WETLAND AND WATERBODY RESTORATION AND CREATION ASSOCIATED WITH MINING

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ABSTRACT. A review of published and unpublished reports was combined with personal experience to produce a summary of the strategies and techniques used to facilitate the establishment of wetlands and waterbodies during mine reclamation. Although the emphasis is on coal, phosphate, and sand and gravel operations, the methods are relevant to other types of mining and mitigation activities. Practical suggestions are emphasized in lieu of either extensive justification or historical review of wetlands mitigation on mined lands.

The following key points should receive attention during planning and mitigation processes:

* Develop site specific objectives that are related to regional wetland trends. Check for potential conflicts among the proposed objectives.

* Wetland mitigation plans should be integrated with mining operations and reclamation at the beginning of any project.

* Designs for wetlands should mimic natural systems and provide flexibility for unforeseen events.

* Ensure that basin morphometry and control of the hydrologic regime are properly addressed before considering other aspects of a project.

* Mandatory monitoring (a minimum of three years is recommended) should be identified as a known cost. Rely on standard methods whenever possible.

Well-designed studies that use comparative approaches (e.g., pre- vs. post-mining, natural vs. restored systems) are needed to increase the database on wetland restoration technology. Meanwhile, regional success criteria for different classes of wetlands need to be developed by consensus agreement among professionals. The rationale for a particular mitigation strategy must have a sound, scientific basis if the needs of mining industries are to be balanced against the necessity of wetland protection.

OVERVIEW

The protection of wetlands is an issue of national concern. Of primary concern is how to mitigate for wetland losses. Few cost-effective opportunities exist to restore and create wetlands, thereby helping to reverse the trend in wetlands loss and perhaps create an increase. Surface mining, which historically has had substantial negative impacts upon the landscape, may offer some realistic and inexpensive mitigation options, if mitigation plans are integrated into mine reclamation plans at an early stage. To help guide those who make day-to-day decisions about wetland mitigation, this review provides a summary of the methods used to create and restore wetlands and waterbodies during mine reclamation. The recommendations presented at the end of this review can serve as a checklist to help ensure that constructed wetland systems function properly.

This review focuses on surface mining for coal, phosphate, and sand and gravel. It must be recognized that mining of these materials will continue in the U.S. into the foreseeable future. Coal is an essential component of electrical energy production, the fertilizer and chemical industries depend heavily on phosphate rock, and the construction industry requires continued access to sand and gravel reserves. Therefore, mitigation decisions should be based on consensus agreement among knowledgeable individuals who are familiar with both mining operations and wetland trends in the particular physiographic region in question.

The principles pertaining to these three extractable materials will, of course, have a bearing on other types of mining and severe landscape disturbances (e.g., placer mining; hydraulic mining and in-stream dredge mining; open pit mining and sand mining for metal ores, limestone and other rocks; peat extraction). Important literature on wetland mitigation from other types of mining is cited where it is relevant to the discussion. The extraction of peat differs markedly from mineral mining, and is beyond the scope of this review. Readers are referred to the following publications regarding peatland values, impacts and mitigation (Carpenter and Farmer 1981, Minnesota Department of Natural Resources 1981, Damman and French 1987).

The impacts of surface mining activities on wetlands and waterbodies have been well-documented (Darnell 1976, Cardamone et al. 1984). They differ depending on the material extracted, the methods used, and regional differences in topography, geology, soils, and climate. Even if it is assumed that reclamation is performed according to current regulations, mining will have significant effects upon the environment. In addition to the direct removal and filling of wetlands, the removal of soil and overburden severely alters local topography. This in turn disrupts local and regional groundwater and surface water flow patterns. Mining activities typically result in a decrease in groundwater tables and an increase in surface water runoff, both of which significantly affect the restoration and creation of aquatic systems. The removal of vegetation and disturbance of land surfaces increases sedimentation rates, with resultant increases in water turbidity. Access roads cause erosion in steep terrain, and can block the flow of water in areas of low relief, resulting in the formation of ponds. Exposed coal mine spoils readily oxidize, causing pollution problems such as acidic mine drainage. There are increases in the formation and deposition of materials, such as iron, manganese, aluminum, and sulfur, sometimes in amounts toxic to biota. Tailings from metal mines also can produce biologically-toxic discharges. Sedimentation rather than metal toxicity is a major problem associated with phosphate and sand and gravel mining.

In summary, habitat loss, chronic environmental stress, and toxic levels of pollution can occur during the mining process, especially if reclamation practices are poorly implemented (Darnell 1976). Any efforts to encourage wetland and waterbody creation on mined lands, whether to mitigate for losses attributable directly to mining, or as a means of increasing wetland area, should be cognizant of mining impacts on surficial and groundwater hydrology as outlined above.

Ten years have passed since the Surface Mining Control and Reclamation Act of 1977 (SMCRA, P.L. 95-87) was enacted. This federal act, coupled with the appropriate state statutes, has halted many of the past environmental abuses associated with surface mining, particularly with respect to the mining of coal. Although viewed as among the most encompassing and detailed pieces of environmental legislation, the Act often relies on vague notions, such as "higher and better uses" to guide decision-makers about reclamation strategies (Wyngaard 1985). Thus, the overall success of this law must be tempered by an examination of the relatively sterile landscapes that are often created under the guise of reclamation. Wetlands and waterbodies are allowed under existing regulations, but provisions are strict, and anything but encouraging. Decades of pre-SMCRA experience with polluted waters have resulted in cautious approaches to managing water on mined lands. Permanent impoundments are allowed under SMCRA guidelines, but "are prohibited unless authorized by the regulatory authority" (Sec. 816.49a). Thus, unless variances are sought, it is often viewed as less expensive to remove an impoundment or wet depression rather than to develop plans to leave it in place (Grandt 1981).

The Experimental Practices section of SMCRA (Sec. 711) produces the same result. Virtually any innovative reclamation technique can be tried if the operator is willing to justify the practice to state and federal regulatory authorities (Thompson 1984). This additional effort is often perceived as adding expense to a project, but overall costs may actually be reduced if permanent wetlands or waterbodies are left in place (Fowler and Turner 1981). The net result of these regulatory stumbling blocks has been to discourage the intentional creation of wetlands on surface mined lands (e.g., Gleich 1985) unless they are either demanded by an informed landowner, or based on in-kind replacement of a wetland that has been lost or degraded during mining. The vast majority of wetlands and waterbodies on mined lands exist not because of astute planning, but by accident.

Mining and related activities have disturbed less than 0.2% of the land mass of the U.S. (Schaller and Sutton 1978), yet in mining regions, disturbances can exceed 20% of a given land area (e.g., coal mining in Clearfield County, Pennsylvania; phosphate mining in Polk County, Florida). Coal reserves occupy large areas in selected regions of the U.S. (Fig. 1). Phosphate deposits, although large in area, occur only in a few regions. Wetland mitigation

