

PLANNING AND EVALUATION TECHNIQUES FOR REPLACEMENT
OF COMPLEX STREAM AND WETLAND DRAINAGE SYSTEMS¹

by

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Abstract. Requirements for restoration of some lands to pre-mining landforms, drainage patterns, and wetland/aquatic systems are becoming more prevalent and stringent. A systematic methodology for determining environmental and ecological parameters and conditions controlling existing systems was used to design a Central Florida Phosphate District wetland/stream system. The approach involves several steps. Existing systems are characterized and hydrological/soil/vegetational profiles are developed for each community type and stream reach. Post-mining requirements and attributes are matched to pre-mining conditions to develop the conceptual plan. The reclaimed complex is then designed in a series of iterative steps to allow reestablishment of each profile until optimal configuration is reached. Unit boundary elevations are defined, and open channel flow procedures are used to define stable channel dimensions for the stream sections. Flow barriers, contouring, and other passive devices are designed to create proper hydroperiod conditions for each community type along the complex. Backwater analysis and other standard methods may be used to evaluate hydroperiod conditions for various flow regimes, to provide balanced systems without further subsidies or manipulation.

Additional Key Words: Reclamation Planning, Vegetation, Hydraulic Design, Florida, Phosphate

Introduction

State and federal mining regulations have emphasized rerouting and designing channels for efficient water removal and flood damage prevention, but new regulations concerning wildlife habitat and restoration to approximate original contour (AOC) are beginning to affect stream routing considerations.

In several states, reclamation requirements are tending to more inclusive treatment of drainage systems restoration. This trend is most prominent in industries and states to which the Surface Mining Control and Reclamation Act of 1977 (SMCRA) does not apply. The Florida phosphate industry is

a key indicator of this trend in regulatory requirements where there is increasing pressure not only to reclaim to AOC, but also to complete replication of existing conditions. Such procedures could result in regulations to restore exact drainage basin boundaries and stream channel locations as well as to replicate pre-mining vegetation types and biotic communities in their original locations and hydrologic situations.

Current reclamation approaches generally do not address the problems of restoration to original conditions, due to a lack of integration of several disciplines such as hydrology, ecology, and wetlands biology.

An experimental reclamation plan was developed in response to agency concerns over mining of wetlands and streams in central Florida. This demonstration project had an objective of providing a diversity of wetland, aquatic, and terrestrial communities approximating the conditions found along a natural drainage. This project serves as an example of an approach that may be used to

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address a challenge which most reclamation planners have not yet encountered, but may meet in the future.

Approach

This approach to planning complex natural drainage systems consists of the following steps:

1. Determine pre-mining hydrologic and biotic conditions of the basin,
2. Characterize ecological requirements of existing wetlands and vegetation types, including hydroperiod, soils, water depth, seepage conditions, and elevational requirements,
3. Determine post-mining hydrologic conditions emphasizing basin size and discharge, soil types, run-off characteristics, and baseflow/peak flow relations,
4. Establish reclamation unit boundaries so that all flood prevention requirements are met at the boundary,
5. Design inlet and outlet inverts, stream gradients, and channel dimensions to meet hydraulic specifications for design flow condition (for a beginning determination, design to maintain mean annual flood at top of channel),
6. Match wetland and community requirements to conditions within each reach of the reclaimed drainage system: conditionally locate units to best approximate existing acreages and locations within constraints of reclaimed system,
7. Determine cross-section dimensions for wetlands and non-channelized portions to adequately provide for transport of water at design event conditions,
8. Design flow control structures for exit from each wetland or unchannelized portion to retain sufficient depth/duration to support design wetland type,
9. Locate wetland elevations along stream gradient in relation to invert levels such that low flow conditions are established by inverts and control structures,
10. Locate and size culverts or discharge structures to control high water levels for each design event (mean annual flood, 5 yr flood, etc.) and model water levels for each wetlands unit,

11. Use iterative steps to adjust discharge structure sizes and locations, or final dimensions and grading specifications for each wetland unit to establish desired hydroperiod within each wetland in conjunction with proper discharge regulation.

