



# Landscape restoration following phosphate mining: 30 years of co-evolution of science, industry and regulation

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## Abstract

The restoration of phosphate mined lands in Florida is large scale, potentially covering over 300,000 acres (121,000 ha), and rivals other restoration efforts like the Florida Everglades in size and complexity. The issues surrounding mining and subsequent restoration of the landscape are global, national, and local in scale. The entire system of phosphate mining and restoration involves local citizens, governmental agencies, research scientists, and industry personnel in a program that might be seen as adaptive management. It is suggested that restoration is managing adaptive self-organization of the ecosystems and landscapes and that it is the domain of ecological engineering. The past 30 years of research concerning various aspects of landscape restoration after phosphate mining are elucidated, and the research's relationship to management and regulation are discussed. Finally, the complex issues that are inherent in large restoration programs are discussed and it is suggested that a cooperative environment and vision may be the key elements that are missing.

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## 1. Introduction

Phosphate mining in Florida is open pit mining (see Fig. 1) where an overburden of approximately 10 m is stripped off and set aside and the clay/sand calcium phosphate matrix is removed.<sup>1</sup> During beneficiation, the calcium phosphate is separated from the sand and clay. The clays, now in a slurry mixture, are returned to

the lands and stored in elevated clay settling areas that occupy approximately 40% of the post-mining landscape. The majority of research on phosphate mine restoration, since it began in the mid 1970s, has been concerned with the restoration of the remaining mined lands that are not used for waste clay storage. Very recently, research has been initiated to evaluate the potential of clay settling areas as the setting for wetlands creation.

Landscape restoration of phosphate mined lands has benefited at times from a tight coupling of research, applied ecological engineering and government regulation. This coupling resembles co-evolution (or recip-

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<sup>1</sup> Definitions of terms used in this manuscript are given in Appendix A.

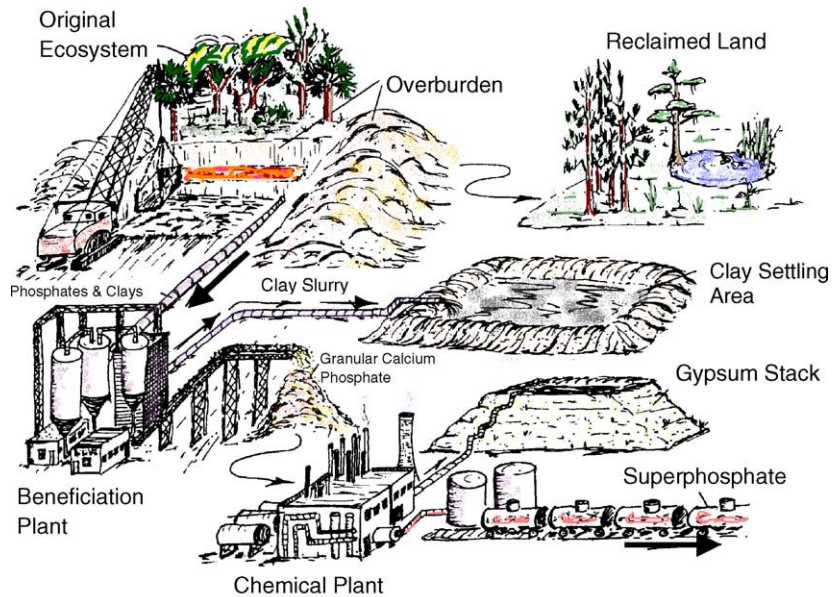


Fig. 1. Schematic diagram of phosphate mining in Florida. The phosphate matrix, at depths of 6–10 m below the ground surface, is open-pit mined where the soils on top of the matrix (overburden) are piled to the side in spoil piles and the phosphate matrix, high in clay content, is slurred and pumped to the beneficiation plant. The by-products from beneficiation are: clays, which are pumped into elevated clay settling ponds, and sand-tailings used to back-fill mined areas (not shown in the illustration). Granular calcium phosphate is converted to super phosphate fertilizer in chemical plants producing a gypsum by-product that is stacked high near the plant. The final land uses after mining are reclaimed land (about 50–60% of the landscape), clay settling areas (40% of landscape) as well as chemical plants, transportation and gypsum stacks (about 10%) which most frequently are constructed on unmined land.

rocal evolutionary change) of: (1) the research community as the need for answers to the question “how do we restore the landscape?” increased; (2) industry, as they applied new techniques as fast as they were being researched and documented; and (3) government regulation of restoration, as agency personnel learned what industry was capable of and what researchers suggested was possible. In some respects, this co-evolution resembles what has been referred to as “adaptive management” (Holling, 1978; Walters, 1986; Walters and Holling, 1990) or the systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Taken as a whole, the research community mostly focused in the academic world, industry, represented by numerous companies and government, including local, state and federal regulatory agencies represents a relatively complex system of actors. Nonetheless, all have as a common goal the restoration of lands in Florida that have been mined for phosphate ore.

In this paper, the 30-years experiment in landscape restoration following passage of legislation by the State of Florida requiring reclamation of phosphate mined lands is described. Much of the research that has been conducted during that time is summarized and related to the ecological engineering practices of industry and changes in the regulatory program of State of Florida’s Bureau of Mine Reclamation (BMR).

### 1.1. Brief historical perspective

Phosphate mining in Florida began in the late 1800s with hundreds of small hard rock mines in north and central Florida. About the same time, pebble phosphate was discovered in and around the Peace River in south/central Florida. This region, known as the Bone Valley, soon dominated phosphate production because of the relatively lower costs of production for pebble phosphate compared to the hard rock. As a result, most mining for hard rock through out the rest of the state dwindled and ceased by the early part of the 1900s.

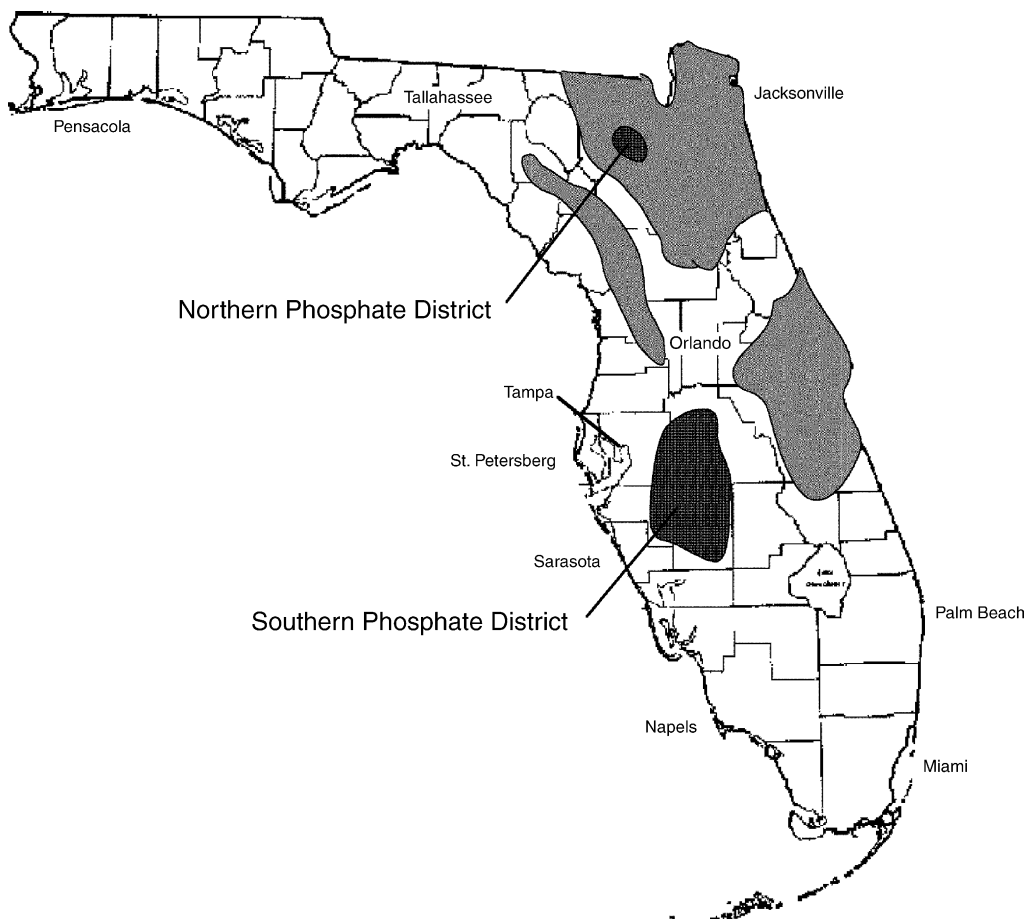


Fig. 2. Map of the phosphate regions of Florida. Gray areas are districts of secondary “reserves”, while the dark areas are the primary phosphate districts. The southern most primary district is also known as the “Bone Valley” formation.

North Florida phosphate mining began in the mid 1960s and continues today near White Springs, FL. Currently there are two active mining areas in Florida (Fig. 2) known as the northern and southern phosphate districts, where about 5000 acres (2000 ha) are mined each year.

