exhibited by natural wetlands of central Florida. It appeared that development of a system "memory" of organic sediments helped to stabilize water chemistry with time.

Studies conducted on natural wetlands have shown that water quality is dictated by sediment redox potential, system productivity (autogenic or allogenic), overland runoff and to a lesser extent climatology (Mitsch and Gosselink, 1989). As nutrient availability changes over time, system productivity will respond correspondingly. Growth and senescence of aquatic plants contribute to both sediment development and cycling of nutrients (phosphorus and nitrogen). Together with input from the surrounding watershed, these processes directly influence water quality parameters in wetlands. Knowledge of successional processes operating within a wetland is therefore important in explaining trends in water quality and for developing predictive models for change over time.

STREAMS

The reclamation of drainage systems has become increasingly important in phosphate-mined landscapes in Florida. However, relocation of streams to allow mining and the subsequent rehabilitation of the system in terms of water quality is considered controversial because virtually no data have been analyzed to demonstrate or refute that a stream and its environs can be reclaimed (Robertson, 1985).

Studies on stream geomorphology (Leopold et al. 1964) and ecology (Hynes 1970) describe streams as open ended dynamic systems that have an inherent ability to cleanse themselves. The most important feature of a stream channel is that it is self-formed and self-maintained by alternating erosion of the banks and bed and deposition of sediment. It is important to note both that streams evolve through geologic time and that the geomorphological processes operating currently are the same as those through which this evolution took place (Hynes 1975). Therefore, streams are persistent features in the changing geologic landscape.

The channel, surrounding watershed, and biotic and abiotic components constitute a stream ecosystem. By processing and exporting particulate detritus, stream ecosystems function in energy transfer among the landscape features to which they are connected (Ward 1989). These may include wetlands, lakes, forested floodplains, or streams of another order.

In addition to their function in the maintenance of hydrologic regime, streams serve as migratory routes for the movement of species between ecosystems (Ward 1989). A stream flowing into another ecosystem provides a constant source of nutrients (nitrogen and phosphorus), and food (detritus, phytoplankton, macroinvertebrates and vertebrates). These benefits are in turn provided to streams by the systems they are connected to. This is of particular importance in the reclamation of disturbed landscapes as streams may serve as pathways along which recovery can take place.

METHODS

WETLANDS

Water chemistry data were compiled from reports supplied by individual mining companies. Due to the spotty nature of the database for some sites, the current analysis has been limited to five constructed and two natural wetlands from this data source. Water chemistry data from these seven sites plus seven additional sites from the database of Kiefer (1991) were used in the current set of analyses.

Data for each physical and chemical parameter for individual sampling events were averaged to provide an annual mean for each wetland included in the database. Each annual mean was then reported relative to its chronological age following wetland construction. This permitted development of general trends for the database relative to wetland age. Parameters included in the current analysis include pH, dissolved oxygen, specific conductance, total phosphorus, total nitrogen and biological oxygen demand.

STREAMS

This section provides an analysis done for a relocated stream and a mine-influenced stream The projects are of different ages and monitoring reports date from 1983 to 1993. Data were compiled from several sources and analyzed to determine:

1) If water quality in relocated and mine-influenced streams resembles that of natural streams.
2) What is the influence of discharge from constructed wetlands on streamwater quality.

We were concerned about both the adequacy of the available information from the relatively sparse database, and whether sufficient peripheral information were included to allow interpretation.

Sampling methods and techniques, frequency of sampling, number of replicates and length of the monitoring record, were important as they affect data analysis and interpretation of observed trends. All data from relocated and mine-influenced streams were discussed relative to comparable data from un-impacted streams of the region where possible.

RESULTS

CONSTRUCTED WETLANDS

Summary tables containing monitoring data for each reclaimed wetland are provided in the appendix for this section. Since the main objective of this study was to analyze emergent trends for water quality, the wetlands are discussed collectively for each parameter considered. Mean yearly values are graphed for each parameter and for each constructed wetland monitored.

pH

The pH of constructed wetlands regardless of age is consistently above 6.0 (Figure 4-1 and 4-2). While the maximum pH reported for wetlands of 0-2 years often ranges between 9.0 and 10.0, there is a tendency for the maximum reported value to decline with wetland age to levels between 8.0 and 9.0 for systems greater than three years age. Values in constructed wetlands often approximate those of natural systems (4.5-6.5 pH) within two years following creation. It should be noted that pH values are strongly influenced by algal photosynthetic rates and thus can show strong diel variation within a system if either phytoplankton or epiphytic algae are major contributors to the productivity base of a system As time of sampling was not provided for any system we were unable to assess whether reported pH values were influenced by this potential error term.

SPECIFIC CONDUCTANCE

The conductivity of most constructed wetlands was consistently in the range of 150-300 umhos regardless of age (Figure 4-3 and 4-4). As with pH, the maximum reported values for individual age classes of wetlands did decline with increasing wetland age. Although the comparative database is limited to two systems, conductivity reported for most constructed wetlands failed to decline to levels reported for natural wetlands of the area (50-150 umhos) even after eight years following construction.

TOTAL PHOSPHORUS

Total phosphorus concentrations display a great deal of inter-wetland variability during the first four years following construction, but by year six, this has been minimized and constructed systems are characterized by concentrations that are within the range (<1 mg/L) seen in natural systems of the area (Figure 4-5). Such variability shortly after construction is expected and is a reflection of both residual total phosphorus in the geologic matrix used to develop the new landscape and the total area draining into the constructed wetland.

Figure 4-1

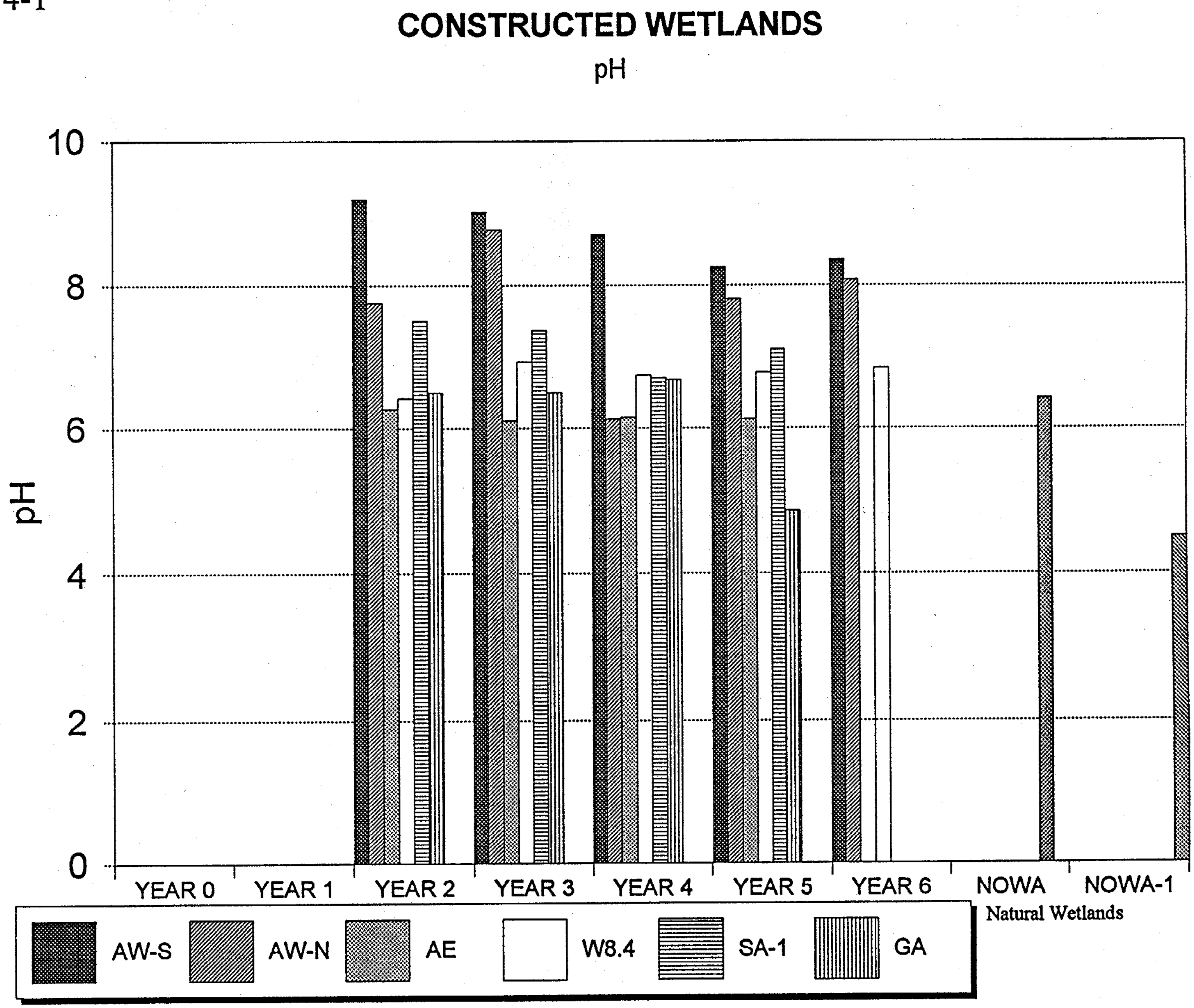

CONSTRUCTED WETLANDS
pH
10
8
6
4
2
0
pH
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NOWA
NOWA-1
Natural Wetlands
AW-S
AW-N
AE
W8.4
SA-1
GA

Figure 4-2
(compiled from Kieffer 1991)

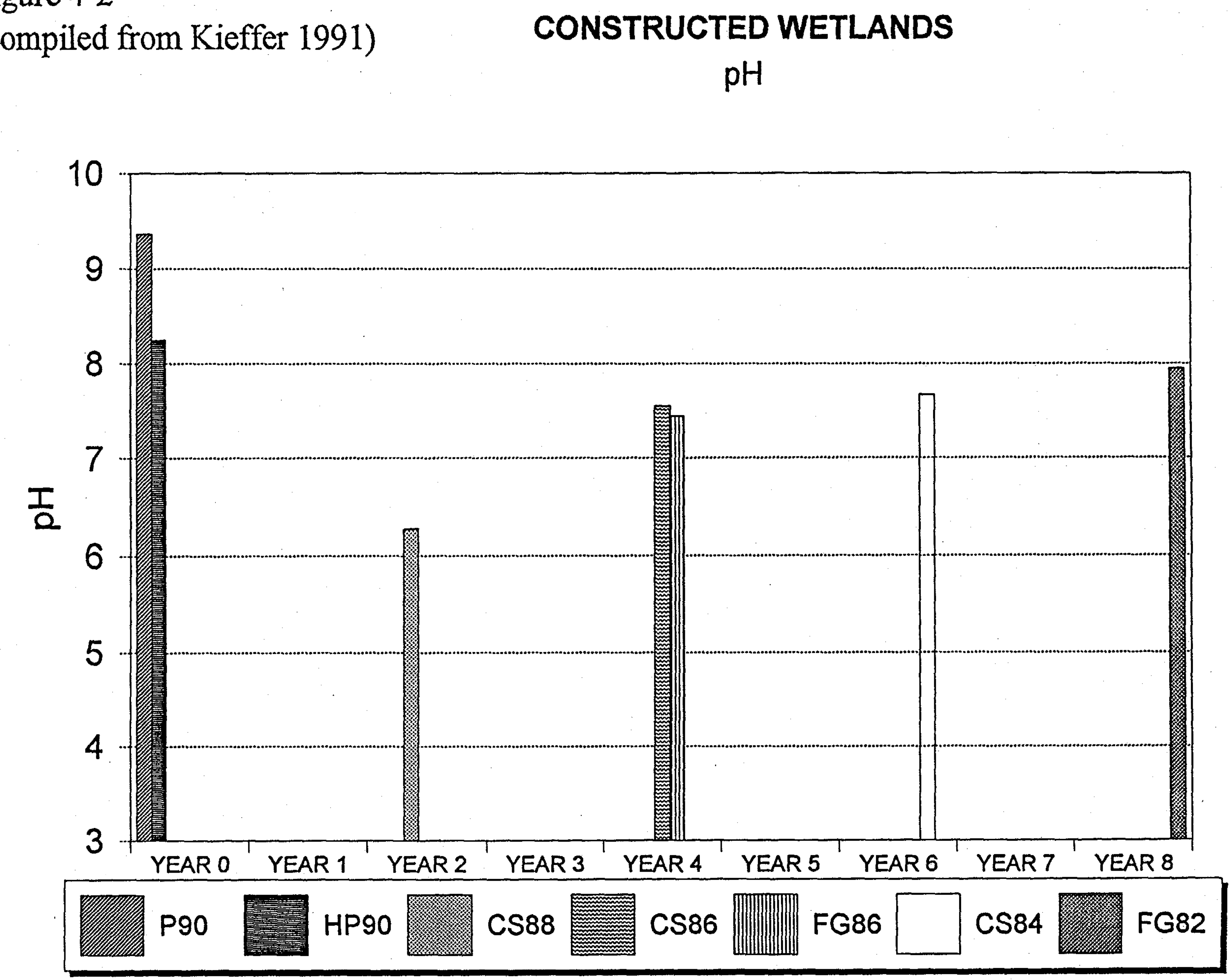
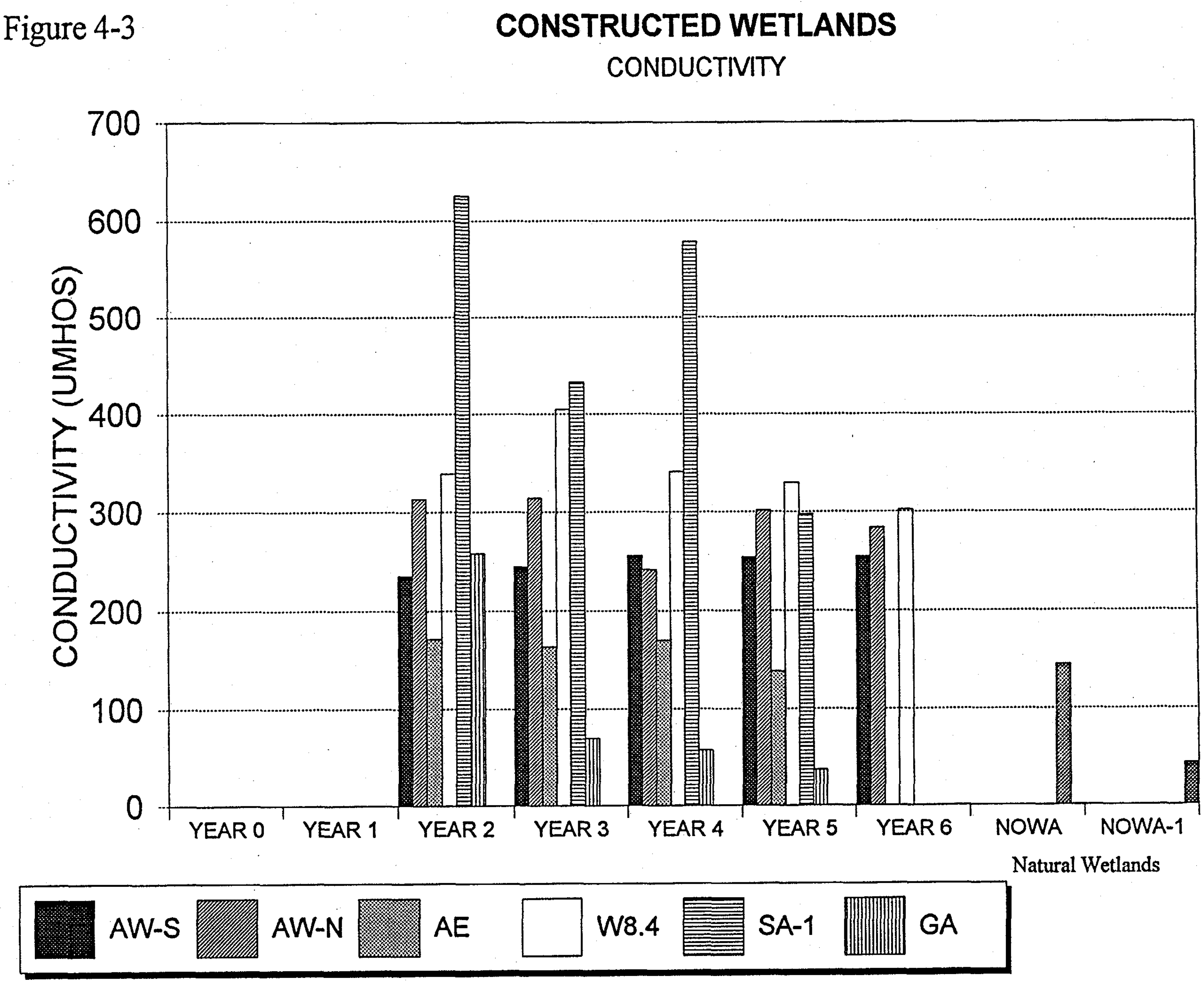


Figure 4-3



CONSTRUCTED WETLANDS
CONDUCTIVITY
CONDUCTIVITY (UMHOS)
700
600
500
400
300
200
100
0
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NOWA
NOWA-1
Natural Wetlands
AW-S
AW-N
AE
W8.4
SA-1
GA

Figure 4-4
(compiled from Kieffer 1991)

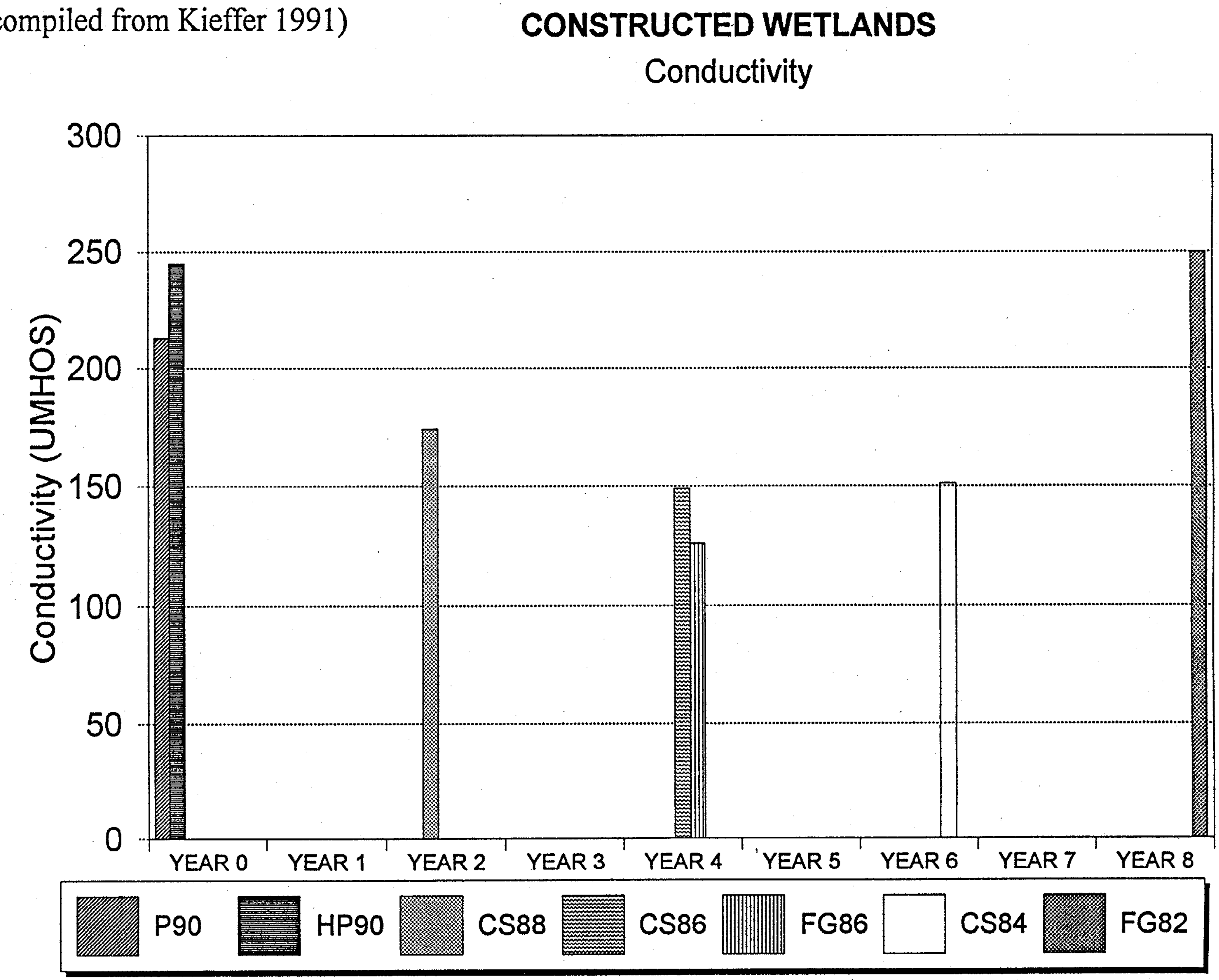
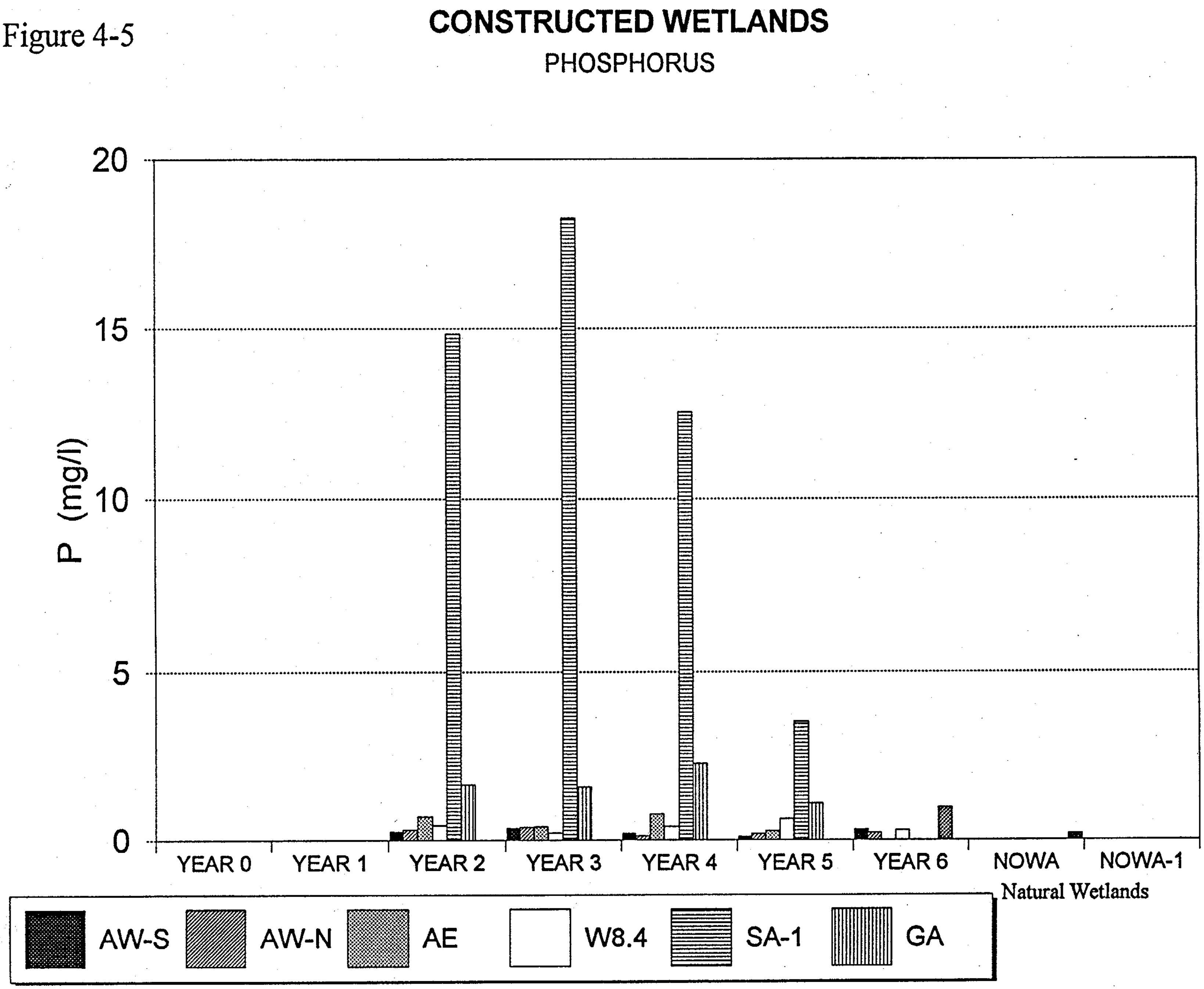


Figure 4-5



4-12

TOTAL NITROGEN

Total nitrogen data were relatively sparse in the compiled database and were totally lacking for systems less than two years old (Figure 4-6). For the age span covered by the database (2-6 years), however, total nitrogen values appeared to change little with age and were for the most part were within or slightly lower than the range reported for natural wetlands of the area (1.3-1.5 mg/L).

DISSOLVED OXYGEN

Dissolved oxygen values approached or exceeded 10 mg/L in wetlands less than two years of age, with older systems displaying greater inter-wetland variability but generally lower maximum values with increasing system age (Figure 4-7 and 4-8). Oxygen values either approximated or exceeded those of natural systems (> 4 mg/L) in at least half of the constructed systems monitored regardless of age. As with pH, dissolved oxygen values are strongly influenced by system photosynthetic rates, especially from phytoplankton, attached algae, and submersed macrophytes, and thus display strong diel patterns. Consistently lower values reported in two of the eleven constructed systems constituting our database may be a reflection of the time of day chosen for field sampling. The precise influence of this error term, however, could not be evaluated from data provided.

BIOLOGICAL OXYGEN DEMAND

Biological Oxygen Demand (BOD) was measured for three constructed wetlands (age 2-6 years) and two natural systems (Figure 4-9). Although a great deal of inter-wetland difference was noted in systems less than three years old with values generally greater than 6 mg/L, wetlands older than three years displayed values that approximated those of natural systems (4 mg/L).

MINE INFLUENCED STREAM

Monitoring was initiated to determine the effects of wetland restoration efforts on the receiving waters of Payne Creek. It was observed that discharge to the stream occurred when water height in Morrow Swamp, a constructed wetland to the west of the river, reached an elevation of 120 feet MSL. Periods of overflow corresponded with winter and summer storm events. Surface water level data were not available for the entire study period which extended from August 1983 to May 1988. Water quality parameters were correlated to water levels and periods of discharge where available.

Several physico-chemical parameters were monitored at four stations along Payne Creek. Station 1 was located in the northern most end of the creek bordering the wetland, Stations 2 and 3 were upstream and downstream from the point of discharge, respectively, and Station 4 was at the southern most end of the creek bordering the wetland. Stations 2 and 3, due to their location immediately above and below the point of discharge, are of particular interest and are the focus of this discussion.

Of the fifteen parameters sampled, the current discussion focuses on pH, dissolved oxygen, turbidity, total nitrogen (TN), total phosphorus (TP), and conductivity.

Figure 4-6

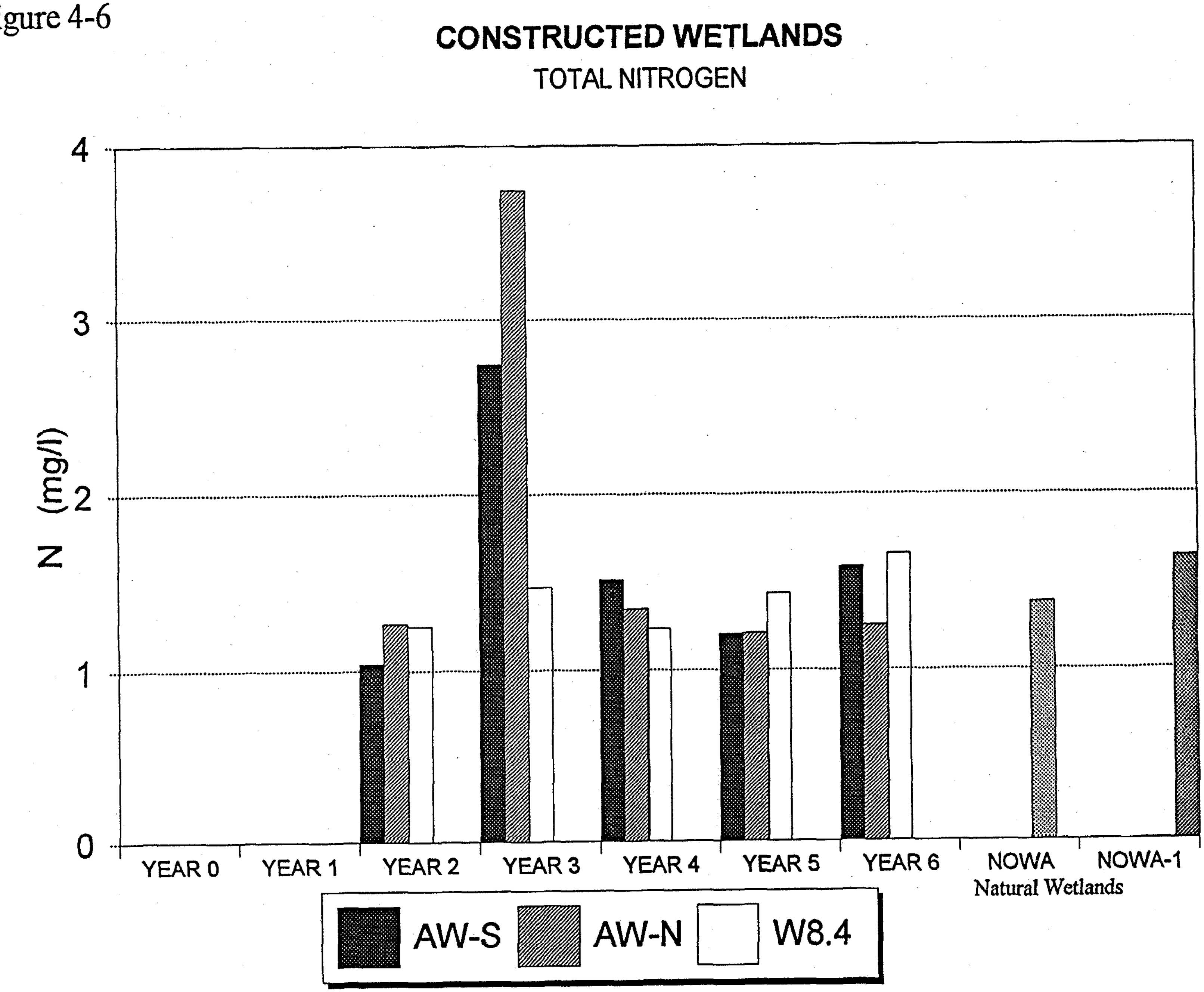
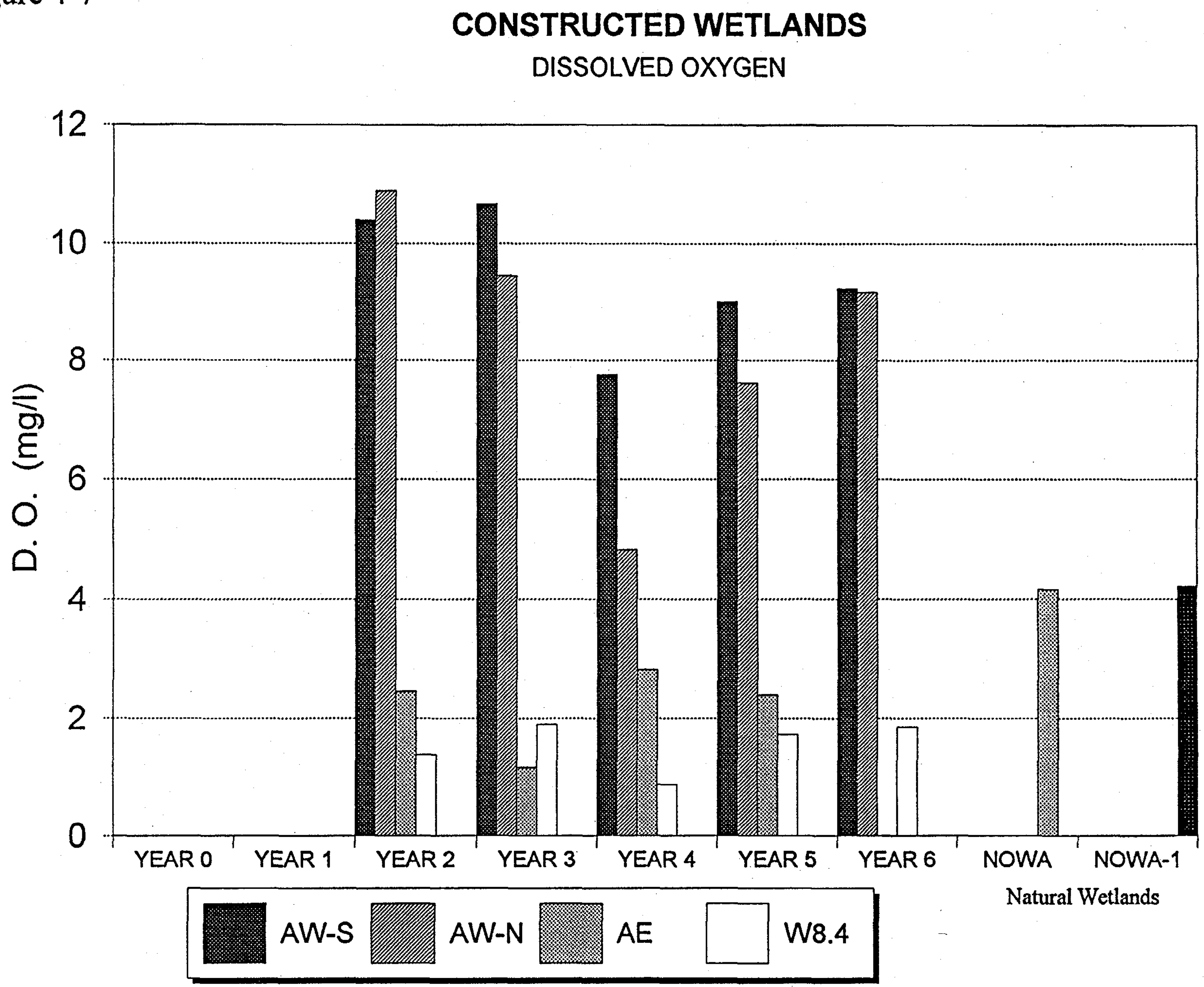

CONSTRUCTED WETLANDS
TOTAL NITROGEN
N (mg/l)
4
3
2
1
0
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NOWA
NOWA-1
Natural Wetlands
AW-S
AW-N
W8.4

Figure 4-7



CONSTRUCTED WETLANDS
DISSOLVED OXYGEN
D. O. (mg/l)
12
10
8
6
4
2
0
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NOWA
NOWA-1
Natural Wetlands
AW-S
AW-N
AE
W8.4

Figure 4-8
(compiled from Kieffer 1991)

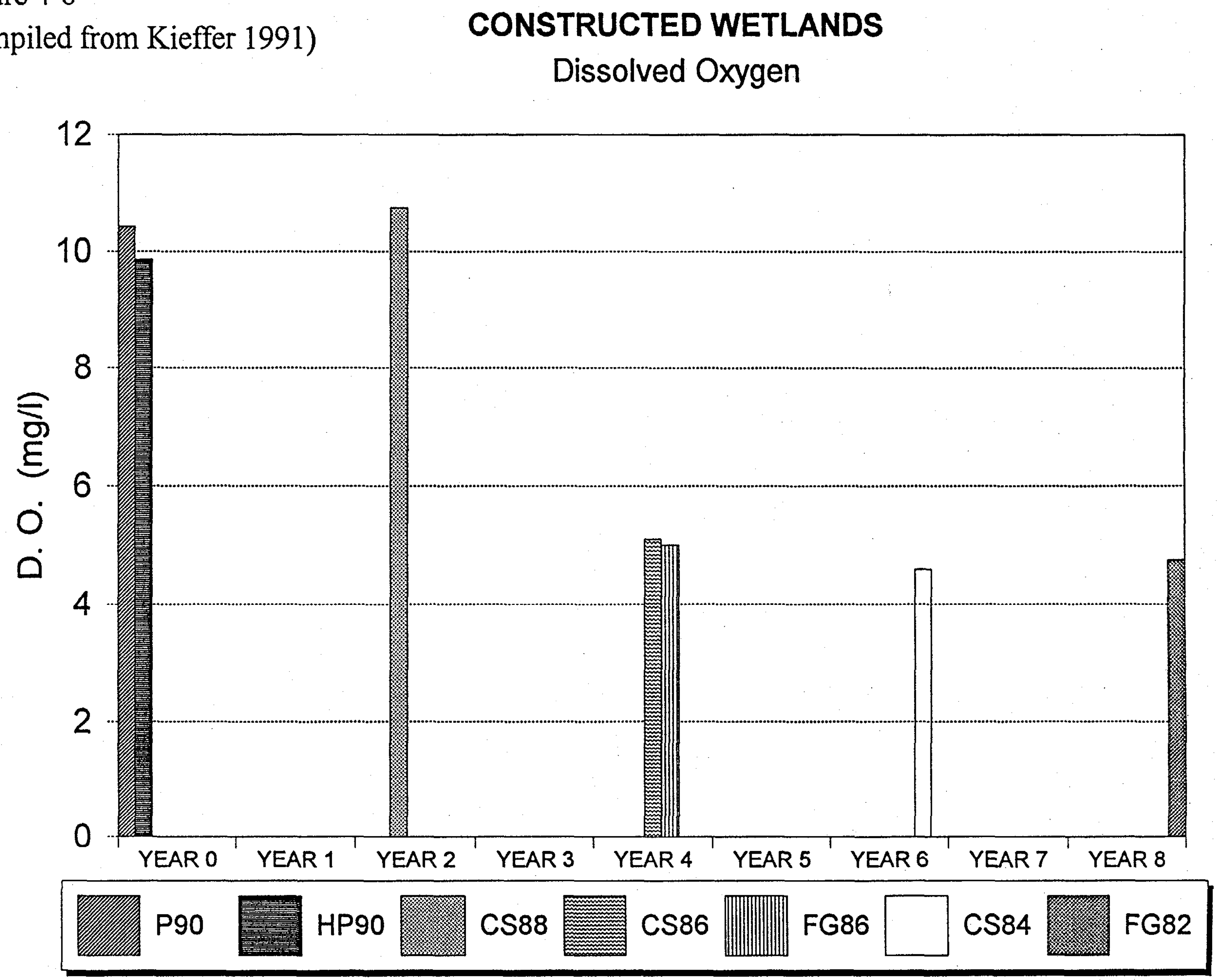
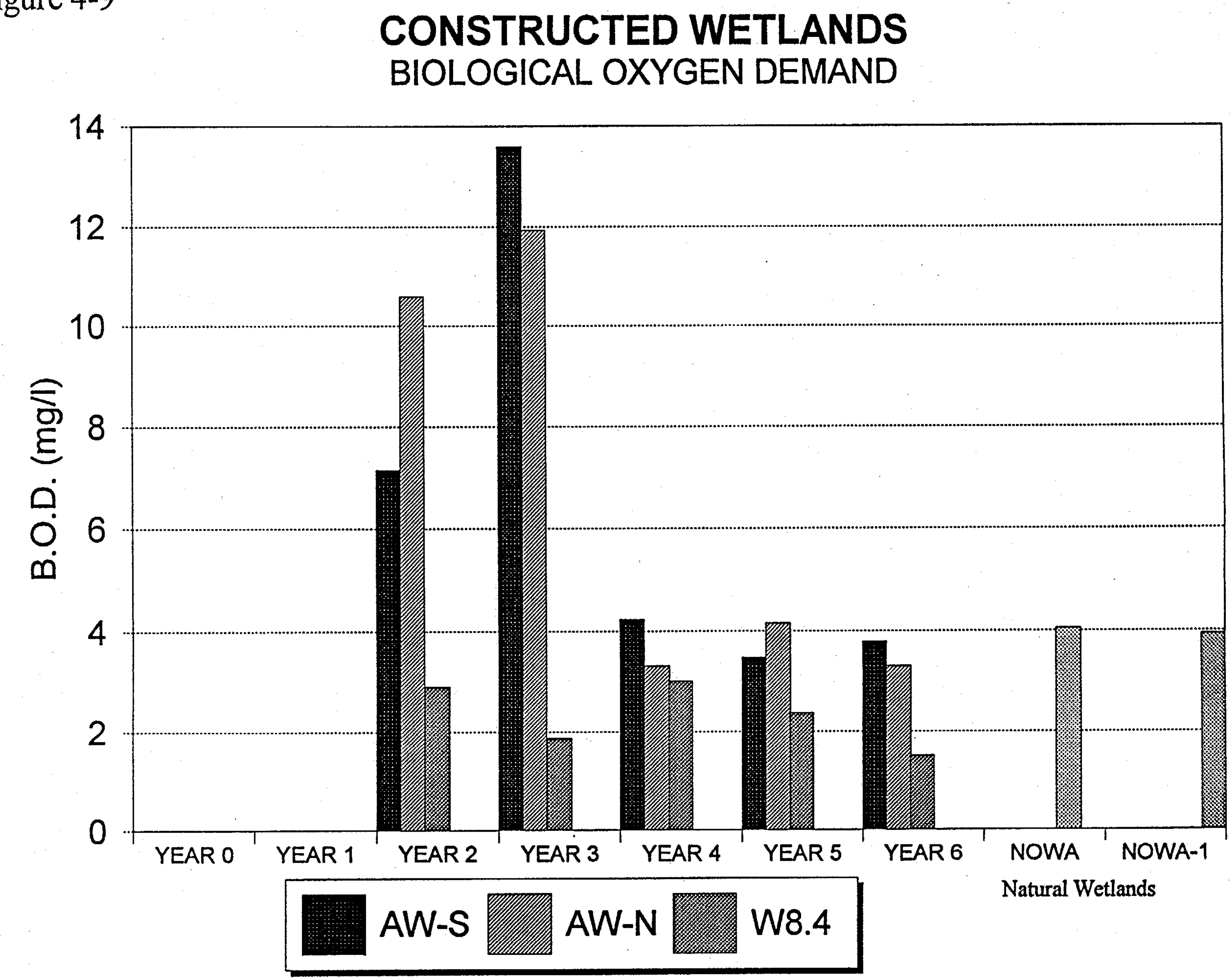


Figure 4-9


CONSTRUCTED WETLANDS
BIOLOGICAL OXYGEN DEMAND
B.O.D. (mg/l)
14
12
10
8
6
4
2
0
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NOWA
NOWA-1
Natural Wetlands
AW-S
AW-N
W8.4

pH

The mean pH value for Payne Creek Station 2 (PC-2) was 6.75 and 6.96 at Payne Creek Station 3 (PC-3) during the five years of monitoring (Figure 4-10). This parameter fluctuated between 6.30 and 7.20 for PC-2, and between 6.5 and 7.2 for PC-3. The effect of discharge from Morrow Swamp on pH of Payne Creek was not pronounced. There was no change in pH (7.20) after wetland discharge in February 1984, and a decrease from 7.10 to 7.00 in August 1984 following wetland discharge. On average pH upstream from point of discharge was lower than that downstream

The trend observed in pH may be similar to that observed for relatively undisturbed systems where there is a general increase downstream as dissolved solids and conductivity increase. Discharge from Morrow Swamp may have no impact on this parameter. However, disturbances in the watershed may accounted for a decrease in pH at PC-2 and PC-3.

DISSOLVED OXYGEN (DO)

This parameter was frequently lower upstream than downstream Mean DO readings for PC-2 was 1.70 mg/l, and for PC-3 2.80 mg/l (Figure 4-11). With the exception of August 1985 when DO increased following discharge from Morrow Swamp, there was a decrease in this parameter when the wetland overflowed into Payne Creek. The oxygen deficit observed in May 1985 may be due to high suspended solids in the water column (28.30 mg/l). The water levels in the swamp were the lowest at this month which suggests that stream flows may have also been low due to dry conditions. Analysis of USGS monitoring data for the watershed shows that time of year was relatively dry and that surface discharge was very low.

TURBIDITY

With the exception of two monitoring periods values for this parameter were on average higher for PC-2 than for PC-3 (Figure 4-12). Following discharge from the swamp turbidity at PC-3 increased above that for PC-2 in March and November 1985. The fact that values for turbidity are higher at station 2 suggests that there may be activities upstream that are affecting water quality of the creek. A decrease downstream occurs due to sedimentation of particulate matter. Discharge from the swamp results in an increase in turbidity but this value continues to be lower than that for upstream stations at other times.

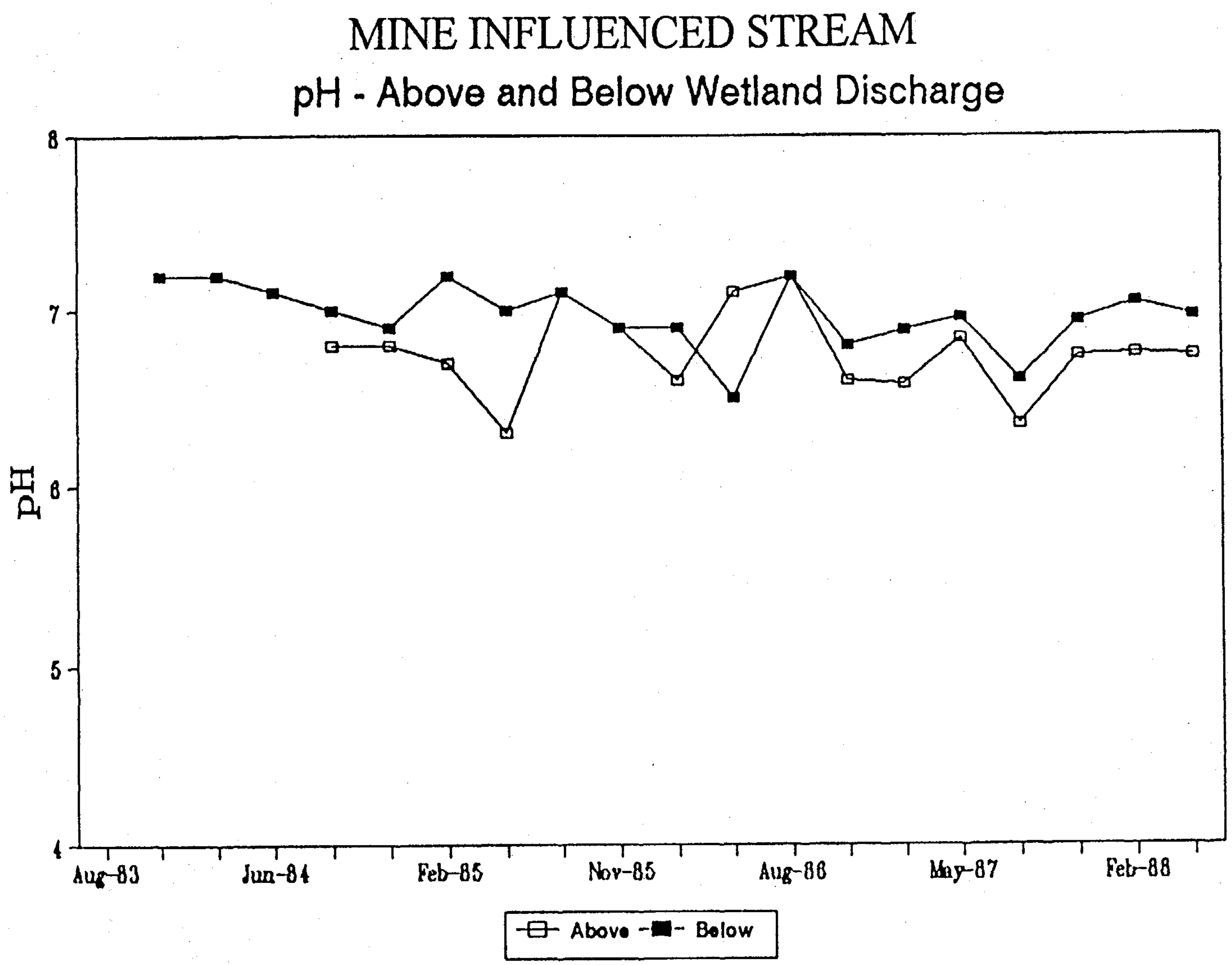
CONDUCTIVITY

There was little variability in this parameter between sample stations. Analysis of data upstream and downstream from the point of wetland discharge showed no significant variability (Figure 4-13). The high values observed in 1983 is the result of disturbance in the watershed due to mining activities and the construction of the wetland. Values returned to levels observed elsewhere in the watershed (USGS 1988) suggesting that the constructed wetland has no significant effect on this parameter.