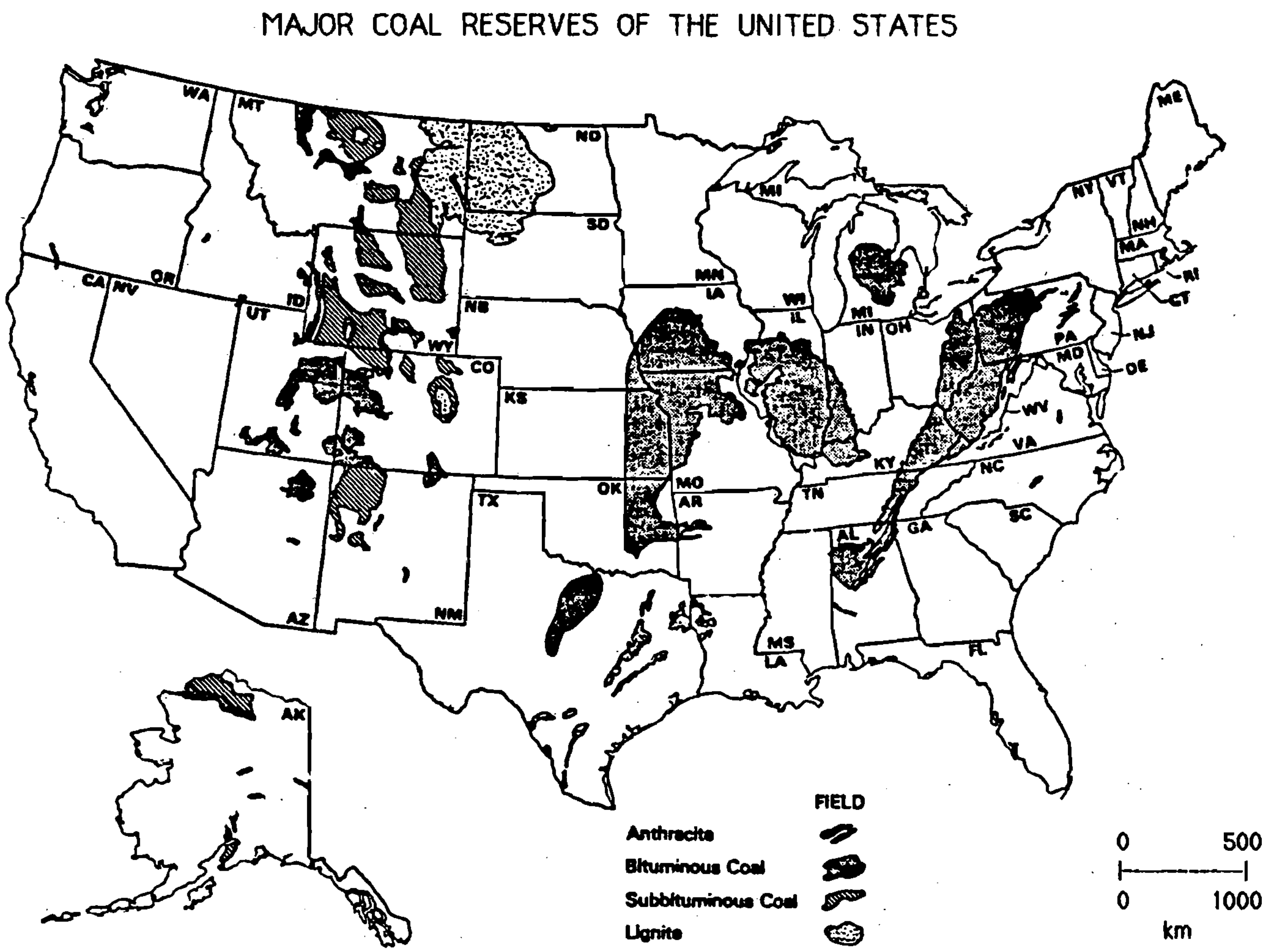

Figure 1. Major coal reserves of the continental United States and Alaska (modified from Energy Information Service 1984).

issues related to phosphate mining occur primarily in Florida (Fig. 2). Sand and gravel deposits are dispersed throughout the U.S.

Mining activity has not always resulted in a net decrease in wetlands. The gain in open-water, palustrine wetlands nationwide during the 1950's to the 1970's (Frayer et al. 1983) is apparent in land use surveys of mined lands. Brooks and Hill (1987) reported that mined lands in Pennsylvania supported 18% more palustrine wetlands than unmined lands, primarily because of a 270% gain in permanent, open water wetlands in the glaciated coal region of the state. Conversely, Hayes et al. (1984) observed a reduction in the number of impoundments, particularly shallow, vegetated waterbodies, following passage of SMCRA in 1977. Palustrine vegetated wetlands are often converted to open-water wetlands, which may result in a significant change in regional wetland types (Tiner and Finn 1986, Brooks and Hill 1987).

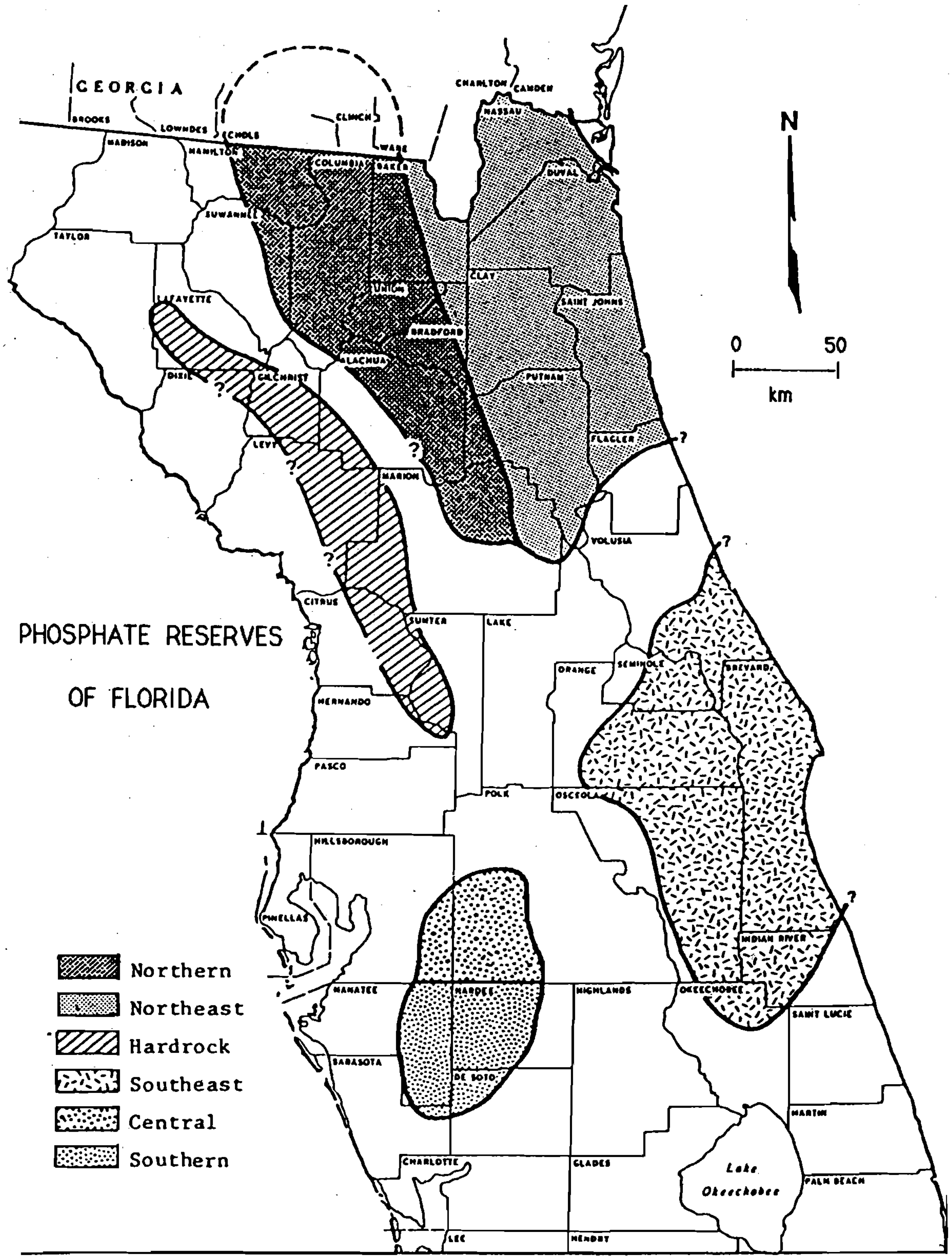

Figure 2. Major phosphate reserves of Florida (modified from Florida Defenders of the Environment 1984).

