An Overview of Phosphate Mining and Reclamation in Florida

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Introduction

Phosphate has significant economic importance in Florida, yet 70% of surveyed Florida residents claimed that they were uninformed about the industry (Breeze, 2002). Residents who are aware of phosphate mining and fertilizer manufacturing in Florida tend to have strong opinions either in favor or in opposition to its presence.

This document is meant to provide an overview of phosphate mining and reclamation in Florida to address the following questions: Why do we care about phosphate? Why is phosphate mined in Florida? How is phosphate mined? Who is impacted by Florida phosphate mining? What happens to the land after mining? What are some of the controversies of phosphate mining?

The following topics will be discussed: phosphate as a resource, the geology of the Florida phosphate deposits, the economics of phosphate mining and fertilizer production, the history of mining in Florida, the regulations involved in mining, the process of phosphate mining, the reclamation or restoration of the mined areas, and lastly--the controversies surrounding phosphate mining in Florida.

Phosphate

Plants and animals are unable to live without phosphorus. It is an essential component in ATP, an energy-bearing compound that drives biochemical processes. Phosphorus also comprises much of the molecular composition of DNA, RNA, and phospholipids that are necessary to the function of cellular membranes. Nitrogen, another essential element, may be fixed from the atmosphere, meaning its supply is limitless. Phosphorus, present as phosphate minerals in the soil, is a non-renewable resource.

Crop nutrition, before the development of phosphate fertilizers, generally involved the application of manure, human excreta, bone meal, or guano to fields. For thousands of years, organics had been added to soils to improve crop growth, but the concept of why these materials worked was vague. In the early 1840s, two scientists independently laid the foundation for the fertilizer industry. Justus von Liebig, a German chemist, proved that phosphorus and nitrogen salts were the key components of plant growth (Ashley *et al*., 2011). John Bennet Lawes, an English agricultural scientist, examined the application of sulfuric acid to bone phosphate (Russel and Williams, 1977). The process created a phosphate product that was more plant-available and cheaper to transport than bone meal or other forms of phosphate. Lawes further conducted experiments proving the increase in crop production, and manufacture of *superphosphate* quickly became an industry. The process is the same today:

Phosphate Rock + Sulfuric Acid = Phosphoric Acid + Gypsum **Equation 1.**

Phosphoric acid is added to other nutrient compounds to complete the fertilizer product.

The Geology of Florida Phosphate

Deposits of phosphate minerals are present throughout much of the United States and the world. In many places, the phosphate deposits are not economically accessible. Much of the Atlantic Coastal Plain contains recoverable amounts of phosphate deposits; however Florida's geological processes created two regions where deposits of the phosphate mineral, *francolite* (carbonate-fluorapatite), are concentrated enough and close enough to the surface for more profitable retrieval. Riggs (1979) stated that the 'abnormal' combination of geologic factors present in the period made this area of Florida a 'phosphate machine.'

In the Neocene period, beginning 25 million years ago, two conditions were present that aided phosphate deposition and concentration in the region. A trough separating the submerged Florida Platform from the rest of the southeast was filled with sediment erosion from the Appalachian Mountains (Figure 1). Continued Appalachian erosion throughout the Neocene covered the Florida Platform, composed mostly of limestone, with layers of silt, sand, and clay (Lane, 1994).

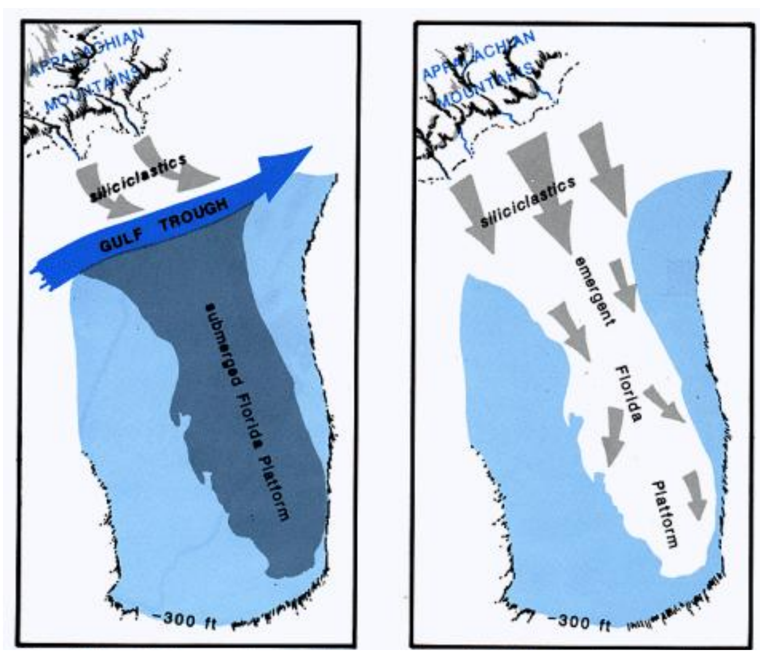

Figure 1. Filling of the Gulf Trough during the Neocene period. (Lane, 1994)

An infusion of cold, phosphorus-rich waters from the deeper ocean basins is believed to have caused a substantial increase in the generation of marine organisms such as plankton. As these organisms died and fell to the sea floor, they were mixed with sediments and resulting reactions formed francolite. Currents and wave action, along with rising and falling sea levels (Figure 2), allowed the concentration of these sediment/organism composites in certain geographic areas. The processes are often termed *reworking*. Geologic structure also played an important role in the concentration of these materials.

These conditions combined to make Florida the most productive phosphate region in the world (Riggs, 1979, Van Kauwenbergh *et al*., 1990).

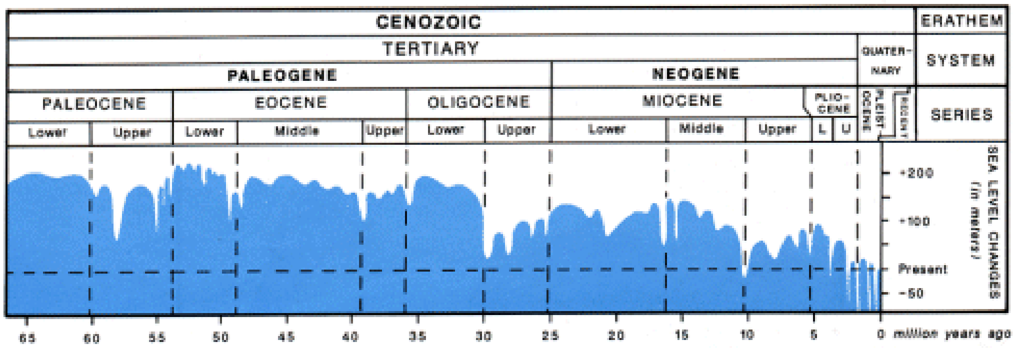

Figure 2. Sea Level Changes during the Miocene and Pliocene. (Lane, 1994)

The phosphate layer is composed of unconsolidated or partly consolidated sand, clay, and carbonate rock. The most abundant minerals present are quartz, francolite, dolomite, and clay minerals. While many phosphate minerals are present, francolite is the only economically important phosphate mineral in the deposit (Van Kauwenbergh, *et al*., 1990).

Phosphate mining is conducted in two regions of Florida (Figure 3). The largest is Central Florida Phosphate District (CFPD) which encompasses parts of Hillsborough, Polk, Hardee, and Manatee Counties. The northern district is located in Hamilton County. The CFPD continues to expand southward into Desoto County.

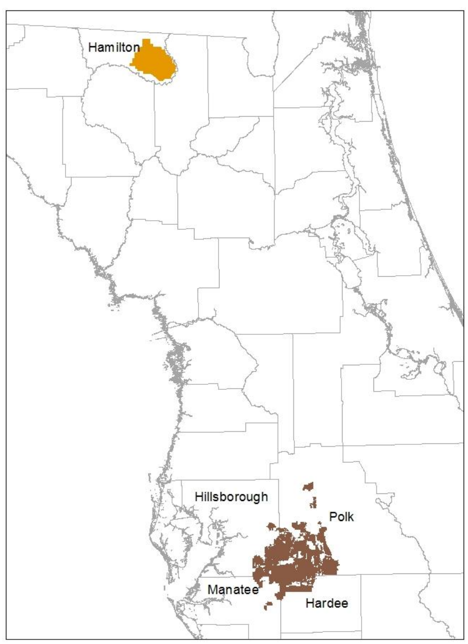

Figure 3. Phosphate Mining Regions of Florida

The Economics of Florida Phosphate

Phosphate rock is used to produce fertilizer, animal feed, detergents, and food and beverage products. Of these products, fertilizer is the most economically important, requiring 90% of the annual world phosphate supply (al Rawashde and Maxwell, 2011).

The United States was the largest producer of phosphate rock; however China greatly increased production between 2004 and 2011 (72.0 million metric tons in 2011) and has surpassed US production. The US produced slightly more phosphate rock (28.4 million metric tons) in 2011 than Morocco (27.0 million metric tons) (Jasinski, 2012). The US is the leading exporter of processed phosphate products, chiefly fertilizer, supplying 25% of the world demand (Jasinski, 2010). The US does not export phosphate rock, but did import 2.5 million metric tons to meet its domestic and foreign demands for fertilizer (Jasinski, 2011).