TOTAL PHOSPHORUS (TP)

Values fluctuated between 0.1 and 1.8 mg/l at PC-2 and PC-3. On average, TP was greater downstream than upstream (Figure 4-14). This trend is consistent with that observed along natural streams - there is an increase in nutrients downstream as the drainage area increases. The variation

Figure 4-10



MINE INFLUENCED STREAM
pH - Above and Below Wetland Discharge
pH
8
7
6
5
4
Aug-83
Jun-84
Feb-85
Nov-85
Aug-86
May-87
Feb-88
Above
Below

Figure 4-11

MINE INFLUENCED STREAM

DO - Above and Below Wetland Discharge

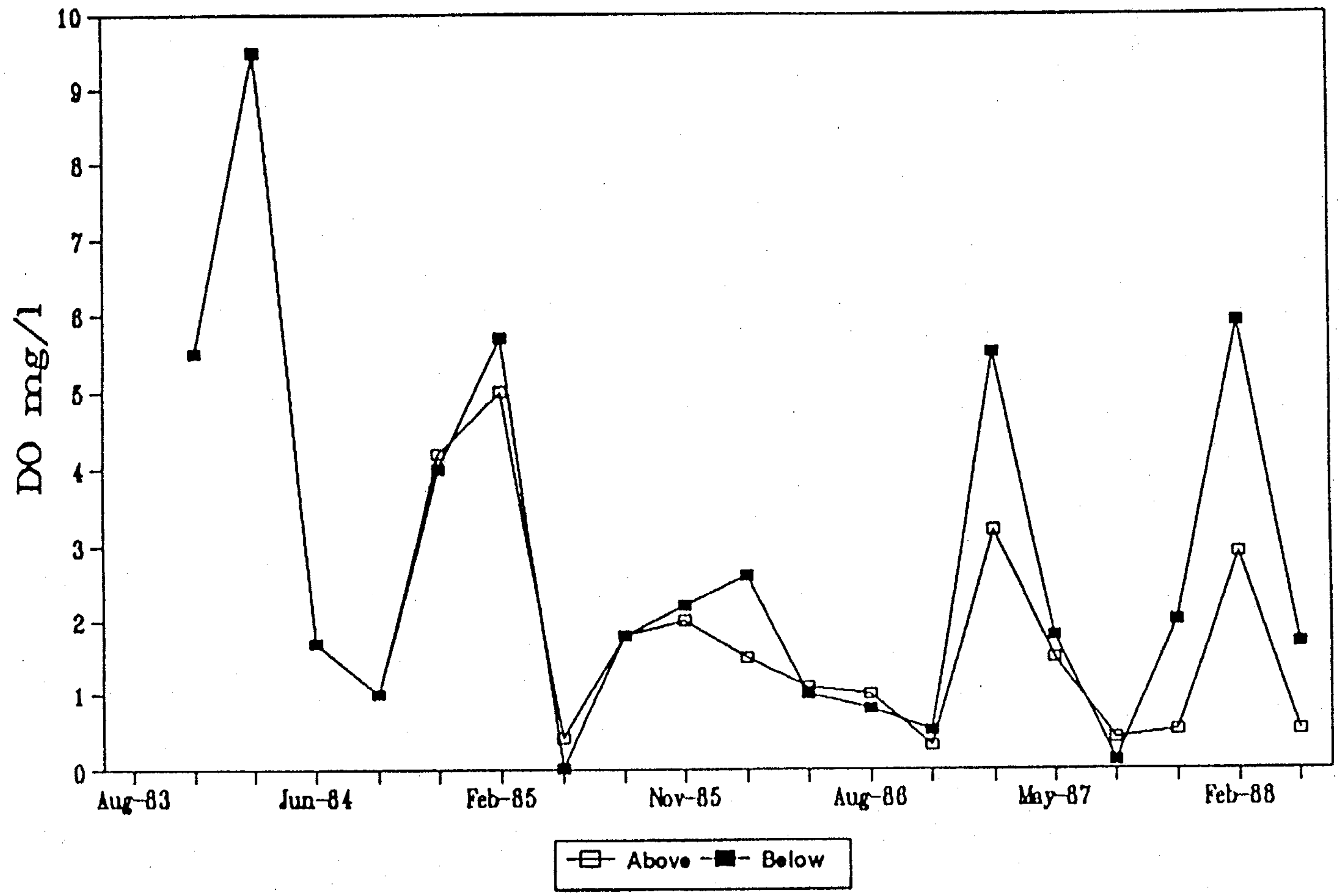


Figure 4-12

MINE INFLUENCED STREAM

TURBIDITY - Above and Below Wetland Discharge

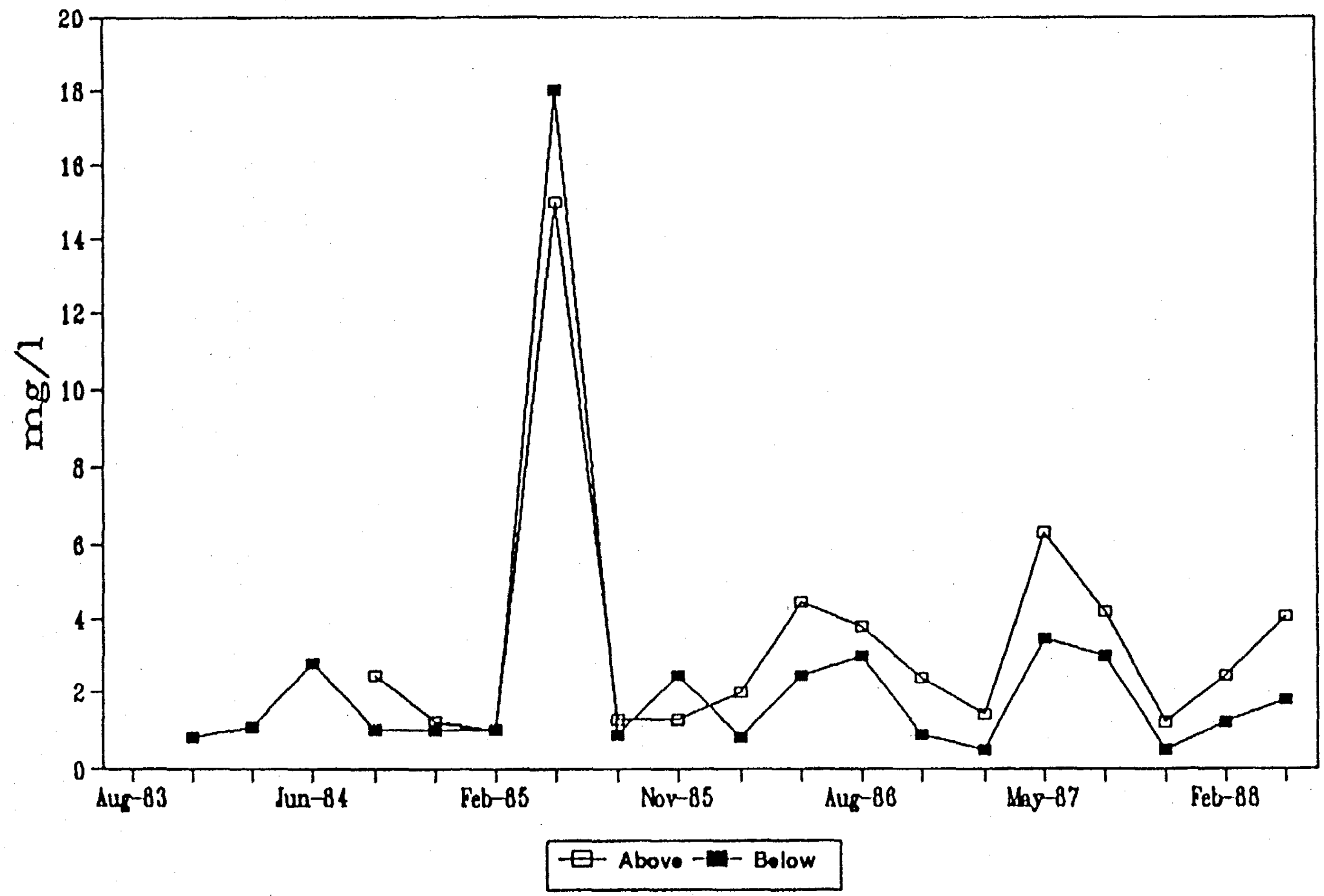
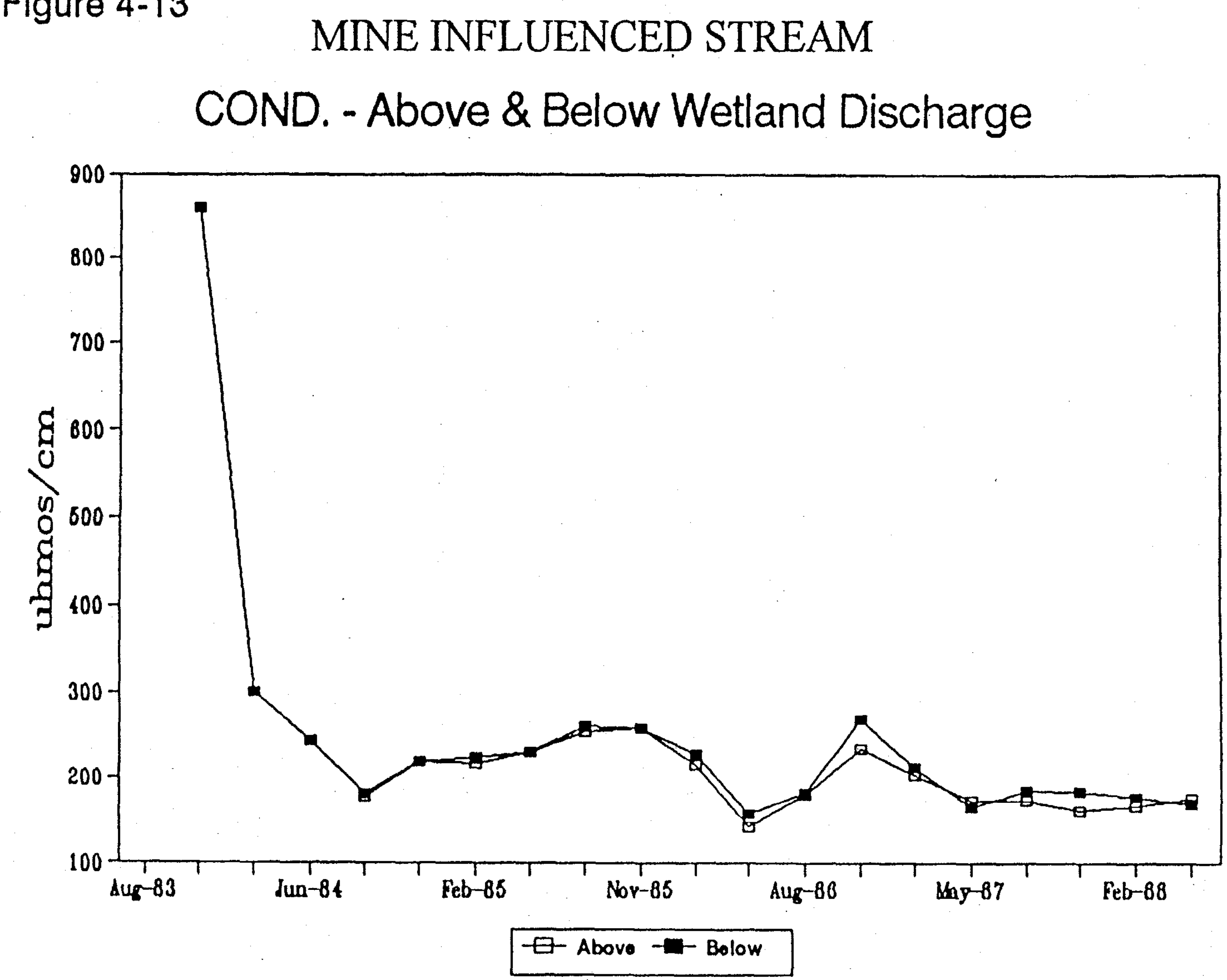


Figure 4-13

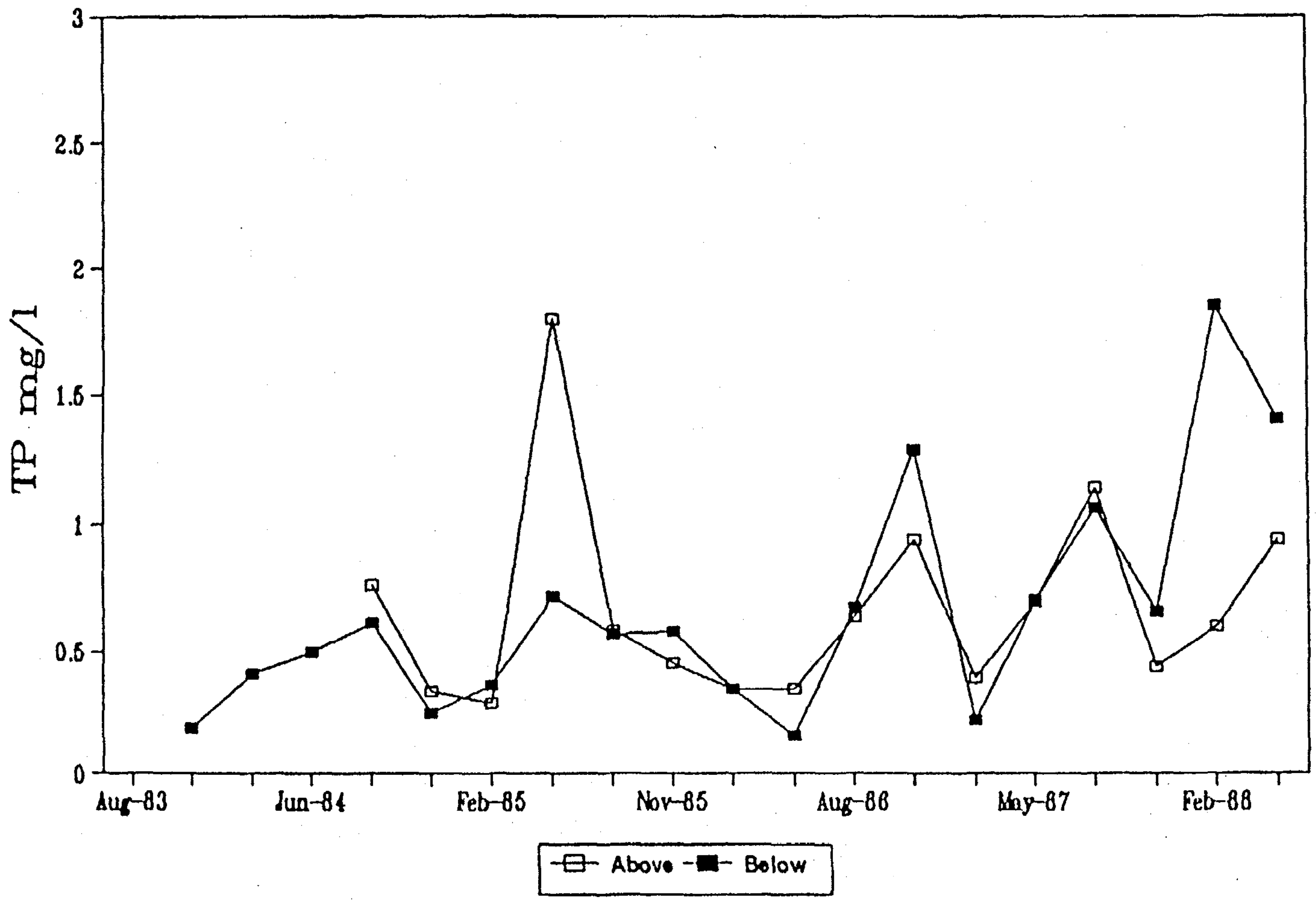


MINE INFLUENCED STREAM
COND. - Above & Below Wetland Discharge
uhmos/cm
900
800
700
600
500
400
300
200
100
Aug-83
Jun-84
Feb-85
Nov-85
Aug-86
May-87
Feb-88
Above
Below

Figure 4-14

MINE INFLUENCED STREAM

TP - Above and Below Wetland Discharge



4-23

between sites is not marked and suggests that the constructed wetland may not a significant effect on TP in the creek.

TOTAL NITROGEN

Wide variations were observed over the sampling period. Values ranged from 0.1 to 2.5 mg/l for PC-2 and from 0.4 to 1.6 mg/l for PC-3 (Figure 4-15). Peaks coincided with heavy rainfall events in the watershed. The peak at PC-3 in February 1985 corresponded with discharge from the constructed wetland. Average TN is higher for PC-3 than for PC-2. In addition to an increase downstream due to input from a larger drainage area, the wetland may be significantly contributing to the trend observed.

RELOCATED STREAM

Monitoring was initiated along the relocated portion of Roaring Creek to fulfill DER permit requirements and to determine the success of the project. Water quality was monitored monthly from January 1991 to April 1993. Four sample stations were set up along the creek. Station 1 (RC-1) was located in the relocation near CR-135; Station 2 (RC-2) about mid-way along the relocation; Station 3 (RC-3), near the headwater connection; Station 4 (RC-4) near the mouth. A fifth station (RC-5) was set up in Camp Branch to provide background data. Roaring Creek discharges into the Suwannee River, therefore, two stations (RC-6 and RC-7) were located upstream and downstream from the confluence. A final station (RC-8) was located in the Audubon/Sierra headwater exit monitoring point.

Flow (cfs), water depth and the depth at which sampling was conducted were reported together with fifteen physico-chemical parameters. Trends observed for pH, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), and conductivity are summarized for the natural stream (RC-5) and the relocated stream (RC-3).

pH

This parameter was significantly higher in the natural stream (mean 6.5) than in the relocated stream (mean 4.0) Figure 4-16. Values obtained for each stream was plotted against stream flow to determine its effect on pH (Figures 4-17 and 4-18). Generally, pH increased as stream flow increased. The steady decrease in pH observed from September 1992 to April 1993 at RC-5 may be related to increased color, total organic carbon and total suspended solids during the period. Most of the carbon in the system was in organic form so that total alkalinity was very low (0.3 to 1.2 mg/l), and was essentially zero for several months. This would explain the considerably lower pH observed along Roaring Creek.

DISSOLVED OXYGEN (DO)

Similar trends were observed for the relocated and natural streams (Figure 4-19). The steady decrease observed from January 1991 to October 1991 is due to an increase in total organic carbon, color and total suspended solids following periods of heavy rain events. Comparisons with the trend

Figure 4-15

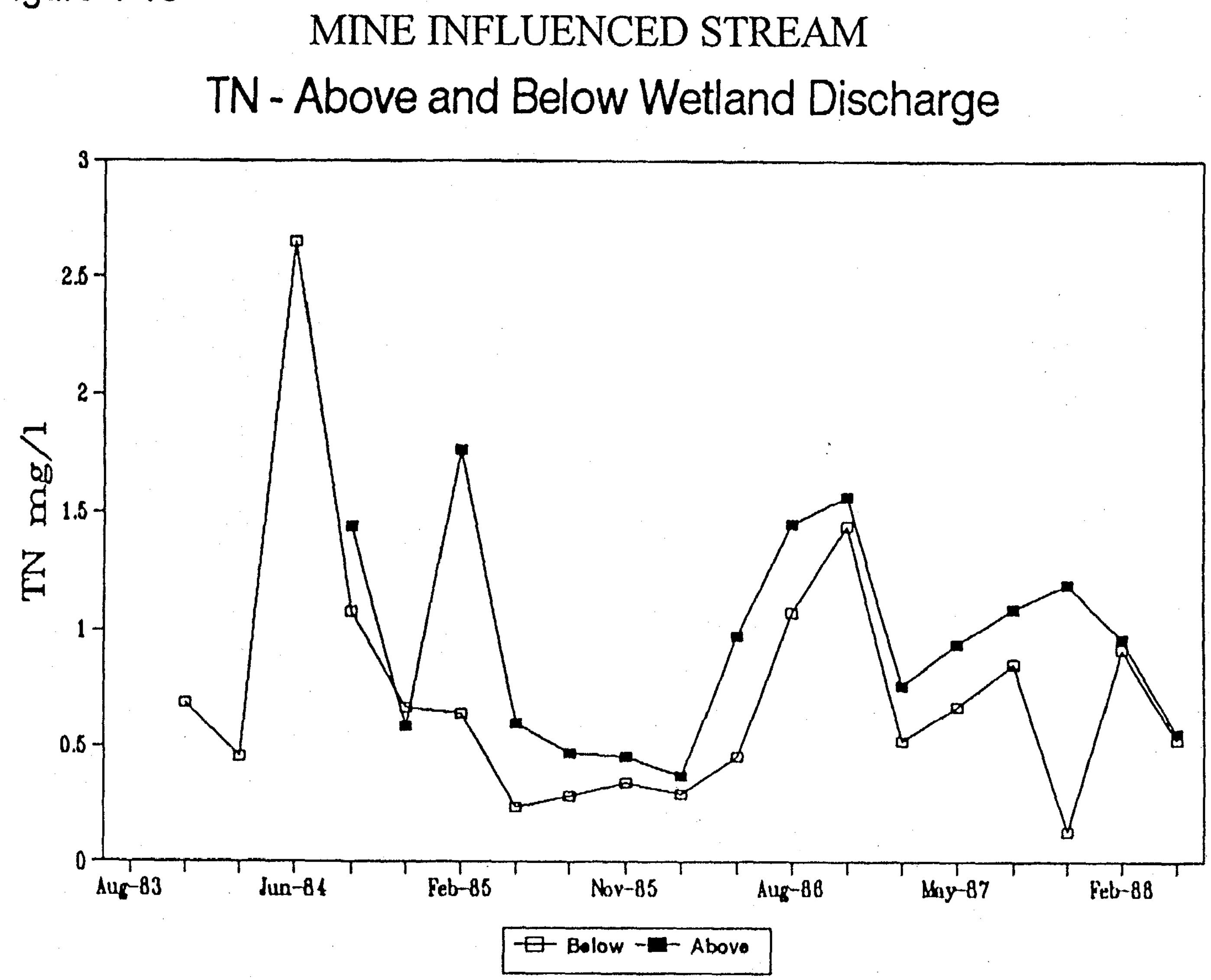

MINE INFLUENCED STREAM
TN - Above and Below Wetland Discharge
TN mg/l
3
2.5
2
1.5
1
0.5
0
Aug-83
Jun-84
Feb-85
Nov-85
Aug-86
May-87
Feb-88
Below
Above

Figure 4-16

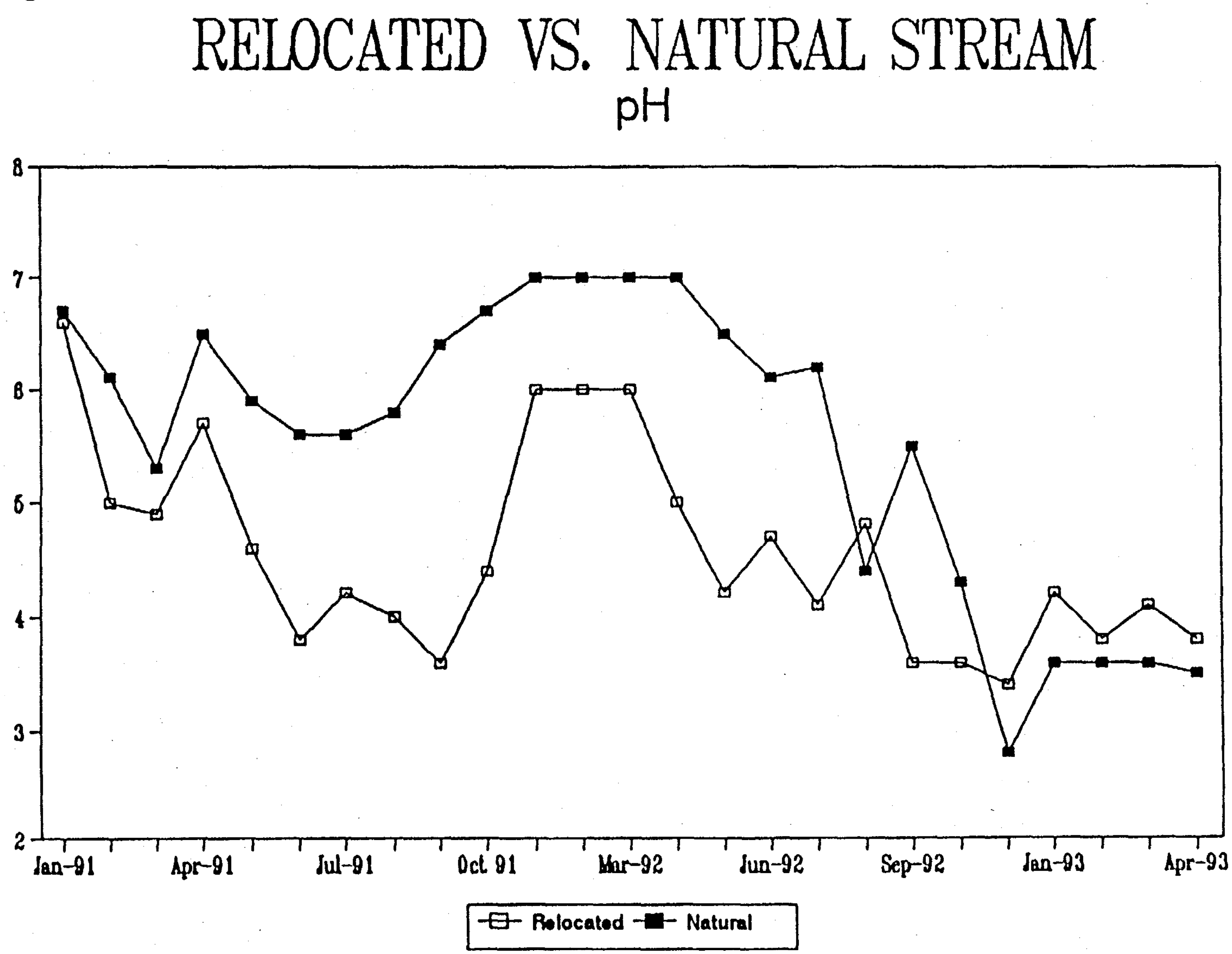

RELOCATED VS. NATURAL STREAM
pH
8
7
6
5
4
3
2
Jan-91
Apr-91
Jul-91
Oct 91
Mar-92
Jun-92
Sep-92
Jan-93
Apr-93
Relocated
Natural

Figure 4-17

RELOCATED STREAM

Flow and pH

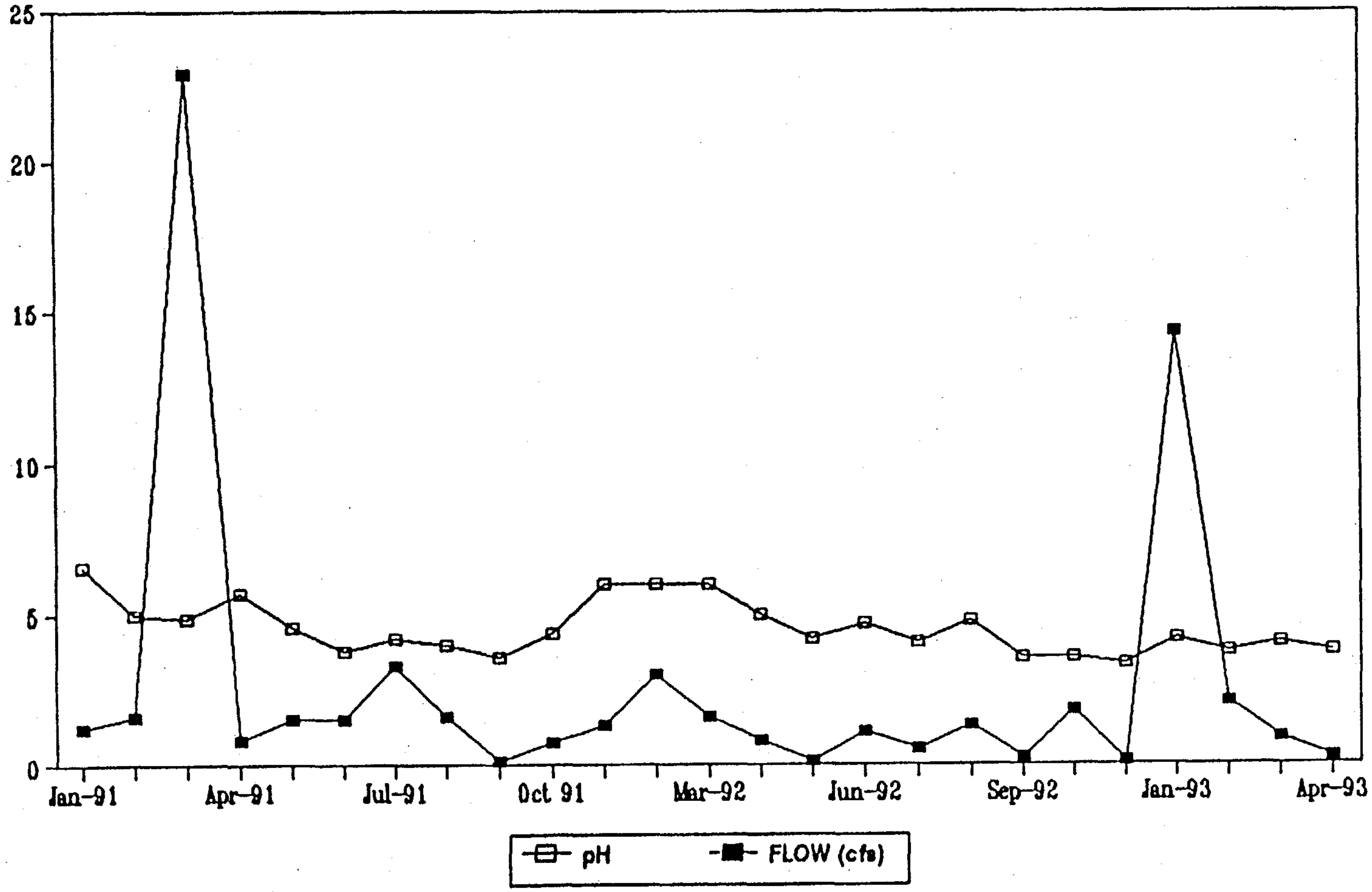


Figure 4-18

NATURAL STREAM
Flow and pH

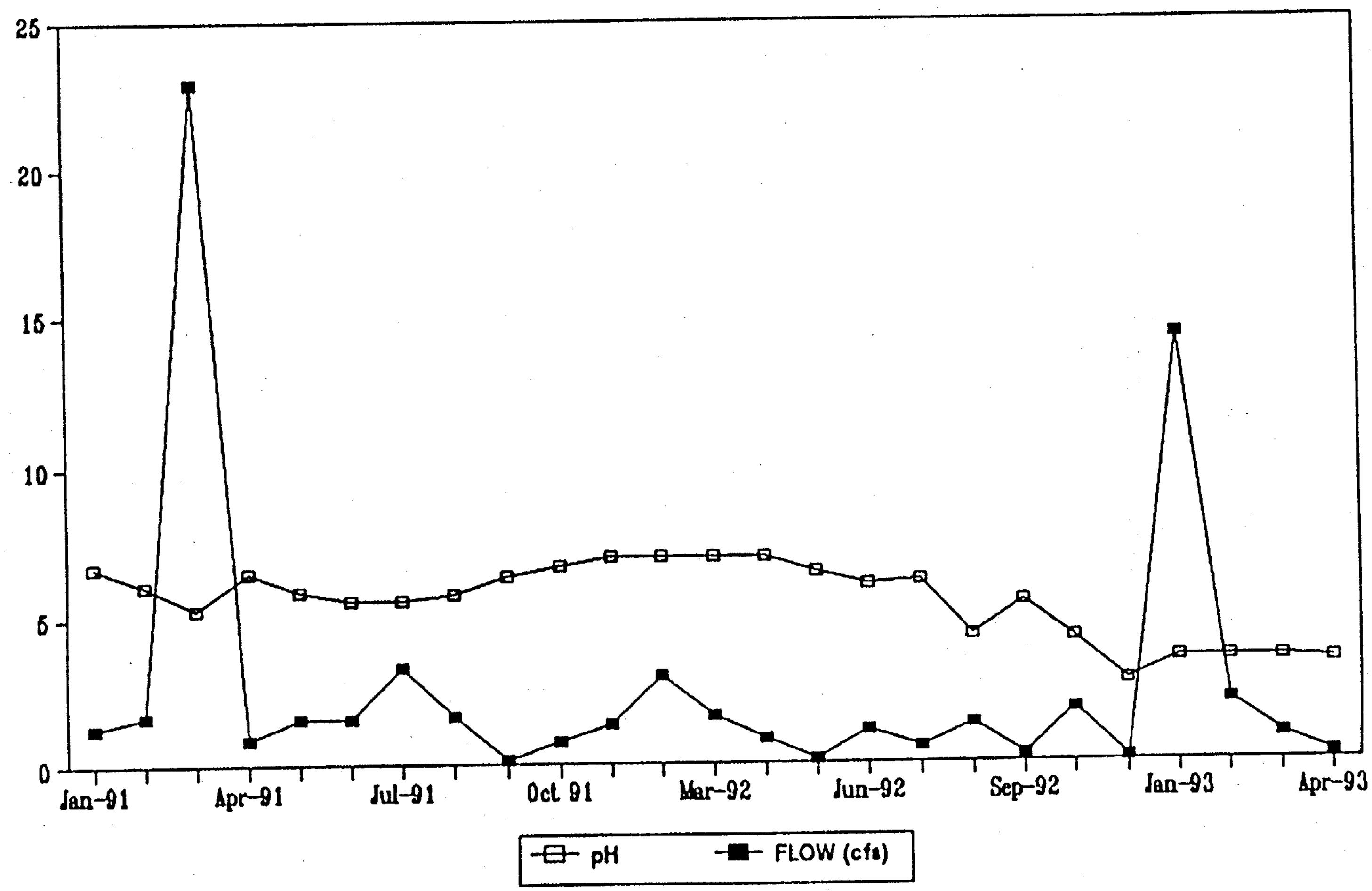
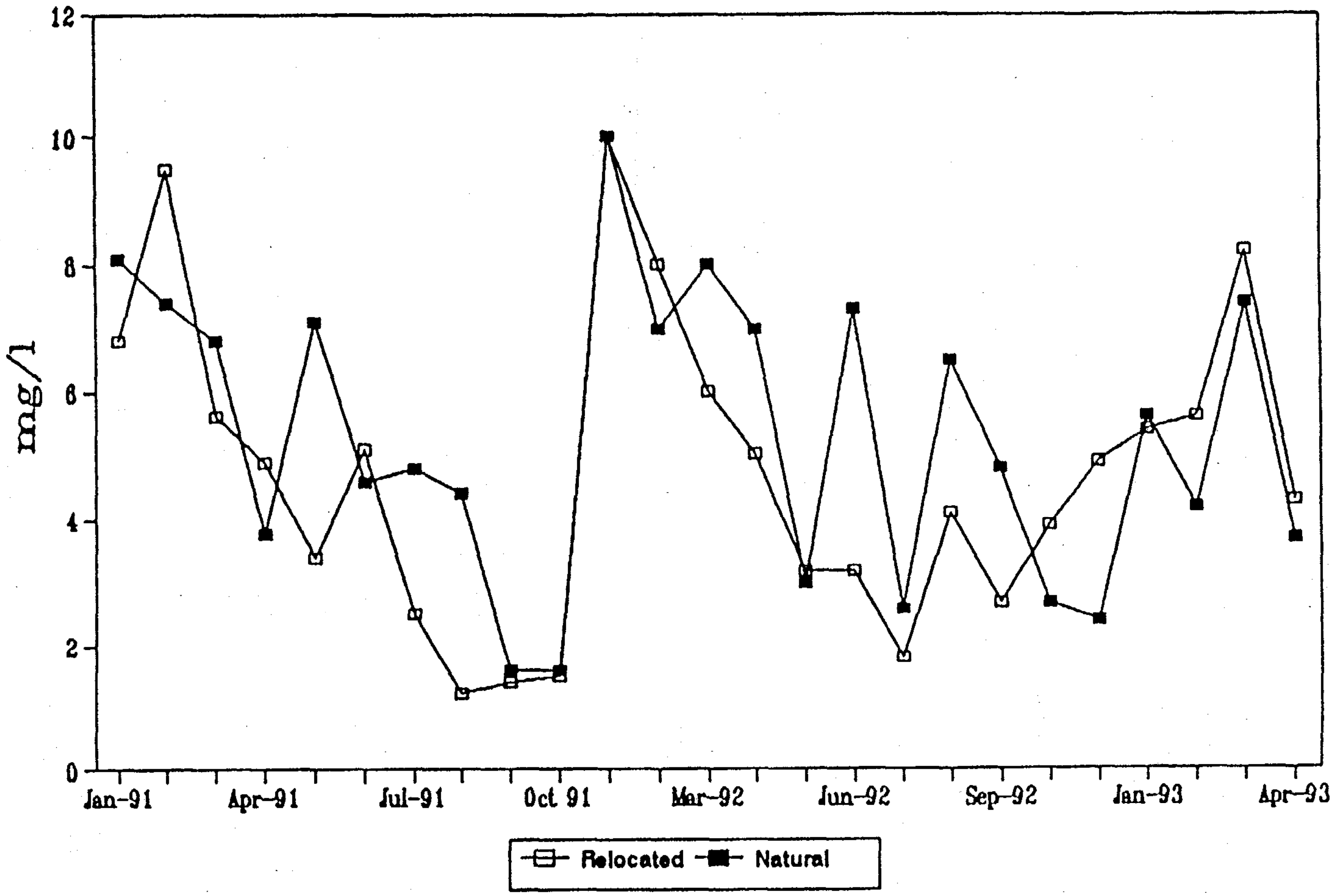


Figure 4-19

RELOCATED VS. NATURAL STREAM

Dissolved Oxygen



for stream flow show that fluctuations in DO correspond to changes in flow rates (Figures 4-20 and 4-21). Peak values correspond with low values for total organic carbon, color and total suspended solids.

TOTAL SUSPENDED SOLIDS

This parameter was generally higher for the relocated than the natural stream Values ranged from 1.0 to 35 mg/l for the relocated stream, and from 0.00 mg/l to 8.0 mg/l for the natural stream (Figure 4-22). Higher values for the relocated stream may be due to initial disturbance in the watershed. The amplitude of the peaks decreased pronouncedly over time (Figure 4-20). Fluctuations in TSS values appear to be positively related to increased stream discharge following rain events (Figures 4-23 and 4-24).

TOTAL DISSOLVED SOLIDS (TDS)

The trends observed for TDS is similar to that observed for TSS. Values for the relocated stream were much higher than those for the natural stream (Figure 4-25). As the disturbed watershed stabilizes, however, the disparity between relocated and natural streams may decrease with time. In a large part, fluctuations are influenced by increased drainage from the surrounding watershed expressed as variations in stream flow.

CONDUCTIVITY

Conductivity was higher for the natural stream than for the relocated one (Figure 4-26). As was observed for other physico-chemical parameters sampled, conductivity fluctuated in response to changes in stream flow. It is somewhat surprising that this parameter is lower for the relocated versus the natural stream given that parameters considered to contribute to conductivity (TSS, TDS) showed an opposite trend. It is not possible with the current database to address this issue in detail.

DISCUSSION

CONSTRUCTED WETLANDS

Water chemistry in created wetlands is controlled both by the nature of the geologic matrix underlying and surrounding the system and biological processes, principally photosynthesis, operating within the wetland proper. Specific conductance is a reflection of the geologic matrix and leaching rates of cations and ions from the surrounding watershed. Given the overall disturbance of the landscape and temporal instability of weathering processes, it is not surprising to find that conductivity of surface waters in constructed wetlands is higher than that reported for natural systems of the region which lie in landscapes of stable geological weathering processes. There is an expected time lag for gradual reduction in conductivity that will be a function of the time it takes to develop both mature terrestrial vegetation communities and stability of soils to reduce cation and ion release via leaching.

Most chemical parameters displayed a great deal of inter-wetland variability during the first two years following construction, but both the maximum reported value and the degree of inter-wetland

Figure 4-20

RELOCATED STREAM

Flow and Dissolved Oxygen

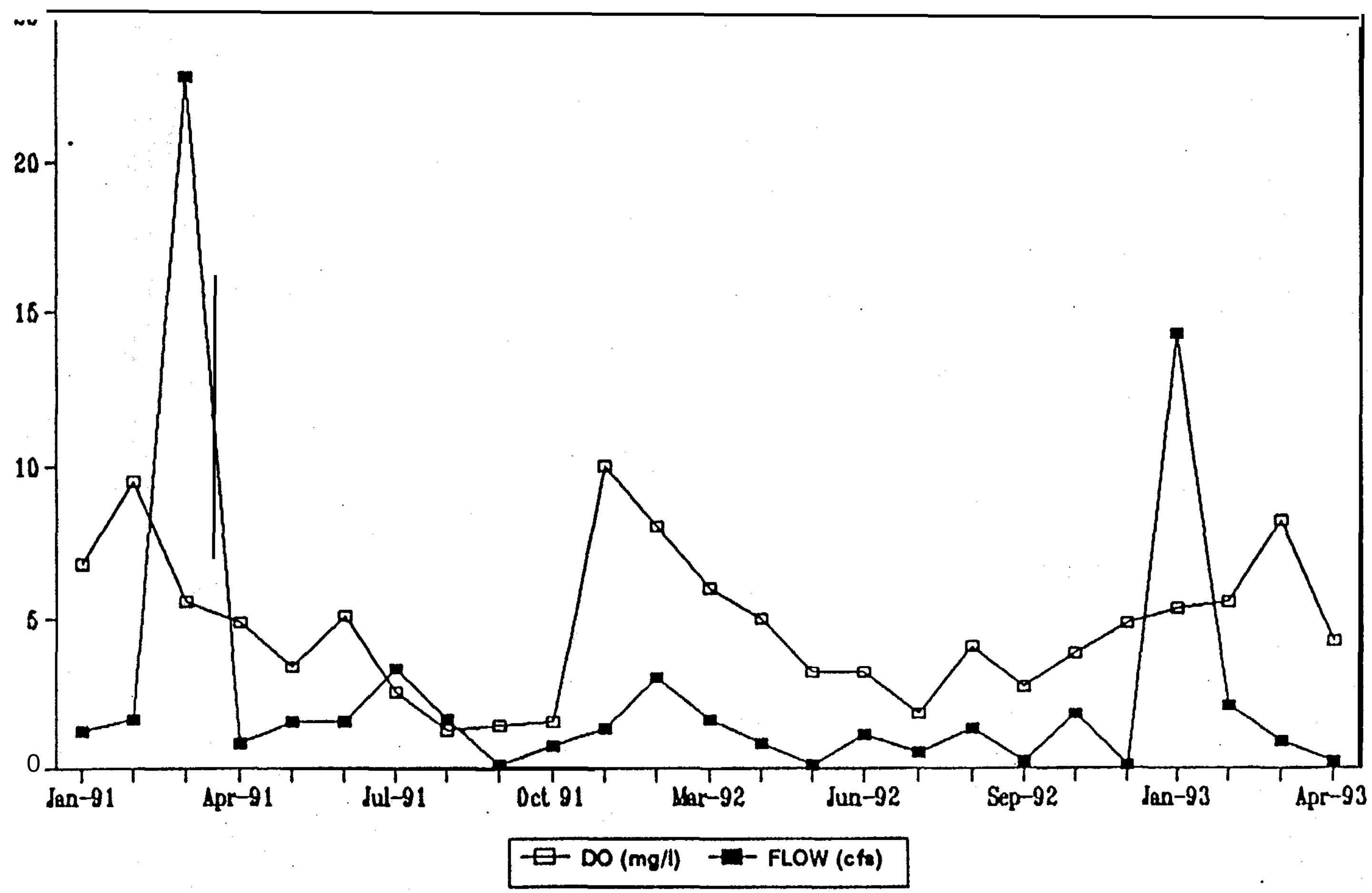
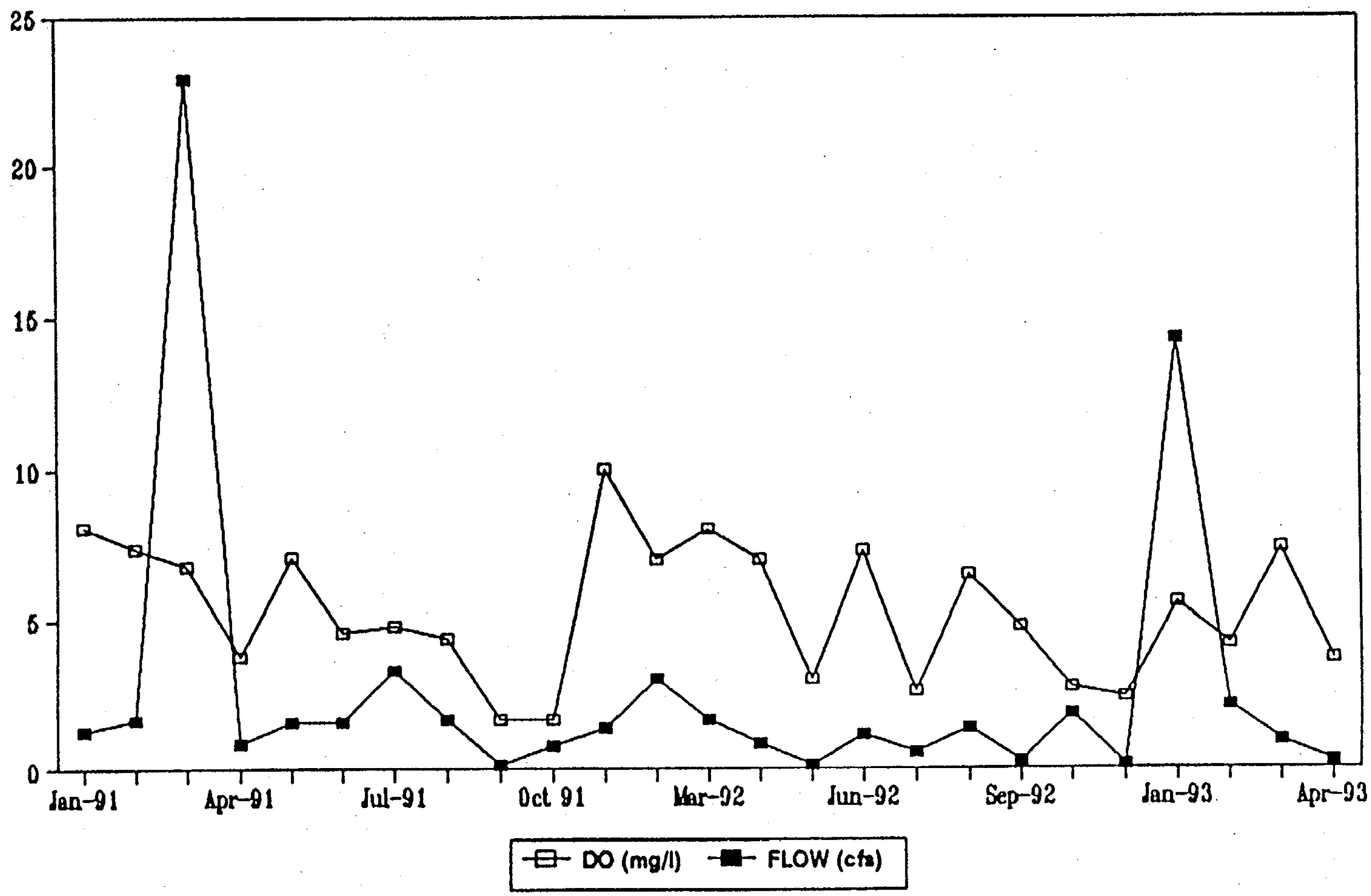


Figure 4-21

NATURAL STREAM

Flow and Dissolved Oxygen



4-32

Figure 4-22

RELOCATED VS. NATURAL STREAM

Total Suspended Solids

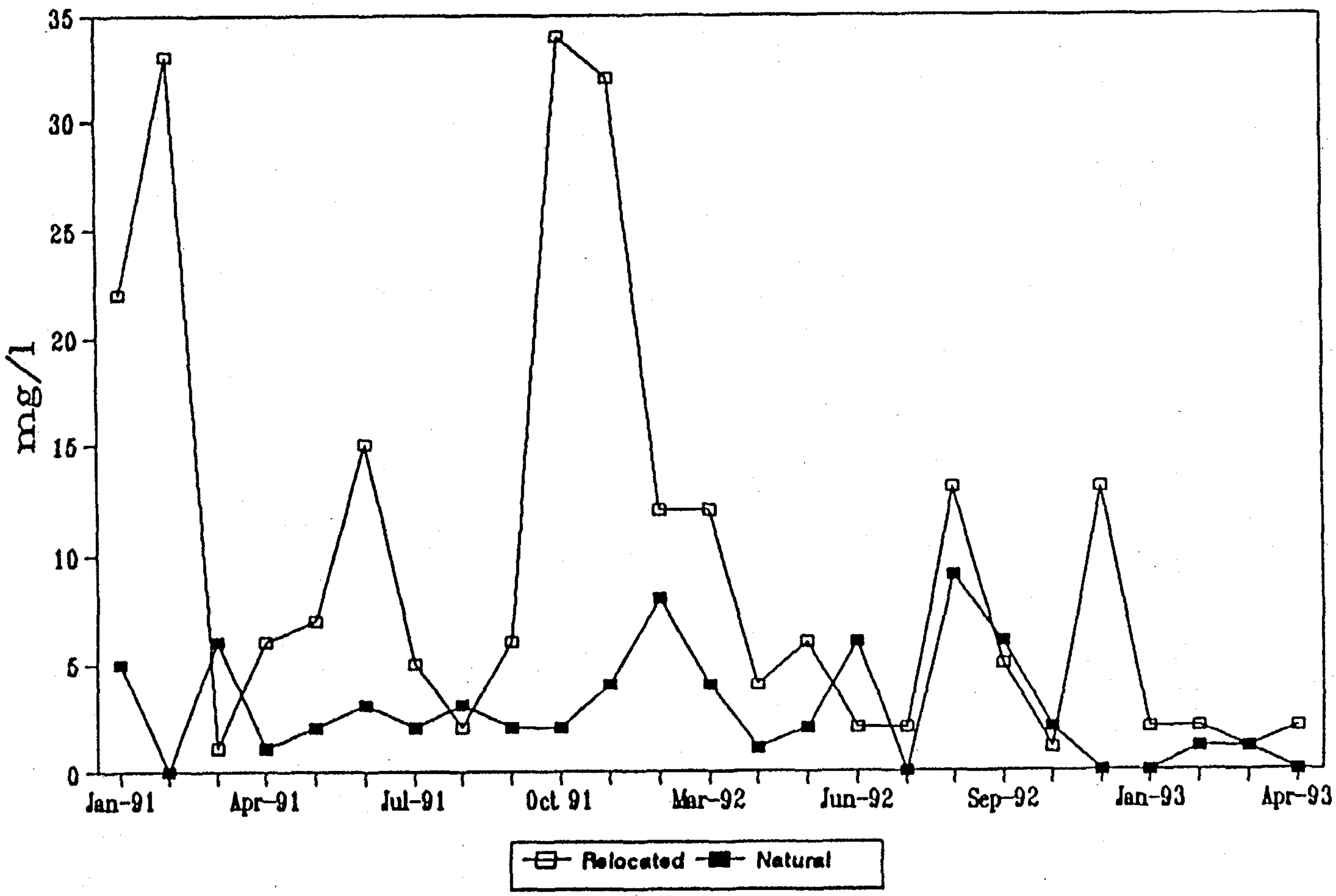
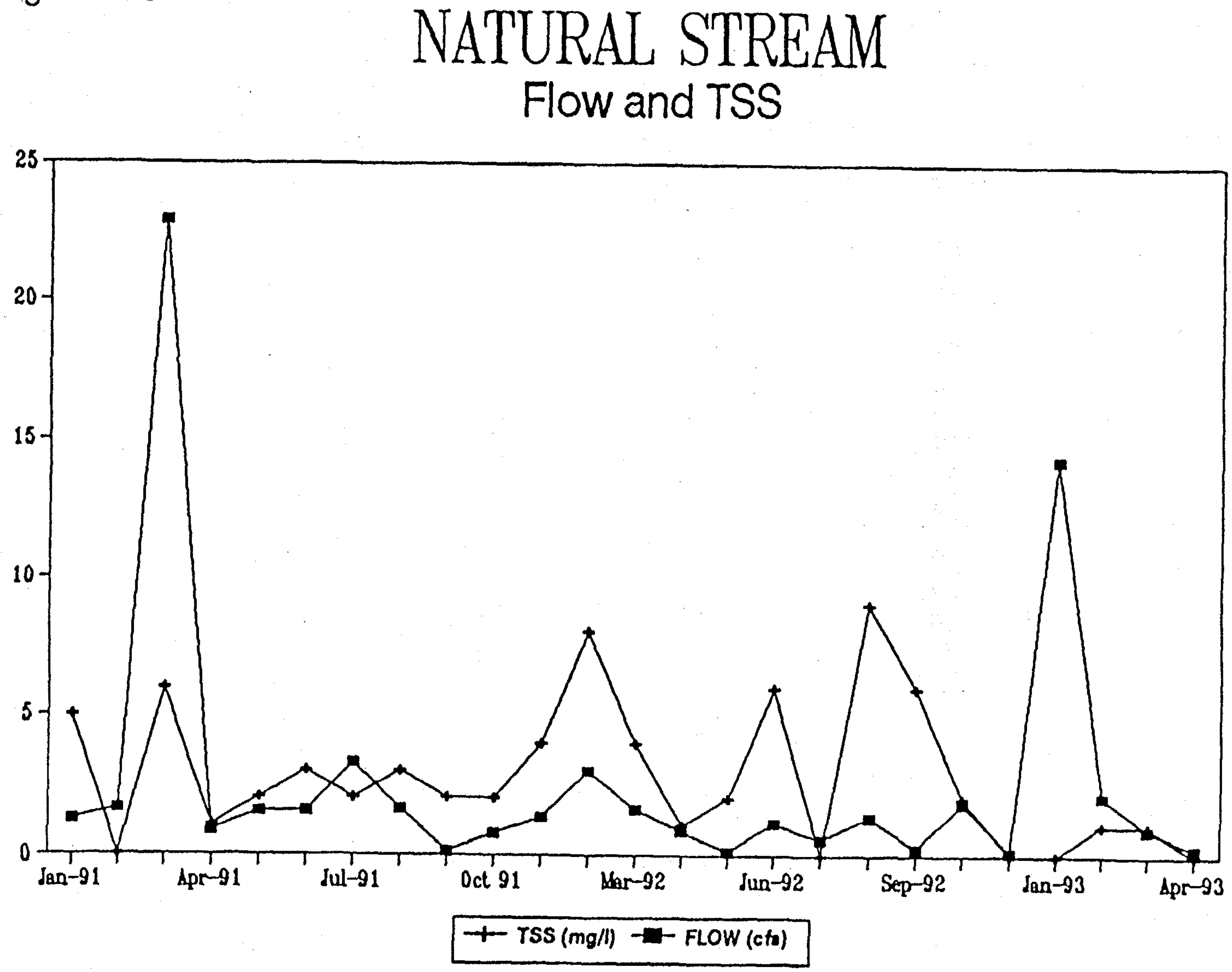


