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EVALUATION OF CONSTRUCTED WETLANDS ON PHOSPHATE MINED LANDS IN FLORIDA

VOLUME I

Project Summary

Prepared By
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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.

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VOLUME I

PROJECT SUMMARY

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
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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

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

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PROJECT SUMMARY

The primary research task of this project was to assess and analyze the available data base on constructed wetlands on phosphate mined lands in Florida, and where necessary, to supplement existing data with limited additional sampling, and computer modeling. Research goals were directed at determining current technical and operational success of created wetlands to develop as persistent, functioning, and integrated ecosystems. This was accomplished through an evaluation of design criteria and the wetland structure and function that has developed on existing sites. Specific research goals of the project are given below followed by a synopsis of major research findings addressing each goal.

RESEARCH GOALS

1. To provide a data base from existing studies to guide operational and policy changes needed to improve design, construction, monitoring and assessment of constructed wetland projects, and to determine the adequacy of the existing data base, providing recommendations to ensure the utility of future research and monitoring efforts;

2. To determine the extent to which existing constructed wetlands are persistent, functioning ecosystems;

3. To determine whether constructed wetlands are properly located in reclaimed landscapes;

4. To determine ecosystem functions and values provided by constructed wetlands, to identify appropriate indicators of functions and values, and to develop quantitative methods of measuring those indicators;

5. To determine how success criteria should be applied in evaluating the attainment of goals and of development trends for constructed wetland projects; and

6. To identify future research needs of industry and regulatory agencies.

RESEARCH FINDINGS

1. What is the adequacy of existing data?

The overall adequacy of data is poor, limited, or lacking in standardization to do quantitative evaluations of constructed wetland success. Hydrological data, including groundwater levels, hydroperiod, and watershed characteristics, is almost nonexistent . Minimal information exists on soil sediment characteristics of natural and created wetlands visited, including physical and chemical properties such as bulk density, compaction, total or available nutrients, and cation exchange capacity. The data base for aquatic fauna and water chemistry is good quality but relatively sparse. Data for analysis of vegetation development was of limited value due to a lack of standardization and limited long-term monitoring. Virtually no site specific wildlife data exists. The majority of data is derived from permit related monitoring conditions that were not generally relevant to the specific research goals oft his project.

2. To what extent are constructed wetlands persistent, functioning ecosystems?

Many of the constructed wetlands observed are apparently persistent. However, those wetlands with poor design, particularly improper hydrology are not persistent, declining in overall "robustness" with age. Constructed wetlands appear to be providing ecosystem functions to greater or lesser degrees. Functions include: surface water attenuation, runoff buffering, water quality maintenance, groundwater and aquifer recharge, shoreline protection, biological integrity, food chain support, provision of wildlife habitat, support of native plant populations, soil processes, and nutrient cycling. Constructed wetlands may provide similar functions as natural wetlands but at different capacities. Most constructed wetlands provide wildlife functions but for different groups of species as typically found in similar undisturbed wetlands.

The majority of constructed wetland projects are young sites and are typically productive ecosystems. These constructed wetlands do not offer the prerequisite habitat requirements for many species and therefore many are absent. The creation of open water habitat in constructed wetlands has increased habitat for many waterfowl and fish species which were more limited in abundance due to the limited natural occurrence of open water in the undisturbed landscape.

3. Are constructed wetlands properly located in reclaimed landscapes?

The present unmined Florida landscape within the phosphate mining region is fragmented by a variety of human activities dominated by agriculture. Reclaimed mine lands are disconnected and dominated by agriculture with numerous fragmented habitats and watersheds. About 5 1% wetland construction projects are within first order drainage basins (smallest) and 16% are within second order (second smallest) drainage basins. Most have direct hydrologic connections to the regional drainage network which may result in long-term hydrological problems associated with the maintenance of sufficient storage and groundwater recharge which may affect maintenance of stream base flow during the dry season.

About 50% of the surveyed constructed wetlands projects are connected, at least minimally (with >l% of border adjacent to natural area), to natural forested lands (mostly riparian), with only about 46% of the perimeter of these sites juxtaposed to natural areas. However, 74% of constructed wetland boundaries were other mined lands with only 13% of all project boundaries natural. The majority of constructed wetland projects that share borders with other reclamation sites are not ecologically connected, or integrated. Since the reclaimed landscape is often a patchwork of reclamation projects in various stages of design, implementation and successional regrowth, it continues to be a real challenge to link reclamation projects and their natural ecological communities together in a cohesive regional habitat network. However, current approaches to reclamation and reclamation planning have improved these linkages to provide a habitat network.

4. What are appropriate indicators of wetland functions? Can they be measured?

Persistent constructed wetlands appear to be providing basic wetland functions to varying degrees. Some appropriate indicators of applicable wetland functions and methods of measurement include:

- Maintenance of water quality can be measured as the assimilative capacity of nutrient uptake capacity for nitrogen and phosphorus of the wetlands expressed as percent reduction in nutrient concentration between input and output waters. Dissolved oxygen, temperature, and pH represent easily measured field parameters that are critical for most aquatic life. Water quality monitoring programs can be very expensive, time consuming and often the results are inconclusive or misleading. However, if the assessment is specifically designed to track parameters of concern, the information obtained can be used to explain biological conditions and trends.

- Support of food chains can be assessed by sampling fish. Freshwater fishes are an important component of wetland systems, filling different trophic levels in the food chain ranging from primary consumers of detritus, algae and vegetation, through intermediate trophic levels such as predators on crustacea and aquatic insects, to top-level carnivores such as piscivores. Fish sampling methodologies can be selective for different species. Dip net sampling is a qualitative method that can be used to collect *Poeciliids, Cyprinodontids* and *Fundulids.* Breder traps will yield the greatest diversity of fish species and relative densities per unit effort and they perform efficiently in both open and dense vegetation with minimal habitat disturbance. Enclosure traps (throw traps), such as the Wegener ring, effectively samples species richness and provides statistically precise density information. These sampling methods can be used at different times of the year to provide data to indicate fish utilization of wetlands and thus habitat and support of food chains.

- Provision of habitat and wildlife utilization can be measured by conducting appropriate wildlife surveys. Semi-quantitative and qualitative studies can provide a reliable measure of this function if conducted at the proper time(s) of the year. Qualitative wildlife surveys along transects should include visual and audible observations for birds. An array of Sherman mammal traps can be used to quantitatively measure small mammals.

- Support of native plant populations can be assessed by evaluating community types within a wetland. An assessment of native plant communities can range from simple visual estimation of species composition and abundance to more exhaustive quantitative methods involving the use of various sizes of quadrats and transects. For simple, less diverse plant communities, visual estimation may be sufficient. However, when many species of similar, diminutive grasses, sedges and herbs are present more quantitative methods will increase the accuracy of the assessment.

- Maintenance of biological integrity of wetlands can be measured over time by documenting the species richness and relative abundance of aquatic macroinvertebrates inhabiting the wetland study area. Comprehensive semi-quantitative and qualitative sampling of all habitat types using two or more methods within a given wetland will reduce sampling bias and seems to provide the most information while containing costs.

- Maintenance of natural hydrologic regimes is critical to successfully establishing specific types of wetlands. Hydroperiod can be assessed by evaluating the balance between inflows and outflows of water the surface contours of the landscape and subsurface soil, geology and groundwater conditions. Wetland hydroperiod, frequency of flooding, duration of flooding and water depth can all be determined by installing and monitoring staff gauges an monitoring wells within each wetland type. Stream gauges should be installed and topographic surveys conducted across wetland cross-sections at gauge and well locations.

- Support of natural soil processes and development can be assessed by evaluating soil compaction, bulk density, organic matter (carbon) and nitrogen content, C:N ration, available and total nutrient content, and cation-exchange capacity. All these parameters can be measured with existing techniques and methodology. However, decreases in bulk density and increases in organic matter accumulation should provide necessary and important information for evaluating the functioning of a wetland with regard to soil development.

5. How should success criteria be applied in evaluating the attainment of goals and of development trends for constructed wetland projects?

Reclamation goals should establish a landscape plan for an entire watershed; types and sizes of habitats, hydrologic pathways, topography, types and levels of functions to be provided. Success criteria should be measurable criteria used to assess the degree of goal attainment. "As built" surveys of wetlands and topography, and post-construction aerial photographs can be used to document the size and configuration of landscape features. Monitoring of constructed wetlands must adequately characterize and evaluate functions given the limitations of time, budget, type of wetland, size of wetland, context, degree of alteration from original wetland, location, and expertise of the investigator. Criteria most often used by regulatory agencies are quantitative measures of individual parameters that deal more with community development and how well the constructed wetland measures up to either a specific reference or "idealized' natural wetland. The use of reference wetlands in success criteria is problematic because most undisturbed, natural wetlands are well developed communities, with attributes and functions commensurate with age.

Long-term trends at the habitat and landscape level are more appropriate than short-term judgments of success. The 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. Alteration of natural hydrogeology does not mean that restoration of the mined landscape functions can not be successfully accomplished, but the concept of matching the pre-mined landscape with a created environment, duplicating the distribution and geographic positions of the natural landscape, should be avoided.

6. What are future research needs?

- Baseline information on wetland community development under natural conditions for wetland types in the phosphate mining regions for comparative purposes.
- 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); and
  - mucking treatments
- 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.
- 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.
- The scope of the preliminary investigation of watershed hydrogeology in both natural and reclaimed basin conducted by the U.S. Geological Survey in 1993, should be expanded to sufficiently quantify all of the necessary parameters.
- 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 investigations of both natural and reclaimed watersheds.
- Investigate reasonable semi-quantitative macroinvertebrate sampling protocols for streams and wetlands, both natural and constructed.
- Develop long-term data to evaluate long-term viability of constructed wetlands.
- Research related to invasive plant species, their persistence within reclaimed landscapes and their impacts, if any.
- Research related to understanding food webs, trophic structure and wildlife utilization of reclaimed landscapes.
- Investigate transpiration of reclaimed landscapes.
- Develop better indicators of success.
- Develop dynamic models of habitat quality as an aid in design and decision making.
- Document species distribution and abundance of mammals, fish, reptiles (in particular turtle species) in both natural and reclaimed habitats in phosphate mining regions.

INTRODUCTION

A significant portion of all wetland creation projects in the State of Florida are derived from the phosphate industry. Since required by state law in 1975, the Florida phosphate industry has been using wetland creation to replace native wetlands lost to mining activities. Agency stipulated success criteria of created wetlands has generally focused on a developing aspect of the vegetative community with the hope that recreation of a similar vegetative composition will create persistent, properly functioning wetland ecosystems. However, to date there have been no comprehensive assessments of the success or failure of created wetland ecosystems on phosphate mined lands.

In an effort to address questions concerning wetland creation and to evaluate wetland construction activity on phosphate mined lands; industry representatives approached the Florida Institute of Phosphate Research (FIPR). By late 1991 FIPR had formed an ad hoc committee with representation from government, industry, environmental organizations, and the scientific community to discuss the need for a comprehensive evaluation of wetland construction on phosphate mined lands in Florida. By 1993 a multidisciplinary team of research scientists received a research grant from FIPR to pursue the first comprehensive study of created wetlands on reclaimed phosphate mined lands. This report represents the culmination of that collaborative research effort.

CHAPTER ORGANIZATION

Research and report writing were organized to address seven components of constructed wetlands relating to ecosystem function and structure:

1. Hydrology
2. Soils
3. Water Quality
4. Aquatic Fauna
5. Vegetation
6. Wildlife
7. Ecosystem and Landscape Organization

The seventh research component evaluated the integration of constructed wetlands into reclaimed phosphate mined landscapes. Chapters 2 through 8 of this project report detail methods and conclusions for each of the seven research components.

GENERAL BACKGROUND

Wetland Values

Wetland ecosystems are recognized for structural and functional values including: high net primary production; wildlife habitat; recreational and research opportunities, their ability to retain nutrients, sediments, and toxins; protection of shorelines; attenuation of peak flows of surface water; recharge of groundwater aquifers; atmospheric gaseous exchange; and nutrient cycling. These "ecosystem services" identify the importance of wetlands protection, construction, and mitigation in order to restore and maintain ecosystem integrity.

Wetland Loss

Florida has lost approximately 3.8 million hectares of wetlands (Dahl 1990). It has been estimated that Florida once had approximately 8.2 million hectares of wetlands that covered 54% of the State's surface area. By the 1980's Florida's wetland acreage had been reduced by 46% to 4.5 million hectares (FDNR 1988, Shaw and Fredine 1956, and Tschinkel 1984). Based on current U.S. Fish and Wildlife Service National Wetlands inventory estimates of past wetland losses, an estimated 162,000 hectares of wetlands in the United States are lost annually, and approximately 10,000 hectares are gained annually.

Wetland Reclamation and Construction

Wetland creation has been advocated to: mitigate for losses, restore or replace degraded wetlands; reduce the impacts of activities in or near wetlands; treat surface and waste waters; provide wildlife and waterfowl habitat; and support aquaculture. In 1987 the U.S. Environmental Protection Agency (EPA) selected a group of scientists to prepare a status report on wetland creation and restoration in the U.S. (Kusler and Kentula 1990). Proceedings from the first comprehensive conference on constructed wetlands for water quality improvement were edited by Hammer (1989).

Wetland mitigation studies within the State of Florida, focusing on permit compliance, include: DER's Report on the Effectiveness of Permitted Mitigation (DER 1991); the Office of the Auditor General's (OAG) Performance Audit of the Management and Storage of Surface Waters Program Administered by the Southwest Florida Water Management District Report # 11537 (OAG 1990); and the Office of the Auditor General's Performance Audit of the Management and Storage of Surface Waters Program Administered by the South Florida Water Management District Under the Supervision of Department of Environmental Regulation Report # 1173 (OAG 1991).

Differences exist between constructed wetlands on phosphate mined lands and wetlands constructed in other landscapes and land-uses. The mining process causes alterations of soils, ground and surface hydrology, and regional landscape that are not typical of other wetland construction projects. The size of constructed wetlands in mine reclamation projects is generally an order of magnitude larger than wetlands constructed in residential or commercial developments. Mine reclamation projects involve large (80-200+ ha) tracts of lands that often include a diversity of reclaimed and preserved habitats connected to the constructed wetlands. More than half of the wetlands studied on unmined lands in Florida were located where surrounding existing or future land-uses may prevent the wetlands from providing the intended functions (Erwin 1991).

Wetland construction is a relatively new science and engineering practice, and constructed wetlands are generally developmentally young. Many wetlands constructed on phosphate mined lands are more than six years old, with a few exceeding 10 years. Average age of completed wetland construction projects, however, is less than three years.