Three other states currently mine phosphate rock—North Carolina, Idaho, and Utah (Jasinski, 2012). Florida represented 65% of U.S. production of phosphate rock in 2010 (Jasinski, 2010). As in many other industries, consolidation has occurred, reducing hundreds of individual companies to three remaining phosphate companies in Florida: the Mosaic Company (Mosaic), Potash Corporation of Saskatchewan, Inc. (PotashCorp), and CF Industries Holdings, Inc. (CF). All three companies are *vertically integrated*, meaning they mine phosphate *and* manufacture fertilizer. In 2003, the industry in Florida directly provided 6,000 jobs (FIPR, 2012).

Phosphate fertilizer consumption increased dramatically between 2006 and 2008. Rising grain and oilseed prices allowed farmers to use more fertilizer. Grain and oilseed prices rose due to climbing oil prices and an increasing biofuel market. Due to increased demand for phosphate, prices rose rapidly, and then declined due to the global economic downturn (al Rawashde and Maxwell, 2011). Phosphate prices rebounded in 2010 (Jasinki, 2011).

Phosphate prices are expected to continue to rise in the coming decade. Morocco will likely become the leading producer due to their extensive reserves, however Florida contains reserves sufficient to remain one of the key producers for several more decades (al Rawashde and Maxwell, 2011).

Estimates of remaining phosphate reserves are highly variable. Some have stated that phosphate reserves will peak in 2033, while the International Fertilizer Development Center estimates enough world reserves to last for 300-400 years (Van Kauwenbergh *et al*., 2010).

The History of Phosphate Mining in Florida

US phosphate mining began in South Carolina and Tennessee. Starting in 1888, phosphate pebble was mined or dredged from the Peace River in central Florida (Figure 4). By 1908, companies began mining phosphate rock, or *land pebble*, adjacent to the river, and Florida became the leading producer

(Pittman, 1990). In the early decades of phosphate mining, much of the actual phosphate product was lost, because processes couldn’t separate and capture all sizes of the rock.

Figure 4. Phosphate workers at Peace Valley Mine in 1900
State Archives of Florida, Florida Memory, http://floridamemory.com/items/show/32605

The use of electric draglines (Figure 5) increased mining efficiency, however much of the phosphate fraction was still being wasted. During the 1920s, when demand for phosphate fertilizer fell significantly due to economic decline, phosphate companies were forced to find ways to remain competitive. Mining and processing techniques were improved to increase the amount of usable phosphate recovered from the matrix. In 1927 the floatation process was started, and this doubled the recovery levels (Pittman, 1990).

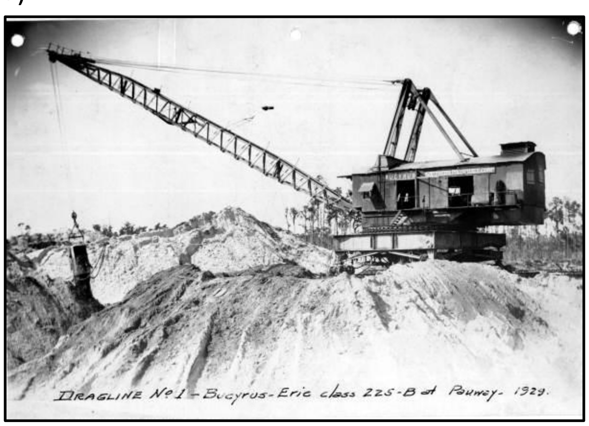

Figure 5. Southern Phosphate Corporation's Bucyrus-Erie class 225B dragline
State Archives of Florida, Florida Memory, http://floridamemory.com/items/show/38806

After World War II, many mining companies began producing the fertilizer near the mine site rather than shipping the rock to other producers. This change reduced the hauling costs, further increasing the efficiency of the industry.

The industry initially concentrated in the north section of the CFPD, where the matrix was composed of a higher percentage of large grain phosphate pebble. Deposits in the north were not only composed of larger grain but also had higher phosphate concentration (14.5%) than the north district or the district extension to the south (Van Kauwenbergh *et al*., 1990).

The Process of Phosphate Mining in Florida

Phosphate mining in Florida is a strip-mining process. *Overburden*, the layers of material above the phosphate, is removed to expose the phosphate reserve (*matrix*). Before mining, exploratory cores are taken to measure the depth of the overburden and the thickness of the phosphate matrix. This coring process is used to determine where mining will be economically feasible. Some of the mine land is owned by the phosphate companies, while in some cases, the companies only have the mineral rights.

When mining is about to begin, an area is cleared of vegetation. Topsoil may be excavated using bulldozers and held in stockpiles for reuse or immediately used at other reclamation areas. A ditch and berm system is constructed to hold water on the mine site. Electric transmission lines are run from the site to the dragline (Figure 6).

Figure 6. Dragline and mine pit (left), people standing near dragline (right). (Florida Geological Survey stock photos—Left by Harley Means and right by Tom Scott)

The process of removing the matrix has remained relatively unchanged with time. Thirty to forty feet of overburden are removed with a dragline and placed aside the mine pits. The phosphate matrix, usually 15 to 25 feet thick, is dug with a dragline and placed into a pit, where the matrix is blasted with a water cannon to turn the matrix into slurry. The slurry is then pumped to the beneficiation plant washer. While cheaper than hauling the matrix by truck, pumping the slurry consumes about one third of the energy used in the process. Approximately 300 million tons of slurry is pumped to the plants each year (Addie *et al*., 2009).

Figure 7. Phosphate matrix (left), larger phosphate pebble (center), pit gun (left). (Florida Geological Survey stock photos—Left and right by Tom Scott; center by Harley Means)

Beneficiation is a physical process that separates the matrix into its components—roughly one part phosphate rock, one part clay, and one part sand. The materials start out highly aggregated and begin breaking apart while being pumped through the pipelines to the plant. The beneficiation plant may be located as far away as 8 miles from the mine. When the slurry arrives at the washer, a 1 mm screen removes all phosphate over that size (*pebble*), leaving sand, clay, and phosphate particles smaller than 1 mm. Hydrocyclones are then used to separate particles less than 0.1 mm. Clay and phosphate particles smaller than 0.1 mm overflow from the hydrocyclone chamber, leaving coarse sand and remaining phosphate particles at the bottom.

The floatation process is used to separate the remaining phosphate particles from the sand. A fatty acid is added to the mixture which coats the phosphate particles and leaves sand uncoated. The coated particles then repel water. Air bubbles are inserted into the compartment and attach to the coated phosphate; the particles rise to the top and can be skimmed and remixed with the larger phosphate pebble (FIPR, 2013b, Tavrides, 1988).

The sands separated out of the matrix, called *sand tailings*, are pumped as slurry from flotation to their disposal sites. Most of the sand tailings material is either used to fill mine pits or cap reclamation areas.

Handling of the clay is the most challenging aspect of the process. Because the clay has been mixed with water, the clay takes up far more volume than when in the ground. The properties of clay allow it to have a very high water holding capacity, making it a significant challenge to separate the water from the clay once it is hydrated. The clay slurry is pumped to an above ground area surrounded by a berm that ranges from 20 to 60 feet in height. These bermed sections, called *clay settling areas* (CSA), are generally 300 to 800 acres in size. The slurry is 3 to 5% solids when pumped into the CSA. The clays are allowed to settle. Some of the water held in the clays will rise to the top and be decanted off in a process called *dewatering*. Settling and dewatering may require several months. When complete, consolidation of the clays begins. Consolidation involves the drying of the surface of the clays. Cracks form, allowing more drying, however the crust that develops over the wetter clays beneath reduces further evaporation. The process is aided by the cutting of extensive drainage channels through the surface of the clays. Consolidation of the clays to 12 to 15% solids can take between 3 and 30 months (Yao and Znidarcic, 1997). For the clay to occupy the same volume while within the matrix before mining, it would require 33% solids (Garlanger and Fuleihan, 1983).

Water used in these processes is recirculated; however water bound up long-term in the clays or lost through evaporation must be replenished from groundwater pumping. Phosphate rock is taken by conveyors to storage piles. Phosphate rock is used to produce wet-process phosphoric acid. The acid is then combined with ammonia and granulated to produce di-ammonium phosphate (DAP) or mono-ammonium phosphate (MAP) (al Rawashde and Maxwell, 2011). The fertilizer is then transported by train to port or other distribution areas throughout the US.

A byproduct of fertilizer production is phosphogypsum (Equation 1 above). For every ton of fertilizer produced, 4.5 tons of phosphogypsum ($CaSO_4$) are produced. While gypsum can be used for many products, the EPA does not allow the use of gypsum produced in Florida due to its elevated radioactivity and the harmful trace minerals this material contains. The gypsum is piled in stacks near the fertilizer processing plants. These stacks are up to 200 feet in height and create significant long-term management challenges (EPA, 2013).