Figure 4-23



NATURAL STREAM
Flow and TSS
25
20
15
10
5
0
Jan-91
Apr-91
Jul-91
Oct 91
Mar-92
Jun-92
Sep-92
Jan-93
Apr-93
TSS (mg/l)
FLOW (cfs)

Figure 4-24

RELOCATED STREAM

Flow and TSS

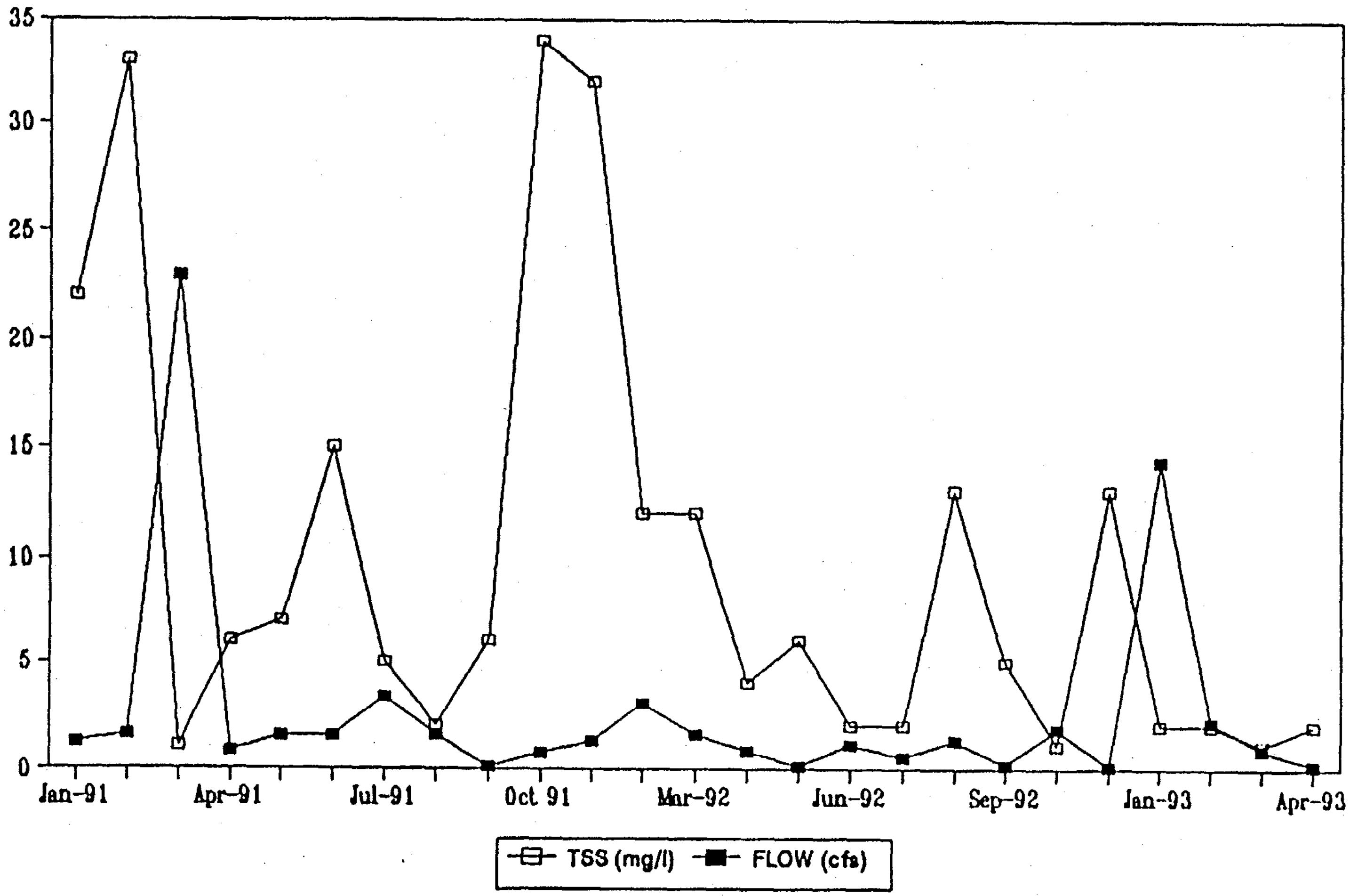


Figure 4-25

RELOCATED VS. NATURAL STREAM

Total Dissolved Solids

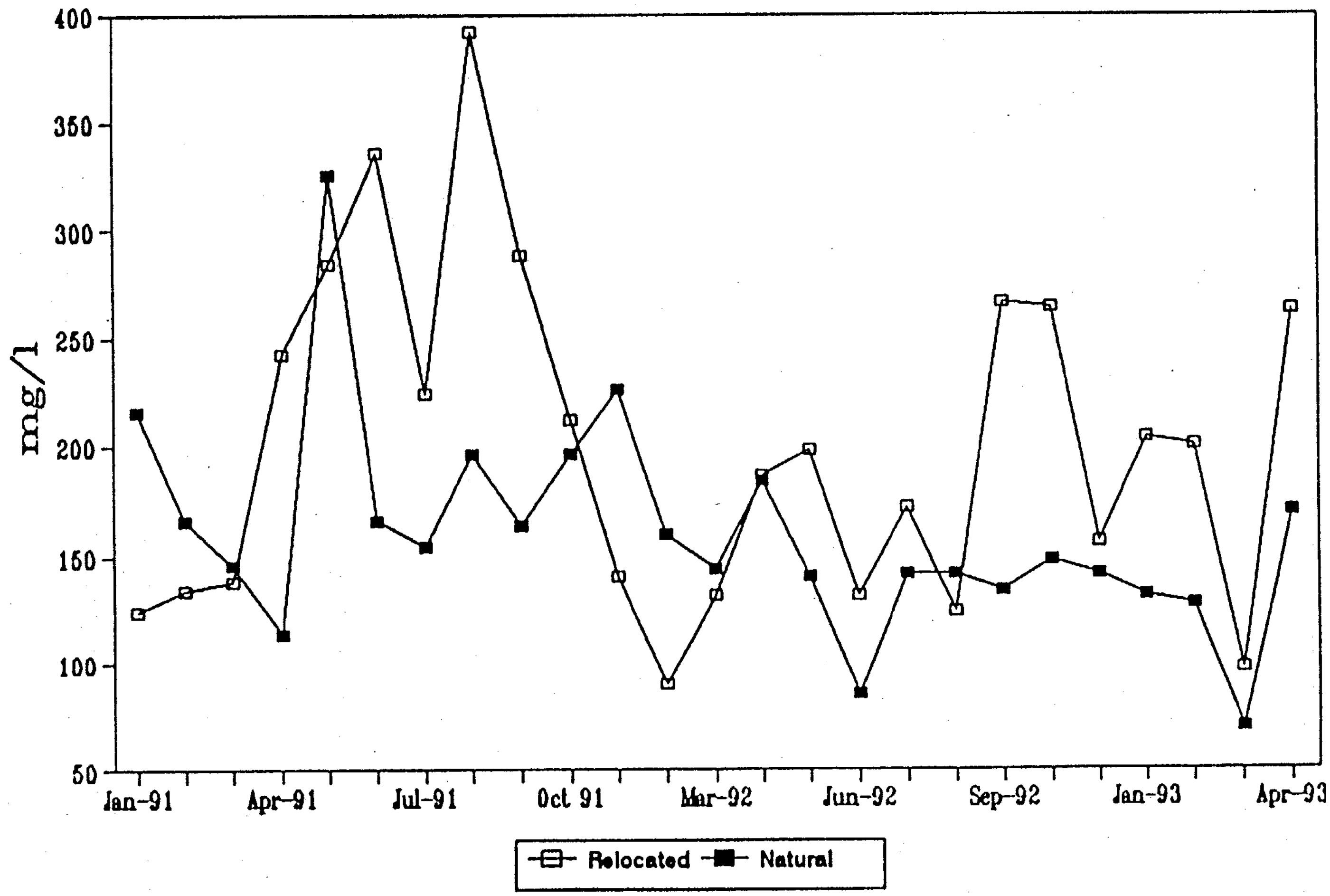
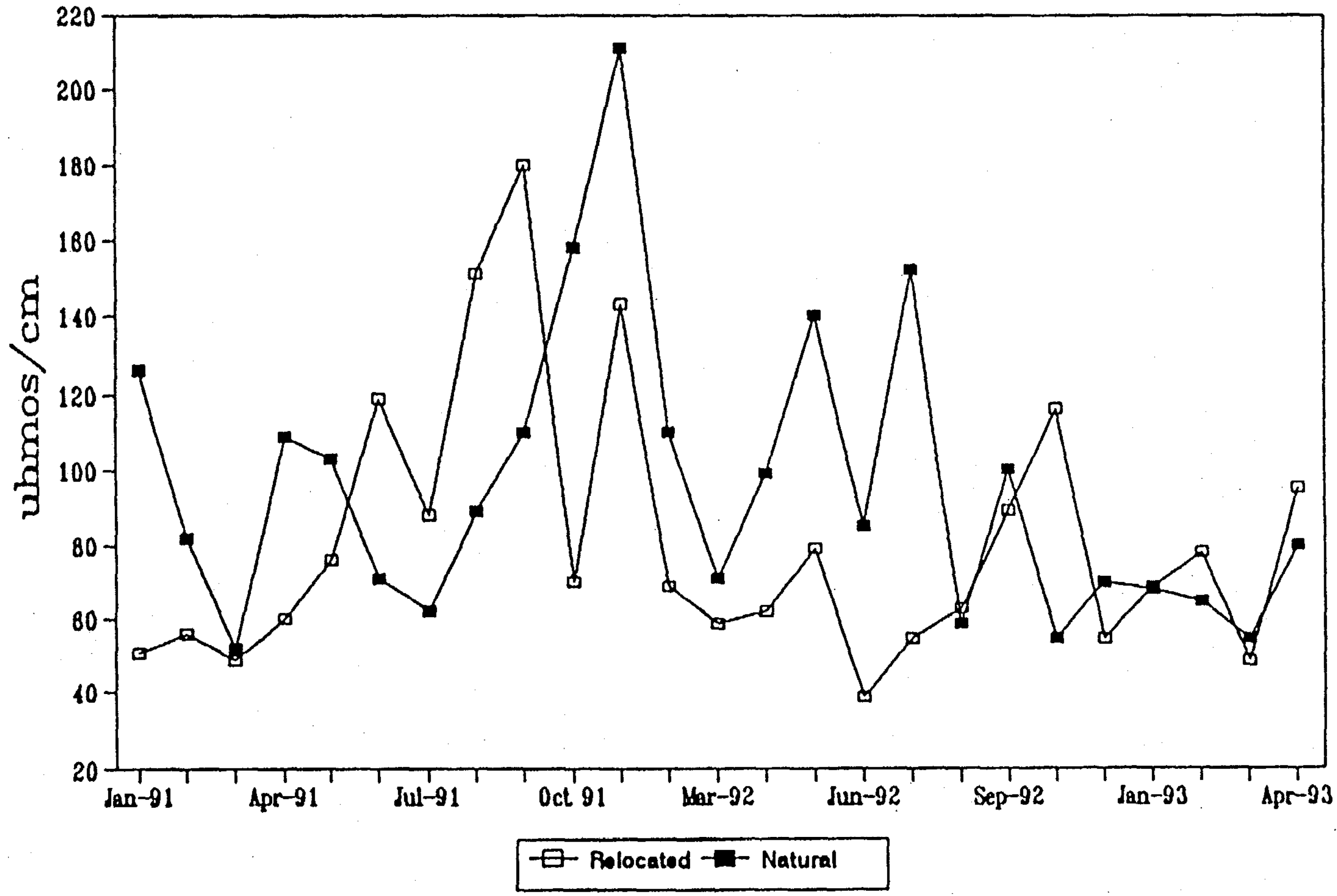


Figure 4-26

RELOCATED VS. NATURAL STREAM

Conductivity



variability decreased with increasing system age. As was noted by Kiefer (1991), our analyses suggest that water chemistry in constructed wetlands approximates that of natural systems of the area within five to six years following creation. It appears that gradual development of wetland soils in created systems to formulate the "memory" of the system helps to stabilize chemical parameters and lead to approximation of conditions typical of natural systems.

Dissolved oxygen values in constructed wetlands either approximated or exceeded those reported for natural wetlands of central Florida in most cases. Thus, from the current database, it appears that oxygen conditions in created systems should not be any more stressful to biota than those of natural wetlands. Along with pH, dissolved oxygen values display a great deal of diel variation due to the controlling influence of photosynthesis and respiration rates. Rates of both parameters are expected to display strong variability both on a diel and seasonal basis. In addition, the depth in the water column where samples were collected will also strongly influence values. Unfortunately we do not know expected daily, seasonal and vertical patterns to be expected for either parameter, thus hindering stricter interpretation of the current database.

MINE INFLUENCED AND RELOCATED STREAMS

Water chemistry in mine influenced and relocated streams is controlled by the nature of the geologic matrix underlying and surrounding the system watershed hydrology and discharge and biological processes operating within the stream proper. It should also be remembered that streams display pronounced changes along their length that are related to increased discharge from an expanding watershed area that they drain. Thus, it is often difficult to compare upstream versus downstream data monitoring stations.

Constructed streams are a relatively new feature of phosphate mined land reclamation, and the database on water quality is extremely sparse. While constructed wetlands are in part influenced by water and chemical export from its watershed, this is the prime influence over stream chemistry. Thus, it is expected that successional trends in stream chemistry and water quality will be much more dependent on upland landscape stabilization via soil formation, compaction, and leaching rates and development of mature communities of terrestrial vegetation. The latter successional process is expected to have a longer lag time that observed in wetlands because of the longer generation times characterizing terrestrial vegetative communities. Thus, the current database is likely too short to expect to see major long term successional trends in the water chemistry and water quality of constructed streams in Florida.

In addition to a relatively sparse database from natural streams for comparison with constructed streams, direct comparison between these two stream types may be hindered due to differences in headwater conditions. Many natural streams of Florida originate from headwater seepage areas unlike most of the constructed streams, whose headwaters are usually constructed wetlands. In addition to possible hydrological differences, headwater wetlands can influence downstream water chemistry via photosynthetic processes and the discharge of particulate organic matter and organic color. While we were able to detect some influence of wetlands on stream chemistry, the current database is insufficient to address this issue.

CONCLUSIONS

The following are our conclusions:

- Both the number of wetlands sampled and the frequency of sampling for individual wetlands is too sparse. Only a small number of the total number of constructed wetlands created on phosphate mined lands have been sampled for water quality. With few exceptions, the sampling record for individual wetlands is extremely short, and both the number and locations of sampling stations and the choice and methodology of parameters sampled changed during the monitoring period.

- From the collected database, a number of general trends relative to water quality can be made. Although both pH and total phosphorus decrease with increasing system age, the latter parameter displays a great deal of intersystem variability. Dissolved oxygen is reasonably high in most systems and remains stable during the course of wetland succession, and nitrogen accumulates during the early years following wetland construction and levels off after the fourth year.

- The peak concentrations for most parameters are during the fourth or fifth year following wetland construction.

- Water quality similarity to natural wetlands is attained approximately five years following wetland construction. Most chemical parameters display a great deal of interwetland variability during the first two to three years following construction, after which systems become more similar to each other. Values approximate those of natural systems for most parameters after the fifth year following construction.

- Streams are a continuum. Streams evolve along their length as the watershed area that they are integrating increases progressively. Thus, one should not expect downstream conditions to mimic those of upstream reaches. This would apply even to the predominately first order streams created on phosphate mined lands.

- Stream chemistry is a function of both watershed processes and vegetation. While the nature of the matrix and weathering rates determine the potential chemical export rates from a watershed, actual watershed release patterns are at least partly regulated by the selective uptake and storage patterns of terrestrial vegetation. In general, younger plant communities that are still in a phase of biomass accrual are actively taking up nutrients, cations and anions, while more mature plant communities with stable biomass often function as chemical flow through systems, the rate of which is controlled by the nature of the sediment matrix and weathering rates. Thus, both vegetation type and relative age of the plant community must be considered both when assessing intrastream successional patterns in water quality and when comparing values between constructed and natural streams.

- Streams lack system memory. Streams are not zones of sediment and chemical accrual but are open ended exporting systems. Thus, there will be no long-term record of either changes in water chemistry or system biotic productivity. The water chemistry of streams reflects current conditions of the watershed including weathering rates and the uptake and storage of elements by vegetation.

- Streams should be expected to exhibit a long lag time to reach "maturity." As streams only reflect current conditions, it is only when watershed chemical export rates stabilize as a reflection of the establishment and maintenance of a "mature" terrestrial vegetative community characteristic of the region that one would expect to see broad similarity between constructed and "natural" streams of the area. The lag time between stream construction and the establishment of a mature floodplain forest is likely to exceed 20 years, thus no constructed stream in Florida phosphate-mined lands may be old enough to display water quality that approximates that of natural streams of the area.

- Headwater differences exist between natural and constructed streams. Headwaters of natural streams in the central Florida phosphate region tend to be seeps. By contrast, those of constructed streams are usually constructed wetlands. Constructed streams are used in landscape design as hydrological regulators (maximum water level) for constructed wetlands. In addition, several constructed streams of central Florida receive overflow waters from constructed wetlands along their length. Thus, water quality in most constructed streams reflects chemical export from associated wetlands over part or most of their length.

- Only two streams have been monitored for more than five years. Given the relationship between the structure of watershed vegetation and water quality, the time following reclamation has been insufficient to evaluate successional trends in water quality for constructed streams. Even for those streams that have been monitored for more than five years, both the choice of parameters and analytical methodology often changed during the study period.

- Sampling frequency was too widely spaced to asses either seasonal or interannual trends in water quality. Water chemistry is expected to change seasonally associated with rainfall and vegetative growth patterns. No attempt was made to relate water chemistry to stream discharge rates. On a daily basis, the time of sampling was not reported nor considered for those parameters such as dissolved oxygen and pH that display pronounced diurnal changes associated with biological physiological activity. Finally, interannual comparisons for individual streams were hindered by the lack of data for comparable seasons.

RECOMMENDATIONS

We make the following recommendations:

- It is recommended that water quality parameters be selected that provide cost effective answers to specific management questions. It is suggested that specific conductance be measured as an indicator of the stability of watershed soils and weathering rates, total phosphorus as a surrogate for wetland trophic state, and dissolved oxygen as an indicator of overall biotic physiological stress. The influence of constructed wetlands on stream water quality can be assessed with specific conductance, color and total organic carbon. Finally, dissolved oxygen should be measured along the stream length as an indicator of potential biotic physiological stress.

- Sampling locations and methodology must be standardized. It is recommended that sampling locations for individual wetlands be held constant during the monitoring period and that laboratory analytical methods be standardized. Quality control programs for all data collected must be followed.

- Diel and seasonal differences for water quality parameters must be assessed. Both pH and dissolved oxygen display strong diel patterns in aquatic systems that are directly related to photosynthesis and biotic respiration. It is imperative that the time of sample collection be given and that any interpretation of these parameters consider potential biological influences on parameter values. Samples must also be collected to account for seasonal differences in parameter values.

- Sampling depth must be standardized. It is recommended that all samples be collected from either the surface or mid-depth in the water column. Above all, sampling must avoid contamination from the sediments.

- Sampling frequency must be standardized. It is recommended that sampling be conducted quarterly and that the monitoring period be initiated immediately following wetlands construction and be continued until the project is released by all appropriate regulatory agencies. Such a regime will account for both seasonal and interannual differences.

- Sampling regimes should account for habitat differences. It is suggested that both vegetated and open water habitats be sampled where available. At the very least, a description of the type of habitat sampled must be reported including vegetation type and water depth.

- The number of natural wetlands sampled should be increased. It is essential that the database on natural wetlands of the phosphate region be increased to account for the overall extent of interwetland variability in parameters used for assessing constructed wetlands. Such databases should also be formulated such that interannual and seasonal variability expected for individual wetlands are assessed.

- The database for natural streams must be expanded. The extent of variability among natural streams of the area has not been adequately assessed. The extent of interannual variability for parameters for individual streams is unknown. Such data must be collected in order to evaluate comparability between constructed and natural streams.

REFERENCES

Hynes, H.B.N., 1970. The Ecology of Running Waters. Liverpool University Press, Liverpool. 555pp.

Kiefer, JH, 1991. Chemical Functions and Water Quality in Marshes Reclaimed on Phosphate Mined Lands in Central Florida. MS Thesis. Gainsville, FL: Univ. of Fla.

Leopold L.B., M.G. Wolman and J.P Miller, 1964. Fluvial Process in Geomorphology. Freeman, San Francisco. 522 pp.

Mitsch, W.J. and James G. Gosselink, 1986. Wetlands. Van Nostrand Reinhold Co., New York.

Robertson, D.J., 1985. Freshwater Wetland Reclamation in Florida, An Overview. Florida Institute of Phosphate Research, Fl.

Ward, J.V, 1992. Aquatic Insect Biology 1. Biology and habitat. John Wiley and Sons, Inc.

APPENDIX - IV

(Raw Data)

WATER QUALITY PAYNE CREEK

	Aug-83	Nov-83	Feb-84	Jun-84	Aug-84	Nov-84	Feb-85	May-85	Aug-85	Nov-85	Feb-86	May-86	Aug-86	Nov-86	Feb-87	May-87	Aug-87	Nov-87	Feb-88	May-88
WATER LEVEL	120.17	119.77	120.27	119.44	120.13	119.22	118.37	117.06	120.07	119.98			120.60	119.40	119.60	120.10				
pH																				
PC-1	7.20	7.40	6.80	6.90	6.80	7.80	7.20	7.10	6.60	7.20	7.10	7.10								
PC-2					6.80	6.80	6.70	6.30	7.10	6.90	6.60	7.10	7.20	6.60	6.58	6.84	6.35	6.74	6.75	6.74
PC-3		7.20	7.20	7.10	7.00	6.90	7.20	7.00	7.10	6.90	6.90	6.60	7.20	6.80	6.89	6.96	6.61	6.94	7.05	6.97
PC-4	7.50	7.60	7.60	7.80	6.90	7.70	7.70	7.40	7.20	7.60	7.30	7.60	7.40	7.50	7.34	6.70	6.90	7.42	7.22	7.58
TURBIDITY																				
PC-1	3.60	0.60	1.10	4.00	2.50	2.20	1.60	3.00	2.40	4.40	4.00	6.20								
PC-2					2.50	1.20	1.00	15.00	1.30	1.30	2.00	4.60	3.80	2.40	1.40	6.30	4.20	1.20	2.50	4.10
PC-3		0.80	1.10	2.80	1.00	1.00	1.00	18.00	0.90	2.60	0.80	2.60	3.00	0.90	0.50	3.60	3.00	0.50	1.20	1.80
PC-4	1.60	0.60	1.20	1.80	1.80	1.60	0.80	0.60	1.60	1.00	1.20	1.60	3.00	1.30	0.70	11.00	3.60	3.80	3.10	2.40
TN (mg/l)																				
PC-1	3.60	2.12	0.48	12.70	1.47	0.83	1.82	0.41	1.77	0.79	0.76	1.09								
PC-2					1.44	0.69	1.76	0.60	0.47	0.45	0.37	0.98	1.45	1.68	0.77	0.94	1.09	1.19	0.98	0.56
PC-3		0.69	0.46	2.66	1.08	0.67	0.65	0.23	0.28	0.34	0.29	0.45	1.07	1.44	0.62	0.68	0.86	0.12	0.92	0.53
PC-4	0.70	0.11	0.02	0.92	0.63	0.32	0.68	0.26	1.42	0.31	0.46	0.34	1.63	1.29	0.16	0.93	0.76	2.83	1.04	[illegible]
FLUORIDE																				
PC-1	1.76	1.78	1.69	1.66	0.74	1.17	1.31	1.21	1.01	1.01	0.93	1.07								
PC-2					0.63	0.61	0.66	0.76	1.66	1.20	0.60	0.46	0.60	0.85	0.49	1.69	1.03	0.67	0.76	0.40
PC-3		0.69	1.67	1.18	0.58	0.62	0.64	0.76	1.91	1.21	0.64	0.66	0.70	1.16	0.56	1.60	1.18	0.80	0.83	0.48
PC-4	1.76	1.62	1.78	0.37	0.66	1.16	0.93	1.11	1.64	1.33	0.95	0.60	0.73	1.32	0.68	0.65	1.15	1.72	0.80	0.54
NO2 (mg/l)																				
PC-1					<0.01	0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01								
PC-2					0.39	0.02	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
PC-3					0.05	0.03	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PC-4					<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.08	0.01	<0.01
NO3 (mg/l)																				
PC-1		0.43	1.61	6.90	1.10	<0.01	0.75	<0.02	<0.02	<0.02	<0.02	<0.02								
PC-2					0.36	<0.01	0.31	<0.02	0.15	0.16	0.19	<0.02	<0.02	0.02	0.24	<0.02	<0.02	0.14	0.28	<0.02
PC-3		0.90	0.39	1.26	0.66	<0.01	0.22	<0.02	0.06	0.06	0.12	<0.02	<0.02	<0.02	0.17	<0.02	<0.02	0.06	0.18	<0.02
PC-4	0.06	0.23	0.03	0.50	<0.02	<0.01	0.08	<0.02	1.00	<0.02	0.13	<0.02	0.04	0.64	<0.02	0.02	<0.02	0.95	0.75	0.09
NH3 (mg/l)																				
PC-1					0.07	0.16	0.61	0.37	0.10	0.11	<0.02	0.17								
PC-2					0.51	0.34	0.03	0.53	0.20	0.03	0.03	0.90	0.26	1.36	<0.02	0.04	0.37	0.15	<0.02	0.06
PC-3					0.36	0.24	0.23	0.20	0.18	0.04	<0.02	0.03	0.10	1.39	<0.02	0.04	0.32	0.03	<0.02	<0.02
PC-4					0.09	0.02	0.03	0.22	<0.02	0.04	0.02	0.05	0.03	<0.02	<0.02	<0.02	0.02	1.47	0.04	0.02
TKN (mg/l)																				
PC-1					0.37	0.81	1.06	0.37	1.14	0.76	0.73	1.06								
PC-2					0.69	0.66	1.44	0.63	0.31	0.29	0.17	0.96	1.42	1.63	0.52	0.91	1.06	1.04	0.67	0.51
PC-3					0.38	0.63	0.42	0.20	0.22	0.28	0.16	0.42	1.04	1.41	0.34	0.65	0.83	0.05	0.71	0.50
PC-4					0.60	0.29	0.69	0.22	0.41	0.28	0.31	0.31	1.68	0.64	0.12	0.72	0.73	1.80	0.78	0.45
PO4 (mg/l)																				
PC-1	0.62	0.60	0.42	0.60	0.92	0.42	1.11	1.12	1.00	0.36	0.60	0.43								
PC-2					0.77	0.34	0.29	1.80	0.59	0.45	0.35	0.35	0.64	0.94	0.39	0.70	1.14	0.44	0.60	0.94
PC-3		0.18	0.41	0.50	0.62	0.25	0.36	0.72	0.57	0.58	0.35	0.15	0.68	1.28	0.22	0.71	1.06	0.66	1.85	1.40
PC-4	0.46	0.28	0.60	0.58	0.79	0.29	0.35	0.25	0.69	0.49	0.51	0.35	0.89	1.00	0.40	0.87	0.60	0.74	0.62	0.40

CREEK WATER QUALITY

	Aug-83	Nov-83	Feb-84	Jun-84	Aug-84	Nov-84	Feb-85	May-85	Aug-85	Nov-85	Feb-86	May-86	Aug-86	Nov-86	Feb-87	May-87	Aug-87	Nov-87	Feb 88	May 88
COND. (umhos)																				
PC-1					206.00	577.00	343.00	318.00	191.00	398.00	431.00	314.00								
PC-2					177.00	219.00	217.00	232.00	256.00	258.00	216.00	142.00	179.00	235.00	202.00	172.00	172.00	162.00	166.00	175.00
PC-3		880.00	302.00	244.00	180.00	218.00	226.00	232.00	262.00	269.00	228.00	166.00	182.00	269.00	212.00	164.00	186.00	184.00	178.00	170.00
PC-4					136.00	256.00	243.00	247.00	246.00	271.00	264.00	182.00	161.00	283.00	201.00	98.00	186.00	256.00	182.00	174.00
BOD (mg/l)																				
PC-1					6.70	3.90	2.80	5.00	4.90	3.60	6.70	6.40								
PC-2					1.50	1.10	1.10	4.00	1.10	1.70	0.90	1.60	2.80	2.60	1.20	2.40	2.60	1.70	0.10	1.70
PC-3		0.40	1.20	3.00	0.60	0.60	0.80	2.00	1.50	1.60	0.60	1.30	1.80	1.20	0.40	1.60	2.20	1.20	1.50	0.70
PC-4					1.60	1.80	1.10	2.00	0.80	6.80	1.60	1.60	1.40	1.40	0.70	2.00	0.90	4.90	1.30	0.50
GROSS ALPHA																				
PC-1					0.30	14.00	0.50	<0.10	8.20	2.60	<0.10	11.60								
PC-2					0.10	<0.10	<0.10	1.20	1.00	1.50	0.70	7.60	1.10	3.10	1.20	0.80	6.40	1.30	2.00	1.00
PC-3		4.40	7.00	1.30	0.60	0.40	<0.10	<0.10	0.80	3.40	2.90	8.40	1.10	1.80	2.40	2.80	1.90	0.20	1.00	1.00
PC-4					1.10	2.40	0.70	<0.10	8.20	2.60	<0.10	10.20	3.40	4.60	3.50	2.00	3.30	4.90	1.00	2.00
TEMP (F)																				
PC-1					78.00	60.00	68.00	76.00	80.00	72.00	66.00	70.00								
PC-2					82.00	63.00	59.00	80.00	85.00	76.00	66.00	73.00	81.00	76.00	59.00	77.00	84.00	74.00	61.00	74.00
PC-3		58.00	65.00	80.00	81.00	63.00	59.00	80.00	86.00	76.00	66.00	72.00	80.00	75.00	58.00	78.00	82.00	72.00	60.00	75.00
PC-4					77.00	63.00	58.00	80.00	82.00	73.00	64.00	70.00	79.00	75.00	66.00	74.00	81.00	73.00	57.00	71.00
DO (mg/l)																				
PC-1					0.10	2.00	2.20	4.20	0.10	1.60	3.00	0.60								
PC-2					1.00	4.20	5.00	0.40	1.80	2.00	1.60	1.10	1.00	0.30	3.20	1.50	0.40	0.50	2.90	0.50
PC-3		5.60	9.60	1.70	1.00	4.00	5.70	0.01	1.80	2.20	2.60	1.00	0.80	0.50	5.50	1.80	0.10	2.00	5.90	1.70
PC-4					4.50	9.00	8.80	6.20	4.40	5.60	7.20	7.40	4.20	6.80	9.50	4.50	4.70	5.10	7.10	7.70
BICARB (mg/l)																				
PC-1					71.00	283.00	81.00	160.00	58.00	191.00	191.00	203.00								
PC-2					52.00	62.00	70.00	72.00	60.00	63.00	57.00	50.00	68.00	65.00	54.00	44.00	84.00	52.00	50.00	55.00
PC-3		56.00	47.00	60.00	56.00	65.00	72.00	90.00	52.00	64.00	64.00	62.00	68.00	67.00	52.00	40.00	73.00	54.00	51.00	65.00
PC-4					29.00	76.00	69.00	98.00	52.00	69.00	50.00	61.00	41.00	57.00	56.00	19.00	43.00	58.00	51.00	58.00
SO4 (mg/l)																				
PC-1					12.00	5.00	68.00	1.00												
PC-2					18.00	30.00	32.00	59.00												
PC-3					17.00	28.00	33.00	50.00												
PC-4					16.00	38.00	35.00	61.00												
TDS (mg/l)																				
PC-1					188.00	374.00	278.60	248.30	201.00	273.00	291.00	331.40								
PC-2					141.00	164.00	148.60	205.00	248.00	179.00	262.00	191.40	147.10	164.00	111.00	194.00	144.00	156.00	110.00	165.00
PC-3		252.00	284.00	202.00	164.00	176.00	182.00	185.00	214.00	170.00	120.00	192.90	141.40	170.00	126.00	134.00	126.00	156.00	132.00	151.00
PC-4					177.00	181.00	171.40	186.30	244.00	190.00	125.70	221.40	161.00	282.00	112.00	146.00	165.00	228.00	158.00	116.00
TSS (mg/l)																				
PC-1					8.00	3.40	3.70	4.60	4.90	3.60	10.40	9.80								
PC-2					6.10	2.60	4.90	28.30	3.20	1.20	4.30	3.60	5.30	8.30	23.00	3.00	11.00	2.00	1.00	5.00
PC-3					1.80	1.30	2.00	28.30	1.00	8.70	1.30	6.60	4.60	2.70	1.00	2.00	9.00	4.00	1.00	1.00
PC-4					4.20	3.30	1.00	1.00	2.20	1.00	2.60	1.50	3.10	0.90	1.00	6.00	3.00	8.00	3.00	4.00
IRON (mg/l)																				
PC-1					1.61	0.22	0.67	0.94	2.94	0.92	1.02	1.48								
PC-2					1.63	0.40	0.73	5.60	0.32	0.38	0.48	0.85	1.46	1.35	0.67	0.40	2.75	0.30	0.70	1.40
PC-3		0.05	0.19	1.56	0.50	0.32	<0.20	4.77	0.16	0.36	0.18	0.65	0.99	0.45	0.23	0.38	2.12	0.43	<0.01	0.50

ROARING CREEK STATION 1 - IN THE RELOCATION NEAR CR 135										
	Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct 91
FLUORIDE	0.5	0.4	0.2	0.4	0.4	0.5	0.3	0.3	0.3	0.6
DO	10.3	9.6	7.2	5.4	8.9	4.4	3.2	4.5	4.8	5.5
pH	6.6	4.7	4.3	4.3	4.3	4.1	4.2	4.1	3.3	4.7
ORTHO-P	0.3	0.2	0.3	0.3	0.4	0.4	1.1	0.9	0.6	0.6
TOTAL P	0.4	0.2	0.4	0.4	0.4	0.5	0.7	0.9	0.5	0.9
GROSS ALPHA (pCi/L)	1.9			0.5			2.1	0	0	3.1
ALKALINITY	2	1	0	0.8	0.8	0	0	0	0	0
TOC	24	40	88	91	80	104	57	76	75	35
BOD	2	1.8	2.3	2.9	2.6	0.8	3	0.3	1.5	2.2
TDS	100	114	164	186	268	244	132	246	178	118
TSS	21	3	10	10	9	4	3	3	12	70
CONDUCTIVTY (mmhos)	31	58	60	85	70	82	58	70	245	58
COLOR (C.U.)	170	215	275	490	490	460	450	425	435	440
TKN	1.1	1.5	1.1	2.9	2.5	3.1	1.5	2.1	2.5	2
NO2/NO3 as N	0.05	0	0.01	0	0.02	0.02	0.04	0.03	0	0.05
FLOW (CFS)		0.2	13.3	0.7	10.4	3.6	19.9	5.7	0.6	0.3
DATE	21	18	18	15	20	17	15	19	16	21
TIME	934	847	959	1132	957	1042	1014	953	1025	1049
WATER TEMP (C)	11.8	10.4	17.4	24.6	23.8	28.4	29.8	28.3	26.2	20.3
WATER DEPTH (FT)	1	1.1	2	1	1.4	1.5	2	1.4	0.9	0.8
SAMPLE DEPTH (FT)	0.5	0.5	0.5	0.3	0.4	0.5	0.5	0.5	0.5	0.5
WEATHER - CURRENT	Cldy	Clear/48	Rain	Cldy/65	Cldy/73	Sun/88	Cldy/86	Clyd/88	Sunny	Cldy/77
-PREVIOUS DAY	Rain	Clear	Cldy	Cldy	Clear	Cldy	Pcldy/92	Clr/93	Sunny	Sunny
WIND DIRECTION & SPEED	W/10	S/5-8	NW/3-5	SE/8-10	SW/10	E/6	SE/10	N/5	S/3	E/8

WATER QUALITY - STATION 1	Jan-92	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93
FLUORIDE	0.3	0.7	0.5	0.3	0	0.1	0.4	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.3
DO	11	6.5	6.4	6	6.2	5.3	3.6	4.9	4.3	6.4	4.9	6.1	7.2	10.3	6 2
pH	5	4	4.2	4	4	3.8	3.9	3.7	3.2	4	3.4	3.9	4.8	3.8	4
ORTHO-P	0.1	1.1	0.7	0.4	0	0.4	0.3	0.1	0.4	0.6	0.1	0.3	0.6	0.2	0.1
TOTAL P	0.5	1.3	0.7	0.6	0.6	0.4	0.9	0.3	0.3	0.5	0.3	0.7	0.3	0.6	0.4
GROSS ALPHA (pCi/L)	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALKALINITY	0.4	0.4	0	0	0.4	0	0.8	0	0	0	0.4	0	0	0	0.4
TOC	61.5	52	75	66	41	61.9	26	76	65	97	45	67	69	54	74
BOD	3.2	1.8	2.4	2.1	2.4	3.2	1.6	2.5	1.6	2.8	0.7	1.1	2.8	6.2	2 5
TDS	162	168	146	162	114	170	88	154	148	176	140	132	166	94	186
TSS	30	10	12	10	12	2	50	6	12	2	13	2	2	2	14
CONDUCTIVTY (mmhos)	156	79	70	75	51	66	52	78	60	53	47	55	53	42	60
COLOR (C.U.)	245	300	360	450	27	425	185	480	480	4	425	295	375	285	440
TKN	1.3	2	2.9	2.2	1.3	3.4	2.5	2.5	2.2	3	1.8	1.6	1.9	2.1	2 4
NO2/NO3 as N	0	0.1	0	0	0	0	0.01	0	0	0.1	0.01	0	0	0	0
FLOW (CFS)	0.6	1.5	1.2	2.8	0.2	6.4	0.4	1.2	0.4	1.5	0.2	9.4	1.6	2.4	0.4

STATION 2 - IN THE RELOCATION ABOUT MIDWAY											
	Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct 91	Jan-92
FLUORIDE	0.5	0.4	0.3	0.4	0.5	0.3	0.3	0.2	1.4	1.2	0 4
DO	5.2	9.4	4.2	7.9	5.3	2.3	3	2.2	1.5	4.2	8
pH	6.6	5.1	4.2	5.1	4.8	4	4.4	4	4.3	5.1	5
ORTHO-P	0.5	0.2	0.6	0.5	0.5	1.2	1.4	1.8	3.6	1.3	1
TOTAL P	0.5	0.4	0.8	0.7	0.6	1.5	0.9	1.4	3.8	1.2	1 1
GROSS ALPHA (pCi/L)	2.5			3.7			3.7	0	0	2.5	4
ALKALINITY	2	1	1	0.8	0.8	0	0	0	0	0	1 2
TOC	20	49	68	69	68	140	62	108	87	55	74 5
BOD	1.6	1.5	1.5	3.4	2.2	1.4	2.8	0.4	1.2	2.1	6
TDS	126	118	148	170	246	322	184	360	258	210	278
TSS	79	7	14	10	23	9	14	1	14	28	88
CONDUCTIVTY (mmhos)	40	62	50	82	71	117	70	110	99	70	209
COLOR (C.U.)	260	240	400	480	440	500	480	475	460	480	475
TKN	1.4	1.4	1.4	1.7	2.5	4.2	2	3.6	3.4	2.5	2
NO2/NO3 as N	0.11	0	0.01	0	0.02	0.03	0.04	0.03	0	0.04	0 2
FLOW (CFS)				3.1	2	0.3	4.6	0.7	0	0	0
DATE	21	18	18	15	20	17	15	19	16	21	
TIME	1123	950	1029	1149	1031	1021	1142	1020	1048	1202	
WATER TEMP (C)	13.6	13.6	19.9	27.5	25.2	29.9	31.2	29	27.3	21	
WATER DEPTH (FT)	2	4.2	4.7	3.4	0.9	0.9	1	0.7	0.6	0.6	
SAMPLE DEPTH (FT)	0.5	0.5	0.5	0.3	0.4	0.5	0.6	0.6	0.6	0 5	
WEATHER - CURRENT	Cldy	Clear/48	Rain	Cldy/65	Cldy/73	Sunny/88	Pcldy/86	Clyd/88	Sunny	Cldy/77	
-PREVIOUS DAY	Rain	Clear	Cldy	Cldy	Clear	Cldy	Pcldy/92	Clr/93	Sunny	Sunny	
WIND DIRECTION & SPEED	W/10	S/5-8	NW/3-5	SE/8-10	SW/10	E/6	SE/10	N/5	S/3	E/8	

WATER QUALITY - STATION 2	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93
FLUORIDE	0.7	0.4	0.3	0.1	0.2	0.3	0.1	0.3	0.2	0.2	0.1	0.1	0.2	0.2
DO	6	6	5	5	5.4	4.1	5.7	2.4	3.7	4	6.4	6.8	9.6	4.3
pH	6	6	5	4.7	4.5	4.7	3.9	4	4	3.6	3.9	3.8	4.2	3.9
ORTHO-P	1.4	1	0.7	0.5	0.4	0.5	0.3	0.4	1.5	0.1	0.5	0.3	0.3	0.3
TOTAL P	1.4	1.3	0.8	0.9	0.5	2	0.7	0.6	1.2	0.4	0 9	0 5	0 5	0 4
GROSS ALPHA (pCi/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALKALINITY	0.4	0.4	0.4	0.8	0.4	0.8	0.4	0.4	0.5	0.4	0.4	0	0	0
TOC	24	38.5	64	66	41.8	42	30	90	143	51	80	95	53	112
BOD	1.7	2.4	3.1	2.4	3	4.4	2.3	1.5	3.5	1.4	1.2	2.3	5.5	3 5
TDS	158	102	186	166	136	132	86	220	274	146	182	186	82	224
TSS	64	16	4	20	0	22	6	11	1	17	2	1	2	2
CONDUCTIVTY (mmhos)	80	52	63	78	32	62	58	73	110	57	59	71	40	82
COLOR (C.U.)	240	245	470	335	375	260	220	495	475	450	275	425	350	480
TKN	1.9	2.1	2.4	1.9	2	1.6	1.8	3.4	4.4	1.7	2.6	3.2	2.3	3 1
NO2/NO3 as N	0.1	0	0	0	0	0	0	0.06	0	0	0	0	0	0
FLOW (CFS)	0.3	0.3	0.2	0	0.7	0.1	0.8	0	0.4	0	1.5	0.5	0.5	0 2
DATE														
TIME														
WATER TEMP (C)														
WATER DEPTH (FT)														
SAMPLE DEPTH (FT)														
WEATHER - CURRENT														
-PREVIOUS DAY														
WIND DIRECTION & SPEED														

ROARING CREEK STATION 3											
	Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct 91	Jan-92
FLUORIDE	0.5	0.3	0.3	0.4	0.5	0.3	0.3	0.2	0.4	0.5	0.3
DO	6.8	9.5	5.6	4.9	3.4	5.1	2.5	1.2	1.4	1.5	10
pH	6.6	5	4.9	5.7	4.6	3.8	4.2	4	3.6	4.4	6
ORTHO-P	1	0.2	0.7	0.1	0.5	0.9	1.6	1.3	1	0.7	0.9
TOTAL P	1	0.3	0.7	0.2	0.7	1.4	1.2	1.1	1.1	0.9	0.9
GROSS ALPHA (pCi/L)	5.6			1.8			2.3	0	0	2.5	1.3
ALKALINITY	2	2	2	1.2	1.2	0	0.4	0	0	0	0 8
TOC	29	58	71	63	82	140	78	110	102	68	42 5
BOD	2.7	1.6	1.5	2	2 7	1.8	2.6	0.6	1 8	3 2	5 6
TDS	124	134	138	242	284	336	224	392	288	212	140
TSS	22	33	1	8	7	15	5	2	6	34	32
CONDUCTIVTY (mmhos)	51	56	49	60	76	119	88	151	180	70	143
COLOR (C.U.)	175	255	425	415	470	485	490	500	485	460	140
TKN	1.4	1.8	1.4	1.9	2.4	5	2.7	4.2	4.1	2 9	1.2
NO2/NO3 as N	0.11	0	0	0	0.01	0.02	0.04	0.07	0.11	0.04	0.1
FLOW (CFS)		0		0.5	10.1	0.7	3.5	1.9	0	0	1 2
DATE	21	18	18	15	20	17	15	19	16	21	
TIME	901	1010	1123	1240	1100	905	1204	1020	1048	1202	
WATER TEMP (C)	12.4	11.3	19.6	27.3	25.2	28.5	30.3	29	27.3	21	
WATER DEPTH (FT)	1	2.4	3.6	2.7	3.2	3	4	0.7	0.6	0 6	
SAMPLE DEPTH (FT)	0.5	0.5	0.5	0.5	0.4	0.3	0.6	0.6	0.6	0 5	
WEATHER - CURRENT	CLdy	Clear/48	Rain	Cldy/65	Cldy/73	Sunny/88	Cldy/88	Clyd/88	Sunny	Cldy/77	
-PREVIOUS DAY	Rain	Clear	Cldy	Cldy	Clear	Cldy	Pcldy/92	Clr/93	Sunny	Sunny/91	
WIND DIRECTION AND SPEED	W/10	S/5-8	NW/3-5	SE/8-10	SW/10	E/6	SECL/10	N/5	S/3	E/8	

WATER QUALITY - STATION 3	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93
FLUORIDE	0.6	0 4	0.4	0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0 2
DO	8	8	6	3.2	3.2	1.8	4.1	2.7	3.9	4.9	6.4	6 6	8.2	4 3
pH	6	6	6	4.2	4.7	4.1	4.8	3.6	3 6	3.4	4.2	3 8	4 1	3 8
ORTHO-P	1.6	1	0.9	0.2	0 4	0.3	0.3	1	1	0.2	0 5	0 3	0 3	0 2
TOTAL P	1.4	0 9	0 8	0.6	0 8	1	0.7	0 3	0 7	0 4	0.9	0 9	0 4	0 3
GROSS ALPHA (pCI/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALKALINITY	0.4	0 8	0.4	0.4	0 4	0.4	0.4	0	0 6	0	0	0	0	0
TOC	18	48.6	63	83	62 9	60	39	116	146	63	66	101	62	128
BOD	3 1	2 3	2.6	2 2	1.7	2	2 6	1.3	2 6	1 8	1 1	2 6	6 7	2 2
TDS	90	132	186	198	132	172	124	266	264	156	204	200	98	262
TSS	12	12	4	6	2	2	13	6	1	13	2	2	1	2
CONDUCTIVTY (mmhos)	69	59	62	79	39	66	63	89	116	56	69	78	49	95
COLOR (C U)	160	290	490	370	400	275	270	490	600	600	340	400	360	400
TKN	1.4	2.6	2.3	2.3	2.3	4.2	1.6	4	4.2	2	2 6	3 2	2.2	3 7
NO2/NO3 as N	0	0.1	0.1	0	0	0	0	0.06	0	0	0	0	0	0
FLOW (CFS)	1.4	1.7	0.6	0	0.7	1.2	0.7	0.2	0 2	0	1.1	0	0	0
DATE														
TIME														
WATER TEMP (C)														
WATER DEPTH (FT)														
SAMPLE DEPTH (FT)														
WEATHER - CURRENT														
-PREVIOUS DAY														
WIND DIRECTION AND SPEED														