The area dominated by phosphate mining totals about 300,000 acres (121,400 ha). In 1990, there were 11 phosphate companies operating in Florida; by 2004, as a result of the changes in ownership and corporate buyouts, there were 3. Each company may have numerous mines. Phosphate mines range in size from about 4500 acres (1800 ha) to about 21,000 acres (8500 ha) with the average size of about 10,000 acres (4000 ha). Each mine is usually planned, mined and reclaimed as a single entity. In the early years, little attention was

given to the lands outside the mining unit but increasingly, regulatory agencies are requiring a broader perspective from industry as mines are planned and eventually reclaimed. Today each mine is permitted by the state and part of the permit application is a conceptual reclamation plan that includes all the lands and details regarding their restoration. The BMR reviews the plans for consistency with adjacent mines and land uses, and with its regional conceptual plan.

Presented next is a review of the State’s regulation of mined land restoration. It is important at this point to call attention to the difference between restoration and reclamation. Restoration (in this paper ecological restoration) is the process of assisting the re-establishment of natural communities, habitats,

species populations or other ecological attributes that have been eliminated or greatly reduced on a given location. Reclamation is a more general term and means the process by which lands disturbed, as a result of mining activity, are reclaimed back to a beneficial land use. A subtle difference, but important. Reclamation as used here only refers to returning lands to a beneficial use, while restoration implies restoring ecological and hydrological functions.

### 1.2. State regulation of reclamation

Throughout the many years of phosphate mining in Florida, there was no requirement for reclamation or restoration of mined lands. The industry only reclaimed lands where there was an economic incentive or an overwhelming aesthetic need. In 1975, the State of Florida passed legislation that mandated all land mined for phosphate after July 1, 1975 must be reclaimed. Further, the State provided some funds from the severance tax on mined phosphate to assist the industry in the reclamation of lands mined prior to 1975. The goal, of course, was to reclaim all lands including those mined prior to the enactment of the reclamation law.

Beginning in 1975, the Florida Department of Natural Resources (FDNR) was assigned the task of regulating reclamation. In response, FDNR adopted rules that covered reclamation (Chapter 16C-16, Florida Administrative Code (FAC)). At first, the rules were designed to hide the evidence of mining. During the first years of regulation, from 1975 to about 1980, phosphate mining companies were required to level spoil piles and plant 10% of the lands in trees. The resulting landscape of recontoured mine pits and uplands was called land and lakes. During the early 1980s, State regulation began to evolve, requiring reclamation of wetlands, according to the quantitative success criteria that required survival of 400 trees per acre, 80% cover by desirable species and no visible evidence of erosion. Beginning in the mid 1980s, State regulations became more prescriptive with several revisions of the States Reclamation Rules. [Appendix B](#) is a summary of current reclamation rules related to the landscape restoration after phosphate mining.

It should be noted that prior to the passage of legislation and rule making that resulted in Chapter 16C-16 FAC, requiring the phosphate industry to reclaim the lands they mined, there was little or no incentive to do

so. Therefore, there was little or no restoration research conducted by industry or the research establishment. The FDNR rules encouraged the phosphate industry to begin restoration research in earnest in the early 1980s. This is not to say that industry is to blame or that they were insensitive to the ecological concerns, it is only to demonstrate that regulation, research and implementation are all necessary to achieve the goals of ecological restoration of drastically altered lands. Regulation has a tendency to direct industry to seek alternatives and research can guide those alternatives.

### 1.3. State of Florida sponsored restoration research

In addition to the legislation that required reclamation, the State of Florida recognized the need for research and passed legislation that funded phosphate research through a statewide research institute. In 1978, the Florida Legislature created the Florida Institute of Phosphate Research (FIPR) by (Chapter 378.101, Florida Statutes) empowering it to initiate, conduct and sponsor the studies to minimize or rectify any negative impact of phosphate mining and processing on the environment and improve the industry's positive impact on the economy. This includes developing better techniques for reclaiming land and developing more efficient mining and processing technologies. The Institute is financed with funds from the state severance tax on phosphate rock. Over the years, FIPR has funded most of the academic research related to the restoration of phosphate mined lands. Its influence on the direction and overall output of restoration research cannot be over-emphasized. Through its research priorities set by technical advisory committees, made up of stakeholders from government, industry, environmental groups and academics, it has had a major impact on the restoration of mined lands. [Table 1](#) is a partial list of the restoration research projects funded by FIPR.

## 2. Phosphate mining in perspective

### 2.1. Phosphate contribution to Florida, USA and the World

[Table 2](#) lists some relevant facts regarding phosphate mining in Florida. It is quite apparent that phos-

Table 1

Partial list of restoration research projects funded by the Florida Institute of Phosphate Research

Project title/agency	Date funded
Development of techniques for the use of trees in the reclamation of phosphate lands, Division of Forestry	06/13/1980
Enhanced ecological succession following phosphate mining, University of Florida	03/20/1981
Interactions between phosphate industry and wetlands, University of Florida	03/20/1981
Ecological considerations in lake reclamation design for Florida's phosphate region, Environ. Science & Engineering Inc.	10/16/1981
Study of a method of wetland reconstruction after phosphate mining, University of Florida	08/20/1982
Pelletization of seeds, University of South Florida	09/15/1983
Development of techniques for reclamation of mined land, University of Florida	01/01/1984
Measurement of recovery in lakes following phosphate mining, VPI & SU	03/01/1984
Interactions of wetlands with phosphate mining, University of Florida	03/01/1984
Water quality in lakes in Central Florida phosphate region, Post, Buckley, Schuh & Jernigan Inc.	05/01/1984
Vegetable production potential of sand-clay mixes, Bromwell & Carrier Inc.	06/18/1984
Propagation and establishment of indigenous Florida plants for revegetation & restoration of phosphate mining sites, University of Florida	10/01/1984
Viability of wetland topsoil for reclamation, FIPR (In-House)	08/01/1985
Restoration techniques for sand scrub, Florida Southern College	01/17/1986
Citrus groves on reclaimed mined lands, Zellars-Williams Co.	06/17/1986
Production of high cash value crops on mixtures of sand tailings and waste phosphatic clays, Bromwell & Carrier	12/20/1986
Hydrologic impacts of phosphate mining in small basins, USGS	04/01/1987
Alternatives for restoration of soil, University of Florida	05/01/1987
Mined Lands agricultural demonstration project, Polk Co. BOCC	03/01/1988
Reintroduction of gopher tortoises to reclaimed, L. Macdonald	05/09/1988
Enhancing tree revegetation on phosphate surface-mined land, FIPR/Clewell	08/29/1988
An evaluation of benthic meiofauna and macrofauna as success criteria for reclaimed wetlands, University of Florida	06/13/1989
Improving upland native plant revegetation potential, USDA Soil Conservation	11/13/1991
Equipment for construction of drainage systems on clay settling areas, Polk County BOCC	03/01/1992
Macro & meiofaunal distributions in headwater streams of the alafia river, Florida, University of South Florida	01/01/1993
Studies of wildlife usage and restoration of upland habitats on phosphate mined land in Central Florida, University of South Florida	04/16/1993
An evaluation of constructed wetlands on phosphate mined lands in florida: vegetation, soils, aquatic fauna, water quality, ecosystem analysis, and values, functions & regulations, University of Florida	06/25/1993
Ecology, physiology and management of cogongrass ( <i>imperata cylindrica</i> ), University of Florida	11/15/1993
Plant competition effects on tree establishment and growth on phosphate mined lands, FIPR (In-House)	03/01/1994
Hydrology and water quality of reclaimed phosphate clay settling areas in West-Central Florida, U.S. Geological Survey	02/01/1995
Evaluation of feasibility of water storage reservoirs on mined lands to meet future agricultural, industrial and public water supply demands, Schreuder Inc.	07/01/1995
Wildlife usage of mesic flatlands and its bearing on restoration of phosphate mined land in Central Florida, University of South Florida	08/11/1995
Managing runoff water quality from clay settling areas used for intensive agricultural production, University of Florida	09/01/1995
Shading effects on nuisance species and succession on phosphate mined lands, University of Florida	03/01/1996
Post-mine reclamation of upland communities, Jones, Edmunds & Associates Inc.	12/01/1996
Development of seed sources and establishment methods for native upland reclamation, USDA	01/02/1997
Synthetic seed production of florida's indigenous plants, University of Florida	04/15/1997
Managing weed competition and establishing native plant communities on reclaimed phosphate mined lands in Florida, FIPR (In-House)	09/01/1998
Self-organization and successional trajectory of constructed wetlands on phosphate mined lands in Central Florida, University of Florida	09/01/1998
Water quality investigation of in situ tailing-sand deposits under natural environmental conditions, Schreuder Inc.	09/01/1998
Rapid production of Florida's indigenous plants via micropropagation, University of Florida	02/19/2000

Table 2  
Phosphate mining facts (Florida Phosphate Council, 2004)

Mined area to date <sup>a</sup>	130,000 ha
Mining rate	2–2500 ha/year
Total to be mined	280,000 ha
Phosphate rock extracted (2003)	28.7 million MT
Taxes paid (2003) (in US\$)	83 million/year
Annual operating expenses (2003)	
Yearly wages (in US\$)	445 million/year
Equip and supplies (in US\$)	1360 million
Electricity (in US\$)	127 million
Services (in US\$)	165 million
Investment in facilities (total) (in US\$) <sup>a</sup>	10 billion

<sup>a</sup> Florida Institute of Phosphate Research (2004), <http://www.fipr.state.fl.us/southintro.htm>.

phosphate mining is an important part of Florida's economy, an essential part of USA agriculture and when placed in a global perspective, a critical component of the world food system. Florida contributes nearly 75% of the USA's phosphate needs and about 25% of the global needs. In 2003 (the last year for which there are complete data (Florida Phosphate Council, 2004)), the phosphate industry extracted 28.7 million metric tonnes of phosphate rock from 4501 acres (1800 ha) of land in Florida. Its contribution to the economy of Florida may be as much as US\$ 10 billion in 2003 from the phosphate and related chemical industries in an economy that totaled about US\$ 500 billion. The economic value of phosphate rock in Florida, based on a price of US\$ 28 per metric tonne, was about US\$ 800 million in 2003.