Wetland Regulation

The Clean Water Act of 1972 is the primary federal legislation protecting and regulating wetlands with its objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Section 404 of the CWA authorized the Army Corps of Engineers, with oversight by the U.S. Environmental Protection Agency, to regulate the discharge of dredged or fill material into "waters of the United States", defined to include wetlands. The primary regulatory legislation in Florida is the Warren S. Henderson Wetlands Protection Act of 1984. This Act adopted a vegetative index that served to expand the Department of Environmental Protection's (DEP) jurisdiction over wetlands; expanded DEP's permit review to include consideration of fish and wildlife values and the public interest; recognized mitigation; and provided for consideration of cumulative impacts. The major State Water Management District program that affects wetlands is the Management and Storage of Surface Waters (MSSW).

Chapter 211 Florida Statutes, first passed in 1971, required severance taxes be paid on mined phosphate. The law was amended in 1975 to require the reclamation of all mined lands, including wetlands. Chapter 378 FS deals specifically with reclamation. The law required DNR to develop criteria and standards for mandatory reclamation. These criteria are included in 62 C-16, Florida Administrative Code (F.A.C.).

Wetland Classification

Several classification schemes have been developed to describe Florida's wetlands (Wharton et al. 1977, FDOT 1985, Myers and Ewel 1990, Kushlan 1990, FDNR 1990, and others). There are three major wetland types found in Florida: wetlands associated with flowing water (i.e., streams and rivers); wetlands adjacent to ponds and lakes; and depressional or stillwater wetlands. These major types can be subdivided into forested and herbaceous wetland categories. Controlling parameters such as source of water (surface or subsurface), hydroperiod (depth, duration and frequency of flooding), fire, and organic matter accumulation, along with placement in the landscape determine wetland type. Brief descriptions of common wetland types found in phosphate mining regions and selected classification schemes are given in Table 1-1.

Table 1. Common wetlands in phosphate mining regions of Florida with reference to various classification systems.

General Type	Abstracted from Ecosystems of Florida	FNAI / FDNR	FLUCFCS	Other Common Names	General Characteristics
Flowing water wetlands	River (stream) swamps; blackwater floodplain forest	Bottomland forest, floodplain forest, blackwater stream, seepage stream, strand, slough	615 stream and lake swamps; 616 inland ponds and sloughs; 617 mixed wetland hardwoods; 630 wetland forested mixed	Swamp forest, swamp hardwoods, bottomland hardwoods, backwater swamps	Forested wetlands within stream or river floodplains generally consist of a wide variety of tree species including cypress, blackgum, ash, elm, some oaks, sugar berry, maple, cabbage palm, sweet gum, hickories.
Lake fringe wetlands	Lake fringe swamps	River floodplain lake, swamp lake	615 stream and lake swamps	Lake fringe swamp, lake fringe forest	Forested wetlands on fringe of lakes can consist of a wide variety of species including cypress, blackgum, ash, elm, some oaks, sugar berry, maple, cabbage palm, sweet gum, hickories.; wet tolerant species such as cypress, blackgum and ash are found in deeper zone with transitional species commonly landward of the land/water interface.
	Lake fringe marshes	Flatwood/prairie marsh lake	any (marsh) 640-series freshwater wetlands, especially 641 freshwater marshes and 644 emergent aquatic vegetation	Lake marsh, lake fringe marsh, lake littoral zone	Herbaceous emergent vegetation within littoral zone of lake
Stillwater, basin or depressional wetlands	Cypress ponds/cypress strands, cypress/gum swamps	Cypress dome or basin swamp, gum swamp, cypress/gum slough, swale or strand	621 cypress; 613 gum swamps; 624 cypress-pine-cabbage palm	Cypress swamp, cypress gum swamp, cypress-gum-bay swamp	Cypress and gum swamps are very similar in characteristics and species composition with a shift in dominant species driven primarily by slight differences in fire frequency and hydropattern. Dominant species include cypress, blackgum, loblolly bay, dahoon holly, sweet magnolias and maple.
	Bay swamps	Baygall	611 bay swamps	Seepage swamps, bayheads, sandhill bog	Bay swamps are generally dominated by loblolly bay and sweet magnolia and maple with some red bay mixed with maple, with cypress and blackgum in deeper portions.
	Mixed hardwood swamps	Bottomland forest	617 mixed wetland hardwoods; 630 wetland forested mixed	Swamp forest, wetland hardwood hammocks, freshwater swamp forest	Forested wetlands composed of a large variety of hardwood species with varying degrees of tolerance to hydric conditions. Common species include red maple, oaks, bays, cypress, black gum, sweet gum, ash, hickory, pines and other hardwoods.
	Flatwoods/depressional marshes	Wet flatwoods, wet prairie, depression marsh	Any marsh 640 series freshwater wetlands, especially 641 freshwater marshes; 643 wet prairie; 644 emergent aquatic vegetation	Hydric flatwood marshes, pine savannahs, marshes, herbaceous wetlands, freshwater marshes	Several common types of depressional marshes exist. Although most have a mixture of herbs and grasses, a few species generally dominate. These marsh communities generally have one or more dominant species including maidencane, pickerel weed, arrowhead, arrowroot, needlerush, bullrush, sawgrass and cattail.

METHODS

RESEARCH TEAM

This research effort was a collaborative effort of scientists whose expertise encompassed the fill scope of the research project. The principal scientific investigative team included G. Ronnie Best, Mark Brown, Tom Crisman, Don Graetz, and Ramesh Reddy from the University of Florida (UF); Mike Duever from The Nature Conservancy (TNC); Herb Kale and Peter Pritchard from the Florida Audubon Society (FAS); Tom Missimer and Buzz Walker from Missimer International; and Kevin Erwin from Kevin L. Erwin Consulting Ecologist, Inc. (KLECE). G. Ronnie Best coordinated the activities of UF; Kevin Erwin coordinated the activities of KLECE, FAS, Missimer International, and TNC. Research team investigators served as principal investigators in their specific areas of expertise and as collaborating co-investigators in other areas. Project research tasks and principal investigator(s) are listed below:

- Constructed Wetlands Data Base - Erwin
- Hydrology - Missimer, Walker & Duever
- Soils - Reddy and Graetz
- Water Quality - Crisman
- Aquatic Fauna - Crisman
- Vegetation - Brown and Best
- Wildlife - Kale and Pritchard
- Ecosystem and Landscape Organization - Brown
- Literature Review - Erwin and Best
- Synthesis - Erwin, Doherty, Brown, Best

RESEARCH PROCEDURE

Data Collection

Upon commencement of the study, all participating phosphate companies were contacted for their inclusion in the research project. A preliminary interview and site inspection was arranged with each company to review the scope of their research and monitoring projects and the extent of reclaimed wetlands on company lands. At this time, arrangements were made with each company to: (1) coordinate transfer of available data to KLECE; and (2) arrange for a 2-3 day period to allow the research team to inspect all permitted and non-permitted constructed and reference wetlands on the property.

Phosphate companies that contributed to the research project were:

Agrico Chemical Company*
Occidental Chemical Company
Cargill Fertilizer, Incorporated
C.F. Industries
IMC Fertilizer, Incorporated*
Mobil Mining and Minerals Company
U.S. Agri-Chemicals, Incorporated

* Agrico Chemical Co. and IMC Fertilizer, Inc. have merged since the initiation of this research project into IMC-Agrico Company

From the beginning of the research project, data sheets were circulated to each participating industry representative(s) requesting information on their respective reclamation projects. Information requested on the project data sheets included agency permit numbers; total area of reclaimed herbaceous, forested, lake, or combination community; type of planting technique; substrate type; age; landscape position; and monitoring report dates. The companies were also asked to provide aerial photographs of the reclamation sites, copies of permits and programs with their associated drawings, mining plans, monitoring reports, and any data or studies on hydrology, soils, wildlife, water quality, and benthic macroinvertebrates of either reclaimed or unmined sites.

Other materials requested were overall plan view drawings containing areas of all parts of the constructed and preserved wetlands and upland habitats, locations of all water management structures, surveys of "as built" elevations (topography, structures, water levels, etc.), locations of all existing and future land-uses within the project watershed, hydrological features such as watershed boundaries and size, groundwater and surface water levels, construction methods and schedule. Lists of species and quantities planted (size and densities) including the source of plants and/or wetland topsoil (mulch) were also requested.

Vegetation and topographic site plans were requested from the companies for each of their reclamation sites. Fifty-five vegetation site plans and fifty-seven topographic site plans were received in CAD format. Where CAD files did not exist, or were not available from companies, maps included in the DEP/DNR permit packages were digitized. SWFWMD land use/land cover, augmented by USGS quadrangle maps, were used to develop a spatial data base of land uses surrounding each reclamation site. A topographic map, site land cover map, and site map with surrounding land cover was created for each site.

The DEP, SWFWMD, SRWMD, and COE provided lists of all issued permits for phosphate mining in wetlands. They were also asked to provide copies of any reports or research studies related to phosphate mining and any written policies or guidelines used in determining requirements for wetland reclamation on phosphate mined lands.

Pertinent literature was obtained at the FIPR library in Bartow and through a computer search. Copies of available publications were obtained, other materials from the library were borrowed for photocopying, and a list of all studies published by FIPR were made available to the investigators. Results of the computer search were distributed to all investigators.

All information collected, including literature, reports, permits and maps, was cataloged using Pro-Cite library software and stored in project libraries at KLECE and the University of Florida's Center for Wetlands. A quantitative data base containing data on age, vegetation characteristics, treatments, land forms, soils, and hydrology was compiled into an ARC/Info compatible format allowing information to be coupled with respective landscape maps. All ARC/Info files were stored at the University of Florida's Center for Wetlands,

Site Visits
In a series of two to three day meetings, the research team visually inspected and collected all available data on nearly all of the seven companies' constructed wetland sites. Follow-up inspections of reclamation sites and company data files were also arranged by individual investigators to gain additional information and to collect materials. Information on 174 sites was evaluated and more than 90 percent of the sites were visually inspected by the research team. The dates of site visits are given below;

Mining Company	Date(s) of Site Visit
Agrico Chemical Co.	June 29 - July 1, 1993
CF Industries	August 11-12, 1993
Occidental Chemical Co.	September 8-10, 1993
Mobil Mining and Minerals Co.	October 11-12, 1993
Cargill Fertilizer, Inc.	January 19-20, 1994
U.S. Agri-Chemicals, Inc.	January 21, 1994
IMC-Agrico Company	February 8-10, 1994

Photographs were taken to document the current conditions of the reclamation areas. Field notes collected by the research team during site inspections included information on vegetation and landscapes, wildlife, aquatic fauna, hydrology, water quality, soils, design, monitoring, permitting, success criteria, and wetland functions.

Data Analysis
Review and synthesis of existing information on status and trends of wetlands construction involved the entire team of research scientists. The entire landscape ecology data base was developed in an ARC/Info compatible format to permit spatial and landscape analyses. Data matrices were created as an organizational tool for evaluating the constructed wetlands included within the data base. Matrices were organized by wetland type, treatment type, landscape position, success criteria, substrate type, monitoring schedule, etc. Due to the large number of categories for which data existed, the matrix was broken down into several sections: wetland type, including size and age of each type; substrate type(s); substrate treatment(s); and monitoring data (requirements and availability by discipline).

Peer Review
A "Wetlands Research Advisory Committee" (WRAC) representing regional, state, and federal regulatory agencies, environmental organizations, and industry was appointed to assist in providing data, reviewing research questions, and assuring the usefulness of the results. Quarterly meetings of the WRAC with the team of research scientists were held to accomplish these tasks. The committee also provided peer review of written documents produced in this study.

Members of the Wetlands Research Advisory Committee (WRAC):

Jeremy Craft, Director, Division of Resource Management, Florida Department of Environmental Protection (FDEP)

Craig Diamond, Environmental Consultant, Resource Analysis and Management

Clark Hull, Chief Regulation Environmental Scientist, Southwest Florida Water Management District (SWFWMD)

Timothy King, Biological Scientist, Florida Game and Freshwater Fish Commission

Bill Kruczynski, U.S. Environmental Protection Agency (EPA)

Neal Parker, Mining Coordinator, Manatee County Planning, Permitting and Inspections Department

Selwyn Presnell, Manager of Reclamation, IMC-Agrico Company

Steven G. Richardson, Reclamation Research Director, Florida Institute of Phosphate Research (FIPR)

Jim Sampson, Technical Service Manager, CF. Industries, Inc.

Ron Silver, Chief, Central Permits Branch, U.S. Army Corps of Engineers (COE)

Robyn Trindell, Florida Department of Environmental Protection (FDEP)

Victoria Tschinkel, Landers and Parsons

External peer reviewers provided input on written reports:

Courtney Hackney, Dept. of Biological Sciences, Univ. of North Carolina at Wilmington

Dan Willard, Professor of Biology, School of Public and Environ. Affairs, Indiana University

RESULTS

INVENTORY OF SITES

Data on wetland type, size, age, substrate, planting treatment, monitoring requirements and success criteria are summarized and discussed below.

Number of Sites

A total of 156 phosphate mined wetland reclamation sites were inventoried by this project. Five “naturally” reclaimed (no input from man) mined sites were also reviewed. Nearly all of the existing wetland reclamation projects were reviewed, and more than 90 percent of these areas were visually inspected by the research team. In addition, six natural wetlands in the area, including three that are being used as reference wetlands were visited.

- wetlands constructed on mined lands	156
- mined, “naturally” reclaimed	5
- wetlands constructed on unmined lands (e.g., dragline crossings)	4
- unmined reference wetlands and other natural wetlands	6
- sand/clay disposal and settling areas	3
Total:	174

Habitat Types on Constructed Wetlands

Of the common wetland plant communities present in the phosphate mining districts, those created include: wet prairie, mixed hardwood swamps, cypress swamps, marshes, and seepage streams, For this study these wetland habitats were placed in two categories: forested (swamps) and herbaceous (marshes). The 156 constructed wetland sites included 10 entirely herbaceous wetland systems, 61 forested wetland systems, 77 wetland sites that include both herbaceous and forested systems, and eight sites for which information on habitat type was not provided (Figure 1-1). Eighteen sites are stream reclamation projects and eleven are on clay settling areas. Eight of the stream reclamation projects are constructed as forested wetland systems, while the remaining ten contain both herbaceous and forested wetland systems. Clay settling areas consist of seven forested wetland systems and four combination forested/herbaceous wetlands (Figure 1-1).