Each component of the beneficiation and fertilizer manufacturing processes is regularly being assessed to improve the efficiency and capture as many of the size fractions of phosphate as possible. A mounting challenge during the beneficiation process is the presence of dolomite. As mining moves south, the matrix deposits contain more dolomite (MgO). Higher dolomite content can make the product unusable. The magnesium contaminates and disrupts the process of phosphate beneficiation. Dolomite is separated from phosphate by grinding the pebble and using a floatation process, however an excess of dolomite can leave a reserve unusable (Gaft *et al*., 2008).

Regulation of the Florida Phosphate Industry

Long before mining operations begin, the phosphate company must submit permit applications and mining and reclamation plans to federal, state, and local agencies. The federal (Army Corps of Engineers and the Environmental Protection Agency) and state agencies (Florida Department of Environmental Protection--FDEP) are primarily involved due to mining's impact on water resources, such as wetlands. Thus, these agencies are not regulating the mining itself, but the impact mining has on the water resources. County agencies have varying levels of involvement. Their interest is in how mining will affect future agricultural or urban development and/or how it will affect the natural resources within their county.

The State of Florida considers mining to be a temporary land use and has two sets of regulations that direct what happens with the land after mining. These two activities can be grouped using the terms *reclamation* and *permitting*.

Reclamation is the activity in which land is put back into *beneficial use* after mining. Beneficial use can include agricultural operations, forestry, recreation, residential and commercial development, or wildlife habitat. Reclamation became a state requirement on any lands mined on or after July 1, 1975. Since that time, more than 190,000 acres have been mined for phosphate in Florida (FDEP, 2010). Approximately 3,000-6,000 acres per year are mined. Key reclamation rules are located in Chapter 62C-16.0051 (Appendix A) and include guidelines for removing mining debris, contouring the land so that steep slopes are removed, and revegetating the land to stabilize it from erosion. Reclamation was not required on lands mined before July 1, 1975, however basic reclamation sometimes occurred.

The permitting process in Florida is called Environmental Resource Permitting (ERP). This program regulates activities involving the alteration of surface water flows, including activities in the uplands that generate storm water runoff. ERP also regulates dredging and filling of other surface waters. When an existing wetland is filled, it can have an impact on the hydrology of the entire area. The same is true if a new wetland is created, or *dredged.* Dredging or filling, conducted improperly, can cause flooding downstream or cause a downstream reduction of streamflow due to the impoundment of water. Even if the dredging or filling have minimal impact on nearby hydrology, the activity could cause ground disturbance that may affect the quality of water entering neighboring wetlands or waterways. The permitting process is meant to provide reasonable assurance that the proposed activity will not cause harm to nearby wetlands and waterways and determines what wetland mitigation will be required.

Part of the permitting process involves deciding which wetlands may be impacted and how much mitigation will be required. Wetlands are scored based on the Uniform Mitigation Assessment Methodology (UMAM). Some wetlands may already be heavily impacted from agricultural drainage that occurred decades before. Impacted wetlands will not score as high as those that have received minimal impact from the effects of agriculture or urbanization.

Wetland mitigation is action taken to replace wetland function impacted by mining. Wetland mitigation may involve the creation of new wetlands, the enhancement of existing degraded wetlands, the preservation of high quality unmined wetlands, or the purchase of mitigation bank credits. In most cases, new wetlands are created in the vicinity of the location of the original wetlands. The FDEP-issued permit will have criteria the wetland must meet before the applicant *is released* from the requirements of the permit. These requirements are generally more stringent than those within reclamation rules. Standard criteria include: a density of 400 or more wetland trees per acre (if the wetland is forested), less than 10% cover by invasive plants, and greater than 80% cover by desirable wetland herbaceous species. There is also typically a criterion meant to assure that the created wetland has composition similar to a *reference wetland.* The reference wetland may be the wetland that was mined or a nearby existing wetland of similar composition to the one that was mined.

There is considerable overlap between the reclamation rules and the wetland permitting rules. The State of Florida is working toward combining the sets of regulations into one system that will still provide needed protection while streamlining the process for the applicant.

Permit applications are also forwarded to the US Fish and Wildlife Service and the Florida Fish and Wildlife Conservation Commission (FWC). Wildlife surveys are conducted before mining to detect the presence of any endangered or threatened animal species. These areas are either avoided during mining, take permits are issued, or in some instances, wildlife may be moved out of the area (*translocated*) and placed in other areas of suitable habitat.

Additional state regulations involve the taxes that are paid for the severance of phosphate from the ground for commercial purposes. This tax, which started in 1971, had totaled 1.35 billion dollars by 2000 (FIPR, 2013b). Money is distributed between the Florida General Revenue, the Conservation and Recreation Lands Trust Fund, counties where mining is located, the Phosphate Research Trust Fund, and the Minerals Trust Fund (Florida State Statutes, 2013).

Reclamation and Restoration

It is easy to confuse the terms *reclamation* and *restoration*. Acceptable reclamation, defined above, may include an effort to return wildlife habitat to an area, but reconstruction of a specific natural community is not necessarily the primary goal. Restoration is a specific focus on transforming a disturbed area toward a particular *ecosystem trajectory* that will allow the area to eventually resemble a natural plant and animal community. Restoration is more costly and challenging, because it involves detailed consideration of soil, vegetation, and structural requirements of the desired natural community (Figure 8). Thus, all post-mining land work is considered reclamation but only some of the reclamation areas are slated for ecosystem restoration. Wetlands are created nearly “from scratch” after mining is complete, and the goal for created wetlands is to closely resemble the wetlands that were impacted. So a wetland creation is an example of reclamation that extends into restoration of a natural community. Within this document, the term *reclamation* is used to include all activities, including restoration, which are implemented to return the land to a beneficial use.

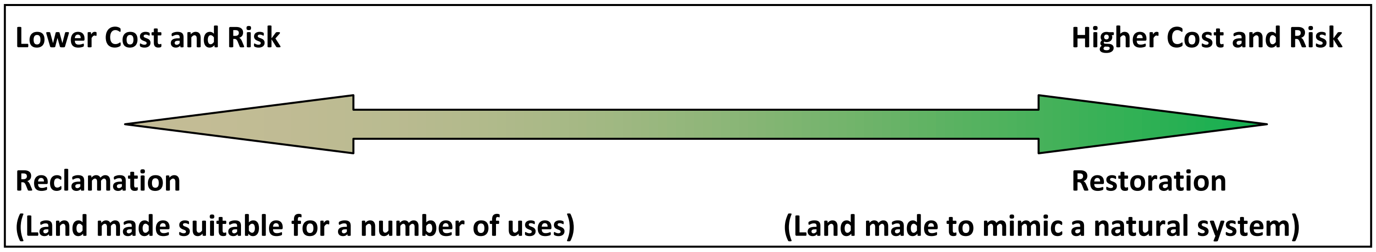

Figure 8. Restoration is usually more expensive and has a riskier outcome than basic forms of reclamation.

Early reclamation often resulted in what is called *land and lakes*. Land and Lakes reclamation areas appear as pastures or wooded areas interspersed with steep sloped, deep pit lakes. Spoil piles were commonly left in place between the lakes and became colonized with Brazilian pepper (*Shinus terebinthifolium*). Most of the native communities typical to Florida—pine flatwoods, sandhills, marshes, and wet prairies were lacking. State reclamation rules were refined several times, and reclamation moved beyond land and lakes into a wider variety of land types, more closely resembling the pre-mining landscape (Clewell, 1981, Brown, 2005).

Planning is crucial for successful reclamation. Wilson and Hanlon discuss reclamation as an opportunity to strategically position future land uses to better facilitate conservation of environmentally sensitive areas while locating economic development in more accessible, less sensitive areas (2012). Phosphate mines range from 4,500 acres to 21,000 acres; the average size is 10,000 acres (Brown, 2005). However mining does not take place throughout the entire mine concurrently. It is conducted in phases by mining unit. In some cases land will remain “in mining operations” for years after mining, because it is being used as a water recirculation area or CSA. Typically, however, reclamation begins soon after the area mining is complete within a mining unit (Wilson and Hanlon, 2012b).

Reclamation begins as overburden spoil piles are pushed into mine pits. Smoothing out the surface of the ground is known as *contouring*. The removal of the matrix leaves a void in elevation. Lakes are still created from some of the voids, however now the lakes are shaped to more closely resemble natural lakes, including littoral zones to improve safety and encourage utilization by more varied groups of wildlife. Sand tailings are pumped in to raise elevations in other areas for the creation of wetlands or uplands. The activity of reclamation is not considered complete until mining debris is removed, vegetation is sufficiently established, and if wetlands are created, they are reconnected to waters of the state.

Wetland Reclamation

In the CFPD, approximately 15% of the phosphate reserves are overlain with wetlands (Robertson, 1985). At least one acre of wetland is replaced for every wetland acre impacted.

The first step in wetland creation is to determine the type of wetland, its location, and its *footprint*. The location and shape may be different from the mined wetlands to account for hydrologic conditions that changed during the mining process. Wetland sizes vary considerably but average approximately 30 acres (Erwin *et al*., 1997). Once those factors are decided, an engineer can formalize the design, calculating proper elevations to assure the appropriate amount of water inflow and outflow to achieve the desired wetland type. The wetland hydrology must be considered within the context of the entire watershed to assure it isn't either holding or releasing too much water.