## 2.2. Emergy evaluation of phosphate and restoration

The monetary value of phosphate rock, based on its current price on the global market, provides a benchmark for what its value is to the market economy. The market price, however, does not provide an estimate of its value as a raw resource used to drive agricultural productivity, instead it provides an estimate of its utility value based on willingness to pay. Another way of estimating its value at the larger scale is related to the total energy required to make it (or its emergy). To do this, it is necessary to determine all the energy from natural processes required for its formation.

There are several theories related to the formation of Florida's phosphate deposits. The most plausible is illustrated in the left side of Fig. 3. The actions of acid waters, formed as a result of organic matter decomposition, carry phosphorus from terrestrial vegetation where it precipitates with calcium carbonate to form calcium phosphate in formations underlying Florida. Odum (1996) estimated the emergy required to concentrate phosphate in this way to be 3.9 E9 sej/g. Mining of phosphate shown on the right side of Fig. 3 requires significant emergy in materials, fuels and human service (5.4 E18 sej/ha). The emergy yield, shown leaving the diagram to the main economy on the right, is over three orders of magnitude greater than the purchased inputs (6.1 E22 sej/ha). When the current price for phosphate rock (about US\$ 28/MT) is expressed in emergy, using a emergy per dollar ratio of 1 E12 sej/\$, the emergy equivalent of its market price is about 2.8 E13 sej/MT or 2.8 E4 sej/g. When compared to emergy of the phosphate rock itself, it is quite apparent that the difference between the value received in the phosphate rock and the emergy represented by the price paid is extremely high. The value received is about five orders of magnitude greater than the price paid (3.9 E9 sej/g/2.8 E4 sej/g = 1.4 E5 to 1). This difference suggests the extremely high value one currently receives when purchasing phosphate rock.

## 2.3. Net benefits of restoration

Ecological restoration, to be successful, should restore ecosystem function. The function and structure of the ecosystems are defined by two aspects: (1) abiotic conditions (temperature, soil type, terrain, disturbance regime, etc.) and resources (water, nutrients, sunlight) and (2) the trophic structure or feeding relationships among the species that shapes the flow of energy through the ecosystem. Ecosystem disruption results in a breakdown of both the function and structure. An impact may disrupt abiotic components (soil structure might be changed, as in mining) as well as trophic structure (the loss of primary producers, as when land is cleared). Restoration efforts should be focused on re-establishing pre-disturbance ecosystem functions and to be effective, it should not cost more than it yields.

The graph in Fig. 4 illustrates the effect of disruption on the ecosystem function. The disordering influence (in this case, phosphate strip mining) impacts ecosys-

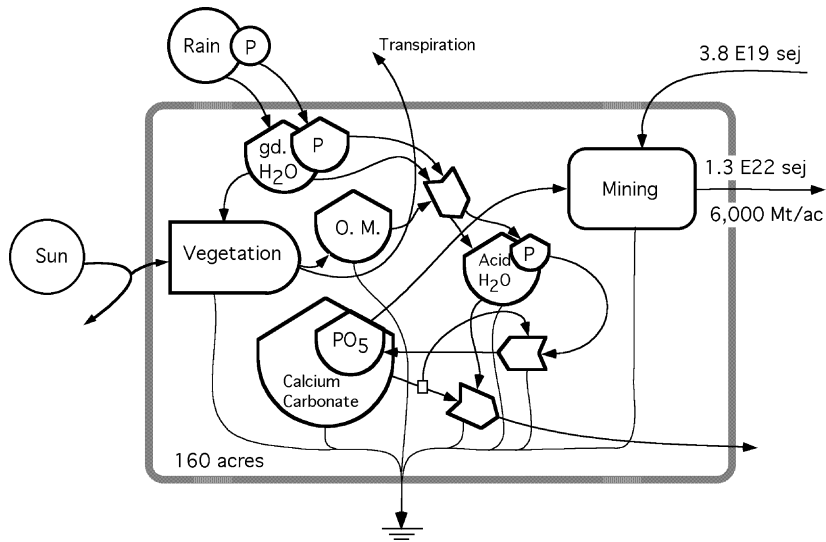


Fig. 3. Systems diagram of phosphate formation and mining. The time frame is 1800 years for formation of phosphate rock and a matter of months for its mining. The flows of energy for mining and energy of the yield are for mine life.

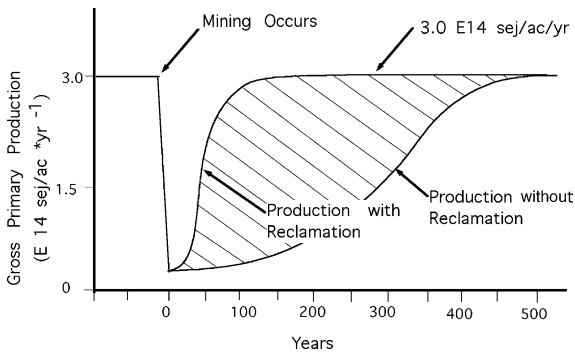


Fig. 4. Natural restoration of mined lands in Florida may take as long as 500 years because of the lack of near by seed sources, while ecologically engineered restoration may only take a little over 100 years (Weber, 1994). The emergy benefit of restoration can be estimated as the area between the two graphs and related to the emergy costs as a benefit cost ratio. It is suggested that effective restoration should have a ratio greater than 1.0.

tem function causing it to decline to very low levels in a short period of time. Left to its own devices, the landscape would re-establish ecological productivity and eventually ecosystem function through natural restoration processes of landscape and ecological succession. Because of the areal extent of phosphate mining and distance to seed sources, natural restoration is estimated to take about 500 years (Weber, 1994). Restora-

tion can be sped up or enhanced, however, through the ecological interventions, for instance, the introduction of seeds and planted vegetation. The difference between the two lines on the graph (the area between the two lines) is the benefit from restoration.

Fig. 5 illustrates that landscape restoration after phosphate mining in Florida consists of recontouring spoils, planting trees and sowing seeds to stabilize soils. An additional input is the human services in engineering design and environmental monitoring. Emergy costs for a typical restoration project are shown in Fig. 5. The inputs are for a 160 acre (65 ha) restoration project in central Florida and assumes 100 years of renewable inputs to reach full replacement of ecological functions.

Quantitatively, the net benefit of phosphate restoration can be estimated if it is assumed that ecosystem function is equal to emergy of gross primary production (GPP). Using Fig. 4 as a guide and the data from Fig. 5, the net benefit from restoration for a typical 160 acre (65 ha) mine can be calculated. Brown and Bardi (2001) estimated emergy value of GPP for average Florida ecosystems as 3.0 E14 sej/(acre year) (7.5 E14 sej/(ha year)). Using the hypothetical graphs in Fig. 4, the benefit from restoration of 160 acres (the area between the two lines = 6.6 E16 sej/acre) is 10.6 E18 sej (6.6 E16 sej/acre × 160 acres = 10.6 E18 sej).

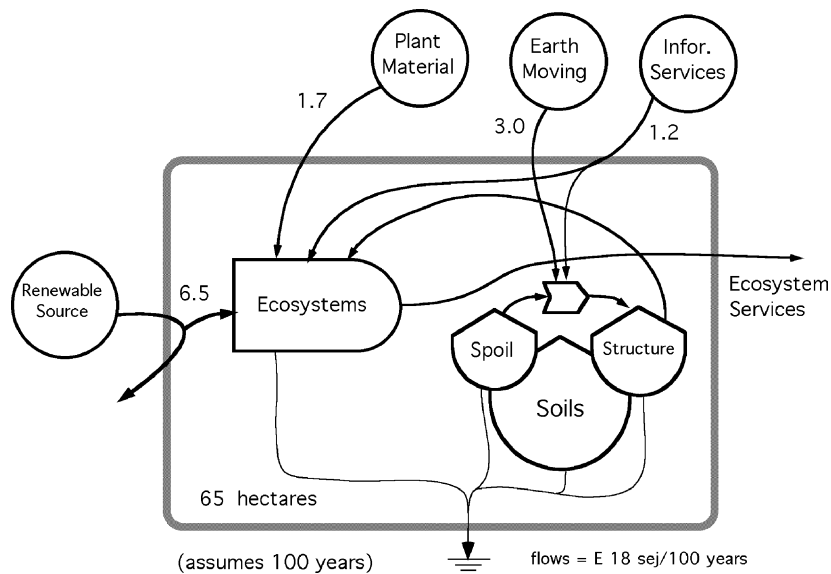


Fig. 5. Total emery required to restore 65 ha of the Florida landscape following phosphate mining, assuming 100 years to restore ecological functions. Values are total emery over 100 year period, calculated as follows:

