Wood Environment & Infrastructure Solutions, Inc.
2000 E. Edgewood Drive, Suite 215
Lakeland, FL 33803
T: 863-667-2345
www.woodplc.com

Technical Memorandum

To: Chris Warn, Doug Robison

From: John Kiefer
Wood Environment & Infrastructure Solutions, Inc.

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Re. Phosphate Mine Area Considerations

Wood Project No. 600542

ISSUE

West central Florida phosphate mining has occurred in portions of the Charlotte Harbor watershed since the late 1800's. Early endeavors included placer mining in the Peace River removing significant amounts of gravel and even repatterning the river channel in places. Land mining with steam shovels and draglines began during the early 20th century, replacing placer mining. Some of the land mining occurred in floodplains prior to regulation, or during periods of less sophisticated approaches to ecological engineering, and thus represents potential restoration opportunities within and along priority restoration corridors.

Phosphate mine reclamation technology, regulation, and practice have undergone a series of substantial changes since 1975 leading to several distinct phases, each with a unique set of objectives and outcomes (Kiefer 2011[1]). Understanding these phases and the biophysical attributes likely to be encountered on lands during each reclamation period can be critical for prioritizing and designing successful restoration on and adjacent to these lands. Kiefer (2011) is attached as background reading, while this memo describes biophysical conditions of each major developmental phase of reclamation technology and ways such sites can be migrated closer to modern restoration concepts.

RECLAMATION LANDFORMS

Four major landforms can be encountered as a result of mining and materials handling during mining. These include cast overburden areas[1], sand tailings backfill areas, clay settling areas, and sand-clay mix settling areas. Cast overburden areas consist of mined landforms where the lithological layers (mostly sand and loam) over the phosphate matrix was excavated and cast

[1] Sometimes also referred to as 'land and lakes.'

aside nearby by draglines to access and remove the underlying phosphate matrix. These sites do not receive any subsequent redisposition of the sand or clay tailings extracted from the phosphate matrix. Depending on project vintage and site-specific objectives the overburden may have simply been left as cast and passively revegetated, or moderately to extensively recontoured with active plantings as reclamation. Overburden areas can have virtually any combination of uplands and wetlands traversable with conventional earthmoving equipment, and deep pockets of muck and silt accumulations in open waterbodies depending on vintage, contouring, and revegetation design. Overburden soil textures are highly variable horizontally and vertically, ranging from sand, sandy-loam, loamy-sand, and loam. Near surface conditions can vary substantially in tilth and permeability, but generally provide a good growing medium for a variety of native and non-native species.

Once the matrix is removed from under the overburden, it is pumped to a remote beneficiation plant that removes the phosphate ore, separating it from the clay and sand associated with that lithological layer. The sand and clay are then returned to selected mined areas for use as reclamation materials by pumping.

Sand tailings backfill areas are similar to overburden areas, except that they receive an appreciable volume of sand tailings backfill to achieve design grade. Depending on vintage, materials balance, and reclamation purpose, the sand may be at the surface, capped by overburden, or the areas may present large patches of both overburden and sand at the surface. The sand tends to be a harsh growing medium if it is not supplemented in at least one of a variety of ways. After supplementation and over time it improves as a growing medium, and has become the preferred surface material for a wide array ecosystem restoration projects on mined lands for its good tillage and infiltration capacity. Sand tailings areas are highly workable using conventional equipment and can be designed to support virtually any regionally applicable natural habitat analogue including pyrogenic uplands, mesic and hydric forests, swamps, marshes, wet prairies, and streams.

Clay tailings are returned to some combination of below and above grade impoundments depending on vintage and materials balance at the mine. The clay is highly plastic, with high water content that gradually consolidates over a period of years. Once fully consolidated, a crust forms on the clay that is exposed to the atmosphere. Prior to the crust forming, specialized floating or low-bearing pressure equipment is required to access and work the area. Where the crust is a few feet thick, it can support conventional equipment. Even after crustal development, some pockets requiring special equipment can occur and most contractors working on clay settling area reclamation rely on specialized machinery. The clay does not form a crust if it remains under water. Clay settling areas can develop good wetland and mesic forest habitats, but are substantially more difficult to contour than overburden or sand tailings areas. As a result, few wetlands are deliberately permitted and constructed on settling areas, but many form passively and would benefit from secondary plantings and nuisance species management. Generally, planned restoration work is restricted to surgical earthwork for improving drainage with ditches and breaches between deeper pockets of stagnant waters, and revegetation of the existing surfaces as they formed after differential consolidation.

Some below and above grade impoundments receive blends of sand and clay tailings referred to as sand-clay mix. This material settles faster than clay alone, but generally much of the sand drops out of the slurry near the outer edges of the mix impoundment, creating a gradient of sand content that decreases toward the interior of the cell. This often led to a deep clay wetland pocket at the interior and better drained and soils around the perimeter.