Usually soon after mining is complete, the ground is contoured to design elevations using bulldozers or scraper pans. The primary substrate material is overburden, but sand tailings are sometimes mixed in with the overburden. If wetland soil is available, it is spread across the surface of the wetland. This technique, known as *mulching*, is one of the more effective methods for herbaceous wetland creation (Clewell, 1981, Robertson, 1985).

An *as-built survey* is usually conducted to assure that the elevations are correct. Contract planting crews arrive and install thousands of herbaceous plants or trees per day. The herbaceous plants are often harvested from older reclaimed wetlands and transplanted into the new wetland. Trees are usually one gallon container plantings but may be up to 7 gallons in size. Planting crews typically use gasoline powered augers to plant the trees. Care is taken to place species in the correct zones. Some wetland plants require standing water, while others prefer moist soils. Timing of tree planting is challenging, because young wetland trees need near-constant moisture, but can be killed if inundated too long.

Many wetlands will have piezometers and rain gauges to monitor hydrology. Water quality is often monitored, too. Wetlands are typically designed to drain into tributaries or creeks, and state law requires that the water meet standards on dissolved oxygen, pH, conductivity, and turbidity, before the wetland is *reconnected* to those tributaries.

In mitigation wetlands, vegetation is quantitatively monitored on an annual basis for a period of 5 to 15 years to determine if trees are surviving and beginning to form a canopy and if desirable native wetland species are dominating the wetland. In most cases, regular maintenance will be required to reduce the cover of invasive plant species. Starting with high quality wetland topsoil and a high density of native herbaceous plantings will reduce the amount of maintenance required (Richardson and Murawski, 2012).

How well are constructed wetlands functioning? A 1997 study found that constructed wetlands with proper hydrology are performing the ecosystem functions of "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" (Erwin *et al*., 1997)

Within 3 to 5 years following construction, most water quality parameters were approaching those of natural systems. The soil pH levels decrease with time and approach the 4.5 to 6.5 range. Conductivities range between 150 and 300 umhos/cm, compared to 50-150 umhos/cm for natural wetlands. Dissolved oxygen in created systems is similar or slightly higher than natural systems. Total phosphorous values approach natural systems by the sixth year (Erwin *et al*., 1997).

Organic matter accumulation increases with wetland age, though native wetlands have significantly higher levels of organic matter accumulation. Nair *et al*. (2001) report an organic C accumulation rate in the A0 and A1 horizons of 320 g/m^2 per year. The C:N ratio and bulk density also decreased with created wetland age.

Soil compaction is frequently observed in constructed wetlands. Compaction is caused by the use of heavy machinery during the contouring phase and can impact the growth of some plants (Erwin *et al*., 1997). Another problem noted in forested wetlands was a lack of microtopographic relief compared to natural forested wetlands. The introduction of *hummocks*, slightly elevated mounds of earth, into a constructed wetland caused an increase in species richness without increasing the coverage by invasive species. Researchers tried various materials for the hummocks and found that sand tailings worked the best while organic matter hummocks did not hold their shape as long (Brown and Carstenn, 2002).

Improper functioning of a constructed wetland system is often attributable to variations in actual hydrologic conditions of a site from anticipated hydrologic conditions. Erwin recommends more time between the final contouring and the construction of the wetland to observe the behavior of the new hydrologic basin (1997).

Herbicide treatment in constructed wetlands is the subject of regular debate due to its expense and the potential for overspray damage to desirable plants. Regular herbicide treatments significantly decrease invasive vegetation compared to wetlands that were not treated. Mean percent cover of invasive plants in non-treated wetlands was 30%, while percent cover in untreated wetlands was less than 10% (Erwin *et al*., 1997).

But, should all weedy "nuisance" vegetation be treated? Some research illustrates that weedy vegetation, such as cattail (*Typha* spp.) and primrose willow (*Ludwigia peruviana*), actually performs important functions in the early successional phase of the wetland. Wetlands with these species were shown to build up organic matter faster and provide shading to forest species accustomed to receiving less light than is present in a newly constructed wetland (Brown and Carstenn, 2002).

Reclamation of Clay Settling Areas

Reclamation of CSAs is discussed separately because these landforms have characteristics that are unique from regular wetland and upland reclamation areas. CSAs comprise approximately 40% of the reclaimed landscape. As mentioned, these structures are large (300-800 acre) areas isolated from the rest of the landscape by a berm.

Urban Development

CSAs are not suitable for urban development because the shrink-swell and water holding characteristics of the clay do not provide a stable foundation for buildings.

Wetlands on CSAs

Much of the CSA remains wet; however, these areas are not allowed for wetland mitigation. CSAs remain dynamic landscapes for decades after reclamation, and achievement of the sort of stable vegetative composition and hydrology required by mitigation wetlands is not possible. Studies of areas mined before reclamation requirements indicate that wetlands on CSAs can become stuck in *arrested succession*, a situation in which a particular plant community dominates for a long period of time and does not allow the system to progress into a climax community. In the case of wetlands in the CFPD, stands of Carolina willows (*Salix caroliniana*) dominate and even after decades, in some cases, a mature hardwood or mixed wetland forest fails to develop. *Flashy* hydrologic conditions are one of the key explanations for arrested succession (Odum *et al.*, 1983). Flashy systems can fluctuate rapidly compared to natural wetlands between periods of inundation and periods of dry cracking soils. Most shrub and tree species are unable to withstand that range of conditions during the establishment period.

Brown *et al*. (2010) conducted a 5-year study of wetlands on CSAs. Hydrologic conditions are determined largely by precipitation, and wetlands on CSAs behave as isolated wetlands. Six CSAs were extensively studied, and the CSAs each contained between 2 and 200 watersheds. Three watershed types were common: 1) small, shallow watersheds less frequently flooded, 2) large watersheds with broad shallow areas that have cycles of flooding and then drying out, and 3) large deep watershed areas that rarely dry out. While several species of planted wetland trees survived and produced significant biomass, recruitment of seedlings was minimal due to the swings between flooding and drought. Herbaceous vegetation was not as diverse as wetlands constructed off of CSAs. The willow systems in this study were productive, served to improve the soil, and may have provided microclimates that improve planted tree survival.

Agriculture on CSAs

CSAs are most commonly used for pasture, though it has been proven that many crops can be successfully grown on them. Drainage improvements are usually required for the soil to be workable with conventional equipment (Hanlon, *et. al*., 1996).

Phosphatic clay contained in CSAs have been shown to have elevated levels of radionulcides compared to natural soils. These radionuclides are believed to somehow become more concentrated by the mining and beneficiation processes. Researchers wanted to know if eating food produced on CSAs could pose unacceptable health risks. A large variety of crops including corn, sorghum, rice, soybean, broccoli, spinach, and carrots were tested. Milk from cows fed on silage from phosphatic clay areas was tested. Beef tissues from cattle fed from forage from CSAs was tested. Some of the CSA crops contained elevated levels of radionuclides. Estimates based on increased exposure increased annual risk of cancer by a negligible amount (Hanlon *et al*., 1996).

Recent studies have been conducted to determine the use of short rotation woody crops for mulchwood or energywood. The most successful species in the study were *Eucalyptus* spp. The studies showed that these species could be grown profitably in certain conditions (Rockwood *et al*., 2006).

Multi-use Landscapes

CSAs, with both uplands and wetlands, can serve to provide a multitude of land uses within a relatively small area, perhaps forming a self-contained multi-product production area. One CSA, with its variability, may have suitable areas for fruit and vegetable crops, pastures and hay production or sod farming, biofuel production, silviculture, aquaculture, and wildlife habitat areas. Rather than being a detriment, ponded areas can be a close and sustainable source of water for crops in the drier areas of the CSA (Hanlon, *et al*., 2011).

Sand/Clay Mix

CF industries pioneered an alternate method of phosphatic clay storage. The idea was to mix two parts sand with one part clay to improve the overall properties of the resulting medium. The method also allowed lower berms and quicker utilization of the land due to faster consolidation. However, this method of phosphatic clay disposal requires 60% of the post-mine landscape area instead of the 40% that conventional CSAs use, and the mix areas are still unsuitable for engineering foundations. Because that leaves 60% of the post-mine area incapable of eventual urban development, Hardee County officials, where this type of reclamation is located, urged CF to return to the use of Conventional CSAs (Hardee Count, 2009).

CSAs and Aquifer Recharge

Schreuder has studied using wetlands and tailings sand as filters to clean water before discharging it back into the Floridan aquifer. This approach was designed to return stormwater and some wastewater to the ground where it is not subject to the evaporative losses that occur in above-ground storage reservoirs. CSAs can be used to temporarily hold water that can then be channeled into a treatment wetland. The water from the wetland then drains into a sand tailings area where it can be further filteredbefpre recharging it in the aquifer (Schreuder, 2010).

Upland Reclamation

Uplands are not given the same legal protection as wetlands, so reclamation of uplands is usually not emphasized with the same vigor as wetlands reclamation (Figure 8 above). The most common upland reclamation outcomes are pasture, pine fields, or oaks mixed with pines. These land types are not difficult to create. However in some cases, there is an attempt to create an upland area more closely mimicking a natural Florida community such as a pine flatwoods, a sandhill, or a scrub. The level of difficulty rises significantly for these community types, and it is this effort that will be discussed in this section. The key challenges are overcoming fundamental changes in soil properties, establishing a ground cover, and protecting plantings from invasive plants.

