HYDROGEOMORPHIC ASSESSMENT (HGM) FOR THE PROPOSED 2,420 ACRE SEVEN HILLS SURFACE MINE, WARRICK COUNTY, INDIANA (IDNR SURFACE MINING APPLICATION # S-00357)

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1. Introduction and Justification

United Minerals, Inc. contracted Eco-Tech Consultants, Inc. to evaluate the wetland system within the Pigeon Creek watershed with respect to the Seven Hills Surface Mine (IDNR Surface Mining Application #S 00357) in Warrick County, Indiana (Appendix A, Figure 1). This project assesses the wetland functions of the Pigeon Creek drainage within and adjacent to the mining permit area to provide an ecosystem community baseline assessment for restoration and enhancement efforts of wetlands disturbed during mining operations.

Eco-Tech applied the Hydrogeomorphic Approach (HGM) developed for Kentucky's Western Coal Field Physiographic Province (Ainslie *et al.,* 1999) to the wetlands of the Pigeon Creek drainage. The coal fields of western Kentucky and southwestern Indiana are both underlain by Pennsylvanian aged rocks, possess similar ecoregions, are within the same climatic regime, and are in the same geological physiographic province, separated only by the Ohio River. The Pigeon Creek and western Kentucky wetlands have a similar origin in that they were originally created during the last deglaciation. Similar plant communities and herpetofaunal, avian, and mammalian species are found in both areas. In summary, the Pigeon Creek riverine wetlands function similarly to those of the Western Kentucky HGM riverine wetlands.

Wetland ecosystems share a number of common attributes including periods of inundation or saturation, hydrophytic vegetation, and hydric soils. There is a wide range of climactic, geologic, and physiographic situations, in addition to the physical, chemical, and biological characteristics and processes, within wetland ecosystems. The HGM method reduces the variability exhibited by wetlands to manageable indices. The method uses geomorphic setting, water source, and hydrodynamics to identify wetland areas according to their functional group (Brinson, 1993; Danielson, 1999; Reinhardt *et al.*, 1997). Geomorphic setting refers to the landform and position in the landscape. Water source refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. Hydrodynamics refers to the level of energy and the direction of water movement through the wetland.

2. Pigeon Creek Site Characterization

The Pigeon Creek drainage wetlands are classified as riverine (Smith *et al.,*1995; Ainslie *et al.,*1999). Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. The dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and the wetlands. These wetlands have poor vertical drainage due to impermeable layers (hardpans), slow lateral drainage, and low hydraulic gradient. Additional water sources are interflow, overland flow from the adjacent uplands, tributary inflow, and precipitation (Bryan and Morris, 1992). Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during

rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater, and evapotranspiration. Channelization affects the original riverine wetlands of Pigeon Creek and its tributaries.

The wetland soils of the Pigeon Creek floodplain consist primarily of Bonnie and Birds silt loams, both typic fluvaquents (Shively, 1979). The soils have low permeability and possess a subsoil clay layer. The floodplain forests are inundated at least once per year. Deciduous forests and agricultural land are adjacent to the floodplain wetlands. The adjacent upland forests provide refugia for the floral and faunal species of the adjacent shrub swamp and floodplain forest during flood conditions.

3. Hydrogeomorphic Method Background

The following sections present the methods, equations for the various Functional Capacity Indices (FCIs), the results, and a brief discussion of the results that were observed with measured variables. These functions are not additive, therefore, a wetland may exhibit high and low values for different functions. The relative value of each function is a subjective judgement and dependent upon basin wetland criteria.

The HGM for the wetlands of the Western Coal Field has been field tested and undergone peer review as a scientifically based method for evaluating wetland functions by measuring physical features of riverine wetlands. The features are then used to calculate an FCI as a measure of the ability of a wetland to provide important ecological functions such as wildlife habitat, storing flood waters, and exporting organic carbon. Reference wetlands are used to determine the range of conditions for which all other wetlands will be judged (Strever, 1999). The functional capacity of a wetland relies on the relationships between the characteristics and processes of the wetland ecosystem. The FCI is normalized to a range from 0.0 to 1.0. Wetlands with an FCI of 1.0 perform the function at a level that is characteristic of reference standard wetlands. As the FCI decreases, it indicates that the capacity of the wetland to perform the function is less than that of reference standard wetlands. In some cases the variable subindex may drop to zero. The justification for the selection of these functions and the structural and system parameters that are measured to estimate these functions are discussed in the next sections and in Ainslie *et al.* (1999).

The HGM approach assesses wetlands and assigns a particular Functional Capacity Index for that wetland. To use the HGM as an assessment tool and model to compare before and after disturbance areas and to assess potential improvement of mitigation sites, a Functional Capacity Unit (FCU) will be calculated by multiplying the FCI by the wetland area. The FCU provides a quantifiable measure of the effectiveness of wetland restoration and enhancement efforts.

4. Methods

Nine assessment sites within the permit boundary were sampled for the Pigeon Creek HGM study (Appendix A, Figure 2; Appendix B). Five forested, one emergent, and three scrub-shrub wetland sites were selected as representative wetlands. These sites were chosen to represent the range of variability that occurs in the Pigeon Creek drainage domain. This domain is defined by its natural processes, natural disturbances, and cultural alterations. A description of field methods used for collection of the raw data is found in Appendix C. The following 27 variables were selected to effectively characterize the Pigeon Creek wetlands:

1. Wetland tract (Vtract)
2. Interior core area (Vcore)
3. Habitat connections (Vconnect)
4. Floodplain slope (Vslope)
5. Floodplain storage volume (Vstore)
6. Macrotopographic features (Vmacro)
7. Overbank flood frequency (Vfreq)
8. Floodplain roughness (Vrough)
9. Soil integrity (Vsoilint)
10. Water table fluctuation (Vwtf)
11. Water table depth (Vwtd)
12. Water table slope (Vwtslope)
13. Subsurface water velocity (Vsoilperm)
14. Subsurface storage volume (Vpore)
15. Surface water connections (Vsurfcon)
16. Soil clay content (Vclay)
17. Redoximorphic features (Vredox)
18. Tree biomass (Vtba)
19. Tree density (Vtden)
20. Snag density (Vsnag)
21. Woody debris biomass (Vwd)
22. Log biomass (Vlog)
23. Understory vegetation biomass (Vssd)
24. Ground vegetation biomass (Vgvc)
25. "O" horizon biomass (Vohor)
26. "A" horizon biomass (Vahor)
27. Plant species composition (Vcomp)

The raw values are then compared to reference wetlands to calculate the FCI. Formulae for FCI calculations are in Appendix C. Reference wetlands serve several purposes:

1. To establish a basis for defining a characteristic and sustainable level of function across the entire domain.
2. To establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables.
3. To provide a physical representation of wetland ecosystems that can be repeatedly observed and measured.

The following eight FCI functions performed by riverine wetlands were selected for assessment to determine the effective functionality in the Pigeon Creek drainage:

1. Temporarily store surface water.
2. Maintain characteristic subsurface hydrology.
3. Cycle nutrients.
4. Remove and sequester elements and components.
5. Retain particulates.
6. Export organic carbon.
7. Maintain characteristic plant community.
8. Provide wildlife habitat.

Temporarily store surface water: The capacity of a riverine wetland to temporarily store and convey floodwaters that inundate riverine wetlands during overbank flood events. Most of the water that is stored and conveyed originates from an adjacent stream channel. Other potential sources of water may include precipitation, surface water from adjacent uplands, subsurface water from adjacent uplands. The retention of floodwater is important in reducing flood damage and erosion.

Maintain characteristic subsurface hydrology: The capacity of a riverine wetland to store and convey subsurface water. Potential sources of subsurface water are direct precipitation, interflow, groundwater flow, and overbank flooding. Groundwater storage ensures that the biogeochemical processes and plant and animal communities that depend on subsurface water continue to exist.

Cycle nutrients: The ability of the riverine or mineral soil flat wetland to convert nutrients from inorganic forms to organic forms and back through a variety of biogeochemical processes such as photosynthesis and microbial decomposition. The cycling of nutrients is a fundamental function that helps to maintain an adequate pool of nutrients throughout the various compartments of an ecosystem. These compartments include the soil, primary producers, consumers, and dead organic matter.

Remove and sequester compounds: The ability of the riverine or mineral soil flat wetland to permanently remove or temporarily immobilize nutrients, metals, and other elements and compounds that are imported to the riverine wetland from upland sources and via overbank flooding. By sequestering these pollutants, riverine or mineral soil flat wetlands help to increase water quality and aquatic habitat in the rivers and streams in which they are associated.

Retain particulates: The capacity of a riverine wetland to physically remove and retain inorganic and organic particulates >0.45μm from the water column. The particulates may originate from either on-site or off-site sources. Retention of particulates is an important function because sediment accumulation contributes to the nutrient capital of the wetland. Deposition of inorganic particulates also increases surface elevation and changes topographic complexity, which has hydrologic, biogeochemical, and habitat implications. Particulate organic matter and woody debris may also be retained for decomposition, nutrient cycling, and detrital food web support. This function also reduces stream sediment load that would otherwise be transported downstream.

Export organic carbon: The capacity of the wetland to export the dissolved and particulate organic carbon produced in the riverine wetland. Mechanisms include leaching of litter, flushing, displacement, and erosion. The high productivity and close proximity of riverine wetlands to streams make them important sources of dissolved and particulate organic carbon for aquatic food webs and biogeochemical processes in downstream habitats. Dissolved organic carbon is also a significant source of energy for the microbes that form the base of the detrital food web in aquatic ecosystems.

Maintain characteristic plant community: The capacity of a riverine or mineral soil flat wetland to provide the environment necessary for a characteristic plant community to develop and be maintained. The ability to maintain a characteristic plant community is important because of the intrinsic value of the plant community and the many attributes and processes of riverine and mineral soil flat wetlands that are influenced by the plant community. Primary productivity, nutrient cycling, and the ability to provide a variety of habitats necessary to maintain local and regional diversity of animals are directly influenced by the plant community. In addition, the plant community of these systems influences the quality of the physical habitat and the biological diversity of adjacent rivers by modifying the quantity and quality of water and through the export of carbon.