Renewable inputs equal to water use in transpiration

transpiration = 0.77 m/year

Gibbs free energy of water = 4.94 J/g

energy in water used = (0.77 m) (1.00E+04 m<sup>2</sup>/ha) (1.00E+06 g/m<sup>3</sup>) (4.94 J/g)

= 3.80E+10 J/ha/year × 100 years × 65 ha = 2.5 E14 J

transformity = 26,096 sej/J (calculated as weighted average of rain and run-in)

Plant material (planting of seedlings and sowing seed)

seed 11.4 kg/ha × 65 ha × 4.7 E12 sej/kg seed = 3.5 E15 sej

planted 10 species at 1 E16 sej/spp = 1 E17 sej

fuel use = 1.8 E7 J/ha × 65 ha × 6.6 E4 sej/J = 7.7 E13 sej

service in planting = \$24,600/ha × 65 ha × 1 E12 sej/\$ = 1.6 E18 sej

total = 1.6 E18 sej + 1 E17 sej + 7.7 E13 sej + 3.5 E15 sej = 1.7 E18 sej

Earth moving

fuel use = 3.2 E8 J/ha × 65 ha × 6.6 E4 sej/J = 1.4 E15 sej

service in earth moving = \$4.6 E4/ha × 65 ha × 1 E12 sej/\$ = 3.0 E18 sej

Information services in engineering design and monitoring

services = \$18.4 E3/ha × 65 ha × 1 E12 sej/\$ = 1.2 E18 sej

The emery costs of the restoration (sum of inputs from Fig. 5) is 5.9 E18 sej and the emery benefit cost ratio is about 1.8:1.

### 3. Phosphate restoration research

Most restoration research related to phosphate mined lands in the early years was primarily concerned with wetlands. There were several reasons for this, the most important of which was the fact that ap-

proximately 15% of the Bone Valley district of Polk and eastern Hillsborough and Manatee counties is overlain by wetlands. Native wetlands include both the herbaceous ecosystems (wet prairies and marshes) and forested or shrub-dominated ecosystems (cypress domes, cypress swamps, mixed cypress–hardwood swamps, bay forests and swamp thickets). In addition to the large wetland acreage, the phosphate industry has been required by law to reclaim wetlands since the adoption of FDNR's rules, which stated that the wetlands affected by mining operations were to be restored



to at least pre-mining surface areas. In other words, wetlands had to be restored acre for acre and type-for-type.

Restoration begins with the recontouring of spoils and the creation of a landscape that includes areas of low topographic relief where surface and groundwaters will contribute to an appropriate hydrologic regime, which will support hydrophytic vegetation. Two techniques have been widely used to introduce wetland vegetation to created wetland areas: mulching and hand-planting. Mulching is the practice of applying organic soils, obtained from wetlands that will be mined, to restoration sites. The thickness varies from a few centimeters to tens of centimeters. These organic soils contain seed material, rhizomes and other genetic material to jump-start restoration. Both planting of the desirable species and mulching are often applied on a given site to further enhance the successful establishment of vegetation.

### 3.1. Early research focused on wetland restoration

The earliest restoration research was carried out by the phosphate companies as demonstration projects often as part of their permitting objectives. In the 5 years following adoption of 16C-16 FAC, most companies had some type of demonstration project, the majority of which were focused on evaluating the potential for herbaceous wetland restoration. Robertson (1985) provides a detailed summary of these early trails by the industry. Several of these industry-sponsored projects evaluated the technique of mulching in the newly constructed wetlands.

In an early test of mulching, Brown et al. (1985) applied mulch in a block design in varying thicknesses. The mulch contained large numbers of propagules and seeds from which a diverse vegetative community developed (Fig. 6). Water levels in the experimental site were lower than the initial design called for, but nonetheless, a full coverage of wetland species germinated from the seedbank.

Most of the early wetland restoration research concentrated on the techniques for establishing a diverse vegetative cover as defined by the Rules of FDNR. An exception was the research by Odum et al. (1983) documenting the interactions between the phosphate industry and wetlands. This multifaceted study evaluated landforms created by mining, the use of detritus as a seed source, tree planting on waste clay sites and the

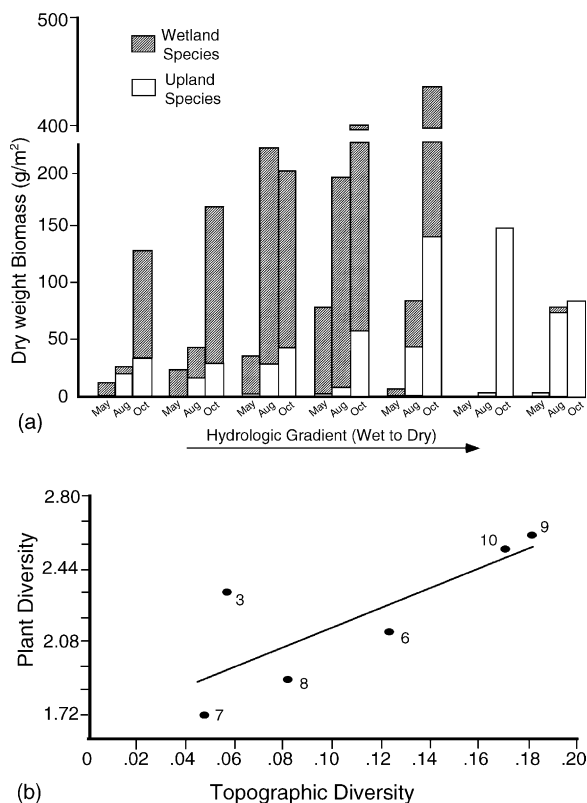


Fig. 6. The mulching of restored wetland sites with organic matter from existing wetlands introduces seeds and rhizomes and other genetic material to jump-start ecosystem development. Hydrology is also an important variable. In the top graph, total biomass and wetland species increase along the hydrologic gradient from wet to dry until they decrease and upland species dominate. An important added benefit of mulching is the topographic diversity that results from uneven application and which translates into higher species diversity because of the variation in “hydrologic habitats” (Brown et al., 1985).

use of tree cores from cypress trees to monitor stress in wetlands. In a continuation of that project, Rushton (1988) focused on the wetland establishment on waste clay sites and documented several general trends that not only applied to waste clay sites but also the overall phosphate mined landscape. These were as follows:

- A pattern of arrested succession emerged that seemed to be related to the distance to seed source.
- The soils characteristic of mined lands tend to have higher concentrations of clay than native soils. These clayey soils tend to lower air and water movement and can range from quite sticky when wet to brick-

hard when dry. They also exhibit considerable expansion and contraction depending on the moisture regime. Soil development is a most important issue.

- Soils and water in phosphate mined areas are high in phosphorus and tend to naturally favor low diversity ecosystem types that are characterized by early successional colonizing species.

### 3.2. *The focus of restoration research shifts to landscape scale*

By the early 1980s, it became apparent that there were critical research needs related to landscape scale restoration. The cumulative area affected by phosphate mining by this time totaled about 200,000 acres (81,000 ha) and the requirements for reclamation had been in effect for over 5 years. Until about 1983, little or no attention had been paid to larger scale restoration issues but instead, research had focused primarily on wetlands and to a lesser extent upland ecosystem restoration. In 1984, the FIPR funded a 5-year restoration research project that was focused on integrated landscape restoration. The study's goals were to develop guidelines for landscape planning and design through studies of Florida watersheds and ecosystems and the integration across landscapes of wetlands, forests and agricultural uses after restoration. Titled "Techniques and Guidelines for Reclamation of Phosphate Mined Lands as Diverse Landscapes and Complete Hydrologic Units" (Brown and Tighe, 1991), the project was designed to provide the phosphate industry with information about the structure and organization of watersheds (sizes, slopes, upland/wetland ratios, spatial organization, etc.) and the structure and organization of ecosystems (dominant species in all strata, soils, topography, hydrologic regime, etc.). In addition, the project team also studied mined lands to characterize typical abiotic conditions in order to cross reference mined lands with appropriate ecosystem types. The results of the study, viewed as a restoration cookbook by its authors, included: (1) design principles and metrics for watersheds, (2) characteristics and design guidelines for streams and floodplains, (3) vegetation and structural characteristics of native ecosystems, and (4) hydrologic regime of native ecosystems.

The study paved the way for additional large-scale research when it concluded that research was needed

to study long-term trends of reclaimed landscapes and suggested six areas for improvement and future research:

1. Restoration of upland and wetland forest ecosystems concentrated exclusively on planting tree species and under-story vegetation was completely absent from restoration planning. A shift in restoration philosophy was needed to insure that species in other strata were included in the restored forested communities.
2. As the lands are reclaimed and surrounding lands are developed, surface hydrology and the overall hydrologic function of the Peace River should be of paramount concern. A regional planning effort is needed to define new watershed boundaries and begin to propose reclamation schemes that enhance regional hydrology.
3. In many areas of the phosphate district, especially older restored lands, non-native vegetation has become important components of the plant community. The long-term consequences of and role of the exotic species on restored lands will become more and more important, especially as mining continues to move southward.
4. The use of phosphate-mined lands for the recycle of treated sewage effluent and sewage sludge should be investigated.
5. The continued practice of requiring the elimination of cattails, primrose willow and Carolina willow (often termed undesirable species) from restoration sites should be re-evaluated.
6. The role of "seed islands" to enhance natural restoration of mined lands through wind and animal seed dispersal should be investigated.