Before examining specifically how wetlands and waterbodies have been restored and created on mined lands, it is useful to discuss the characteristics and functions of volunteer wetlands, which are much more abundant than those purposefully designed. As mining practices differ, so do the types of aquatic environments left behind. The following will profile the inadvertent creation of aquatic environments by past mining and reclamation practices.

SURFACE MINING FOR COAL

Based on a survey of the literature, the following types of wetlands (listed approximately in order of declining numerical abundance) are commonly found on coal-mined lands: 1) sediment basins; 2) shallow wet depressions and emergent marshes; 3) moss-dominated springs and seeps; 4) final-cut and other deep lakes; 5) intermittent streams; and 6) slurry ponds and other coal refuse disposal areas.

During surface mine reclamation for coal, wetlands and waterbodies are created intentionally for erosion and sedimentation control as sediment basins. Basin size is determined by the anticipated runoff for a mine site and thus, is a function of the area of land disturbed. Sediment basins are usually <0.5 ha in size (Brooks and Hill 1987); often only 0.1 ha (Fowler and Turner 1981). They are geometrically shaped (i.e., circular, oval, rectangular), and have steep slopes (usually >30°), and flat bottoms. Volunteer palustrine wetlands also occur as a function of local changes in hydrology following reclamation. These include moss-dominated springs and seeps, persistent and non-persistent emergent marshes, and shallow wet depressions (similar to the prairie potholes of the northcentral U.S. (Cole 1986).

Before the advent of reclamation legislation, final-cut lakes were left inadvertently when the final excavation was not back-filled. Characteristics of these lacustrine waterbodies vary considerably, but they are often linear in shape, large (1-50 ha), deep (2-30 m), and have poorly developed littoral zones (Jones et al 1985a, Hill 1986). Other deep water bodies are formed after pits are excavated in regions with water tables near the surface. Lakes of varying shape and size have formed in this manner in glaciated regions of Pennsylvania (Brooks and Hill 1987), and several midwestern states (Jones et al. 1985b, Klimstra and Nawrot 1982); 6,000 ha of these lakes exist in Illinois (Coss et al. 1985) and 3,600 ha in Ohio (Glesne and Suprenant 1979) (Fig. 1).

After coal is processed, coal fines and associated particles are discharged into basins known as slurry ponds. The usual reclamation procedure for these typically acidic disposal areas is to cover them with at least 1.3 m of topsoil. However, a variety of vascular hydrophytes will colonize slurry ponds, thus establishing emergent wetlands (Nawrot 1985) (Fig. 3).

Although a discussion of streams and rivers is beyond the scope of this review, intermittent streams containing emergent vegetation are also fairly common, and therefore, constitute another wetland type. Relocation and restoration of major streams is discussed in another chapter of this document (see Jensen and Platts).

A variety of ecological functions and economic uses have been documented for the types of wetlands listed above, including wildlife and fisheries habitat, agricultural and recreational activities, sediment retention, treatment of acidic mine drainage, and public water supplies.

Sediment basins provide for uses beyond their intended purpose. They provide habitat for a variety of vertebrate taxa, including birds (Burley and Hopkins 1984, Sponsler et al. 1984, Brooks et al. 1985a), mammals (Brooks et al 1985a), and herpetofauna (Fowler and Turner 1981, Brooks et al. 1985a). A diverse macroinvertebrate community also has been identified with sediment basins (Hepp 1987).

Mine lakes are known to produce excellent fisheries (Jones et al. 1985b, Mannz 1985), in part due to adequate primary production (Brenner et al. 1985) and macroinvertebrate production (Jones et al. 1985a). They can serve as foci for recreational activities such as fishing, boating, and waterfowl hunting (Klimstra et al. 1985). Other uses, particularly in the Midwest, include lake-side housing and community open spaces, crop irrigation and livestock watering, and water supplies for homes, fire protection, and industrial purposes (Glazier et al. 1981).

Vegetated wetlands dominated by either vascular or non-vascular species can effectively sequester some of the constituent of mine drainage. Observations on the removal of metals by naturally occurring Sphagnum moss (e.g., Wieder and Lang 1986) has led to further investigations of how mosses, algae and macrophytes with their associated bacteria, can be used to ameliorate the effects of mine drainage (see Girts and Kleinmann 1986 for a review).

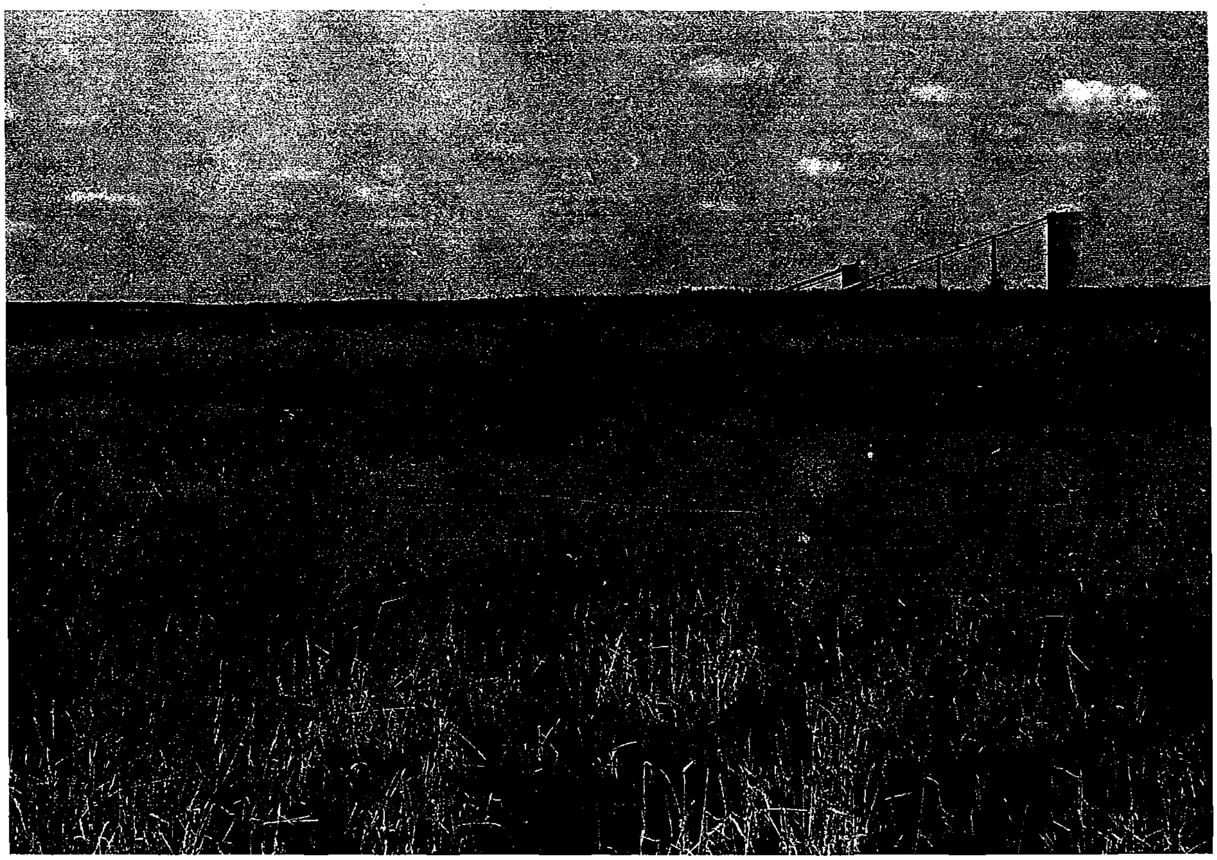

Figure 3. Seasonally inundated zone of a wetland created on coal slurry in Indiana showing four years of growth. (Courtesy of Jack Nawrot, Cooperative Wildlife Research Laboratory, Southern Illinois University.)