Provide wildlife habitat: The ability of a riverine or mineral soil flat wetland to support the wildlife species that utilize these wetlands during some part of their life cycles. The focus of attention in most HGM evaluations is on the avifauna component of habitat based on the assumption that, if conditions are appropriate to support the full compliment of avian species found in reference standard wetlands, the requirements of other groups will be met. However, we also considered habitat for other species such as amphibians, reptiles and mammals in our evaluation. The performance of this

function ensures habitat for a diversity of vertebrate organisms, contributes to secondary production, maintains complex trophic interactions, and provides access to and from wetlands for completion of aquatic species life cycles.

Field crews visited the nine evaluation sites and recorded observations made from various sampling methods, including a walking reconnaissance of the assessment area, 0.04 hectare (ha) plots, 0.004 ha subplots, meter squared ($1m^2$) subplots, 2-15m transects, topographic maps, and aerial photographs. Plots were selected within each wetland type to assure representation of the typical vegetation, topography, and hydrology for each of the types. Specific field measurement protocols for each of the 27 variables, normalized linear transformations, and FCI equations are located in Appendices C and D.

5. Results

Each of the functions identified in this HGM evaluation has several variable subindices that are used to produce an FCI assessment model. These variables were determined using the data gathered from field investigation, aerial photographs, topographic maps, soil surveys, and National Wetland Inventory maps.

Table 1 displays a summary of the data measured and calculated. The area for wetland tract (Vtract) was measured from I-64 south through the permit boundary to a point near Squaw Creek. This area was chosen as the most contiguous tract of wetland adjacent to the permit area. Flood frequency (Vfreq) was estimated from regional dimensionless rating curves and conversations with local inhabitants. The Pigeon Creek wetlands are inundated at least once every year. Water table fluctuation (Vwtf) and redoximorphic (Vredox) features are listed either as present (P) or absent (A). The data from Table 1 were then compared to graphs for standard reference wetlands for each variable (Appendix D). Field data was then converted from raw data to the standardized subindices in Table 2.

Combinations of the subindices were then used to calculate the Functional Capacity Indices for each function for each site based on the FCI equations found in Appendix C (Table 3). Note that the mean value for each site is a general representation of the site's functionality. A lower value for a particular function will lower the overall score, but a particular site may still be functioning adequately in other aspects.

Table 1. Summary of data collected and measured for the Pigeon Creek wetlands within the Seven Hills permit area.

	Site 1	Site 2	Site3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Wetland type	PEM	PFO	PFO	PFO	PSS	PFO	PSS	PSS	PFO
Soil type	Bonnie	Bonnie	Bonnie	Bonnie	Birds	Birds	Birds	Birds	Birds
Vtract (ha)	890	890	890	890	890	890	890	890	890
Vcore (%)	47	47	47	47	47	47	47	47	47
Vconnect (%)	72	72	72	72	72	72	72	72	72
Vslope (%)	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Vstore	55.6	56.5	51.6	260.0	312.5	88.2	377.8	53.2	55.0
Vmacro (%)	6	6	6	6	6	6	6	6	6
Vfreq (yrs)	1	1	1	1	1	1	1	1	1
Vrough (n)	0.23	0.15	0.16	0.18	0.20	0.17	0.19	0.18	0.19
Vsoilint (%)	0	0	0	0	0	0	0	0	0
Vwtf (P or A)	P	P	P	P	P	P	P	P	P
Vwtd (in)	1	1	1	1	1	1	1	1	1
Vwtslope (%)	26	26	26	26	26	26	26	26	26
Vsoilperm (in/hr)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Vpore (%)	43.5	43.5	43.5	43.5	43.5	43.5	43.5	43.5	43.5
Vsurfcon (%)	100	90	75	50	75	100	100	100	100
Vclay (%)	0	0	0	0	0	0	0	0	0
Vredox (P or A)	P	P	P	P	P	P	P	P	P
Vtba (m^2 / ha)	NA	28.5	40.6	2.6	6.4	49.5	1.9	0	15.3
Vtden (stems/ha)	NA	900	525	225	150	550	125	0	600
Vsnag (snags/ha)	NA	225	50	0	225	225	50	2,500	250
Vwd (m^3 /ha)	50.3	29.4	59.1	1.5	42.1	58.7	17.3	0.0	45.9
Vlog (m^3 /ha)	17.5	35.0	26.2	0.0	35.0	8.7	8.7	0.0	17.5
Vssd (stems/ha)	1,475	500	1,500	12,200	4,725	575	950	60,000	700
Vgvc (%)	85	70	25	95	88	47	90	5	40
Vohor (%)	76	100	100	95	100	98	84	100	84
Vahor (%)	25	71	51	0	56	81	31	0	75
Vcomp (%)	75	100	56	83	44	33	67	0	83

Table 2. Standardized indices for the Pigeon Creek wetlands.

	Site 1	Site 2	Site3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Wetland type	PEM	PFO	PFO	PFO	PSS	PFO	PSS	PSS	PFO
Soil type	Bonnie	Bonnie	Bonnie	Bonnie	Birds	Birds	Birds	Birds	Birds
Vtract (ha)	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Vcore	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vconnect	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vslope	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vstore	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vmacro	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vfreq	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vrough	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vsoilint	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vwtf	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vwtd	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vwtslope	0.99	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Vsoilperm	0.70	1.00	1.00	0.70	0.70	1.00	0.70	1.00	1.00
Vpore	0.70	1.00	1.00	0.70	0.70	1.00	0.70	1.00	1.00
Vsurfcon	0.00	0.10	0.25	0.50	0.25	0.00	0.00	0.00	0.00
Vclay	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vredox	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vtba	0.00	1.00	1.00	0.10	0.30	1.00	0.10	0.00	0.75
Vtden	0.00	0.85	1.00	0.50	0.30	1.00	0.30	0.00	1.00
Vsnag	0.00	0.10	1.00	0.00	0.10	0.10	1.00	0.10	0.10
Vwd	1.00	1.00	0.90	0.10	1.00	0.50	0.90	0.00	1.00
Vlog	1.00	1.00	1.00	0.00	1.00	0.75	0.75	0.00	1.00
Vssd	0.50	1.00	0.50	0.50	0.50	0.90	0.50	0.50	0.60
Vgvc	0.30	0.50	0.90	0.15	0.25	0.70	0.10	1.00	0.80
Vohor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vahor	0.30	0.90	0.60	0.00	0.70	1.00	0.35	0.00	0.90
Vcomp	0.70	1.00	0.50	0.80	0.40	0.30	0.65	0.00	0.75

Table 3. Functional Capacity Indices (FCI) for each site.

	Site 1	PFO Site 2	PFO Site3	PFO Site 4	Site 5	PFO Site 6	Site 7	Site 8	PFO Site 9
Function 1:	**Temporarily store surface water**								
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Function 2:	**Maintain characteristic subsurface hydrology**								
	0.84	0.93	0.93	0.79	0.79	0.93	0.79	0.93	0.93
Function 3:	**Cycle nutrients**								
	0.52	0.90	0.82	0.31	0.63	0.85	0.49	0.42	0.84
Function 4:	**Remove and sequester elements and compounds**								
	0.91	0.99	0.95	0.87	0.96	1.00	0.92	0.87	0.99
Function 5:	**Retain particulates**								
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Function 6:	**Export organic carbon**								
	0.00	0.56	0.69	0.62	0.71	0.00	0.00	0.00	0.00
Function 7:	**Maintain characteristic plant community**								
	0.59	0.98	0.87	0.74	0.59	0.81	0.65	0.00	0.90
Function 8:	**Provide wildlife habitat**								
	0.57	0.87	0.92	0.60	0.63	0.79	0.75	0.34	0.83
Mean	**0.68**	**0.90**	**0.90**	**0.74**	**0.79**	**0.80**	**0.70**	**0.57**	**0.81**

Functions 1 (Temporarily store surface water) and 5 (Retain particulates) exhibit that they are fully functioning as compared to standard reference wetlands for all sites. Function 2 (Maintain characteristic subsurface hydrology) and Function 4 (Remove and sequester elements and components) also display very high functional values for all sites.

Most functional variability is found in Function 3 (Cycle nutrients), Function 6 (Export organic carbon, Function 7 (Maintain characteristic plant community), and Function 8 (Provide wildlife habitat). Function 3 FCIs range from 0.31 to 0.90, with a mean of 0.64. Function 6 (Export organic carbon) has a range from 0.00 to 0.71, and a mean of 0.29. Function 7 FCIs range from 0.00 to 0.98, with a mean of 0.68. Function 8 FCIs range from 0.34 to 0.92, with a mean of 0.70.

Results by Site

Site 1 (PEM): Site 1 has a mean score of 0.68, and a range from 0.52 to 1.00. Functions 1, 2, 4, and 5 display the highest values (1.00, 0.84, 0.91, 1.00, and, respectively, while Functions 3, 6, 7, and 8 exhibit the lowest FCIs (0.52, 0.00, 0.59, and 0.57, respectively. Site 1 is least effective in cycling nutrients, maintaining characteristic plant community, and providing wildlife habitat.

Site 2 (PFO): Site 2 has mean function score of 0.90, and a range from 0.56 to 1.00. The lowest score is for Function 6: Export organic carbon, with a score of 0.56.

Site 3 (PFO): Site 3 mean score is 0.90, and ranges from .069 to 1.00. The lowest score is 0.69 for Function 6: Export organic carbon.

Site 4 (PFO): Site 4 has a mean score of 0.74 and a range from 0.31 to 1.00. The lowest scores are Function 3: Cycle nutrients (0.31) and Function 8: Provide wildlife habitat (0.60).

Site 5 (PSS): Site 5 has a mean of 0.79 and range from 0.59 to 1.00. Low scores are for Function 3: Cycle nutrients (0.63), Function 7: Maintain characteristic plant community (0.59), and Function 8: Provide wildlife habitat (0.63).

Site 6 (PFO): Site 6 has a mean of 0.80, and a range from 0.00 to 1.000. The lowest scores are from Function 6: Export organic carbon (0.00) and Function 8: Provide wildlife habitat (0.79).