	ROARING CREEK - STATION 5										
	Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct 91	Jan-92
FLUORIDE	0.5	0.3	0.3	0.3	0.4	0.3	0.4	0.2	0.4	0.5	0.3
DO	8.1	7.4	6.8	3.8	7.1	4.6	4.8	4.4	1.6	1.6	10
pH	6.7	6.1	5.3	6.5	5.9	5.6	5.6	5.8	6.4	6.7	7
ORTHO-P	0.6	0.4	0.7	1	1	1.1	1.4	2.7	2	2.4	1 5
TOTAL P	0.6	0.6	0.8	1.3	1.4	1.4	1	1.4	2	2	1 1
GROSS ALPHA (pCi/L)	2.2			1.8			1.6	0	0	0 9	1
ALKALINITY	2	3	2	2.8	1.8	1.2	0.8	0.8	0	0	2
TOC	83	67	70	36	70	66	63	54	37	9	69 5
BOD	2	0.5	2	0.7	4.7	0.7	2.4	0.4	0.8	2.3	5 8
TDS	216	166	146	114	326	166	154	196	164	196	226
TSS	5	0	6	1	2	3	2	3	2	2	4
CONDUCTIVTY (mmhos)	126	82	52	109	103	71	62	89	110	158	211
COLOR (C.U.)	75	72	85	280	500	325	440	455	4	85	205
TKN	2.2	1.8	1.7	1.5	2	1 9	1.4	1.4	1.7	0.8	1
NO2/NO3 as N	0.02	0	0	0.75	0.01	0.01	0.02	0.02	0	0.02	0
FLOW (CFS)	1.2	1.6	22.9	0.8	1.5	1.5	3.3	1.6	0.1	0.7	1 3
						All values in mg/L, except as noted					
DATE	21	18	18	15	20	17	15	19	16	21	
TIME	1310	1132	810	920	814	829	912	824	845	1001	
WATER TEMP (C)	12.6	11.3	16.4	21.8	23.8	25.4	26.8	25.4	23.3	23	
WATER DEPTH (FT)	1	1.3	2.2	2.2	1.4	1.2	1	1.4	1.1	1.1	
SAMPLE DEPTH (FT)	0.5	0.5	0.5	0.6	0.5	0.4	0.6	0.5	0.6	0.5	
WEATHER - CURRENT	Cldy	Clear/48	Rain	Cldy/65	Cldy/73	Sunny/88	Cldy/86	Clyd/88	Sunny	Cldy/77	
-PREVIOUS DAY	Rain	Clear	Cldy	Cldy	Clear	Cldy	Pcldy/92	Sunny/93	Sunny	Sunny/81	
WIND DIRECTION AND SPEED	W/10	S/5-8	NW/3-5	SE/8-10	SW/10	E/6	SE/10	N/5	S/3	E/8	

STATION 5

	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93
FLUORIDE	0 4	0 3	0 6	0	0.3	0 3	0 2	0.2	0 1	0.1	0.1	0 1	0 2	0 2
DO	7	8	7	3	7.3	2.6	6.5	4 8	2.7	2.4	5 6	4 2	7 4	3 7
pH	7	7	7	6 5	6.1	6.2	4.4	5.6	4.3	2.8	3.6	3 6	3 6	3 5
ORTHO-P	1.7	1.1	1.9	1.5	0.3	1 2	1.6	0 9	0 4	1 2	0 3	0 5	0 3	0 1
TOTAL P	1 9	1 4	1 8	1 6	1	3 2	1.7	0 8	0 3	1 8	0 6	0 3	0 3	0 1
GROSS ALPHA (pCi/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALKALINITY	0	1 6	2	3.2	2	3 2	0.8	2	0 3	0	0	0	0	1 2
TOC	32	56 5	41	43	56	24	69	39	77	67	69	71	57	89
BOD	2 1	2 6	1 6	2	2 8	1.4	1.9	1 4	3 4	1	0 8	1 8	6 1	2 1
TDS	160	144	184	140	85	142	142	134	148	142	132	128	70	170
TSS	8	4	1	2	6	0	9	6	2	0	0	1	1	0
CONDUCTIVTY (mmhos)	110	71	99	140	85	152	59	100	55	70	68	65	65	80
COLOR (C.U.)	225	316	420	170	450	186	480	270	500	465	285	325	385	400
TKN	1 6	2	1 8	0 8	2 2	1.1	1 9	1 8	1 8	1 7	2 1	2 5	2 2	2 2
NO2/NO3 as N	0	0	0	0	0	0	0	0 05	0	0	0	0	0	0
FLOW (CFS)	3	1 6	0 8	0.1	1.1	0.6	1.3	0 2	1.8	0 1	14 3	2 1	0 9	0 2
DATE														
TIME														
WATER TEMP (C)														
WATER DEPTH (FT)														
SAMPLE DEPTH (FT)														
WEATHER - CURRENT														
-PREVIOUS DAY														
WIND DIRECTION AND SPEED														

	STATION 6 - IN THE SUWANNEE RIVER, UPSTREAM OF ROARING CREEK										
	Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct 91	Jan-92
FLUORIDE	0.3	0.2	0.1	0.2	0.3	0.2	0.3	0.1	0.2	0.4	0.3
DO	10	6.2	6	4.5	10	5	3.9	2	4.9	6	10
pH	4.3	3.8	3.6	3.9	4	3.7	4	3.9	3.9	3.8	4
ORTHO-P	0.2	0.2	0.2	0.2	0.2	0.3	0.9	0.4	0.3	0.8	1
TOTAL P	0.1	0.2	0.3	0.2	0.4	0.2	0.2	1.5	0.3	0.2	0.7
GROSS ALPHA (pCi/L)	0.5			9			1.3	0	0	0.9	1.3
ALKALINITY	1	1	0	0	0.8	0	0	0	0	0	0.4
TOC	75	68	65	76	68	73	60	52	72	52	85.5
BOD	1.8	0.4	1.3	0.6	1	0.5	2	0.8	0.7	2	6.8
TDS	130	152	136	118	210	162	132	206	180	198	172
TSS	6	0	1	4	6	5	1	0	6	10	0
CONDUCTIVTY (mmhos)	60	61	62	80	78	79	70	65	82	77	198
COLOR (C.U.)	410	360	425	460	470	290	460	445	440	275	240
TKN	1.7	1.9	1.7	1.8	2.1	2.3	1.3	1.8	2.2	2	1.1
NO2/NO3 as N	0.01	0	0	0	0.01	0.01	0.01	0.02	0	0.02	0
FLOW (CFS @ Benton)			11450	2350	1086	2311	3669			337.5	327.5
						All values in mg/L, except as noted					
DATE	21	18	18	15	20	17	15	19	16	21	
TIME	1400	814	939	1058	945	1128	1105	915	1011	1128	
WATER TEMP (C)	13.1	8.5	16.8	24.2	25.3	27.9	28.3	26.2	25.6	20.3	
WATER DEPTH (FT)			97.1	83.6	78.5	83.5	87			76.1	
SAMPLE DEPTH (FT)	0.5	0.5	0.8	0.6	0.5	0.5	0.5	0.5	0.6	0.5	
WEATHER - CURRENT	Cldy	Clear/48	Rain	Cldy/65	Cldy/73	Sunny/88	Cldy/86	Clyd/88	Sunny	Cldy/77	
-PREVIOUS DAY	Rain	Clear	Cldy	Cldy	Clear	Cldy	Pcldy/92	Sunny/93	Sunny	Sunny/81	
WIND DIRECTION AND SPEED	W/10	S/5-8	NW/3-5	SE/8-10	SW/10	E/6	SE/10	N/5	S/3	E/8	

STATION 6

	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93
FLUORIDE	0.3	0.2	0.2	0	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DO	8	5	7	7	7.7	5.8	6.6	6.3	7.8	5.8	6.2	7.8	9.9	6.2
pH	4	4	4	3.4	3.7	3.4	3.1	3.1	3.9	2.8	3.7	3.7	3.6	3.6
ORTHO-P	0.9	0.7	0.1	0.3	0.3	0.3	0.5	0.2	1.1	0.3	0.3	0.4	0.3	0.1
TOTAL P	0.8	0.6	0.2	0.3	0.2	0.6	0.8	0.2	0.7	0.5	0.5	0.3	0.3	0.1
GROSS ALPHA (pCi/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALKALINITY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOC	39	57	45	56	51.6	59	62	63	63	48	47	45	44	54
BOD	2.3	1.8	1.4	1.6	2.6	1.2	1.6	0.4	3.8	0.7	0.6	1.3	5.1	2
TDS	100	108	130	136	162	150	134	156	108	92	100	98	106	100
TSS	0	6	2	2	0	4	4	5	1	0	0	2	2	2
CONDUCTIVTY (mmhos)	84	61	63	72	58	70	78	70	71	64	52	51	38	59
COLOR (C.U.)	240	285	390	305	445	320	480	335	425	350	265	295	350	340
TKN	2	2.4	1.9	1.4	1.9	1.8	2.3	2.5	1.8	1.7	1.4	1.8	1.5	1.5
NO2/NO3 as N	0	0	0	0	0	0.08	0	0	0	0	0	0	0.02	0
FLOW (CFS @ Benton)	2512	1624	1786	375	1072	747.5	2146	1102	2679	2586	5510	3706	2080	3593
DATE														
TIME														
WATER TEMP (C)														
WATER DEPTH (FT)														
SAMPLE DEPTH (FT)														
WEATHER - CURRENT														
-PREVIOUS DAY														
WIND DIRECTION AND SPEED														

				STATION 7 - IN THE SUWANNEE RIVER, DOWNSTREAM OF ROARING CREEK							
	Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct 91	Jan 92
FLUORIDE	0.3	0.1	0.1	0.1	0.2	0.1	0.4	0.1	0.2	0.3	0.2
DO	8.9	7.1	5.6	5	10.3	5.8	5	3.5	5.6	6.6	11
pH	4.4	3.8	3.6	5.2	4.3	3.8	4	3.9	4	4.3	5
ORTHO-P	0.4	0.1	0	0.1	0.3	0.3	0.9	0.3	0.5	1.4	0.4
TOTAL P	0.2	0.1	0.2	0.1	0.4	0.3	0.2	0.1	0.3	0.3	0.3
GROSS ALPHA (pCi/L)	1.8			0.2			1.1	0	0	2.4	0.2
ALKALINITY	1	1	0	0	0.8	0	0	0	0	0	0.8
TOC	80	64	68	76	70	64	57	60	69	54	75
BOD	2	0.1	1.1	0.8	0.8	0.5	2.1	0.8	1	2	4.3
TDS	150	122	124	106	216	152	140	186	158	168	132
TSS	7	1	1	4	5	2	2	2	2	8	0
CONDUCTIVTY (mmhos)	55	58	60	59	66	73	62	70	71	60	103
COLOR (C.U.)	81	74	90	460	490	295	450	470	470	325	175
TKN	1.6	1.4	1.6	2	2	1.7	1.3	1.6	2.1	2	1
NO2/NO3 as N	0.02	0	0	0	0.02	0.01	0.03	0.02	0	0.08	0
FLOW (CFS @ White Spgs)			38000	2893	885	2886	4800	6760	1788	396.8	360.8
						All values in mg/L, except as noted					
DATE	21	18	18	15	20	17	15	19	16	21	
TIME	1034	911	848	1011	846	1155	950	1124	915	1029	
WATER TEMP (C)	13.1	12.9	16.4	22.8	25.1	26.5	27.6	28	25	20.8	
WATER DEPTH (FT)			96	60	54.8	60	65	70.1	56.9	52.2	
SAMPLE DEPTH (FT)	0.5	0.5	0.5	0.6	0.4	0.5	0.6	0.6	0.8	0.5	
WEATHER - CURRENT	Cldy	Clear/48	Rain	Cldy/65	Cldy/73	Sunny/88	Cldy/86	Clyd/88	Sunny	Cldy/77	
-PREVIOUS DAY	Rain	Clear	Cldy	Cldy	Clear	Cldy	Pcldy/92	Sunny/93	Sunny	Sunny/81	
WIND DIRECTION AND SPEED	W/10	S/5-8	NW/3-5	SE/8-10	SW/10	E/6	SE/10	N/5	S/3	E/8	
							SE/10				

STATION 7

	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93
FLUORIDE	0 2	0.2	0.2	0	0.1	0 1	0.1	0 1	0 1	0.1	0 1	0 1	0 1	0 1
DO	9	6	8	7.4	6.8	6.2	7 1	6 9	8 5	6 1	7 5	7 8	9 1	6 3
pH	4	5	4	3 9	4 1	3 6	3.2	3	4	2 9	3 9	7 8	3 7	3 6
ORTHO-P	1	0.7	0.4	0.6	0.3	0.4	0.1	0 3	0.6	0	0 5	0 4	0 6	0 1
TOTAL P	0.6	0 6	0.4	0.3	0.3	0 6	0.3	0 2	0 2	0 3	0.6	0 3	0 4	0 1
GROSS ALPHA (pCI/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALKALINITY	0	0	0	0.4	0.4	0	0	0	0.3	0	0	0	0	0
TOC	38	61.6	46	62	60	57	59	61	68	49	49	46	44	53
BOD	2	1.7	1	1.6	2.6	1.2	1.4	0 2	7.7	0 1	0 6	1 7	5	1 8
TDS	132	110	118	116	140	134	142	136	116	94	94	106	62	110
TSS	2	4	1	0	0	0	16	6	2	3	2	3	2	1
CONDUCTIVTY (mmhos)	77	66	69	59	62	62	70	62	69	55	50	48	61	51
COLOR (C U)	220	325	410	310	410	326	460	380	440	440	290	286	345	336
TKN	2 1	1 7	1.7	1 3	1.9	1.1	1.9	2 3	1 6	1 5	1 6	1 7	1 9	1 6
NO2/NO3 as N	0	0	0	0	0	0.02	0.03	0	0	0	0	0	0 03	0
FLOW (CFS @ White Spgs)	2696	2245	1824	428	1124	660	2011	1281	3033	2814	5684	4174	2544	4282
DATE														
TIME														
WATER TEMP (C)														
WATER DEPTH (FT)														
SAMPLE DEPTH (FT)														
WEATHER - CURRENT														
-PREVIOUS DAY														
WIND DIRECTION AND SPEED														

SECTION 5 - AQUATIC FAUNA

By
Thomas L. Crisman, Principal Investigator

with
Gregory Bitter and Valma Jessamy

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 5 - AQUATIC FAUNA

EXECUTIVE SUMMARY

The purpose of this section is to determine if the current database on macroinvertebrate communities in constructed wetlands is adequate and/or useful. Our main goal is to determine if the structural/functional attributes of constructed wetlands mimic those of natural wetlands. More specifically we are looking to see if there are any apparent successional trends in the macroinvertebrate communities and if so how long until an endpoint of stability is reached. We are also concerned with determining if this endpoint approximates macroinvertebrate communities in natural wetlands.

The current database consists of macroinvertebrate data from approximately twenty wetlands. This is a very low percentage of the total number of constructed wetlands. We have attempted to compare the data from these constructed wetlands both with each other and with macroinvertebrate communities from natural wetlands. The relatively low number of wetlands examined must be taken into account when regarding our results and conclusions.

Macroinvertebrate data were broken down into four taxonomic levels for the purpose of analysis. Total invertebrate density/abundance was examined and compared with data collected from natural wetlands. Data were broken down into specific taxonomic classes and orders in order to determine how the groups are effected by the growth of the constructed wetland. The family Chironomidae was further subdivided by two methods: 1) into subfamilies and 2) into feeding guilds. This is due to the fact that chironomids made up the highest percentage of the macroinvertebrate communities that we studied.

The results of our analysis indicate that for nearly every taxonomic level we examined there seems to be an evident trend. It appears that there is a increase in macroinvertebrates during the first two to three years after construction, followed by a gradual decrease in density/abundance after the third year to a level endpoint. It also appears that this endpoint is approximately similar to macroinvertebrate density/abundance levels found in natural wetlands.

It is our conclusion that a successional trend appears evident within constructed wetlands. With the data available we can conclude that by the fourth to fifth year after construction macroinvertebrate communities are similar to those found in natural wetlands. These conclusions, however, must be considered tentative. There are several factors that may effect the reliability of our conclusions. The relatively low number of wetlands sampled must be taken into account. There are also several problems with sampling methodology that could affect our conclusions. Future monitoring for macroinvertebrates and the standardization of sampling techniques would improve the database and possibly support our conclusions.

SECTION 5 - AQUATIC FAUNA

INTRODUCTION

CREATED WETLANDS

Benthic macroinvertebrate data have been reviewed for several constructed and natural wetlands. The purpose of this review was to determine if the available database is adequate to evaluate if the structural/functional attributes of constructed wetlands mimic those of natural wetlands and if so, how long until this similarity becomes evident. More specifically, we are looking to see if there were any apparent successional trends in the macroinvertebrate community and if so how long until an endpoint of stability is reached. We were also concerned with determining if this endpoint approximates macroinvertebrate communities in natural wetlands.

In order to analyze the macroinvertebrate database we have divided the data into four subsets:

1) total macroinvertebrate density/abundance
2) density/abundance of selected taxonomic groups
3) density/abundance of Chironomidae families
4) density/abundance of Chironomidae feeding guilds,

The purpose of breaking the data into smaller groups was to look for successional trends at different levels of complexity.

In addition to the data from the available monitoring reports we also included macroinvertebrate data collected by Mr. David Evans as part of a FIPR funded project to Thomas Crisman of the University of Florida (UF).

CONSTRUCTED AND MINE-INFLUENCED STREAMS

Since most streams are heterotrophic, energy is in the form of detrital material derived from the watershed. Primary producers also contribute to instream production of energy, especially in “open” streams. Detrital material is made up of coarse (>1mm) and fine (<1mm) particulate organic matter, the food source of many macroinvertebrates. Dissolved organic matter leached from particulate organic matter provides food for microorganisms which are consumed by macroinvertebrates (Cummins 1974).

Thus, macroinvertebrates represent a critical pathway for the utilization of energy within systems (Cummins 1974). They are grouped into functional categories according to the feeding mode, particle size and character of the food consumed (Pennak 1984; Merritt and Cummins 1989). The major functional groups are collector-filterers, collector-gatherers and predators.

Abundance and community structure of invertebrates can be directly related to the state of their environment, both biotic and abiotic (Borchadt 1993; Barnes and Minshall 1983; Allan 1975). Competitive or facilitatory interactions between species for food and microhabitats shape the resultant population. Abiotic environmental factors including substrate, physico-chemical parameters of water, hydrology, channel morphology and meteorology determine which species persist over time (Hynes 1970, Mundie 1978, Gore and Judy 1981, Resh and Rosenberg 1984, Ward 1992).

If preferred habitat is available, the community colonizing the system would be preadapted for existence in a highly variable environment. Ecological strategies such as migration and life cycle changes accommodate prevailing patterns of environmental variation and disturbance in a locale (Poff and Ward 1990).

Several studies conducted on the recovery of lotic systems following natural and anthropogenic disturbance have identified invertebrates as a major component of the pioneer colonizing biota (Fisher 1990, Reice et al. 1990, Wallace 1990, Reice 1985, Stanford and Ward 1983). However, unlike terrestrial reclamation projects in which plants and animals have been introduced, it has not been feasible to introduce invertebrates into constructed streams successfully (Gore 1985).

Comparison of macroinvertebrate community structure in disturbed and undisturbed streams have been used to predict rates of recovery following disturbance (Fisher 1990; Gore and Milner 1990; Gore et al 1990; Kelly and Harwell 1990). These studies have provided the basis for the use of macro-invertebrates in determining the success of stream reclamation projects (Gore 1985; Robertson 1985; Starnes 1985).

OVERVIEW OF STREAM RECLAMATION

Stream ecologists have defined four levels of disturbance in streams based on the scale at which perturbation took place (Gore and Milner 1990). Disturbance has been defined as any physical or biological event that occurs outside the normal range of predictable frequencies, severities or intensities for that system (Resh et al. 1988).

In landscapes where mining activities have led to the complete destruction of communities in a stream reach, disturbance has been classified as “level 2A”. Recolonization in the reclaimed habitat is by primary succession followed by primary fauna1 organization (Gore and Milner 1990).

Reclamation of streams from “level 2A” disturbance must not be confused with recovery from point and non-point sources of pollution (Cairns 1990, Kelly and Harwell 1990), the effects on stream ecosystems from agricultural activities (Richards et al 1993), deforestation (Osbourne and Kovaicic 1993, Sweeney 1993), or road construction (Newbury and Gaboury 1993). However, useful information can be obtained from these studies of colonization and organization of macroinvertebrates in streams following anthropogenic disturbance.

Case histories provide evidence of recovery from "level 2A" disturbance of stream ecosystems (Gore 1979, Gore 1982, Gore 1985, Starnes 1985, Sedell et al. 1990). In all cases, it has been demonstrated that the creation of suitable habitat facilitated colonization of macroinvertebrates.

During reclamation of a river which had been routed through an abandoned surface coal mine, addition of substrate and embankment materials in the channel offered some suitable habitat for macroinvertebrate colonization (Gore 1978). Trees anchored in the embankment to act as snags, and rubble piles of large cobble placed in the reclamation had the highest density and diversity of macroinvertebrates (Gore 1979).

Use of meanders is a potential design technique to stabilize reclaimed channels (Hasfurther 1985), and meanders have been identified as a primary means of dissipating excess stream energy (Leopold et al 1964). Downstream bends in the channel result in deflection of water movement to produce differential rates of erosion on concave banks and deposition on convex bank. Distinct hydraulic habitats form across bends in the channel in response to change in depth, flow velocity and substrate (Newbury and Gaboury 1993; Rabeni and Jacobsen 1993; Borchardt 1993).

There are no documented studies relating meander parameters to macroinvertebrate colonization and distribution in stream channels. However, meander parameters have been utilized successfully to enhance hydraulic habitat for fish populations in many streams (Newbury and Gaboury 1993, Rabeni and Jacobsen 1993, Borchardt 1993). A wealth of information is available on the longitudinal distribution of macro-invertebrates in pools and riffles of natural streams that may be useful in the "soft engineering" of stream channels. (Vannote et al 1980, Minshall et al. 1985, Perry and Schaeffer 1987, Pringle et al. 1988, Brown and Brussock 1991, Brussock and Brown 1991).

Research on the colonization of disturbed habitats by macroinvertebrates indicates that an undisturbed source area of colonizers must be available for recovery to take place (Gore 1982, Fisher 1990, Gore and Milner 1990, Reice et al 1990). Benthic organisms repopulate or colonize stream habitat by four general mechanisms: 1) drift of organisms from upstream, 2) upstream migration within the water, 3) movement within the substrate and 4) colonization from aerial sources. Of the four mechanisms, drift? of benthos appears to be most important, contributing as much as 60% of the total fauna in a Florida stream (Cowell and Carew 1976).

Gore (1979, 1982) studied trends in colonization and establishment of equilibrium benthic communities in a reclaimed coal strip-mined river channel. There was a lag of at least 75 days to attain maximum densities and diversities for every 200 m stream length increased away from the upstream source of drift colonizers. A logarithmic plot of these data predicted a recovery time of 6.5 years for the most downstream substrate areas of a reclaimed riffle of 1.2 km long. Reclamation of coal-mined streams provides the best analogy to phosphate-mined streams of Florida. In both cases, landscaping and channelization events have created new land surfaces not previously acted upon by running water. The ability to recreate a stream ecosystem is therefore paramount in the reclamation and enhancement of recovery of mined landscapes (Poff and Ward 1990).

Since a stream ecosystem and its energy dynamics are products of external and internal actions (Hynes 1975; Vannote et al. 1980), restoration must include considerations of in-stream habitat improvement and hydrologic stability, riparian restoration, and water quality improvement (Gore, 1985). Thisviewpoint is supported in the "physical habitat template" concept proposed by Poff and Ward, 1990.

They define the physical habitat template as the minimum elements of the "long-term temporal pattern of physical variability (described primarily by streamflow and thermal regimes) in conjunction with substrate heterogeneity and stability". It is suggested that the provision of this template will decrease recovery time as preadapted species will colonize it. Uncertainty lies in whether or not organisms will persist as the system evolves.

STATUS OF STREAM RECLAMATION IN FLORIDA

The reclamation of drainage systems has become increasingly important in phosphate-mined landscapes in Florida. However, relocation of streams to allow mining and the subsequent rehabilitation of the system in terms of water quality, aquatic biota and riparian habitat are considered controversial because virtually no data have been collected to demonstrate or refute that a stream and its environs can be reclaimed (Robertson, 1985).

Industry-wide, only a few stream relocation and reclamation projects have been completed. Four general stream types have been created on reclaimed sites:

(1) Channels with trapezoidal or "v" shaped steep slopes which function as conduits for the efficient transport of water.
(2) Shallow vegetated swales or ditches
(3) Meandering channels in reforested and/or unmined flood plains
(4) Channels (one of the design types) which have not been connected to existing stream drainage networks.

Headwaters of these streams are often reclaimed or natural wetlands which also form part of the riparian corridor. In watersheds where mining activities are ongoing, connection of reclaimed streams with downstream waters of the state has been delayed until large scale landscape restoration is completed.

At present, water quality data are available for only one reclaimed stream, and macroinvertebrates have been monitored in five reclaimed streams. Water quality and macro-invertebrate data are also available for a mine-influenced stream These data have not been analyzed to determine whether reclamation projects are successful.

Macro and meiofaunal distributions are currently being compared for natural, mine-influenced and phosphate-mined reclaimed streams in Central Florida (Cowell, 1993). The findings of Cowell's research will provide valuable information on the community structure and function of invertebrates in reclaimed streams of Florida.

METHODS

CREATED WETLANDS

The available macroinvertebrate database consists of monitoring reports from six constructed wetlands and two natural wetlands. In addition to these wetlands, the UF database provides data from ten additional constructed wetlands.

WETLAND AW
In this wetland, grading, planting, and mulching were completed in 1982. The land was recontoured from overburden and sand tailings. Some sections were mulched from a donor marsh. The wetlands area covers approximately 60 hectares.

WETLAND AE
Contouring, hand planting and mulching of this wetland was completed in 1986. The wetland area covers approximately 83 hectares.

WETLAND W8.4
Contouring, hand planting and mulching of this wetland was also completed in 1986. The wetland area covers approximately 3.3 hectares.

WETLAND SP-4
Contouring and grading of this wetland was completed in 1986. It was also capped with sand tailings in 1986. This wetland encompasses approximately 40 hectares.

WETLAND SA-1
Contouring and grading of this wetland was finished in 1987. This 4 hectare area was also capped with sand tailings in 1987. No mulch or overburden was placed on this wetland.

WETLAND GA
Contouring and grading of this wetland was also finished in 1987. Overburden saved from pre-mining was placed over the wetland area in 1987. This wetland area covers approximately 4 hectares.

NOWA-1
A natural palustrine wetland located in the central pebble district of Florida.

NOWA
A natural palustrine wetland located in the central pebble district of Florida.

P90
This UF monitored wetland was built by contouring sand tailings in 1989. Planting was completed in 1990. It has an area of 24.3 hectares. ‘Ibis wetland was sampled for two years at the estimate ages of 0.2 and 1 years old and is denoted by P90a for year 0 and P90b for year 1.

HP90
This UF monitored wetland was contoured with sand tailing and capped with mulch in 1990. This wetland is approximately 7.3 hectares in size. This wetland was sampled for two years at the estimate ages of 0.5 and 1.5 years old and is denoted by HP90a for year 0 and HP90b for year 1.

CS88
Grading and planting is this UF monitored wetland was completed in 1989. This 3.6 hectare wetland was estimated at 2 years old when sampled.

CS86
Grading in this UF monitored wetland was completed in 1985 and planting was finished in 1987. This 24.3 hectare wetland was estimated at 4 years old when sampled.

FG86
This UF monitored wetland is the same as wetland AE. At the time of sampling this wetland was 4 years old.

CS85
Final grading in this UF; monitored wetland occurred in 1985 and the area was mulched and planted in 1985. This 6.9 hectare wetland was approximately 6 years old at the time of sampling.

CS84
This UF monitored wetland was mulched and planted in 1985. It was 2.4 hectare wetland was estimated to be 7 years old at the time of sampling.

CS83
This UF monitored wetland was graded in 1981 and mulched and planted in 1985. This 2.4 hectare wetland was estimated to be 7 years old at the time of sampling.

FG82
This UF monitored wetland is the same as wetland AW. At the time of sampling it was estimated to be 8 years old.

TAXONOMIC BREAKDOWN

The macroinvertebrate data have been divided into four categories:

1. Total yearly densities/abundances have been plotted for each wetland.

2. The data have been divided into those taxonomic groups (Annelida, Odonata, Coleoptera, Chironomidae, Diptera and Insecta) comprising majority of macroinvertebrates collected.
3. The data have also been broken down into Chironomidae families. Chironomids make up the majority of the macroinvertebrates and we wanted to see if there were any trends among important groups including the families Chironominae, Orthocladinae, Tanypodinae and the subfamily Tanytarsini.
4. The Chironomidae data have also been assigned to individual feeding guilds. This was done to assess the functional makeup of the macroinvertebrate assemblage. Feeding guilds have been defined by Merritt and Cummins (1984) as collector/gatherers, shredders and predators, with shredders being at the base of the macro-invertebrate food web and predators being at the top.

SAMPLING METHODOLOGY

Benthic macroinvertebrates were sampled using a number of methods including: sediment cores, Hester-Dendy multiple substrate samplers, dip-nets and the stripping of macrophytes. Generally, each wetland was sampled at more than one location and with multiple replicates of the samling method. It is our opinion that the only method that affords truely quantitative analysis is that of sediment cores. This is the only method that allows the number of benthos to be corelated with a fixed area. Wetland AW and all of the UF monitored wetlands were sampled using core tubes. Wetland AE and wetland W8.4 were sampled using Hester-Dendy samplers.

Wetlands SA-1, SP-4 and GA were sampled with a combination of dip nets, Ponar grabs and sediment cores. Unfortunately, the data from these various methods were combined in monitoring reports to form a single sample for each sampling station.

CONSTRUCTED AND MINE-INFLUENCED STREAMS

The goal of this project is to review available data on reclaimed or mine influenced streams and determine if their macrofaunal communities are comparable to relatively undisturbed natural systems. We provide an analysis done for five reclaimed streams and mine influenced stream The reclamation projects are of different ages and monitoring reports date from 1983 to present.

In order to categorize the data and make comparisons between projects, several questions were addressed. We were concerned about the adequacy of the available information and whether or not sufficient peripheral information were included. Sampling methods and techniques, frequency of sampling, number of replicates, qualitative versed quantitative data, and length of record were important as these factors affect statistical analysis of data and interpretation of trends observed.

Many problems were encountered in compiling and interpreting the data set. There is much disparity in sampling protocol employed at different sites. These problems and the questions of concern are addressed in the discussions which follow.

Since in most cases it was not possible to relate the invertebrate data to the physical habitat sampled, research was conducted to determine the community structure in reclaimed streams in relation to the created habitat. Four stream segments, representing three design types, and a natural stream were sampled. Results obtained are discussed in the section on the effect of physical habitat template.

RESULTS AND DISCUSSION

CREATED WETLAND

The macroinvertebrate data, as mentioned above, were treated at four levels of complexity. They were also treated separately according to the method of collection. It is our opinion that the quantitative data gathered from wetland AW and the UF monitored wetlands cannot be compared directly with the qualitative, Hester-Dendy data collected in wetlands AE and W8.4.

There have been no analyses performed on the data from wetlands SP-4, SA-1 and GA. The data available from these wetlands were compilations of several sampling methodologies, and there is no way to distinguish the proportion of each sub-habitat that has been sampled.

TOTAL DENSITY/ABUNDANCE

There appears to be an apparent trend in total invertebrate density in wetland AW (Figures 5-1 and 5-2). After an initial surge in density in the fourth year, there was a decrease towards an equilibrium state by the fifth year. The density in this wetland, however, was still much greater than that found in the natural system No trend was evident in the UF wetlands (Figure 5-3), as the density in these wetlands remained very high regardless of age.

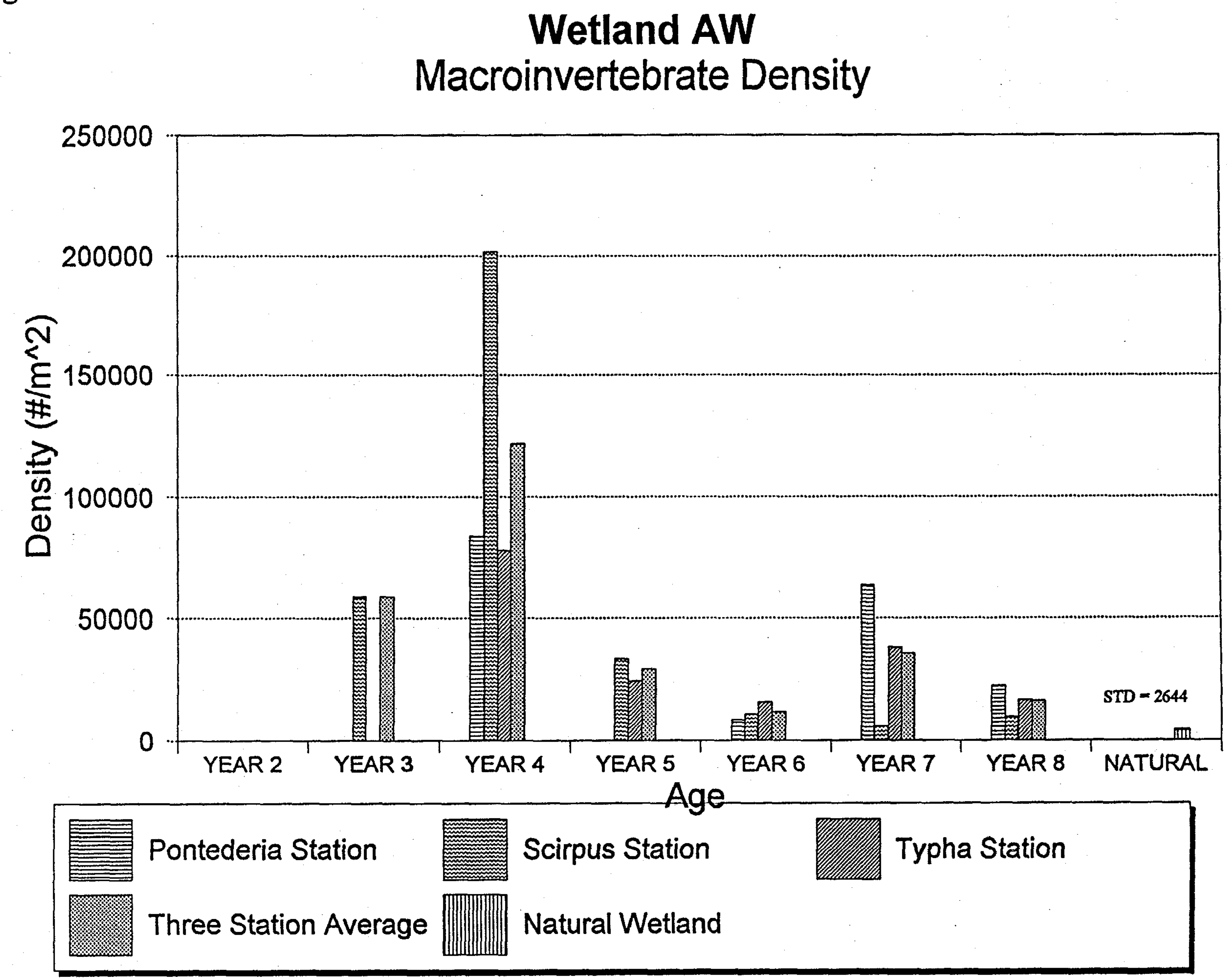
Abundance within both wetlands AE and W8.4 declined progressively and appeared to be moving to an equilibrium point (Figure 5-4).

TAXONOMIC GROUPS

SEDIMENT CORE SAMPLING

The density of annelids in both wetland AW and the UF wetlands seems to be highly variable (Figures 5-5 and 5-6). No trends can been seen for this order. The density of odonates does seem to be stabilizing in wetland AW and approximating the density found in the natural system (Figure 5-7). There is variability in the UF wetlands (Figure 5-8), although the densities in these wetlands is close

Figure 5-1



Wetland AW
Macroinvertebrate Density
Density (#/m^2)
250000
200000
150000
100000
50000
0
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL
Age
STD = 2644
Pontederia Station
Scirpus Station
Typha Station
Three Station Average
Natural Wetland

Figure 5-2

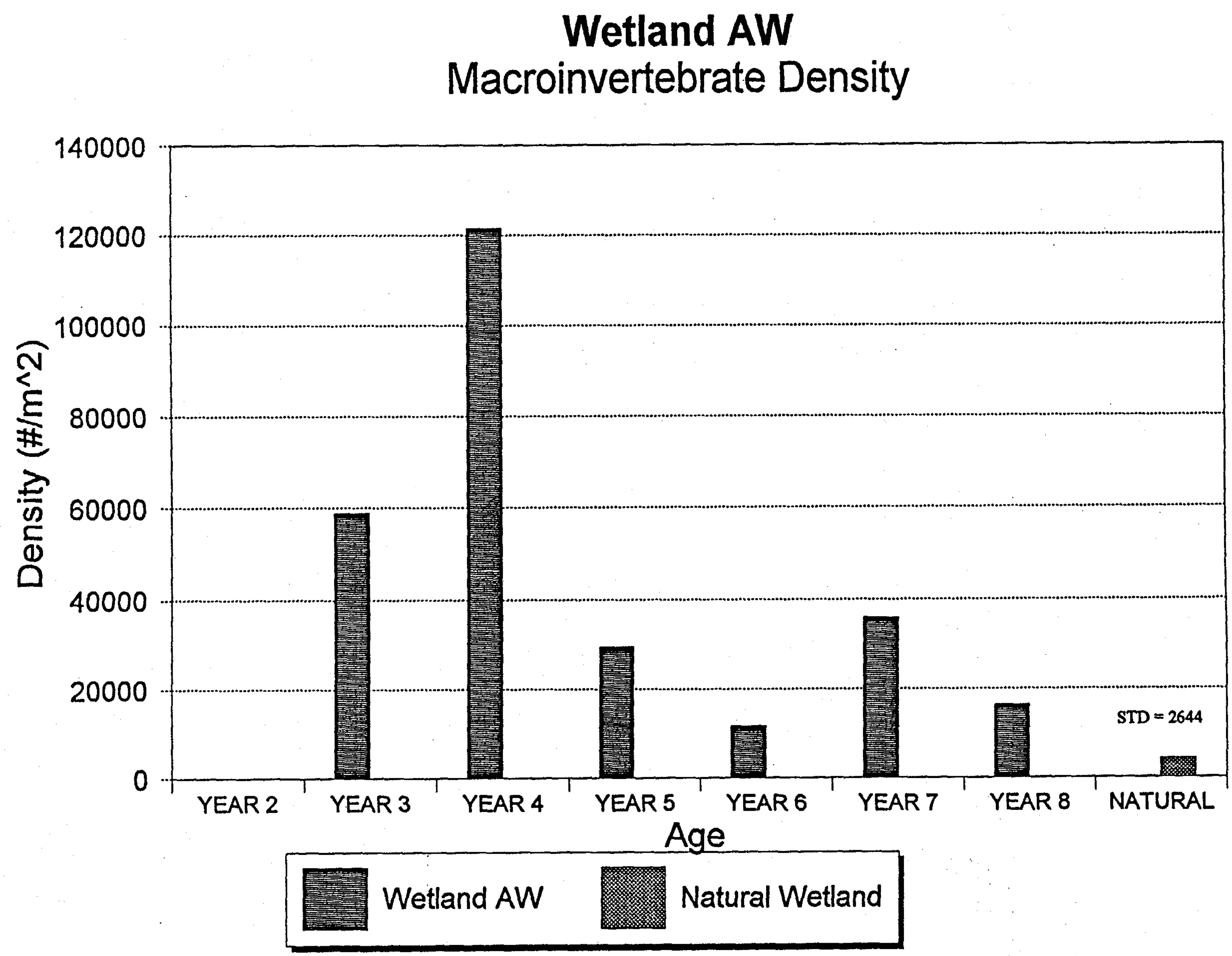
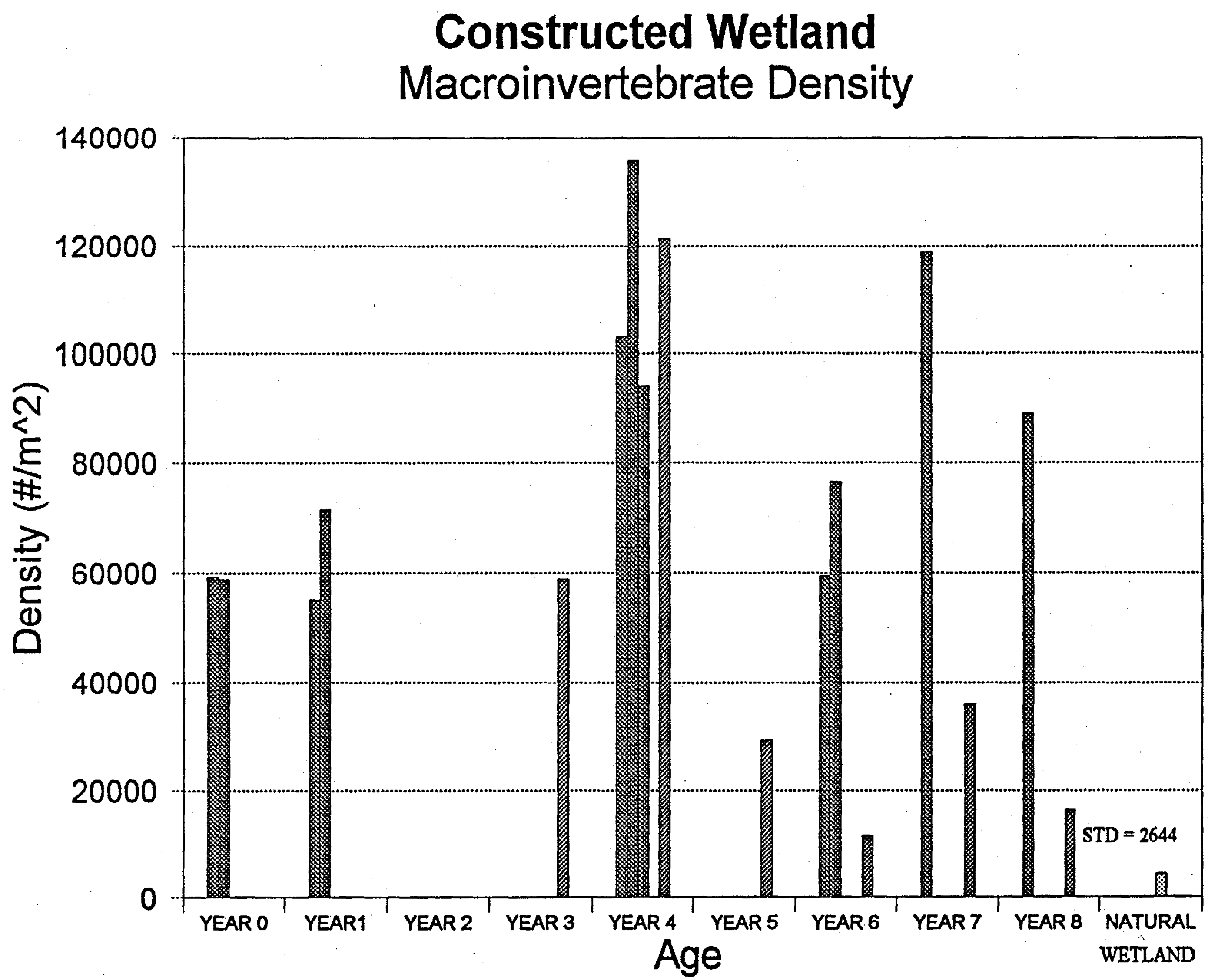

Wetland AW
Macroinvertebrate Density
140000
120000
100000
80000
60000
40000
20000
0
Density (#/m^2)
STD = 2644
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL
Age
Wetland AW
Natural Wetland

Figure 5-3
(D. Evans database)



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-4

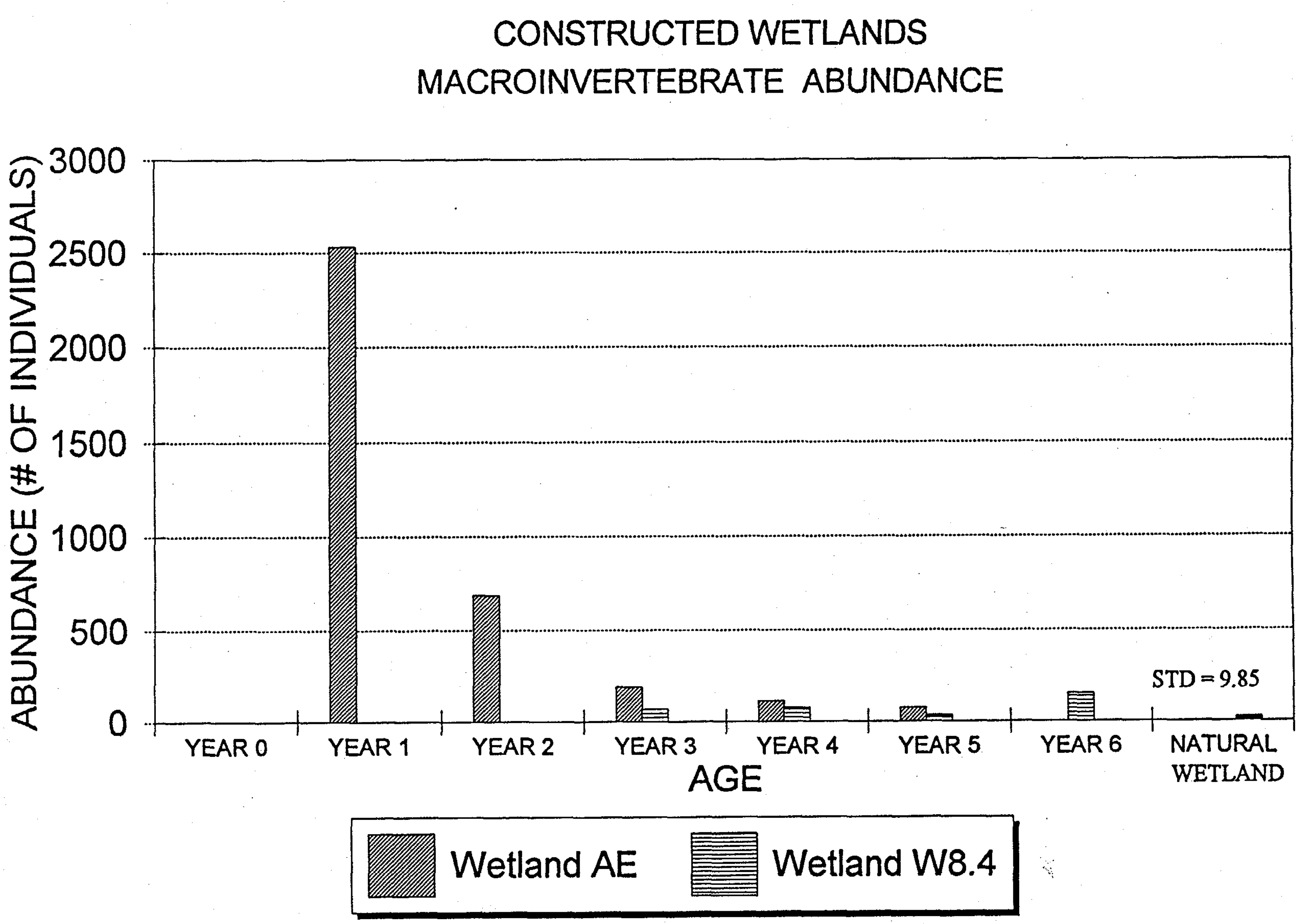

CONSTRUCTED WETLANDS
MACROINVERTEBRATE ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
3000
2500
2000
1500
1000
500
0
STD = 9.85
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-5

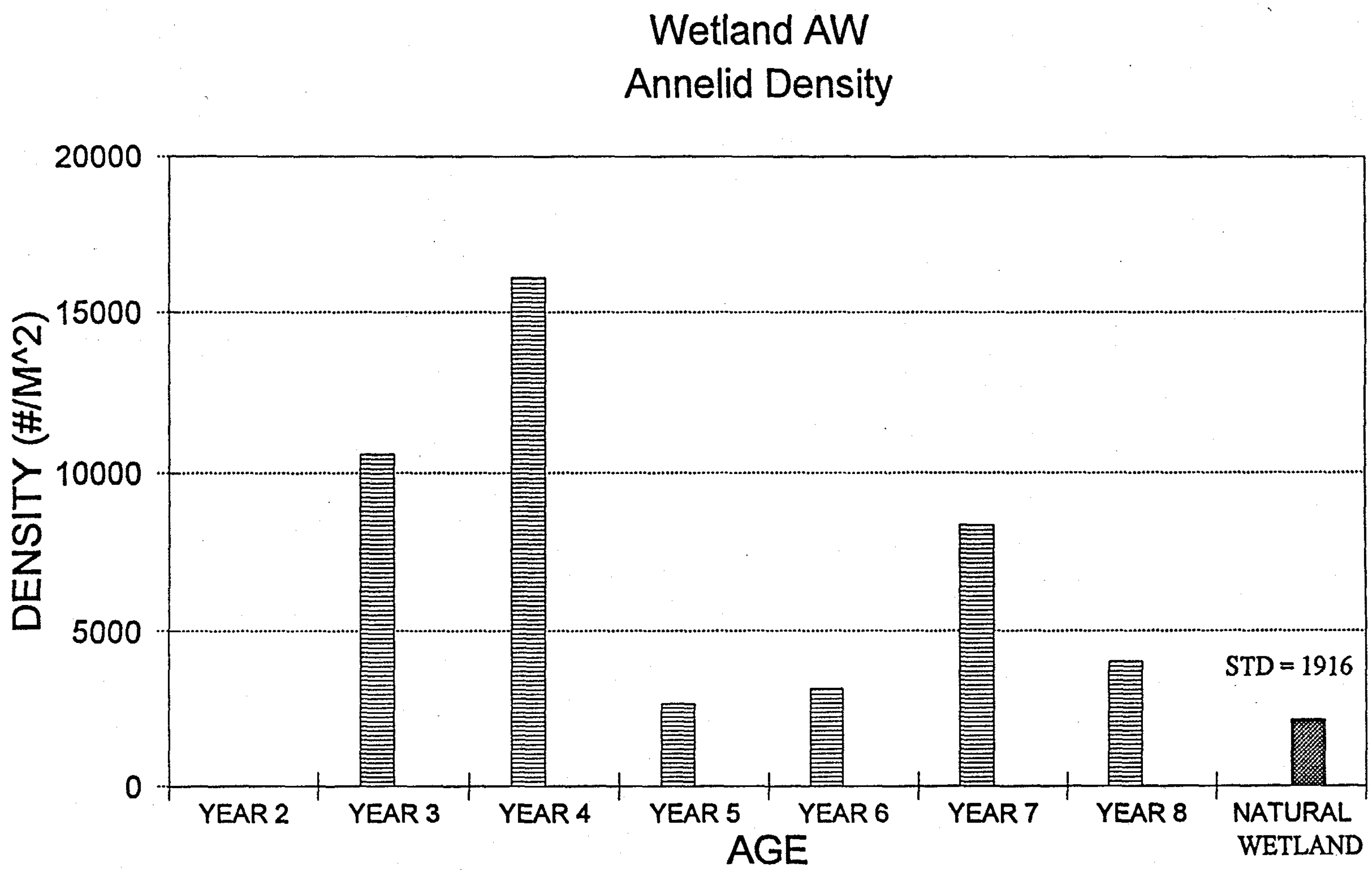
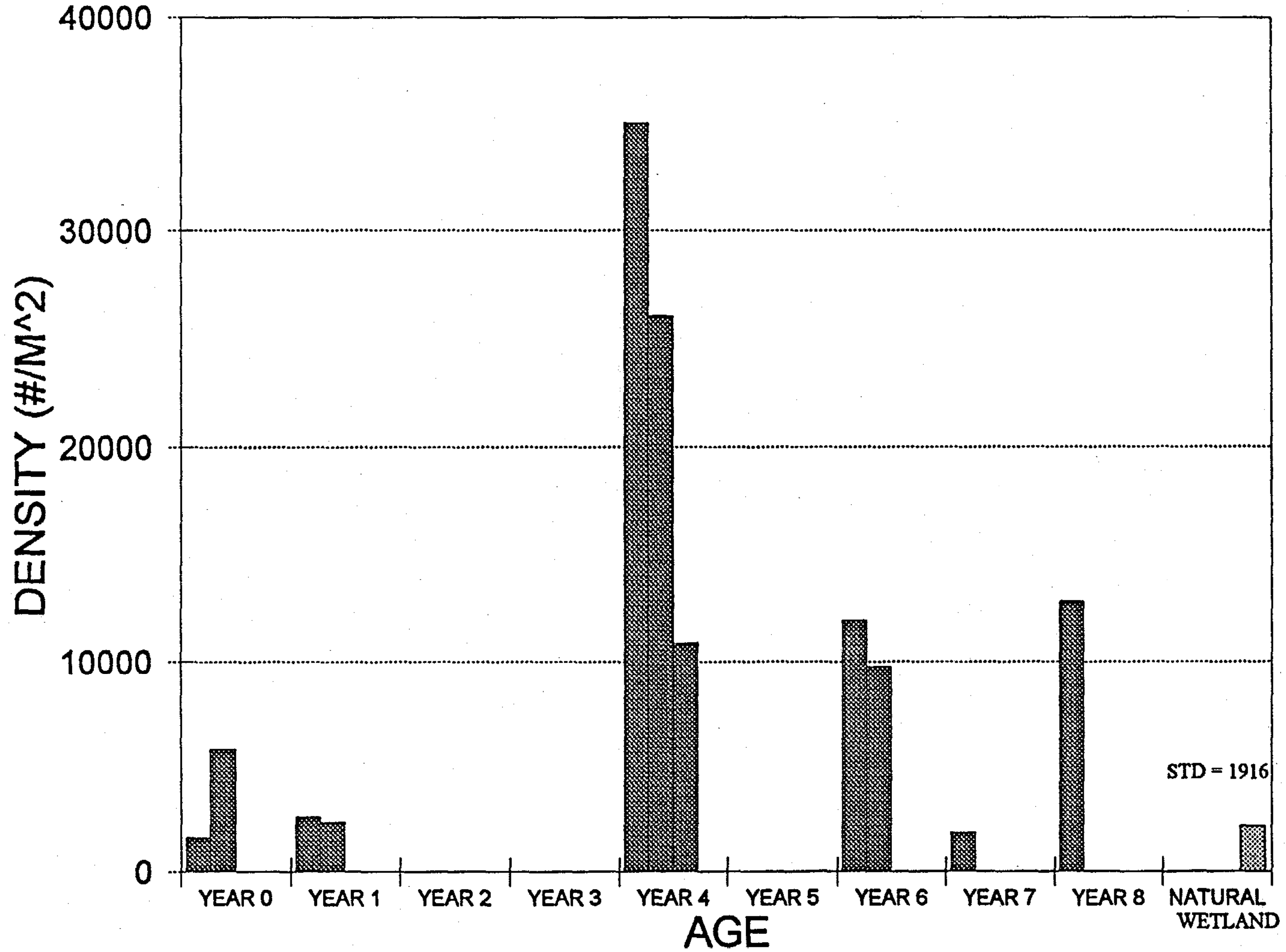