Substrates Used in Wetland Construction

Most of the wetlands (83 sites) were constructed on graded overburden. A combination of overburden and sand tailings was used on 38 sites. Sand tailings alone were used on eight sites. Four reclamation sites used sand/clay mix as substrate. Eleven were constructed on clay settling areas. We were unable to obtain substrate information on the remaining 12 created wetlands. The number of forested and herbaceous wetlands constructed on the various substrate types or combinations of substrates are shown in Figure 1-2. The numbers of wetlands that used mulching (application of organic wetland soil) are also portrayed in this graph. Mulch is also an organic or other type of surface layer used to control erosion or reduce soil moisture loss on uplands as a substrate treatment.

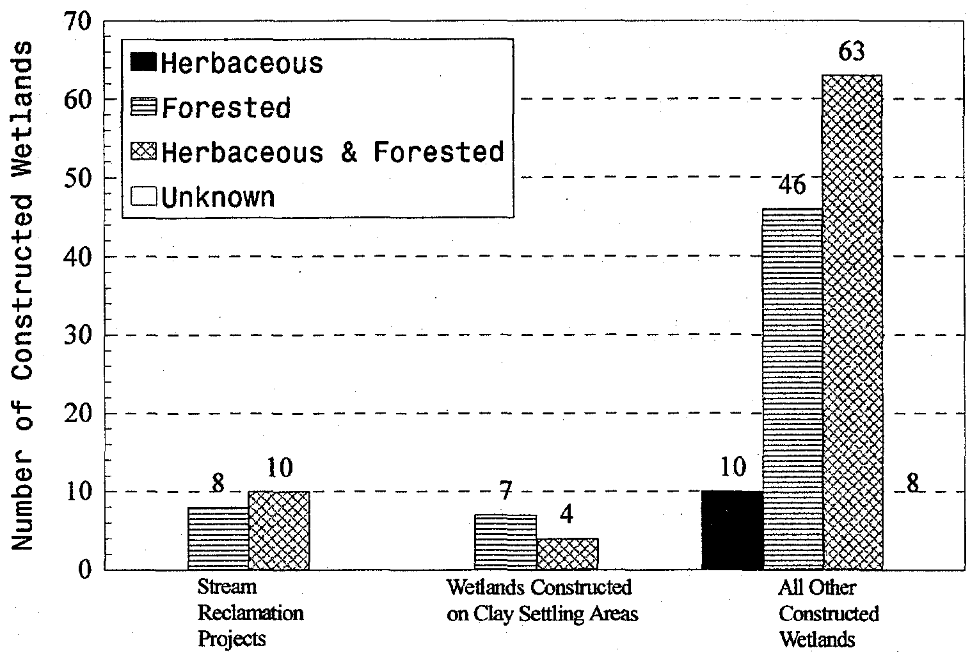

Figure 1. Habitat types represented in wetlands constructed on phosphate mined lands

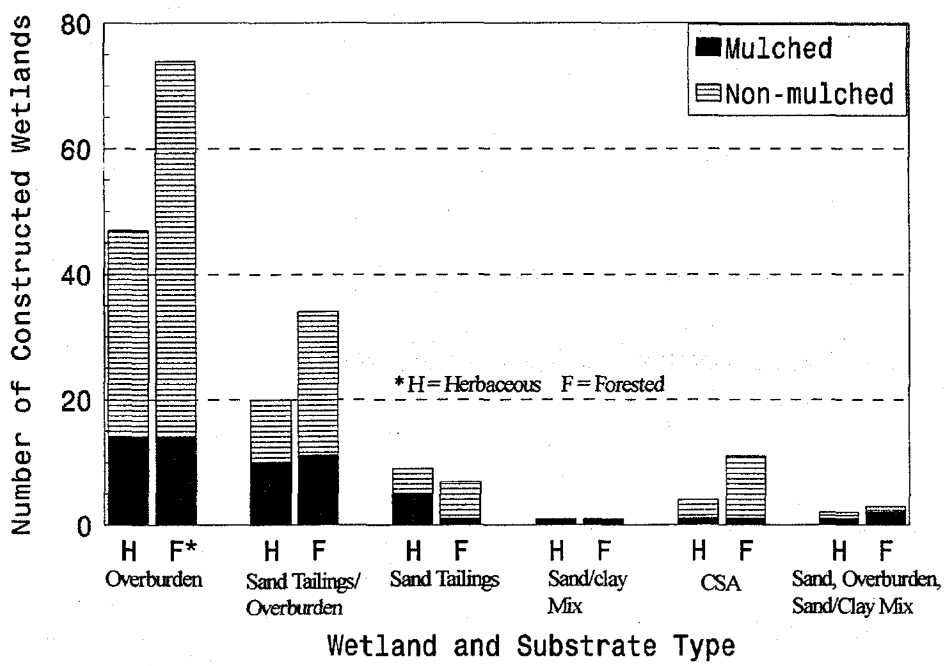

Figure 2. Substrate type and use of mulching in herbaceous and forested constructed wetlands

Most of the forested wetlands that have data on substrate type, were constructed on contoured overburden. The majority of herbaceous wetlands were also constructed on overburden. The second most frequently used substrate for forested and herbaceous wetlands was a sand tailings/overburden combination.

Mulching and Planting Treatments

Following grading and contouring of the reclamation foundation substrate, three substrate treatments were typically applied to hasten revegetation of the wetland area with desirable species. These treatments included applying wetland topsoil or a mulch (muck) layer obtained from a donor wetland, planting or sprigging, and/or direct seeding. Untreated reclamation areas were left to revegetate strictly from volunteer seed deposited by wind or animals from adjacent wetland areas.

Information on the type of substrate/planting treatment was available for 148 of the 156 inventoried wetland reclamation sites (94%). Fifty-four of the reclamation sites (36%) received mulching as their substrate treatment. Within these sites, herbaceous wetland areas were mulched more often than forested areas. With one exception, all mulched sites also were planted. Thirty-one (37%) of 83 herbaceous wetland areas were mulched, whereas only 28 (22%) of 128 forested wetland areas were mulched (Figure 1-2). Thirteen (19.6%) of the forested wetlands constructed on overburden used wetland mulch, whereas 12 (29%) of the herbaceous wetlands constructed on overburden used mulch.

At sites constructed on sand tailings and overburden, 10 (30%) of forested and 13 (56.5%) of herbaceous wetland areas were mulched. Eighty-six (55%) of the wetland reclamation areas received planting as their only type of substrate treatment, while 119 (80%) received planting in conjunction with one or both of the other treatments. Three (2%) of the reclamation areas received seeding as a substrate treatment and even then it was used only in conjunction with either planting or mulching. Five (3%) of the inventoried reclamation areas were left to revegetate strictly from volunteer seed deposited by wind or animal from adjacent wetland areas.

Size of Constructed Wetlands

The largest wetland reclamation area was a 280-acre wetland, which included 147 acres of herbaceous marsh and 133 acres of forested wetland. Reclamation areas constructed as a combination of both forested and nonforested wetlands were on average 66 acres in size. Forested wetland reclamation areas ranged from 0.6 to 248 acres in size and averaged 32 acres. This average does not include the five naturally reforested wetland reclamation areas that averaged 158 acres in size and ranged from 106 to 209 acres.

Nonforested herbaceous marsh reclamation areas ranged from one to 210 acres in size. The average size of nonforested reclamation areas was 38 acres.

Numbers of herbaceous and forested wetland area in various size ranges are shown in Figure 1-3. The 2-10 acre size wetland contained the greatest number of both herbaceous and forested wetlands than any of the other size classes examined. Stream reclamation projects ranged from 1,000 to 5,280 feet in length. The constructed widths of stream reclamation wetlands ranged from 200 to 350 feet. Open water areas ranged in size from one to 336 acres with an average of 42 acres.

Age of Constructed Wetlands

The five naturally reclaimed forested wetlands inventoried during this study represent some of the oldest known reclaimed phosphate mine sites with ages ranging from 30 to 80 years and averaging 48 years. The eleven constructed wetland areas on clay settling areas were of relatively moderate age, ranging from one to 54 years and averaging 17 years. The remaining 149 inventoried constructed wetland sites, approximately 88 percent of the total, were on average five years old. These relatively young sites consisted of nonforested herbaceous marsh systems (zero to 13 years), forested wetland systems (less than one year to 20 years), and stream reclamation projects (one to 13 years). To analyze the age distribution of the wetlands further, the constructed wetland sites were broken down into their herbaceous and forested components (Figure 1-4). Sixty-three percent of herbaceous wetlands (48 wetlands) and 63 percent of forested wetlands (72 wetlands) were less than five years old. The remaining 28 herbaceous and 43 forested wetlands were greater than five years old. Only one herbaceous wetland was greater than ten years old, while eleven forested wetlands were greater than ten years old at the time of the site inspections.

Monitoring Requirements and Success Criteria

For each wetland reclamation project, all applicable permits were reviewed and information on monitoring requirements and success criteria summarized (Table 1-2). Baseline and time zero monitoring were required and conducted for only three projects. Most post-reclamation monitoring required included vegetation data (70 projects) while the remaining parameters were required to be monitored far less often.

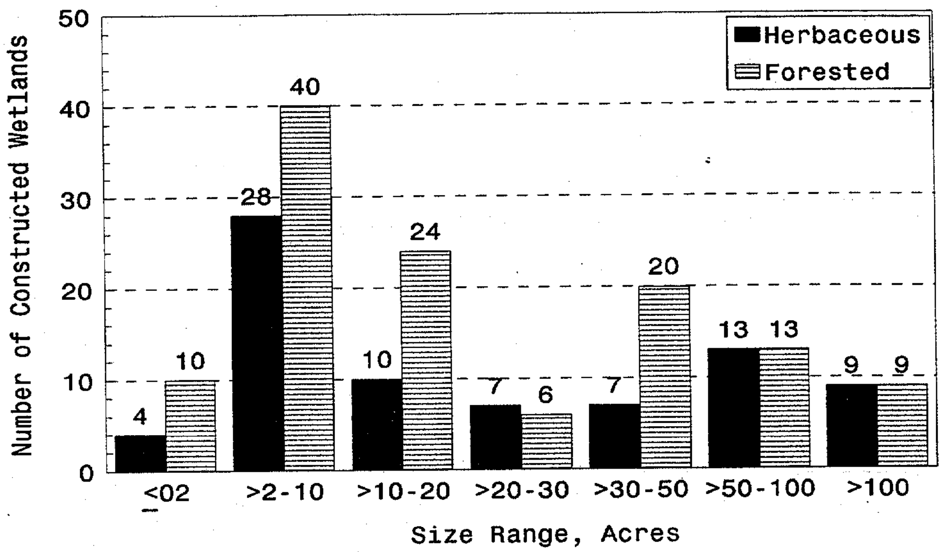

Figure 3. Size distribution of herbaceous and forested constructed wetlands

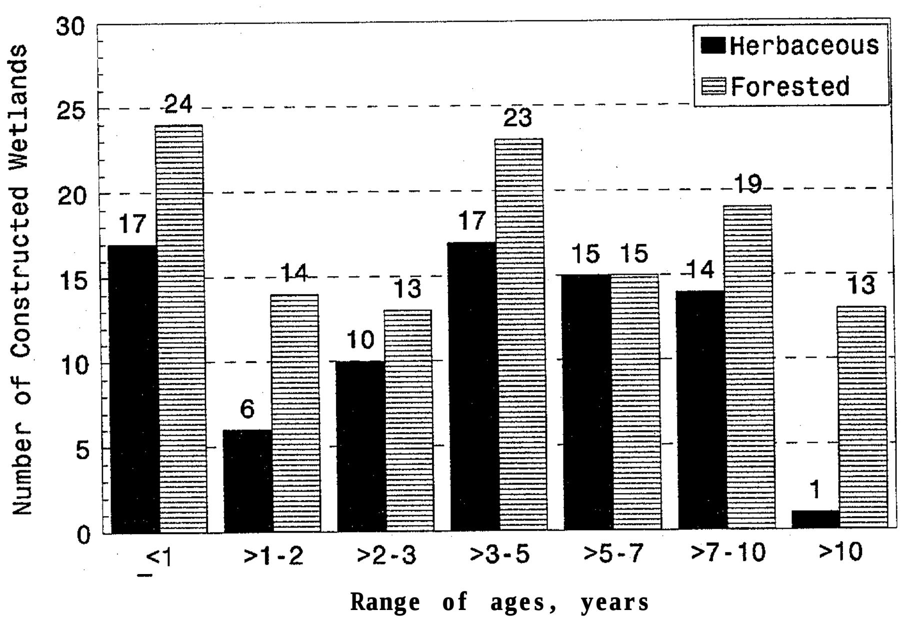

Figure 4. Age distribution of herbaceous and forested constructed wetlands

Table 1-2. Summary of monitoring requirements for wetlands constructed on phosphate mined lands.

Type of Monitoring	Constructed Wetlands			
	Permitted		Not Permitted	
	Monitoring Data Present	No Monitoring Data	Monitoring Data Present	No Monitoring Data
Pre-Rec. Baseline	3	67	0	81
Post Reclamation: Time Zero	2	68	0	81
Vegetation	45/8F	17	8	73
Water Quality	19/4F	47	1	80
Macroinvertebrates	14/2F	54	1	80
Wildlife	9	61	3	78
Hydrology	9/2F	59	1	80
Soils	4	66	0	81

Note: Permit status is unknown for five sites
F= Future monitoring is planned

Reference Wetlands

Twenty-five wetland construction sites have permit success criteria that required comparison of the constructed wetland community to a “control wetland,” “reference wetland,” or “similar undisturbed off-site communities.” A total of three reference wetlands were inspected by the research team during the site inspections. All three were forested systems. The Rocky Branch reference wetland is approximately 27 acres in size. At least six additional reference wetlands (herbaceous marshes) were identified in monitoring reports and have been regularly monitored in accordance with permit requirements. Parameters typically monitored include vegetation (tree growth and herbaceous species cover), aquatic macroinvertebrates, and water quality.

Several other natural wetlands near the constructed wetland sites were visited by the team of researchers to provide a basis for qualitative comparison of constructed vs. naturally occurring wetlands in the phosphate region.

RESEARCH COMPONENT RESULTS

HYDROLOGY

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. The following summarizes conclusions from our investigation of hydrology and hydraulic conditions of constructed wetlands. It is cautioned that some conclusions drawn here are based largely on a single study that was conducted during a time when annual rainfall in the region was below what is considered normal.