The entire soil profile is destroyed during the mining process. The substrate after mining will either be sand tailings, overburden, clays or an unknown mixture of those components. These combinations can be highly suitable for agriculture and pasture, but restoring a specific ecosystem with a growing medium that does not possess similar soil properties and profiles to a natural Florida soil order creates several difficulties including atypical moisture and nutrient regimes.

Overburden is highly variable material, with texture characterized varying from sand to sandy clay loam to clay. Overburden can be yellow, orange, tan, brown or mixtures of those colors. Overburden commonly contains clay concretions and mottles (Segal et al, 2001). Unless sand tailings are used, reclamation soils are typically less sandy, higher in plant nutrients, and less acidic than native soils (See Table 1). Sand tailings are usually composed of fine white sand nearly devoid of organic matter (Segal et al., 2001).

	Nutrient Levels	SOM	WHC	CEC	pH
Overburden	Higher	Lower	Higher	Higher	Higher
Sand Tailings	Extractable P and Ca higher; lower K, Cu, Mn	Lower	Lower	Lower	Higher
Phosphatic clays	Much Higher	Lower	Much higher	Much Higher	Higher
Sand/Clay Mix Areas	Higher	Lower	Higher	Higher	Higher

Table 1. Properties of post-mine soil materials compared to typical Florida natural soils. (Information Derived from Wilson and Hanlon 2012a).

For restoration of upland ecosystems, two methods of ground cover establishment are generally used: topsoil transfer or direct seeding. Both methods are often supplemented with containerized plantings of herbaceous grasses, forbs, and/or trees and shrubs. Most of the early efforts at upland restoration included transfer of topsoil from a natural area to be mined. The idea is to improve the growing medium while also transferring desirable propagules to the site. The topsoil, including roots, herbaceous plants, and seed bank is transported and deposited at varied thicknesses (between 6 inches and one foot) on the area to be restored. The topsoil itself is usually a light gray to dark gray fine sand. The substrate is typically a combination of sand tailings and overburden with layers of overburden usually forming the layer directly beneath the transferred topsoil. A detailed study of ten early reclamation sites showed that for greater success of the soil transfer method, the moisture characteristics of the topsoil donor site should be closely matched to the moisture characteristics of the chosen soil material of the recipient reclamation area. Scrub or sandhill topsoil should be placed on sand tailings. Topsoil from a mesic or hydric flatwoods should be added to a sandy or loamy overburden (Segal et al., 2001).

Another soil related challenge discussed in the Segal *et al*. study is compaction. Overburden, with its high moisture content, is prone to compaction when heavy equipment is used to spread it. The researchers recommended deep subsoiling is as a final step after contouring takes place (Segal *et al*., 2001).

Ground cover establishment is the most difficult aspect of upland restoration. Given proximate seed and propagule sources, a disturbed site may eventually restore itself. However in phosphate mining, there are often many hundreds of acres impacted at a single time, and adjacent lands are either already impacted or soon to be impacted, so nearby native propagules are rare, and weedy propagules are plentiful. It is essential to somehow introduce native propagules or plants to the site to establish a ground cover.

Topsoil transfer, already discussed, is a means of trying to capture as much of the native ground cover diversity from a site as possible. However, that method is not always feasible due to hauling costs or the unavailability of appropriate topsoil material. Another common method of establishing a natural upland plant community is direct seeding.

The native seed industry is still rather young in Florida. Because there are few producers and production is challenging, it is typical to see a desirable native flatwoods species' seed ranging between $30 and $300 per pound. With appropriate planting rates requiring several pounds per acre, the cost of the seed is high. Many restorationists chose seed blends harvested from natural area donor sites that were burned the previous summer to enhance seed production. These mixes are often collected using a piece of equipment called a *flail vac*. The flail vac is attached to another piece of equipment such as a front end loader. The equipment is driven through a natural area, and brushes on the flail vac operate much like the brushes on a vacuum cleaner, drawing the seeds into the holding area of the machine. The seed mix is planted using a seed drill that is designed to plant the light, fluffy seed common in Florida natural communities. There is a short window of time in which the harvesting takes place, because the seed operation must occur at a time when the majority of key species have ripe seed. Sometimes the mix will be supplemented with hand collected seed of important species that ripen before or after the flail vac harvest time.

After establishment of the ground cover, maintenance is always required. Regulations require that invasive plants be controlled to less than selected or specified threshold levels, and maintenance of these invasive species is a significant component of the reclamation costs (Richardson and Murawski, 2012). Aggressive weedy species will be present across all soil types whether dominated by sand tailings or overburden, however moist or high nutrient soils will favor these species compared to native species that are adapted to low moisture and low fertility soils. The use of sand tailings directly beneath the topsoil may reduce incursion by invasive plants, but it may also present conditions that are too droughty even for the establishment of plants that are accustomed to scrub conditions (Segal *et al*., 2001).

Herbicide and fire are the most common means of natural community maintenance. Cover by invasive plants is inevitable in restoration sites, however percentages appear to be reduced when topsoil is used versus when it is not used and when a larger number of native propagules are used in the initial planting.

Cogongrass (*Imperata cylindrica*), arguably the worst weed in the CFPD, thrives in all post-mining soil types. Cogongrass spreads by seed and through rhizomes. Cogongrass surrounds reclamation areas and often remains viable in soil piles that are then spread over the surface of the soil by contouring equipment. Cogongrass is a prolific producer of rhizomes, so a small patch of cogongrass, disturbed and spread throughout a site, has the potential to produce hundreds of new patches. Herbicide treatment of the plant before mining operations can greatly reduce the post-mining occurrence of cogongrass.

Most upland Florida natural communities are fire adapted. Fire, prescribed at an appropriate interval after establishment, will usually assist in the development of the community. Concoby illustrated this for a scrub reclamation project during a 2004 study. Burning, in combination with herbicide treatment, reduced nuisance and exotic species cover, increased bare ground (an important component of scrub), and decreased canopy to levels more appropriate for scrub (Concoby, 2004).

Phosphate Mining Controversies in Florida

Opposition to phosphate mining has resulted in numerous legal challenges involving local governments, environmental groups, the FDEP, and the Army Corps of Engineers. Land aesthetics are often given as a reason for the opposition. Many people see areas mined before mandatory reclamation rules and are concerned that all post-mine landscapes will look like that, or they see the CSAs and phosphogypsum stacks as permanent scars marring the typically level Florida landscape. Many of the legal challenges have centered on the phosphate industry's impacts to water resources. Others are more concerned about habitat loss or hydrologic and habit fragmentation.

Impacts to Water Resources

Perhaps the most controversial topic regarding mining is its potential impact on water resources. There are two primary categories of concern regarding water resources: impacts on hydrology by phosphate industry water usage and land use changes and impacts on water quality by discharges of industry water into the waterways.

Hydrology

There is no question that mining has impact on the hydrogeology of the shallow aquifer system and watershed hydraulic characteristics (Erwin *et al*., 1997). Structural changes in the superficial aquifer occur due to removal of material and refilling with alternate materials, possessing different hydraulic properties. Reclaimed areas have more silt and clay-sized particles, causing basins to show a slower response to rainfall recharge. Permeability decreases and bulk density increases, reducing infiltration and increasing above-ground storage. Hydraulic conductivities become much more variable. Overburden basins have slower conductivity than clay settling basins or sand/clay mix basins, presumably due to cracks in the clay containing basins. Sand tailings basins have the highest conductivities. Water-table tests indicate a reduction in confinement between the surficial and intermediate layers. Overburden-capped sand tailings basins most closely match unmined basins in fluctuations to the surficial aquifer levels. Sand/clay mix and clay basins are elevated above the natural grade, and show little connection with hydraulic groundwater systems in the area. Ongoing differential settling of clay-containing basins will create regularly changing equilibrium conditions.

These factors create a complex hydraulic system that is difficult to accurately model. Sand containing trenches may increase groundwater flow and mine-trench orientation will have a large impact on ground water outcomes (Erwin *et al*., 1997).

A 2007 study examined hydrologic impacts to the Peace River watershed. The study determined that urbanization, agriculture, and mining had impacted the Peace River watershed in different ways. Mining operations consumed a large amount of groundwater until the late 1970s when the industry began storing and reusing much of its water. And as discussed, mining also changes the shape and structure of the landscape and its soils, causing additional water storage in some areas and faster discharge in other areas (PBS&J, 2007).

Concern about the potential of streamflow reduction due to mining-induced land changes compelled several studies. Schreuder (2006) found that streamflow was higher in mining basins than in agricultural basins. Streamflow in agricultural basins and mining basins increased during the period between 1980 and 2000. However, the streamflow increase is attributed to two different factors. In mining, it is believed to be a result of reduced evapotransportation due to younger vegetation. In the agricultural areas, the increased streamflow is thought to be due to agricultural pumping of water from confined aquifers to the shallow surficial aquifers. In both cases, changes in rainfall amounts had the greatest impact on streamflow.