Wetland AW
Annelid Density
DENSITY (#/M^2)
20000
15000
10000
5000
0
STD = 1916
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-6
(D. Evans database)

Constructed Wetlands
Annelid Density



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-7

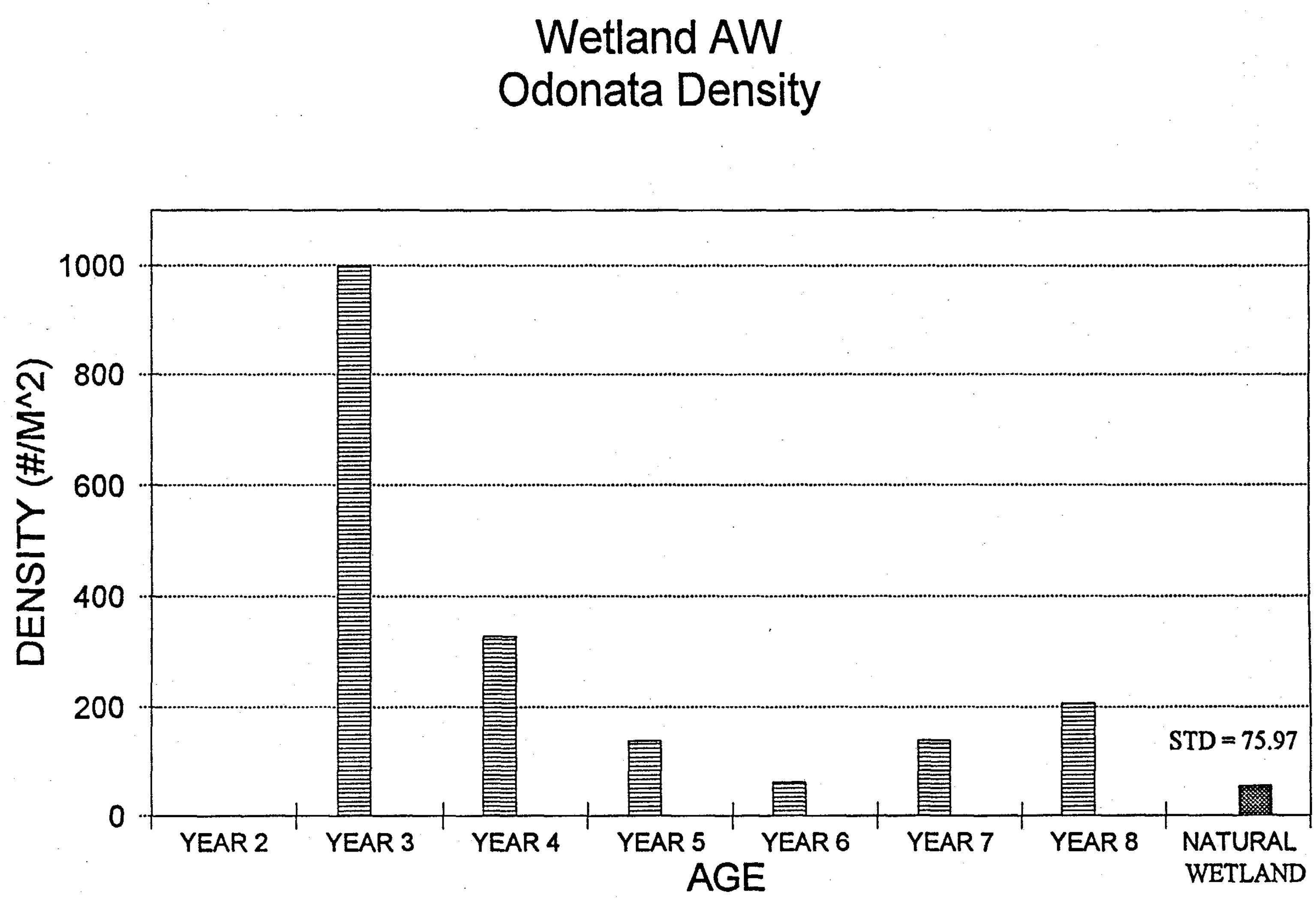
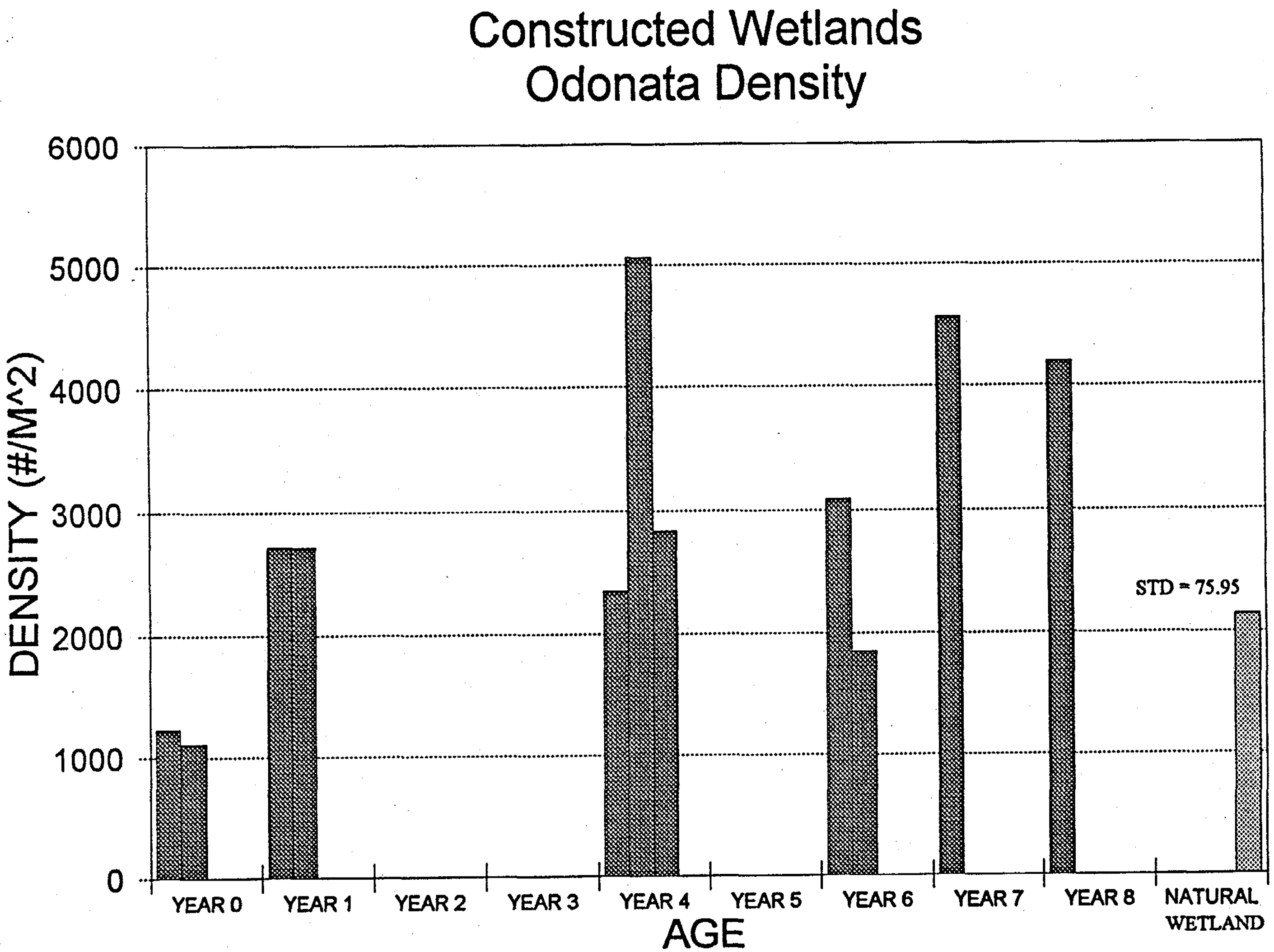

Wetland AW
Odonata Density
DENSITY (#/M^2)
1000
800
600
400
200
0
STD = 75.97
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-8
(D. Evans database)



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

to those of the natural system

Coleopteran density appears to be increasing from year 5 through year 8 in wetland AW (Figure 5-9). There is much variability in Coleopteran densities among the UF wetlands (Figure 5-10). Chironomids appear to reach an equilibrium state near that of the natural system around the fifth year in wetland AW (Figure 5-11). Again, there are no evident trends in Chironomid densities in the UF wetlands (Figure 5-12).

The apparent equilibrium seen in the Dipteran density in wetland AW (Figure 5- 13) can be accounted for by the trend seen in Chironomid density (Figure 5-11), as Chironomids make up the largest part of the Dipterans. The same can be said for the variance seen in the UF wetlands (Figure 5-14). The trend seen in Insect density in wetland AW (Figure 5-15) is again a reflection of Chironomid density (Figure 5-11). This explanation also accounts for the lack of any trends in the UF wetlands (Figure 5-16).

HESTER-DENDY SAMPLERS

Annelid abundances appear to level off in the fifth year in both wetlands AE and W8.4 (Figure 5-17). Both of these systems appear to be similar to the natural wetland. There seems to be a trend towards and equilibrium point for the Odonata abundance in wetlands AE and W8.4 (Figure 5-18). This equilibrium level is similar to the abundance found in the natural systems.

Coleoptera abundances in wetlands AE and W8.4 appear to decline to an equilibrium similar to that of the natural wetland (Figure 5-19). The abundance of Chironomids in wetlands AE and W8.4 drops in the second year and reaches an equilibrium similar to the abundance in the natural wetland (Figure 5-20).

The trends evident in the abundance of both Dipterans and Insects in wetlands AE and W8.4 (Figures 5-21 and 5-22) are controlled by Chironomid trend (Figure 5-20). Both Diptera and Insecta are dominated by Chironomidae.

CHIRONOMIDAE FAMILES

SEDIMENT CORE= SAMPLING

Densities for Chironominae seem to reach equilibrium in the fourth year in wetland AW (Figure 5-23). There is no apparent trend among the UF wetlands (Figure 5-24). There is wide variability in Orthocladinae numbers in both wetland AW and the UF wetlands (Figure 5-25 and 5-26). Orthocladinae is only found in three of the UF wetlands, P90, HP90 and FG82.

There seems to be a trend towards equilibrium of Tanypodinae density within wetland AW (Figure 5-27). This equilibrium is reached in the third year. Again, there is no evident trend among the UF wetlands (Figure 5-28). Equilibrium in Tanytarsini numbers appears in the third year in wetland AW (Figure 5-29), while no trend is evident among the UF wetlands (Figure 5-30).

Figure 5-9

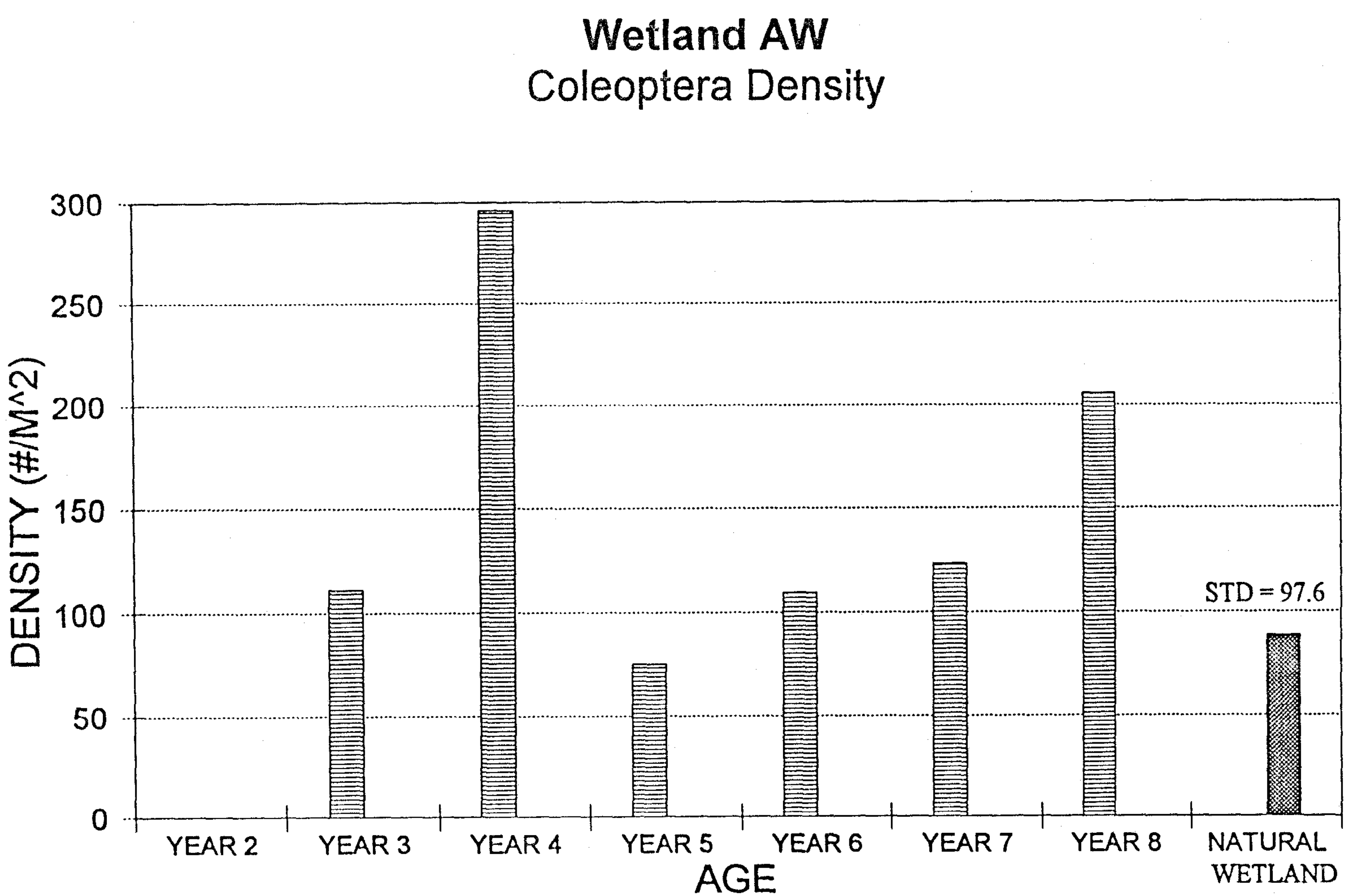
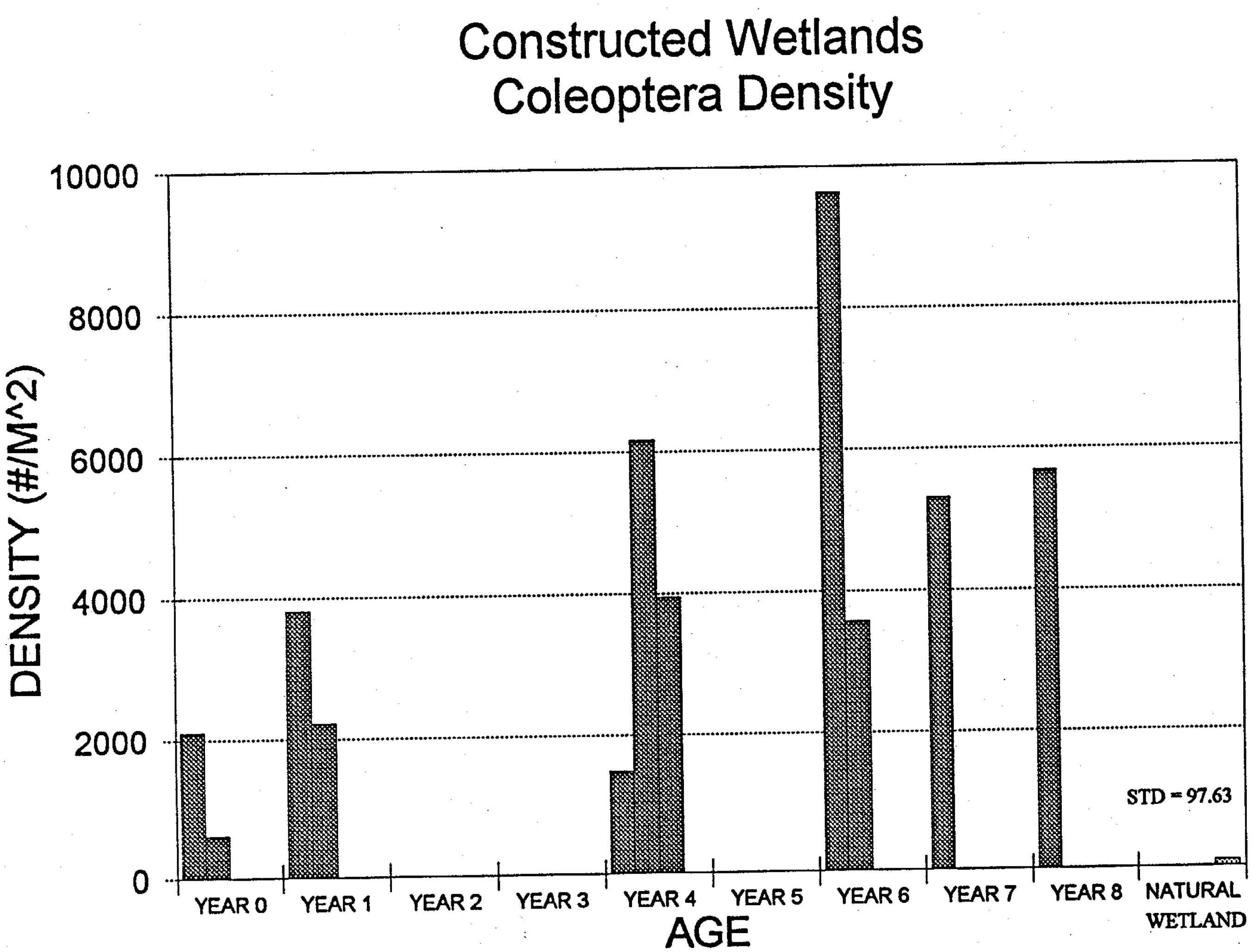

Wetland AW
Coleoptera Density
DENSITY (#/M^2)
300
250
200
150
100
50
0
STD = 97.6
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-10
(D. Evans Database)



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-11

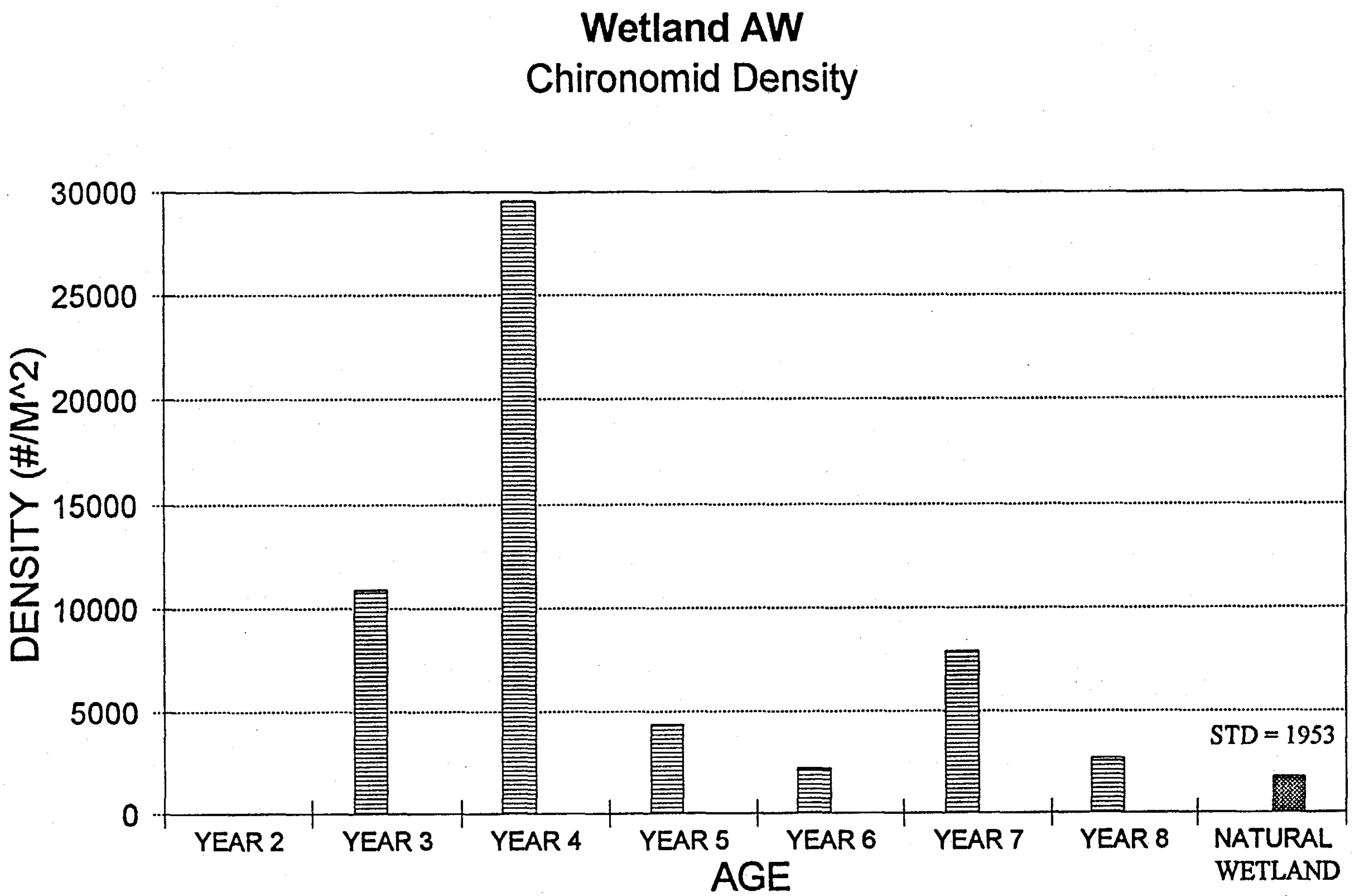

Wetland AW
Chironomid Density
DENSITY (#/M^2)
30000
25000
20000
15000
10000
5000
0
STD = 1953
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-12
(D. Evans database)

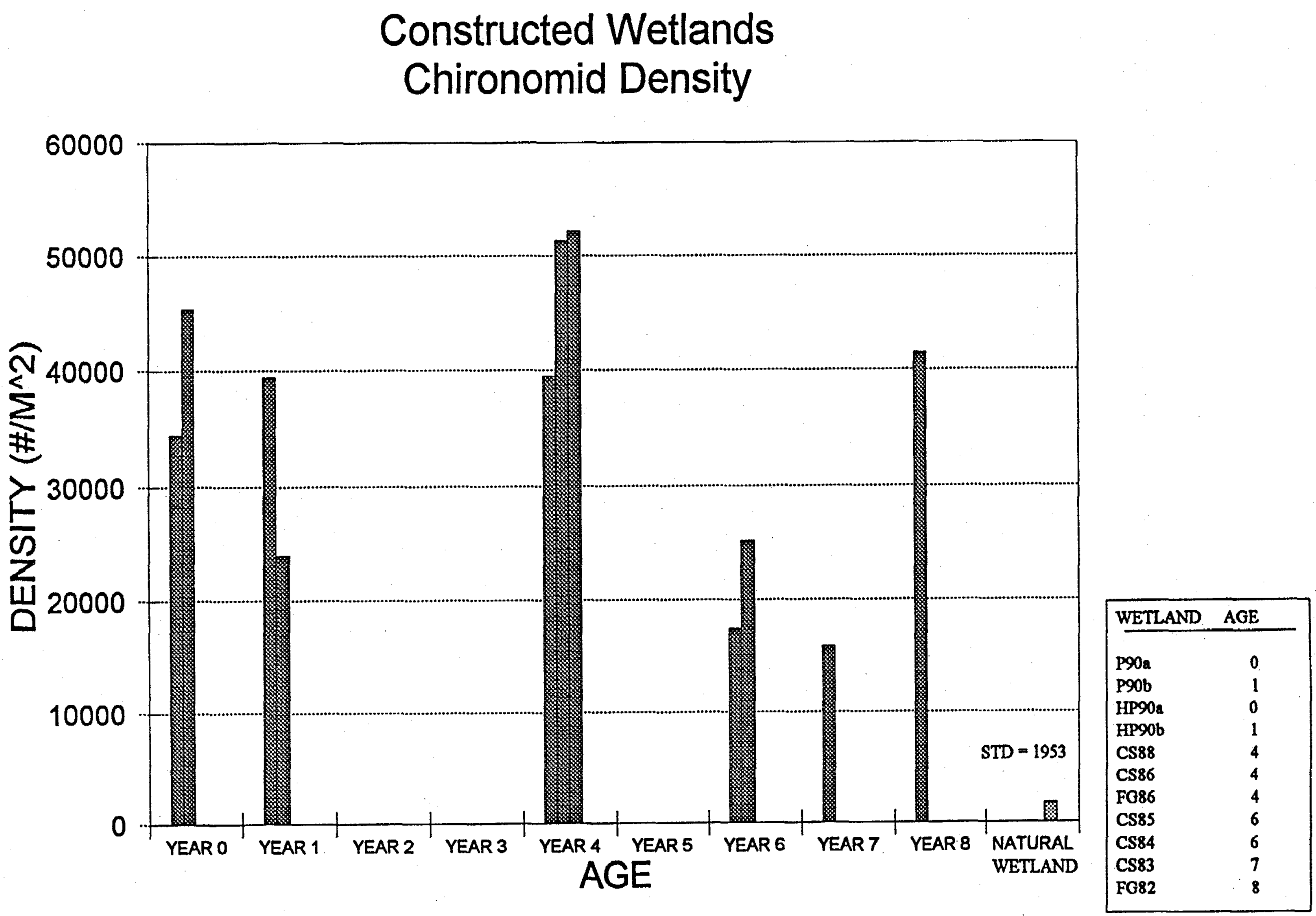


Figure 5-13

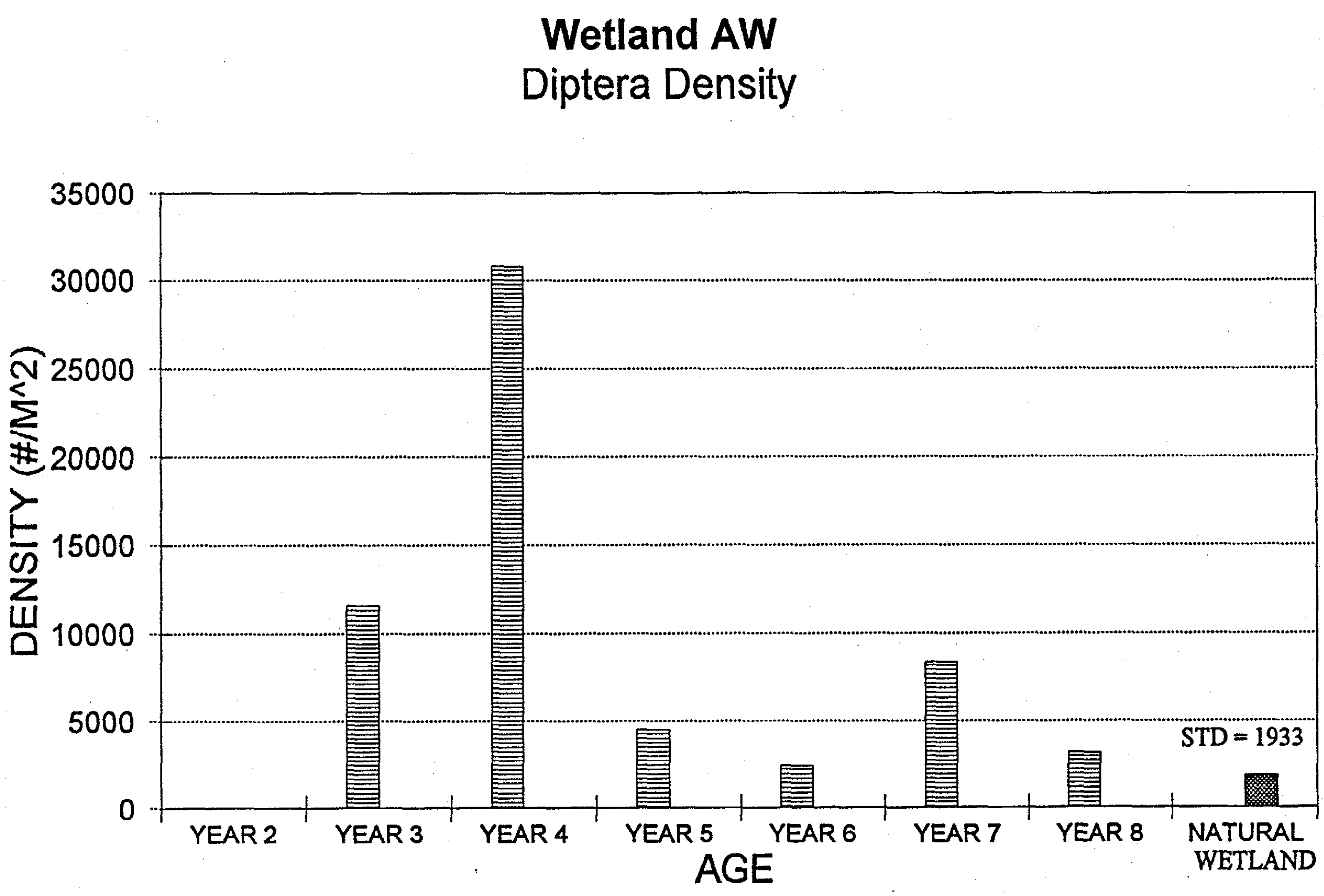
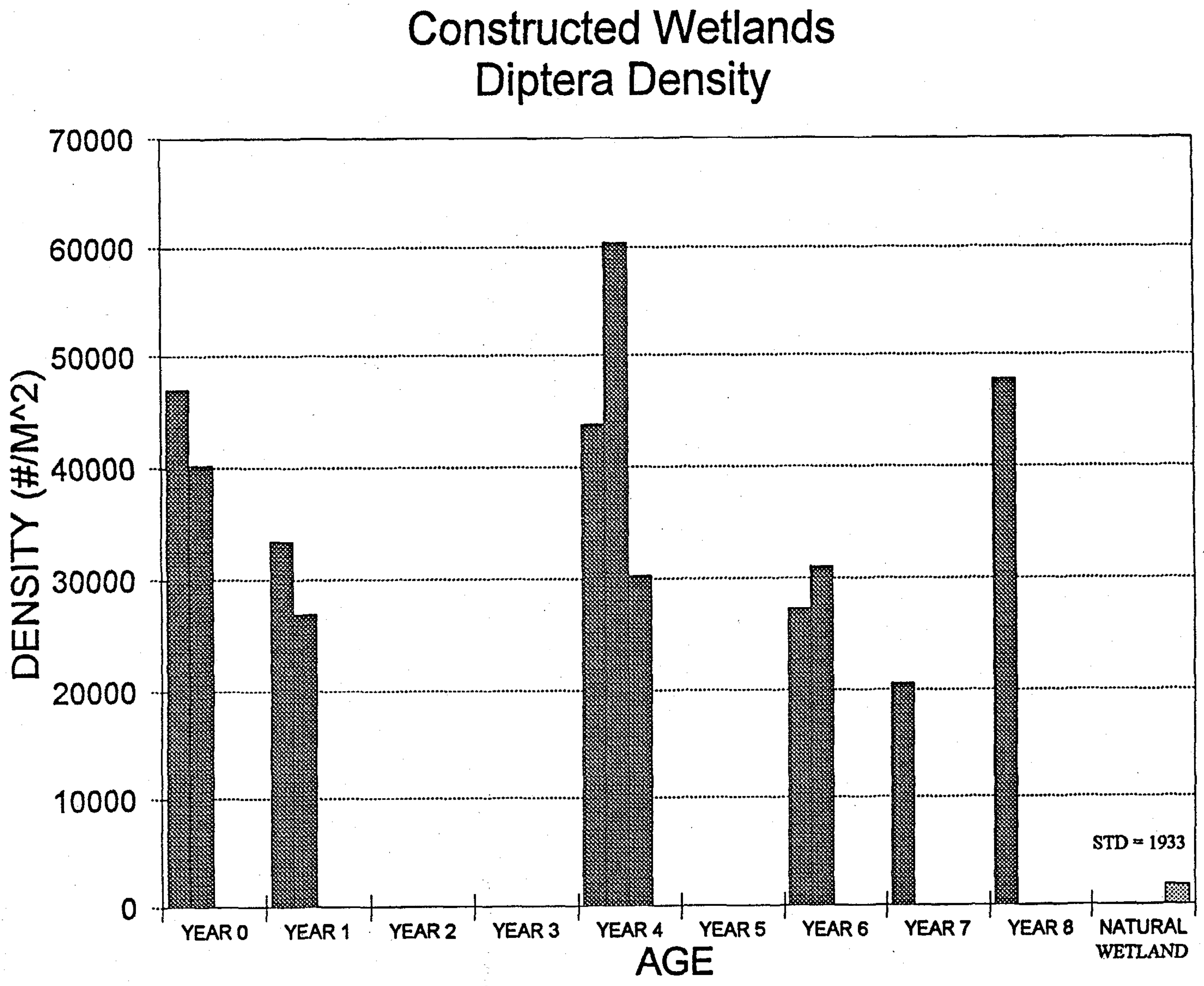
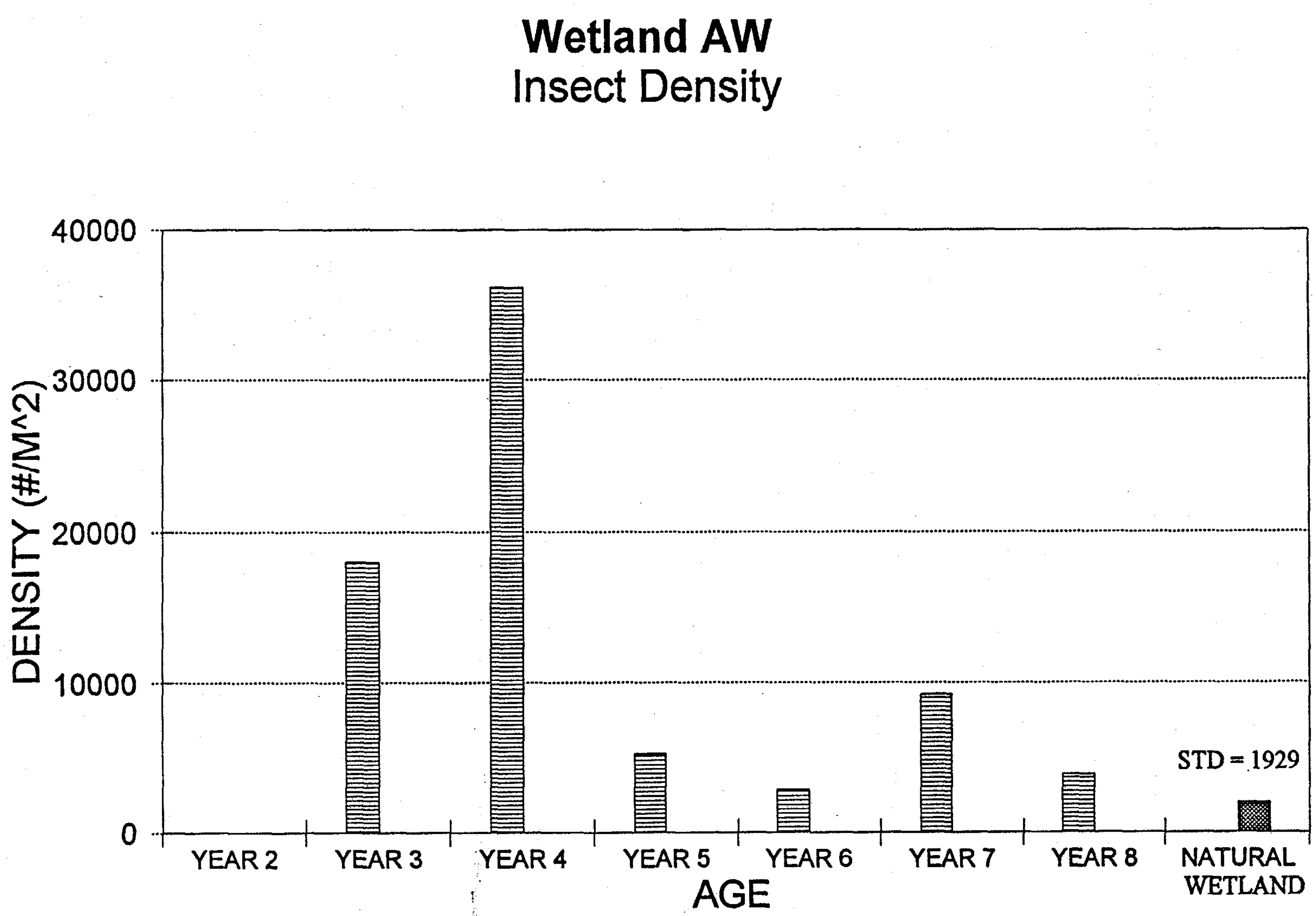

Wetland AW
Diptera Density
DENSITY (#/M^2)
35000
30000
25000
20000
15000
10000
5000
0
STD = 1933
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-14
(D. Evans database)



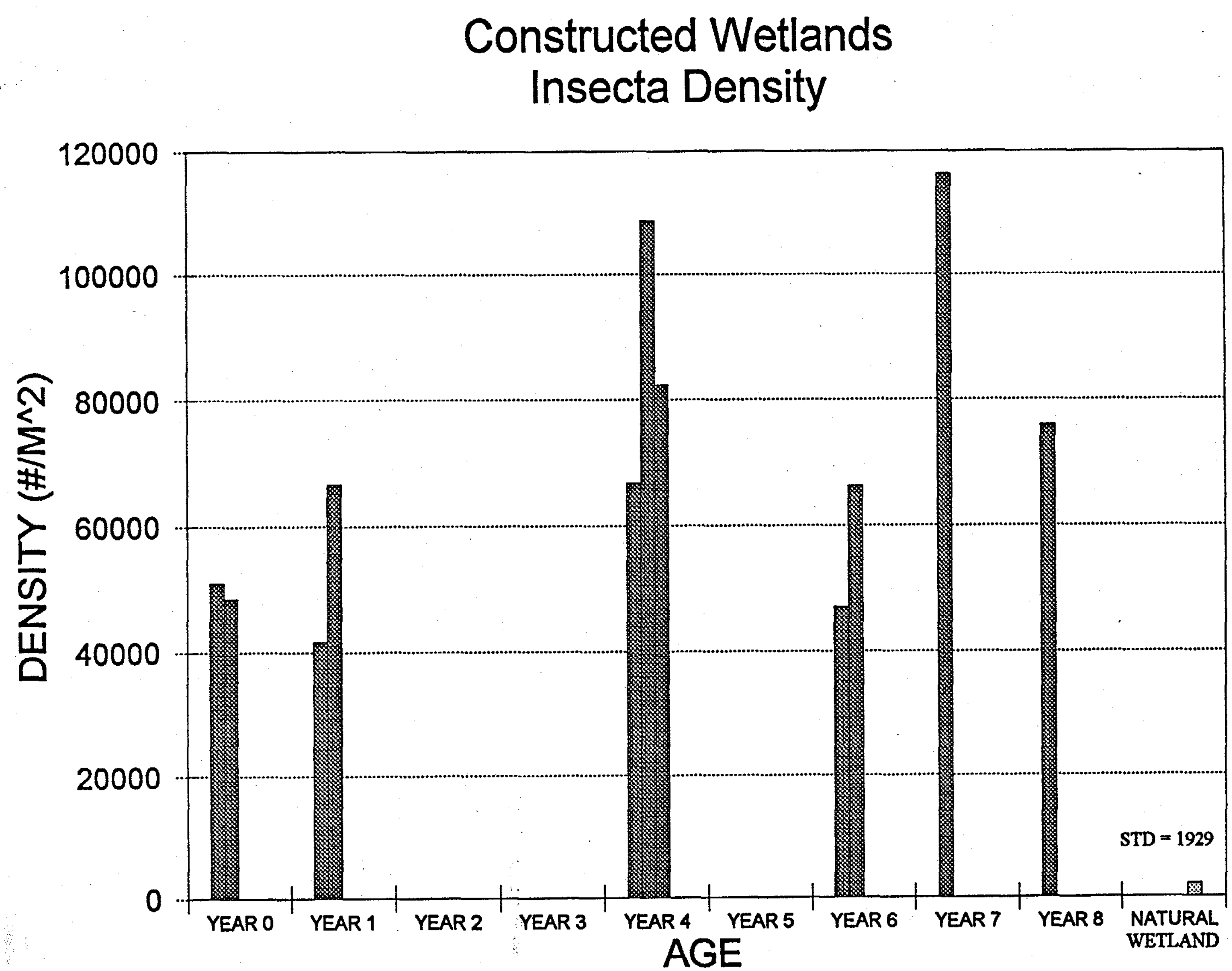
WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-15



Wetland AW
Insect Density
DENSITY (#/M^2)
40000
30000
20000
10000
0
STD = 1929
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-16
(D. Evans database)



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-17

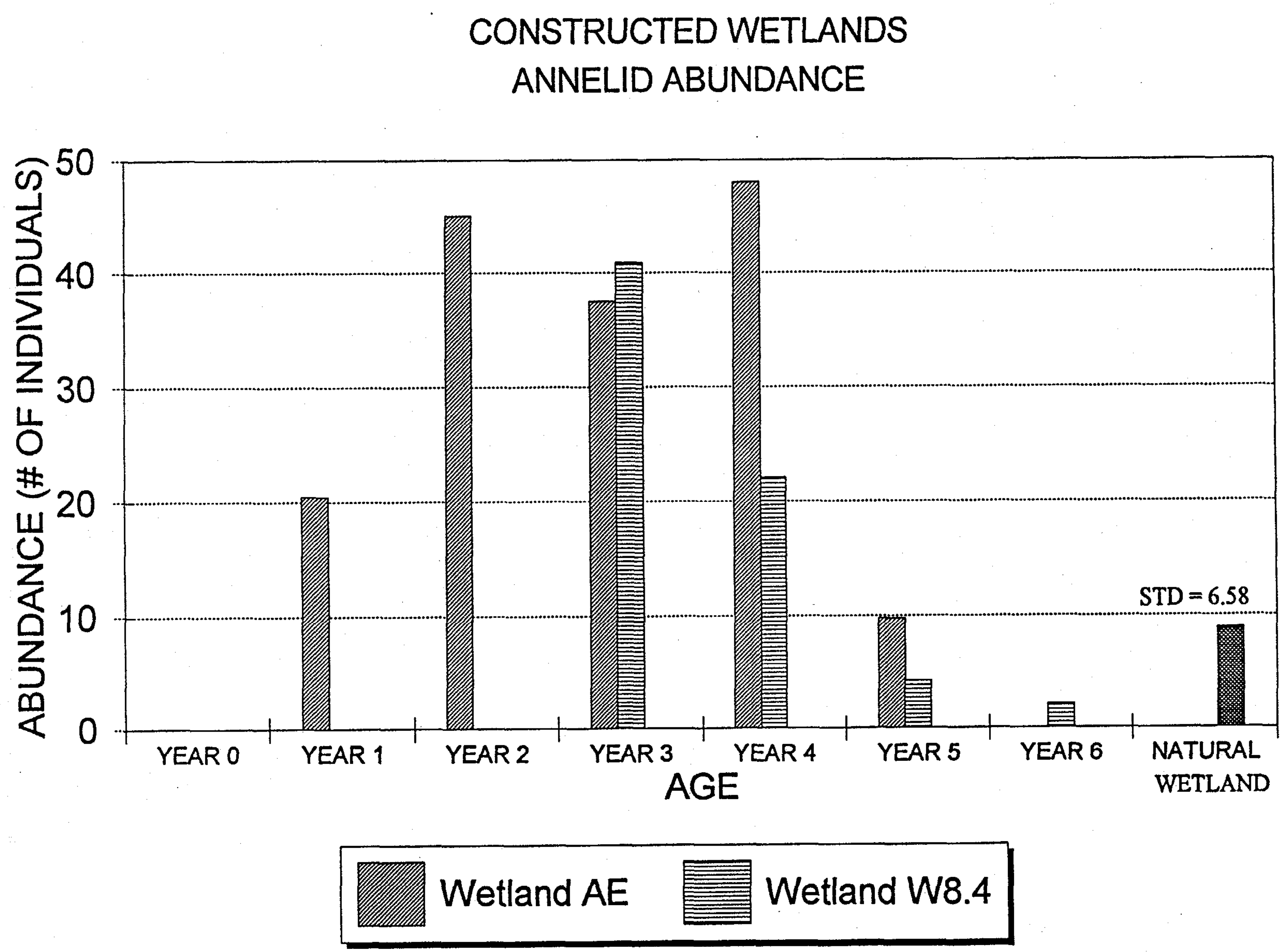

CONSTRUCTED WETLANDS
ANNELID ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
50
40
30
20
10
0
STD = 6.58
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-18