Alteration of Water-Table and Intermediate Aquifer Geology

Mining of phosphate involves the extraction of part of the sediments forming either the water-table aquifer or the confining beds between the water-table and intermediate aquifers. This removal of material and subsequent refilling of the mining trenches causes structural changes in the aquifer system that influence both the composition of the water-table aquifer and the rates and patterns of groundwater flow. Reclaimed lands tend to contain greater quantities of silt and clay-sized particles in near-surface soils. This composition change causes reclaimed basins to show a generally slower response to rainfall recharge. This different response is likely caused by the increase in bulk density and lowering of permeability of surface soils that in turn causes decreased rates of infiltration and percolation and increases storage capacity (Riekert et al 1991). The most extreme changes are observed in clay-settling areas, where rainfall recharge is substantially reduced (Lewelling and Wylie 1993).

With a limited data set, hydraulic conductivity of the newly created surficial aquifer were measured in five reclaimed basins by slug recovery testing (Lewelling and Wylie 1993). Two clay settling basins have calculated conductivities 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 is the relatively high hydraulic conductivity of the sand-clay settling basin which ranges from 1.2 to 11 ft/d and average 5.6 ft/d (possibly due to cracks or uneven sand distribution). Not surprising, the sand-tailings basin had the highest conductivity, averaging 33.1 R/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. These sand tailings commonly used for the 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. However, this is not a problem if the site remains saturated.

In three mined basins (sand-clay settling, sand tailings and contoured overburden) some of the wells tapping both the water table and intermediate aquifers had water levels generally within one foot of each other. This indicates the degree of confinement was reduced and both aquifers are functioning as one unconfined aquifer in these basins.

Groundwater level fluctuations in the overburden-capped sand-tailing basin most closely resembled those fluctuations in the surficial aquifer in unmined basins, but water level response to rainfall recharge was still slower than in the unmined basin. Water levels in the contoured-overburden basin fluctuated less in response to seasonal rainfall variations than did those levels in the overburden-capped sand-tailings basin.

A study of a clay settling area showed slow water level responses to rainfall recharge, but the authors related this response to the air content in the normally wet clays (Riekert et al 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 indicate that in these low permeability basins groundwater levels do not fluctuate in response to variations in stream flow which suggests to them that the surface water and groundwater systems have little hydraulic connections.

Alteration in Topography and Watershed Water Levels

As a generalization, clay and sand-clay settling basins are 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). On the other hand, contoured-overburden basins are usually at a lower elevation than they were before mining because no new material is brought in to replace the volume lost from removing the ore matrix. Overburden-capped sand-tailing basin types are normally close in land surface altitudes between the pre-mining and reclaimed areas. Land and lakes type reclaimed areas have the greatest differences in pre-mining and post-mining topography. However, differential settling of the land surface due to consolidation and dehydration over fairly long periods of time after final contouring can present problems, particularly in clay and sand-clay settling basins. Water levels, both groundwater and surface water, will reflect the new watershed water storage components as the local flow system develops a new dynamic equilibrium condition.

Changes in Water Balance in Aquifers

It appears that the clay and'sand-clay settling basin types have the greatest degree of aquifer inflow and outflow water balance differences when compared with unmined basins. Probably the most critical factor related to these types of basins is the fact they are constructed above the natural grade. However, due to 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 outflows in these elevated basins may occur as lateral seepage through dikes if they were built from the more permeable waste materials.

Groundwater outflow from the surficial aquifer system to the intermediate aquifer system is most likely 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 elevations 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 flows is a major water balance outflow factor.

Changes in Water Balance of Steams and Flowways

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 give 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). 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). This feature affects the basin water balance equation by storing more water during and after rainfall events when compared with unmined basins and the one clay-settling basin.

Establishment of Corridors of Enhanced Hydraulic Conductivity

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 reasonably predict the inflow, outflow, and storage components of any given area within the created watershed. 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.

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 original mine trenches may affect the direction of the flow system and rates of outflow and inflow of the system.

Hydrologic Viability of Constructed Wetlands

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 dependent on groundwater inflows, the floodplain forests and swale environments are most dependent on surface-water inflows, and the wet prairie is most dependent on precipitation. In terms of outflows, wet prairies, bay and hardwood swamps, and marshes, water is lost primarily to evapotranspiration, and in swale, floodplain forests and streams, primarily to surface flows.

Construction of Isolated Wetlands

Some isolated wetlands located atop the former clay settling areas can be successful, especially when they have a sufficient area of upland basin to supply them with groundwater and surface-water runoff. In creating an isolated wetland or pond, the primary design considerations should be the hydrogeology of the site and the geographic position in the watershed. Reconstructing the former features of any watershed in terms of the geographic positions of the upland and wetland environments is not possible, once the shallow aquifer system has been greatly altered. This means that the location of isolated wetland environments in created watersheds typically will not occur in the pre-existing pattern.

Construction of Floodplain Wetlands

The successful construction of any type of wetland environment associated with a stream or river channel is greatly dependent on the restoration of the stream watershed above the altitude of the wetland creation location.

Floodplain wetlands such as swale and floodplain forest have been created in the phosphate mining district. The occurrence and conditions of floodplain forests are 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.

Bottomland forest is perhaps more difficult to create successfully than the floodplain forest. There are two reasons that the bottomland forest are difficult to create. First, creating the natural hydrologic characteristics of a stream is necessary. If the created stream tends to flood more frequently then the bottomland forest may be 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 dependent to some degree on the inflow of groundwater from the adjacent uplands environments. The flow of groundwater must be sufficient to maintain the forest and this depends on the character of the adjacent soils and on the orientation of the mine cuts in relation to the stream. Bottomland forests observed to be in rather poor condition appeared in some cases to be starved for water and others to be stressed by too frequent flooding. In a few cases, poor performance of the bottomland forest may be related to a change in the geographic size of the upper watershed and therefore the amount of water reaching the wetland.

Construction of Flowway Wetlands

One of the types of flow-way wetlands created is the swale, which is a wide wetland belt that functions as a broad, shallow, low gradient stream. In some cases the channel is 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. 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 in a flat low gradient area. The most successful swale environments lie in broad "valleys" surrounded by uplands and in certain cases by large clay settling areas. The key factor affecting the hydrology is the size of the basin supplying water to the swale. Surface-water runoff, inter-flow and groundwater inflow provide the necessary water supply to the swale. In the cases of poor swale environments, the drainage basin feeding the swales was too small or water depth too deep. 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.

Construction of Lake Littoral Zone Wetlands

Lake littoral zone 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. However, the narrow width of this fringe often did not allow development of a wetland community. The hydrology of lake littoral 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 may be too large and the success of the littoral zone wetlands will be poor.

SOILS

The common soil parameter found in many reports is organic matter which is regarded as an important parameter in milestone reports, particularly in the Occidental Chemical Corporation monitoring reports (Environmental Services and Permitting). Soil and sediment data exist for other constructed wetlands: IMC's Parcel B, Agrico's Morrow Swamp, CF Industries, and Mobil Pasture Pond (Brown and Tighe, eds. 1991). Existing reports, however, contained 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). An effort was made to carefully observe soil profile development at the created wetlands examined on this project.

In addition to the above analyses, soil samples (184 total) were taken along transects at selected sites to determine criteria that may be used to better determine successful wetland progression.

Wetland Soil Criteria and Data Interpretation

Criteria selected for evaluation included compaction, bulk density, organic matter (carbon) and nitrogen content, C/N ratio, available and total nutrient content, and cation-exchange capacity. Bulk densities of soils in central Florida reclamation sites varied widely, ranging from 0.2 to 2.7 g cm^{-3} (Appendix Table A3-2.1). Subsurface soils in north Florida had bulk densities of 0.8 to 2.3 g cm^{-3} (Appendix Table A3-2.2).

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, Haynesworth, K6, and in some sites of Four Comers and Noralyn/Phosphoria mines, however, were moderately acidic (pH 5.0-5.9). 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 $\lesssim$ 7.0) than those in central Florida. Highly acidic soils were found in McCallum Bay area (native soils) where pH values ranged from 3.79 to 4.49.

Accumulation of organic matter is an indication of a productive wetland. 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 organic matter content. Organic matter accumulation was measured across a transect from an upland to a wetland area of Morrow Swamp. Assuming that no significant organic matter accumulation occurred in the upland area during the past thirteen years the wetland has been in existence, an accumulation rate of organic C (A0 and A1 layers) was 320 g-C/m^2/yr. This rate is comparable to that of the marshes in Louisiana (200-300 g-C/m^2/yr) (Hatton et al 1982) and the Water Conservation Area of the Everglades (86-387 g-C/m^2/yr).

Results suggest that increases in total C (which was >95% organic C for most of the wetland soils visited) can potentially increase N availability to plants (refer to Figure 3-5 in Chapter 3). This observation is of particular importance in productive wetlands. Both C and N progressively increased along an upland-wetland transect in Morrow Swamp. Available nutrients such as Fe, Cu, Zn, K, Ca, and Mg 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. Available P in surface soils, which ranged from about 350 to 450 mg P kg^{-1}, showed considerable variation along the transect. 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 the good and poor growth areas of each site showed no differences in compaction (or 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 soil supporting good plant growth from soil supporting poor plant growth in each wetland were total C and N contents and the depth of the well-developed surface soil.

Chemical soil characteristics were evaluated for a 15 year old reconstructed wetland (Parcel B site) and a natural wetland (Peace River floodplain site). Total C content in the undisturbed. wetland measured about four times higher than in the reconstructed wetland. The undisturbed wetland had two times more N than the reconstructed wetland. 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 undisturbed floodplain.

Effect of Age on Wetland Soil Characteristics

Five wetlands of different ages (East Old Fort Green Road - one yr, Miles Grove - two yr, Section 12 - four 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. 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 - 1.0 g cm^{-3} after about four years. This decreasing bulk density reflects the increasing amount of organic C accumulating in the soil. Organic C, which is a measure of organic matter, increased from < 0.5% in a new wetland to nearly 6% in a 16-year-old wetland. Most of the accumulation was in the surface layer. Nitrogen concentration also increased with time but at a faster rate than carbon. A progressive decrease in the C/N ratio of soil organic matter with increasing age was observed. Sampling at a 2 year old constructed wetland on overburden without mucking (East Old Fort Green Road wetland at the Haynesworth mine) confirmed this trend.

Effect of Mucking on Wetland Soil Characteristics
In the wetland creation 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 its nutrient content and effect on water-holding capacity. Bulk density, carbon and nitrogen concentrations, and C/N ratios were measured for 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, two (Tadpole) and four (Section 12) years of age. As shown previously, C and N concentrations generally increase with age, and C/N ratio decreases. Although making a rigorous comparison of mucking effects with these small sample numbers is difficult, it appears that mucking increases the rate of wetland establishment as measured by soil properties. However, separating the effects of added muck from the potential of enhancing productivity due to mucking is difficult.

WATER QUALITY

Water quality parameters displayed pronounced variability immediately following construction and gradually approached increased stability (in other words a reduction in “extremes” in variability) within 1-2 years post construction. Within a few years (3-5 years) post construction, most water quality parameters showed trends approximating conditions of natural wetlands and streams. The trend for most water quality parameters for both constructed wetlands and streams are briefly discussed for each parameter below.

pH -- The pH of constructed wetlands regardless of age measured consistently above six. Although maximum pH for newly constructed wetlands ranged from 9-10, the range declined to 8-9 within three years. Within a couple of years post construction, mean pH values show a trend of declining toward the pH range typifying natural systems (4.5-6.5 pH). The pH of constructed streams is higher than for natural streams (mean pH of 6.5). Since most created streams occur in areas that are under current or recent mining activities, there is insufficient data to extrapolate on long term trends regarding pH of constructed streams. Because pH data are strongly influenced by photosynthetic activity, in addition to local geology, and therefore can display both pronounced within day and seasonal variability, it is impossible to determine if observed trends in this parameter are significant for either wetlands or streams in the current database.

Specific Conductance -- Conductivity of most constructed wetlands and streams, regardless of age, range between 150-300 umhos, as compared to 50-150 umhos for natural wetlands. A trend of declining conductivity with increasing age was, however, observed for constructed wetlands. Since specific conductance is a reflection of the geologic matrix and leaching rates of cations and anions from the surrounding watershed, given the overall disturbance of a phosphate mined landscape and the temporal instability of the weathering process, it is not surprising to find that conductivity of surface water in constructed wetlands is higher than for natural wetlands. One would also, however, expect that as constructed wetlands mature, cations and anions stored and released through plant uptake, growth and decomposition would cause specific conductance to approach steady state.

Total Phosphorus -- Phosphorus concentrations display a great deal of inter-wetland variability during the first four years post construction. However, by year six, variability in phosphorus decreases to concentrations within the range typical of natural systems (<l mg/L).

Total Nitrogen -- Nitrogen data are relatively sparse making it difficult to do much more than speculate on general trends. However, based on the limited data base, total nitrogen concentrations (range between 1-2 mg/L) appear to change little with age of constructed wetlands and, generally, are similar or slightly lower than for natural wetlands in the area.

Dissolved Oxygen -- Dissolved oxygen values approach or exceed 10mg/L in wetlands less than two years of age, with older systems showing both greater inter-wetland variability and usually lower maximum values. Generally, oxygen concentrations of constructed wetlands are similar or slightly higher than for natural wetlands (about 4 mg/L). Relocated and natural streams show similar dissolved oxygen trends. Since dissolved oxygen values in constructed wetlands approximate or exceed those of natural wetlands in the phosphate mining regions, it appears that oxygen conditions in constructed wetlands should not be any more stressful to biota than those of natural systems.

Biological Oxygen Demand -- Although data on biological oxygen demand on constructed wetlands are very limited, newly constructed wetlands display a great deal of inter-wetland variability with BOD values generally greater than 6 mg/L. Older constructed wetlands, on the other hand, tend to have BOD values approximating those of natural wetlands (4 mg/L).

In general, most chemical parameters display a great deal of inter-wetland variability during the first two years post construction. However, as the wetlands mature, both inter-wetland variability and extremes in variability begin to stabilize and approximate ranges typical of natural wetlands. It appears that development of wetland vegetation concomitant with the gradual development of wetland soils begin to formulate a "memory" for the system helping to stabilize chemical parameters and ultimately lead to conditions approximating those of natural wetlands.

AQUATIC FAUNA

Variations in sampling techniques and a low number of sampled sites impeded the analysis of data collected for aquatic fauna, However, trends were evident for nearly every taxonomic level examined. Specifically, there is an increase in macroinvertebrates during the first two to three years after wetland construction, followed by a gradual decrease in density and abundance after year three that approaches conditions typifying natural wetlands in the phosphate regions. Trends for specific taxonomic groups are briefly discussed below.