Site 7 (PSS): Site 7 has a mean of 0.70 and a range from 0.00 to 1.00. The lowest scores are for Function 3: Cycle nutrients (0.49), Function 6: Export organic carbon (0.00), Function 7: Maintain characteristic plant community (0.65), and Function 8: Provide wildlife habitat (0.75).

Site 8 (PSS): Site 8 has a mean score of 0.57 and a range from 0.00 to 1.00. The lowest scores are for Function 3: Cycle nutrients (0.42), Function 6: Export organic carbon (0.00), Function 7: Maintain characteristic plant community (0.00), and Function 8: Provide wildlife habitat (0.34).

Site 9 (PFO): Site 9 has a mean score of 0.81 and a range from 0.00 to 1.00. The lowest scores are for Function 6: Export organic carbon (0.00),and Function 8: Provide wildlife habitat (0.83).

6. Functional Capacity Index Discussion and Recommendations

All of the wetlands studied in the Pigeon Creek drainage are adversely affected either directly or indirectly by channelization of Pigeon Creek. The banks of Pigeon Creek consist of elevated levees constructed during channelization. Natural levee breaches occur at the confluences of Pigeon Creek and several tributaries.

The systems with higher function values are forest wetlands (Table 3). Site 4 is the lowest ranked PFO; it is a relatively young forest with abundant saplings, several trees, and a distinct lack of woody debris and snags. The lowest rated functional wetland is Site 8 (PSS). Site 8 is unique in that it is semi-permanently flooded and consists of a buttonbush monoculture. The restrictive nature of the site precludes effective nutrient cycling, organic carbon export, plant community maintenance, or wildlife habitat.

Discussion by Function:

Function 1: Temporarily store surface water. All sites effectively have the capacity to store floodwaters.

Function 2: Maintain characteristic subsurface hydrology. The wetlands rated highest are primarily forested wetlands (PFOs). The forested wetlands are functioning at higher productivity rates, thereby creating better soil structure than the other wetlands. Sites 4, 5 and 7 (PSS) have lower ratings due to previous anthropogenic disturbance modifying soil permeability and porosity.

Function 3: Cycle nutrients. The PFO sites (except Site 4) have the highest ratings because of greater amounts of total vegetative biomass and woody debris. The lowest ratings (sites 1, 4, 7, and 8) result from lack of complete O-horizon coverage and woody debris.

Function 4: Remove and sequester elements and compounds. All areas are fairly effective, but the PEM and PSS sites are slightly lower because of less A and O horizon soil coverage. Site 4 (PFO) is the lowest rated (0.87).

Function 5: Retain particles. The function of trapping particulates depends upon the ability of the ground and soil layers to trap and hold water. All sites exhibit sufficient roughness to retain particles.

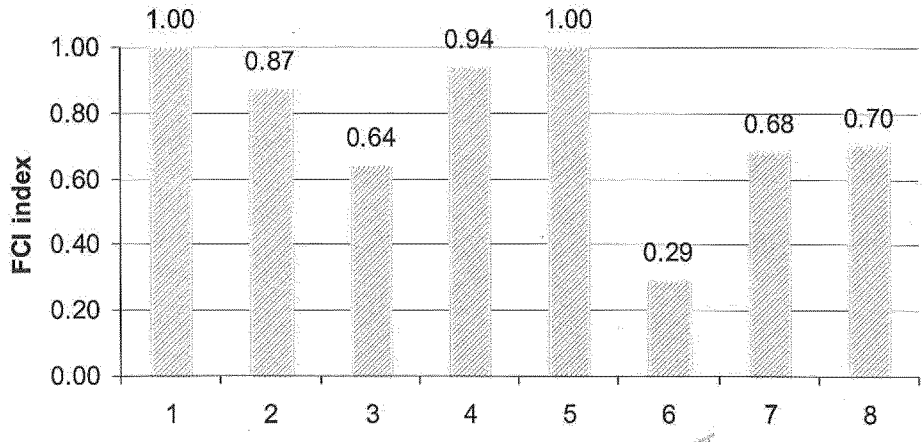
Function 6: Export organic carbon. This function is the lowest of all functions in all sites. The highest rated site is Site 5 (0.71). Sites 1 (PFO), 6 (PFO), 7 (PSS), and 8 (PSS) have the lowest ratings due to less woody debris and vegetative ground cover, and poor surface connections.

Function 7: Maintain characteristic plant community. The two sites that exhibit the highest FCIs for maintaining plant community are the least disturbed forested communities in the study area (Sites 2 and 9, PFO). Higher FCI values for the maintenance of the plant community are the result of good internal structure of the community. Structural features measured include components of the tree, shrub, and herbaceous community, soil structure and exotic species. The lowest site for maintenance of plant community is Site 8 (PSS) which suffers from of a lack of natural soil structure and no overstory species.

Function 8: Provide wildlife habitat. The lowest scores are for Sites 1 (PEM, 0.57) and 8 (PSS, 0.34). The function of maintaining wildlife habitat depends not only upon structural features of the community such as trees, plant species richness, and microtopography and ground features, but also upon the surrounding habitat. A very important consideration for maintaining wildlife habitat is the size of the habitat. Small, isolated, and structurally sound communities can lose species from disasters or disturbances and not have any provision for re-establishment.

The lowest mean scores are for Functions 3, 6, 7, and 8 (Figure 3). These three functions provide the most potential for improving wetland function. In order to address these functions, the variables used to calculate the functions need to be assessed.

Figure 3. Mean FCI values for eight functions



The variables that contribute to Function 3: Cycle nutrients, are:

Tree biomass (Vtba)
Woody debris biomass (Vwd)
Understory vegetation biomass (Vssd)
Ground vegetation biomass (Vgvc)
"O" horizon biomass (Vohor)
"A" horizon biomass (Vahor)

The variables that contribute to Function 6: Export organic carbon are:

Overbank flood frequency (Vfreq)
Surface connections (Vsurfcon)
"O" horizon biomass (Vohor)
Woody debris biomass (Vwd)

The variables that contribute to Function 7: Maintain characteristic plant community are:

Overbank flood frequency (Vfreq)
Soil integrity (Vsoilint)
Water table depth (Vwtd)
Tree biomass (Vtba)
Tree density (Vtden)
Plant species composition (Vcomp)

The variables that contribute to Function 8: Provide wildlife habitat are:

Wetland tract (Vtract)
Interior core area (Vcore)
Habitat connections (Vconnect)
Macrotopographic features (Vmacro)
Overbank flood frequency (Vfreq)
Tree biomass (Vtba)
Tree density (Vtden)
Snag density (Vsnag)
Log biomass (Vlog)
"O" horizon biomass (Vohor)
Plant species composition (Vcomp)

To improve wetland function, the variables that can be effectively altered or enhanced need to be identified. Some variables cannot be adjusted from a practical standpoint (e.g. increasing soil A horizon or wetland tract area). Variables that can be directly adjusted include tree density, plant species composition, snag density, understory vegetation biomass, and surface connections. Variables that can be indirectly influenced include tree biomass and overbank flood frequency.

Tree biomass is the common variable among all three functions. Tree biomass is a measure of tree diameter and stem density. Increasing tree diameter is a slow process, but by thinning selected trees within the wetlands, stimulated growth of the remaining species can be expected.

Overbank flood frequency is a common factor between Functions 6, 7, and 8. Overbank flood frequency can be enhanced by breaching the levees created when Pigeon Creek was channelized. The breaches will allow the riparian areas to flood during moderate flows, instead of the high flows now necessary to overtop the levees.

Tree density is also common to Functions 7 and 8. Tree density (along with understory vegetation biomass) can be accomplished by plantings. Plant species composition can be improved by a combination of thinning unwanted species and planting desirable species.

Function 6: Export organic carbon is the lowest rated function. The variable that is most readily altered is surface connections (Vsurfcon). Surface connections can be improved by breaching levees along Pigeon Creek, thereby promoting surface water transport of organic carbon.

7. Functional Capacity Units (FCUs)

For each site, a Functional Capacity Unit (FCU) was derived. The FCU is a quantified value of the functionality of wetlands. It is calculated by multiplying the mean Functional Capacity Index (FCI) by the number of acres of the wetland type. The FCU is used to quantify the amount of gain or loss in wetland function, to establish restoration goals for created or enhanced wetlands, and to determine the amount of credit or deficit resulting from restoration efforts. The net balance determines the area necessary to mitigate during wetland restoration or enhancement. Additionally, this assessment methodology defines quantifiable success criteria and thresholds to be met during the monitoring phase.

For example, Table 4 indicates that there are a total of 755.08 acres of wetland (excluding PAB wetlands) within the permitted area and a total of 641.91 FCUs. The permit area has a mean FCI value of 0.66. PFO wetlands total 622.73 acres, PEM wetlands total 40.95 acres, and PSS wetlands total 91.40 acres.

Note: Nine sites were selected as representative of the varied wetland vegetation, hydrology, and soils within the permit area. Assessed and estimated wetlands included PEM, PSS, and PFO areas. Sites PFO 1.1 and PFO 1.2 are subdivisions of PFO 1 based on distinct forest characteristics. The nine **Bold** items indicate wetlands individually assessed using the HGM technique. The remaining wetlands were assigned estimated FCI values based on visual comparison with the assessed sites. The estimated sites/values are designated with an '*' in Table 4.

Table 4. Functional Capacity Units for the Seven Hills Mine individual wetlands.
Note: **Bold** indicates assessed sites. Estimated values are designated with an '*'.