Above grade clay and sand-clay mix areas are ringed by earthen dams that can be 10 to 40+ feet above original grade and these are typically reclaimed by contouring them flatter after the settling area is retired. Such contouring usually leaves the berms at least a few feet above the prevailing grade of the interior of the settling area and adjacent outside topography. Portion(s) of the contoured berm are deliberately breached at lower depths to accommodate drainage swales to convey runoff from the consolidated settling area to adjacent downgradient lands. The berms consist of overburden or sand tailings. In modern designs the dam often has an overburden core and tailings toe apron to manage groundwater pressure and flow through the embankment. Although the clay has very low permeability, the clay crust often develops deep cracks, thus forming a macroporous surficial aquifer with substantial infiltration capacity for rainfall. The macroporous aquifer may be perched or in variable contact with the natural surficial aquifer especially along the berm interface.

RECLAMATION PHASES

The main vintages of reclamation technology are as follows:

1. Non-Mandatory Lands[2]. Prior to 1975. Reclamation was not required by law until 1975 and most lands mined prior to the law were simply abandoned and allowed to revegetate passively. This led to a wide variety of outcomes ranging from impressive cover by live oaks and other native upland forest species on overburden and native wetland forests on clay, to large expanses of nuisance exotic plant cover on either. Non-mandatory lands tend to have rough topography, often with pronounced linear and reticulated pockets of open water and terrestrial areas. However, much of this is obscured by dense forest cover on aerial images. It is often only readily apparent on LiDAR-derived topographic maps available from the Southwest Florida Water Management District and some counties. Non-mandatory lands were eligible for reclamation funding sourced from a severance tax paid by companies active after 1975 and administered by FDEP. Those funds mostly were captured to simply place the land into a usable condition, often for development. So, non-mandatory lands offer a spectrum of potential restoration scenarios and are necessarily evaluated with significant ground truthing. A good example of various ecosystem restoration improvements that can be made to non-mandatory lands are those at the Tenoroc Fish Management Area near Lakeland FL, administered by the Florida Fish and Wildlife Conservation Commission. Improvements included wetland creation, drainage improvements, pit lake habitat improvements, and creation of gopher tortoise recipient sites.
2. First Generation. 1975 through the 1980's. This was the first body of reclamation work driven by mandatory permit requirements. It is a period of comparatively low ecological emphasis in reclamation, but with much experimentation aimed at determining what was possible. All uplands reclaimed during this period received at least some contouring, grassing and some native forest revegetation. Many of the forest plantings have persisted and grown into impressive mature specimens, usually as dense patches distributed around the reclamation area. These sites can thus present as a mixed distribution of partially native and non-native zones, highly suitable for restoration activities. Wetland restoration was pursued in earnest during the 1980's, with generally very promising results. Some sites do not meet current requirements, however, and would be good candidates for future

[2] Sometimes referred to as 'Old Lands.'

restoration. In fact, agencies welcome modernization of First Generation reclamation projects to improve their ecosystem functions. This includes retrofitting stream restoration to the reclaimed landscape, increasing native biodiversity of uplands and wetlands, and limited contouring to promote drainage enhancements. The Mosaic Company recently acquired another company's First Generation project site specifically to improve its ecosystem functions for mitigation. That project, called the Bowlegs Enhancement Project, provides a good example of a variety of improvements that can be made to this generation of reclaimed lands. Planned improvements include establishing pyrogenic communities on reclaimed uplands and wetlands, vegetating seepage slopes that formed passively onsite with specialist native species, enhancing simple native forests with greater structural and bio- diversity, retrofitting eroded swales with natural channels and their floodplains, enhancing the biodiversity of existing marshes dominated by cattails, and eradicating and managing cogon grass and other aggressive nuisance species. Lands reclaimed during this phase generally lacked emphasis on landscape ecology, and are often rather discernable on aerial images presenting a variety non-natural polygonal attributes in plan view.

3. <u>Second Generation</u>. 1990's through early 2000's. Most of the ecosystem restoration work conducted during this vintage was conducted at a sophisticated level of planning and design, with very good outcomes spurred by advanced hydrology modeling and grading techniques. Work during this phase was driven to comply with a distinct elevation in permitting requirements by multiple county, state, and federal agencies. Landscape ecology was increasingly incorporated into the plans during this phase, leading to consolidated and separate large-scale zones of lands reclaimed to support a wide variety of native plant communities existing along subtle hydrologic gradients versus blocks of land reclaimed to support agricultural, industrial, and residential development. Some of the work incorporated landscape ecology so effectively in the design that it is hard to pick out on aerial today. Great examples exist at portions of the Four Corners mine in Manatee County and at the South Pasture Mine in Hardee County. The main opportunities for advancing the ecosystem functions of the reclamation of this vintage would be to acquire and provide long-term management of the restoration areas as public parks, and to acquire and restore yet to be developed lands that were deliberately reclaimed as pasture and are adjacent to blocks of unmined or restored habitat along priority corridors. In some cases, pilot projects were constructed ahead of their generation of work, and some such areas are also adjacent to non-mandatory and first generation properties of lesser ecological integrity. This presents excellent opportunities to improve the ecological connectivity of the pilot projects by retrofitting significant landscape ecology benefits on the adjacent properties. The Maron Run Stream and Wetland Restoration Project is one case located upstream of the aforementioned First Generation Bowlegs Enhancement Project. The latter is being restored to provide an improved hydrologic and wildlife corridor along the entire Maron Run valley, thus literally extending the ecological reach of the Maron Run project.
4. <u>Current Practice</u>. Early 2000's through the present. This phase focuses on fully marshalling what was learned from previous phases to maximize the value of phosphate mine restoration at the landscape scale. Stream restoration was added as a mandatory