Annelids -- Density of benthic annelids (collected in sediment cores) in constructed wetlands was highly variable, ranging from as few as 2,500 to more than 30,000 individuals/m^2, values well above densities found in natural wetlands (about 2,500 individuals/m^2). There were no evident trends relevant to age post construction for this order. Annelid abundance on Hester-Dendy samplers placed in the water column ranges from <10 to >40 individuals/m^2 in constructed wetlands. Comparable annelid densities in natural wetlands were slightly less than 10 (SD = 7) individuals/m^2. Differences noted between these two sampling techniques clearly illustrate the bias that is often apparent from artificial sampling techniques such as Hester-Dendy.

Odonates -- Although trends for benthic odonates are similar to those for annelids, densities of odonates are lower (ranging between 1,000 to 3,000 individuals/m^2), with numbers approaching those of natural wetlands (about 2,500 individuals/m^2) with increasing system age. By contrast, Odonata abundance collected by Hester-Dendy samplers is highest in newly constructed wetlands (>5 individuals/m^2), declining with age to numbers approximating natural wetlands (about 2 individuals/m^2).

Coleopterans -- Density of benthic coleopterans is highly variable both between and within constructed wetlands with no clearly discernible trend with wetland age. Numbers ranged from fewer than 500 to 9,000 individuals/m^2 in constructed wetlands. However, sampling methods varied greatly both within (years) and between sites and, as discussed for both annelids and odonates, likely contributed to observed differences within the database. In one of the older more carefully and thoroughly monitored constructed wetland, Agrico's Morrow Swamp (or Agrico West), coleopteran densities of the constructed wetland ranged from about 100-300 coleoptera/m^2 to approximately 100 coleoptera/m^2 for a reference wetland. Coleopterans collected by Hester-Dendy samplers, on the other hand, are comparatively low ranging from as few as two to more than twenty individuals/m^2 in constructed wetlands compared to 1-2 for a reference wetland.

Dipterans -- Since chironomids dominate dipteran populations, trends for dipterans essentially parallel the trends for chironomids (see discussion for chironomids below).

Chironomids -- In natural wetlands, populations of chironomids are highly variable and can range from as few as 1,000 to over 3,000-4,000 individuals/m^2. Comparable ranges for constructed wetlands range from 5,000 to 50,000 individuals/m^2. Trends relevant to age since construction for chironomid abundance of constructed wetlands are variable. For some constructed wetlands, there is no age-related trend. However, for Agrico's Morrow Swamp, there is an initial increase in density, with abundances after year five approximating those found in a reference wetland. Chironomids collected with Hester-Dendy samplers show a definite decrease in abundance with increasing age of constructed wetlands with densities approximating those of natural wetlands in older systems, Chironomid Feeding Guilds -- In most constructed Wetlands, there seems to be a sharp increase in benthic collector/gathers in year four followed by a decrease to equilibrium in year five. Shredders display a similar trend toward equilibrium, while predators remain stable regardless of wetland age. As one would expect, collector/gatherers are the most abundant, followed by shredders then predators. The abundance of collector/gatherers, however, is not only more stable, but it is much higher than similar feeding guilds in natural wetlands. It is apparent from data for all four guilds that macroinvertebrate communities display high abundance in the early years post construction, followed by, gradual in some cases, or sharp in other cases, reductions in abundance beginning between years three and five. In summary, chironomid taxa and feeding guilds show some variability, but they seem to reach an equilibrium between 3-5 years post construction.

VEGETATION

A total of 55 wetland sites had some vegetation data that might be evaluated. Of the 178 sites evaluated, 162 are constructed wetlands. Of this total, 67 have no vegetation monitoring requirements according to permits or programs, seven are scheduled for future monitoring. Leaving 82 sites, for which some data would be expected. The data from the 56 sites were organized into a data base according to the variables of interest. The data base was designed to evaluate the structure of plant communities within created wetlands, evaluate trends in community development, and evaluate effects of various treatments on wetland establishment and growth. There were 40 variables for which descriptive and plant community data were sought for each site. The descriptive section of the data base consisted of 15 data categories used to record the company, permit number, and project name, etc. In addition, this section was used to categorize the wetland by type (forested, marsh, isolated, lake border, etc.), the major soil components (overburden, sand tailings, or clay), the total area of the site, and the date monitoring began. Finally, construction and monitoring costs were included if available.

Plant community categories of the data base were designed to characterize community structure and evaluate trends in community development. The data were also evaluated to assess the likelihood of plant community persistence or future changes. The question of persistence was evaluated in this study by looking for trends in the growth and survival of plant species, and where sufficient data existed, we searched for evidence that shifts in species composition away from wetland species were not occurring. To evaluate trends of vegetation development, growth and persistence in relation to site design criteria and post-mining treatments, several categories related to soil type (“overburden,” “sand tailings,” and “clay settling area”) were used. The category “mulch added” was used to evaluate the effect of adding wetland topsoil (muck) to created systems.

Herbaceous Community Development

Species Used in Marsh Plantings. The relative importance of shrub species planted in marsh wetlands was minor; 10% of the marsh sites were planted in shrub species. The most frequently used herbaceous species used in marsh plantings was *Pontedaria cordata, Sagittaria lancifolia* and the next most frequently used species was *Juncus effusus.* The most common naturally occurring species were *Spartina bakeri, Panicum hemitomon, Pontederia cordata.,* and *Juncus effusus*

Percent Cover With Time. Forty-one sites were used for evaluating percent cover in herbaceous wetlands. Methods of field data collection for this parameter can be grouped into two distinct methodologies. On some of the sites, percent cover was evaluated using more than one stratum, and in the other, only the ground stratum was used. In the first case, percent cover can be greater than 100%, while in the second it can never be greater than 100%. Sites using only the ground cover stratum (percent cover = 100%) exhibited relatively constant percent cover from an overall mean of about 71% in the first year to about 74% in the fifth year. There were several sites that had marked reductions in cover. Sites using two strata exhibited relatively constant percent cover. There is a minor trend in the data that shows a decrease in cover after the 6th year.

Species Richness. Overall species richness (including wetland, upland, and nonnative species) was evaluated on 34 sites. Mean species richness for all sites over all years appears to be about 50 species.

Species Richness of Obligate Wetland Species. Overall, mean obligate wetland species richness was about 25 species, or about half of total richness. While there is no strong pattern to the data, there is a trend for obligate wetland species to decline over time. A majority of sites evaluated had 3 years of data and over half of these sites exhibited declines in obligate species in the first three years. For those sites with over 4 years, three increased by about 20%, while 2 declined by about 45%. The general trend after the fourth year is for obligate species richness to decline. It is possible that this decline represents a loss of floating aquatic species in favor of rooted species as marsh communities shift to less open water systems

Development of Herbaceous Vegetation Within Forested Wetlands. Interaction of planted trees and community development in the herbaceous stratum was evaluated by studying trends in percent cover and species richness in the herbaceous cover within forested wetlands. Twenty-two sites had combined herbaceous and tree data that was complete enough to evaluate the interaction of forest canopy on herbaceous community structure. There appears to be a very slight decline in herbaceous cover as the forest canopy developed. Whether this is due to different species, lower overall richness, or space and nutrient limitation is unclear. It is doubtful that the difference is related to shading by the tree canopy. The data indicate no marked difference in species richness over time.

<u>Forested Wetland Development</u>

Tree Survival and Growth. Fifty sites had sufficient date to evaluate survival and growth. Number of trees planted per acre varied between 1500 and 300 trees per acre (mean = 556 trees/acre). Average survival for all trees and all sites in the first year was 72%, in the second year about 62%, continuing to decline to about 43% in the eighth year. The largest declines are in the first three years.

Species Survival, Species specific survival rates were analyzed in this study for 6 sites and by Davis et al. (1991) in an earlier study. In this data set, *Taxodium distichum, T ascendens, Magnolia virginiana, Quercus virginiana, Ulmas americanas,* and *U. floridanus* had highest survival (100% to 85%). Davis et al (1991) found that *Taxodium distichum,* and *T. Ascendens* had highest survival (greater than 80%) while *Acer rubrum, Fraxinus caroliniana, Liguidamber styraciflua,* and *Gordonia lasianthus* had among the lowest survival rates (as low as 5%). The data are hard to interpret as long term data sets are few and species specific rates reflect only survival on a small number of sites rather than an industry average.

Tree Canopy Cover. Tree crown width increased in all surviving trees by about 150% in five years as an industry average on 15 sites with 5 years of data and by 210% on a single site with 7 years of data. Canopy width averaged about 20 cm in the first year and was about 50 cm at the end of 5, years.

Tree Height. Tree height exhibited increases of about 172% (from mean height of 87 cm to 189 cm) in 4 years and nearly 210% (to 269 cm) in 6 years of data. Data suggest a slowing of growth rate after 7 years. Site average growth rates were variable and when compared with survival rates for individual sites showed survival and growth were not strongly correlated. Some sites had high survival, but low growth, suggesting hydrologic factors, but lack of data made analysis of hydroperiod affects impossible.

Tree Densities. Initial planting densities for tree seedlings on constructed wetland sites averaged 566 stems/acre, with survival falling from an average of 72% after one year to about 50% after 6 years. Continued mortality of about 2-3% per year will result in tree densities of 300-350 trees/acre in mature constructed wetlands. These density estimates agree with tree densities in natural forested wetlands.

Tree Species Richness. Fifty sites had data to analyze species richness, although the number decreases rapidly with age of site. In general, there was no apparent change in species richness over time. The largest number of sites have tree species richness of between 8 and 11 species (17 sites) and 4-7 species (15 sites). Four sites had richness of between 20-24 species.

Tree Species and Planting Mixtures. Tree species most frequently planted on sites were (in order of frequency); *Acer rubrum, Liquidamber styraciflua, taxodium distichum, Fraxinus caroliniana, Illex casine, Nyssa sylvatica* var. *biflora,* and *Quercus laurifolia.* When percent of total mixture was taken into account *Taxodium disticum* had highest percent of mixture (28%), while *Nyssa sylvatica* var. *biflora* was next highest (20%).

Evaluation of Site Treatments

Tree Survival and Herbaceous Cover vs. *Soil Types.* Survival data on soil types were analyzed for overburden and sand/overburden mix sites. First year survival appears to be greater on overburden sites, and sand/overburden sites appear to continue to have lower survival per year based on slope of curves, although after 6 years, survival on both soil. types is relatively similar (43% sand/overburden sites and 47.5% overburden sites)

Herbaceous Community Development on Mulched and Non-Mulched Sites. Variation in percent cover in the first year is greater and total percent cover at the end of one year is lower on non-mulched sites when compared to mulched sites. The trends continue but are primarily driven by the first year. In all, the trends in percent cover in herbaceous wetlands suggest that mulching has a positive effect (albeit difficult to discern due to the paucity of data). Species richness data indicate that there were no discernible differences between mulched and non-mulched sites.

Nuisance Species, Herbicide, and Community Development. “Nuisance species control” and “method of control” were included to evaluate the effectiveness of control and possible impacts on other herbaceous and woody vegetation when combined with percent cover of herbaceous species and tree survival and growth. Thirty-eight sites had data related to percent cover of nuisance species. There is no doubt that control of nuisance species is effective. Percent cover of nuisance species averaged about 27% in year five on uncontrolled sites, and only about 4% in year five on sites where there was herbicide treatment. Species richness of the herbaceous community on herbicided and non-herbicided sites was also evaluated. Overall, mean species richness from year to year is higher on sites without herbicide treatment. Data on tree survival on herbicided and non-herbicided sites is very limited. However, there appears to be a trend of increased survival of tree species on treated sites compared to untreated sites.

Comparisons with Undisturbed Wetlands

Literature derived values for species richness and density in relatively undisturbed native Florida forested wetlands and richness and percent open water in marsh wetlands was summarized to provide a basis for comparison with the created systems. Forested wetland richness varied from 6.8 to 13.5 species/hectare. Density varied from a high of 2,336 stems/hectare to a low of 1,183 stems/hectare. When compared with native sites, constructed forested wetlands were planted with greater species richness (mean of 10, varying from 24 to a low of 3). Densities of planted trees on created wetlands were roughly the same as in native Florida wetlands (about 2000/ha), however because of mortality, densities fall to about 900/ha.

Species richness in native Florida marshes varied considerably for Juncus/Pontederia marshes, ranging from only four species to more than 85 species. The mean species richness is about 28 species, Richness in constructed marsh wetlands is considerably higher than that found in native systems. Several sites had over 175 species and mean richness for all sites was about **50** species.

WILDLIFE

No wildlife standards dealing with wildlife species, numbers, or biomass have been established and required for wetland construction/reclamation by regulatory agencies. As a result, few quantitative studies of wildlife utilization of constructed wetlands on phosphate mined lands have been conducted and practically no data are available for review or evaluation. However, several studies have been conducted and some industry monitoring reports have included incidental wildlife observations that have lead to relatively complete lists of species known to occur on phosphate mined lands. These sitings and studies report that 24 species of mammals, excluding bats, 200 species of birds, and 72 species of herpetofauna (reptiles and amphibians) frequent phosphate mined lands, primarily wetlands.

Mammals and herpetofauna are present year-round in or near wetlands and are considered to be permanent. Some wider ranging mammals may occur only sporadically as they move from site to site. Avian species occur as: permanent residents, winter residents, summer residents, and spring and fall transients (migrants that pass through the state to and from their breeding grounds farther north and wintering areas to the south). Florida serves as the wintering grounds for many northern species of birds, hence more species and numbers of individuals are present in wetlands in the winter than in the summer.

Fall shorebird (plovers and sandpipers) migration begins earlier (July/August) than that of most other birds (September/October), and during this time many migrants appear in clay settling ponds of phosphate mines and on constructed wetland sites during their initial stages of construction. Although most of these shorebirds migrate into Central and South America, many of them also winter in Florida.

Chapter 7 presents a list (Table 7-5) of those species or groups of species that are wetland-dependent, i.e., species that occur only in wetland habitats and nowhere else. Many of these species require open bodies of water-a lake or pond, or a stream-associated with the wetland for feeding, resting, and breeding. Without this feature they will be absent, or, if present, will be so in greatly reduced numbers and frequency. Most waterfowl-pelicans, ducks, etc., require open water.

Table l-3 is a list of wildlife species that serve as indicators of a suitable habitat on constructed wetlands. Many require open bodies of water to be associated with the wetland. Some of the species listed, for example, the common yellowthroat, red-winged blackbird and boat-tailed grackle are not wetland-dependent in that they occur in a variety of terrestrial habitats also, although they are present in most Florida wetlands. Therefore, such species, alone, should not be used as “indicators” of successful wetland creation. On the other hand, their absence from a wetland habitat would be cause to raise questions.