Water Quality

Intentional discharges of stormwater are managed through NPDES permits. The NPDES is a federal program managed by the FDEP. Regular water discharges by industries are monitored at certain points to assure compliance with state and Federal water quality standards. However, there have been several instances of emergency discharges or accidental discharges.

Process water is stored in ponds on top of phosphogypsum stacks. Input into the process water ponds will usually match evaporation and withdrawal for re-use, however, if heavy rainfall occurs or the fertilizer plant is temporary shut down and not reusing the water, storage of the water becomes difficult and discharge of the water becomes a necessary option. The water is acidic, averaging a pH of 1.75, and contains many ions, including fluorine and sulfate (Foley and Pollock, 2000). To discharge the water, it must be limed in a two-stage process. Even then, the water may not be of acceptable quality for release (Jardine *et al*., 2005).

Storing process water requires a lot of space and creates a liability. In 1962, a gypsum stack dike break occurred at American Cyanamid Phosphate Complex in Brewster, Florida. Approximately 3 billion gallons of process water were released into Hooker's Prairie. The water was contained and limed on-site before the water was discharged into the South Prong of the Alafia River.

In 1994, a sinkhole opened up under a gypsum stack in Polk County, releasing 4 million cubic feet of phosphogypsum and acidic water into the underlying aquifers (Galloway *et al*., 2013). In 1997, Mulberry Phosphate had a gypsum stack dam break that resulted in the release of approximately 50 million gallons of waters into adjacent marshes and ponds. Acidic water eventually traveled down the Alafia toward Tampa Bay. Estimates of fish killed ranged from 50,000 to 3,000,000 (Foley and Pollock, 2000). In September 2004, a breach at a Riverview phosphogypsum stack caused the release of 65,000 gallons of process water into Hillsborough Bay, impacting coastal ecosystems, including sea grasses and mangroves (PAS and LES, 2005).

Habitat Utilization of Reclaimed Lands

Habitat loss is frequently mentioned by those opposed to mining. Several studies have examined the return of wildlife to reclaimed/restored areas. The most recent and exhaustive study, conducted by Durbin *et al*. (2008), found 299 species of vertebrates on 62 reclaimed sites. The number of species (*species richness*) by site varied from 22 to 127, with higher species richness found on sites that were near a body of water, wildlife corridor, or natural area. Findings from the study lead to three key landscape level recommendations: 1) include habitat heterogeneity in reclamation design, 2) assure connectivity with wildlife corridors and natural areas, and 3) establish habitat targets with measurable goals. At the site level, the study placed emphasis on soil composition stating that appropriate soil composition is the starting point of producing good habitat, and soil compaction is inversely related to the presence and number of some species groups.

Mushinsky and McCoy (1996, 2001) also advocate increased habitat heterogeneity, larger habitat units, and less isolation between reclaimed areas and other natural areas. These researchers emphasize that a broader, regional approach is important to providing the best reclamation for wildlife. Their study analyzed the habitat species of approximately 28 *focal species*. Focal species were chosen by being abundant on their non-mined research sites, but reduced or lacking on the mined sites. No single habitat factor could account for the difference in number. For amphibians, breeding site characteristics were important. For birds, a deficient mid-canopy layer accounted for the lower number of bird species likely to utilize the reclaimed land.

Some vertebrates are not well equipped to recolonize a reclaimed area due to isolation or other barriers. In some cases, certain species must be moved into a new reclamation site to become established. Gopher tortoises, scrub jays, and burrowing owls have been translocated into reclaimed areas with suitable habitat components. These species have specific habit requirements, so the process must be carefully planned and monitored by well-trained biologists.

Landscape Connectivity

Several studies, in addition to the wildlife studies mentioned above, have exposed the need to have greater large scale planning of reclamation efforts. Erwin *et al*. (1997) found that the majority of constructed wetland projects located adjacent to other reclamation areas do not have an ecological connection with those adjacent areas. The projects are really more of a disjointed patchwork.

In 1994, Bud Cates of FDEP and Tim King of FWC addressed this problem by creating a plan for the Integrated Habitat Network. They developed a framework for connecting the reclamation areas via the already-protected river and creek systems (1994). Wilson and Hanlon provide a helpful analogy, calling the larger streams and riparian corridors “the ecological and hydrological backbones of the landscape” (2012b). These stream and riparian corridors provide the best hope for connectivity for a heavily impacted area and have since the 1990s provided regional guidance in connecting reclaimed areas.

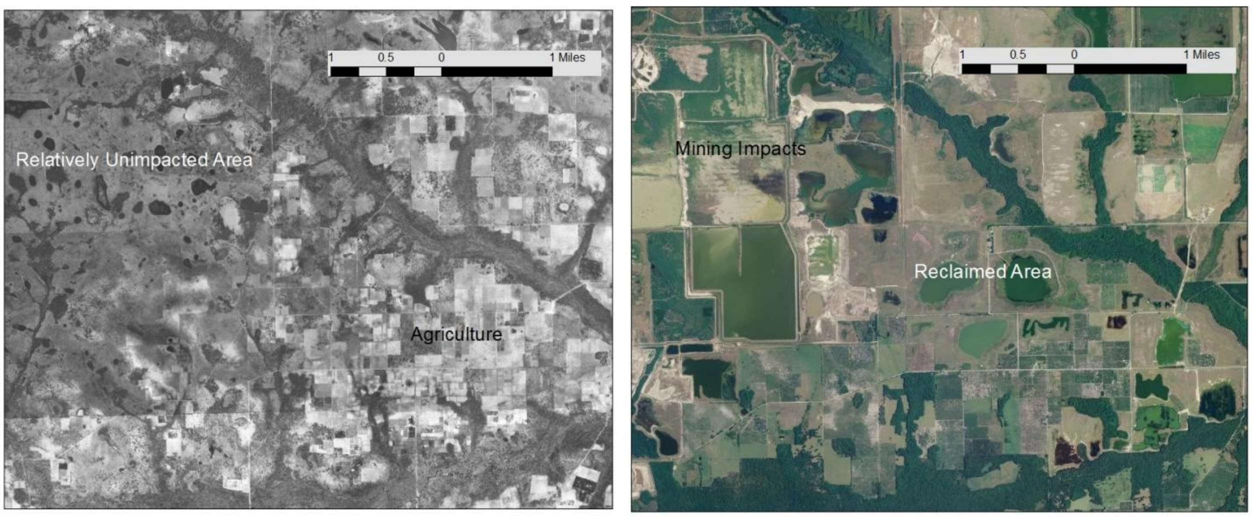

Figure 9. Comparison of 1940s image of Payne Creek and 2004 image of Payne Creek. (Images created by C. Beavers using State of Florida aerials).

Summary

Phosphate is an essential component of plant and animal life. Two regions in Florida have phosphate deposits that are economically profitable to mine. Though no longer the top producer, Florida will remain an important worldwide producer of phosphate fertilizer for several decades. Phosphate mining has a significant impact on the land. Before strip mining begins, phosphate companies apply for permits through local and State governments, as well as the Federal government.

After 1975, state law required the reclamation of phosphate mined lands. Reclamation and restoration have progressed along with increasing regulations; however, many important challenges remain in the field of reclamation. An understanding of soil properties and hydrology is essential for successful reclamation and restoration. Invasive plants, especially cogongrass, are a significant impediment to restoration of native ground covers.

The concerns about mining typically center on its potential effects on hydrology, water quality, habitat utilization, and landscape aesthetics and connectivity. There is room for a great deal more research from the many disciplines that make up the field of reclamation. The focus should be to more efficiently and completely return mined areas to beneficial uses and in the case of ecosystem restoration, to learn to recreate some of the more obscure but important functions of Florida natural communities.

References

Addie, G.R., L. Whitlock, and A. Sellgren. 2009. Centrifugal slurry pump concentration limit testing and evaluation. FIPR Pub. 04-069-233.

al Rawashdeh, R., and Maxwell, P. 2011. The evolution and prospects of the phosphate industry. Mineral Economics, 24(1): 15-27.

Ashley, K. D. Cordell, and D. Mavinic. 2011. A brief history of phosphorous: From the philosopher's stone to nutrient recovery and reuse. Chemosphere 84: 737-746.

Breeze, M. 2002. Public knowledge and attitudes regarding the florida phosphate industry and related issues. FIPR Pub. 00-PUB-184.

Brown, M.T. 2005. Landscape restoration following phosphate mining: 30 years of co-evolution of science, industry, and regulation. Ecol. Eng. 24: 309-29.

Brown, M.T., M. Boyd, W. Ingwersen, S. King, and D. Mclaughlin. 2010. Wetlands on clay settling areas. FIPR. Publication No. 03-149-238.

Brow, M.T., and S.M. Carstenn. 2002. Successional Development of Forested Wetlands on Reclaimed Phosphate Mined Lands in Florida. Volumes 1 and 2. FIPR Publication No. 03-131-193.

Carstenn, S. M. and Mark T. Brown. 2009. Successional Trajectories of Constructed Forested Wetlands. Florida Institute of Phosphate Research. Publication No. 03-142-231.

Clewell, A.F. 1981. Vegetational restoration techniques on reclaimed phosphate strip mines in Florida. Wetlands. 1(1): 158-170.