Wetland	Area (ac)	FCI	FCU
PEM 1	5.89	0.68	4.01
PEM 2*	0.93	0.68	0.63
PEM 16*	2.26	0.68	1.54
PEM 17*	2.30	0.68	1.56
PEM 18*	0.10	0.68	0.07
PEM 19*	0.02	0.68	0.01
PEM 20*	1.10	0.68	0.75
PEM 21*	0.05	0.68	0.03
PEM 22*	0.31	0.68	0.21
PEM 23*	0.07	0.44	0.03
PEM 24*	3.56	0.44	1.57
PEM 25*	8.88	0.44	3.91
PEM 26*	0.10	0.44	0.04
PEM 3-15*	4.74	0.44	2.09
PEM 27-44*	10.64	0.44	4.68
PFO 1	481.29	0.90	433.16
PFO 1.1	25.00	0.74	18.50
PFO 1.2	62.00	0.90	55.80
PFO 2	51.40	0.81	41.63
PFO 3*	0.65	0.81	0.53
PFO 4*	0.17	0.56	0.10
PFO 5*	0.02	0.56	0.01
PFO 6*	0.68	0.56	0.38
PFO 7*	0.29	0.56	0.16
PFO 8*	0.71	0.56	0.40
PFO 9*	0.52	0.56	0.29
PSS 1*	1.16	0.80	0.93
PSS 2*	1.44	0.80	1.15
PSS 3 *	0.38	0.80	0.30
PSS 4*	0.47	0.80	0.38
PSS 5*	2.08	0.80	1.66
PSS 6	11.50	0.79	9.09
PSS 7*	20.50	0.79	16.20
PSS 8	31.90	0.79	25.20
PSS 9	10.07	0.57	5.74
PSS 10*	7.78	0.79	6.15
PSS 11*	3.29	0.79	2.60
PSS 12*	0.17	0.52	0.09
PSS 13*	0.17	0.52	0.09
PSS 14*	0.49	0.52	0.25
Total acreage	**755.08**		
Mean FCI		**0.66**	
Total FCU			**641.91**

8. Conclusions

The Pigeon Creek HGM evaluates wetland functions by measuring parameters of the community's vegetation, hydrology, soils, and the surrounding landscape. The method provides a quantitative measure of wetlands that is a useful tool for wetland restoration, creation, and enhancement.

One of the primary uses for the HGM approach is to identify communities that may provide some of the better ecosystem functions and values that remain in the drainage. The higher rated wetlands are then used to establish guidelines for long range planning for ecosystem restoration of the Pigeon Creek drainage. The incorporation of existing wetland functions into the restoration effort will improve successful wetland value restoration. The plant communities with good internal structural can be used as core habitats from which the area could be enlarged, enhanced or sufficiently buffered to act as the source of material for surrounding restoration efforts.

Functional capacity can be most effectively increased in the Pigeon Creek drainage by reconnecting Pigeon Creek to the adjacent riparian areas. The creek cannot be raised to its former elevation, but several cuts in the levee along the length of Pigeon Creek would allow floodwaters to more easily penetrate into the wetlands, as well as re-establishing the surface connection from the wetlands to Pigeon Creek. The improved surface connection would improve nutrient cycling, the lowest functional capacity for nearly all sites.

9. References

Ainslie, W.B., R.D. Smith, B.A. Pruitt, T.H. Roberts, E.J. Sparks, L.West, G.L. Godshalk and M.V. Miller. 1999. A Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands in Western Kentucky. U.S. Army Corps of Engineers, Washington, D.C. Technical Report WRP-DE-17. 130pp. and appendices.

Arcement, G.J. Jr., and V.R. Schneider. 1989. "Guide for selecting Manning's roughness coefficients for natural channels and flood plains ". U.S. Geological Survey Water-Supply Paper 2339, U.S. Government Printing Office, Washington, D.C.

Brinson, M.M., 1993. "Changes in the functions of wetlands along environmental gradients". National Wetlands Newsletter. Environmental Law Institute. Volume 13, Number 2

Bryan, H. and R. Morris. 1992. Rainfall Driven Wetlands: Restoration of Atypical Forested Communities. Abstract and paper presented at the 19th Annual Conference on Wetland Restoration and Creation. May 14-15, 1992. Tampa, Florida.

Danielson, T.J., 1999. Evaluating Wetland Health Through Bioassessment. National Wetlands Newsletter. Environmental Law Institute. Volume 21, Number 1

Rheinhardt, R. D., M. M. Brinson and P. M. Farley. 1997. "Applying wetland reference data to functional assessment, mitigation, and restoration". Wetlands 17(2): 195-215.

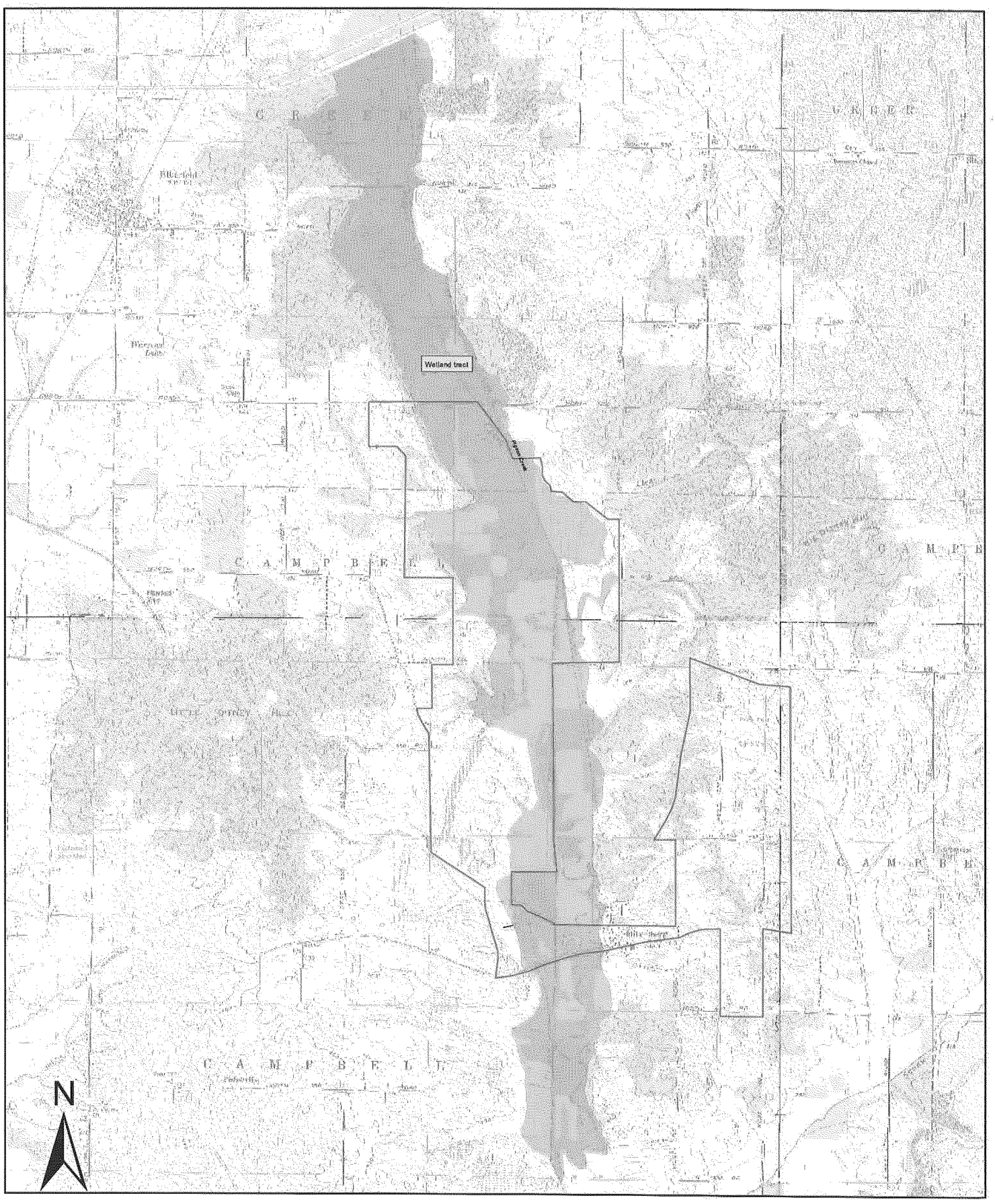
Shively, J.L. 1979. Soil Survey of Warrick County, Indiana. U.S. Department of Agriculture. Soil Conservation Service, in cooperation with Purdue University Agricultural Experiment Station.

Smith, R.D., Ammann, A., Bartoldus, C., and Brinson, M.N. 1995. "An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices". Wetlands Research Program Technical Report WRP-DE-9. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Strever, B., 1999. "Performance standards for wetland creation and restoration under Section 404". National Wetlands Newsletter. Environmental Law Institute. Volume 21, Number 3

Appendix A

Site Maps



Legend

- Wetland Tract
- Permit Boundary

STATE OF:	**Indiana**
COUNTY OF:	**Warrick**
SCALE:	**1:48,000**

FIGURE 1. LOCATION OF WETLAND TRACT AND PERMIT AREA, PIGEON CREEK DRAINAGE

ECO-TECH
1003 E Main St.
Frankfort, KY 40601
502-695-8060

Legend

Permit Boundary

Wetland Tract

STATE OF: **Indiana**

COUNTY OF: **Warrick**

SCALE: 1:26,900

FIGURE 2. LOCATION OF HGM ASSESSMENT SITES

ECO-TECH
1003 E Main St.
Frankfort, KY 40601
502-695-8080

Appendix B

Site Photographs

Site 1. PEM wetland. Mean FCI is 0.80.

Site 2. PFO wetland. Mean FCI is 0.96.

Site 3. PFO wetland. Mean FCI is 0.93.

Site 4. PFO wetland. Mean FCI is 0.76.

Site 5. PSS wetland. Mean FCI is 0.82.

Site 6. PFO wetland. Mean FCI is 0.89.

Site 7. PSS wetland. Mean FCI is 0.82.

Site 8. PSS wetland. Mean FCI is 0.66

Site 9. PFO wetland. Mean FCI is 0.94.

Appendix C.

A. Description of variables and methods

B. Equations used for Functional Capacity Index (FCI) calculation

A. Description of variables and methods.

1. Wetland tract (Vtract)

a. Measure/Units: The area of wetland in hectares that is contiguous with the wetland assessment area and of the same regional wetland subclass

b. Determine the size of the area of wetland of the same regional subclass that is contiguous with the assessment area using field reconnaissance, topographic maps, National Wetland Inventory maps (NWI), or aerial photography

c. Report the size of the wetland tract in hectares

2. Interior core area (Vcore)

a. Measure/Units: The percent of the wetland tract with a buffer zone >300 m separating it from nonforested habitat.

b. Determine the area of the wetland tract within a buffer of at least 300 m using field reconnaissance, topographic maps, NWI maps, aerial photography, or other sources.

c. Divide the area of the wetland within the buffer by the total size of the wetland tract and multiply by 300. The result is the percentage of the wetland tract within a buffer zone >300 m.

d. Report the size of the area within a 300-m buffer as a percentage of total tract area.