Vertebrate Survey and Census Methods

To ascertain whether or not a site provides suitable or adequate habitat for wildlife. one-needs to observe and list the wildlife present on the site over a period of time (ideally monthly, but at least seasonally). There are numerous techniques for sampling wildlife populations including which can be grouped into: (1) visual and aural observations, (2) trapping arrays. In all cases it is suggested that quantitative techniques be used so that data are comparable between sites and within sites over time.

Because a goal of wetland construction is to provide habitat for wildlife, and it may take considerable time before some species become established, trapping methods that are lethal (snap-traps, or flooded pitfalls, for example) are not recommended.

It is important to demonstrate whether a constructed wetland attracts or supports a significant fauna. Techniques are available for the quantitative sampling of small fauna, especially mammals and amphibians, by means of trapping or intensive collecting along limited transects

Table 1-3. Wildlife species found on constructed wetlands that serve as indicators of suitable habitat (compiled from Table 7-6, Chapter 7).

Herbaceous Marshes (including early stages of forested wetlands):

Mammals

Raccoon	*Procyon lotor*	Rice Rat	*Oryzomys palustris*
River Otter*	*Lutra canadensis*	Florida Water Rat	*Neofiber alleni*
Bobcat	*Felis rufus*	Marsh Rabbit	*Sylvilagus palustris*

Birds

Pied-billed Grebe*	Osprey*	Belted Kingfisher*
American White Pelican*	Rails	Sedge Wren
Brown Pelican*	Purple Gallinule	Marsh Wren
Double-crested Cormorant*	Common Moorhen*	Common Yellowthroat
Anhinga*	American Coot*	Swamp Sparrow
bitterns, herons, egrets, ibises	Limpkin*	Red-winged Blackbird
Wood Stork*	Shorebirds*, gulls*, terns*	Boat-tailed Grackle
ducks*, geese*		

Reptiles

American Alligator*	Florida Green Watersnake
Snapping Turtle*	Brown Water Snake
Common Musk Turtle*	Florida Water Snake
Florida Mud Turtle*	Striped Crayfish Snake
Striped Mud Turtle*	South Florida Swamp Snake
Peninsular Cooter*	Eastern Mud Snake
Florida Softshell*	Florida Cottonmouth

Amphibians: Amphiumas, sirens, newts, salamanders, toads, frogs

Forested Wetlands (shrub through mature stages)

Mammals

Raccoon	*Procyon lotor*	Bobcat	*Felis rufus*
River Otter*	*Lutra canadensis*	Eastern Gray Squirrel	*Sciurus carolinensis*
Cotton Mouse	*Peromyscus gossypinus*	Rice Rat	*Oryzomys palustris*
Marsh Rabbit	*Sylvilagus palustris*		

Birds

Red-shouldered Hawk	Acadian Flycatcher	Northern Parula
American Woodcock	Eastern Phoebe	Yellow-rumped Warbler
Yellow-billed Cuckoo	Great Crested Flycatcher	Palm Warbler
Eastern Screech-Owl	Blue Jay	American Redstart
Barred Owl	Tufted Titmouse	Prothonotary Warbler
Chuck-will's-widow	Carolina Wren	Ovenbird
Whip-poor-will	Blue-gray Gnatcatcher	Northern Waterthrush
All woodpeckers	White-eyed Vireo	Common Yellowthroat
Eastern Wood-Pewee	Red-eyed Vireo	Red-winged Blackbird

- Species requiring open bodies of water (lake, pond, or stream) associated with wetlands.

or in very small areas. Birds and larger mammals will come and go, and their numbers will fluctuate. But for avifauna, as well as for amphibians, species diversity is as valid a criterion of success as is sheer numbers of individuals or absolute biomass. It is recommended that a biodiversity index for fauna, couched essentially in terms of number of species, either consistently present or occasionally encountered, may be the best to use.

Vertebrate Indicators

Based on review of the literature several species of wildlife have lifestyles that are closely associated with wetland habitats and could be used as indicator species of healthy wetland systems. Table 1-4 lists wildlife species found in emergent wetlands associated with patches of open in central Florida.

While mature forested wetlands host a suite of birds not found in herbaceous wetlands, of the same species found are also present in upland forests, thus indicator species for forested wetlands are more difficult to list. In central Florida several species of woodpeckers, the tufted titmouse, Carolina wren, red-eyed vireo, and northern parula breed in forest habitats, including forested wetlands. These species may also be present in developing forested wetlands when trees reach heights approaching canopy state. During early "shrub" stages of development, species found in both herbaceous and forested wetlands may occur.

Table 1-4. Potential indicator wildlife species for herbaceous wetlands in Central Florida (including early stages of forested wetlands).

Mammals	
river otter	raccoon
rice rat	Florida water rat
Birds	
Pied-billed grebe	double-crested cormorant
anhinga, least bittern	American bittern
great blue heron	great egret
snowy egret	little blue heron
tricolored heron	green heron
white ibis	wood stork
blue-winged teal	American wigeon
ring-necked duck	common moorhen
American coot	king rail
sora	osprey
belted kingfisher	marsh wren
swamp sparrow	
Herpetofauna	
American alligator	
frogs (including the southern leopard frog, cricket frog, and chorus frog)	
various species of turtles (Florida soft-shelled turtle, peninsular cooter, and yellow-bellied turtle)	

Because forested wetlands are more productive of invertebrate fauna than are upland forests (primarily pine forests in central Florida), they provide important habitats for migratory birds, especially neotropical migrants.

So long as an adequate supply of water is able to maintain wetland plant species and associated invertebrate fauna, a wildlife community will be present. Wildlife use of an area is greatly influenced by the productivity of the food base - the greater the diversity and quantity of food, the greater the diversity and numbers of wildlife that will frequent the site. Vegetation structure (density, height, cover and nest/perch sites) and the variety of micro-habitat also plays a role in determining the variety and numbers of wildlife species on a site. Marsh systems that do not include patches of open water contain fewer species than do wetlands associated with water bodies.

Fauna1 diversity, may be maximized by promotion of wetland aggregates that incorporate a mosaic of marshes and seasonal wetlands, open permanent water, and islands elevated above inundation during times of high water. Islands, although they may be very small, will generally be free of direct disturbance by both humans and predatory mammals. Islands may support crucial nesting and roosting habitats for wading and other colonial birds, as well as basking and nesting sites for alligators and turtles.

ECOSYSTEM AND LANDSCAPE ORGANIZATION

Spatial analyses and model simulations of ecosystem and landscape-scale interactions indicate the influence of scale, connectedness and development time on the successional trajectories and fitness of constructed wetlands within the mined landscape. Results in this section are presented for 2 research components: Landscape Ecology Analysis and Computer Modeling of Constructed Wetlands

Landscape Ecology

Findings regarding the success of wetland reclamation at the landscape scale are organized by three main landscape scale subject areas: (1) Ecological Connectedness, (2) Hydrological Connectedness, and (3) Community Fitness.

Analysis of Ecological Connectedness

Ecological Connectedness, Analysis of ecological connectedness indicates that most reclamation sites were adjacent to either natural or reclaimed landscapes, with 40% adjacent to natural ecosystems and between 50 and 60% adjacent to reclaimed areas or mined areas. A significant majority of project boundaries were shared with mined lands (71%) while only 16% of project boundaries were in common with natural lands, and 13% of boundaries were shared with agricultural lands. Only about 24% of wetland sites were connected to habitat reserves or stream corridors that were connected to core habitat reserves (as proposed by King and Cates, 1994). Corridors were found to exist on 89% of all the reclamation sites.

Analysis of Hydrological Connectivity

Hydrological Connectedness. Analysis of hydrological connectivity showed that of the sites in the database, 51% were in first order (smallest) drainage basins, 16% were in second order (second smallest) drainage basins, and 10% in third order drainage basins. About 23% were constructed with no apparent hydrologic connection. Wetlands generally make up a higher percentage of the surface area of the headwaters and upper regions of drainage basins than in the lower reaches (Sullivan 1991). The trend for a larger number of sites in the upper areas of the drainage basin tends to agree with her analysis of native Florida drainage. Position (upper third, middle third, or lower third; more or less corresponding to headwaters, mid-reach, and lower reach as classified by Cross (1991)) was evaluated within basins. Approximately 43% of the sites were in the upper third of their respective drainage basins (most of which were in 1st order basins), 40% are in the middle zone of the basin and 17% are in the lower third. In the upper zones of watersheds, there were 43% of constructed wetlands that had no apparent hydrological connection to downstream channelways (ie, isolated wetlands) and 57% that did have a connection. Based on the finding of Sullivan (1991) related to native Florida hydrologic basins, a higher percentage of wetlands in the upper zone should be of isolated types (cypress domes, isolated marshes, and bayheads).

<u>Analysis of Community Fitness</u>

The mean area for the reclaimed sites under study was 172.9 ha. Fifty four percent of the sites were between 10 and 130 hectares, 37.7% were between 140 and 270 hectares, and 8.2% were greater than 280 hectares.

Land use/cover richness. The occurrence of each type of land cover within all reclamation sites was summarized to evaluate richness. The most common single land cover types in order of occurrence were identified as cropland and pasture land (27%), marshes (14%) tree plantations (12.5%) forested-mixed wetlands and lakes (11% each). Combining land cover types into level 1 classifications, the following percent occurrences result: Agriculture, 30%; forests, 27%; water, 12%; wetlands about 31%. It appears that reclamation sites are dominated by agricultural and range land. Marshes are to dominant wetland community type constructed on smaller sites (0-130 ha), forested wetlands comprise about 65% of the wetland communities on medium sized sites 140 - 270 ha) and equal percentages of marsh and forested wetlands (about 16%) are constructed on the largest sites (greater than 280 ha).

Site complexity. On the average, reclamation sites have 5 unique land cover types per project. Perimeter/area ratios were used to calculate relative complexity of the reclamation sites. There is a general trend for complexity to decrease as the size of the reclamation site increases, falling by more than 50% between the smallest reclamation sites and the largest. It is difficult to determine if this trend results from the fact that more details are drawn on small site plans than on large ones, or as a result of the industry actually creating fewer complex landscapes on larger sites. Site visits seem to confirm the latter, where the largest sites had largest areas associated with each land cover type. Landscape heterogeneity of wetlands is relatively low, when compared with the native Florida landscape.

Upland/wetland Ratios. Average upland/wetland ratios for wetland reclamation projects were considerable lower than those found for native Florida landscapes, especially in the larger reclamation projects (most of the landscape is covered by wetlands). The values range from approximately 1/1 for largest reclamation sites, to about 2.25/1 for medium sized sites. The smallest sites had upland/wetland ratios of about 1.75/1. Sullivan (1991) found that mean upland/wetland area ratios decreased significantly as basin size increased from 13/1 for basins smaller than 100 hectares, to 3/1 for the largest basins (greater than 10,000 hectares). The reclamation site size classes fall within Sullivan's basin classes that averaged between 8 and 13 upland acres for each wetland acre.

Because of low upland wetland ratios, constructed wetlands on these sites may be more dominated by rainfall, with shorter hydroperiods and more frequent cycles of flooding and drying, possibly making the creation of wetland ecosystems that require long sustained hydroperiods difficult to establish and maintain. Low upland/wetland ratios combined with the relatively small amount of uplands that are planted in forests translates into lowered overall carrying capacity for faunal species that require a mix of upland and wetland habitats for life support functions. While it is true that larger wetland areas can mean larger populations of wetland dependent species, many species require good quality upland forests of portions of their life cycles, or portions of their life support functions.

The most common community types associated with lakes (i.e., planted around their margins) were herbaceous wetlands (about 40% of all lake margins are dominated by herbaceous wetlands). This is probably a good juxtaposition of land cover types. However, often these wetland lake margins are planted as thin bands around the edges, lowering their habitat value because of a high edge to interior ratios.

Comparison of Mined and Unmined Landscapes

Analyses of Florida landscapes was conducted at three scales (65 ha, 200 ha and 450 ha) that correspond to the size classes used to analyze data on reclaimed sites for comparative purposes. Reclaimed landscapes have fewer polygons per unit area in all three size classes. The divergence increases as the size class increases. Land cover richness (the number of unique polygons per unit area) is lower in reclaimed landscape; again the divergence increases as the size classes increase. Perimeter/area ratios are similar between reclaimed and native landscapes. Upland/wetland ratios appear to be lower in reclaimed landscapes especially in the largest size class. Reclaimed landscapes appear to have similar percent wetlands, although the spread in native landscapes is relatively large. Agricultural landscapes have lower percent wetlands than to natural landscapes. The reclaimed landscapes appear to resemble the percent wetlands of native landscapes more than agricultural landscapes. As might be suspected, reclaimed landscapes have higher lake to wetland ratios than native landscapes.

Generally, reclaimed landscapes appear to be less complex (as indicated by number of polygons and land cover richness) have smaller upland/wetland ratios than native landscape, and have much higher lake/wetland ratios.

Modeling and Simulation of Constructed Wetlands

Model Development and Calibration

A computer model was developed to simulate vegetative competition and succession in central Florida wetlands. For given initial conditions, the model simulates the change of floral composition over time, and the biomass and diversity of the final tree, shrub, and herbaceous communities. The model was first simulated using data from natural Florida forested wetlands for sensitivity analysis and to test accuracy. Then it was simulated for conditions found in the phosphate region for newly constructed wetlands. The purpose was to evaluate potential regrowth of forested wetlands under differing hydrologic regimes, and seed availability.

Simulation of Wetlands Reclamation

Simulation results of the constructed forested wetland succession indicate that initial planting of trees sped the growth of tree biomass slightly as compared to natural reseeding. However, since seed availability on phosphate mined areas remains a serious question, tree planting at increased density and diversity was the only way of achieving long term community development. When germination conditions were always favorable, tree diversity declined initially, as elms invaded the site and displaced other species. However, as planted trees reached maturity and produced seeds, diversity climbed back to its initial value. When germination conditions were favorable only half the year, tree diversity continued to decline, reaching a steady-state value of 60% of planted diversity.

In the simulation, shrubs (willows) quickly dominated reclaimed lands, reaching a density of 8 kg/m^2 after three years. After about five years, trees began to displace willows, surpassing them in biomass after about 10 years. Willow biomass declined to a steady-state value of 2-3 kg/m^2 (depending on germination conditions); a willow understory persisted indefinitely.

Typha and *Ludwigia* also invaded the site at first, but after the first year, were reduced by willow shading. However, they were persistent for up to 25 years, until the tree canopy was sufficiently dense.