Demonstration Site Description

These steps were used in designing a complex stream/drainge system for a site in central Florida. The site consisted of a 3,500 ft segment draining a 1.2 mi² basin. Average stream slope was 0.06%: mean annual flow was estimated at 1.1 cfs. Natural vegetation directly associated with the drainage system, of which 37 acres (53%) were wetlands, included maidencane-dominated shallow marsh, blue flag-dominated deep marsh, oak-dominated mesic hammock, black gum swamp, and bayhead swamp.

The mine plan required mining of the stream corridor and adjacent lands, and relocating a stream system approximately 1,500 ft from the pre-mining location which would be covered by a sand and overburden dike forming one side of a waste clays settling area. Two mine cuts would be made in the vicinity of the proposed reclaimed channel parallel to the existing channel. The existing drainage would be relocated temporarily through a diversion ditch along the property boundary. After mining, the mine cuts would be filled with sand tailings and overburden, with the bulk of the tailings on the side adjacent to the settling pond. The level of clays inside the settling area dike would be approximately 20 ft above grade. A state highway along the other side of the reclamation unit and the plant access road would constitute the other boundaries of the unit.

Demonstration of Methodology

Determination of Pre-Mining Conditions

The confidence level for reclamation design is usually a function of the amount of data available. However, with a limited amount of field data and a high degree of experience in dealing with the appropriate systems, substantial information can be derived from a limited data base. The following parameters are the most important pieces of information that will be required for further planning:

Hydrologic Parameters.

Basin Size and limits
Basin Discharge Volumes
Soil Types
Run-off Characteristics
Length of Drainage
Elevations
Slope
Cross-Sectional Areas
Seepage Conditions

Biotic Parameters.

- Wetland/Community Types
- Stand Boundaries
- Stand Areas
- Dominant Species of Deepest or Largest Zones
- Soil Types
- Basin Configurations
- Degree of Connection

From these parameters and available information on ecological requirements of various species, community characterizations can be developed, and the resultant design parameters for each type specified. Tables 1 and 2 list representative pre-mining conditions and parameters for the demonstration site. For this site, no pre-mining discharge data was available for the drainage basin. Estimates of discharge were made by extrapolating from data for three nearby monitoring stations on similar systems with similar drainage basin characteristics. These data were converted to a discharge per square mile of drainage basin, and averages from the three stations were used to estimate values for the project area.

Determination of Post-Mining Conditions

The above hydrologic parameters are then determined for the reclamation unit. In many cases, these can only be estimated or inferred early in the planning process due to a lack of data on post-mining conditions.

For the demonstration project, numerous uncertainties existed. A lake system proposed for the upper end of this basin extended into another drainage basin. Outfall locations and volumes were subject to change. The clay settling area adjacent to the unit also was a source of uncertainty for the degree of surface discharge that might be permitted and also for the degree of seepage that might occur.

Best estimates of post-mining condition were made on the basis of most likely scenarios. The analysis indicated that discharge volumes of the basin as a whole would be similar to that of the pre-mining condition. Calculations

Table 1. Pre-Mining Physical Parameters for Demonstration Site.

Parameter	Value
Drainage Basin Area	1.17 mi ²
Length of Drainage	3,500.00 ft
Upstream Elevation	75.50 ft msl
Downstream Elevation	73.00 ft msl
Slope	0.06 %
Mean Annual Flow	0.96 cfs
Mean Annual Flood	20.00-25.00 cfs

Table 2. Pre-mining Biotic Parameters For Demonstration Site.