In the late 1980s, recognizing the need for an integrated effort to plan the restoration of the phosphate district, the FDNR's Bureau of Mine Reclamation (BMR) began an Integrated Habitat Network (IHN) plan and published "A Regional Conceptual Reclamation Plan for the Southern Phosphate District" in 1992 (Cates, 1992). The BMR designed the IHN plan (shown in Fig. 7) to be a guide for the reclamation of mined phosphate lands throughout the southern phosphate district. The core lands of the habitat network were the riverine floodplains along major rivers of the district, which were already State property. Lands adjacent to these core areas were to be reclaimed and act as buffer lands

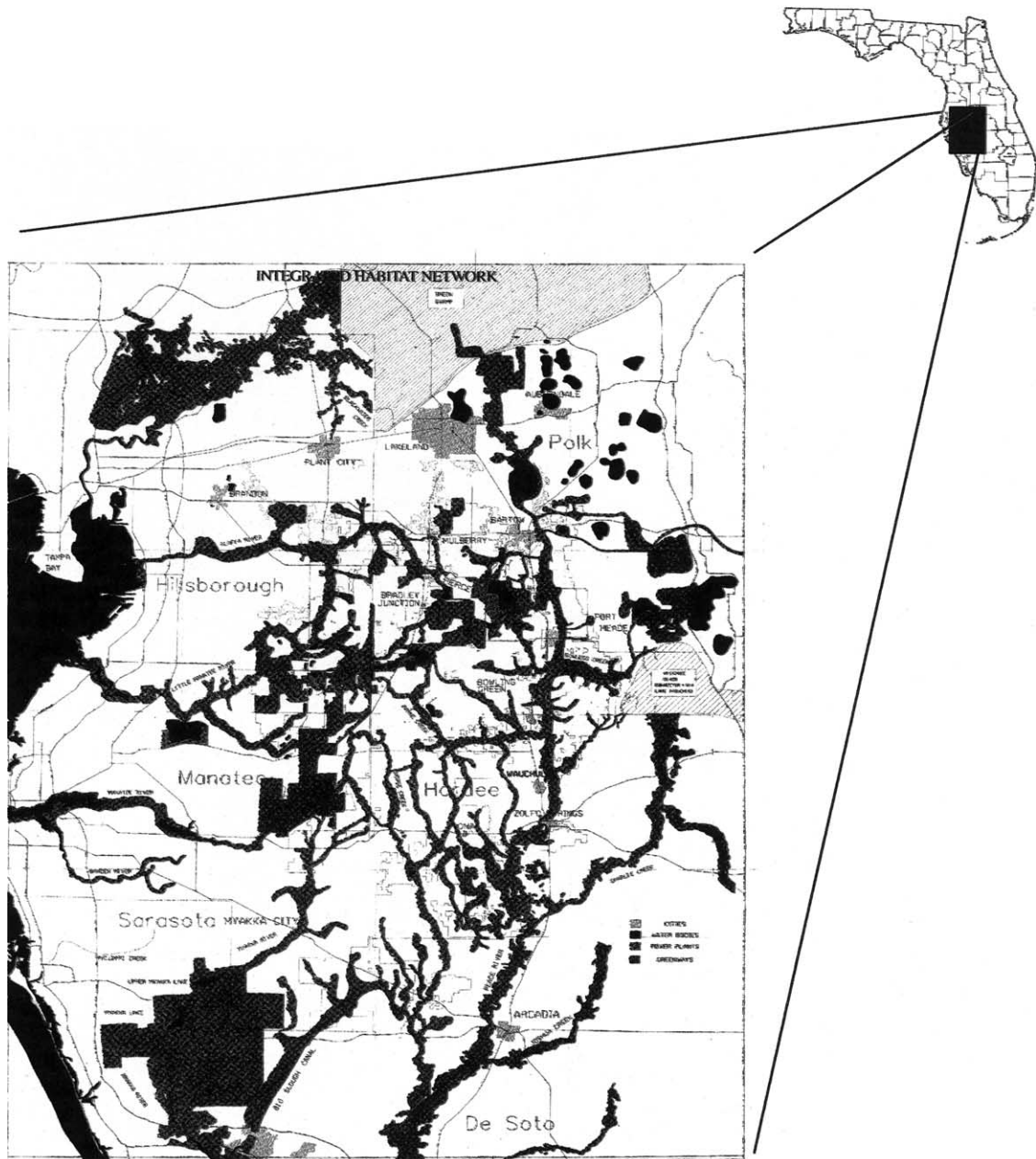


Fig. 7. Integrated Habitat Network (IHN) as proposed by the Florida Bureau of Mine Reclamation. The area shown encompasses all or portions of nine counties totaling 2.56 million acres (1.44 million ha). By 2025, most of the central portion of the map will have been mined. The concept for the IHN is to have a regional network whose core is composed of floodplain ecosystems of streams and rivers connecting several state parks and reserves (rectangular areas). “Adjacent to the floodplain will be a zone which contains mesic/transitional forests, upland forests and other habitats considered “critical” and in need of protection. In general, the progression will be from less-intensive land uses near the floodplain to more-intensive as distance from the floodplain increases” (Cates, 1992).

that would compliment and enhance the habitat value of the core lands, benefit the water quality and quantity in the area and serve as upland habitat connections between the mining region's rivers and significant environmental features outside the mining region (Cates, 1992).

In June 1988, FIPR funded the Central Florida Regional Planning Council to develop a geographical database for the southern mining district. The database was to depict present land use and projected land use to 2010. Recognizing that by 2010, most of the minable phosphate ore will have been extracted from the northern portions of the district and the industry's emphasis will shift almost exclusively to restoration, the study's goals were to develop a GIS database of land use and land cover with projections to 2010. The issues that fostered concern and lead to the regional planning effort were related to the industry's utilization or disposition of their land areas which were being reclaimed and released by the permitting agencies. Some firms were expected to retain ownership of their reclaimed land and use them for agricultural, timber or cattle production. In other areas, because of their close proximity to expanding urban areas, there was the potential for industrial land uses such as waste treatment facilities, power plants, warehousing and other enterprises which could take advantage of the low residential density and in-place infrastructure (roads, railroads, power lines, deep wells, etc.). The regional area was also experiencing population growth pressures and an increased demand for residential, commercial and recreational land. It was felt that the phosphate industry was in a unique position to contribute to the orderly and environmentally sound development of the region (Long and Orne, 1990).

### 3.3. Restoration research becomes regulation driven

Following the 1980s era of macro-scale restoration research, there was a shift towards research that addressed some of the "regulatory dogmas" that were driving restoration. Chief among these was that a successfully restored ecosystem should not contain what state and federal agencies called undesirable species. These included cattail (*Typha* spp.), primrose willow (*Ludwigia peruviana*) and Carolina Willow (*Salix caroliniana*), among others. Several studies (Brown et al.,

1998, 2000; Richardson and Kluson, 2000) were conducted with funding from FIPR to evaluate the effects of so-called nuisance species at the ecosystem level as well as on the growth and survival of planted trees on the restored sites. Simulation models were used to predict the effects of nuisance species on the ecosystem function showing that while they may dominate during early ecosystem development, they soon declined in abundance and importance, but in so doing provided an important service by increasing soil organic matter and nutrient retention (Fig. 8). Field evaluations and simulation models of competition, and structural and functional analysis of ecosystems with and without these species concluded that pioneer species were not as detrimental to community development and in fact may facilitate development.

This was a time of reflection as well. To take stock and learn from restoration efforts to date, FIPR funded several projects that took hard looks at restoration over the 20-year period since the beginning of restoration in 1975. A coalition of researchers, in 1995, from private consulting, environmental organizations and universities embarked on a 2-year study of wetlands restoration by the phosphate industry (Erwin et al., 1997). The primary research task of this ambitious project was to assess and analyze the available database for 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 the existing sites. The project team identified six specific research goals as follows:

1. to provide a database from existing studies to guide operational and policy changes needed to improve design, construction, monitoring and assessment of the constructed wetland projects, and to determine the adequacy of the existing database, 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;