3. Habitat connections (Vconnect)

a. Measure/Units: The percent of the perimeter of the wetland tract that is "connected" to the total length of the perimeter of the wetland.

b. Determine the total length of the wetland perimeter using field reconnaissance, topographic maps, or aerial photography.

c. Determine the length of the wetland perimeter that is "connected" to suitable habitats such as other wetlands, upland forests, or other wildlife habitats.

d. Divide the length of "connected" wetland perimeter by the total length of the wetland perimeter.

e. Convert to a percent of the perimeter by multiplying by 100.

f. Report as the percent of the perimeter of the wetland tract that is "connected"

4. Floodplain slope (Vslope)

a. Measure/Units: Percent floodplain slope.

b. Determine the change in elevation between two points along the floodplain center line (i.e, center line of the meander belt of the active channel) on a river reach representative of the area being assessed . This can be accomplished using the contour lines on a standard 7.5-minute USGS topographic map. The distance between the two points should be great enough so that local anomalies in floodplain slope do not influence the result. As a rule of thumb, the line between the two points should intersect at least two contour lines on a 1:24,000 scale (7.5-minute) USGS topo map.

c. Determine the distance between the two points.

d. Divide the change in elevation by the distance between the two points. For example, if the change in elevation between the two points is 10 ft (3 m) and the distance between the two points is 1 mile (5,280 ft) (1,609 m) the slope is 10 ft/5,280 ft = 0.002 (3m/1,609 m = 0.002).

e. Convert the slope to a percent slope by multiplying by 100.

f. Report floodplain slope as a percent.

5. Floodplain storage volume (Vstore)

a. Measure/Units: The ratio of floodplain width to channel width (i.e., floodplain width/channel width).

b. Measure the width of the floodplain and the width of the channel using surveying equipment or by pacing in the field. A crude estimate can be made using topographic maps, or aerial photos, remembering that short distances on maps and photographs translate into long distances on the ground (e.g., a section line on a 1:24,000 USGS topographic map represents about 30 ft (9.1 m) on the ground).

c. Calculate the ratio by dividing the floodplain width by the channel width.

d. Report the ratio of floodplain width to channel width as a unitless number.

6. Macrotopographic features (Vmacro)

a. Measure/Units: The percent of the WAA occupied by macrotopographic features.

b. If the area being assessed is greater than 1 km^2, the percentage of the area that

consists of macrotopographic features is used to quantify this variable. Measure it with the procedure outlined under Alternative 1 if the area being assessed is greater than 1 km^2 or Alternative 2 if the area is less than 1 km^2.

(1) Alternative 1: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in the assessment area.

(2) Alternative 2: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in a 1-km^2 area around the assessment area. For instance, a 1-km^2 template can be placed on a map or aerial photograph of appropriate scale and the percentage of that area covered by macrotopographic features can be estimated.

c. Report the percentage of the area being assessed that is covered with macrotopographic features.

7. Overbank flood frequency (Vfreq)

a. Measure/Units: Recurrence interval in years.

b. Use one of the following methods to determine recurrence interval.

(1) Data from a nearby stream gage;

(2) Regional flood frequency curves developed by local and State offices of USACE, USGS-Water Resources Division, State Geologic Surveys, or NRCS (Jennings, Thomas, and Riggs 1994);

(3) Hydrologic models such as HEC-2 (U.S. Army Corps of Engineers 1981, 1982), HECRAS (U.S. Army Corps of Engineers 1997), HSPF (Bicknell et al. 1993);

(4) Local knowledge; or

(5) Regional dimensionless rating curve (Pruitt and Nutter unpublished manuscript).

c. Report recurrence interval in years.

8. Floodplain roughness (Vrough)

a. Measure/Units: Manning's roughness coefficient (*n*).

b. Alternative 1 (not recommended): Compare the area to be assessed to the

photographs of forested floodplains presented in Arcement and Schneider (1989). These photographs illustrate a variety of conditions for which Manning's roughness coefficient has been calculated empirically and can be used in the field to estimate Manning's roughness coefficient for sites that are well stocked with trees.

c. Alternative 2: Use Arcement and Schneider's (1989) method for estimating Manning's roughness coefficient based on a characterization of the different components that contribute to roughness on floodplains which include: micro and macrotopographic relief (*n*TOPO), obstruction (*n*OBS), and vegetation (*n*VEG). Complete the following steps:

(1) Determine the value of *n*BASE (i.e., the contribution to roughness of bare soil). Arcement and Schneider (1989) suggest using 0.03, the value for firm soil.

(2) Using the descriptions in Table B1, assign an adjustment value to the roughness components of *n*TOPO , *n*OBS , and *n*VEG.

(3) Sum the values of the roughness components.

Table C1. Adjustment Values for Roughness Components.

Roughness component	Adjustment to *n* value	Description of conditions
Topographic relief (*n*topo)	0.0	Representative area is flat with essentially no microtopographic relief (i.e.,hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales).
	0.005	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers 5-25% of a representative area.
	0.01	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers 26-50% of a representative area.
	0.02	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers >50% of a representative area.
Obstructions (*n*obs)	0.0	No obstructions present
	0.002	Obstructions occupy 1-5% of a representative cross-sectional area.
	0.01	Obstructions occupy 6-15% of a representative cross-sectional area.
	0.025	Obstructions occupy 16-50% of a representative cross-sectional area.
	0.05	Obstructions occupy >50% of a representative cross-sectional area.

Vegetation (*n*veg)	0.0	No vegetation present
	0.005	Representative area covered with dense herbaceous or woody vegetation where depth of flow exceeds height of vegetation by 3 times.
	0.015	Representative area covered with dense herbaceous or woody vegetation where depth of flow exceeds height of vegetation by by 2-3 times.
	0.05	Representative area covered with herbaceous or woody vegetation where depth of flow is at height of vegetation.
	0.1	Representative area fully stocked with trees and with sparse herbaceous or woody understory vegetation.
	0.15	Representative area partially to fully stocked with trees and with dense herbaceous or woody understory vegetation.

9. Soil integrity (Vsoilint)

a. Measure/Units: The percent of the sampling plot with altered soils.

b. Determine if any of the soils in the area being assessed have been altered. In particular look for alteration to a normal soil profile. For example, absence of an "A" horizon, presence of fill material, or other types of impact that significantly alter soil integrity.

c. If no altered soils exist, assign the variable subindex a value of 1.0. This indicates that all of the soils in the assessment area are similar to soils in reference standard sites.

d. If altered soils exist, determine what percent of the assessment area has soils that have been altered.

e. Report the percent of the assessment area with altered soils.

10. Water table fluctuation (Vwtf)

a. Measure/Units: Presence or absence of a fluctuating water table.

b. Determine the presence or absence of a fluctuating water table using the following (in order of accuracy and preference):
(1) Monitored groundwater well data;

(2) Redoximorphic features such as oxidized rhizospheres, reaction to *a, a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994, Hurt et al. 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions;
(3) The presence of a fluctuating seasonal high water table according to the

Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the Soil Survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

c. Report fluctuating water table as present or absent.

11. Water table depth (Vwtd)

a. Measure/Units: Depth to the seasonal high water table in inches.

b. Determine the depth to the seasonal high water table using the following (in order of accuracy and preference):

(1) Monitored groundwater well data;

(2) Redoximorphic features such as oxidized rhizospheres, reaction to *a, a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994, Hurt et al. 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions;

(3) The presence of a fluctuating seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the Soil Survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

c. Report the depth to the seasonal high water table in inches.

12. Water table slope (Vwtslope)

a. Measure/Units: The percent of the WAA with an altered water table slope.

b. Determine if the slope of the ground surface has been altered, by ditching, tiling, dredging, channelization, or other activities with the potential to modify the water table slope.

c. If the slope of the water table has not been altered the percent of the area altered

is 0.0.

d. If the water table slope has been altered in any portion of the area being assessed, determine the soil type and the "depth of the alteration." For example, if the ditch has been dug, the depth of the alteration is the depth of the ditch measured from the original ground surface (Figure 13, main text). If a stream channel has been dredged, the depth of the alteration is the difference between the old and new channel depth.

e. Use Table B2 to determine the lateral distance that will be affected by the alteration. For example, if the soil is in the Bonnie series and the depth of the alteration is 5 ft (1.5 m) the lateral ditch effect is 544 ft (165.8 m). The procedures used to calculate the values in this table are based on the Ellipse Equation (USDA NRCS 1977).

Table C2. Lateral Effect of Ditches

Soil Series	Depth of Ditch or Change in Depth of Channel, ft							
	3	4	5	6	7	8	9	10
Bonnie / Birds	235	341	427	503	574	642	706	769
Stendal / Wakeland	424	614	769	908	1036	1157	1273	1386

f. Using the lateral distance of the effect and the length of the alteration, estimate the size of the area that will be affected by the alteration. For example, if the lateral effect of the ditch is 544 ft (165.8 m) and the ditch is 50 ft (15.2 m) long, the area affected is 544 × 50 = 27,200 ft2 (0.62 acres) (0.25 ha).

g. Calculate the ratio of the size of all areas within the area being assessed that are affected by an alteration to the water table slope to the size of the entire area being assessed. For example, if the area affected by the alteration is 0.62 acres (0.25 ha), and the area being assessed is 10 acres (4 ha), the ratio is 0.62 / 10 = 0.062 (0.25/4 = 0.062).

h. Multiply the ratio by 100 to obtain the percentage of the area being assessed with an altered water table slope.

i. Report the percent of the area being assessed with an altered water table slope.

13. Subsurface water velocity (Vsoilperm)

a. Measure/Units: Soil permeability in inches per hour.

b. Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment, construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

c. If soils have been altered, select one of the two following alternatives, otherwise skip this step.

(1) Assign a value to soil permeability based on a representative number of field measurements of soil permeability. The number of measurements will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. A procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(2) Assign a variable subindex based on the category of alteration that has occurred at the site using the information in Table C3. (Note: in this particular situation no value is assigned to soil permeability, rather, a variable subindex is assigned directly).