Community Type	Area (Ac)	Deepest Zone (ft)	Dominant Species	Soil Type
Shallow Marsh	24.0	1.3	Maidencane	Sand
Deep Marsh	3.2	4.0	Blue Flag	Peat
Hardwood Swamp	10.0	3.5	Black Gum	Peat
Mesic Hammock	33.1	0.0	Live Oak	Sand

indicated that under high flow conditions, the surface runoff and flow entering the upstream end of the reclamation unit would be somewhat greater than pre-mining conditions because of the increase in basin area from the lake and settling area surfaces. Under high flow conditions, most of the discharge was projected to be discharged into this system via an emergency spillway.

Under low flow conditions, the volume of surface flow entering the area was projected to be somewhat lower, due to the storage capacities of the lake and settling area and to the location of the normal lake discharge structure in the adjacent basin. Thus flows in the upper reach of the reclamation unit were projected to be more seasonal, with lower hydrologic subsidy in the dry season. Groundwater seepage to the upper portion of the system was projected to be less than pre-mining conditions.

Conditions in the lower reaches were projected to include peak flows similar to pre-mining conditions. In contrast to the upper reaches, baseflow was projected to increase due to seepage through the porous sand tailings from the adjacent waste clays storage area. The hydrostatic pressure of the storage area was projected to maintain permanent lateral groundwater baseflow at depths of two to six feet below the ground surface throughout the eastern half of the reclamation unit.

Establishment of Flood Control Boundaries for Reclamation Unit

The demonstration project was designed as a natural area for wildlife and low intensity agricultural uses with access and future development potential limited by the adjacent setback limits of the roads and settling area. Therefore, the entire unit was designed as a flood-prone area with flood control regulations in effect only at the boundary. For the demonstration area, the boundary was set at the +7 ft level relative to the exit invert. Maximum water level elevations for the 25 yr and 100 yr flood events were established at the +4 ft and +5 ft levels, insuring that flood control objectives would be met.

Channel Dimension and Slope Determination

Design of the post-mining drainage system begins with the development of hydraulic specifications for a simple channel system sized to retain design flows. Invert elevation and base of channel at the upstream and downstream end of the unit are determined by matching the highest design water level to the design flood elevation at the edge of the unit. In the demonstration area, the upper edge of the reclamation unit was set at 7 ft above the discharge invert level. Channel bed at the lower reaches also was set at a base elevation of 0 ft, equal to that of the pre-mining channel bed. In order to maintain the slope of the drainage system at a level similar to that of the pre-mining system (0.03% vs. 0.05%), the channel bed at the upper end of the unit was set at +3 ft relative elevation.

Mean flow velocity for the mean annual flood event in the pre-mining channels was estimated at 1.2 to 1.6 fps. Bankfull channel dimensions for the reclaimed area were sized to yield similar flow velocities and similar depths of channel (Table 3). Meanders were designed to anticipate equilibrium with the bankfull conditions to insure long-term stability.

Location of Reclaimed Wetland Units

Once the basic elevations, slopes, and cross-sectional area specifications are completed and benchmarked by the channel specifications, the inclusion of wetlands and non-channelized aquatic portions may be addressed. The size and type of wetland areas to be included are functions of several considerations, including:

1. Type and extent of pre-mining wetlands,
2. Available elevation range within reach,
3. Available hydrologic subsidy within reach, and
4. Availability of suitable base flow/peak flow relations.

Location of these units can be considered as a modelling process. Given sufficient data and accuracy in measurements, sophisticated ecological and hydrologic modelling may be employed to establish accurate hydrographs and water balances for each section.

In actual practice available data usually lacks the precision to allow meaningful modelling. Therefore in most applications, modelling may consist only of matching the ecological parameter requirements of various communities or species to predicted specifications for each reach.

In the pre-mining demonstration site, the upper reach of the system was occupied by a bayhead-black gum swamp system, a wetland type characterized by relatively deep flooding, long hydroperiods, and soils which are saturated through most of the year. A seepage slope on one side of this system contributed to the saturated condition. However, the upper reaches of the reclaimed system would be characterized by reduced dry season flows and reduced seepage baseflow. Consequently, the long hydroperiods and saturated conditions of the original system can not be replicated in this section, and a bayhead or long hydroperiod wetland type should not be considered for this location.