SURFACE MINING FOR PHOSPHATE

Primary phosphate deposits in the U.S. occur in Florida, Tennessee, South Carolina, and the Phosphoria Formation of Montana, Wyoming, Idaho and Utah. However, surface mining activities affecting wetlands occur almost exclusively in Florida, where wetlands typically comprise 8-17% of the landscape area (Florida Defenders of the Environment 1984) (Fig. 2). The principal focus of reclamation in Florida has been on mitigating for wetland losses. Substantial progress in developing restoration and creation technology has been made through the combined efforts of the phosphate industry and state regulatory agencies. Florida provides an example of how regulatory pressures can accelerate a desired technology if the pressures are firmly and reasonably applied.

Reclamation of phosphate mines in Florida was voluntary until 1975, when the Department of Natural Resources developed regulations (Florida Administrative Code Section 16C-16, 16C-17) in response to legislation (Florida Statute 211.32, 370.021). Due to extraordinary residential and commercial development, there have been increasing efforts to push reclamation technology toward the goal of replicating original wetland conditions as a provision of mining. Public pressure combined with a flat topography suitable for wetland establishment and awareness of wetland functions and values has led to sophisticated efforts to restore and create complex wetland systems.

Historically, the removal of phosphate ore by draglines produced mounds of sand tailings interspersed among waterbodies and clay settling ponds. Many of these waterbodies were used by wintering waterfowl that were attracted by volunteering hydrophytes (e.g., Najas spp.). Gradual filling of these waterbodies with clay produced a successional trend from submergent species, to emergents (e.g., cattail, Typha spp.), and finally to shrubs (e.g., willow, Salix spp.) (Clewell 1981). Wildlife use diminished during this process (King et al. 1980). After 1975, reclamation required regrading of the sand tailings, and planting them to pasture. Depressions left from the removal of phosphate ore fill with water, producing a mosaic of pastures and lakes. Marion and O'Meara (1983) reported that the reclamation laws had produced both positive and negative effects on wildlife. One of the positive impacts, was an increase in wetland edge following reclamation.

Boody (1983) studied 12 reclaimed lakes, 6 classified as deep, and six that were considered shallow. Deep lakes had a mean area or 59 $\pm$113 ha (range = 2-287 ha) with depths of 3-5 m. Shallow lakes had a mean area of 9 $\pm$ 17 ha (range = 2-30 ha) with depths of 2-3 m. The pH was typically 5-7, but ranged from 4.2-9.3. Most reclaimed lakes supported fewer species of fish (mean = 10 $\pm$ 6 species, range = 4-22) than the 4 natural lakes that were studied (mean = 18 $\pm$ 2 species, range = 16-20). Of the 29 fish species collected, 27 were native and 2 were introduced (Brice and Boody 1983).

Recent reclamation plans have included littoral zones and periodically flooded areas as part of the lake ecosystem. Freshwater emergent marshes have been successfully established, and to a lesser extent, forested wetlands have been created (Haynes 1984).

The clay settling ponds, which usually occupy >50% of a mine site, continue to pose problems and are perceived negatively by the public. Waste clays from the mining process are suspended in a slurry and pumped into settling ponds. Attention has been focused on de-watering these ponds as rapidly as possible; typically within 10 years. Although the ponds support fewer plant species than natural wetlands, site management in conjunction with planned species introductions can create a heterogeneous mix of wetland vegetation and open water (Robertson 1983). Montalbano et al. (1978) discussed the value of clay settling ponds as wintering habitat for waterfowl (7 species reported), and suggested that water level manipulation would help create high interspersion of emergents and open water. Haynes (1984) believes that these settling ponds may have substantial positive values, and thus should be manipulated and managed as productive wetlands. The settling ponds are large (81-405 ha) and are currently increasing at a rate of 1,000 ha/yr beyond the 30,000+ ha already present. Several authors advocate a drainage basin approach for mitigating wetland losses in the phosphate region, so that areas beyond the individual mining unit are considered in the planning process (Breedlove and Dennis 1983), although Fletcher (1986) believes that the current knowledge is only suitable for restoration of small drainage basins.

SURFACE MINING FOR SAND AND GRAVEL

Sand and gravel is defined as unconsolidated mineral and rock particles. Generally the particles have been transported by water, and therefore, many deposits still occur in and around waterbodies. Inland deposits are typically classified as fluvial, glacial or alluvial depending on their origin.

Sand and gravel is vital to the construction industry. Excavation is the chief method of removal, and 18% of the lands disturbed by mining are for sand and gravel. Sand and gravel operations are regulated primarily through state laws. Demand continues to increase, with deposits near urban areas in highest demand. More excavation can be expected in nearly every state in the U.S. (National Research Council 1980). Concurrently, opportunities for restoration and creation of wetlands on reclaimed sand and gravel sites will also increase.

Although waterbodies that remain following sand and gravel mining have been used for a variety of purposes, reclamation plans have often lacked advanced planning and imagination (McRae 1986). Fishing, boating, and wildlife observation commonly take place in water-filled sand and gravel pits in both the U.S. and Great Britain (Koopman 1982, McRae 1986, respectively).

Lomax (1982) found that reclaimed lakes in the southern coastal plain of New Jersey were colonized first by emergents (e.g., Typha spp., Cyperus spp., Juncus spp., Scirpus spp.), and then by woody vegetation such as black willow (Salix nigra), red maple (Acer rubrum), and black tupelo (Nyssa sylvatica). Occasionally, bog-like communities developed in pits <1 ha in area. Lomax recorded use by 194 species of vertebrates over a 16-year period. Gallagher (1982) found that the Delta Ponds of Eugene, Oregon became completely revegetated through volunteer colonization. Species found included cattail, pondweed (Potamageton spp.), willow, and alder (Alnus spp.). Birds (78 species), mammals, and fish were observed using the 65-ha area.

Street (1982) reported on the gravel-pits of Great Britain. Pits ranged in size from 1-100 ha, and were 3-30 m deep. Most had steep sides and flat bottoms. A restoration project was initiated at the gravel-pit complex of the A.R.C. Wildfowl Centre in Great Britain in 1972, and has developed into a highly productive 37-ha wetland system. Waterfowl density within the managed site ranged between 2.4 to 38.7 birds/ha, whereas avian density on unmanaged gravel pits did not exceed 2.8 birds/ha. By manipulating basin morphometry, plant communities, and the availability of organic matter, both vertebrate and invertebrate numbers and diversity were increased.

RECOMMENDATIONS FOR RESTORATION AND CREATION WETLANDS AND WATERBODIES ON MINED LANDS

There have been recent efforts to stimulate the restoration and creation of wetlands on mined lands (e.g., Klimstra and Nawrot 1982, Brooks 1984, Brenner 1986, Brooks 1986, Haynes 1986, McRae 1986). Sufficient recommendations exist to provide guidance for wetland mitigation on mined lands. Due to procedural and regional differences in mining coal, phosphate, and sand and gravel, the recommendations will be discussed under separate headings below.

One cannot incorporate all possible mitigation into a single wetland project. It is best to work within clearly stated objectives that are tied to specific wetland functions. Only then can the wetland be designed optimally with respect to the desired objectives. There may be conflicts among objectives which should be resolved in the planning process (e.g., public water supply vs. ecological productivity, recreational fishery vs. habitat for diverse amphibian community). Whenever possible, pre-mining conditions and regional reference wetlands should be used as guides to how a wetland ought to be created or restored.

WETLANDS AND WATERBODIES ON COAL MINED LANDS

Basin Morphometry

Area--

The area covered by a wetland or waterbody is constrained both by objective and site location. Peltz and Maughan (1978) suggested that several ponds of small size (0.25-1.0 ha) were preferred to a few large ones with regard to fish production; 0.1 ha being the minimum recommended size. Sandusky (1978) found that some species of waterfowl (e.g., blue-winged teal, Anas discors) nested on ponds as small as 0.04-0.2 ha. Hudson (1983) recommended pond areas >0.5 ha for waterfowl production in stock ponds, as did Allaire (1979) for wildlife in general. Based on an inventory of 35 existing wetlands on mined lands in Pennsylvania, Hill (1986) recommended areas of 1-3 ha to maximize wildlife diversity. For natural habitats, bird species richness has been found to increase with wetland area, but to level off for areas >4 ha (Williams 1985). As sediment ponds are typically less than 0.5 ha in area, a slight increase in pond size, while still maintaining a diversity of sizes, would seem to meet multiple objectives.