reclamation requirement, and much of the original science our team uses to restore chains-of-wetlands at non-mined lands was developed to meet this requirement on mined lands. Although some stream corridor restoration projects can be found in earlier generations, this is the first phase that explicitly requires natural channel design (NCD) as a restoration requirement. NCD requires planning at the drainage area scale to properly pattern and dimension stream channels and their wetland floodplains to fit their watershed flow and sediment deliveries. The industry currently has many miles of stream systems implemented as NCD. This aspect ties nicely to the emphasis on landscape ecology because of the role headwater streams perform in connecting uplands to downstream waters. Dr. Mark Brown captured the essence of what is now unfolding, describing it as work that "potentially covers 300,000 acres (121,000 ha), and rivals other restoration efforts like the Florida Everglades in size and complexity (Brown 2005[2])". He calls for careful integration of planning and design at multiple scales and for collaborative visioning and adaptive management approaches to be implemented among industry representatives, research scientists, government agencies, and the local citizens. In essence, this CHNEP watershed plan can become a major guidance document for how to proceed along those lines.

[1] Kiefer JH. 2011. Key Advances in the Conceptualization and Design of Phosphate Mine Reclamation Since 1975. Comments submitted to USACE Phosphate Mine Areawide EIS. AMEC-BCI Engineers and Scientists, Inc. Lakeland, FL
[2] Brown MT. 2005. Landscape restoration following phosphate mining: 30 years of co-evolution of science, industry and regulation. Ecological Engineering 24(4): 309-329.

Key Advances in the Conceptualization and Design of Phosphate Mine Reclamation Since 1975

John H. Kiefer, Ph.D., P.E., P.W.S.

AMEC-BCI Engineers and Scientists, Inc.

Introduction and Executive Summary

Reclamation is the science and industry of returning surface mined land to a useful condition. Reclamation became mandatory for Florida phosphate mines in 1975. A lot has changed since 1975, and phosphate mine reclamation approaches are no exception. Only a summary of key advances in reclamation, particularly those related to ecosystem rehabilitation, is provided here. Research scientists, regulatory agencies and industry members have progressively sought ways to improve upon reclamation practices as knowledge increased and technologies improved. I have participated directly in much of this process since 1991 as an employee at Agrico, from 1993-2002 at CF Industries, and as a consultant at AMEC-BCI since 2002. I served on the reclamation technical advisory committee for the Florida Industrial and Phosphate Research Institute (FIPR) during most of my professional career prior to 2002.

The industry has pursued a wide range of objectives and concepts over time. Scientific advances and regulatory changes were the major drivers. State reclamation rules went through substantial improvements in the late-1980s and 2006. Beginning in 1980, the first mandatory reclamation rules enacted by the state, for lands mined after 1975, regulated the design and maintenance of clay storage dams and required that spoil piles and mine pits be contoured and planted with pasture grass to increase visual appeal. Areas reclaimed under these rules have a characteristic landscape of hills and slopes interspersed with finger lakes and large ponds. These reclamation efforts, although an improvement over the non-mandatory reclamation prior to 1975, did not have the same goals of restoring the ecological and hydrologic functions of the lands that exist today.

State wetland protection and mitigation rules first went into effect in 1984 and then underwent a major change with the Environmental Resource Permitting (ERP) regulations. In 1984, Wetland Resource Permits were required for impacts to non-isolated wetlands; it was one of the first rules to consider hydrology and water quality and quantity on and off-site. The reclaimed habitats resulting from application of these two sets of rules were better designed and created with more appropriate topography, suitable vegetation, and active management plans (i.e., exotic species removal, etc.), and were a significant improvement over the previous “land-and-lakes” reclamation landscapes.

Beginning in 1995, an Environmental Resource Permit (ERP) was required prior to mining both for management and storage of surface waters on-site, as well as for impacts to both isolated and connected wetlands and surface waters. This permitting program required an assessment of impacts to ground and surface waters, wetlands, soil composition, listed wildlife and plant species, habitat restoration and connectivity, and disturbance to surrounding lands and protected areas. Increased attention to these environmental resources would need to be apparent not only in reclamation design, but also in the planning of mining operations and in extensive pre-mining plant and wildlife surveys, groundwater monitoring, and hydrologic modeling.