The solution arrived at for the demonstration project was to design a wetland system in the upper reaches which was adaptable to seasonal flooding and subsequent dry downs, with up to six months of unflooded conditions. Consequently, the design specifications for wetlands in this section called for shallow, maidencane-dominated marshes and bottomland hardwood swamp communities.

Conversely, conditions at the lower reaches of the reclaimed system would be characterized by greater seepage and base flow, with potential for longer hydroperiods, deeper long-term water depths, and continually saturated soils.

Table 3. Hydraulic Specifications for Channel Bankfull Conditions at Mean Annual Flood Stage for Reclaimed Tributary.

Location	Q ₂ 2.33 Year Flood Flow (cfs)	V Mean Velocity (fps)	A Cross Sectional Area (ft ²)	P Wetted Perimeter (ft)	D Mean Depth (ft)	D max Maximum Depth (ft)	W _T Top Width (ft)	R _H Hydraulic Radius
Upstream Reaches	22.5	1.380	16.303	12.359	1.15	1.44	14.16	1.319
Downstream Reaches	30.5	1.434	21.262	14.442	1.31	1.64	16.18	1.472

In the proposed design solution, the bayhead or deep swamp type communities were relocated in this portion of the system.

Determination of Flow Characteristics and Control Levels for Wetland Units

In the demonstration area, the conceptual plan included communities in the upper reaches controlled by surface flows and in which water levels are determined by the balance of incoming surface flow to evapotranspiration and percolation. In the lower reaches, dry season conditions are functions of seepage and baseflow conditions instead.

Optimal hydroperiod and maximum water depth are next determined for each wetland type. In the upper reaches of the demonstration system, design conditions for each wetland area were effected by control structures for retarding flow and retaining water up to the maximum depth. In this case, the system functions as a series of basins which fill and then spill over into the next segment of the drainage system. Cross sectional areas and profiles were determined for each wetland area which maintained maximum water levels near design specifications, while maintaining low velocity flows (0.05 - 0.3 fps) over the greatest possible wetland area.

Comparison of hydraulic specifications of wetlands and channels gives some guidelines for wetland requirements. In the demonstration area, channel dimensions calculated by standard engineering parameters for the mean annual storm yield width:depth ratios of 7 to 12. The width:depth ratios for the wetland areas range from 30 to 60. Flow velocity for the mean annual storm in the wetland units averages about one-tenth

that of the channel segment. Wetland specifications for the demonstration area are shown in Table 4.

Permanent or deep wetlands can be controlled not only by the outfall control structure, but also by the elevation of the wetland bed in relation to the channel bed and the groundwater or seepage water table. In the demonstration project, the base elevations of the surface flow-controlled wetlands in the upper reaches were similar to those of the channel bed. In the lower reaches, however, the base elevations of the deeper wetlands were significantly below the bed of the channel. The resulting elevational relationships control hydroperiod.

Control structures for the upstream wetlands consisted simply of wide berms or lips around the wetlands with low slopes and flow velocities below 3 fps. Berms may be vegetated or covered with rip rap or fibers for additional stability. For the demonstration project, top widths of about 12 ft and downstream aprons of 40 ft with a slope of 1 to 4 % were designed.

Final Grading and Discharge-Flow Control Structure Specifications and Adjustments

The initial design sequence as described is based on an assumption of open channel flow, and also on the assumption that the controlling factor in the system at the exit from the unit has the same specifications as the channel. In the demonstration area example, this assumed a trapezoidal flume or box culvert of approximately 15 X 6 ft with the base of the culvert on plane with the bed of the channel.