Mine lakes can be as large as the remaining mined pit or depression. Lakes exceeding 10 ha are not uncommon (Jones et al. 1985a). Glazier et al. (1981), Nelson (1982), and Doxtater (1985) provide scenarios for planning multiple-uses of large, deep-water lakes.

Depth–

The need for water permanence will determine the appropriate depth of a given wetland or waterbody. Again, project objectives coupled with mining operations will influence the eventual depth characteristics of the wetland. It is important to remember that deep water lakes will tend to be either mesotrophic or oligotrophic, whereas shallow waterbodies and vegetated wetlands usually have higher primary productivity, tending toward eutrophic conditions.

To enhance year round survival for fish, Peltz and Maughan (1978) recommended depths of 2-3 m for ponds with groundwater sources, and >5 m for ponds supplied by surface runoff alone. Although water depth in excess of 3 m may be desirable for fish survival, retention of flood waters, as a water supply reservoir, and for some recreational activities, most investigators have stressed the need for construction of an extensive littoral zone. Many species of sport fish require depths of 0.5-2.0 m for spawning (Peltz and Maughan 1978, Leedy 1981). Some submergent hydrophytes grow better in depths >0.5 m (e.g., Potomageton spp., Chara spp.). The regulatory guidelines of SMCRA require stability of water levels in impoundments, but this may not be feasible or desirable for many wetlands. Colonization by emergent hydrophytes requires fluctuating water levels. Cole (1986) found that water volume, and hence depth, varied by >40% in five ponds on mined land in Illinois. These changes in water level exposed the littoral zone much like the wetlands of the Prairie Pothole region further west. Fluctuating water depths of <0.5 m are recommended to promote the growth of emergent hydrophytes, which in turn encourage macroinvertebrate production in the littoral zone.

Slope–

Whereas a shelf 1 m in depth may benefit aquatic species such as fish, other species benefit from slopes that grade gently from upland to wetland. A wetland basin that has a variety of slopes, ranging from <5° to almost 90° will benefit a diversity of wildlife species and provide visual variety. The majority of the shoreline should have gentle slopes. Amphibians, reptiles, and some fishes require gentle slopes, typically <15°. Sand and mud flats used by foraging shorebirds should have slopes of <5°. Access areas for swimming and boating also require gently sloping terrain. Some species will benefit from steeply sloped or overhung banks, including burrow-dwelling muskrats (Ondatra zibethicus, Brooks and Dodge 1986), belted kingfisher (Cerle alcyon, Brooks and Davis 1987), swallows, cliff-nesting raptors, and some fishes.

Shape–

The shorelines of wetlands and waterbodies should be convoluted to produce an irregular shape (Brooks 1984). Basins with a high shoreline development index (i.e., length of shoreline divided by the circumference of a circle of equal area, Wetzel 1975) provide more edge for wildlife, and reduce wind and wave action on larger waterbodies (Coss et al. 1985). Coves, peninsulas, and islands contribute substantially to shoreline development (Leedy and Franklin 1981, Brooks 1984). Islands (>3 m in diameter, Emerick 1985) and even large rocks (0.5-1.5 m in diameter, O'Leary et al. 1984) provide nesting and resting places for many species of waterfowl and shorebirds. Irregularities in basin shape tend to disperse water flows thus helping to maximize retention time in the basin if flood control or water treatment are desirable characteristics of the wetland.

Soils--

It is important to consider both hydric soils within a wetland and the soils of adjacent uplands. Proper management of upland soils will protect aquatic systems from unnecessary sediment, chemical, and thermal pollution (Rogowski 1978, Leedy 1981).

Upland Soils--

During reclamation of mined land it is preferable to have topsoil cover the overburden to protect and conserve the available water and provide a better medium for plant growth. Vegetated topsoil will reduce evaporation, allow more infiltration into groundwater supplies, produce temporary ponds in depressions, and reduce peak infiltration rates that lead to abnormal fluctuations in the water table and droughty surface conditions (Rogowski 1978). The ability of a soil to retain water is dependent on its texture (i.e., sand is more droughty than clay), depth, the content of organic matter, and the distribution of pore size (Schaller and Sutton 1978). Thus, a careful study of soil conditions will enhance the probability of successful restoration and creation of wetlands, and the reclamation of upland areas.

Sediment yields from exposed soils are typically highest in the first 6 months after regrading, and are halved in subsequent 6-month periods as the site progressively revegetates (Schaller and Sutton 1978). Silts and sediments that enter waterbodies tend to reduce light transmission (and hence, photosynthesis), raise water temperature, and cover sensitive organisms (Leedy 1981). Thus, it is important to revegetate exposed soils as rapidly as possible to avoid interfering with wetland establishment.

Based on the reclamation literature for upland portions of mined sites, several recommendations can be made to protect aquatic systems from upland runoff. Exposed soils must be seeded, fertilized, and mulched as soon as possible. Rafaill and Vogel (1978) recommended 60 lbs/acre (67 kg/ha) of nitrogen and 100 lbs/acre (112 kg/ha) of phosphorus, but no potassium for reclaiming mined land in Appalachia. In acidic areas, soil should be limed to a pH of at least 5.5. Use of high quality seeds is advised (i.e., high germination and purity percentages, McGee and Harper 1986). Seeds and fertilizer should be applied first, followed by an appropriate mulch to avoid perching seeds above the ground's surface (Schaller and Sutton 1978). Straw and hay were suggested as the best mulch to use, particularly if applied by a mulch blower that cuts, shreds, and evenly spreads the material. Estimated costs for purchase and application of straw were \$100-200/ton (909 kg) with an application rate of 1-2 tons/acre (2,245-4,490 kg/ha), whereas nets and mats may cost > \$1,500/acre (\$3,700/ha), especially on steep slopes (Mining and Reclamation Council of America and Hess and Fisher Engineers 1985). Advice for selecting the appropriate plant species, and seeding, fertilizing, and liming rates for a given soil type are generally available from mining agencies (e.g., Office of Surface Mining, U.S. Bureau of Mines, state mining agencies) and county offices of the Soil Conservation Service.

Vegetative buffers should be installed around wetland basins. Although recommendations for buffer widths range from 1-300 m, vegetated strips as narrow as 15-20 m can remove 50-75% of the sediments (Barfield and Albrecht 1982). Whenever appropriate for a given region, buffers should include shrub and forested zones. Gilliam (1985) studied unmined agricultural areas in North Carolina and found that wooded buffers about 100 m wide removed >50% of the sediment, including much of the nitrogen and phosphorus. In addition to serving a water quality function, vegetative buffers can act as travel corridors and refugia for wildlife, thereby reducing the isolation of the wetland. If desired, wetland edges can be shaded by planting properly oriented tree species that will grow to a height of twice the distance to the water (Leedy 1981).

In severe cases of upland runoff, structural diversions may be necessary to divert sediment-laden waters. Diversion ditches, concave depressions, and sediment traps are some of the techniques available. Mining agencies, the Soil Conservation Service, or experienced consultants can provide the expertise needed to design these systems.

Hydric Soils--

Hydric soils, or those previously saturated, usually must be constructed, unless soil is available from a wetland scheduled to be altered or removed. Routine cleaning of roadside ditches or other wet depressions can also act as a source of hydric soil, although pollutants such as road salt, oil, or lead may be present in substantial quantities. Hydric soils should be stockpiled, preferably for less than one month, and then spread to the desired thickness in newly constructed basins. These soils typically have a relatively high organic matter content, and often act as a seed source or seed bank. Longer storage periods will result in desiccation of plant materials, and possibly re-oxidation of metals and other potentially damaging materials.