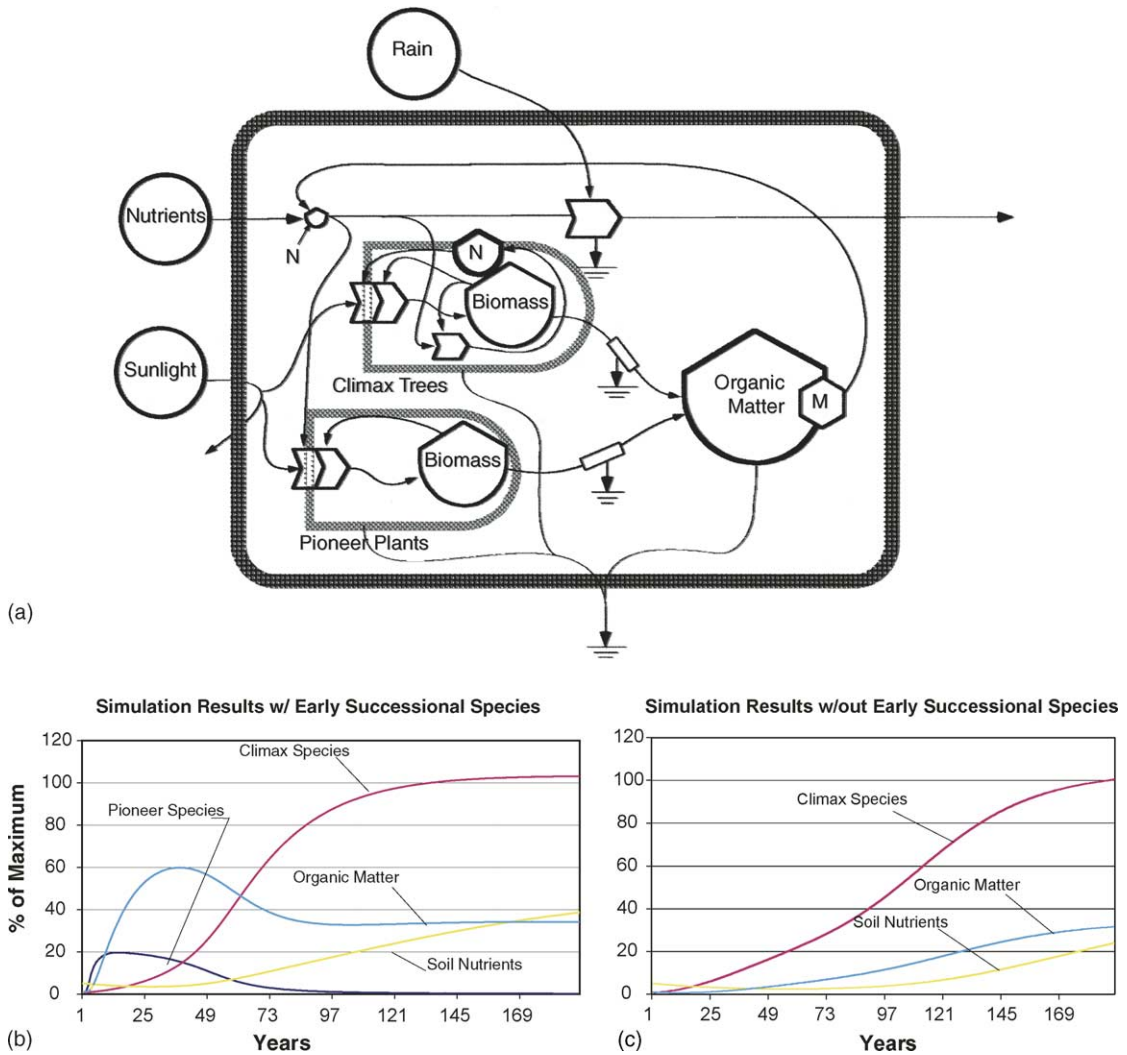


Fig. 8. Simulation model of role of early successional pioneer species in ecosystem development. (a) The competition for sunlight and nutrients between pioneer species and climax species. (b) Graphs of simulation results show ecosystem development is facilitated by pioneer species, primarily in the buildup of organic matter and nutrients. (c) Lower overall storage of organic matter and delayed development of mature community result when pioneer species are eliminated.

3. to determine whether constructed wetlands are properly located in the reclaimed landscapes;
4. to determine ecosystem functions and values provided by the 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 devel-

- opment trends for constructed wetland projects;
6. to identify future research needs of industry and regulatory agencies.

The study concluded with four main areas of concern:

- The overall adequacy of data was poor, limited or lacking in standardization to do quantitative evaluations of constructed wetland success.

- Many of the constructed wetlands observed were apparently persistent. Constructed wetlands were providing similar functions as natural wetlands but at different capacities. Most constructed wetlands provide wildlife functions but sometimes for different groups of species than typically found in similar undisturbed wetlands.
- Reclaimed mine lands are disconnected and dominated by agriculture (primarily pasture and grazing lands) with numerous fragmented habitats and watersheds. 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 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.
- 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 a measurable criteria used to assess the degree of goal attainment. As built surveys of wetlands and topography, post-construction aerial photographs can be used to document the size and configuration of landscape features.

The research team suggested over a dozen needed research topics that spanned scales from regional planning issues to consequences of herbicide spraying in newly constructed wetlands. The document described in detail the successes and failures of past restoration efforts and indicated where industry and the regulatory agencies needed change. Unfortunately, to date it appears that the recommendations have been largely ignored.

### 3.4. *Current restoration research*

As the phosphate ores of the northern portions of the southern phosphate district are mined out, the industry is moving southward. The permitting of new mines is a lengthy process and often contentious. There appears to be significant local opposition to expanding the mined area farther south, and stakeholders have used several

environmental issues as key elements in their challenges. Chief among these is the long-term restoration of these newly mined lands into a functional landscape. There is particular concern regarding the area of land that will be dominated by waste clay settling basins, estimated to occupy as much as 40–60% of the landscape after mining. Another is the effect of mining on regional hydrology. Current research funded by FIPR is addressing both of these topics as well as wildlife utilization of restored lands.

What may be needed is funding of planning research that provides a vision of how the landscape will look and function after mining has ceased and restoration is complete. Without such a vision, there is not a clear goal in mind for measuring restoration success. For instance, the landscape illustrated in Fig. 9 is a conceptual restoration plan for a mine that shows agriculture and wildlands that are integrated into the larger landscape. Hydrologic connections are also stressed. The mosaic of upland and wetland forests that dominates the western portions of the restored landscape is a wildlife corridor that creates a link across the landscape. Large-scale restoration may require an integrated effort of citizens, industry, government and planning agencies to articulate a vision for the entire region and may be an essential exercise to develop consensus and restoration goals.

## 4. **Restoration of phosphate mined lands: an adaptive endeavor**

Adaptive is defined as taking available information into account or able to be adjusted for use in different conditions. One way of looking at this, when applied to living systems, is related to what has been termed adaptive self-organization (Laszlo, 1972) or the ability for living systems to use new information. A second way might refer to the act of management as in adaptive management (Gunderson et al., 1995; Holling, 1978).

### 4.1. *Ecological engineering and adaptive self-organizations*

The management of nature's adaptive self-organization is the field of ecological engineering. With the increased rates and spatial scales of human induced

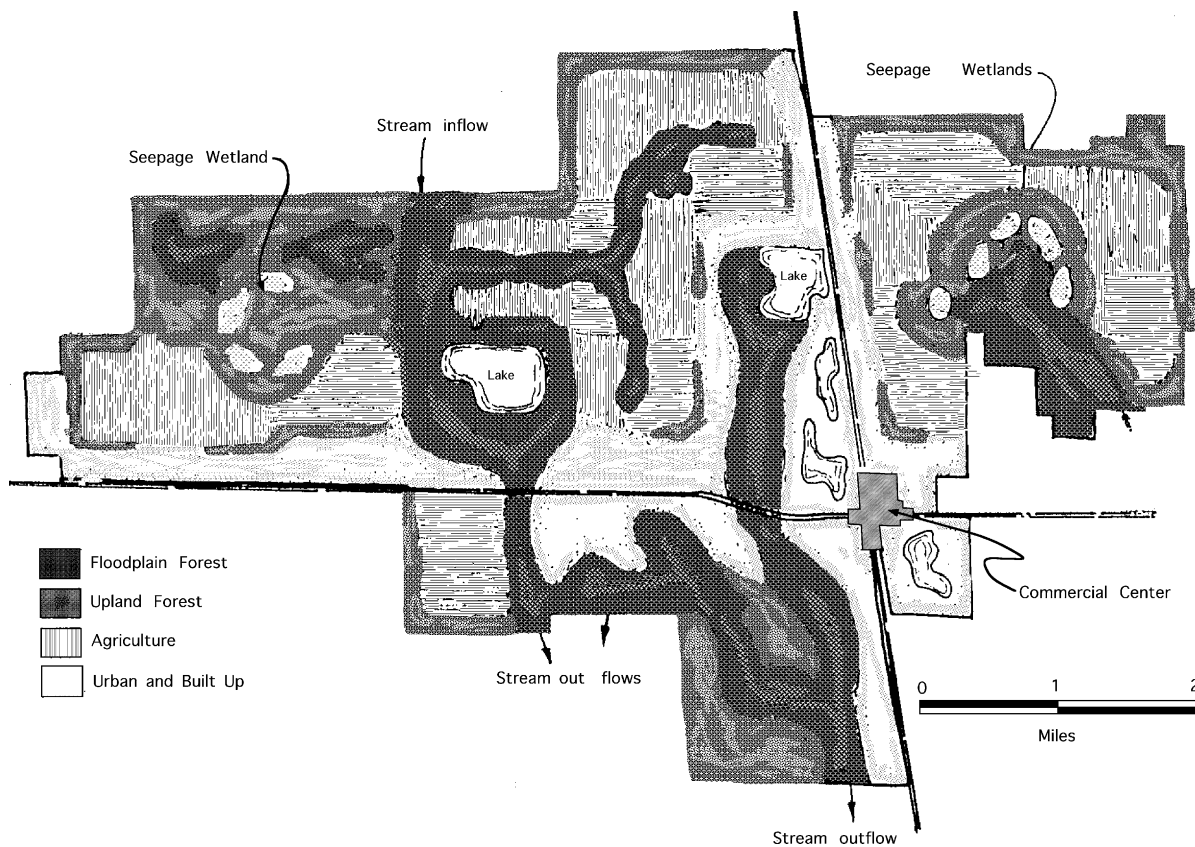


Fig. 9. Conceptual master plan used to visualize what the landscape will look like after restoration. Regional master plans may be necessary so that goals and objectives of restoration and management are articulated and consensus can be reached between stakeholders. The plan integrates ecological, hydrological and human systems both with and in relation to surround lands.

changes to the landscape pattern and processes, the work of ecological engineers through feedback of services and actions controlling self-organization is much needed. The present changing conditions associated with the activities of humans is causing adaptation of the earth's ecosystems to fit them. Ecological engineers can help in this transition by facilitating the movement of species to fill new situations.