It is more difficult to place clear timelines on scientific advances than regulations because the science tends to unfold over time, moves through different organizations at varying paces, and is often accompanied by a social dynamic known as a paradigm shift. In other words, as the science advanced, practitioners respond by changing their thinking about what was possible and practical. Regulations usually followed thereafter, but in some cases were the drivers of change. This means that different goals and objectives were subsequently pursued, and some of the most well-received were then codified as rule changes or regulatory reinterpretations.

Since the mid-1970s, mining and reclamation techniques have continued to advance. For example, hydrologic modeling and extensive pre-mining data now allow better prediction of the conditions needed to achieve target land elevations and hydroperiods for the reclaimed landscape, while reclamation technology continued to advance, notably, more refined laser- and GPS-guided earthmoving equipment that could achieve much more precise topographic tolerances than previously achievable. This has enabled much more precise contouring of areas proposed for wetland or habitat creation, allowing better and more accurate means to achieve the elevations needed to establish desired wetland hydroperiods.

In general, the dominant areas of ecological reclamation focus over the years can be characterized as follows:

- 1975-early 1980's. The leading question was "What can be done on reclaimed landforms?" Research focused on a variety of ways to handle clay tailings, sand tailings and overburden. Basic questions concerning what could be grown on these reclamation materials were also being addressed. A wide array of favorable plant species and growing media were identified.

- Mid 1980's through early 1990's. "How can we best create wetlands?" became the main question. Florida's Henderson Wetland Protection Act was passed in 1982 spawning a flurry of demonstration projects and treatment trials. Water quality and wildlife benefits were documented.

- Early to late 1990's. "Upland habitats matter too," was the motto. Encouraged by many of the early wetland creation attempts, focus expanded to look at ways to create native uplands and how to best arrange wetland and upland habitats into wildlife corridors.

- Mid 1990's through early 2000's. "Second Generation Techniques," involved a leap forward in technical sophistication and specificity driven by advances in predictive hydrology modeling and precision grading technology. This specificity enabled designers to design and build very shallow wetlands with greater confidence such as wet prairies, seepage swamps, and headwater streams.

- Early 2000's through the present. "Integrated Marshalling of Resources." This has been a period of refinement and more holistic application of previously determined best practices to maximize net ecosystem benefits. As a result, the most recent plans are designed by large multi-disciplinary teams with increased focus on soil profiles, groundwater flow regimes associated with sub-grading design, stream corridor restoration, and landscape level planning. Also, what the 1980's were to wetland techniques and the 1990's to uplands, the 2000's have been to stream corridors. Therefore, this period could also be termed, "How do we best reclaim entire landscapes to support local and regional stream corridors?"

Early reclamationists were faced predominantly with questions related to things like "What plants will grow best on reclaimed soils?" "What can really be done with reclaimed landforms and what objectives are worth pursuing?" Today, the biggest questions revolve more about what net benefits should be most aggressively pursued. For example, "Should we maximize uniquely developable lands or increase the size, quality and position of wildlife corridors?" "Should we enhance deep aquifer recharge or improve local and regional stream flows?" The nature of changing reclamation viewpoints and associated scientific advances makes it important to understand the reclamation period and associated paradigm under which a project was conceived when interpreting its outcomes. The existing paradigm focuses most heavily on trying to return aspects of mined and reclaimed landscapes, not to the condition immediately prior to mining, which is typically a somewhat artificially ditched and drained condition, but to something closer to a more natural condition without the adverse affects of prior land use patterns. Advances in hydrology modeling, soil science, grading and sub-grading techniques, fluvial geomorphology, weed management, etc., have made this goal reachable. Existing practices are the result of more than a quarter-century of learning and running discourse among multiple stakeholders.

The rest of this document is organized into technical sections based on fundamental issues for successful reclamation and briefly describes how each issue was addressed over time, culminating with the current state-of-the-art. The technical sections include use of soil materials, predicting hydrology, grading and sub-grading, managing vegetative community succession, and designing for landscape-scale benefits. This covers soil, water, plants, and ecosystem function. This white paper represents the opinions of the author and not necessarily the opinion of any organization, public or private. I apologize for any omissions. A lot of great thought and work has been accomplished over the decades and it would be impossible to acknowledge all of it in this format.

Use of Reclamation Materials as Soil Progenitors

One of the first items to consider was how to best utilize reclamation materials as a growth medium for native vegetation and crops. The available materials include clay and sand tailings, overburden (a highly variable sandy loam), and native topsoil. Various case studies and some experiments were carried out on these soil parent materials by amending them in a variety of ways to balance their fertility, water holding capacity, tilth, or microflora. (e.g. with fertilizer, green manure, mulch, mycorrhizal inoculates, etc.). In general, most such amendments were determined to be unnecessary.