Concoby, R. 2004. Xeric reclamation techniques and prescribed fire: Florida phosphate mines. 16th International Conference, Society for Ecological Restoration. Victoria, Canada. 24-26 Aug. 2004.

Durbin, D. J., S. Gonzalez, H. Mushinsky, E. McCoy, R. Moore, N. Halstead, and K. Robbins. 2008. Wildlife habitat and wildlife utilization of phosphate-mined lands. FIPR Publication No. 03-147-230.

Erwin, K.L., S.J. Doherty, M.T. Brown, and G.R. Best, editors. 1997. Evaluation of constructed wetlands on phosphate mined lands in Florida. Volumes I-III. FIPR Publication No. 03-103-139.

EPA. 2013a. About Phosphogypsum. Environmental Protection Agency. [www.**epa**.gov/rpdweb00/neshaps/subpartr/about.html](www.epa.gov/rpdweb00/neshaps/subpartr/about.html) (accessed 11 Jan. 2011).

FIPR. 2013b. Phosphate Primer. Florida Institute of Phosphate and Industrial Research. http://www1.fipr.state.fl.us/PhosphatePrimer (accessed 1 Feb. 2012).

FIPR. 2013. Severance Tax of Phosphate. http://www.fipr.state.fl.us/sevtax99.htm (accessed 1 Feb. 2013).

Florida Department of Environmental Protection. 2010. Rate of Reclamation Report from July 1, 1975 through December 31, 2010.

Florida Department of Environmental Protection. Environmental Resource Permitting. http://www.dep.state.fl.us/water/wetlands/erp/permitting.htm (accessed 5 Apr 2013).

Florida State Statutes. 2013. Chapter 211.3103 Levy on tax on severance of phosphate rock. http://flsenate.gov/laws/statutes/2011/211.3103 (accessed 1 Feb. 2013).

Foley, D. P. and A.L. Pollock. 2000. Evaluation of the effectiveness of neutralizing accidental spills of acidic waste water from holding ponds. FIPR Publication No. 01-155-160.

Gaft, M., R. Stana, I. Sapir-Sofer, and H. Modiano. 2008. LIBS Module for dolomite content evaluation on a conveyor. FIPR Publication No. 04-067-224.

Galloway, D., D.R. Jones, and S.E. Ingebrits. Land Subsidence in the US. US Geological Survey. Circular 1182. http://pubs.usgs.gov/circ/circ1182/#pdf (accessed 5 Apr 2013).

Garlanger, J.E. and N.F. Fuleihnd. Reclamation Options for Clay Settling Areas. 1983. In: Robertson, D.J., editor, Reclamation and the Phosphate Industry. Proceedings of Reclamation and the Phosphate Industry Symposium, Clearwater Beach, FL. 26-28 Jan. 1983. FIPR Publication No. 03-036-010.

Hanlon, E.A., R.A. Jerez, and J.A. Stricker, editors. 1996. The mined lands agricultural research/demonstration project: summary of experiments and extension recommendations. FIPR Publication No. 03-093-128.

Hanlon, E.A., M. Wilson, C. Beavers, and J. Cates. 2011. Landscape Diversity: Multiple-Use Lndscapes for Reclaimed Phosphatic Clay Ares. UF IFAS EDIS Publication SL229. http://edis.ifas.ufl.edu/pdffiles/SS/SS44900.pdf (accessed 2 Feb. 2013)

Hardee County Planning and Zoning Board. 2009. *Minutes of 5-21-09 Meeting*. [Comment by David Gossett of CF Industries].

Jardin, K. J., W. N. Futch, and D. H. Michalski. 2005. Piney Point Pond Water Remediation Using Reverse Osmosis. FIPR Publication No. 01-183-214.

Jasinski, S.M. 2010. Phosphate Rock. In: 2010 Minerals Yearbook. U.S.Geological Survey. 56.1-56.10.

Jasinski, S.M. 2011. Marketable Phosphate Rock—Crop Year 2011. In: Mineral Industry Surveys. U.S. Geological Survey.

Jasinski, S.M. 2012. Phosphate Rock. In: Mineral commodity summaries 2012. U.S. Geological Survey. 118-119.

King, T. and Cates, W. 1994. A Three-Part Regional Habitat Mitigation Plan as the Foundation for the Southern Phosphate District of Florida's Integrated Habitat Network.

Lane, E., editor. 1994 Florida's geological history and geological resources. Florida Geological Society. Special Publication No. 35. Tallahassee, FL.

Nair, V.D., D.A. Graetz, K.R. Reddy, and O.G. Olila. 2001. Soil Development in Phophate-Mined Created Wetlands of Florida, USA. Wetlands. 21(2): 232-239.

Odum, H.T. 1983. Interactions of Wetlands with the Phosphate Industry. FIPR Publication No. 03-007-025.

PBS&J. 2007. Peace River Cumulative Impact Study. Florida Department of Envrionmental Protection. http://www.dep.state.fl.us/water/mines/pr_cis.htm (accessed 2 Feb. 2013).

Pittman, W. E. 1990. The Florida phosphate industry. Nutrient Cycling in Agroecosystems, 25(3), 193-196.

Polaris Applied Sciences, Inc. and Lewis Environmental Services. 2005. Preassessment data report, Mosaic acidic process water release, Riverview, FL.

Riggs, S. R. 1979. Phosphorite sedimentation in Florida; a model phosphogenic system. Economic Geology, 74: 285-314.

Robertson, D.J. 1985. Freshwater wetland reclamation in Florida: an overview. FIPR Pub. 03-000-033.

Russel, D.A. and G.G. Williams. 1977. The history of chemical fertilizer development. SSSA 41: 737-746.

Schreuder, P. 2006. Impact of phosphate mining on Streamflow. FIPR Publication No. 03-145-220. Schreuder, P. 2010. Wastewater treatment with wetland and tailings sands filtration prior to confined aquifer recharge. FIPR Publication No. 03-153-239.

Tavrides, .G. 1988. Assessment of present phosphate mining and beneficiation practice and the evaluation of alternative technology. FIPR Pub. 04-031-068.

Van Kauwenbergh, S. J.; Cathcart, J. Bachelder, and McClellan, G. H. 1990. Mineralogy and alteration of the phosphate deposits of Florida. USGS Bulletin No. 1914.

Van Kauwenberg, S. J. 2010. World phosphate Rock Reserves and Resources. International Fertilizer Development Center. Muscle Shoals, Alabama.

Wilson, M. and E. Hanlon. 2012a. Florida Reclaimed Phosphate Mine Soils: Characteristics, Potential Uses, and Management Considerations. UF IFAS EDIS Publication SL370. http://edis.ifas.ufl.edu/pdffiles/SS/SS57100.pdf (accessed 2 Feb. 2013).

Wilson, M. and E. A. Hanlon. 2012b. Multiple-Use Landscapes: Reclaimed Phosphate Mined Lands. UF IFAS EDIS Publication SL374. http://edis.ifas.ufl.edu/pdffiles/SS/SS57500.pdf (accessed 2 Feb 2013).

Yao, D. T. C. and D. Znidarcic. 2001. Crust formation and desiccation characteristics for phosphatic clays: user's manual for computer program CONDES0. FIPR Pubication No. 04-055-134.

Appendix A: Chapter 62C-16.0051 Reclamation and Restoration Standards.

This section sets forth the minimum criteria and standards for approval of a conceptual plan or modification application.

(1) Safety.

(a) Site cleanup. All lands reclaimed shall be completed in a neat, clean manner by removing or disposing of all visible debris, litter, junk, worn-out or unusable equipment or materials, as well as all footings, poles, pilings, and cables in conformance with the requirements of subsection (9) of this section. If any large rocks or boulders exist as a result of mining, these should be left either at the surface where they are distinctly visible or placed in mined-out areas and covered to a minimum depth of four (4) feet.

(b) Structures. All temporary buildings, pipelines, and other man-made structures shall be removed with the exception of those that are of sound construction with potential use compatible with the reclamation goals.

(2) 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 four (4) feet horizontal to one (1) foot vertical to enhance slope stabilization and provide for the safety of the general public. For long continuous slopes, mulching, contouring, or other suitable techniques shall be used to enhance stabilization. Should washes or rills develop after revegetation and before final release of the area, the operator shall repair the eroded areas and stabilize the slopes to eliminate any further similar erosion.

(b) The operator shall inform the department of the nature and an estimate of the amount of strata planned to be removed during mining operations that is unsuitable for general reclamation use because of its potential hazard to the health and safety of the general public. Material of this type that occurs naturally within the general mine site shall be replaced in the mine cut beneath all other backfill material. Any material that is not naturally occurring within the general mine site shall be disposed in accordance with the provisions of paragraph 62C-16.0051(9)(c), F.A.C.

(3) 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.

(4) Wetlands within the conceptual plan area that are disturbed by site preparation or mining operations shall be restored at least acre-for-acre and type-for-type. At a minimum, type-for-type shall mean restoration at least to Level II of the Florida Land Use, Cover and Forms Classification System (DOT 1999) (FLUCCS), as incorporated by reference herein. When using FLUCCS, the following shall apply: wetlands on the site shall be given a 600 prefix; natural streams shall be designated as 511; ditched or otherwise channelized natural streams shall be designated as 512; a ditch through a wetland area shall be designated as 513; and a ditch cut through uplands shall be designated as 514. Non-wetland flood plain areas that are designated as other surface waters in accordance with Rule 62-340.600, F.A.C., shall be given the appropriate upland land use cover classification with a suffix of "O" indicating "other surface waters." Furthermore, restoration shall be designed to reflect the biological structure and hydrology of the wetland community that was disturbed, but shall not require total replication of the previous wetland vegetation.