Any combination of culverts or exit structures that have a similar cross sectional area (plus allowances for

Table 4. Hydraulic Specifications for Wetland Areas at Mean Annual Flood Stages for Reclaimed Tributary.

Location	Q ₂ 2.33 Year Flood Flow (cfs)	V Mean Velocity (fps)	A Cross Sectional Area (ft ²)	P Wetted Perimeter (ft)	D Mean Depth (ft)	D max Maximum Depth (ft)	W _T Top Width (ft)
Wetland Area A Shallow Marsh	22.0	0.23	96.00	59.62	1.60	2.00	60.00
Wetland Area B Shallow Marsh	22.5	0.04	456.00	193.64	2.40	3.00	190.00
Wetland Area C Hardwood Swamp	25.0	0.09	288.00	183.32	1.60	2.00	180.00
Wetland Area D Deep Marsh	30.5	0.04	760.00	193.64	4.00	5.00	190.00
Pre-Mining Area 1 Bay Swamp	30.5	0.09	336.00	142.09	2.40	3.00	140.00

friction effects in smaller dimension openings) within the +6 ft design elevation also could pass the maximum design flow (100 yr event in this example).

Below the +6 ft level, any combination of exit structures may be used to control water levels for lesser flow events. For example, two 48" circular culverts will a similar flow as a 4 x 6 ft box culvert at maximum flow. However, at lower flows when the water surface is at elevations of +1 ft, the circular culvert arrangement will convey only about 30% of the capacity of the box culvert. Thus water levels will be forced to rise. By varying the size, shape, number, and invert levels of culverts or other discharge structures, an infinite number of combinations of water level elevations for different flow events can be created.

Water level elevations throughout the reclamation unit can then be determined for any combination through the use of backwater profile modelling. Subsequent iterations can be made to adjust and refine water surface profiles to meet the hydrologic requirements of each wetland unit. In the demonstration project, the water levels for 5 yr and longer flow events appear to be within specifications. However, it is questionable that flow events less than the mean annual flood will be of sufficient magnitude to cause over-the-bank flooding and support wetland vegetation along the lower sites adjacent to the stream channel. In this case, circular culverts of smaller dimensions might be used to raise water levels during lower flow events and enhance wetland hydroperiods. The larger capacity culverts may be located at higher invert levels such that they function only after water levels have been raised sufficiently to increase flooding frequency at low flow conditions. At 5 yr and greater flow event levels, total discharge and water level will be relatively unaffected.

Summary

As greater regulatory emphasis is put upon restoration of natural areas and pre-existing conditions, reclamation

managers will be challenged by design of complex drainage systems with naturally functioning wetland and aquatic systems. This demonstration project in central Florida presents an approach which appears useful in addressing problems of constructing these complex systems and providing for natural ecological functions.

Characterizing the existing system, estimating characteristics of the reclaimed system, and establishing basic configurations of the reclaimed system can be done on many levels of sophistication. It is doubtful that sufficient definition in ecological data is available to justify the use of complex models. At the present level of data confidence, a "seat-of-the-pants" approach may yield results of similar or better quality at low levels of effort, provided that sufficient knowledge and expertise is available.

Refinement of hydraulic parameters may be readily accomplished using conventional engineering techniques such as backwater analysis. The degree of effort required for this refinement and the number of iterations would until recently have made this analysis prohibitive. Advances in the use of micro-computers for hydrologic modelling, three dimensional analysis, and engineering uses, as well as the interactive mode of operation of the micro-computer systems, now make such analysis practical.

Drainage systems suitable for this reclamation approach will be relatively small basins with low and/or intermittent flows. The approach described in this paper and the analytical techniques possible from computer system advances are sufficient to allow the necessary computations with a level of effort that is consistent with current reclamation costs. A properly designed system should only incorporate passive control systems and minimal additional grading and excavating. With sufficient pre-reclamation planning, it appears that such complex system construction may be accomplished at reclamation and maintenance costs that are not significantly greater than those associated with conventional practices.