When existing hydric soils are not available, they can be constructed by using a relatively fertile topsoil. Good plant survivorship and seed germination rates have been obtained by mixing about 30% (by volume) livestock manure in with the topsoil to act as a source or organic matter and nitrogen (Brooks, unpublished). Small quantities of superphosphate were added to the soil around each planted propagule. Chemical fertilizers have been recommended as an additive to ponds and lakes designed for fish production; 12-12-12 or 8-8-2 (nitrogen-phosphorous-potassium; Glesne and Surprenant 1979, Leedy 1981, respectively). Leedy (1981) suggested that no more than 200kg/ha of 8-8-2 fertilizer be added at one time, although application rates for infertile waters might exceed 1,500 kg/ha/yr.

Whenever possible, soil tests should be made to provide more accurate estimates of fertilizer and lime additions for both hydric, and adjacent upland soils depending on the plant species desired and the intended use of the wetland or waterbody. Basins constructed on mined lands often contain acidic soils. Assuming that a circumneutral pH is desired (although some wetland plants require acidic or alkaline conditions), the pH of the bottom soils should be raised to about 6.5 using lime (Peltz and Maughan 1978). If the pH of the soil is less than 5.5, then at least 1,000 kg/ha of lime is probably needed (Leedy 1981). Slurry ponds with acidic soils require more alkaline additions to promote growth of hydrophytes; >20,000 kg/ha of limestone (Nawrot 1985). Warburton et al. (1985) reported improved growth rates for bulrushes (Scirpus spp.) with addition of slow-release fertilizer tablets (22-8-2) to each propagule. If acidophilic plants occur naturally on the site or their presence is a desired objective of reclamation, then it may not be necessary to adjust pH. The presence of certain species of moss and algae in springs and seeps is a good indicator of waters with low pH and usually low concentrations of nutrients (Brooks, unpublished).

Basins constructed below the water table rarely need to be sealed, whereas perched wetlands need a water-conserving layer of material on the bottom and sides of the basin. Clay is commonly used in this manner and should be compacted to a thickness of about 30 cm (Soil Conservation Service 1979). Bentonite, and synthetic membranes can also serve as sealants. Specifications for a specific soil type and climate are generally available from county offices of the Soil Conservation Service or mining agencies.

Vegetation

Studies of existing wetlands have shown that a diversity of hydrophytes will volunteer over time. Cattail (Typha latifolia) is by far the most successful vascular hydrophyte on mined lands. Cattail, soft rush (Juncus effusus), and woolgrass (Scirpus cyperinus) were the first invaders of four wetland basins in central Pennsylvania; all were present within 1-1.5 years of regrading (Hepp 1987). Twelve species of vascular plants had volunteered on one site after 6 years. Fowler et al. (1985) found that cattail, soft rush, and spike rush (Eleocharis obtusa) rapidly invaded sediment ponds in Tennessee; 10 species were eventually present. Coss et al. (1985) found 14 species of vascular hydrophytes growing in four lake complexes in Illinois. The lake with the greatest hydrophyte diversity had 7 species.

After volunteer macrophytes were observed on slurry ponds in southern Illinois (e.g., reedgrass (Phragmites australis), a planting program was started in that has led to revegetation of more than 200 ha of wetlands on 12 sites (Nawrot 1985). Investigators found that perennial rootstocks of hardstem bulrush (Scirpus acutus), three-square (S. americana), and prairie cordgrass (Spartina pectinata) were more dependable than seed because sub-surface conditions were more amenable to plant establishment than surface conditions. Rootstocks were collected at a rate of 75-100 propagules/man-hour, and hand-planted with bars and shovels. Collection of propagules in early spring is preferred over autumn collection. Spacing was on 0.3-1.5 m centers, and each propagule was planted in 5-13 cm of soil, depending on the species. They recommended a water-level control structure to assure adequate control over seasonally variable water levels. Plants collected locally under similar conditions had better survival rates than commercially available stock. Whenever possible, local planting stock should be used.

We have constructed smaller wetlands, designed specifically for treating acidic mine drainage (Brooks, unpublished). Cattail rhizomes were collected from existing sediment basins at a rate of 50-100/man-hour, and planted at a rate >100/man-hour. Multi-stemmed clumps of sedges (Carex gyandra) and soft rush (20-cm dia. plugs) were also collected. Both were planted on 0.5-1.0 m centers. We had 75-80% survival of these plants after one year. Costs for constructing wetlands designed to treat mine drainage are slightly less than $\$10/m^2$ ($\$1/ft^2$) (Girts and Kleinmann 1986, Rightnour, pers. comm.), including all planting and basin construction costs.

There are several ways to enhance the proliferation of aquatic vegetation if a decision is made to encourage volunteer colonization. The morphometry of the basin, as previously discussed, must be suitable with respect to depth and slope. The desired zones of vegetation can be controlled by manipulating morphometric variables. Emergent species will colonize the littoral zone up to about 1 m in depth. Shrubs will be restricted to very shallow or seasonally flooded zones. By creating topographic diversity within a site, there will be more opportunities for a variety of species to successfully colonize. Mitigated wetlands that have hydrologic connections with natural wetlands or other mitigated sites will be more likely to receive plant propagules, either through wind, water, or animal dispersal.

Fauna

Diverse vertebrate and invertebrate communities have been found in wetlands and waterbodies on coal surface mines. Brooks et al. (1985a) reported that 125 vertebrate species were observed on 35 wetlands studied in western Pennsylvania (86 birds, 19 mammals, 11 reptiles, and 9 amphibians). The mean number of vertebrates per wetland was 23 $\pm$ 12 (1 SE), with a range of 7-60 species/wetland (Hill 1986). Hepp (1987), in a more intensive study on four wetlands in the same region, reported use by 90 vertebrate species (64 birds, 15 mammals, 3 reptiles, and 8 amphibians) and more than 39 invertebrate taxa. O'Leary et al. (1984) observed 76 avian species, including 18 species of waterfowl, and 10 mammalian species on 47 wetlands in southwestern Illinois. Also in Illinois, Coss et al. (1985) studied four mined lake complexes and found 89 vertebrate species. In nine sediment ponds in Tennessee, Fowler et al. (1985) reported use by 61 invertebrate taxa, 6 fish species, and 12 amphibian species. Jones et al. (1985a), in a study of 33 mine lakes in Illinois and Missouri, identified almost 200 invertebrate taxa and 33 fish species. Nineteen species of fish were collected from one 86-ha mine lake in Illinois (Jones et al. 1985b).

With the exception of fish species and some invertebrate taxa (e.g., Mollusca), most species voluntarily colonize surface mine wetlands. Some invertebrates can be introduced by water birds as larvae attached to feet and feathers. Fish are also introduced by local anglers. If wetlands are hydrologically connected with other reclaimed or natural systems, the opportunities for rapid colonization are greatly improved. If wetlands are juxtaposed to a variety of upland habitats that provide shelter and travel corridors, colonization rates and numbers probably will be greater. Hepp (1987) reported rapid colonization rates (within 3 years of final grading) for both invertebrate (e.g., dipterans, coleopterans, hemipterans) and vertebrate (e.g., amphibians, some small mammals, and many birds) species, followed by a period of stabilization in community structure. Pentecost and Stupka (1979) found that common amphibian species invaded sediment ponds within one month of formation; founder populations were located 100 m away.

Artificial structures and substrates can be introduced to supplement existing shelter, such as nest boxes for cavity nesters and artificial reefs for fish and invertebrates. As with flora, wetlands designed with specific objectives will provide suitable habitat for the desired species, whether fish, waterfowl, or a diversity of faunal groups.