(5) Surface waters other than wetlands, as identified and delineated pursuant to Rule 62-340.600, F.A.C., within the conceptual plan area that are impacted by site preparation, mining or mining operations shall be restored based upon the type of natural systems present at the time of submittal of the conceptual reclamation plan application, e.g., natural streams, natural lakes (including ponds) and non-wetland flood plains. When wetland communities are directly associated

with other surface waters, restoration of such wetland communities shall be integrated into the restoration of the surface waters. Natural lakes (including ponds) and non-wetland flood plains shall be restored at least acre-for-acre and type-for-type. However, non-wetland flood plains may be restored as wetlands provided the floodplain functions of the system are maintained or improved. Natural streams include streams that have been subjected to man-made or man induced alteration or replacement of the historic flow channel, including but not limited to channelization, canalization, or flow modifications. Natural streams do not include man-made or man induced tributaries or channel extensions beyond the lateral or upstream boundary of the historic stream channel when such do not represent a direct modification of or replacement for the flows of the historic channel. Natural streams shall be restored based upon at least replacement of the linear footage of the stream impacted, as it existed at the time of conceptual plan submittal. Therefore, when a natural stream has been subjected to previous alteration that replaces the function of the historic channel, the length of channel requiring restoration shall reflect the existing condition, at the time of conceptual plan submittal, and not the pre-alteration condition of the stream. However, when the impact is to an altered segment of a natural stream between existing unaltered segments, and that impact consists of mining operations that include excavation of the overburden underlying the stream segment, the entire length between the segments must be restored as a natural stream. If the impact consists only of stream crossings, then the restoration need only reflect the existing condition of the stream segment. Restoration of natural streams shall be designed to conform the length of a restored stream to at least Rosgen Level II channel classification in the basin as needed to meet the definition of restoration in Rule 62C-16.0021, F.A.C., considering the historic and reclaimed landscapes as determined using Applied River Morphology (Rosgen 1996), as incorporated by reference herein, or other comparable classification system approved by the department, unless mitigating factors indicate that restoration of previously modified streams as a different type of lotic system would produce better results for the biological system and water quality. Other than altered natural streams, as previously noted, restoration shall not be required for artificial surface waters that are not wetlands, constructed in areas that would otherwise be uplands.

(6) Wetlands and Water Bodies. The design of created wetlands and water bodies shall be consistent with health and safety practices, maximize beneficial contributions within local drainage patterns, provide aquatic and wetland 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 other than streams shall consist of an annual zone of water fluctuation to encourage emergent and transition zone vegetation. If the area meets the definition of a wetland in Rule 62C-16.0021, F.A.C., then it will also meet the requirements of subsection (4) above. 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) Other than streams, at least 20% of the low water surface shall consist of a zone between the annual low water line and six feet below the annual low water line to provide fish bedding areas and submerged vegetation zones.

(c) The operator shall provide 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 feet wide and shall have a slope no steeper than 30 feet horizontal to one foot vertical.

(7) Water Quality.

(a) All waters of the state on or leaving the property under control of the operator shall meet applicable water quality standards of the department.

(b) Water within all wetlands and water bodies shall be of sufficient quality to maintain their designated use as defined in Rule 62-302.200, F.A.C.

(8) 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.

(9) Waste Disposal.

(a) Clay Wastes.

1. Disposal areas shall be reclaimed as expeditiously as possible. Experimental methods which speed reclamation and which are consistent with these rules are encouraged.

2. To the greatest extent practical, all waste clays shall be disposed in a manner that reduces the volume needed for disposal.

3. Above-ground disposal areas shall be reclaimed in a manner so that long-term stabilization of retention dikes and dams is assured.

4. Waste clays shall be disposed in a manner which minimizes the length of time waste disposal sites are needed for mining operations, reduces the impact on drainage patterns and premining topography, and considers post-reclamation land use potential.

(b) Sand Tailings.

1. Sand tailings should not be permanently spoiled above natural grade unless needed to meet regulatory or environmental requirements.

2. The operator shall give highest priority to the use of sand tailings for backfilling mine cuts. This priority shall not exclude the use of sand clay mix in reclamation when approved by the department. Sand tailings shall not be permanently disposed or deposited within, or used for the construction of, clay settling areas unless authorized by the department.

(c) Solid Waste.

1. Solid waste that is generally considered to be not water soluble and non-hazardous in nature, and that is generated as a result of mining operations may be disposed on-site during reclamation in accordance with any applicable permit conditions. Such waste includes steel, glass, brick, concrete, asphalt material, pipe, gypsum wallboard, and lumber, as well as rocks, soils, tree remains, trees, and other vegetative matter.

2. Solid waste that could create a public nuisance or adversely affect the environment or public health, such as garbage, white goods, automotive materials including batteries and tires, petroleum products, pesticides, solvents, or hazardous substances, shall be managed in accordance with the requirements of Chapter 62-701, F.A.C.

3. Solid waste that is a hazardous waste shall be managed in accordance with the requirements of Chapter 62-730, F.A.C.

4. In no case shall solid waste be disposed in any natural or artificial body of water, including groundwater. Clean debris may be used as fill material in any area, pursuant to Sections 403.703(33) and 403.707(2)(f), F.S.

(10) 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 one 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 premining 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 tree species. 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 one 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 one year after planting and shall be protected from grazing, mowing, or other adverse land uses for three years after planting to allow establishment.

2. Wooded wetlands shall achieve a stand density of 200 trees/acre at the end of one year after planting and shall be protected from grazing, mowing, or other adverse land uses for five years or until such time as the trees are ten feet tall.

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

(11) Wildlife.

(a) The operator shall incorporate measures into the conceptual plan or conceptual plan modification to offset fish and wildlife values lost as a result of mining operations and shall identify special programs to restore, enhance, or reclaim particular habitats, especially for endangered and threatened species, as identified by the Florida Fish and Wildlife Conservation Commission or the U.S. Fish and Wildlife Service.

(b) The operator may designate specific locations within the mine as “Wildlife Areas” and include a plan for reclamation and management for sites so designated. Slopes, revegetation, and erosion control requirements may be modified by the department in such areas on a case-by-case basis where such changes will benefit the overall plan for the propagation of wildlife.

(12) Time Schedule for Reclamation Parcels.

(a) Each operator shall develop a time schedule for completion of the reclamation process in the area covered by a reclamation parcel. The time schedule shall include an estimate of:

1. When removal of phosphate rock in the area will be completed, including the estimated acreage to be mined in each calendar year that mining will occur.

2. When any other mining operations phase in the area will be completed and an explanation of such operations.

3. When waste disposal will be started and completed.

4. When contouring will be started and completed.

5. When revegetation will be started and completed.

(b) Completion dates.

1. Where mined-out areas will be used for waste disposal, waste disposal shall be completed as soon as practical after mining has occurred. Waste disposal on other sites shall also be completed as soon as practical. The completion date for waste disposal shall consider the availability and volume of materials needed.

2. Contouring for all acres mined shall be completed no later than 18 months after an area is capable of being contoured. When additional mining operations, such as waste disposal, occur in a mined area, then contouring shall be completed no later than 18 months after an area is capable of being contoured. If contouring is needed on lands that are disturbed by mining operations, but not mined, then contouring on such lands shall be completed no later than the end of the year following the year in which mining operations ceased on such lands.

3. Revegetation shall be completed as soon as practical after each acre is contoured, but no later than six months after contouring is required to be completed. The department may allow a later completion date upon a showing of good cause.

4. Reclamation and restoration shall be completed within two (2) years of the actual completion of mining operations, exclusive of the required growing season to ensure the growth of vegetation, except that where sand-clay-mix or other innovative technologies are used, the department may specify a later date for completion. The required completion date may vary within a reclamation parcel, depending upon the specific type of mining operation conducted.

5. The completion dates for each phase of the reclamation and restoration activities shall be extended by the period of any delays attributable to causes beyond the reasonable control of the operator.

6. Initiation and completion dates should be specified by month and year only with initiation being the first day of the month and completion being the last day of the month.

7. The actual completion dates for contouring, revegetation, and the period of establishment shall be based on information provided in the annual reports, as required by Rule 62C-16.0091, F.A.C., and verified by the department.

(13) Exceptions and Innovations. In order to encourage the development of new technology that will hasten reclamation or improve the quality of restored lands, the Secretary may grant a variance to any of the requirements of Rule 62C-16.0051, F.A.C., to accommodate experimental or innovative techniques when the technology is not proven.

Specific Authority 378.207 FS. Law Implemented 211.32, 378.207, 378.209 FS. History–New 10-6-80, Amended 7-19-81, Formerly 16C-16.051, Amended 2-22-87, Formerly 16C-16.0051, Amended 2-19-02, 5-28-06.