Overburden Cap

Pre-1975 mined areas comprised of clay tailings and of overburden typically supported dense forest cover (Zellars-Williams, 1980). Sand tailings piles typically lacked such cover due to their droughty nature, low cation exchange capacity, and low fertility. Early experiments growing cattle forage crops indicated that overburden was the best growing medium for bermuda grass (Mislevy and Blue, 1985). These facts led to rule requirements for an overburden cap to be placed on sand tails. That recommendation was implemented by typically spreading a foot or more of overburden over sand tailings areas to achieve final grade on virtually all reclamation sites, upland and wetland until the late 1990's.

The main reason this requirement was dropped is that it often inverted the hydraulic conductivity of the soil profile, reducing groundwater infiltration. Furthermore, the overburden cap sometimes reduced the soil potential for fossorial vertebrates (Mushinsky and McCoy, 1996).

Functional Soil Profiles

An overburden cap is described as an inversion of the soil profile because overburden generally has infiltration rates several times lower than sands or most histosols surface layers. Most native upland soil profiles in the mining region have at least an upper foot of fine sand, and wetlands typically have at least several inches of muck, often over thicker layers of sandy material. The surficial layer is underlain by the loamy material which comprises the dominate component of the overburden.

Given a desire to provide a sandy surface layer, the 1990's ushered in greater experimentation with amendments to sand tailings and the use of native topsoil layers. Since the 1980's, wetland muck had been demonstrated to provide an excellent growing medium in marshes and swamps (Best etal., 1987) and had been used extensively already. Experimentation in the use of xeric upland topsoils, especially as a source of propagules began in the late 1980's (King etal., 1992). Experimentation with flatwoods soils also showed positive results as not only a superior growing medium for that type of system, but also as a propagule source (Segal etal., 2001).

Soil amendments using green manure, a process of growing an annual cover crop on sand tails and then disking it into the soil to add organic material also renders the tailings a suitable growing medium. Reclaimed upland soils develop basic natural horizons in keeping with their seasonal high water table fluctuations over time. Nair etal. (2001) found that reclaimed wetland soils approached natural carbon:nitrogen ratios and steadily increased organic soil matter accumulation with favorable decreases in bulk density. Kiefer (1991) documented rapid organic soil development positively affecting created wetland water quality functions after the second growing season with a level of maturity akin to natural systems occurring at about 10 years after site implementation.

Current thinking is that the promotion of good surface soil infiltration is more important for ecosystem function than using an overburden cap as a grass-growing medium. Bare tailings are rarely planted without either a cap of native topsoil or green manure to assure acceptable initial growth of a wide variety of vegetation types.

Clay Tailings

Riverine bottomland species of wetland trees planted on clay and sand-clay mix grow well (Odum etal., 1991). Many pre-1975 clay tailings areas are covered in dense wetland vegetation. Because modern clay settling areas (CSAs) are typically reclaimed at elevations above natural grade, the FDEP and Corps do not give mitigation credit for wetland creation on them. Recent research by Brown, et al. (2010), describes the wetland hydrology of CSAs and provides a foundation for what to expect when attempting to create sustainable wetlands on them. This work establishes a blueprint for designing and evaluating wetland functions on CSAs and perhaps will pave further regulatory consideration for how to credit the unique wetlands that can be established on these landforms. This is important, because if at least some wetlands could be created upon clay settling areas for mitigation credit, more upland habitat, developable lands, or aquifer recharge projects could be created on sand tailings backfill areas. This remains in regulatory stasis.

When CSAs are well-drained, they can support a wide array of agricultural (Hanlon et al., 1996) and forestry products (Rockwood etal., 2008). The most common reclaimed use of CSAs today is for cow-calf operations. Research into growing different crops on CSAs continues. Future shifts in either agricultural and energy crop markets could lead to the high moisture retention and fertility of the dense soils in CSAs to be tapped for their tremendous growth potential.

Predictive Hydrology

All reclaimed landforms consist of materials that originated from the local landscape, including: fine to medium sands, colloidal clays, and loamy overburden. Each of these materials has different hydrologic properties. The clays swell significantly after mining and this fact alone precludes replacing the materials precisely into the lithological layers from which they were originally derived. Therefore, the resulting landforms can have unique drainage characteristics (Lewelling and Wylie, 1993). Knowledge of the different hydraulic characteristics of each reclamation material and how they will be arranged in the landscape is important to achieve targeted reclamation outcomes. This is because Florida ecotypes and land use potential are highly sensitive to local drainage conditions and water table elevations relative to land surface. The hydrologic properties of the reclamation materials are known, and therefore the materials can be arranged in a manner that creates the desired drainage condition and water table elevations.