WETLANDS AND WATERBODIES ON PHOSPHATE MINED LANDS

Basin Morphometry

The same parameters discussed for coal mined lands are equally important for phosphate areas (e.g., area, depth, slope, shape). A major difference exists for the Florida landscape, however, because of its low relief. To accommodate the sheet flow of water over flat lands and to match the adaptions of plant species to subtle changes in elevation, the slopes of basin banks and bottoms need to be carefully established. In addition, hydroperiod variations between wet and dry seasons must be considered in project design. Wetland systems must be capable of storing large quantities of water during the wet season. This can be accomplished by designing wetlands of sufficient size. During the dry season, when the water table drops below the land surface, there must be enough deep depressions to harbor aquatic organisms, such as fish, amphibians, and invertebrates (King et al. 1985). Depressions should be at least 2 m below the high water marks to maintain aquatic habitat during droughts (King et al. 1985). Reduced slopes (<3%) will allow the development of wide soil moisture zones. This will provide a wider tolerance zone for many species of wetland vegetation and compensate for environmental disturbances, such as drought, fluctuating water tables, and fire. Conversely, steeper slopes result in narrow moisture zones that leave little room for error in predicting the eventual composition of the floral community.

Soils

Soils of the central phosphate region in Florida are typically circumneutral and quite fertile due to the abundance of phosphorus and calcium, although potassium may be limiting (Clewell 1981). Phosphate deposits further north may be more acidic and less fertile. Soils being prepared for the establishment of wetlands are usually regraded to the proper elevation and conformation using the sand tailings. Additional overburden, if available, can then be added up to a depth of 30 cm (Erwin 1985). Numerous studies have shown that the addition of wetland topsoil (i.e., mulch, organic muck) from natural wetlands scheduled for mining greatly enhances the chances for successful reclamation (Clewell 1981, Dunn and Best 1983, Erwin 1985). "Topsoiling" or "mulching" can provide a variety of propagules (e.g., seeds, roots, rhizomes) from native plant species that result in a more natural vegetative community at the exclusion of weed species.

Vegetation

Wetland restoration efforts in the Florida phosphate region have focused on the establishment of three major types of wetland communities: open water, emergent marshes, and forested wetlands. Open water areas are primarily a function of water depth and need not be discussed further. The two types of vegetative communities will be discussed separately. The techniques developed have been influenced by regulations that require rapid revegetation (within one year) and the creation of a self-sustaining community.

Emergent Marshes--

Techniques used to establish herbaceous hydrophytes include: 1) transplanting from natural wetlands; 2) application of hydric topsoil from natural wetlands; and 3) reliance on voluntary establishment. Florida allows licensed individuals to remove native species from natural wetlands for the purpose of mitigation. In addition, plants from wetlands scheduled for mining can be transplanted to newly prepared sites. However, the availability of plants from natural wetlands may not always match the timing of mitigation projects.

For the Agrico Swamp project in central Florida (restoration of 61 ha of wetland on a 148 ha project site) Erwin (1985) and Erwin and Best (1985) reported that the application of wetland topsoils resulted in the establishment of 41 plant species in a restored marsh, whereas overburden alone resulted in the establishment of only 26 species. The common species present included, cattail (Typha latifolia), pickerelweed (Pontederia cordata), rushes (Scirpus californicus), dog fennel (Eupatorium capillifolum), and arrowhead (Sagittaria lanceolata). The topsoil areas contained both perennial and annual species, whereas the overburden areas contained primarily annuals. The rapid establishment of late-successional species, such as many perennials, either through "topsoiling" or transplanting may help to eliminate undesirable species such as cattail (Erwin and Best 1985).

Volunteer plants contribute substantially to restoration efforts in Florida. Certain factors can increase the role of volunteers. When natural communities are proximal to restored sites, the likelihood of propagule dispersal is enhanced. Hydrologic connections with streams can also distribute the seeds and propagules of desirable species. Self-sustaining seed banks with their inherent benefits can become established within 3 years if artificial planting is done (Erwin 1985), and within 4-5 years if based solely on volunteer species (Dunn and Best 1983).

Restoration of emergent marshes in Florida is further enhanced if good quality planting stock is used and if specific site preparation and planting methods are properly applied (Haynes 1984). Several long-term monitoring studies of wetland mitigation projects are underway in Florida (e.g., Erwin 1985) which should help determine how closely created match natural conditions.

Forested Wetlands--

The slow growth of woody species prevents rapid assessment of the success of creating forested wetlands, but there are indications that the techniques applied in Florida will be successful. As part of the 61 ha of wetlands created on the Agrico Swamp project site, 66,000 tree seedlings were planted. Twelve species were represented. The most abundant species included, cypress (Taxodium distichum), Florida red maple (Acer floridium), loblolly bay (Gordonia lasianthus), black gum (Nyssa sylvatica), sweetgum (Liquidambar styraciflua), and Carolina ash (Fraxinus carolinia). Seedlings were planted on about 2-m centers by hand in the summer and fall of 1982. Survivorship was 72% in 1982, 77% in 1983, 72% in 1984, and dropped to 58% in 1985 following a drought (Erwin 1985). Growth of some species was apparently enhanced when water levels during the wet season did not exceed 20 cm (Best and Erwin 1984).

Gilbert et al. (1980) reported on the success of planting 10,400 seedlings representing 16 species. After the first year, survival was 85% for cypress and green ash (Fraxinus pennsylvanica), 72% for sweetgum, and 62% for red maple (Acer rubrum).

Clewell (1981, 1983) also had tree seedling survival in excess of 70% while creating a riverine forested wetland in central Florida. Mechanical planting of potted, nursery-grown seedlings increased efficiency and enhanced survival, but may not be feasible, depending upon the substrate. Direct seeding may also be possible, but germination and survival rates are lower. Clewell (1983) suggested that enclaves of saplings could be established through transplanting to provide shade for shade-tolerant species. A combination of seedlings, saplings, topsoil, and natural colonization were recommended.

Fauna

Studies of faunal communities on reclaimed phosphate mines have been less common than studies of vegetation. Erwin (1985) reported that 56-62 taxa of macroinvertebrates were collected seasonally in open water, submergent, and emergent wetland communities for an annual total of 107 taxa. A total of 83 bird species were recorded on the same 148 ha site. Use of clay settling ponds by waterfowl and shorebirds has also been reported (Montalbano et al. 1978). King et al. (1985) provide extensive recommendations for enhancing fish and wildlife habitat on both wetland and upland mine sites in the phosphate region. To maximize fish and wildlife diversity, they suggest the creation of heterogeneous physical and vegetative habitats among a diversity of aquatic systems.

WETLANDS AND WATERBODIES ON SAND AND GRAVEL MINES

As many of the recommendations discussed for coal and phosphate mining apply to sand and gravel, only those techniques that differ will be included in this section. Mining of mineral sands for rare metals (e.g., rutile, zircon) is a unique type of sand mining. Although most prevalent in Australian coastal zones, the wetland restoration techniques developed by this industry also warrant inclusion in this section (e.g., Brooks 1987, 1988).

Basin Morphometry

Most authors recommend increasing the area of wetland basins, and having a heterogeneous shoreline. Slopes with a horizontal to vertical ratio as gentle as 10:1 or 20:1 are recommended to increase the zone widths of plant communities (Street 1982, Crawford and Rossiter 1982). Water-level control devices are encouraged to allow optimal management of vegetation.

Soils

The addition of topsoil to pit floors was recommended where plant colonization is desired (Crawford and Rossiter 1982). Leaving some areas bare will meet the foraging requirements of wading birds and shorebirds (Lomax 1982), and the spawning needs of fish (Herricks 1982). The bare zones should have a variety of particle sizes as substrate to meet the specific needs of various species. Compaction of bottom material is an effective means to discourage volunteer plant species. In newly reclaimed sites, organic matter is often lacking, so straw or hay can be added as food and substrate for both plants and invertebrates; 1 kg/m^2 of straw was suggested by Street (1982). Nutrients are often lacking as well, so fertilizing may be necessary. Stabilization of upland banks and surrounds is also emphasized to reduce erosion and sedimentation (Branch 1985).