Table C3. Variable Subindices for Altered Soils.

Alteration category	Typical soil permeability after alteration	Average depth of alteration effects	Variable subindex
Silviculture: normal activities compact surface layers highly variable and spatially top 6 in. of soil and reduce permeability to a depth of about 6 in. (Aust, 1994)	highly variable and spatially heterogeneous	top 6 inches of soil profile	0.7
Agricultural Tillage: some surface compaction occurs highly variable and spatially as well as generally decreasing the average size of pore spaces which decreases the ability of water to move through the soil to depth of about 6 in. (Drees et al. 1994).	highly variable and spatially heterogeneous	top 6 inches of soil profile	0.7
Construction Activities / Surface Mining: highly variable and spatially entire soil profile 0.1 compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

d. If the soils have not been altered, select one of the two following alternatives.

(1) Assign a value to soil permeability based on a representative number of

field measures of soil permeability. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. A procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(2) Assign a value to soil permeability by calculating the weighted average of median soil permeability to a depth of 20 inches. Information for the soil series that occur in riverine wetlands is in Table C4. Calculate the weighted average of median soil permeability by averaging the median soil permeability values to a depth of 20 inches.

Table C4. Soil Permeability at Different Depths for Soil Series

Soil Series	Depth, in.	Range of Soil Permeability (in./hr)	Weighted Average Soil Permeability in top 20 in. (in./hr)
Bonnie / Birds	0-20	0.2-0.6	0.4
Stendal / Wakeland	0-20	0.6-2.0	1.3

e. Report soil permeability in inches/hour.

14. Subsurface storage volume (Vpore)

a. Measure/Units: Percent effective soil porosity is the measure of this variable.

b. Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

c. If soils have been altered:

(1) Assign a value to soil permeability based on a representative number of field measures of soil bulk density. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties.

(2) Assign a variable subindex based on the category of alteration that has occurred at the site shown in Table C3. (Note: in this particular situation, no value is assigned to the metric, rather, a variable subindex is assigned directly).

d. If the soils have not been altered, quantify percent effective soil porosity using one of the following options.

(1) Collect a representative number of field measures of bulk density to determine percent effective soil porosity. The number of field measures of ` bulk density will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties.

(2) Use the percent effective soil porosity values for particular soil series provided in Table C5.

Table C5. Soil Series and Effective Soil Porosity Values.

Soil Series	Median bulk density (g/cm)	Total porosity (%)	Residual water content (%)	Effective soil porosity (%)	Soil texture
Bonnie / Birds	1.4	47	4.0	43.0	SiCL
Stendal / Wakeland	1.47	45	1.5	43.5	SiL

e. Report subsurface storage volume as percent effective soil porosity.

15. Surface water connections (Vsurfcon)

a. Measure/Units: The percent of the linear distance of stream reach adjacent to the plot that has been altered is the measure of this variable.

b. Conduct a visual reconnaissance of the plot and the adjacent stream reach. Estimate what percent of this stream reach has been modified with levees, side cast materials, or other obstructions that reduce the exchange of surface water between the stream channel and the riverine wetland.

c. Report percent of the linear distance of the stream reach that has been altered.

16. Soil clay content (Vclay)

a. Measure/Units: The difference in clay content in the top 20 in. (50.8 cm) of the soil profile in the plot is used to quantify this variable.

b. Determine if the native soil in any of the area being assessed has been covered with fill material, excavated and replaced, or subjected to any other types of impact that significantly change the clay content of the top 20 in. (50.8 cm) of the soil profile. If no such alteration has occurred, assign the variable subindex a value of 1.0 and move on to the next variable. A value of 1.0 indicates that none of the soils in the area being assessed have an altered clay content in the top 20 in. (50.8 cm).

c. If the soils in the part of the area being assessed have been altered in one of the ways described above, estimate the soil texture for each soil horizon in the upper 20 in. (50.8 cm) in representative portions of these areas. Soil particle size distribution can be measured in the laboratory on samples taken from the field, or the percent of clay can be estimated from field texture determinations done by the "feel" method.

d. Based on the soil texture class determined in the previous step, the percentage of clay is determined from the soil texture triangle. The soil texture triangle contains soil texture classes and the corresponding percentages of sand, silt, and clay that comprise each class. Once the soil texture is determined by feel, the corresponding clay percentage is read from the left side of the soil texture triangle. The median value from the range of percent clay is used to calculate the weighted average. For example, if the soil texture at the surface were a silty clay loam, the range of clay present in that texture class is 28-40 percent. A median value of 34 percent would be used for the clay percentage in that particular horizon.

e. Calculate a weighted average of the percent clay in the altered soil by averaging the percent clay from each of the soil horizons to a depth of 20 in. (50.8 cm). For example, if the "A" horizon occurs from a depth of 0-5 in. (0-12.7 cm) and has 30 percent clay, and the B horizon occurs from a depth of 6-20 in. (15.2-50.8 cm) and has 50 percent clay, then the weighted average of the percent clay for the top 20 in. (50.8 cm) of the profile is $((5 \times 30) + (15 \times 50)) / 20 =$ 45 percent.

f. Calculate the difference in percent clay between the natural soil (i.e., what existed prior to the impact) and the altered soil using the following formula: percent difference = (percent clay after alteration - % clay before alteration). For example, if the percent clay after alteration is 40 percent, and the percent clay before alteration is 70 percent, then $| 40 - 70 | = 30$, and $(30 / 70) = 43$ percent.

g. Average the results from representative portions of the altered area.

h. Multiply the percent difference for each altered area by the percent of the riverine wetland being assessed that the area represents.

i. Report the percent difference in the soil clay content in the area being assessed.

17. Redoximorphic features (Vredox)

a. Measure/Units: The presence or absence of redoximorphic features is the measure of this variable.

b. Observe the top 20 in. (50.8 cm) of the soil profile and determine if redoximorphic

features, accumulation or organic matter, or other hydric soil indicators are present or absent.

c. Report redoximorphic features as present or absent.

18. Tree biomass (Vtba)

a. Measure/Units: Tree basal area in square meters per hectare is the measure of this variable.

b. Measure the dbh in centimeters of all trees in a circular 0.04-ha sampling unit (Pielou 1984), hereafter called a plot.

c. Convert each of the diameter measurements to area, sum them, and then convert to square meters. For example, if 3 trees with diameters of 20 cm, 35 cm, and 22 cm were present in the plot, the conversion to square meters would be made as follows. The diameter of a circle (D) can be converted to area (A) using the relationship $A = 1/4\pi D^2$, it follows that $1/4\pi 202 = 314$ cm^2, $1/4\pi 352 = 962$ cm^2, $1/4\pi 222 = 380$ cm^2. Summing these values gives 314 + 962 + 380 = 1,656 cm^2 and converting to square meters by multiplying by 0.0001 gives 1,656 cm^2 × 0.0001 = 0.17 m^2.

d. If multiple 0.04-ha plots are sampled, average the results from all plots.

e. Convert the results to a per hectare basis by multiplying by 25, since there are 25 0.04-ha plots in a hectare. For example, if the average value from all the sampled plots is 0.17 m^2, then 1.7 m2 × 25 = 4.3 m^2/ha

f. Report tree basal area in square meters per hectare.

19. Tree density (Vtden)

a. Measure/Units: The number of tree stems per hectare.

b. Count the number of tree stems in a circular 0.04-ha plot.

c. If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

d. Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then 20 × 25 = 500 stems/ha.

e. Report tree density in stems/hectare.

20. Snag density (Vsnag)

a. Measure/Units: The number of snag stems per hectare.

b. Count the number of snag stems in a circular 0.04 plot.

c. If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

d. Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 2 stems, then 2 × 25 = 50 stems/ha.

e. Report the number of snags as stems per hectare.

21. Woody debris biomass (Vwd)

a. Measure/Units: Volume of woody debris in cubic meters per hectare is the measure of this variable.

b. Count the number of stems that intersect a vertical plane along a minimum of two transects located randomly and at least partially inside a 0.04-ha plot. Count the number of stems in each of three different size classes along the transect distance prescribed below. A 6-ft transect is used to count stems >0.25 to 1.0 in. in diameter, a 12-ft transect interval is used to count stems >1 to <3 in. in diameter, and a 50-ft transect is used to count stems >3 in. in diameter.

c. Convert stem counts for each size class to tons per acre using the following formulas. For stems in the >0.25- to1.0-in. and >1- to 3-in. size classes use the formula:

$$\text{Tons / acre} = (11.64 \times n \times d^2 \times s \times a \times C) / N \times l$$

where
n = total number of intersections (i.e., counts) on all transects
d^2 = squared average diameter for each size class
s = specific gravity (Birdsey (1992) suggests a value of 0.58)
a = nonhorizontal angle correction (suggested value: 1.13)
C = slope correction factor (suggested valued: 1.0, since slopes in forested floodplains are negligible)
N = number of transects
l = total length of transects in feet

For stems in the >3-in. size class, use the following formula:

$$\text{Tons / acre} = (11.64 \times \Sigma\, d^2 \times s \times a \times C) / N \times l$$

Σd^2 = the sum of the squared diameter of each intersecting stem

When inventorying large areas with many different tree species, it is practical to use composite values and approximations for diameters, specific gravities, and nonhorizontal angle corrections. For example, if composite average diameters, composite average nonhorizontal correction factors, and best approximations for specific gravities are used for the Southeast, the preceding formula for stems in the 0.25-1.0 in. size class simplifies to:

$$\text{Tons / acre} = 2.24\ (n)\ /\ N \times l$$

For stems in the >1.0- 3.0 in. size class the formula simplifies to:

$$\text{Tons / acre} = 21.4\ (n)\ /\ N \times l$$

For stems in the >3.0 in. size class the formula simplifies to:

$$\text{Tons / acre} = 6.87\ (\Sigma d^2)\ /\ N \times l$$

d. Convert tons per acre to cubic feet per acre using the formula:

$$\text{Cubic feet / acre} = (\text{tons / acre} \times 32.05)\ /\ 0.58$$

e. Convert cubic feet per acre to cubic meters per ha by multiplying by 0.072.

f. Report woody debris volume in cubic meters per hectare.