SWFWMD and FDEP signed a Memorandum-of-Understanding requiring pre-mining and post-reclamation flood event modeling to assure that drainage conditions would not result in offsite flooding or erosion. Event modeling is not particularly useful for predicting long-term watershed performance characteristics like seasonal stream flow regimes or wetland hydroperiods. During the 1980’s through the early 1990’s, wetlands were typically designed with either no continuous time series modeling support or with simple water budgets, full of assumptions related to large components of the water budget such as evapotranspiration (ET) rates and rainfall infiltration volumes. Groundwater modeling via MODFLOW was at a high level of sophistication, but the unsaturated soil zone, where much of the most important action occurs was not. To more precisely design the post-reclamation landscape, a need existed for a modeling software code that was physics-based, representing the unsaturated zone processes and its integrated surface water and groundwater interactions. The Florida Institute of Phosphate Research (FIPR) contracted with the University of South Florida, SDI, and BCI consultants to develop such a model in the early 1990’s.

Until the mid-1990's a lack of integrated modeling capabilities often led to conservative approaches in wetland design. Wetlands were typically positioned at low-lying areas flanking riparian preserves to assure ample runoff toward them and to intercept known groundwater table elevations. Morrow Swamp and Ag East are two well-studied examples (KLECE 1982-1991; KLECE 1988-1991). Furthermore, lack of confidence in hydrology predictions also led designers to favor a philosophy of "deeper is better." If you are going to err, err in a way that will assure the presence of standing water. Instead of taking a sub-basin approach, state regulatory agencies focused on each wetland polygon, holding companies accountable to create wetlands shaped exactly like they were drawn on plan sheets. This approach, coupled with the uncertainty in water level predictions, caused designers to favor contouring wetlands with relatively steep side slopes along their edges. Gradual ecotones were therefore rarely contemplated because a small error in water level could lead to many acres of wetland shape being out of sync with the lines on a map. Wetland acreage was typically consolidated into parts of the landscape known to be most likely to support them. These factors, coupled with the requirements to reclaim with an overburden cap, led to many designs resulting in wetlands with long perennial, or nearly perennial, hydroperiods. Small isolated wetlands, very shallow wet prairies, headwater streams, and seepage wetlands were comparatively seldom targeted for creation.

This changed pretty rapidly beginning in the early 1990's. By then, it was becoming clear that on overburden and sand tailings backfill areas contoured fairly close to original grade, that water tables could be achieved akin to that of natural ground. The USACE was also promoting a hydrogeomorphic approach to wetland characterization and functional assessment during this time frame (Smith etal., 1995). These factors led to the development of wetland restoration designs based on principals of hydrogeomorphology, essentially creating topological analogues to natural systems at the Fort Green and Payne Creek mines, including sites such as the seasonally wet SP2D marsh and the large headwater system called the Big Marsh. The idea was to scatter wetlands across varied landscape positions, with a variety of depth and edge/volume ratios to promote a spectrum of hydroperiods beneficial to wildlife on a landscape scale (Kiefer and Kale, 1993). Afterwards, IMC (now Mosaic) designers created the first bay swamp seepage wetland consistent with hydrogeomorphic design principles, Alderman Bay (Kiefer 2005).

The FIPR Institute's integrated hydrology model was ready for use by 1992, and other integrated codes subsequently became available, including BCI-FLO, Vadose W, modified HELP, and MIKE SHE. These kinds of modeling codes reduced reliance on assumptions and gave more realistic representations of the physics of groundwater and surface water interactions. With these tools, reclamation designers could explore a greater variety of site-specific and landscape level design approaches and hone in on cost-effective subgrade placement of sand tails and overburden to achieve rather specific levels of stream baseflow, wetland depths and hydroperiods, and upland soil drainage characteristics in a wide range of landscape positions across the mine property. The combined effects of clay settling areas and other landforms on offsite stream flow and aquifer recharge could be determined with better reliability as well.

The industry wasted little time putting these tools to use. CF Industries was the first to do so for an entire mine, when in 1995 the company commissioned an integrated model of its South Pasture Mine reclamation plan (SDI 1995). The life-of-mine reclamation plan was designed using the aforementioned hydrogeomorphic principles (CF 1994). The model results confirmed the general utility of that approach on sand tailings backfill areas, and proved useful for adjusting contours for sand-clay mix areas to be reclaimed above original grade and lakes reclaimed below it. Integrated modeling tools are perhaps the single most important development in reclamation design since the advent of the mandatory reclamation rule. It has facilitated designer confidence in the planned success of many shallower wetland types that were previously de-emphasized, including headwater stream corridors, seepage swamps, wet flatwoods, and wet prairies/zoned marshes.

Grading and Subgrading

Soil and lithological lensing is often necessary to achieve the degree of fine control necessary to create the shallower and more ephemeral wetland types in the reclaimed landscape. Precise and accurate surface grading is also required for these kinds of systems. Since the early-1990's advanced surface grading techniques using laser-level controls on grading equipment and Global Positioning Systems (GPS), in addition to traditional ground survey and staking methods, resulted in projects being graded to vertical tolerances of less than an inch when deemed necessary.