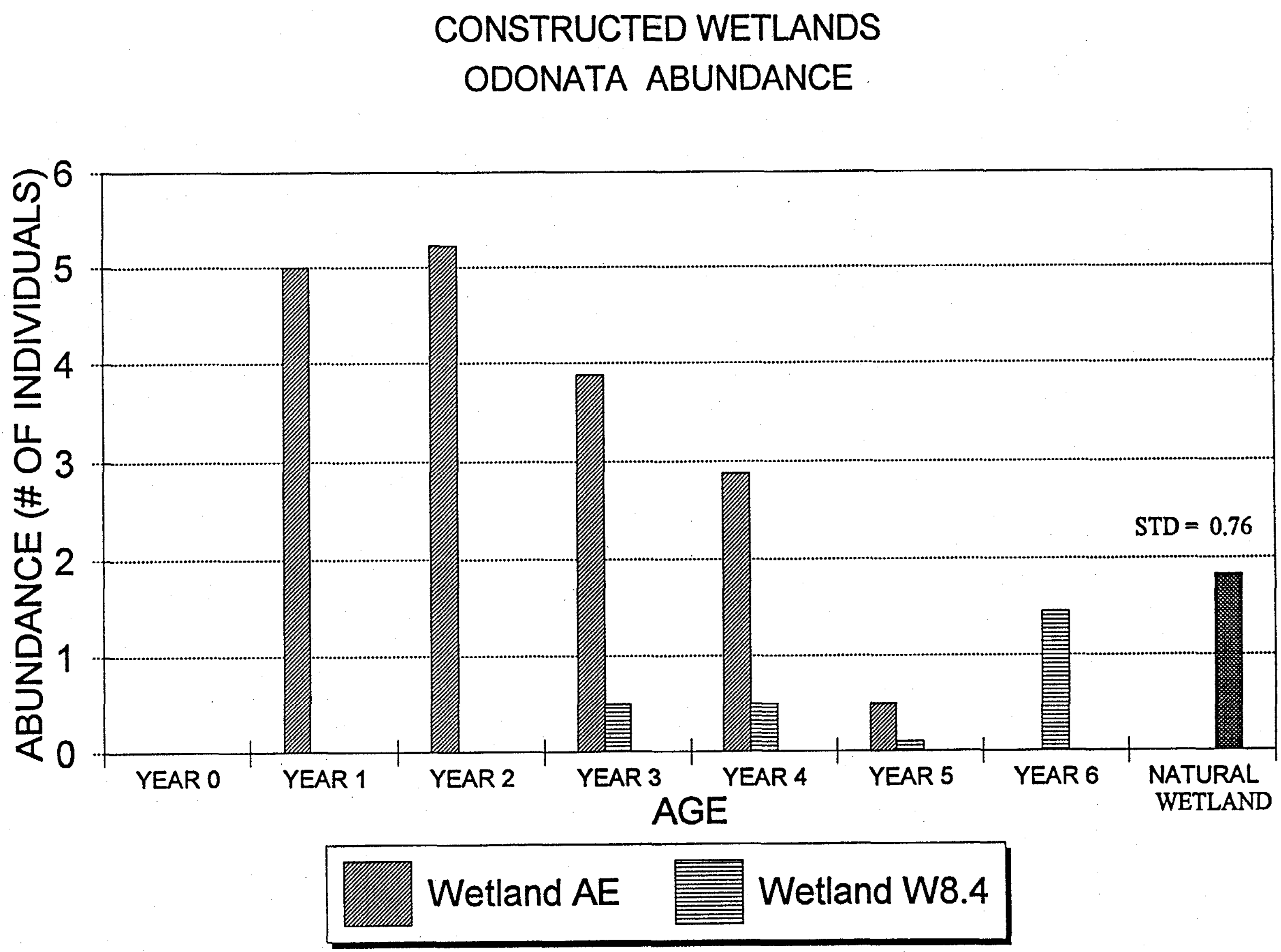
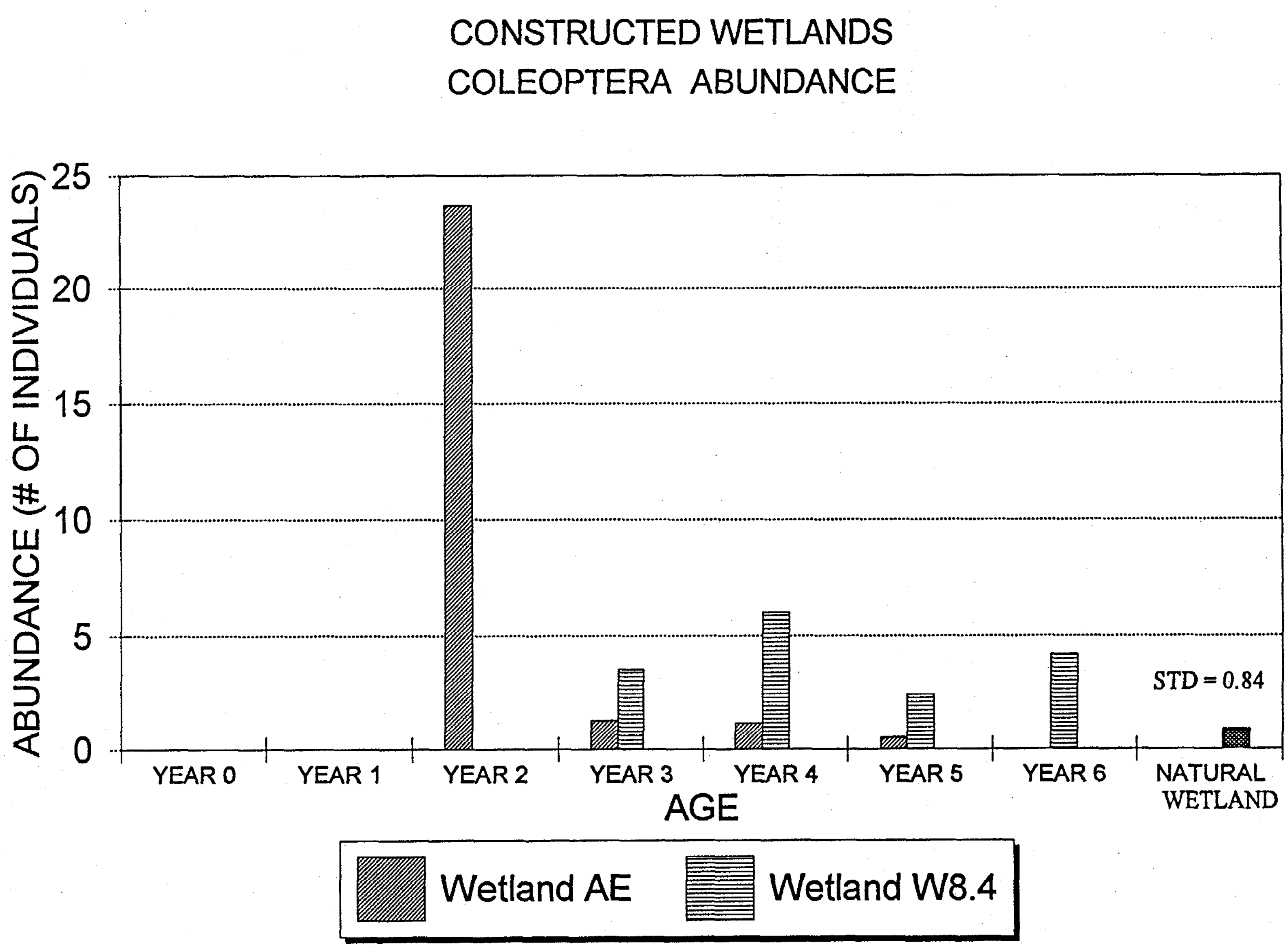

CONSTRUCTED WETLANDS
ODONATA ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
6
5
4
3
2
1
0
STD = 0.76
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-19



CONSTRUCTED WETLANDS
COLEOPTERA ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
25
20
15
10
5
0
STD = 0.84
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-20

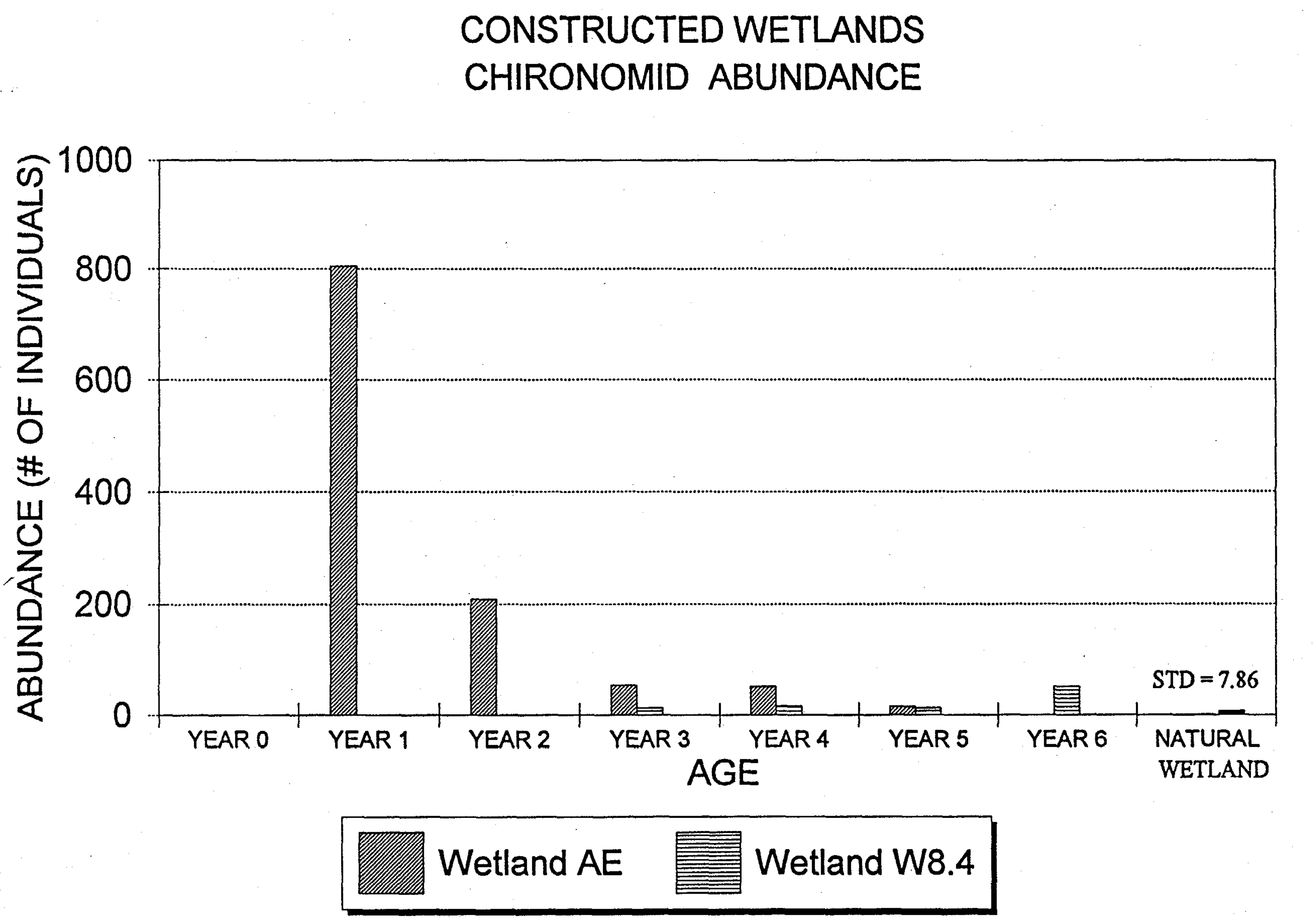
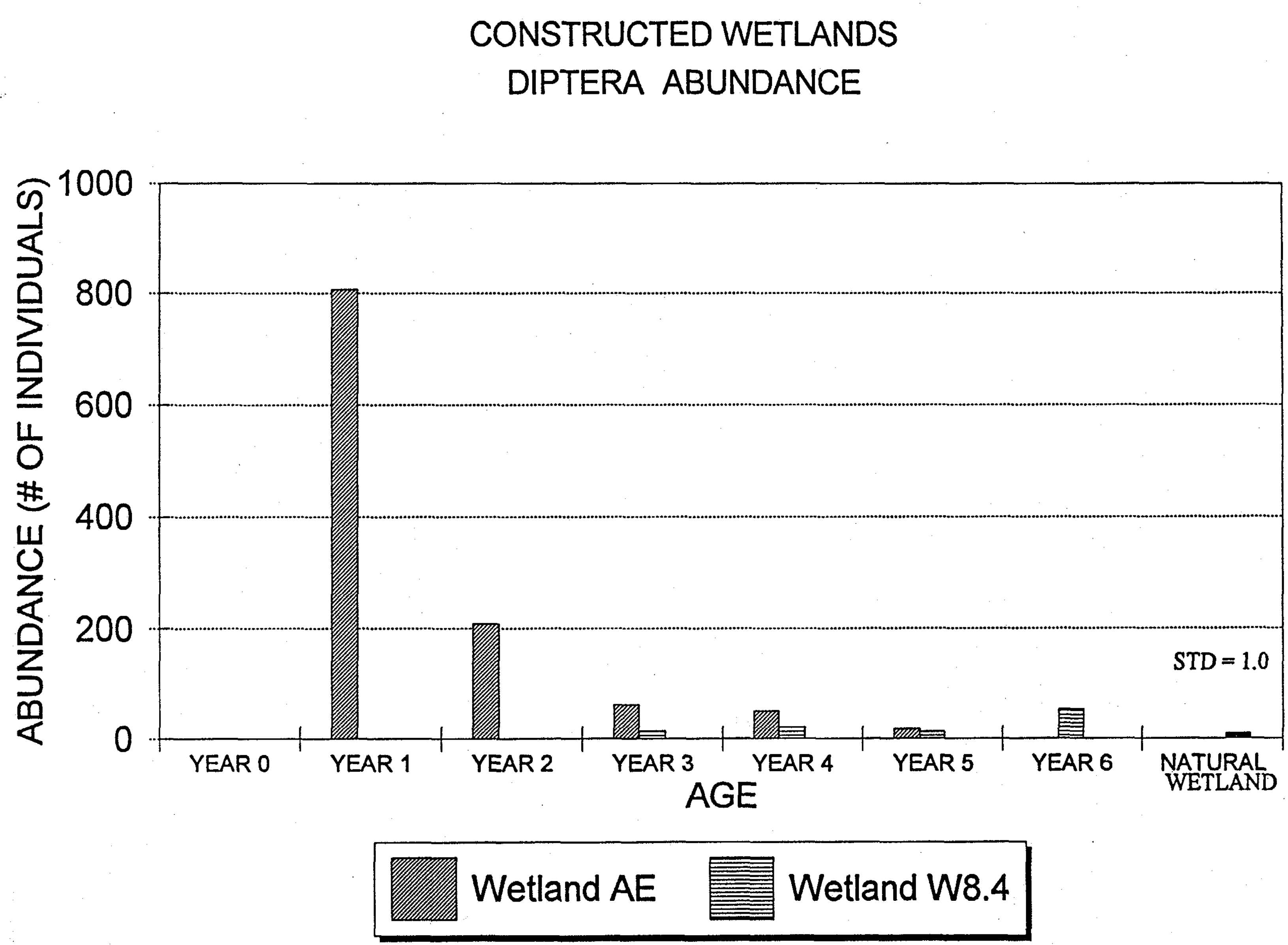

CONSTRUCTED WETLANDS
CHIRONOMID ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
1000
800
600
400
200
0
STD = 7.86
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-21



CONSTRUCTED WETLANDS
DIPTERA ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
1000
800
600
400
200
0
STD = 1.0
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-22

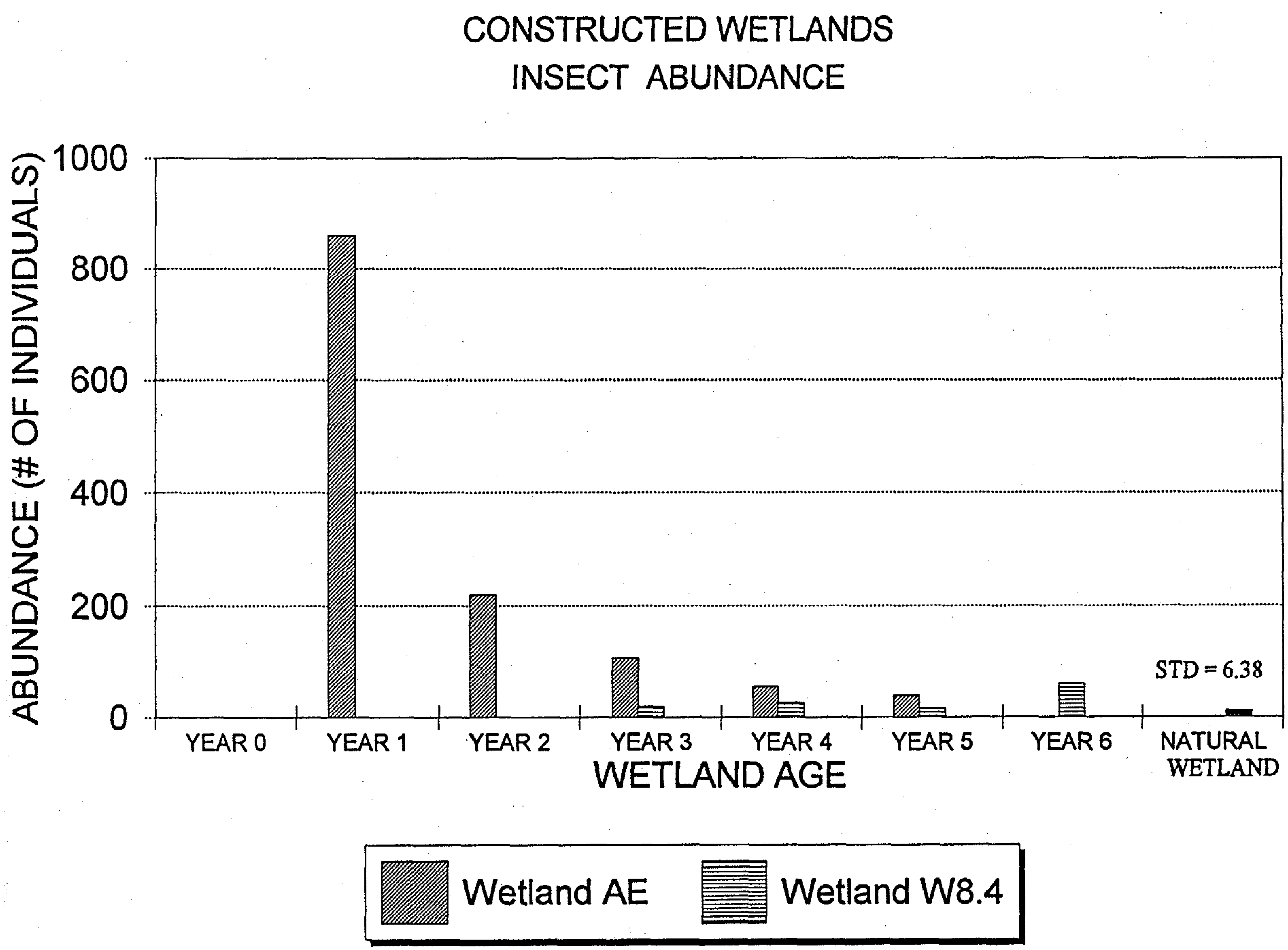
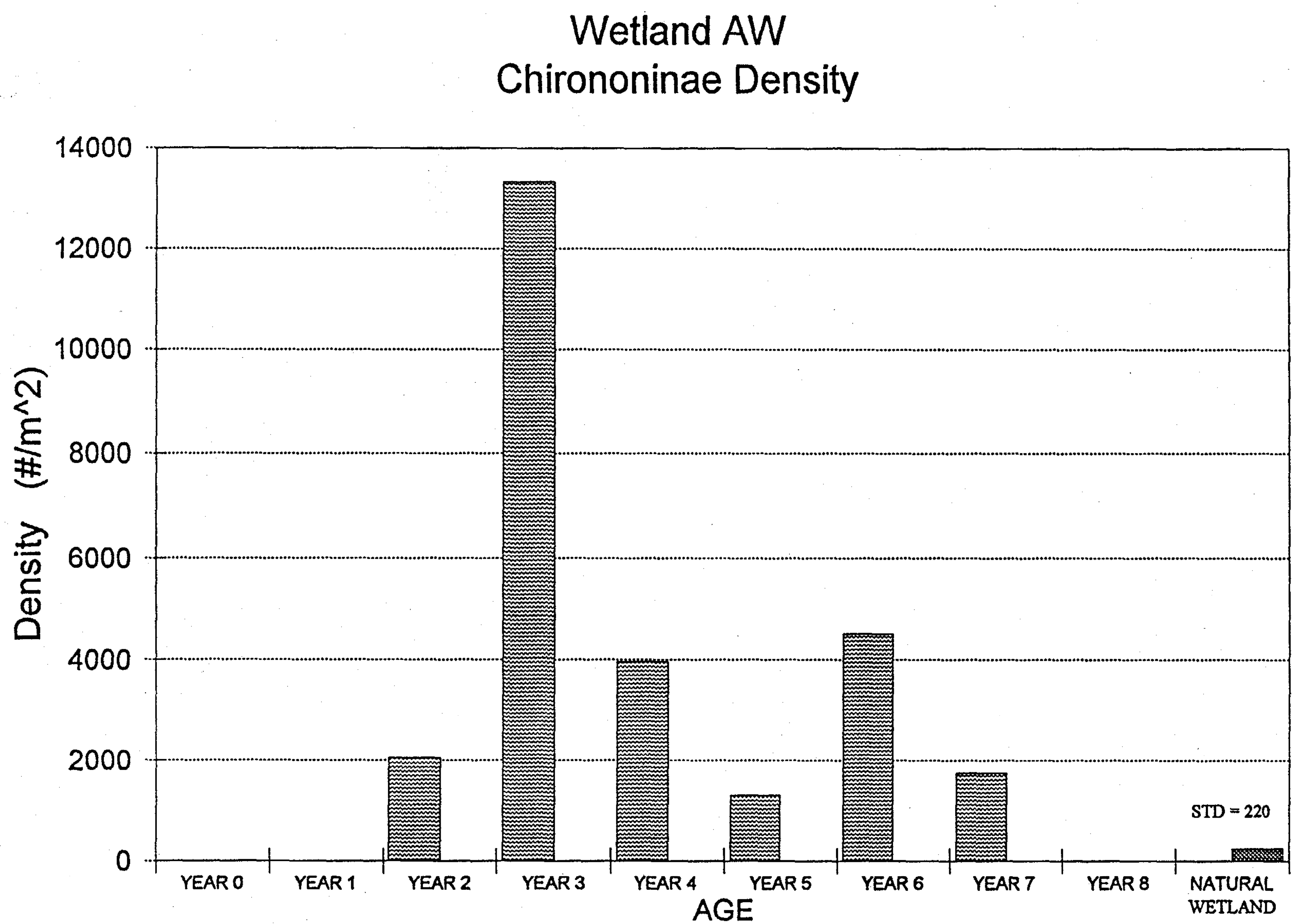

CONSTRUCTED WETLANDS
INSECT ABUNDANCE
ABUNDANCE (# OF INDIVIDUALS)
1000
800
600
400
200
0
STD = 6.38
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
WETLAND AGE
Wetland AE
Wetland W8.4

Figure 5-23



Wetland AW
Chirononinae Density
Density (#/m^2)
14000
12000
10000
8000
6000
4000
2000
0
STD = 220
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-24

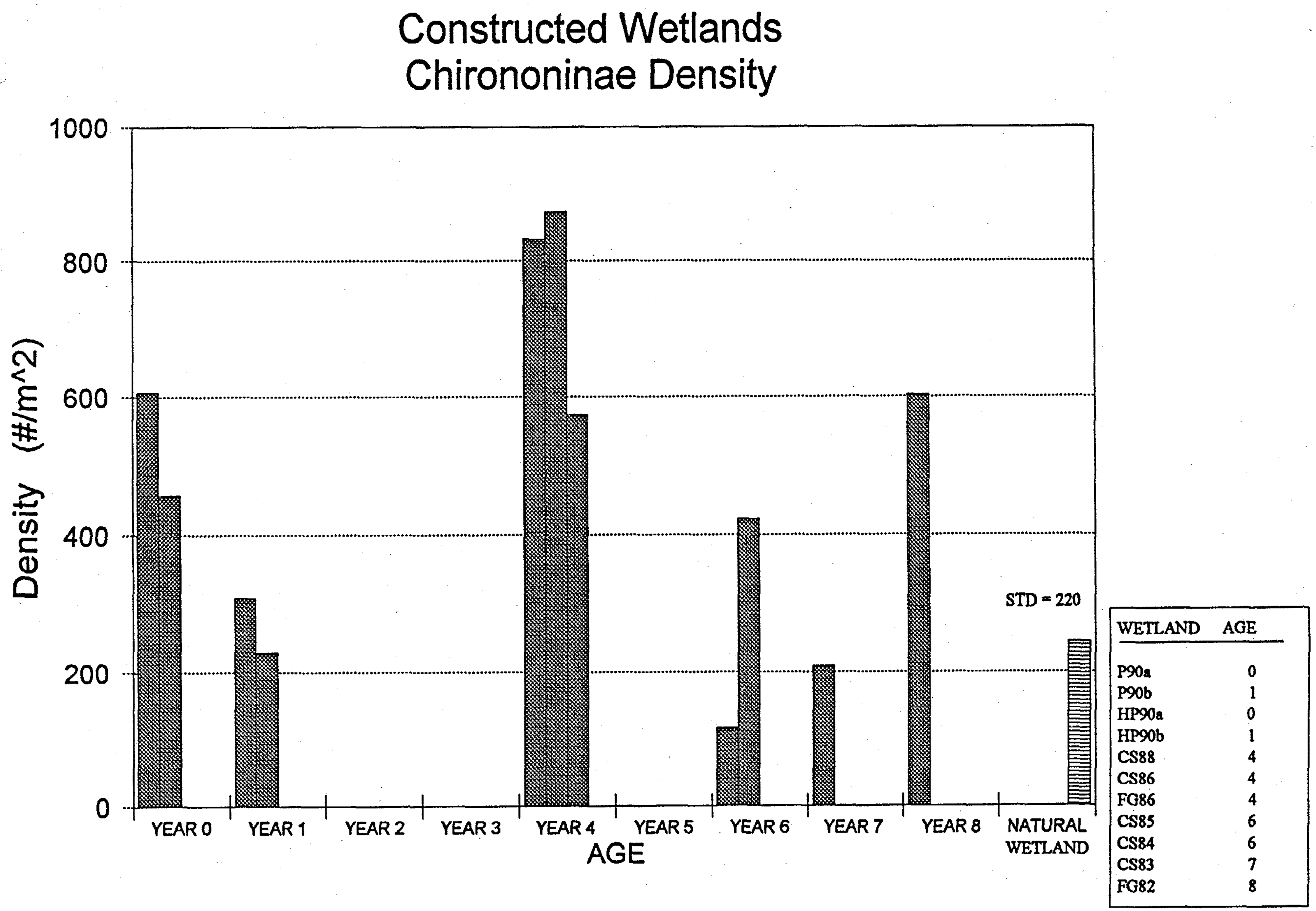
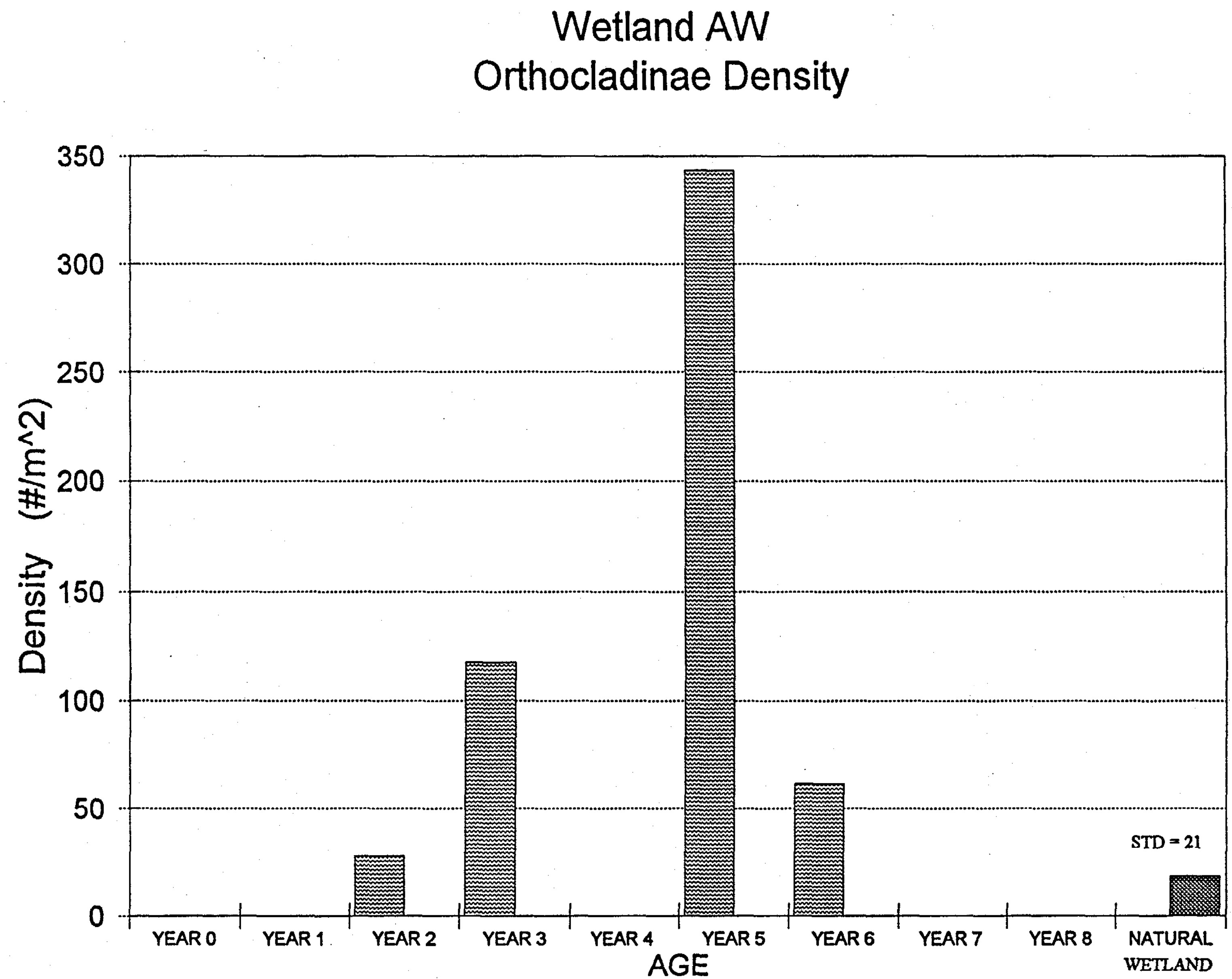

Constructed Wetlands
Chirononinae Density
1000
800
600
400
200
0
Density (#/m^2)
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE
STD = 220
WETLAND AGE
P90a 0
P90b 1
HP90a 0
HP90b 1
CS88 4
CS86 4
FG86 4
CS85 6
CS84 6
CS83 7
FG82 8

Figure 5-25



Wetland AW
Orthocladinae Density
Density (#/m^2)
350
300
250
200
150
100
50
0
STD = 21
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-26

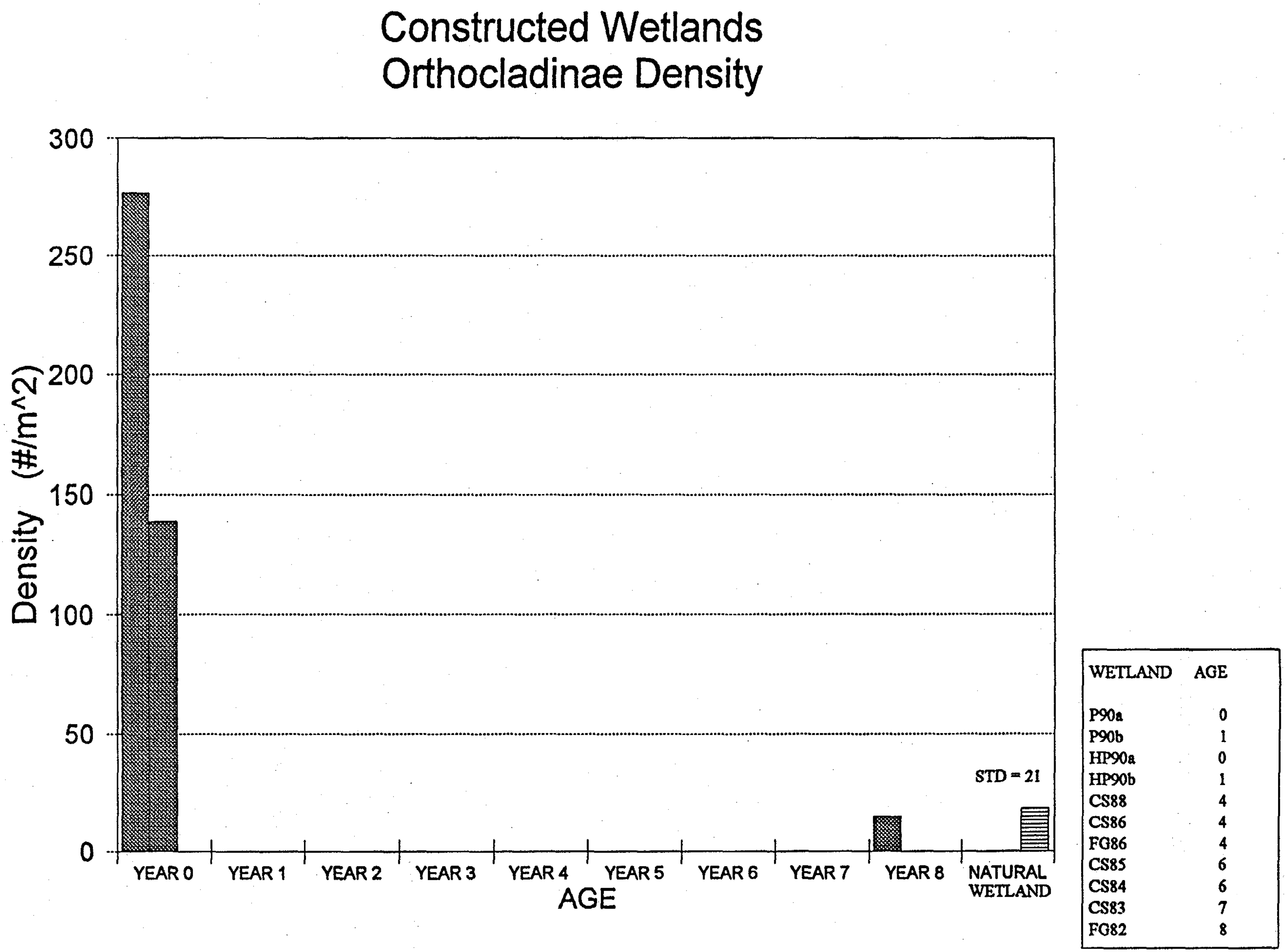
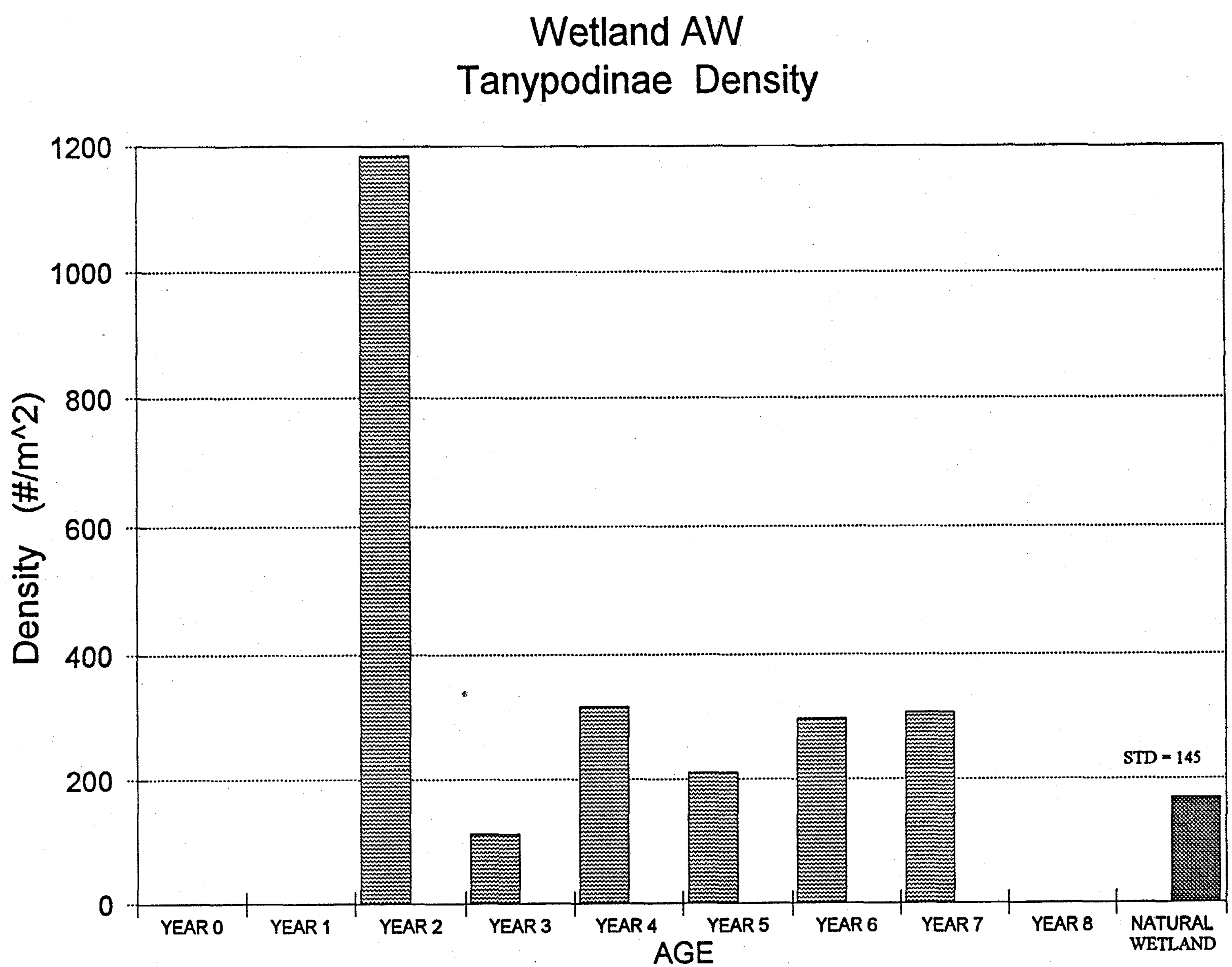
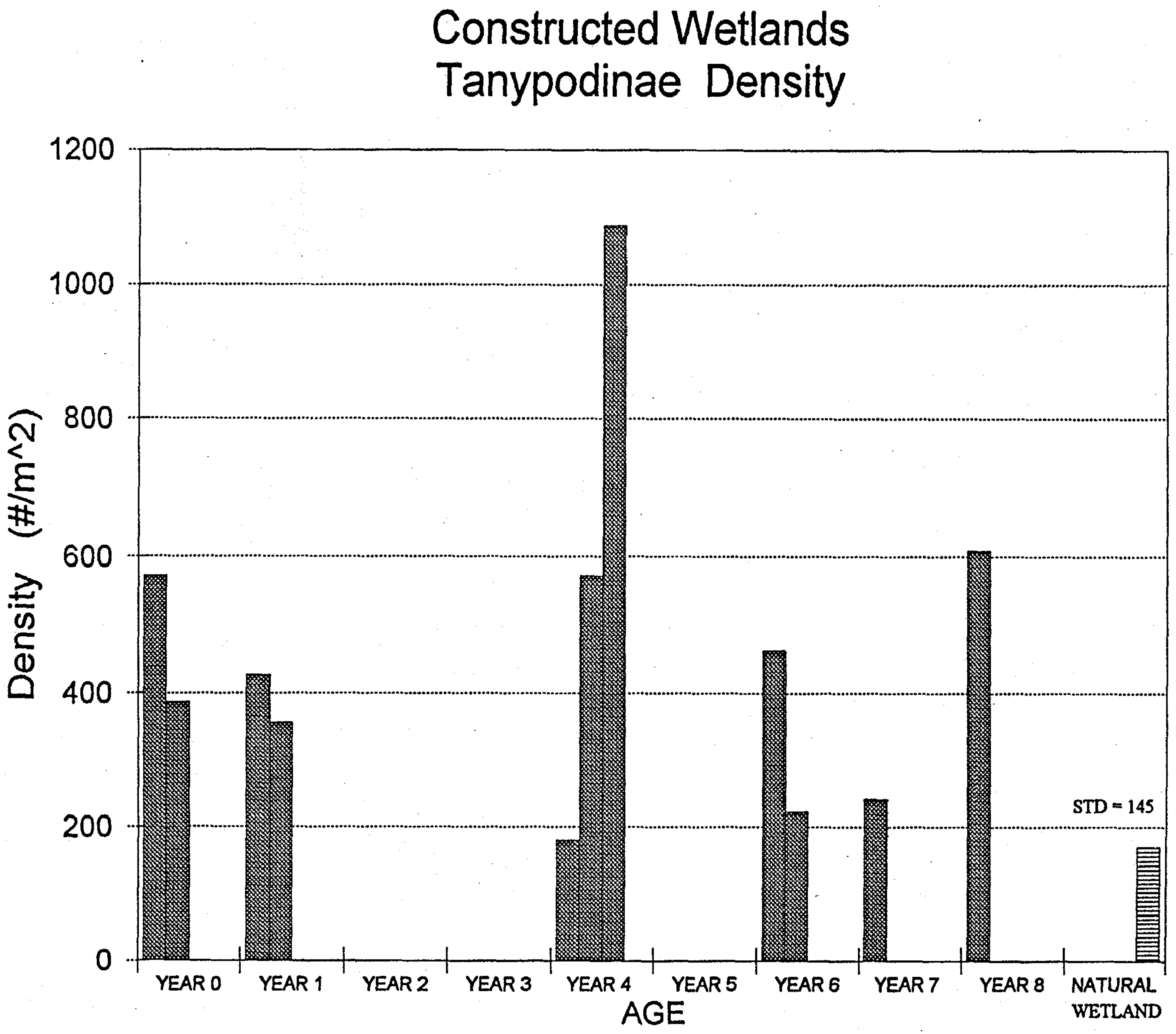

Constructed Wetlands
Orthocladinae Density
Density (#/m^2)
300
250
200
150
100
50
0
STD = 21
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE
WETLAND AGE
P90a 0
P90b 1
HP90a 0
HP90b 1
CS88 4
CS86 4
FG86 4
CS85 6
CS84 6
CS83 7
FG82 8

Figure 5-27



Wetland AW
Tanypodinae Density
Density (#/m^2)
1200
1000
800
600
400
200
0
STD = 145
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-28



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-29

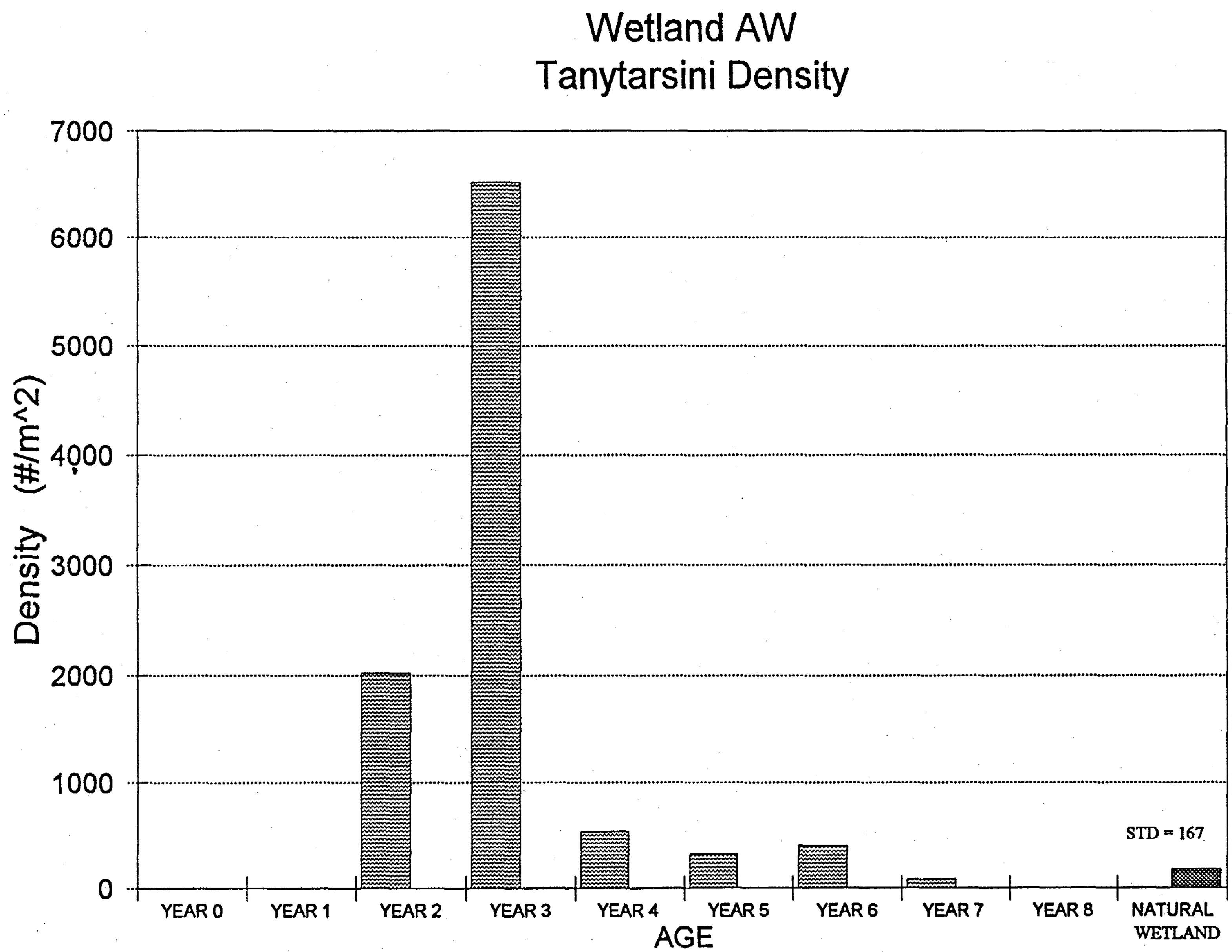
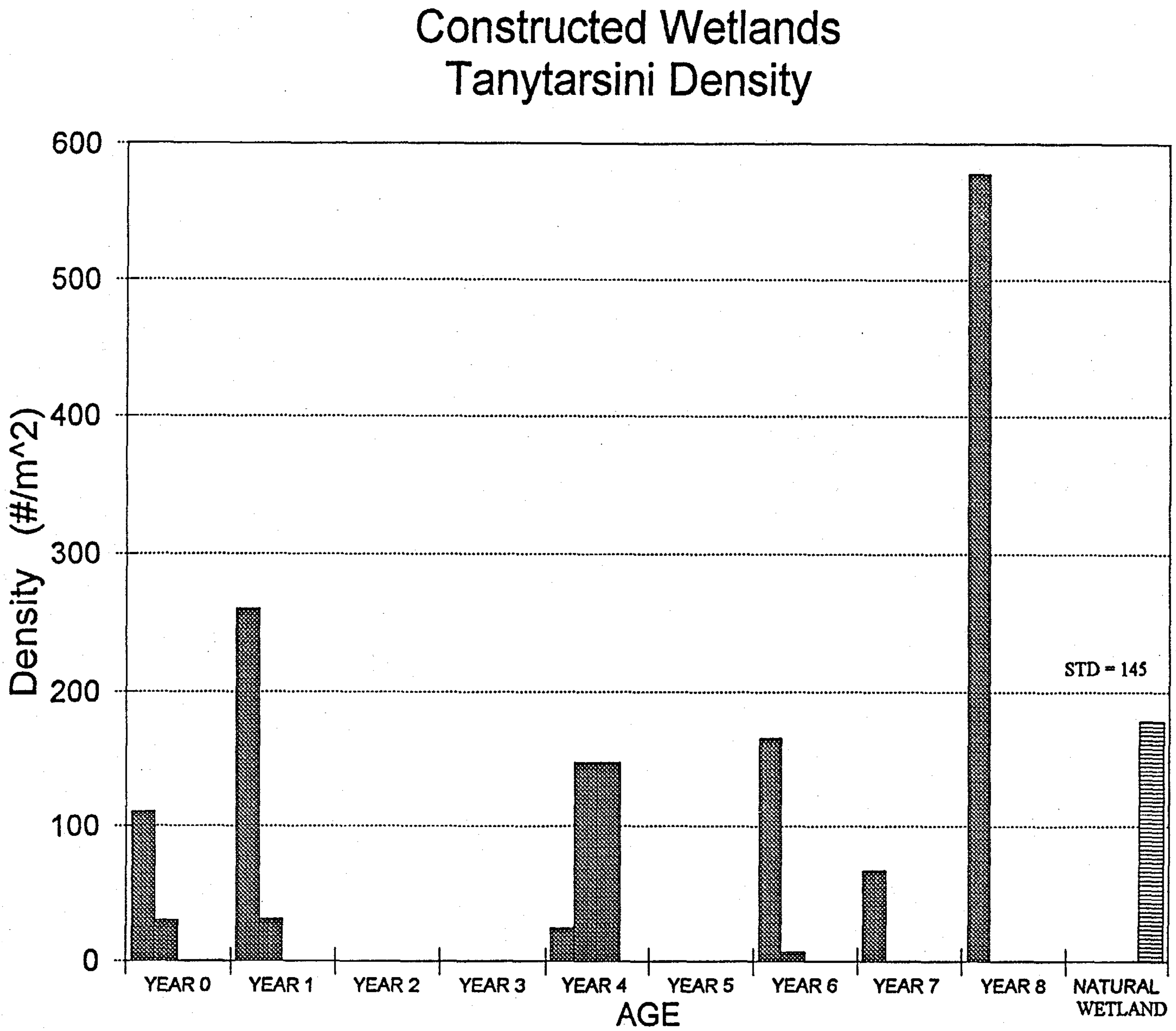

Wetland AW
Tanytarsini Density
7000
6000
5000
4000
3000
2000
1000
0
Density (#/m^2)
STD = 167
YEAR 0
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-30



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

It appears that there is a general trend among the families of Chironomidae, with an initial surge followed by a decrease to equilibrium in the fourth to fifth years following construction.

HESTER-DENDY SAMPLERS
Chironominae abundance shows a sharp decrease down to a steady state for wetland AE, while numbers in wetland W8.4 are relatively low for the whole monitoring period (Figure 5-31). Orthocladinae abundance is very patchy in wetland AE, and this group does not even appear in wetland W8.4 (Figure 5-32). In wetlands AE and W.4., both Tanypodinae and Tanytarsini abundances are very sporadic during the entire monitoring period (Figures 5-33 and 5-34, respectively).

CHIRONOMIDAE FEEDING GUILDS

SEDIMENT CORE SAMPLERS
In both wetland AW and the UF wetlands, there seems to be a sharp increase in collector/gatherers in year four followed by a decrease to equilibrium in year five (Figures 5-35 and 5-36, respectively). The shredder feeding guild displays a trend toward equilibrium for both wetland AW and the UF wetlands (Figures 5-37 and 5-38, respectively).