In this simulation, neither willow nor herbaceous invasion affected the long-term survivability, growth, or natural propagation of planted trees. Without introduction of a diverse array of shrubs or herbs, the resultant monoculture understory and ground cover would not support much of the wildlife found in natural forested wetlands. Decline of tree diversity over time was proportional to the absence of natural reseeding opportunities; the less often conditions were favorable, the worse the repropagation of less competitive species.

When the model was simulated using conditions found on phosphate mined lands and using initial conditions characteristic of wetland reclamation, forest regeneration to a steady-state pattern was achieved about 30 years earlier (about 20% less time) than in the “natural” regeneration, because of the initial input of tree seedlings. While total biomass was no different from the naturally regenerated forest, diversity was lower because of a lack of inputs from outside. In other words, the diversity of material planted during reclamation directly effects long term total biomass.

While relatively intuitive, the important thing is that without favorable conditions for germination, regeneration and replacement of planted species is not possible. The developing ecosystem has lower overall diversity of tree, shrub, and herbaceous species because of a lack of internal regeneration. Hydroperiod and depths of inundation are very important variables and have large consequences on long-term community organization.

The question of overly competitive shrub and herbaceous vegetation “holding” a developing community at a lower stage of successional development was addressed. This was addressed indirectly though comparison of rates of growth of shrub and herbaceous vegetation between natural regeneration and the reclamation models. In the short run, shrub biomass and diversity in the reclaimed wetland are lower than in the natural regeneration condition, while herbaceous biomass and diversity are higher in the reclaimed wetland. These conditions prevail because of the higher initial tree biomass that results from the planting of tree seedlings. In other words, with high tree densities, shrub biomass is kept lower through competition for available space and sunlight, and herbaceous biomass is higher because of a lack of shading from the shrub layer. Over time, however, herbaceous biomass declines as trees reach canopy status and shade the lower herbaceous layer.

Simulation results indicate that forested wetlands succession on phosphate mined lands is highly dependent upon hydrologic conditions and seed availability. Tree, shrub and particularly shrub diversity on reclaimed sites does not attain diversities typical of native Florida forested wetlands, suggesting that constructed wetlands are very sensitive to seed availability. But probably of more importance, is the effect of favorable germination conditions on long term community development. While germination conditions are not so important for native Florida ecosystems because of the prevalence of seeds throughout the natural landscape, they are extremely important on reclaimed sites. The simulation model makes explicit these effects. When conditions for seed germination are reduced by half, diversity of tree and shrub species are reduced significantly (declining 40% and 80% for trees and shrubs respectively). Herbaceous diversity is reduced by 50%. These simulations indicate how sensitive long term community development and stability are to hydroperiod as well as seed availability.

Using data for growth rates of indigenous Florida tree and shrub species, and conditions typical of reclaimed phosphate mines, the model was simulated to evaluate the long-term competitive effects of cattail *(Typha* spp.) and primrose willow *(Ludwigia* spp.) Simulation results show no long term negative effects of early dominance by cattail, primrose willow, or Carolina willow.

CONCLUSIONS AND RECOMMENDATIONS

In this section, general conclusions, recommendations, and research needs are summarized, based on conclusions drawn from this research project, organized by the seven research components. It should be noted that current design approaches are routinely being updated by industry based on new information. Thus, some of the recommendations in this report may be included in new reclamation plans, permits, and pending projects.

A key lesson to learned from this project is the need to standardize data collection and analysis methods used in monitoring programs. Much of the monitoring data compiled to date is inconsistent and incomparable. The large volumes of existing data sets lack standardization thereby reducing utility. Coordination of monitoring efforts and data collection standards should provide a data base for analytical interpretation, allowing for a more comprehensive assessment of constructed wetland success.

HYDROLOGY

General Conclusions

- Very limited information exists on hydrological (surface/ground) characteristics of phosphate mined reclaimed wetlands.
- Hydrological design of created wetlands at any particular site is significantly influenced by federal and state regulatory criteria, standards and mandates.
- Mining may remove or disrupt the confining layer between the surficial and the intermediate aquifer systems, thus affecting the water balance relationships on/in the created watersheds.
- The orientation of mine cuts in relation to natural and/or created drainage patterns have hydrologic importance. Mining results in somewhat linear features that can either retard or enhance seepage and may even influence flow direction within the reclamation framework.
- 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.
- The most successful constructed wetlands observed were the large wetlands located near streams at the base of the new watershed. It is noted that these are typically older wetland projects that have had relatively long periods of successional development.

Recommendations

- 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.
- 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.
- 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.

- 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.
- 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.
- 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.
- Limit wetland creation to types of wetlands that do not rely on subtle changes in the geology, such as minor seepage wetland types.
- 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.
- Create wet prairie type wetlands in terraced flat areas in clay tailings impoundments, excavated to a lower altitude than most of the feature.
- Design the created wetlands to utilize natural energies and hydrologic processes associated with the water balance.
- In most situations, do not create wetlands prior to reclamation of a majority of the upstream watershed. Generally, if hydrologic conditions are changed, the effort will be less successful. In some cases, such as floodplain wetlands, reclamation may be successful prior to reclamation of the majority of the upstream watershed.
- 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.
- 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.
- Give the system time. Wetlands are not functional overnight and several years may elapse before nutrient retention, soil formation or wildlife habitat begin to develop. Strategies that try to short-circuit ecological succession or over-manage often fail.

Research Needs

- Continue to upgrade and improve the FIPR model to make it a more useful in designing created watersheds.

- Investigate methods of creating wetland types (seepage wetlands) that rely on subtle changes in the geology.
- Study the creation of wet prairie type wetlands in terraced flat areas where clay tailing impoundments have been excavated or have settled to a lower elevation than most of the feature.
- Conduct baseline studies of various natural wetland types in the region. This work would be most beneficial if conducted in association with similar studies of vegetation and wildlife.
- Conduct a comparative analyses of upland watershed to wetland (all types) area ratios for natural and apparently successful created habitats.

SOILS

General Conclusions

Limited information exists on soil/sediment characteristics and physico-chemical properties of phosphate-mined reclaimed wetlands. The only common soil parameter found was organic matter content which, apparently, is occasionally used as a milestone parameter. Organic matter accumulation is one of the indicators of a productive wetland. Nutrient content, compaction, and bulk density of soils are seldom addressed. However, by supplementing the limited soils information with a synoptic soil sampling program of numerous constructed wetland sites and a few natural wetland sites in both phosphate regions, trends in wetland soil development of constructed wetlands became evident.

- Organic matter increases with constructed wetland age and across transects going from uplands toward the center of the wetlands.
- Most constructed wetlands show a definite increase in organic matter content with time in either- the litter layer and/or the soil mineral layer, albeit at varying rates.
- Extent of organic matter accumulation in the younger wetlands varies considerably, but nearly all show some evidence of organic matter accumulation.
- Native wetlands generally have greater organic matter accumulation both in the litter and mineral soil surface. This is to be expected since native wetlands have been in existence for a very long time.
- C:N ratios of the soil organic matter decrease with wetland age and approach values commonly found in natural wetland soils.
- This change in C:N 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 native wetlands.
- Improvement in the quality of organic matter is also indicated by an increased cation exchange capacity with age of constructed wetland.
- Bulk densities of the initial substrate material after placement in the constructed wetlands is often quite high due to the lack of organic matter and increased soil compaction resulting from operation of heavy machinery. Incorporation of organic amendments and/or deep tillage subsequent to land leveling activities could ameliorate this problem.
- Bulk density decreases with increasing organic matter content in created wetland soils.

- Areas that had lower bulk density and higher organic matter content also appear to support better vegetative growth, however, areas with greater vegetative growth would be expected to also accumulate more organic matter.
- The pH of the created wetland soils is near neutral (pH 6.0-7.4) to slightly alkaline (pH 7.5-8.0) reflecting the high pH of the initial substrate material. Comparatively, 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.
- Constructed wetland soils show evidence that the high pH of the initial substrate materials decreases with wetland age.
- Penetrometer measurements may be used as an in situ evaluation of overall soil compaction and an indication of compact layers within the soil horizon.
- Penetrometer measurements show 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.
- Based on this synoptic survey, the recreated wetland soils surveyed are developing into “typical” wetland soils based on parameters such as organic matter content, C:N ratio, bulk density, pH, and nutrient content.
- 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

- Rate of development of a constructed wetland could, in all probability, be enhanced by at least three practices at the time of wetland construction, i.e., minimizing compaction, incorporating organic matter and slow release fertilizing. Additions of controlled amounts of composted organic materials would provide the latter two requirements. These enhancement recommendations require additional study to validate their potential.
- Since rate of wetland development appears to be closely associated with hydrology, 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.

Research Needs

- Since soil sampling in this project was done on a synoptic basis on a limited number of constructed and even fewer native wetland sites, definite conclusions correlating soil parameters 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.
- 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.
- 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. A better understanding of these practices could lead to significant improvements not only in the quality of wetlands, but also in their rate of development.

WATER QUALITY

General Conclusions

Constructed wetlands, while displaying a great deal of inter-wetland variability during the first two to three years following construction, generally approximate physical and chemical conditions characteristic of natural systems within approximately five to six years after construction.

- By year six, total phosphorus values for six constructed wetlands were characterized by concentrations that are within the range (< mg/L) seen in natural systems of the area.
- Wetlands older than three years displayed biological oxygen demand values that approximated those of natural systems (4 mg/L).
- The conductivity of most constructed wetlands (150-300 umhos) regardless of age failed to decline to levels reported for natural wetlands of the area (50-150 umhos) even after eight years following construction.
- Regarding mine impacted and relocated streams, the current data base is insufficient (only two streams have been monitored for more than five years) to evaluate long term trends in water chemistry and quality due in part to the long generational time of terrestrial vegetation and slow successional changes.

Recommendations

- The choice of water quality parameters to be monitored in constructed wetlands and streams needs to be examined carefully. It is suggested that the choice of parameters be those that are indicative of watershed geological leaching rates (specific conductance), wetland trophic state (total phosphorus), and physiological stress for aquatic biota (dissolved oxygen).
- Care should be taken to ensure that the data collected are interpretable relative to a clear set of questions needed to evaluate water quality.
- For parameters such as dissolved oxygen that can display pronounced diel or seasonal variability as a reflection of ecosystem metabolism rates, care must be taken to ensure that such variability is accounted for in the database.

- There is great need for improved standardization of sampling locations and methodology. It must be taken into account that open water and vegetated regions can display major differences in chemical parameters.
- The database for comparable natural systems of the region needs to be expanded in order to evaluate water quality trends in constructed wetlands.

Research Needs

- There is little information on within habitat differences for water quality in natural and constructed wetlands and within the mosaic of vegetative communities that exist within each wetland. Information on water quality variability between and within wetlands would aid greatly in evaluating the rate at which these ecological functions are reestablished.
- The database for comparable natural systems of the region needs to be expanded in order to evaluate water quality trends in constructed wetlands.

AQUATIC FAUNA

General Conclusions

- Macroinvertebrate populations in constructed wetlands increased during the first two to three years after wetland construction, then decreased approached numbers similar to native wetlands.
- Aquatic faunal communities tended to decrease and stabilize in abundance.
- The final steady-state community of aquatic faunal feeding guilds is often comparable to those of natural wetlands.
- Initial colonization of invertebrates in constructed streams is determined by the proximity of a source area (wetland or stream segment) and the suitability of the physical conditions.
- Species abundance of constructed streams decreased with increasing distance from the source area, and community structure changed in response to the physical habitat.
- Construction of streams with substrate materials similar to that of natural streams in the area will enable the development of macroinvertebrate communities which resemble natural ones.
- Florida streams can be influenced by interconnection with wetlands along their length. Positioning of wetlands can greatly influence macroinvertebrate communities of streams through discharge of organic matter and the drift of wetland invertebrates.
- Stabilization of the watershed and establishment of a riparian forest are important in ensuring the success of stream reclamation. Once initial colonization has taken place, the riparian forest will influence the community that ultimately will persist by controlling light availability, nutrients and allochthonous organic matter input as a food for stream invertebrates.

Recommendations

- Monitoring of constructed wetlands and streams immediately after reclamation may aid in determining colonization patterns of macroinvertebrates.

- Long term monitoring is recommended so that rates of recovery and factors affecting recovery can be established.
- Streams need to be surveyed so that the created physical habitat can be used to explain patterns of invertebrate distribution and abundance. Parameters of interest include substrate type, snags, vegetation and channel morphology.
- Since a stream cannot be isolated from its watershed, efforts must be made to ensure that terrestrial reclamation is successful, thus stabilizing nutrient and sediment release into streams.
- Guidelines for the development of a physical habitat template that will complement the landscape, provide hydrologic stability, and meet requirements for biotic colonization, need to be developed. Incorporation of these guidelines into plans for large-scale reclamation will result in the improvement of the design of future reclamation projects.
- A significant problem regarding assessing aquatic fauna in constructed wetlands and streams is the relative lack of information. There have been literally hundreds of wetlands constructed on phosphate mined land, but macroinvertebrate data are available for only approximately twenty. If macroinvertebrate communities are to be used as a monitoring device, more wetlands should be sampled.
- There is an overall lack of standardization for sampling methodology. Sampling parameters that need to be standardized include:
    - sampling techniques
    - sampling frequency including seasonal sampling
    - sampling record
    - number of sampling stations
    - taxonomic uncertainty

  It cannot be stressed enough that standardization of monitoring techniques is needed in order to utilize the collected data in the most useful manner.

Research Needs

- A complete assessment of benthic macroinvertebrate seasonality in Florida would have helped in analyzing the current database.
- More information on the hydropattern of constructed wetlands and streams would complement information on macroinvertebrate populations.
- Finally, a study of ecotonal areas both within wetlands and stream segments as well as between wetlands/streams and associated uplands would help to characterize the complexity and diversity of constructed wetlands and streams.

VEGETATION

General Conclusions

The data set for evaluating plant community development in constructed wetlands was of limited value in evaluating effects of site design and treatments, or long-term successional trends of constructed wetlands. Nonetheless, based on existing data from a variety of sources, trends in plant community development were evaluated.

It should be understood that the plant community development trends reported here are based on a handful of constructed wetlands with incomplete data sets and monitoring, in most cases, of only a few years.