Some pre-mining and post reclamation conditions may have combinations of comparatively high relief and natural surficial aquifer lithology dominated by a low-conductivity subsoil underlying a much thinner, sandier, better drained surface layer. In such cases, reclaiming land to original grade retains the high relief, but does not necessarily replicate the surficial aquifer conductivity. This is because the reclaimed lithology typically, but by no means always, starts out as rows of alternating overburden and sand tailings up to a mile in length. These rows, if oriented perpendicular to the aquifer's gradient, can retard groundwater baseflow to the preserved stream valley, and if oriented parallel to the gradient, can promote excessive baseflow thereby dewatering the hillslope and wetlands preserved or reclaimed on it.

First, the spoil geometry is modeled prior to reclamation to check if these kinds of problems are at issue. In some cases, the relief is too flat to matter, or the preservation boundary's soil profile acts as the dominant control. In some cases the highwall along the boundary can be modified in a manner that creates the necessary balance between groundwater outflow and water table elevation along the hillslope. An example of that design approach is along Horse Creek at the pending Ona-South Fort Green Mine (J. Garlanger, personal communication 2003). In other cases it is necessary to break up the efficiency of the sub-surface drainage through sand tailings conduits by spanning them at strategic locations with "overburden saddles." These lower-conductivity saddles retard over-drainage via excessive baseflow and increase the water table so it can support wetlands. Some baseflow, in the range necessary to support either the preserved or reclaimed stream and seepage corridors, is thus maintained. The saddles create the proper balance and key design parameters of such saddles include the hydraulic conductivity, location, thickness and elevation relative to ground surface. These factors interact, and often require numerical modeling to hone in on a good design. An example of this approach is described for the Gilshey Branch Unit at the South Fort Meade Mine (BCI 2006).

Plant Materials, Weed Management and Managed Succession

Wetlands

Wetland plant materials were not always easy to come by prior to the early 1990's. Therefore, Agrico (now Mosaic) developed its own plant nursery during the late 1980's. It remained in operation until 1993. It was discontinued because a large industry of Florida wetland plant growers emerged that more cost-effectively served the entire market. Seminole Fertilizer (now Mosaic) pioneered techniques to cost-effectively produce large quantities of sawgrass.

Today, most herbaceous wetlands are created using wetland topsoil (muck) from sites permitted for mining. The muck provides ample plant propagules for depressional marshes, especially flag marshes (e.g. pickerelweed). In some cases, muck is stored in flooded mine cuts or under overburden caps to prevent it from oxidizing, sometimes for many years prior to application. Herbaceous wetlands are often mucked several inches thick, and the site is evaluated during its first summer. If certain desired plant species are missing, or if cover emerging from the muck is too sparse, supplemental stock is transplanted to the site.

Weed management tends to be straightforward on these sites, and the main target species include cattail, primrose willow, and Carolina willow, which are tall plants that are generally easy to kill without adversely affecting the desired lower-growing species. With good initial establishment and weed management, marshes reach their climax conditions quickly, often in less than 5 years (Kiefer 1991).

Forested wetlands take longer, mainly because trees take many years to mature and form a closed canopy (Brown and Carstenn, 2009). Almost all trees are installed from nursery grown containers. These systems require greater care in weed management and also can be more susceptible to extremes in climate that can kill the planted saplings. Supplemental plantings are therefore more the norm than the exception. Experiments planting larger stock tend to show little, if any, advantage to doing so.

Wet prairies and the similar outer zones of deeper depressional marshes have very different plant communities than the deeper flag marshes. Therefore, starting a few years ago, when appropriate topsoil is available, the industry began segregating wetland topsoil based on the donor site zone from which it was removed and placing it into concordant reclamation site zones. Some wet prairie species composition overlaps with upland flatwoods vegetation, and companies specify seed collections to aid in direct seeding of the ecotone between flatwoods and the marsh.

Mesic Uplands

62C-16 requires at least 10% of the reclaimed uplands to be forested. A system was defined as forested if it had more than 200 trees per acre. As a result, most upland reforestation consisted of dense pine and mixed hardwood plantings. Slash pine was a preferred species in earlier reclamation because it can grow well under a wide range of soil moisture conditions and grows quickly. This combination of high survivorship and rapid growth made it the tree of choice for meeting the reforestation requirement. These kinds of simple forest communities proved easy to establish and a movement to reclaim a broader array of more diverse and natural upland vegetative communities began in earnest during the mid-1990's for mesic systems, especially pine flatwoods.