Brooks (1987, 1988) identified three major factors that enhanced the recovery of both herbaceous and woody vegetation after mining for mineral sands. First, basin morphometry must be reclaimed properly to provide suitable drainage patterns and water-level control. Second, the use of drains before and after mining under saturated conditions facilitated the establishment of seedlings by avoiding excessive drying or flooding. Drains were removed once the plants adapted to the variable water regime. Third, careful manipulation of existing topsoil enhanced the survival of propagules of native species. A "double-stripping" method was used. The upper 20-25 cm was removed and stockpiled in large lumps. A second layer that was 10-15 cm deep was stockpiled separately. Topsoil layers were returned in their original order after mining. Storage time was usually 1-3 months. This additional care later reduced planting costs during reclamation. Other recommendations for enhancing restoration of vegetation and fauna were similar to those discussed for coal and phosphate.

CONCLUSIONS AND RESEARCH NEEDS

There are examples throughout the U.S. and other countries of innovative approaches to successful restoration and creation of wetlands during mine reclamation, however, specific guidance applicable to different physiographic regions is still needed. The recommendations presented in this chapter should provide the basis on which to build a mitigation plan for a specific project. We are still in a rapid learning phase in restoration technology, and thus, must be open to new ideas and willing to experiment with innovative methods.

Managers need to move away from easily constructed geometric shapes and must attempt to create landforms that mimic natural systems. Overly engineered designs with specifications that are difficult to meet are not appropriate given the nature of biological systems and the current level of understanding in restoration technology. Designs and plans must be flexible to allow room for error and unpredictable events. Regulatory reform may be necessary to allow this flexibility to occur.

One way to ensure that the proper information is collected is to require mandatory monitoring programs of all wetland mitigation projects. It is suggested that a 3-year monitoring period be part of the known costs to a permittee before a project gets underway (e.g., Brooks and Hughes 1987). Short-term monitoring of individual sites coupled with a few long-term research projects will enhance our ability to predict the outcome of mitigation policies. As there is some scientific evidence for the stabilization of emergent marsh systems after 3 years (e.g., Erwin 1985, Hepp 1987), a 3-year period will allow evaluation of the project's success after three growing seasons. Also, some annual variability in climatic and growing conditions can be assessed during this time period. Finally, a modest 3-year monitoring plan does not put an unbearable economic burden on the permittee.

Long-term studies should seek to improve our predictive capabilities regarding the seasonal, annual, and successional variation inherent in most wetland systems. How do fluctuating water levels influence the composition and abundance of floral and faunal communities? What is an acceptable load of pollutants for a wetland to absorb before significant changes are observed in food webs and the health of individual organisms?

A number of studies have used comparative approaches to gain insight into how to replicate the functions of natural wetlands. Pre-mining and post-mining studies are valuable, as are comparisons between natural and restored systems, the latter being quite scarce (e.g., Brooks and Hughes 1987, Brooks 1988). Land managers need to establish their mitigation policies in the context of what changes are occurring in wetland types throughout a given physiographic region, not just on a particular mine site. In some regions (e.g., glaciated) wetland restoration has a greater chance for success because of inherent water and soil characteristics. Thus, what may work well for one area, may fail in another.

Based on this survey of the literature, it appears that the techniques appropriate to restoration and creation of simple open water and emergent marsh wetlands are fairly well established. The success of shrub and forested wetland projects, because of their slower rates of succession, has been more difficult to assess, and therefore, needs more attention. Questions remain with regard to plant materials: Are the proper propagules available? What is the best mix of native and exotic species to use? How do we balance the variable success of different planting methods against economic realities? How adept are we at predicting the successional outcome of a newly restored wetland system?

Success criteria for wetland mitigation need to be established. I do not believe, however, that satisfactory criteria can be developed on a national scale. Criteria necessarily vary with the type of wetland being established (e.g., tidal mud flats vs. freshwater emergent marshes vs. evergreen forested swamps). They also vary with the differential pressures placed on wetland resources within a region. For some wetland types, we may not yet know how to characterize their hydrology or biotic diversity, let alone satisfactorily replicate them.

At the current level of knowledge, it is ludicrous to demand 100% replication of species richness and abundance for all projects, but what are the minimum standards for replacing equivalent functions? Allowances must be made for variable growth patterns among floral species and for seasonally and annually fluctuating hydrologic regimes. Naturally occurring changes in wetland characteristics are commonplace. How will these changes be assessed, and then applied to a mitigation project? As with many environmental regulations, success criteria must evolve incrementally as new information becomes available. In time, a broad criterion such as "establish locally-occurring plant species" will be replaced by quantitative specifications for designated species arranged in suitable patterns on the landscape.

An interim solution is to establish regional success criteria for major wetland classes through consensus agreement among knowledgeable individuals (e.g., academics, regulatory scientists, industrial researchers, professional consultants). These criteria should be compatible with regional mitigation policies that are established by even broader representation from the community (i.e., planners, administrators, politicians, citizen's groups, business and industry leaders). Dames and Moore (1983) used a questionnaire sent to phosphate mining companies to gather opinions regarding success criteria for wetland restoration projects. Combined with information from regulatory authorities, this type of survey could form the basis for establishing success criteria for any physiographic region.

More attention must be placed on how to decide among multiple objectives for a given mitigation project. When are the utilitarian functions of wetlands (e.g., water supply, water treatment) to be substituted for in-kind replications of natural systems? Numerous authors suggested that planning and decision-making by consensus among scientific, industrial, regulatory, and citizen's groups is the appropriate strategy for establishing mitigation policy.

It needs to be mentioned that as wetland restoration technology improves, the mining industries will demand access to additional reserves. Therefore, the rationale for a particular mitigation strategy must have a sound, scientific basis if we are to successfully balance the needs of industry with the necessity of wetland protection.

RECOMMENDATIONS

PLANNING

1. Develop site-specific objectives that are related to regional wetland trends. Check for potential conflicts among the proposed objectives.

2. Wetland mitigation should be integrated with mining operations and reclamation plans at the beginning of any project, especially with regard to hydrologic plans for the site.

3. Project planning and evaluation should include input from trained professionals and local constituencies.

4. Mitigation plans for single wetlands should be related directly to the adjacent waterbodies and uplands. Be cognizant of regional trends and needs.

IMPLEMENTATION

1. Designs for wetlands should mimic natural systems and provide flexibility for unforeseen events.

2. The key elements to successful wetland restoration and creation are basin morphometry and hydrologic control. Assess these parameters first before specifying requirements for soil preparation or establishment of floral and faunal communities.

3. Varying the areas of the wetlands and waterbodies constructed between 0.5-10 ha will meet the needs of many species, as well as human users.

4. Bank slopes and basin bottoms should be varied with emphasis on gentle slopes and irregular bottoms unless dictated otherwise by project objectives.

5. A heterogeneous shoreline is recommended to increase habitat diversity. Extensive littoral zones should be encouraged.

6. A capability to regulate the hydroperiod using water-level control structures is highly recommended.

7. The addition of upland or hydric topsoil provides a good substrate for plant growth, serves as a source for seeds and propagules, and reduces moisture loss of exposed substrates.

8. An integrated approach to establishing vegetation that incorporates direct seeding, transplanting, "topsoiling or mulching", and natural colonization can increase plant diversity and survivorship at a reasonable cost.

9. Revegetate exposed substrates rapidly, preferably with native species. Vegetative buffers around wetlands and waterbodies are essential.

10. Diverse vertebrate and invertebrate communities will colonize newly restored wetlands if basin morphometry and vegetative communities are suitable.

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