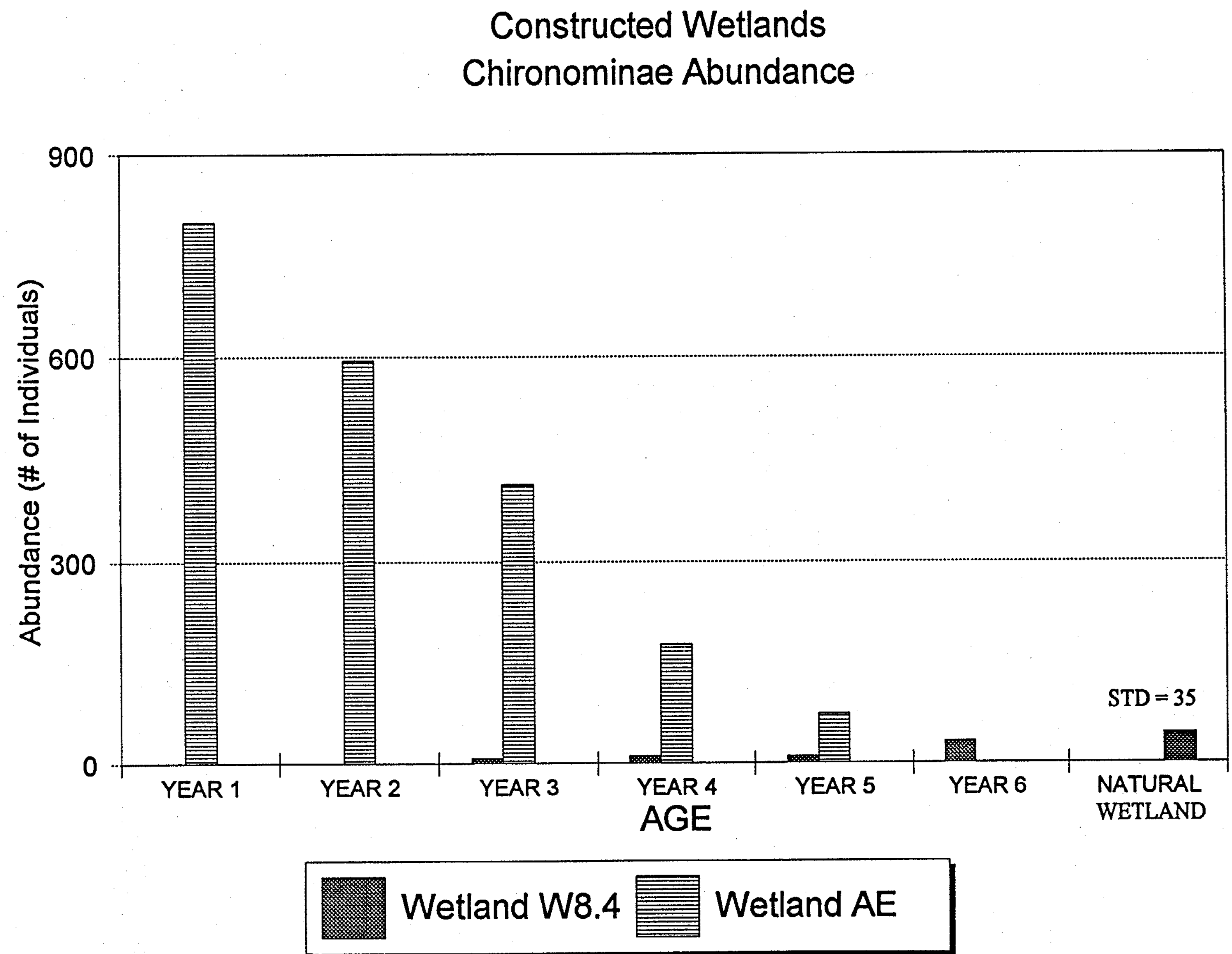
The predator feeding guild in both wetland AW and the UF wetlands seems to remain stable regardless of wetland age (Figures 5-39 and 5-40, respectively). The feeding guild data show a general trend towards equilibrium during the forth year for both shredders and collector/gatherers, while predators remain stable throughout. As expected, the collector/gatherer guild was the most abundant, followed by shredders and then predators.

HESTER-DENDY SAMPLERS
Within wetlands AE and W8.4, there seems to be consistency in collector/gatherer abundance Figure 5-41). This abundance is much higher than that found in the natural system Within wetland AE, there is a dramatic decrease in the shredder feeding guild after the second year (Figure (5-42). The shredder guild in wetland W8.4 seems to remain level during the sampling period (Figure 5-42).

Within wetlands AE and W8.4, there seems to be a gradual decrease in predators after the second year (Figure 5-43). Trends within the feeding guilds in wetlands AE and W8.4 do not seem as strong as those seen in the wetlands sampled with sediment cores.

It is apparent from all four data categories that macroinvertebrate communities display high density/abundance in the early years after construction followed by in some cases gradual, in other cases sharp reductions in density/abundance beginning between the third to fifth year. When the total macroinvertebrate population is examined the equilibrium point occurrs about the fifth year. Correspondingly, the density/ abundance for each of the taxonomic groups also reaches an equilibrium point about the fifth year. Chironomidae families and feeding guilds show some variability, but they to seem to reach an equilibrium between the third to fifth years.

Figure 5-31



Constructed Wetlands
Chironominae Abundance
900
600
300
0
Abundance (# of Individuals)
STD = 35
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland W8.4
Wetland AE

Figure 5-32

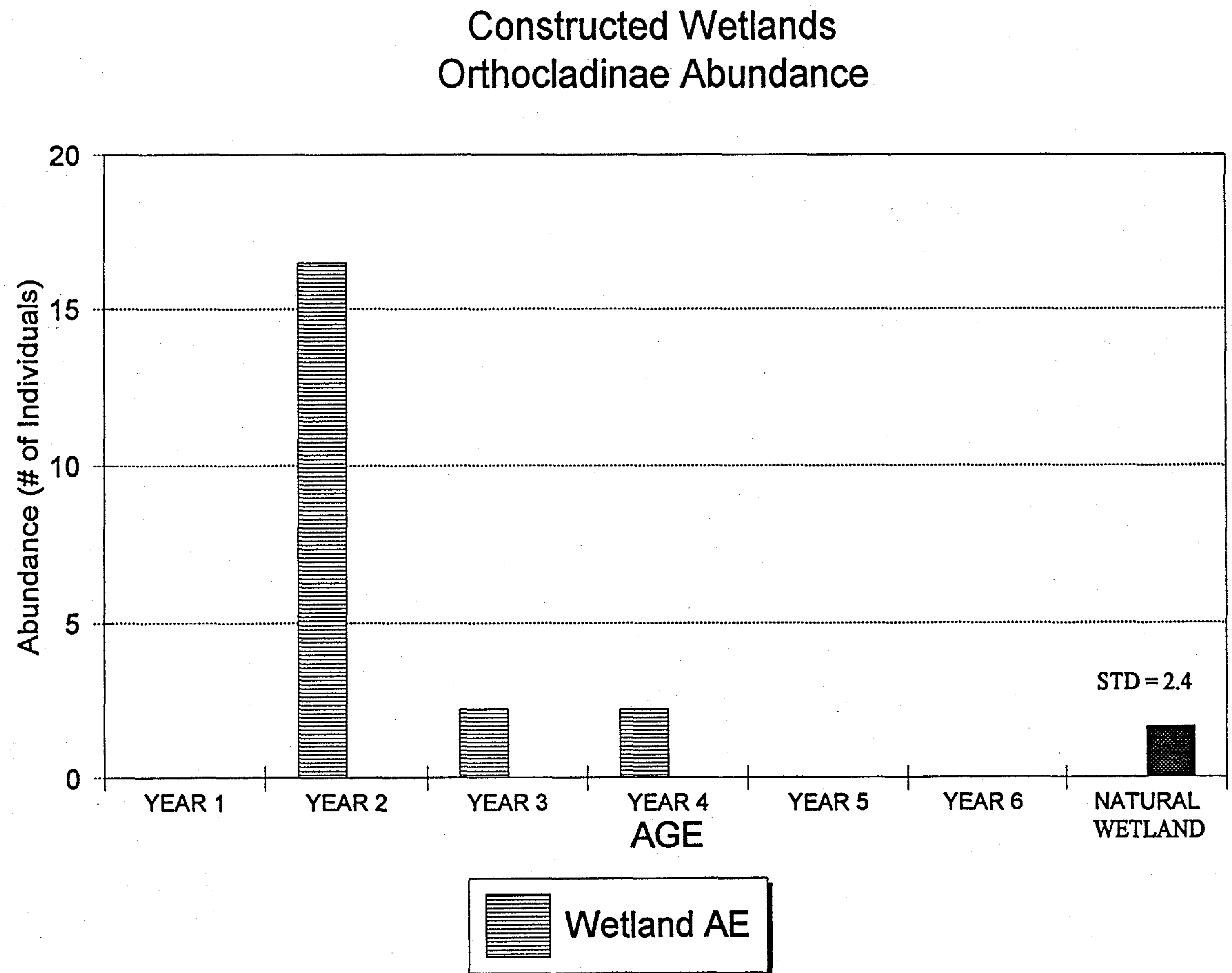

Constructed Wetlands
Orthocladinae Abundance
20
15
10
5
0
Abundance (# of Individuals)
STD = 2.4
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE

Figure 5-33

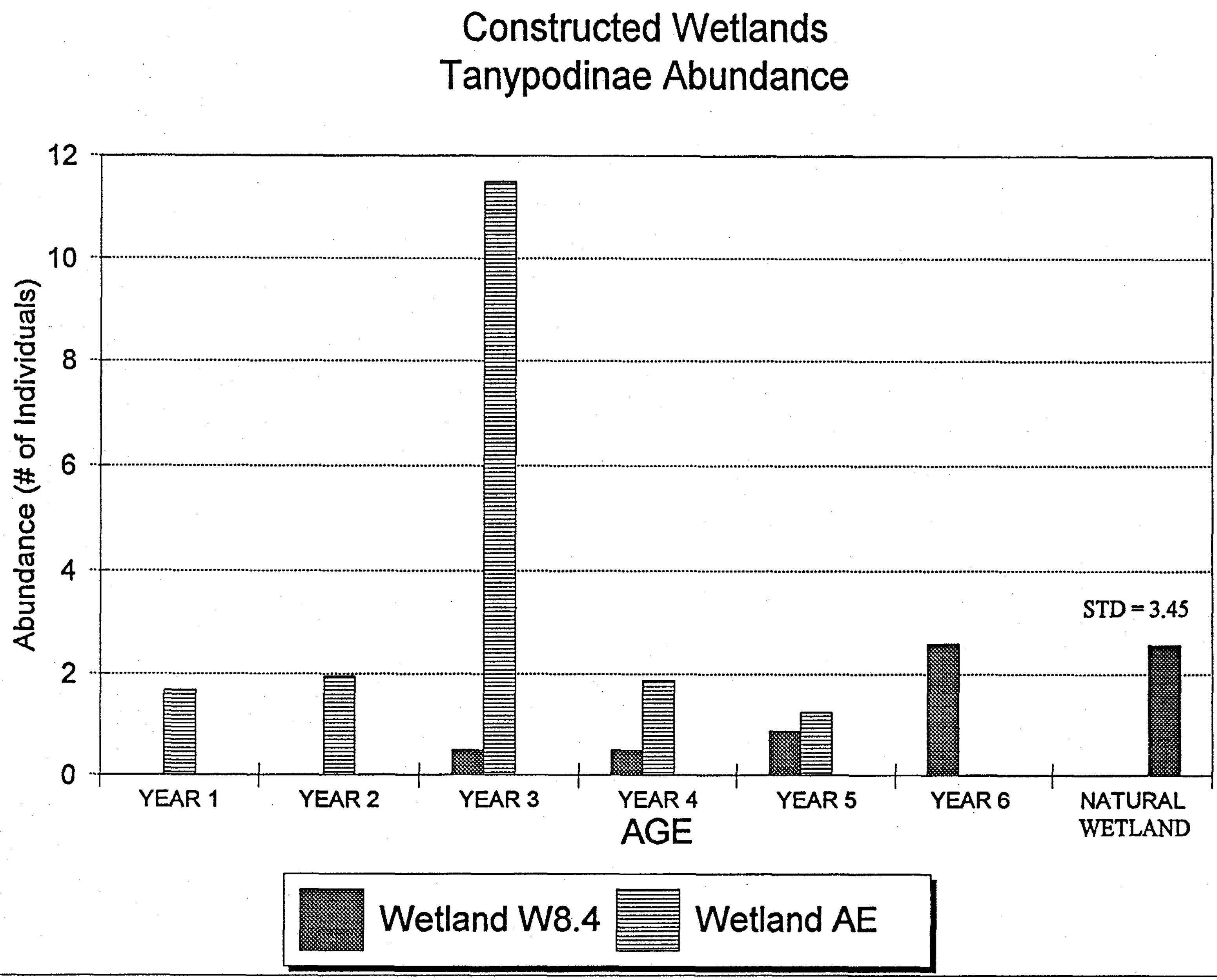
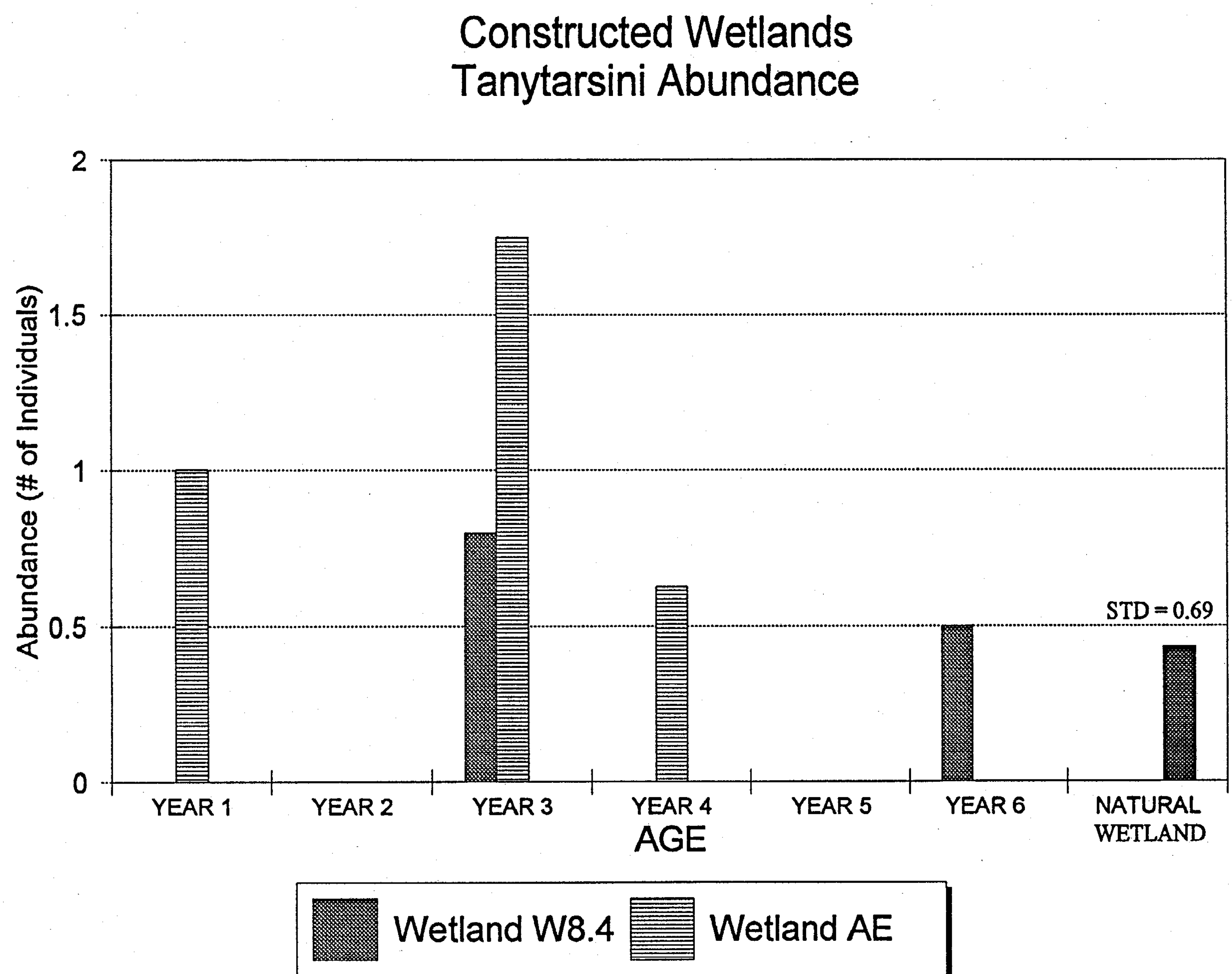
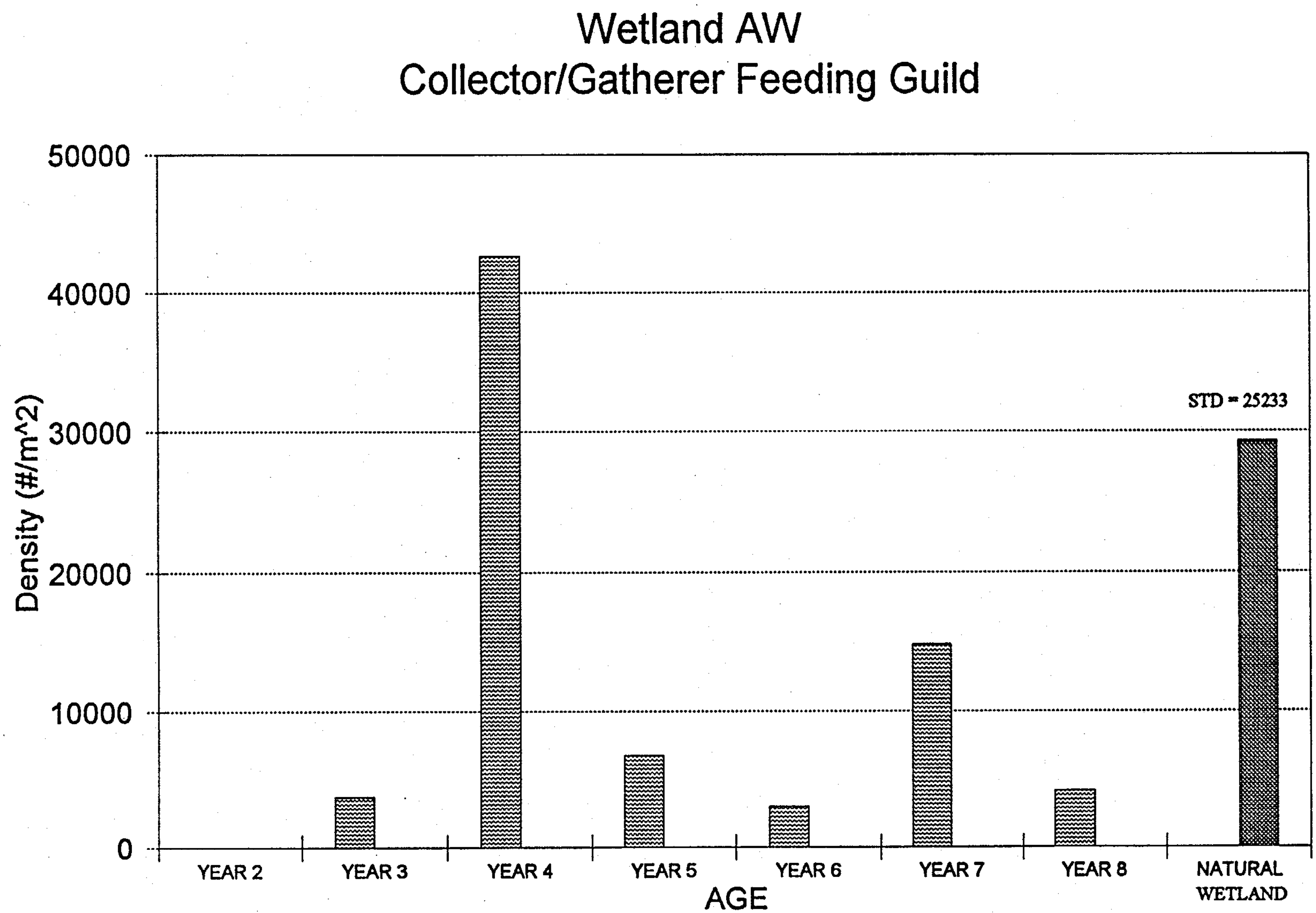

Constructed Wetlands
Tanypodinae Abundance
Abundance (# of Individuals)
12
10
8
6
4
2
0
STD = 3.45
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland W8.4
Wetland AE

Figure 5-34



Constructed Wetlands
Tanytarsini Abundance
Abundance (# of Individuals)
2
1.5
1
0.5
0
STD = 0.69
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland W8.4
Wetland AE

Figure 5-35



Wetland AW
Collector/Gatherer Feeding Guild
50000
40000
30000
20000
10000
0
Density (#/m^2)
STD = 25233
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-36
(D. Evans database)

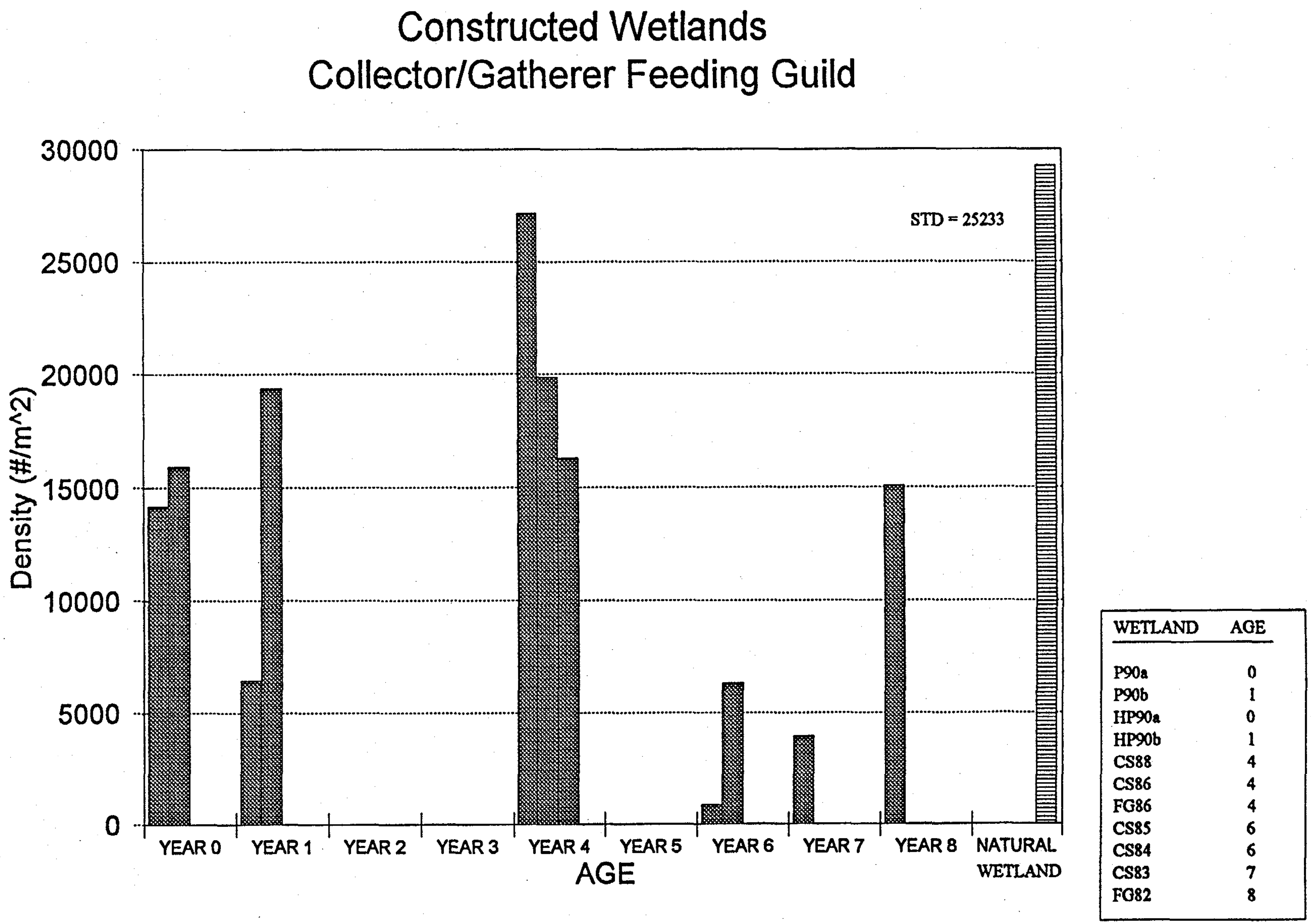
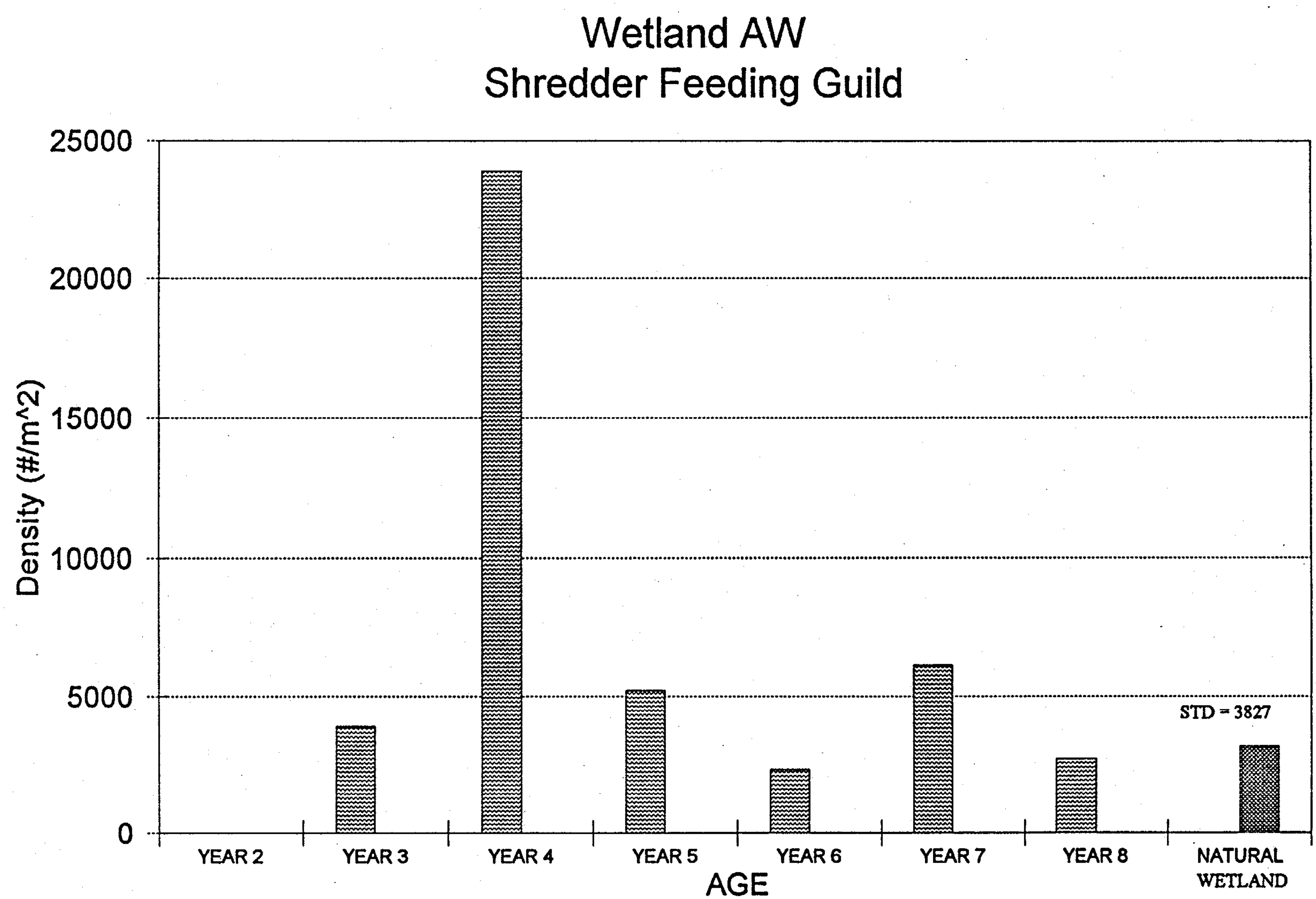
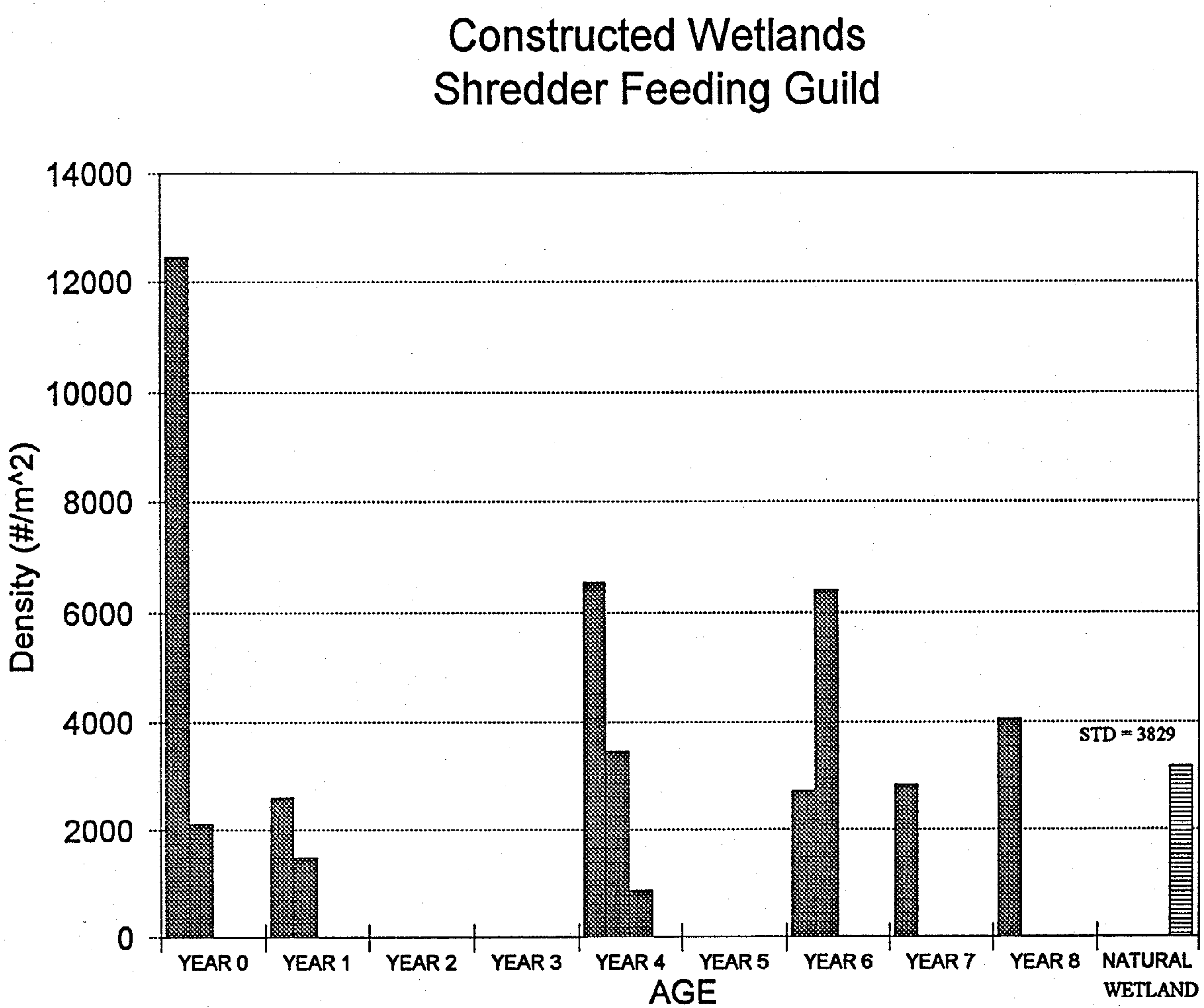


Figure 5-37



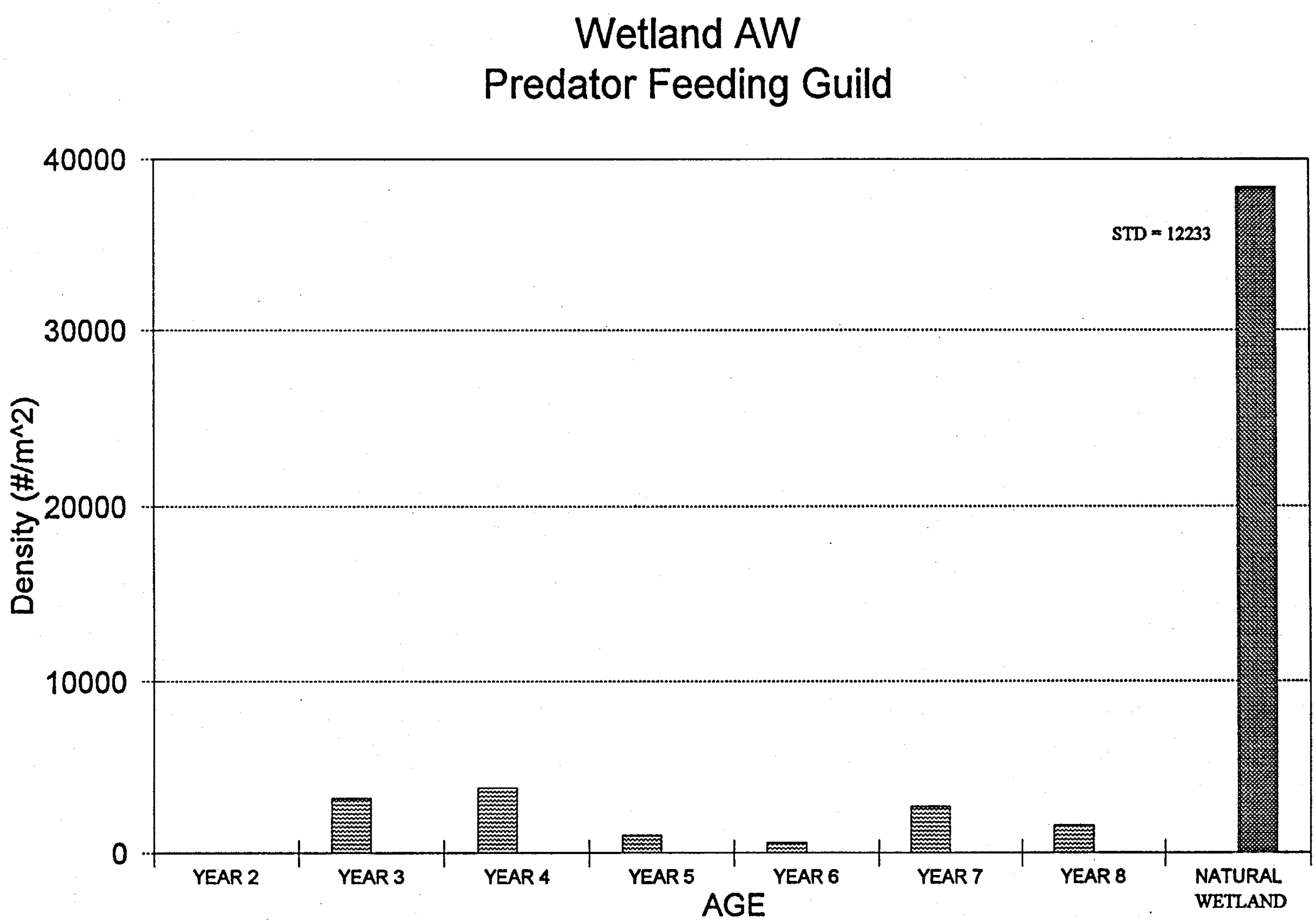
Wetland AW
Shredder Feeding Guild
Density (#/m^2)
25000
20000
15000
10000
5000
0
STD = 3827
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-38
(D. Evans database)



WETLAND	AGE
P90a	0
P90b	1
HP90a	0
HP90b	1
CS88	4
CS86	4
FG86	4
CS85	6
CS84	6
CS83	7
FG82	8

Figure 5-39



Wetland AW
Predator Feeding Guild
40000
30000
20000
10000
0
Density (#/m^2)
STD = 12233
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
YEAR 8
NATURAL WETLAND
AGE

Figure 5-40
(D. Evans database)

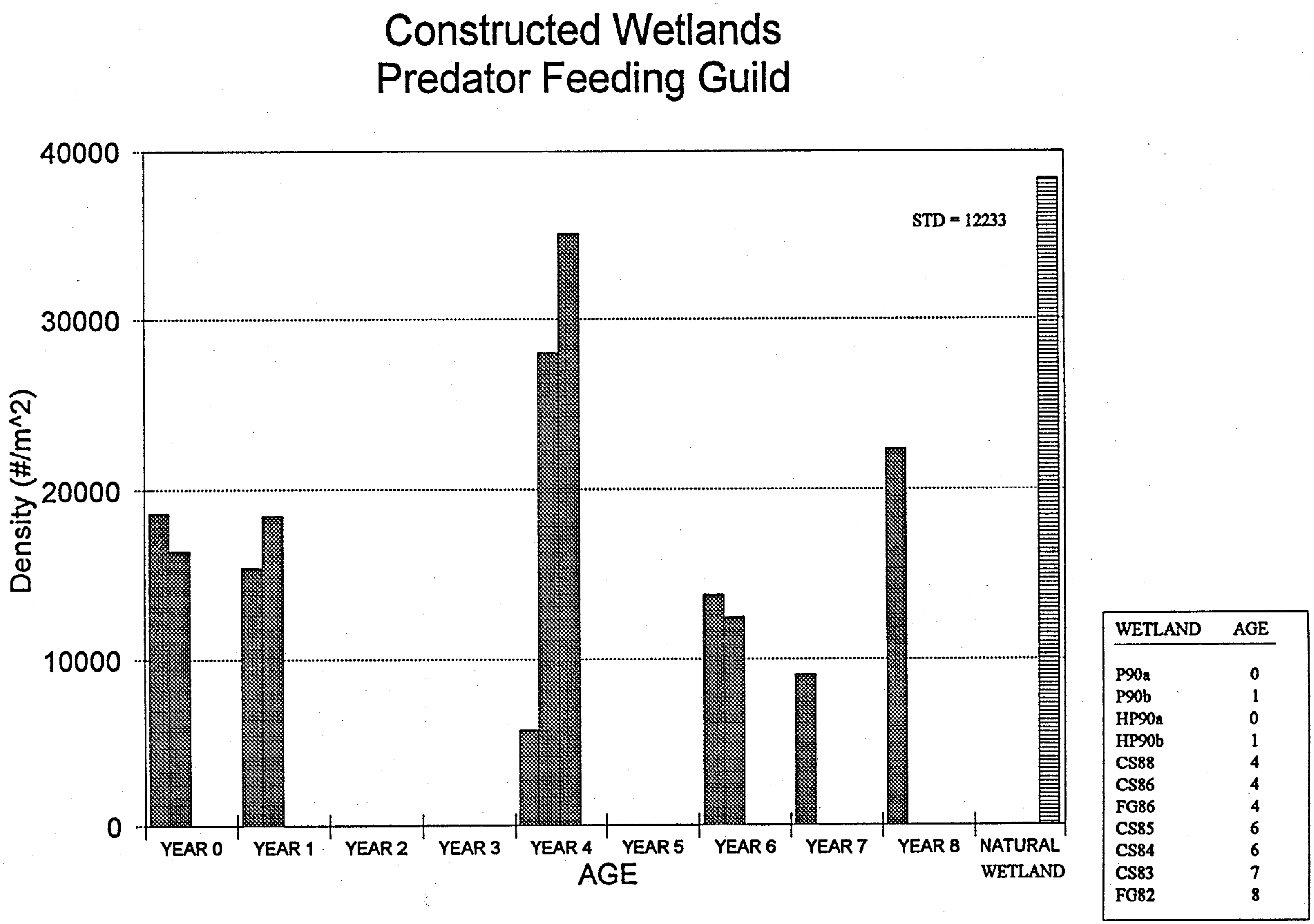
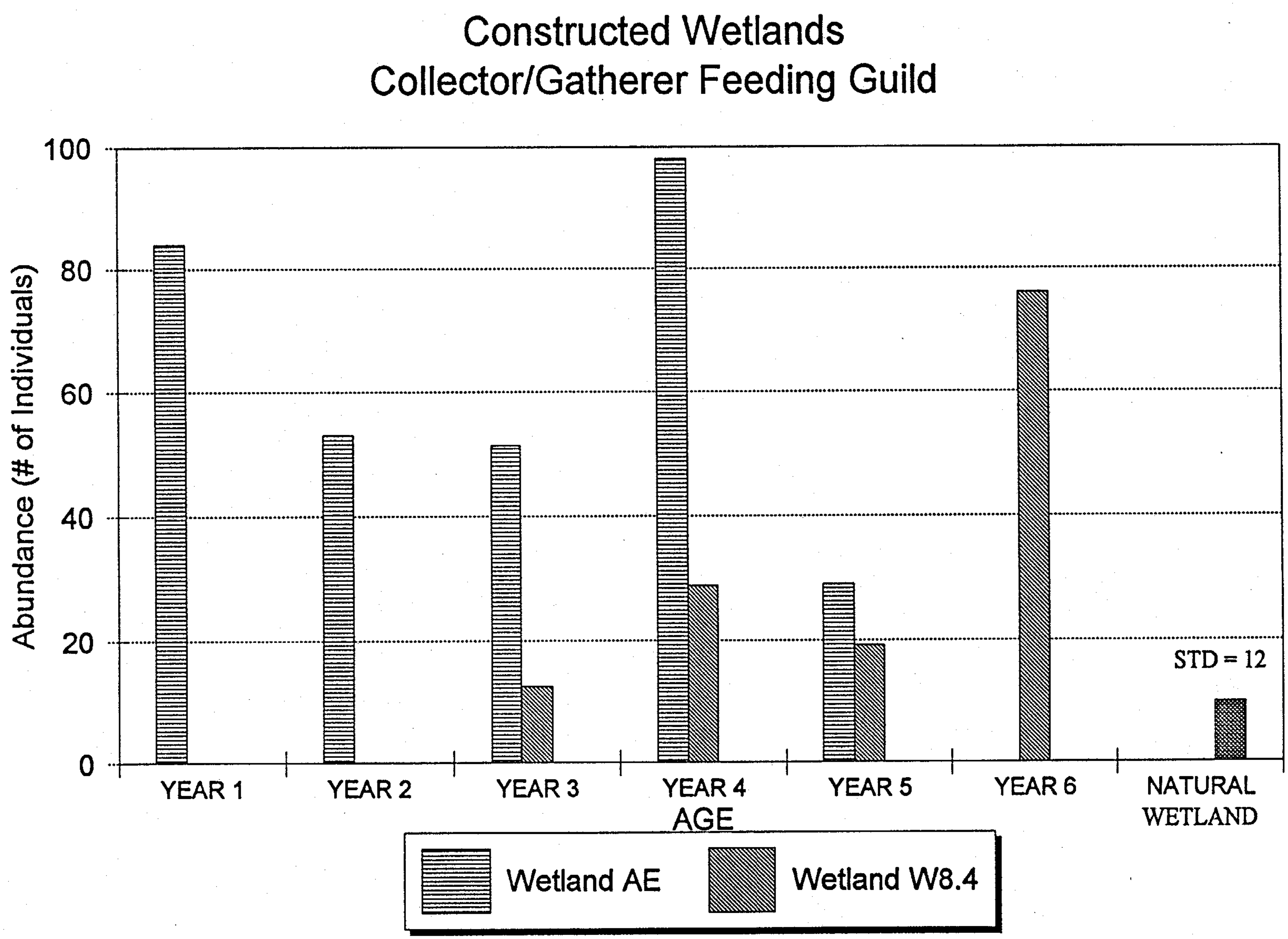
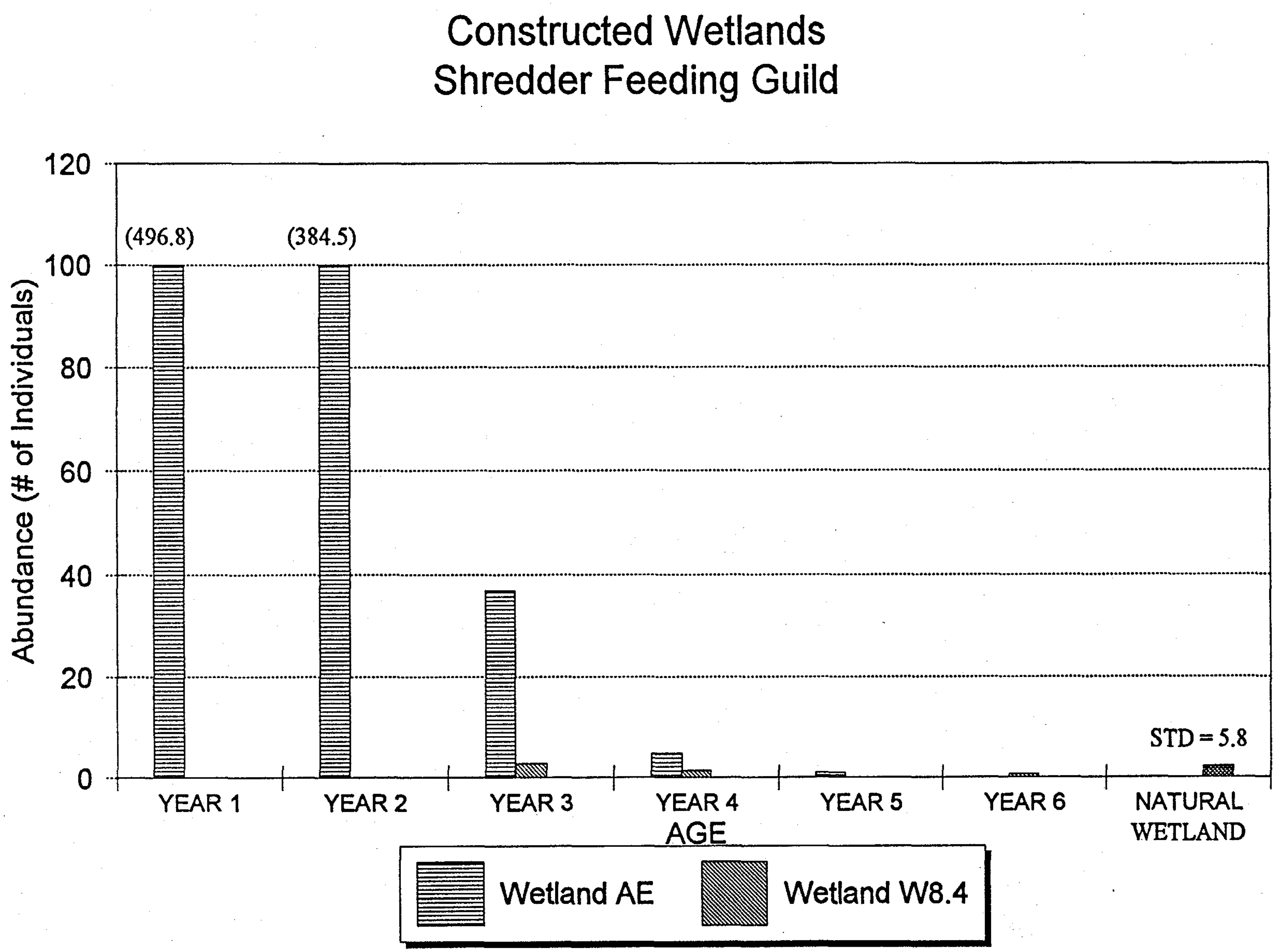


Figure 5-41



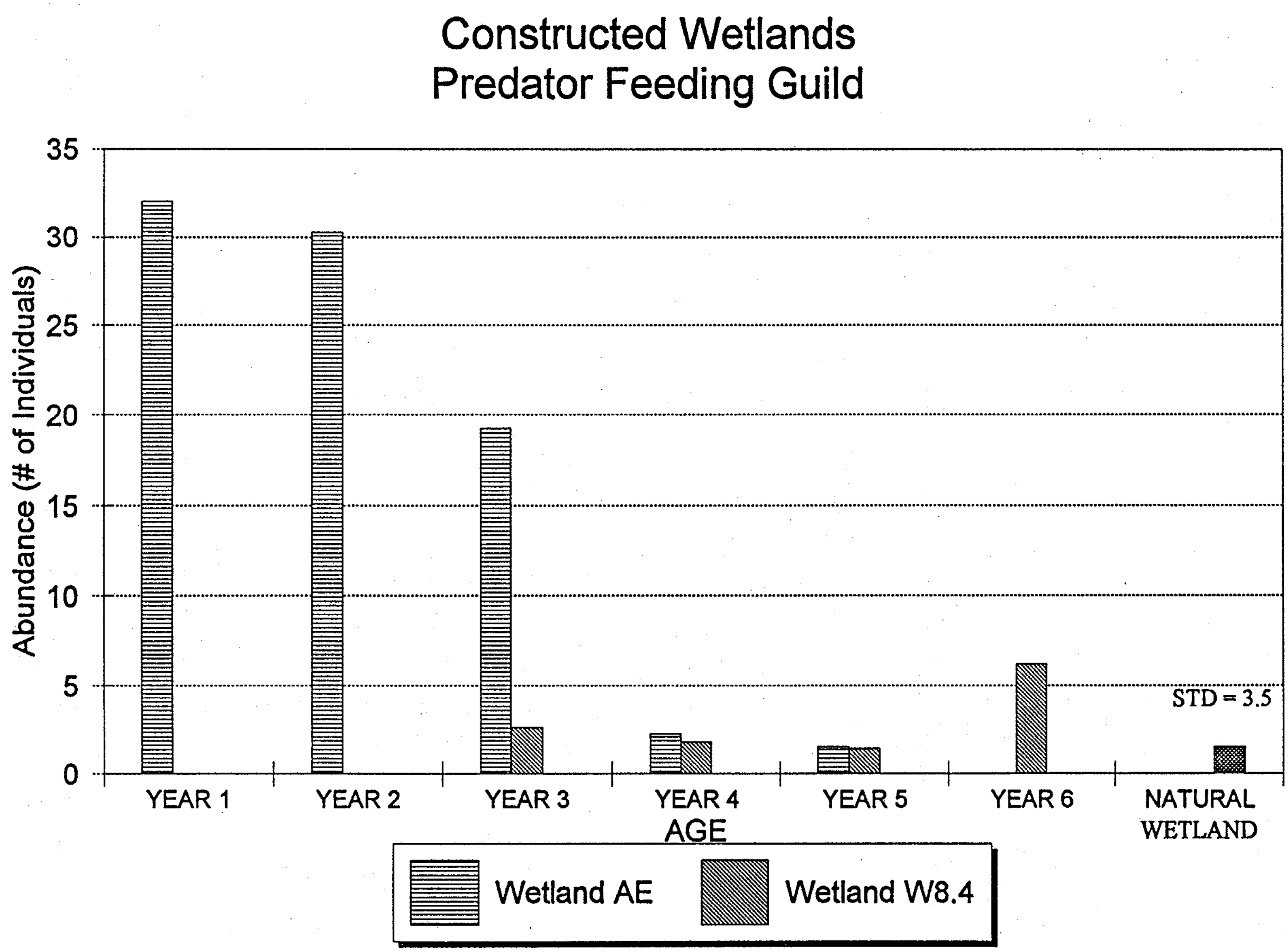
Constructed Wetlands
Collector/Gatherer Feeding Guild
Abundance (# of Individuals)
100
80
60
40
20
0
STD = 12
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-42



Constructed Wetlands
Shredder Feeding Guild
120
100
80
60
40
20
0
Abundance (# of Individuals)
(496.8)
(384.5)
STD = 5.8
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Figure 5-43



Constructed Wetlands
Predator Feeding Guild
Abundance (# of Individuals)
35
30
25
20
15
10
5
0
STD = 3.5
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
NATURAL WETLAND
AGE
Wetland AE
Wetland W8.4

Unfortunately, data from wetlands SP-4, SA-1 and GA were unable to corroborate these findings. This set of unusable data is part of the many problems faced when trying to analyze the current database.

EFFECT OF DISCHARGE FROM CONSTRUCTED WETLANDS

Monitoring was conducted from August 1983 to June 1988. Hester-Dendy samplers were used after a 28-day incubation period. The number of individuals and taxonomic groups observed downstream were considerably higher for downstream than for upstream sampling stations (Figure 5-44). Peaks in the number of invertebrates collected corresponded to peak stream flow following heavy rainfall events. Low taxa abundance observed between June 1986 and June 1987 corresponded to low surface discharge for the entire watershed. Analysis of USGS monitoring data showed that this period was dry and rainfall was below normal This suggests that the trends observed are a reflection of invertebrates drifting downstream and colonizing on the artificial substrate.