Recognizing that most of the plant diversity of natural flatwoods occurs within the groundcover and that this groundcover provides a critical functional role in promoting the fire ecology of the ecosystem, techniques were developed to establish native, pyrogenic groundcover as a key component to "reforestation." This was a greater point of emphasis than dense tree establishment which would shade the groundcover (Kiefer and Wertschnig, 1998). The first challenge was to secure seed sources. FIPR funded research that attempted to catalyze seed source development with accessions of several native species that could be grown and harvested from cultivated fields (Pfaff etal., 2002). Techniques were also developed for harvesting from native systems (Bissett 2006). Protocols for use of upland topsoil were also explored and put into practice, sometimes in combination with direct seeding efforts. Bissett (2006) also developed successful protocols for direct seeding reclaimed uplands. Longleaf pine was historically the dominant upland conifer over most of the mineralized district in the flatwoods. These pines typically created a scattered open canopy akin to a savanna, and companies now plant accordingly.

Weed management is critical in these sites. The most noxious species is cogon grass, and FIPR sponsored research to control it and other upland weeds such as natal grass (Schilling etal., 1997). Bahia and Bermuda grass also require diligent control at flatwoods reclamation sites. If any of these weeds are allowed to establish well into their exponential growth phase, they can take over a site before the slower-establishing natives can develop into the climax community.

Xeric Uplands

Pioneering efforts to reclaim analogues to xeric uplands (e.g. xeric oak, sandhills, sand pine scrub) began in the 1980's with early successes achieved by topsoil transfers (King etal, 1992) and nursery grown stock (Segal etal., 2001). Weed management is a critical issue on these sites, akin to that of the flatwoods.

Landscape Design

During the 1980's, many advanced ecosystem reclamation efforts were seemingly built on favorable sites that were available at the time of conception. This led to individual reclamation sites being created in a rather geographically isolated or disjunctive manner without strong consideration of landscape ecology. Landscape ecology emphasizes how the whole is greater than the sum of the parts, i.e., how the various habitats tie in to create a unified landscape. Landscape ecology was rapidly incorporated into designs during the 1990's. As it becoming increasingly apparent that an array of xeric upland, wetland and lacustrine habitats could be created on mined lands, practitioners and regulatory agencies began to ponder how to best assemble these pieces for wildlife and other benefits. Wildlife corridors emerged as early obvious solutions. This thinking led the FDEP to develop a conceptual Integrated Habitat Network (IHN) consisting of a massive network of reclaimed and natural habitat corridors spreading across the mineralized region and beyond (Cates, 1992). CF Industries provided the first mine-wide plan to incorporate IHN concepts during 1994-5 (CF 1994).

Landscape planning not only includes contiguous wildlife corridors, but has also more recently invoked meta-population concepts in naturally "insular" or isolated habitats like xeric scrubs.

The prime example is that the Mosaic Company spearheaded what ultimately became a multiple landowner initiative to improve regional population dynamics for the Federally threatened scrub-jay in eastern Manatee County (D. Gordon, personal communication 2010). This plan used a combination of natural scrub preservation and restoration to provide a substantial net increase in the long-term, sustainable viability of the jays in this region to offset jay habitat losses related to mining.

Mine sites also offer the opportunity to provide net ecosystem benefits related to improving the function of headwater wetlands systems and chains of wetlands that are ditched or drained by eroded and artificially incised stream channels, by replacing these kinds of systems on-site with reclaimed chains-of-wetlands contoured and vegetated to a much more natural, unditched condition. Subsequent to 2004, new stream classification and restoration tools have been developed for peninsular Florida, sponsored by FIPR (Kiefer, 2010; Blanton, 2008). These advances were rapidly adopted by CF Industries in their proposed stream restoration plans for their South Pasture Extension (BCI 2011). Stream reclamation developments are addressed in a separate white paper (Kiefer and Nowak, 2011).

Conclusion

After 1975, the main questions among phosphate mine reclamationists regarded things like whether or not certain native wetland plant species could be grown on reclaimed soils, whether the plants would reproduce, and whether wildlife would colonize the sites. The industry has long-since progressed beyond these fundamentals and is now addressing concepts related to how to best use reclamation and preservation in concert to achieve regional net environmental benefits. This thinking enables the industry to help reverse damage done to wildlife populations and riparian corridors from the 1940's through the 1970's prior to mining.

The modern era or "Second Generation," in mine reclamation nominally began in the mid-1990's. Second Generation techniques involve tapping resources that would have seemed more like science fiction to the earliest practitioners from the 1970's. Some examples (mentioned above) include GPS and laser guided construction equipment, integrated groundwater and surface water modeling software and hardware that can make millions of calculations in a matter of minutes, LiDAR-based topographic surveys, and narrow-spectrum herbicides that kill the weeds and leave the good plants healthy. The proper use of this technology is aided by many studies on the responses of vegetation, hydrology, soils development and wildlife utilization that have occurred during the last three decades. Encouraged and inspired by what is possible, a new vision has emerged for mined and reclaimed lands, resulting in net environmental benefits for the watersheds in which mining occurs.

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