Mining, like many other activities of humans, disrupts both organization and driving energies of the landscape which results in ecological restructuring through adaptive self-organization. Throughout the landscape, at the interface between human dominated systems and the natural environment, stand emerging ecosystems. These interface systems often look terrible, disrupted, patchy, stunted and low in productivity. Left alone, nature, using available energy sources and

whatever species are at hand, will eventually develop ecosystems adapted to the new conditions. On the other hand, ecological engineers can assist this adaptive self-organization through their management inputs and facilitate the spread of genetic information that these new emerging environments require.

Since humans have disturbed and displaced large areas of the landscape in which conditions are much different, new species may be required to form new ecosystems. It may be necessary to foster large-scale multiple transplantation of species to develop new designs and new ecosystems. While self-organization and re-establishment of ecological systems will take place anyway, ecological engineers can speed the process by providing new species in tests of adaptive self-organization in carefully selected situations. The mining landscape may need a successional jump-start as

the new conditions associated with mining may require new ecosystems and, therefore, new assemblages of species.

The millions of species of plants, animals and microorganisms are the raw materials of self-design and the palette of the ecological engineer for building new ecosystems. The use of species from different systems generates new combinations of organisms that may self-organize around these changed landscapes. Multiple seeding and the ensuing self-organization, as an ecological engineering technique, may provide new ecosystems for these new conditions, however, sometimes regulation stands in the way of this adaptive self-organization. For instance, the introduction of non-native plants is often forbidden in restoration on the basis that non-natives may be too aggressive and take over large areas to the detriment of native species. In the past, there have been such introductions that some feel have resulted in non-natives becoming problematic. The cogon grass (*Imperata cylindrical*) that was first planted in the early 1900's for forage and erosion control is an example.

Some may consider the presence of non-native species in restored landscapes as not true restoration. Yet because the soils of mined lands (the surface parent material) have been altered and in most cases do not resemble those characteristic of native ecological communities, the likelihood of developing ecosystems with the same suite of species found in the native communities is diminished. Add to this, the fact that today there are many more “introduced” species in the Florida landscape than in the past, and it is quite probable that restored phosphate mined lands will contain non-natives. For these reasons, if restored lands are not highly maintained, the presence of non-natives may be impossible to control. Calling non-natives alien species, Ewel and Putz (2004) have suggested that there is a place for them in restoration, and that “blanket condemnation of alien species in restoration efforts is counterproductive”. Further they suggest . . .

Risk is always an issue when alien species are involved, but greater risk-taking is warranted where environmental conditions have been severely modified through human activity than where reassembly of biological community is the sole goal of restoration (Ewel and Putz, 2004, p. 354)

Certainly, phosphate-mined lands qualify as severely modified. The new situations created by restoration are dynamic. The flows of energy and organizations of abiotic components often are quite different from conditions prior to the alterations that have led to restoration. Good restoration under these dynamic conditions recognizes that adaptive self-organization calls for flexibility and that the goal should be to develop functional ecosystems and landscapes which may or may not resemble the ecosystems and landscapes which were found there prior to disruption. In addition, a rigid ideal of what a restored ecosystem or landscape should look like fails to recognize the dynamic nature of restored systems.

#### 4.2. Large-scale restoration as adaptive management

It goes without saying that the phosphate mining district of Florida is a coupled human and natural system. Additionally, it is obvious that there are many actors or stakeholders involved in the landscape transformation of the phosphate district. Scientists, engineers and regulators work directly with shaping restoration efforts, while the citizens who live in and around the district and who are affected by all aspects of the mining system have had significant (and it might be suggested, increasing) impact on present day mining through their interest in and questions concerning the efficacy of restoration. In all, the stakeholders, including scientists, miners, regulators and local citizens are involved in a program of co-evolution of science, management and policy that somewhat parallels the practice of modern resource management known as adaptive management (Holling, 1978; Walters, 1986; Walters and Holling, 1990; Gunderson and Holling, 2002).

Adaptive management is, as the phrase implies, management through adaptively changing interventions as queues from the system that is being managed suggest change is needed. In other words, management that is tightly coupled with and observant of the system that is being managed. A key difference between the co-evolution that has occurred through the 30 years of phosphate mine restoration and what is termed adaptive management is related to how learning occurs. Most of the literature on adaptive management suggests that improving management policies and practices by learning from the outcomes of operational programs



should be based on quantitatively explicit hypotheses about expected system behaviors (Gunderson, 1999; Walters, 1997). In other words, management activities are crafted as *experiments* complete with testable hypotheses to gain knowledge, which implies a formal process of problem assessment, study design, implementation, monitoring, evaluation, and feedback (Nyberg, 1998). Learning that has occurred in the large-scale restoration of phosphate mined lands has occurred by-and-large as a trial and error endeavor in that there is no formal process as outlined above. In fact, because of the diffuse nature of the organization of stakeholders involved, it would be difficult to develop integrated testable hypotheses at the landscape scale.

To be sure, the science behind phosphate restoration research has been driven by testable hypotheses related to the details of restoration. What is lacking in order for the entire regime of landscape restoration after phosphate mining to more closely fit the definition of adaptive management is a formal process where management activities are crafted as experiments. Because of the diffuse nature of restoration research, implementation and land management that is centered in numerous companies, research institutions and governmental agencies, the management process is incremental and often does not formally direct the research process.

It seems to be the case of all large-scale restoration projects that they involve a very diverse and, in some ways, diffuse organization of stakeholders. How to develop successful mechanisms for effective communication and coordination between the various players is a major concern. By the very nature of large-scale restoration programs and the fact that stakeholders are from numerous organizations, it is difficult to act as a coordinated whole and to foster good communication. Yet, adaptive management requires communication and cooperation. Science must understand the overall goal of the management team and develop scientific investigations that reinforce that goal. The management team must understand what the goal is they are striving for, often provided by the regulatory community on behalf of the citizens of the area. Unfortunately, communication over the last 30 years within the combined system of phosphate stakeholders has not been as strong as might be needed for effective restoration.

A key element of adaptive management is learning; some say, learning by doing (Holling, 1978). In 1995, the efforts of Erwin et al. (1997) to evaluate the first 20 years of wetlands restoration in the phosphate districts was an attempt to learn from what had been done in the past. However, learning requires the time to reflect, stop, observe, process and integrate that which has been observed. While a report was written which documented their findings, it appears that it had a little effect. It was quite apparent to the researchers on the Erwin team that wetlands restoration showed marked improvements over the 20 years of active restoration that had thus far been conducted. What was lacking was a broader perspective, one that integrated wetlands and uplands, natural lands and human dominated land uses. They saw that the broader perspective was also missing from hydrologic planning of the watershed. Further, they recognized that a closer working relationship was needed between industry, regulators and citizens. To function as an adaptive management unit, the stakeholders must work together. Adversarial relationships between citizens, industry, scientists and regulators may hinder effective restoration and in fact may be quite detrimental.

Large-scale restoration requires adaptive management. The restoration of phosphate mined lands if treated incrementally, one mine site at a time and one wetland at a time will not result in an integrated landscape, either hydrologically or ecologically. An overarching vision is needed. In addition, overall management and regulation must be adaptive and flexible and must be capable of self-reflection and internal communication. Above all, large-scale restoration may require that all stakeholders be internalized to the process and that they work together as a single management team.

#### 4.3. Phosphate mining restoration compared to Everglades restoration

It has been suggested that Everglades restoration is the largest single restoration program yet undertaken by humanity. In terms of size and dollar amount, no doubt, this is true. However, if one compares the degree of repair necessary, the restoration of phosphate mined lands may be a far greater challenge. In the Everglades, the emphasis is on getting the water right, while in the phosphate districts, it is on

Table 3  
Comparison of the restoration of phosphate mined lands with the Everglades restoration

	Phosphate reclamation	Everglades restoration
Total area	0.7 million acres	1.5 million acres
Total cost (in US\$)	3.6 billion	7.8 billion
Yearly operating costs (in US\$)	0.0	182 million

re-establishing functional landscapes from otherwise barren ones. Table 3 compares Florida phosphate restoration with that of the Everglades. In the end, the area of restored phosphate mined land will equal about half that of the Everglades and its cost almost half as well. Reclaimed phosphate mined lands will be concentrated in the Bone Valley area of central Florida with a lesser area in the north Florida mining district near the Suwannee River. A key difference between the two programs is that the Everglades will cost about US\$ 182 million per year to operate, while restored phosphate mined lands should require no operating expenses, although if these lands are managed in the future, there will be some costs associated with land management.