- Percent cover in marsh wetlands initially increased in constructed wetlands then appeared to stabilize within 3-5 years.
- Evaluation of the growth and survival of planted tree species suggests that after several years survival is about 50% with year to year mortality stabilizing to between 2.5-4% per year after the first year.
- Industry wide percent increase in mean forest cover in forested wetlands was between 1.5 and 2% per year.
- Species richness of reclaimed marshes appears to rival the most diverse native marshes. Zonation and patch diversity within marshes was not testable with the data set, but anecdotal evidence from the site visits suggests that at least some reclaimed marshes were planted to achieve these characteristics.
- In marshes, species richness of obligate wet herbaceous species appeared to decline on average, to about 40% of initial conditions. It is possible that the shift is from floating obligates to the more stable rooted obligate species typical of most native Florida marshes in the regions.
- Species richness of planted trees in forested wetlands is higher than richness found in native mixed hardwood swamps.
- However, there is a dearth of single species dominated wetlands like bayheads, cypress swamps or cypress/gum swamps being created.
- The number of trees planted per acre, on average (600-800), appears to be similar to native wetlands when all age classes are considered. Survival indicates that stand densities will be about 400 trees per acre at the end of 5 years and that yearly mortality of about 2-3% may continue; thus mature constructed wetlands will have between 300 and 350 trees per acre. This appears to agree with densities of mature trees in native forested wetlands.
- There are no data on long term recruitment of herbaceous and shrub species within forested wetlands. Anecdotal evidence from site visits suggests that this may be a serious short coming for the development of vertical structure in forested wetlands.
- Survival of planted trees on sand tailing/overburden sites appears to be similar to survival on overburden sites. However, first year survival appears to be better on sand tailings/overburden sites.
- Mulching does appear to have positive benefits for herbaceous wetlands. Percent cover was higher in the first year and appeared to continue for 4 or 5 years. Species richness of the herbaceous community appeared to be little affected by mulching.
- There is no question that herbiciding controls nuisance species. The data show that mean percent cover of nuisance species on non-herbicided sites reached about 30% in the 6th year, while it was kept below 10% on herbicided sites. Species richness on herbicided sites appears to be lower than on non-herbicided sites (although the data are limited).
- Nuisance species control in forested wetlands appears to benefit tree survival in the early years.

- There are no data related to microtopographic relief, but site visits confirm that, in most cases, forested wetlands are created with extremely "smooth" topographies. Micro-relief on the order of less than 1 meter would increase diversity of hydrologic regimes and in turn potentially increase survival and growth of planted species.

Recommendations

- Anecdotal evidence suggested a disturbing trend of invasion by exotics on older sites that were "released" and therefore of less concern for continued maintenance by industry. We strongly urge a detailed survey and program for control, lest the reclaimed phosphate district become dominated by exotics.
- Forested wetlands should be constructed with greater microtopographic relief. If trees are planted on hummocks, water levels could be deeper without threatening tree survival, and greater surface storage could be accomplished.
- Provision should be made to plant shrub and herbaceous species in constructed forested wetlands once the canopy begins to close.
- Use of Bahia grass should be encouraged only where environmental conditions promote the spread of Cogon grass. In other areas, use of annual crops for soil stabilization should be encouraged.
- Since survival of some tree species is low, it probably makes little sense to plant only a few individuals of any one species. Planting a minimum of 10% of the total trees per acre should probably be the cut off.
- Overall there is a need for standardization of methods of field data collection and analysis.
- At the very least, a minimum amount of data should be collected on all wetland reclamation sites. As it now stands there are not sufficient data to determine overall success of the industry's reclamation of wetlands. Of the total sites visited, over 60% had no data what-so-ever.
- The quality and quantity of data falls off rapidly 2 to 3 years after wetland construction. More attention should be given to standardization and a longer term commitment to monitoring.
- There is a need for controlled experiments in assessing the value of mulching and other revegetation techniques.

Research Needs

- Probably the single most important information gap is the fact that sufficient long term data do not exist to evaluate long term viability or trends of constructed wetlands. Therefore, the establishment of several regularly monitored long term constructed sites is necessary for clearly defining long term ecological trends for constructed wetlands.
- There is a strong need for development and adoption of industry wide field measurement techniques, methods for summary and synthesis of collected data, and format for reporting monitoring data
- A trend in the decline of obligate wetland species in herbaceous wetlands, coupled with no decline in overall species richness may indicate a need for additional research that would help to illuminate the reasons for the trend.

- An urgent need for additional research relates to the long term trends in invisibility of herbaceous wetlands by nuisance and exotic species and the documentation of trends in effort expended for controlling them over time.
- Develop and implement a standardized sampling plan to address the following:
  - Site monitoring and evaluation
  - Plant community monitoring
  - Hydroperiod monitoring
  - Water quality monitoring.

WILDLIFE

General Conclusions

- Few data are available for review and evaluation of wildlife usage of created wetlands, although some monitoring reports have included incidental wildlife observations.
- Through sources that do exist, it appears that adequate information is available for birds and large mammals, but data on small mammals, reptiles and amphibians are sparse.
- Evidence of a very limited variety of species of freshwater turtles throughout a wide diversity of created wetlands and open water habitats was found. There is an apparent absence of many expected species in created wetlands in phosphate mined regions.
- Wildlife has been ignored in the development of "success" criteria for created wetlands on phosphate mined lands.
- In Florida four species of mammals, numerous bird species, several reptiles and many amphibians are wetland-dependent and sufficiently abundant and wide spread to serve as indicator species for created wetland habitats.
- Wildlife diversity appeared highest in wetlands that include open bodies of water intermixed with marsh.
- The oldest of the created forested wetlands is still essentially in the seral shrub/forest ecotone stage of development and are inhabited by wildlife species typical of this habitat.
- Many of the old unreclaimed, but naturally revegetated, 'mines are now forested and have become rich in wildlife values, providing habitat for wetland and terrestrial species alike. These areas would be set back rather than enhanced by retroactive reclamation.

Recommendations

- Agencies and industry should support research directed towards the development of habitat design and performance standards that result in restoration of wildlife in created wetlands within a reasonable time period.
- Simple techniques for monitoring selected groups of wildlife species near the end of a wetland creation project should be devised during the course of project development.
- Strategic location of constructed wetlands may be critical for the interchange of animals among watersheds and regions, and to provide breeding sites for upland terrestrial species (frogs, toads).

- Efforts should always be made to include an upland buffer zone or preserve adjacent to a created wetland.
- Criteria should be developed utilizing a suite of selected species of wildlife as indicators of successful wetland creation.
- Once a constructed wetland community has become established seasonal qualitative monitoring and sampling of the mammals, birds and herpetofauna using the site would help in determining whether or not that particular wetland is on track towards an appropriate climax configuration.
- The numbers and distribution of isolated wetlands on phosphate mined lands should not be altered to the point of adversely affecting the amphibian populations of a basin or region.

Research Needs

- A major gap exists in our knowledge of the kinds of wildlife inhabiting most of the created wetlands on phosphate mined lands and natural wetlands in the region.
- Conduct studies on several undisturbed natural wetlands, both herbaceous and forested, and on selected samples of each of the various types of created wetlands (marsh with water bodies and those without) and isolated wetlands, both natural and constructed.
- Initiate a study to document the species, distribution and abundance of freshwater turtle species in created and natural aquatic habitats in phosphate mining regions and in mineralized, unmined lands of the region.
- Understanding the food web of phosphate mined lands and constructed landscapes of differing ages is an important area of research not yet undertaken.
- Develop criteria for monitoring and sampling wildlife to establish ranges of wildlife utilization appropriate for various stages of created wetland development.
- Determine society's goals for wetland reclamation in the region.
- Investigate reintroduction of certain species of mammals, reptiles and amphibians into created isolated wetland systems.

ECOSYSTEMS AND LANDSCAPE ORGANIZATION

General Conclusions

Conclusions are organized by three main landscape-scale subject areas: (1) Ecological Connectedness, (2) Hydrological Connectedness, and (3) Community Fitness. Separately each of these subject areas describes characteristics and trends in reclamation design and implementation; taken together they suggest trends in successful landscape-scale reclamation.

Ecological Connectedness - There are two levels of connectedness, the first is site connections to surrounding land cover that provides wildlife access and potential for seed transfer from mature systems. The second is a purposefully integrated and designed connection of forested land cover that serves as wildlife corridors to and from what King and Cates (1994) have termed Core Habitat Reserves.

- About 50% of surveyed wetland reclamation projects are connected directly to natural forested lands, but only about 16% of the perimeter of these sites abuts natural areas. Thus connections are often weak between existing natural areas that act as seed refugia and wildlife habitat and the individual wetlands on a reclamation site.
- Forty-eight percent of projects are connected to relatively mature reclaimed lands.
- The average length of border that is shared between wetland reclamation projects and adjoining reclaimed areas is about 46% of the sites perimeter.
- The majority of reclamation sites that share borders with other reclamation sites are not ecologically connected, or integrated.
- Twenty-four percent of wetland reclamation projects are integrated into a regional habitat system by having forested connections to core habitat reserves.
- Since the reclaimed landscape is often a patchwork of reclamation projects in various stages of design, implementation, and successional regrowth, it continues to be a real challenge to link reclamation projects and their natural ecological communities together in a cohesive regional habitat network.

Hydrological Connectedness - Hydrological connections are important to insure that the landscape functions as a hydrological unit, so that storm flows and base flows in downstream surface waters are accommodated and maintained. The pre-mining landscape was organized hydrologically in drainage basins that have for the most part been altered. Using a system of ordering drainage basins that gives lowest number to the smallest basin and increasingly larger numbers to larger sized basins, it is apparent that while there have been minor alterations to the largest basin drainage divides, there is increasing alteration to drainage divides and thus area of basin, as the order decreases. Most post-mining hydrologic organization is a function of ditches, canals, mine pits, and roads, effectively reducing the role of previous natural topography, although functioning drainage networks have been and are being reclaimed. The challenge is to continue reestablishing drainage basins in the post-mining landscape and connect them into a regional drainage network.

- About 50% of wetland reclamation projects are within 1st order (smallest) drainage basins, yet most 1st order basin have direct hydrologic connections to the regional drainage network. The fact that they are connected may result in serious long term hydrological problems associated with the maintenance of sufficient storage, groundwater recharge, and maintenance of stream base flow during the dry season.
- About 16%, of reclamation projects are constructed in second order drainage basins (second smallest), and 10% are constructed in third order basins.
- About 23% are constructed with no apparent hydrologic connection.
- Of those wetland reclamation projects in 2nd and 3rd order basins about equal percentages are hydrologically directly connected to the drainage network and hydrologically isolated.
- About 43% of all wetlands reclamation projects are in the upper 1/3 of drainage basins (roughly equivalent to the headwaters of the drainage basin), while about 40% are within the middle 1/3, and 17% are within the lower 1/3.

- Thus about 20% of all wetland reclamation projects (50% of the 43% of projects that are hydrologically isolated) depend on rainfall and groundwater levels for maintenance of hydrology, with little or no surface water inputs.

Community Fitness - Community fitness results from the interplay of land cover type and acreage within a reclamation site as well as the interplay of the site with surrounding lands. Several separate indices of community organization and interaction were calculated, that taken as a whole, address how well reclamation sites and their associated land covers fit within the larger landscape mosaic.

- The most common land cover type in reclamation projects is agriculture (primarily pastureland).
- Between 25 and 35% of the land area of reclamation projects is devoted to agriculture, and agriculture has the highest number of polygons on reclamation projects.
- While agriculture can be a land cover compatible with wetlands, often management practices and animal foraging can be detrimental to wetland habitat.
- Landscape heterogeneity (the number of polygons, and number of unique polygons) of wetlands reclamation projects is relatively low, when compared to the native Florida landscape.
- Average upland/wetland ratios for wetland reclamation projects appears to be somewhat lower than those found for native Florida landscapes, especially in the larger reclamation projects (this in essence means a larger percentage of the landscape is covered by wetlands).
- When lakes are included as a wetland type, the percent of reclamation projects that is "wet" (both wetlands and lakes) is even higher, between 30% and 50%. This may translate into wetlands and lakes that are more dominated by rainfall events and less driven by groundwater inflows.
- Low upland/wetland ratios combined with the relatively small amount of uplands that are planted in forests (on average about 20%) may translate into lowered overall carrying capacity for faunal species that require a mix of upland and wetland habitats for life support functions.
- Lake borders, on the average are planted with herbaceous wetlands far more frequently than any other cover type (about 40% of all created lakes are dominated by herbaceous wetland margins). This is probably a good juxtaposition of land cover types. However, often these wetland lake margins are planted as thin bands around the edges, lowering their habitat value because of high edge to interior ratios.

Recommendations

Landscape Ecology:

- Standardize submittal requirements for reclamation plans that would include standardized format for plans and topography maps, site plans that show off-site ecosystems and drainage patterns, planting lists giving species and planting densities for each community type, cross-sections of site topography showing predicted ground and surface water elevations and indicating zones of each community type.

- Make reclamation planning units dependent on faunal habitat requirements, hydrologic basins, and logical landscape scale habitat units instead of on mining units.
- Increase the required area of upland forested communities so that constructed wetlands can achieve better off-site ecological connectedness.
- To increase the likelihood of achieving appropriate wetland hydrology, reclaim on a drainage basin basis beginning with headwaters areas and proceeding down slope to the basin's mouth.
- Develop region wide reclamation schemes that promote integrated approaches to habitat restoration similar to that proposed by King and Cates (1994).
- In all, it will be important to establish new criteria, but rather than making the reclamation process harder by adding more restrictions, explore ways that better reclamation can be achieved through cooperation and incentives rather than through stricter controls.

Wetland Reclamation Model Simulation:

- The control of nuisance species in the early years of establishment of forested wetland communities, and the removal of canopies of shrub species (primarily willow) may not be necessary since model simulation results suggest that tree species compete well and soon overtop these early colonizers. There is, as yet, little data to confirm this.
- Simulation results confirm the need for more "micro-topographic relief" in created forested wetlands. The smooth topography that is characteristic of most created wetlands favors lower diversity of tree, shrub and herbaceous species in the mature communities.
- Simulation results suggest that there is a strong need for the introduction of shrub and herbaceous species within created forested wetlands, although the lack of micro-topographic relief and high light levels in the early years make their survival problematic. Introduction of these species during a later phase of succession might be warranted.

Research Needs

- Develop long term studies on significance of an integrated reclaimed landscape in enhancing direction and rate of plant community development.
- Evaluate methods for integrating mining and reclamation into a landscape-scale, integrated watershed-based reclaimed landscape.
- Encourage development of ecosystem simulation models to assist in directing and assessing short and long term trends in wetland ecosystem development.
- Understand landscape scale nutrient dynamics through research into the role of wetlands, lakes, and uplands in contributing to nutrient cycling and mobilization.

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