22. Log biomass (Vlog)

a. Measure/Units: Volume of logs in cubic meters per hectare is the measure of this variable.

b. Use the volume of logs calculated for woody debris biomass (*VWD*).

c. Report log volume in cubic meters per hectare.

23. Understory vegetation biomass (Vssd)

a. Measure/Units: Stem density in number of stems per hectare.

b. Count the stems of understory vegetation in either a 0.04-ha plot, or each of four 0.004-ha sampling units, hereafter called subplots, located in representative portions of each quadrant of the 0.04-ha plot. Sample using four 0.004-ha

subplots if the stand is in an early stage of succession and a high density of stems makes sampling 0.04-ha plots impractical.

c. If 0.004-ha subplots are used, average the results to serve as the value for each 0.04-ha plot.

d. If multiple 0.04-ha plots are sampled, average the results from all 0.04-ha plots.

e. Convert the results to a per hectare basis by multiplying by 25. For example, if the average of the 0.04-ha plots is 23 stems, then 23 × 25 = 575 stems/ha.

f. Report the number of understory vegetation stems as stems per hectare.

24. Ground vegetation biomass (Vgvc)

a. Measure/Units: Percent cover of ground vegetation.

b. Visually estimate the percentage of the ground surface that is covered by ground vegetation by mentally projecting the leaves and stems of ground vegetation to the ground surface in each of four 1-m^2 sampling units, hereafter called subplots, placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize an area will depend on its size and heterogeneity.

c. Average the values from the four 1-m^2 subplots.

d. If multiple 0.04-ha plots are sampled, average the results from these plots.

e. Report ground vegetation cover as a percent.

25. "O" horizon biomass (Vohor)

a. Measure/Units: Percent cover of the "O" horizon.

b. Visually estimate the percent of the ground surface that is covered by an "O" horizon in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

c. Average the results from the subplots.

d. If multiple 0.04-ha plots were sampled, average the results from these plots.

e. Report "O" horizon cover as a percent.

26. "A" horizon biomass (Vahor)

a. Measure/Units: Percent cover of the "A" horizon.

b. Estimate the percent of the mineral soil within the top 15 cm (6 in.) of the ground surface that qualifies as an "A" horizon by making a number of soil observations in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. For instance, if, in each subplot, 12 soil plugs are taken and 6 show the presence of a 7.5-cm (3-in.) thick "A" horizon, the value of "A" horizon cover is (6 / 12) × 100 = 50%. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

c. Average the results from the 1-m^2 subplots.

d. If multiple 0.04-ha plots were sampled, average the results from these plots.

e. Report "A" horizon cover as a percent.

27. Plant species composition (Vcomp)

a. Measure/Units: Percent concurrence with the dominant species in all vegetation strata.

b. Identify the dominant species in the canopy, understory vegetation, and ground vegetation strata using the 50/20 rule.1 Use tree basal area to determine abundance in the canopy strata, understory vegetation density to determine abundance in the understory strata, and ground vegetation cover to determine abundance in the ground vegetation strata. To apply the 50/20 Rule, rank species from each strata in descending order of abundance. Identify dominants by summing the normalized abundance measure beginning with the most abundant species in descending order until 50 percent is exceeded. Additional species with ≤20 percent normalized abundance are also considered as dominants. Accurate species identification is critical for determining the dominant species in each plot. Sampling during the dormant season may require a high degree of proficiency in identifying tree bark or dead plant parts.

c. For each vegetation strata, calculate percent concurrence by comparing the list of dominant plant species from each strata to the list of dominant species for each strata in reference standard wetlands in Table C6. For example, if all the dominants from the area being assessed occur on the list of dominants from reference standard wetlands, then there is 100 percent concurrence. If 3 of the 5 dominant species of trees from the area being assessed occur on the list, then there is 60 percent concurrence.

Table C6. Dominant Species by Vegetation Strata in Reference Standard Sites.

Tree	Shrub / sapling	Ground vegetation
Acer rubrum	*Acer rubrum*	*Arundinaria gigantea*
Betula nigra	*Betula nigra*	*Aster* sp.
Carya laciniosa	*Carya laciniosa*	*Boehmeria cylindrica*
Celtis laevigata	*Carpinus caroliniana*	*Campsis radicans*
Fraxinus pennsylvanica	*Celtis laevigata*	*Carex squarosa*
Liquidambar styraciflua	*Celtis occidentalis*	*Eragrostis alba*
Quercus pagodifolia	*Fraxinus pennsylvanica*	*Glyceria striata*
Quercus phellos	*Ilex decidua*	*Hypericum* sp.
Quercus lyrata	*Liquidambar styraciflua*	*Impatiens capensis*
Quercus imbricaria	*Nyssa sylvatica*	*Panicum* sp.
Quercus michauxii	*Quercus imbricaria*	*Parthenocissus quinquefolia*
Quercus stellata	*Quercus lyrata*	*Pilea pumila*
Quercus palustris	*Quercus phellos*	*Quercus phellos*
Salix nigra	*Quercus palustris*	*Salix nigra*
	Quercus pagodifolia	*Saururus cernuus*
	Quercus stellata	*Smilacina racemosa*
	Platanus occidentalis	*Smilax rotundifolia*
	Salix nigra	*Sparganium* sp.
	Ulmus americana	*Toxicodendron radicans*

B. Equations used for Functional Capacity Index (FCI) calculation.

1. Temporarily store surface water:

$$\left[\left(\frac{Vfreq \times Vstore}{}\right)^{1/2} \times \left(\frac{Vrough + Vslope}{2}\right)\right]^{1/2}$$

2. Maintain characteristic subsurface hydrology:

$$\left\{\left[\frac{\left(\frac{Vpore + Vwtf}{2}\right) + \left(Vsoilperm + Vwtslope\right)^{1/2}}{2}\right]\right\}$$

3. Cycle nutrients:

$$\frac{\left[\left(\frac{Vtba + Vssd + Vgvc}{3}\right) + \left(\frac{Vohor + Vahor + Vwd}{3}\right)\right]}{2}$$

4. Remove and sequester elements and compounds:

$$\left[\left(\frac{Vfreq + Vwtd}{2}\right) \times \left(\frac{Vclay + Vohor + Vahor + Vredox}{4}\right)\right]^{1/2}$$

5. Retain particulates:

$$\left[\left(Vfreq \times Vstore\right)^{1/2} \times \left(\frac{Vslope + Vrough}{2}\right)\right]^{1/2}$$

6. Export organic carbon:

$$\left[\left(Vfreq \times Vsurfcon\right)^{1/2} \times \left(\frac{Vohor + Vwd}{2}\right)\right]^{1/2}$$

7. Maintain characteristic plant community:

$$\left\{\left[\frac{\left(\frac{Vtba + Vtden}{2}\right) + Vcomp}{2}\right] \times \left(\frac{Vsoilint + Vfreq + Vwtd}{3}\right)\right\}^{1/2}$$

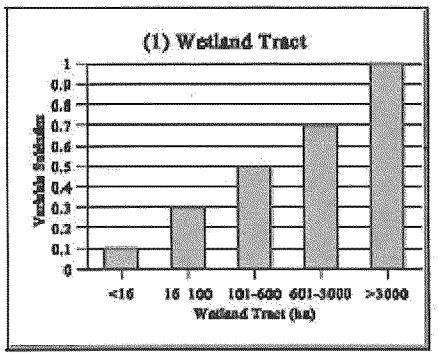
8. Provide habitat for wildlife:

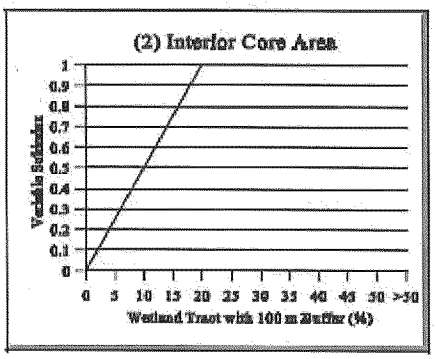
$$\left\{\left[\frac{\left(\frac{Vfreq + Vmacro}{2}\right) + \left(\frac{Vtract + Vc + Vcore}{3}\right)}{2}\right] \times \left(\frac{Vcomp + Vtba + Vtden + Vsnag + \left(\frac{V\log + Vohor}{2}\right)}{5}\right)\right\}^{1/2}$$

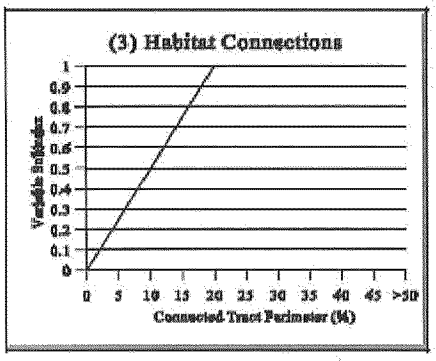
Appendix D

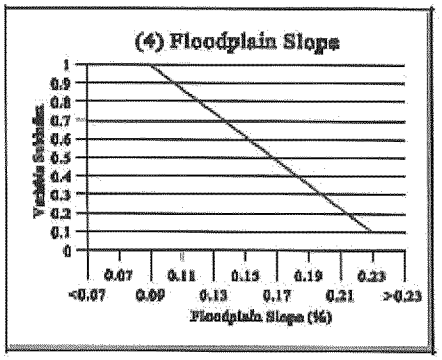
Standard Wetland Reference Graphs

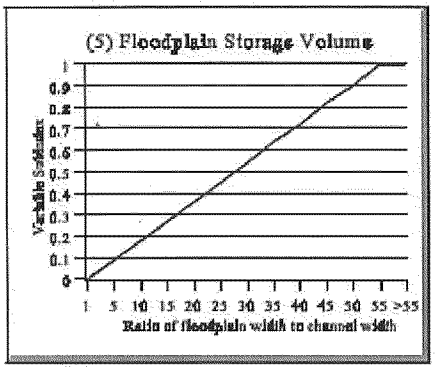
The graphs below transform the variable measurements to variable subindices (Ainslie *et al.*,1999).