## 5. Concluding remarks

The large-scale restoration of phosphate mined lands is ecological engineering on a grand scale. It requires an understanding of the adaptive self-organization in ecological systems, the dynamics of political systems and the demands of social systems. The following are several essentials we have learned from the evolving, adaptively managed system of phosphate mining and restoration:

- Restoration research has stressed the importance of developing complete ecosystems that incorporate all strata, over-story, mid-story and under-story vegetation ... with the understanding that the resulting ecosystems would then develop a full compliment of fauna. But it appears that successful ecological restoration is often only judged by survival of a single strata. There have been few, if any attempts, to develop complete ecosystems on mined lands.

- Research results have shown the beneficial role of all early successional, pioneer species as necessary parts of ecological self-organization, yet there remains a relatively stubborn belief that pioneer species are undesirable and must be eliminated from reclaimed ecosystems.
- The requirement for type-for-type ecosystem restoration may be counter to what is needed in large-scale restoration. The conditions in newly constructed landscapes often do not resemble conditions prior to disruption and, therefore, expecting that replacement of type-for-type may be unrealistic.
- The branding of some species as undesirable because they are non-native to the region of restoration may be limiting restoration potential and restoration success. New conditions call for new assemblages of species.
- Large-scale restoration requires large-scale planning. Without an overall vision and goal, the resulting landscape will suffer from disjointed incrementalism and the political and social systems that revolve around the landscape will continue to be at odds with direction and potential outcomes they cannot perceive.

We have learned much regarding restoration of drastically altered lands. Most of what has been learned is related to the details ... what species are characteristic of native ecosystems, the benefits of mulching related to ecosystem development, wildlife use of restored lands, hydrology of mined lands and so forth. Future research should address the larger scale issues related to adaptively managing the restoration landscape and how it will be hydrologically and ecologically organized and how humans will fit within that organization. Future management need be visionary. Since restoration is incremental and phased as lands are mined, it needs to have a vision of the whole that can be articulated and understood by stakeholders and that can then drive both adaptively managed restoration and the science that is driving it.

## Appendix A. Definitions

*Ecological restoration:* The process of assisting re-establishment of a natural community, habitat, species population, or other ecological attribute that

has been eliminated or greatly reduced on a given location.

*Ecosystem functions:* The dynamic attributes of ecosystems, including interactions among organisms and interactions between organisms and their environment ([http://www.ser.org/content/ecological\\_restoration\\_primer.asp#3](http://www.ser.org/content/ecological_restoration_primer.asp#3)).

*Landscape:* A heterogeneous land area composed of two or more ecosystems that exchange organisms, energy, water and nutrients.

*Landscape restoration:* Assisting the re-establishment of ecological and hydrological functions of landscapes composed of two or more ecosystems.

*Hydrologic function:* The dynamic attributes of the hydrologic systems of an area including base flow, overland flow, recharge, energy transfer and flooding regime and how these attributes affect nutrient cycling, water quality, and aquatic and terrestrial life.

*Disjointed incrementalism:* A policy making process which produces decisions only marginally different from past practice (after Lindblim, 1959).

*Beneficiation:* The process of separating a wanted mineral from other material that also is contained in the matrix. In the case of phosphate, this means separating clay and sand from the phosphate rock. A mechanical process called washing is used to separate the larger phosphate pebbles from the ore. A process called flotation is used to recover the finer particles of phosphate from sand ([www.imcglobal.com/general/education\\_corner/phosphates/terms.htm](http://www.imcglobal.com/general/education_corner/phosphates/terms.htm)).

*Reclamation:* The process by which lands disturbed as a result of mining activity are reclaimed back to a beneficial land use. Reclamation activity includes the removal of buildings, equipment, machinery, other physical remnants of mining, closure of settling areas and impoundments and other mine features, and contouring, covering and revegetation of disturbed areas.

*Overburden:* Layers of soil or rock overlaying a deposit of useful materials or ores. In surface mining operations, overburden is removed using large equipment piled in spoil piles and later used to backfill areas previously mined or in the construction of clay settling area dikes.

*Phosphate matrix:* A mixture of phosphate pebbles, sand and clay found about 10m beneath the ground surface.

## **Appendix B. Rules pertaining to landscape restoration as set forth by the Bureau of Mine Reclamation in Chapter 62C-16, Florida Administrative Code**

### *B.1. 62C-16.0051 Reclamation and Restoration Standards*

This section sets forth the minimum criteria and standards which must be addressed in an application for a program to be approved.

- (1) *Backfilling and contouring:* The proposed land use after reclamation and the types of landforms shall be those best suited to enhance the recovery of the land into mature sites with high potential for the use desired.
  - (a) Slopes of any reclaimed land area shall be no steeper than 4 ft horizontal to one foot vertical to enhance slope stabilization and provide for the safety of the general public.
- (2) *Soil zone*
  - (a) The use of good quality topsoils is encouraged, especially in areas of reclamation by natural succession.
  - (b) Where topsoil is not used, the operator shall use a suitable growing medium for the type vegetative communities planned.
- (3) Wetlands which are within the conceptual plan area which are disturbed by mining operations shall be restored at least acre-for-acre and type-for-type.
- (4) *Wetlands and water bodies:* The design of artificially created wetlands and water bodies shall be consistent with health and safety practices, maximize beneficial contributions within local drainage patterns, provide aquatic and wetlands wildlife habitat values, and maintain downstream water quality by preventing erosion and providing nutrient uptake. Water bodies should incorporate a variety of emergent habitats, a balance of deep and shallow water, fluctuating water levels, high ratios of shoreline length to surface area and a variety of shoreline slopes.
  - (a) At least 25% of the highwater surface area of each water body shall consist of an annual zone of water fluctuation to encourage emergent and transition zone vegetation. This area will also qualify as wetlands under the requirements of

subsection (4) above, if requirements in paragraph 62C-16.0051(9)(d) are met. In the event that sufficient shoreline configurations, slopes or water level fluctuations cannot be designed to accommodate this requirement, this deficiency shall be met by constructing additional wetlands adjacent to and hydrologically connected to the water body.

- (b) At least 20% of the low water surface shall consist of a zone between the annual low water line and 6 ft below the annual low water line to provide fish bedding areas and submerged vegetation zones.
  - (c) The operator shall provide either of the following water body perimeter treatments of the high water line:
    1. A perimeter greenbelt of vegetation consisting of tree and shrub species indigenous to the area in addition to ground cover. The greenbelt shall be at least 120 ft wide and shall have a slope no steeper than 30 ft horizontal to one foot vertical.
    2. A berm of earth around each water body which is of sufficient size to retain at least the first one inch of runoff. The berm shall be set back from the edge of the water body so that it does not interfere with the other requirements of subsection (5).
- (5) *Water quality*
- (a) All waters of the state on or leaving the property under control of the taxpayer shall meet applicable water quality standards of the Florida Department of Environmental Protection.
  - (b) Water within all the wetlands and water bodies shall be of sufficient quality to allow recreation or support fish and other wildlife.
- (6) *Flooding and drainage*
- (a) The operator shall take all reasonable steps necessary to eliminate the risk that there will be flooding on lands not controlled by the operator caused by silting or damming of stream channels, channelization, slumping or debris slides, uncontrolled erosion or intentional spoiling or diking or other similar actions within the control of the operator.
  - (b) The operator shall restore the original drainage pattern of the area to the greatest extent

possible. Watershed boundaries shall not be crossed in restoring drainage patterns; watersheds shall be restored within their original boundaries. Temporary roads shall be returned at least to grade where their existence interferes with drainage patterns.

- (7) *Revegetation*: The operator shall develop a revegetation plan to achieve permanent revegetation which will minimize soil erosion, conceal the effects of surface mining, and recognize the requirements for appropriate habitat for fish and wildlife.
  - (a) The operator shall develop a plan for the proposed revegetation, including the species of grasses, shrubs, trees, aquatic and wetlands vegetation to be planted, the spacing of vegetation and, where necessary, the program for treating the soils to prepare them for revegetation.
  - (b) All upland areas must have established ground cover for 1 year after planting over 80% of the reclaimed upland area, excluding roads, groves or row crops. Bare areas shall not exceed one-quarter (1/4) acre.
  - (c) Upland forested areas shall be established to resemble pre-mining conditions where practical and where consistent with proposed land uses. At a minimum, 10% of the upland area will be revegetated as upland forested areas with a variety of indigenous hardwoods and conifers. Upland forested areas shall be protected from grazing, mowing or other adverse land uses to allow establishment. An area will be considered to be reforested if a stand density of 200 trees/acre is achieved at the end of 1 year after planting.
  - (d) All wetland areas shall be restored and revegetated in accordance with the best available technology.
    1. Herbaceous wetlands shall achieve a ground cover of at least 50% at the end of 1 year after planting and shall be protected from grazing, mowing or other adverse land uses for 3 years after planting to allow establishment.
    2. Wooded wetlands shall achieve a stand density of 200 trees/acre at the end of 1 year after planting and shall be protected from grazing, mowing or other adverse land uses

for 5 years or until such time as the trees are 10 ft tall.

- (e) All species used in revegetation shall be indigenous species except for agricultural crops, grasses and temporary ground cover vegetation.

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