EFFECT OF SAMPLING METHOD

CORE/PONAR VS. QUALITATIVE TECHNIQUE

These methods were used to collect macroinvertebrates along a relocated stream and a natural stream It was found that the number of samples collected by each method was different (Figure 5-45). When pooled, the total organisms observed at a site increased. However, these techniques were not used consistently. There were variations in the type of taxonomic groups collected by each technique. As a result, it was difficult to use these data to do statistical analyses.

Comparison of the number of individuals collected from the natural stream to that from the relocated stream, showed that the natural stream supported a larger invertebrate population than the relocated one (Figure 5-46). This may be accounted for by the better water quality observed in the natural stream (Refer to Section 4 of this report - Water Quality).

HESTER-DENDY

Artificial multiplate samplers were utilized to collect macroinvertebrates from a reclaimed stream This stream had a natural wetland as the headwater, and its watershed was reforested. Pre-mining sampling was conducted from April 1984 to October 1984. Following reclamation, the stream was monitored from April 1990 to May 1991.

In pm-mining samples, amphipods and isopods were the dominant taxonomic groups (Figure 5-47). Dipterans and amphipods were the dominant taxa found in the reclaimed stream (Figure 5-48). It was not possible to relate monitoring data from pre and post reclamation sampling events to the physical habitat in which the invertebrates were collected since supplementary information was not provided on water quality, substrate type, water depth and velocity, or the surrounding watershed.

Figure 5-44

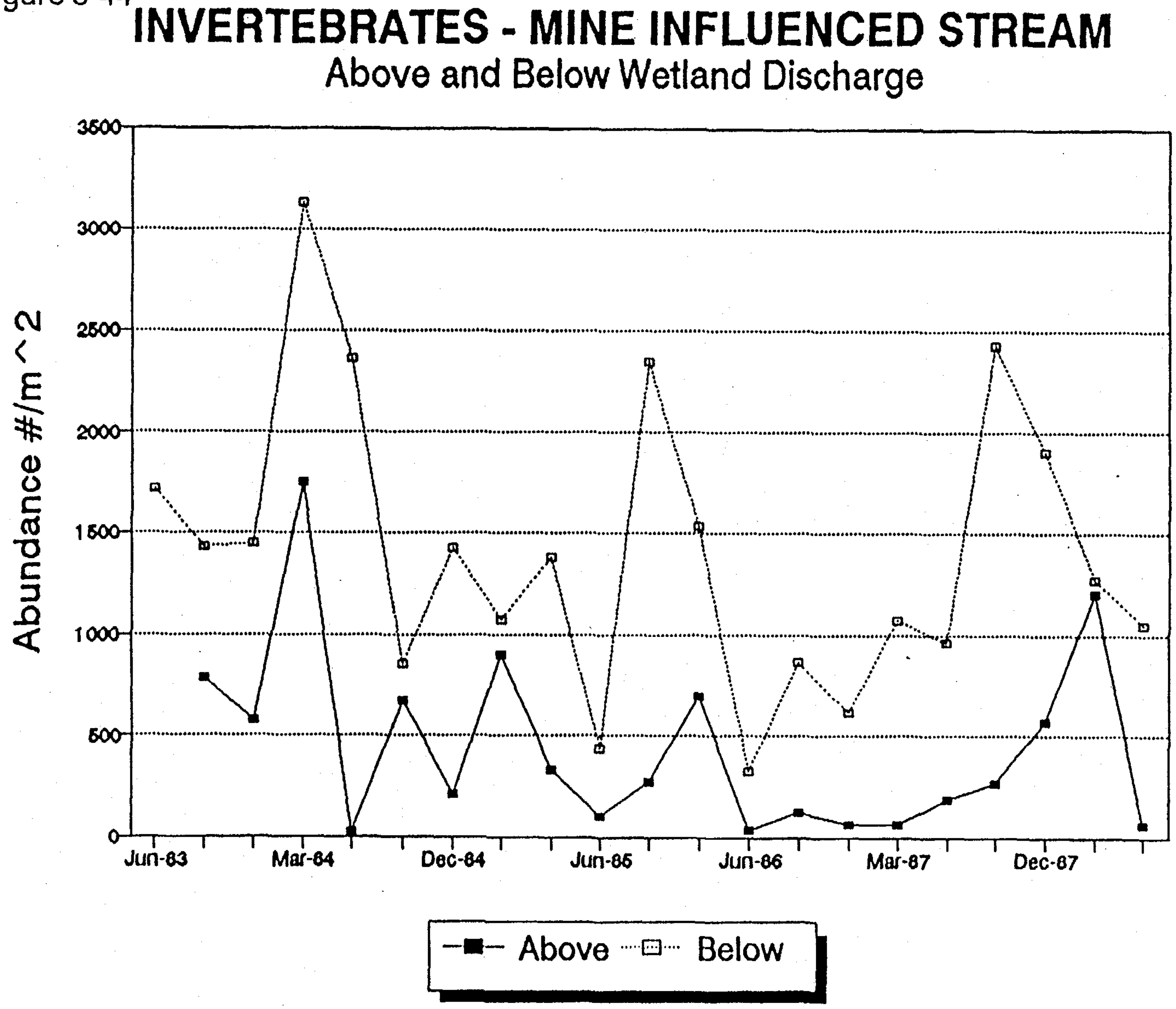
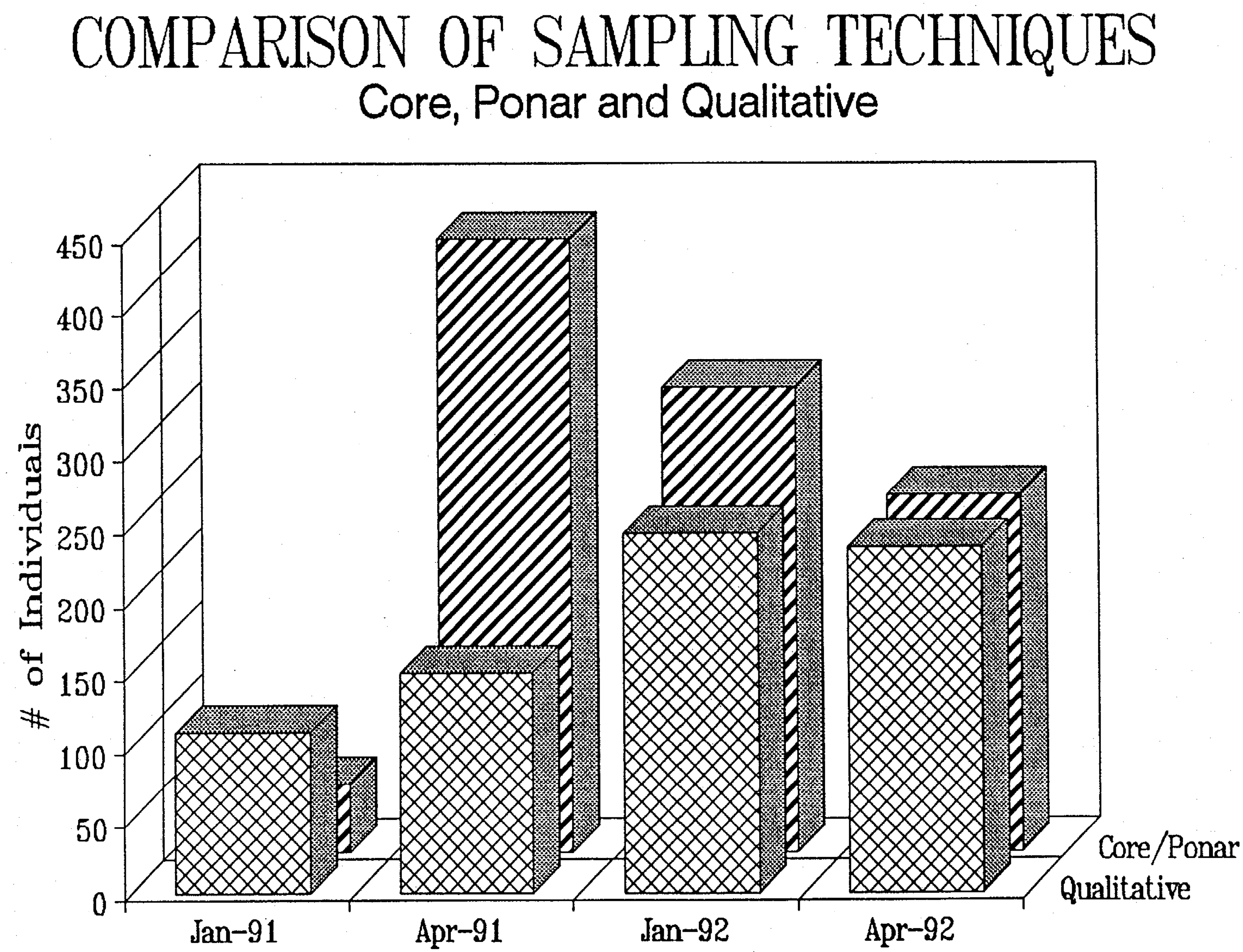
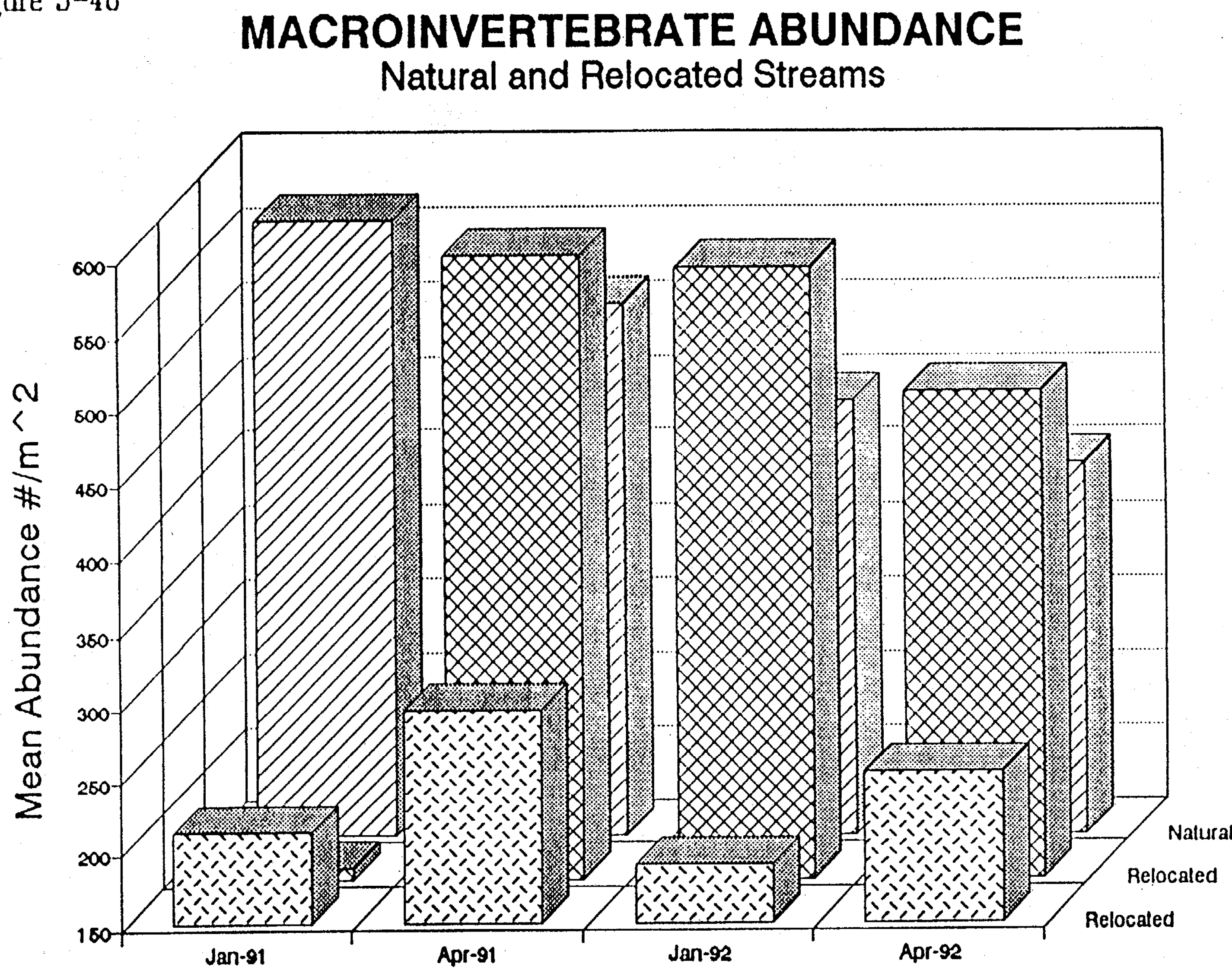

INVERTEBRATES - MINE INFLUENCED STREAM
Above and Below Wetland Discharge
Abundance #/m ^2
3500
3000
2500
2000
1500
1000
500
0
Jun-83
Mar-84
Dec-84
Jun-85
Jun-86
Mar-87
Dec-87
Above
Below

Figure 5-45



COMPARISON OF SAMPLING TECHNIQUES
Core, Ponar and Qualitative
# of Individuals
0
50
100
150
200
250
300
350
400
450
Jan-91
Apr-91
Jan-92
Apr-92
Core/Ponar
Qualitative

Figure 5-46


MACROINVERTEBRATE ABUNDANCE
Natural and Relocated Streams
Mean Abundance #/m^2
600
550
500
450
400
350
300
250
200
150
Jan-91
Apr-91
Jan-92
Apr-92
Natural
Relocated
Relocated

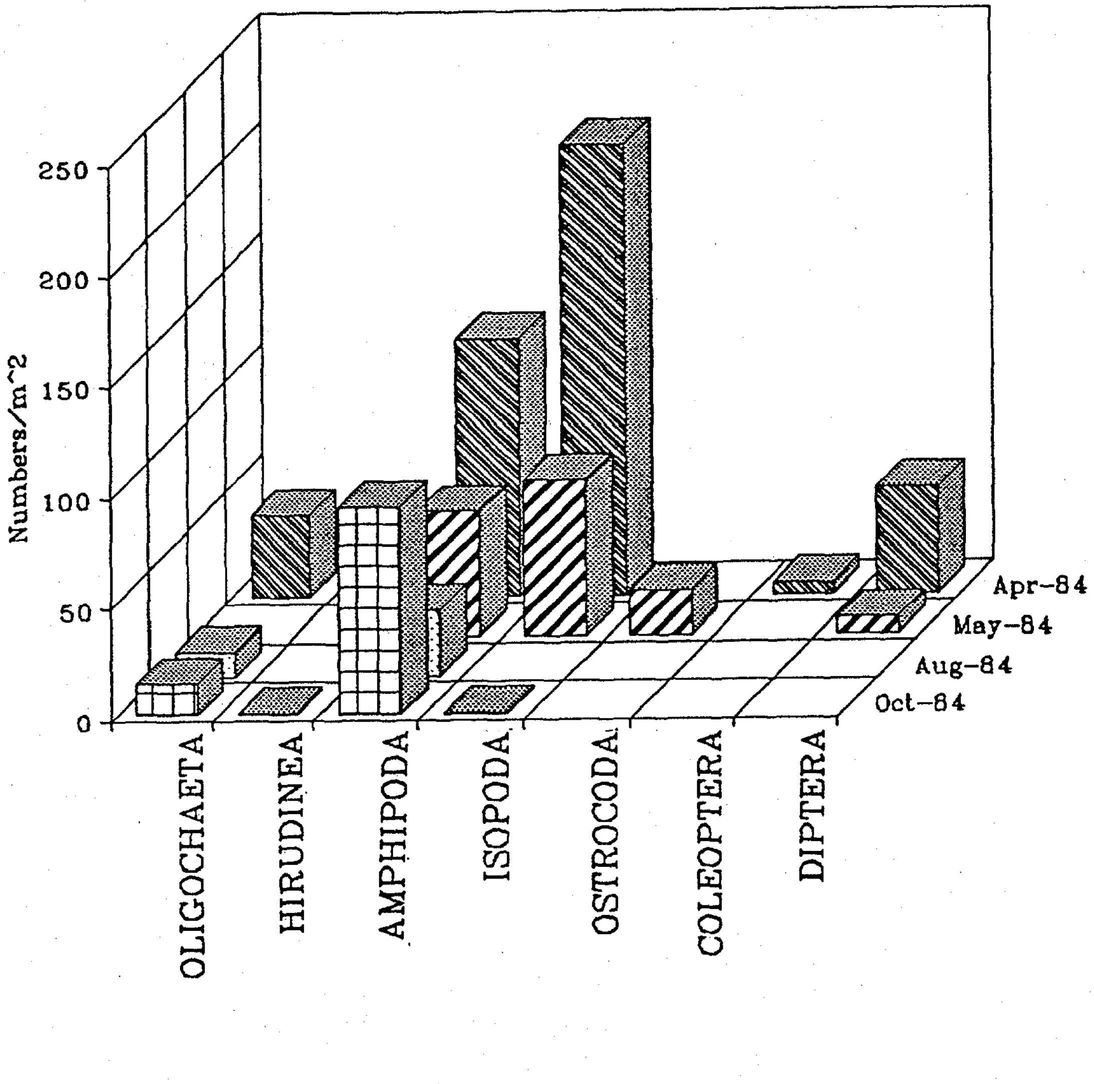


Figure 5-47 Macroinvertebrate abundance and distribution Pre-mining sample Station 2.

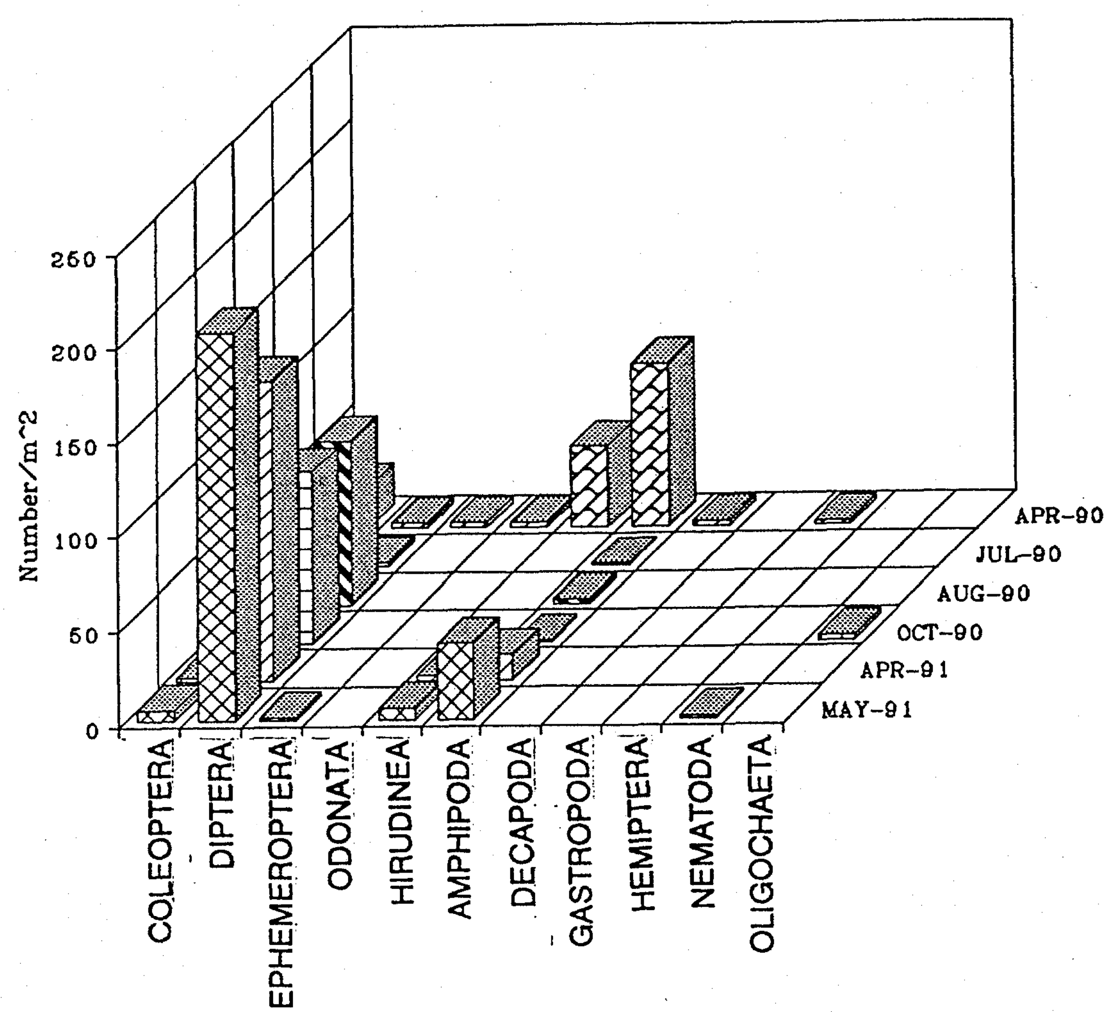


Figure 5-48 Macroinvertebrate abundance and distribution Post-relocation sampling Station R7.

The high abundance of amphipods, isopods, and dipterans collected during both sampling periods may be a result of downstream drift from the wetland. These groups are usually found in abundance among aquatic vegetation (Merritt and Cummins 1989, Pennak 1984). Macroinvertebrates which are typically found in lotic habitats were not very abundant or were absent from most samples. These were mainly ephemeropterans and trichopterans, but also included larvae of coleopterans and odonates (Merritt and Cummins 1989).

Use of Hester-Dendy plates to sample a lotic habitat only account for the organisms which are drifting downstream and not those within the substrate (Hughes 1978). The samples collected, therefore, provide an indication of the potential numbers of invertebrates which may enter a site but not necessarily colonize the substrate. In addition, macroinvertebrates may be settling on the plates in preference to the substrate, which is new (Modde and Drewes 1990).

Analysis of USGS data on rainfall and stream flow for the watershed showed July 1990 to be a dry period, with little rainfall and low flow. This explains the low invertebrate abundance recorded for that month and further negates the use of Hester-Dendy plates to sample the reclaimed habitat.

EFFECT OF PHYSICAL HABITAT TEMPLATE

Conceptual diagrams have been developed to summarize the results of this study (Figures 5-49 and 5-50). The size of each circle represents the relative abundance of macroinvertebrates in the different habitats. Open stream areas were characterized by aquatic macrophytes and sand overlain by detrital material. These sites were the most productive with higher species abundance and diversity. The opposite trend was observed for closed sites, whose substrate consisted of sand and leaf litter.

Riffle habitats had the highest species abundance, but lower diversity than other reclaimed habitats. Species abundance increased as the substrate changed from silt to sand, gravel then rocks. Flow rates increased in the same order, and was highest in the rocky (riffle) habitat.

Hardwood trees provide a lower quality food source than shrubs and macrophytes. Species abundance and diversity thus decreased with a change in habitat from aquatic macrophytes to shrubs than hardwood trees. The shrub and young hardwood habitat contained a richer invertebrate community than the mature hardwood habitat.

Collector-gatherers was the dominant functional group in open sites which contained aquatic macrophytes. Their abundance decreased as percent cover increased and was low also at the sites which contained rocky substrate. At those sites collector-filterers were prevalent.

The construction of streams with substrate materials similar to that for natural streams in the area will enable the development of macroinvertebrate communities which resemble natural ones. The physical template found in the lower reclaimed of stream 2 is not typical for Floridian streams. As a result the macroinvertebrate community, dominated by dipterans, is different to that found elsewhere.

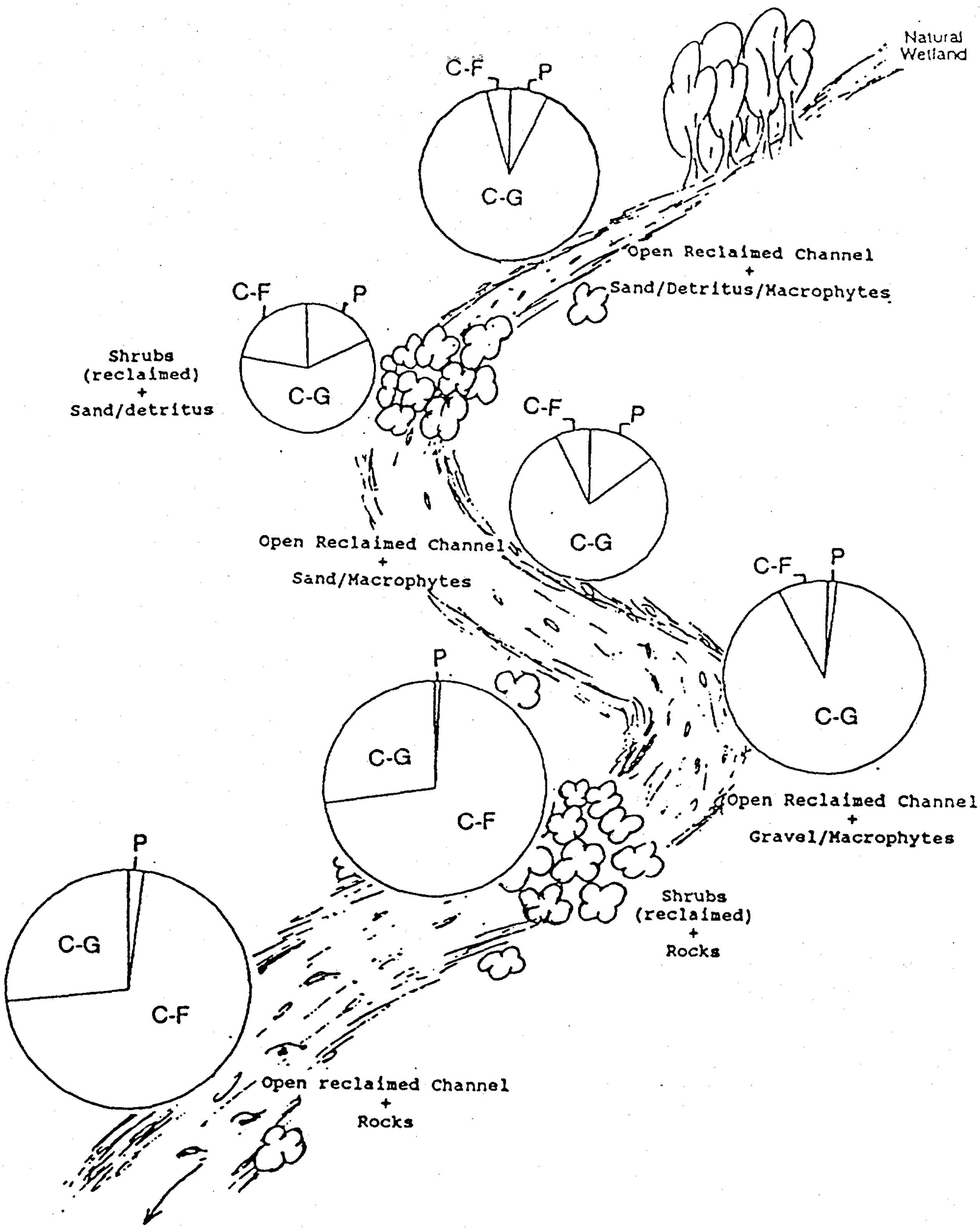


Figure 5-49. Conceptualized diagram showing the relative macroinvertebrate abundance among habitat types in stream 2 (C-F - Collector-filterers; P - Predators; C-G - Collector-gatherers)

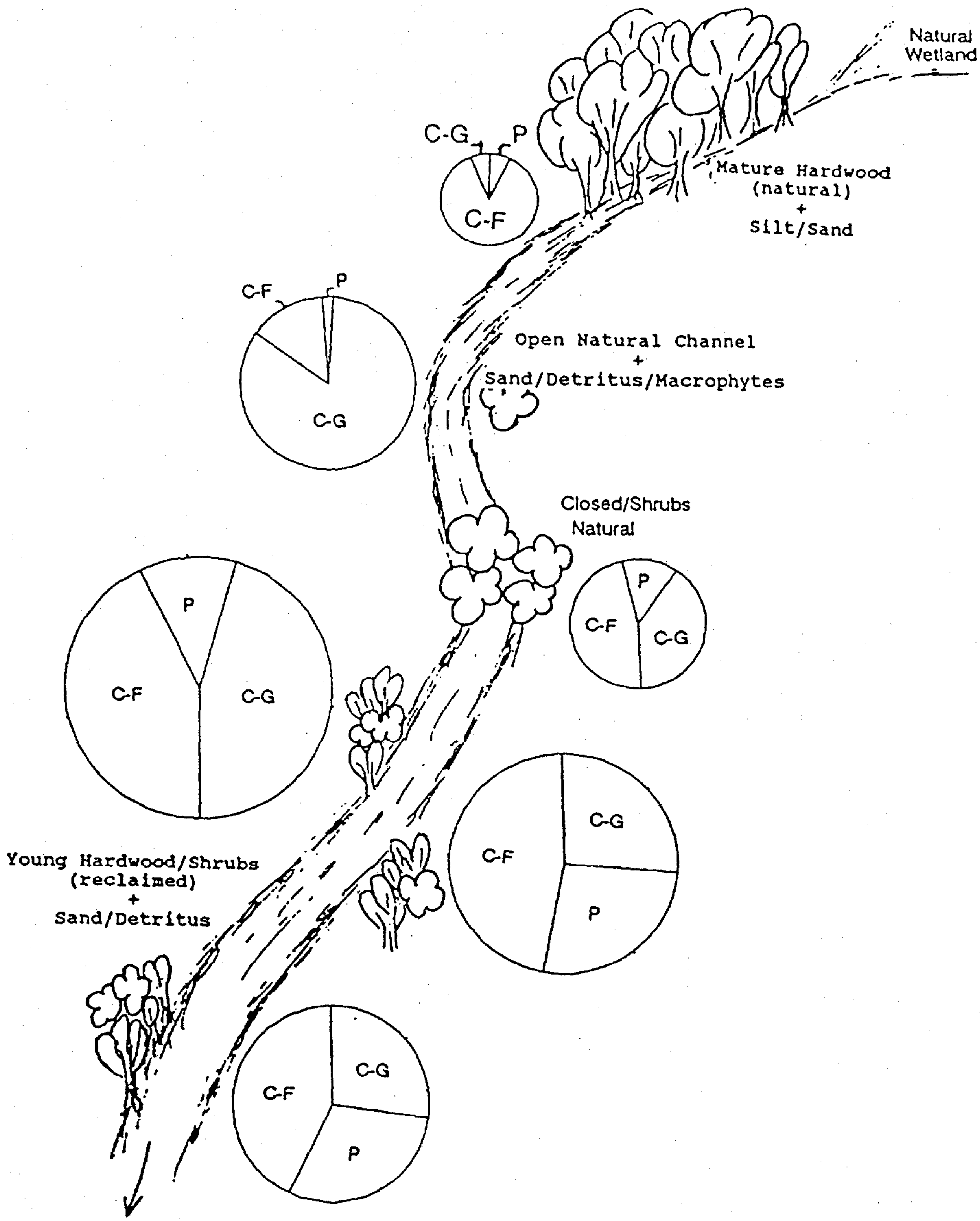


Figure 5-50. Conceptualized diagram showing the relative macroinvertebrate abundance among habitat types in stream 3 (C-F - Collector-filterers; P - Predators; C-G - Collector-gatherers)

As the stream ecosystem changes over time, the macro-invertebrate community will adjust until a new equilibrium is achieved The community observed in the upper segment of stream 2 will change with time as the hardwood trees planted in the surrounding floodplain grow up to form a canopy. Species assemblage will resemble that found in the reclaimed segment of stream 3.

CONCLUSIONS

The following are our conclusions:

- The database on macroinvertebrate communities of constructed wetlands and streams is sparse. Data exist for only about 20 constructed wetlands, and the database for individual wetlands is temporarily restricted. Few data exist for systems greater than five years of age. The current database on stream invertebrates is too sparse to assess successional trends in constructed streams. The extent of expected differences in stream communities is unknown, both sampling methodology and stations often changed during the monitoring period.

- Total invertebrate abundance increased during the first two or three years following wetland construction but decreased significantly by the fifth year. Invertebrate communities of constructed wetlands display a classical trophic surge immediately following system construction associated with a pulse in planktonic productivity. Overall abundance decreases significantly by the fifth year following construction as organic sediments develop in the basin.

- There is a progressive change in invertebrate trophic guilds during aging of constructed wetlands. Collector-gatherers dominate invertebrate communities during the initial two to three years following wetland construction but are replaced by collector-filterers with increasing wetland age. Such changes reflect a change in the availability of food of various particle sizes.

- Invertebrate communities of constructed wetlands evolve to approximate those of natural systems. Analysis of the existing monitoring database suggests that invertebrate communities gradually evolve to approximate those of natural wetlands of the region. Although of limited extent, the data suggest that system correspondence occurs approximately five to seven years following construction.

- There has been a great disparity in sampling protocol for streams. Samples have been collected by sweep nets, ponar grabs and Hester-Dendy traps. Sweep nets are purely qualitative and Hester-Dendy traps collect only those organisms able to colonize an artificial substrate during a set period. Only ponar grabs or similar sediment samplers provide reasonable quantitative data for assessing the invertebrate communities of streams.

- A stream is an ecological continuum. Both water quality and invertebrates evolve along the length of a stream Thus, one should not expect invertebrate communities below a perturbation to show structure similar to that seen about the disturbance. Even in first order streams, like those created on phosphate-mined lands, such upstream-downstream differences in biotic structure is expected.

- Initial colonization of streams by invertebrates is determined by biotic source area and stream substrate. Invertebrates colonize streams via immigration of terrestrial adults, upstream migration of larval stages, and introduction via birds and mammals. Distance from potential biotic sources and the inability to migrate upstream from natural streams have not been considered when evaluating benthic invertebrate communities from constructed streams.

- The headwaters of natural and constructed streams are often very different. The headwaters of natural streams are often seeps, while those of constructed streams are usually constructed wetlands. Thus, there are expected differences in the type of invertebrates colonizing downstream reaches of these two system types. Such differences have not been considered when comparing natural and constructed stream invertebrate communities.

- Natural and constructed streams often display pronounced differences in substrate types. Snags are usually lacking in constructed streams because of a uniform channel design. Grain size may differ from natural streams due to insufficient time to see pronounced sorting via currents. Burrowing invertebrates display a strong preference for sediments of a particular organic-inorganic mix and grain size, and several taxa require attachment surfaces such as provided by snags. Constructed streams with the coarsest sediments displayed the most diverse invertebrate communities.

- Riparian vegetation determines invertebrate feeding types present in streams. Most headwater streams are considered heterotrophic systems, whose foodchain is driven by allochthonous organic matter input primarily from terrestrial vegetation. Thus, the structure of the terrestrial vegetative community, as a determinate of food quality, can be a strong controlling element for the structure of the benthic invertebrate community in streams.

- communities of constructed streams approximate those of natural streams of the area. Given the close interrelationship between terrestrial vegetation and invertebrate communities, one would expect that invertebrate community structure in constructed and natural streams would likely be most similar once a “mature” vegetative community developed in the floodplain of the former system Thus, a lag time of at least 20 years may be expected between stream construction and similarity in invertebrate community structure with that of natural streams.

- Isolated streams hinder succession. The common practice of not connecting constructed streams to natural drainages downstream until the project is released by regulatory agencies hinders upstream migration of invertebrates and fish and thus delays the process of succession and structural similarity to natural systems.

RECOMMENDATIONS

The following are our recommendations:

- Field and laboratory methodology must be standardized. It is recommended that sampling stations be kept constant during the monitoring period and that sample collection be standardized to a natural substrate sampler such as a ponar grab or coring device. Hester-Dendy samplers should be eliminated. There must be agreement on the degree of taxonomic precession needed for monitoring. Data should be collected only to a degree of taxonomic precision for which ecological interpretations can be made.

- Sampling frequency should be standardized. It is recommended that macroinvertebrate samples be taken quarterly from the time of wetland construction until the project is released by the appropriate regulatory agencies. Sampling should be conducted uninterrupted throughout the monitoring period.

- Supporting information should be collected concurrent with macroinvertebrate samples. habitat characteristics including vegetation type, water depth and substrate type must be collected concurrently with all macroinvertebrate samples. Such data will aid in interpretation of invertebrate communities. Stream channel characteristics including width, depth and substrate type and vegetation type, both terrestrial and aquatic, must be collected concurrently with all macroinvertebrate samples. Such data will aid in interpretation of invertebrate communities.

- Structure should be added to constructed streams. Snags, channel sinuosity and pools add habitat heterogeneity and thus will facilitate community diversity of invertebrate communities. Inclusion of such habitat diversity should facilitate invertebrate succession and comparability with natural streams.

- Connection of constructed streams with downstream natural drainages should be encouraged. Biotic succession in constructed streams is likely hindered by lack of connection with downstream waters and the associated absence of an upstream migration corridor for invertebrate and vertebrate communities. Early connection with natural waters should be encouraged to speed biotic succession.

- Data should be collected from both vegetated and open water habitats. It is recommended that data on the two major habitat types found in constructed wetlands be collected. It is essential to know how habitat complexity affects invertebrate community structure and possible pathways for energy transfer through food chains.

REFERENCES

Allan, J.D., 1975. The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. Ecology 56: 1040-1053.

American Public Health Association, 1989 17th ed. Standard Methods for the Examination of Water and Wastewater. Ed by: Lenore S. Clesceri, Arnold E. Greenberg and R. Rhodes Trussell.

Anderson, B.W., 1985. Riparian Revegetation as a Mitigating Process in Stream and River Restoration, In: the Restoration of Rivers and Streams - theories and experiences. Ed. by J.A. Gore, 1985. Butterworth Publishing, Boston.

Barnes, J.R and G.W. Minshall, 1983. Stream Ecology: Application and Testing of General Ecological Theory. Plenum Press, New York.

Beck, W.M., Jr. 1965. The Streams of Florida. Bulletin of the Florida State Museum 10(3): 91-126.

Benke, AC., T.C. Van Arsdall, D.M. Gillespie and F.K Parrish, 1984. Invertebrate Productivity in a Subtropical Blackwater River: The Importance of Habitat and Life History. Ecological Monographs 54(1): 25-63.

Borchardt, D., 1993. Effects of flow and refugia on drift loss of benthic macroinvertebrates: implications for habitat restoration in lowland streams. Freshwater Biology 29: 221-227.

Brown, A.V. and P.P Brussock, 1991. Comparisons of benthic invertebrates between riffles and pools. Hydrobiologia 220: 99-108.

Brussock, P.P and AV. Brown, 1991. Riffle-pool geomorphology disrupts longitudinal patterns of stream benthos. Hydrobiologia 220: 109-117.

Cairns, J., 1990. Lack of Theoretical Basis for Predicting Rate and Pathways of Recovery. Environmental Management 14 (5): 5 17-526.

Chow Ven Te. (Ed), 1964. Handbook of Applied Hydrology. McGraw-Hill, New York. 1200 pp.

Cowell, B.C., 1993. Macro- and Meiofaunal distributions in Headwater Streams of the Alafia River, Florida. Annual Report January-December, 1993. Florida Institute of Phosphate Research, Fl.

Cowell, B.C and W.C. Crew, 1976. Seasonal and die1 periodicity in the drift of aquatic insects in a subtropical Florida Stream Freshwater Biology 6: 587-594.

Cummins, K.W., 1992. Catchment Characteristics and River Ecosystems. pg 125-136 In: River Conservation and Management. Ed by P.J Boon, P. Calow and G.E. Petts. John Wiley and Sons, New York.

Downes, B.J., 1993. Spatial variation in the distribution of stream invertebrates: implications of patchiness for models of community organization. Freshwater Biology 30: 119-32.

Erman, D.C. and N.A. Erman, 1984. The response of stream macroinvertebrates to substrate size and heterogeneity. Hydrobiologia 108: 75-82.

Felley, J.A., 1992. Medium-Low-Gradient Streams of the Gulf Coastal Plain. pg 233-270 In: Biodiversity of the Southereastem United States Aquatic Communities. Ed by C. T. Hackney, S. M. Adams and W. H. Martin. John Wiley and Sons, Inc., New York.

Fisher, S.G., 1990. Recovery Processes in Lotic Ecosystems: Limits of Successional Theory. Environmental Management 14 (5): 725-736.

Gore, J.A., 1978. A technique for predicting instream flow requirements of benthic macroinvertebrates. Freshwater Biology 8: 141-151.

Gore, J.A, 1979. Patterns of initial benthic recolonization of reclaimed coal strip-mined river channel. Canadian Journal of Zoology 57: 2429-2439.

Gore, J.A, 1982. Benthic invertebrate colonization: source distance effects on community composition. Hydrobiologia 94: 183-193.

Gore, J.A and AM. Milner, 1990. Island Biogeographical Theory: Can It Be Used to Predict Lotic Recovery Rates? Environmental Management 14 (5): 737-753.

Gore, J.A., J.R Kelly and J.D. Yount, 1990. Application of Ecological Theory to Determining Recovery Potential of Disturbed Lotic Ecosystems: Research Needs and Priorities. Environmental Management 14(5): 755-762.

Gore, J.A and RD. Juday, 1981. Predictive models of benthic macroinvertebrate density for use in instream flow studies and regulated flow management. Canadian Journal of Fisheries and Aquatic Sciences. 38: 1363-1370.

Gore, J.A., J.B. Layzer and LA. Russell, 1992. Non-traditional Application of Instream Flow Techniques for Conserving Habitat of Biota in the Sabie River of Southern Africa. pg 161-178 In: River Conservation and Management. Ed by P. J. Boon, P. Calow and G.E. Petts. John Wiley and Sons, New York.

Gore, J.A., 1985b. Mechanisms of Colonization and Habitat Enhancement for Benthic Macroinvertebrates in Restored River Channels. pg 81-102 In The Restoration of Rivers and Streams: theories and experience. Ed by J.A Gore. Butterwoth Publishers, Boston.

Gore, J.A, 1985a. The Restoration of Rivers and Streams: theories and experience. Butterworth Publishers, Boston. 280 pgs.

Griffith, M.B and S.A Perry, 1993. Colonization and processing of leaf litter by macroinvertebrates shredders in streams of contrasting pH. Freshwater Biology 30: 93-103.

Hasfurther, V.R, 1985. The use of Meander Parameters in Restoring Hydrologic Balance to Reclaimed Stream Beds. In: The Restoration of Rivers and Streams - theories and experiences. Ed by J.A. Gore, 1985. Butterworth Publishing, Boston.

Hawkins, C.P., M.L. Murphy and NH. Anderson, 1982. Effects of Canopy, Substrate Composition, and Gradient on the Structure of Macroinvertebrate Communities in Cascade Range Streams of Oregon. Ecology 63 (6): 1840-1856.

Hughes, B.O., 1978. The influence of factors other than pollution on the value of Shannon's diversity index for benthic macroinvertebrates in streams. Water Research 12: 359-364.

Hynes, H.B.N., 1970. The Ecology of Running Waters. Liverpool University Press, Liverpool. 555pp.

Hynes, H.B.N., 1975. The Stream and its Valley. Edgardo Baldi Memorial Lecture. Verh. Internat. Verein. Limnol. 19: 1-15.

Kelly, J.R and M.A Harwell 1990. Indicators of Ecosystem Recovery. Environmental Management 14 (5): 527-545.

Kershner, J.L. and W.M. Snider, 1992. Importance of Habitat-level Classification System to Design Instream Flow Studies. pg 179- 194 In: River Conservation and Management. Ed by P. J. Boon, P. Calow and G.E. Petts. John Wiley and Sons, New York.

Lancaster, J., A.G. Hildrew and C.R Townsend, 1990. Stream flow and predation effects on the spatial dynamics of benthic invertebrates. Hydrobiologia 203: 177-190.

Leopold L.B., M.G. Wolman and J.P Miller, 1964. Fluvial Process in Geomorphology. Freeman, San Francisco. 522 pp.

Matter, J.M and J. J Ney, 198 1. The impact of Surface Mine Reclamation on Headwater Streams in Southwest Virginia. Hydrobiologia 78: 63-71.

Meier, H., 1989. Macroinvertebrate community structure in a first order sand bottom stream in Florida. Masters thesis, University of Florida, Gainesville, Fl.

Minshall, G.W., K.W. Cummins, RC. Petersen, C.E. Cushing, D.A Burns, J.R Sedell and RL. Vannote, 1985. Developments in Stream Ecosystem Theory. Canadian Journal of Fisheries and Aquatic Sciences. 42: 1045-1055.

Minshall, G.W., 1984. Aquatic Insect-Substratum Relationships. pg 358-400 In: The Ecology of Aquatic Insects. Ed by V.H. Resh and D.M. Rosenberg. Praeger Scientific, New York.

Modde, T. and H.G. Drewes, 1990. Comparison of biotic index values for invertebrate collections from natural and artificial substrates. Freshwater Biology 23: 171-180.

Mundie, J.H., 1978. Substrate size selection by stream invertebrates and the influence of sand. Limnology and Oceanography 23(5): 1030-1033.

Newbury, RW., 1984. Hydrologic Determination of Aquatic Insect Habitats. pg 323-357 In: The Ecology of Aquatic Insects. Ed. by V.H. Resh and D. M Rosenberg. Praeger Scientific, New York.

Newbury, R, and M. Gaboury, 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behavior. Freshwater Biology 29: 195-210.

Osborne, L.L., P.B.Bailey, L.W.G. Higler, B. Statzner, F. Triska and T.M. Iversen, 1993. Restoration of lowland streams: an introduction. Freshwater Biology 29: 187-194.

Perry, J.A., and D.J. Schaeffer, 1987. The longitudinal distribution of riverine benthos: A river dis-continuum? Hydrobiologia 148: 257-268.

Petersen, RC, L.B.-M. Petersen and J. Lacoursie're, 1992. A Building-block Model for Stream Restoration. pg 293-310 In: River Conservation and Management. Ed. by P. J. Boon, P. Calow and G.E. Petts. John Wiley and Sons, New York.

Poff, N and J.V. Ward, 1990. Physical Habitat Template of Lotic Systems: Recovery in the Context of Historical Pattern of Spatiotemporal Heterogeneity. Environmental Management 14 (5): 629-645.

Pringle, C.M., RJ. Naiman, G. Bretschko, J.R Karr, M.W. Oswood, J.R Webster, RL. Welcomme and M.J. Winterbourn, 1988. Patch dynamics in lotic systems: the stream as a mosaic. Journal of the North American Benthological Society. 7(4): 503-524.

Pusch, M.H.E., M. Pusch and U, Braukmann, 1991. Restoration of channelized streams- a benthological study. Verh. Internat. Verein. Limnol., 24 (3) 1851-1855.

Reice, S.R, RC. Wissmar and R. J. Naiman, 1990. Disturbance Regimes, Resilience, and Recovery of Animal Communities and Habitats in Lotic Ecosystems. Environmental Management 14(5): 647-659.

Reice, S.R., 1985. Experimental disturbance and the maintenance of species diversity in a stream community. Oecologia 67: 90-97.

Resh V.H. and D.M. Rosenberg, 1984. The Ecology of Aquatic Insects. Praeger Scientific, New York. 625 pgs.

Rhoads, B.L., and M.V. Miller, 1990. Impact of Riverine Wetlands Construction and Operation on Stream Channel Stability: Conceptual Framework for Geomorphic Assessment. Environmental Management 14(5): 799-807.

Richards, C. and G.E. Host, 1993. Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment. Freshwater Biology 29: 285-294.

Robertson, D.J., 1985. Freshwater Wetland Reclamation in Florida, An Overview. Florida Institute of Phosphate Research, Fl.

Sedell, J.R, G. H. Reeves, F. R. Hauer, J.A. Stanford and C.P. Hawkins, 1990. Role of Refugia in Recovery from Disturbances: Modem Fragmented and Disconnected River Systems. Environmental Management 14 (5): 71l-724.

Smock, L.A and E. Gilinsky, 1992. Coastal Plain Blackwater Streams. pg 271-314 In: Biodiversity of the Southeastern United States Aquatic Communities. Ed. by C.T. Hackney, S.M. Adams and W.H. Martin. John Wiley and Sons, Inc., New York.

Stanford, J.A and J.V. Ward, 1983. Insect Species Diversity as a Function of Environmental Variability and Disturbance in Stream Systems. pg 265-278 In Stream Ecology : Application and testing of General Ecological Theory. Ed by J.R Barnes and G.W. Minshall. Plenum Press, New York.

Starnes, L.B., 1985. Aquatic Community Response to Techniques Utilized to Reclaim Easter U.S Coal Surface Mine-Impacted Streams. In: The Restoration of Rivers and Streams - theories and experiences. Ed by J.A. Gore, 1985. Butterworth Publishing, Boston.

Statzner, B., J.A. Gore and V.H. Resh, 1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Society. 7: 307-360.

Sweeney, B.W., 1993. Effects of Streamside vegetation on Macroinvertebrate Communities of White Clay Creek in Eastern North America. Proceedings of the Academy of Natural Sciences of

Philadelphia 144: 291-340.

Townsend, C.R, 1989. The patch dynamics concept of stream community ecology. Journal of the North American Benthological Society. 8: 36-50.

Vannote, RL., G.W. Minshall, K.W. Cummins, J.R Sedell, and C.E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37: 130-137.

Vinikour, W.S, 1980. Biological consequences of stream routing through a final-cut strip mine pit: benthic macroinvertebrates. Hydrobiologia 75: 33-43

Wallace, J.B., 1990. Recovery of Lotic Macroinvertebrate Communities from Disturbance. Environmental Management 14 (5): 605-620.

Walton, O.E., 1978. Substrate attachment by drifting insect larvae. Ecology 59: 1023-1030.

Ward, J.V, 1992. Aquatic Insect Biology 1. Biology and habitat. John Wiley and Sons, Inc.

Webster, J.R, M.E. Gurtz, J.J. Hains, J.J. Meyer, W.T. Swank, J.B. Waide and J.B. Wallace, 1983. Stability of Stream Ecosystems. pg 355-396 In Stream Ecology: Application and Testing of General Ecological Theory. Ed by J.R. Barnes and G.W. Minshall. Plenum Press, New York.

Welch, P. S., 1948. Limnological Methods. The Blakston Company.

Williams, D.D., 1981. Migrations and distributions of stream benthos, pps 155-208. Perspectives in Running Water Ecology. Eds M.A. Lock and D.D. Williams. Plenum Press, London.

Winget, RN., 1985. Methods for Determining Successful Reclamation of Stream Ecosystems. pg 165-192 In the Restoration of Rivers and Streams: theories and experience. Ed by J. A. Gore. Butterworth Publishers, Boston.

Yount, J.D. and G.J. Niemi, 1990. Recovery of Lotic Communities and Ecosystems from Disturbance - A Narrative Review of Case Studies. Environmental Management 14 (5): 547-569.