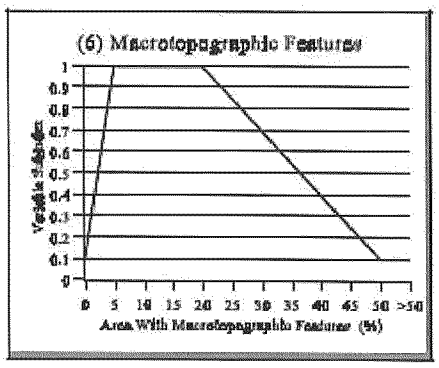


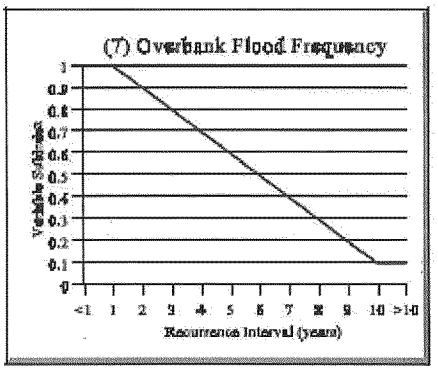


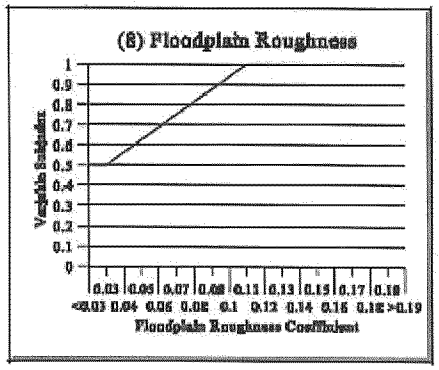


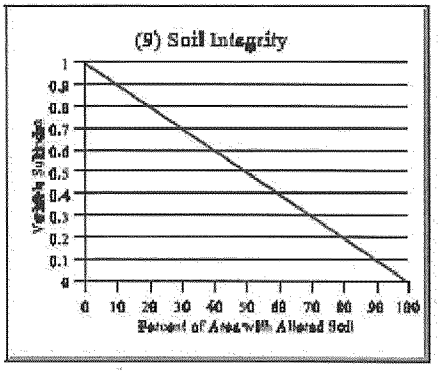


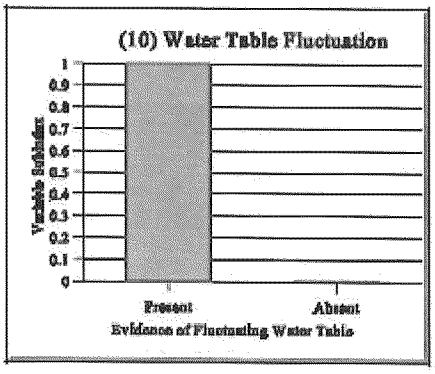


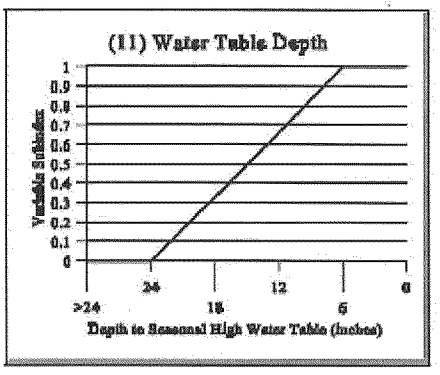


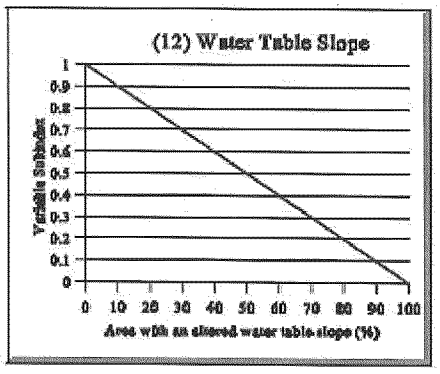


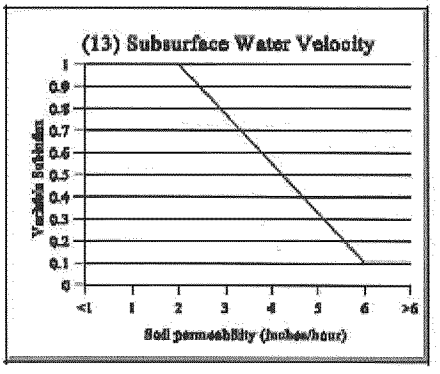


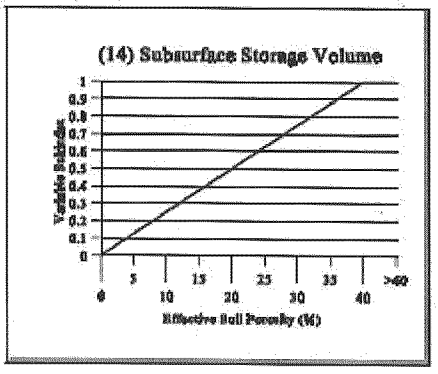

(9) Soil Integrity
Variable Subindex
Percent of Area with Altered Soil

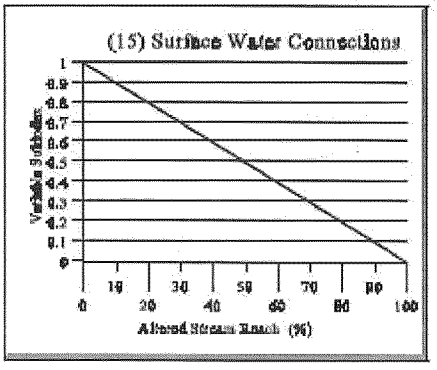

(10) Water Table Fluctuation
Variable Subindex
Present
Absent
Evidence of Fluctuating Water Table

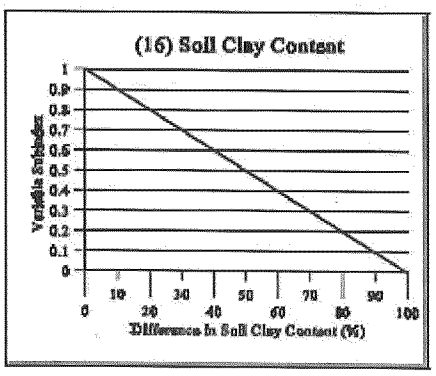

(11) Water Table Depth
Variable Subindex
>24
24
18
12
6
0
Depth to Seasonal High Water Table (inches)

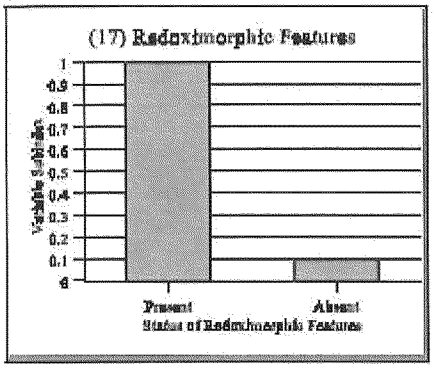

(12) Water Table Slope
Variable Subindex
Area with an altered water table slope (%)

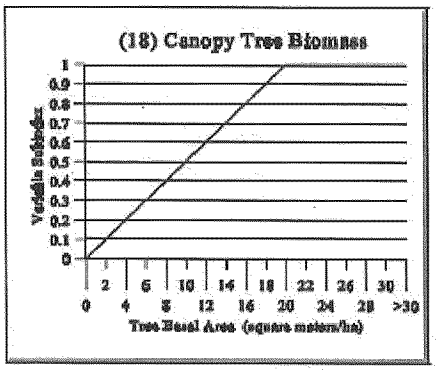

(13) Subsurface Water Velocity
Variable Subindex
<1
1
2
3
4
5
6
>6
Soil permeability (inches/hour)

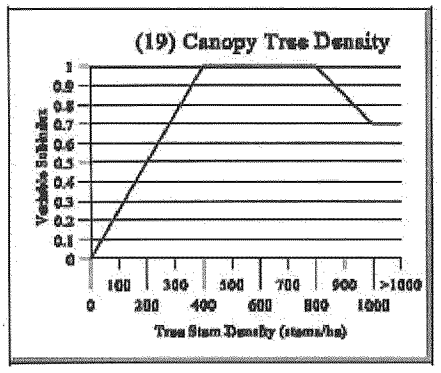

(14) Subsurface Storage Volume
Variable Subindex
Effective Soil Porosity (%)

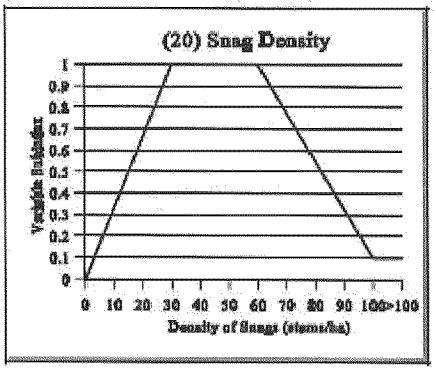

(15) Surface Water Connections
Variable Subindex
Altered Stream Reach (%)

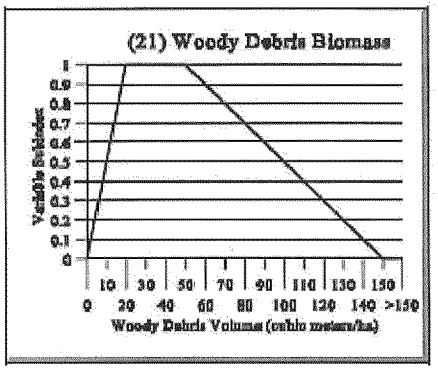

(16) Soil Clay Content
Variable Subindex
Difference in Soil Clay Content (%)

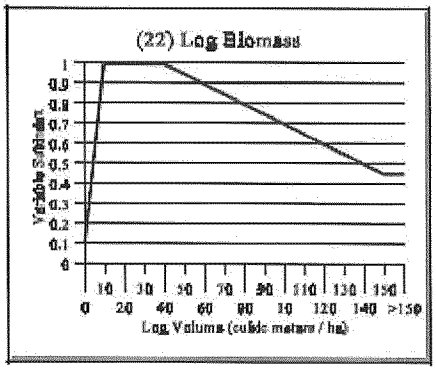

(17) Redoximorphic Features
Variable Subindex
Present
Absent
Status of Redoximorphic Features

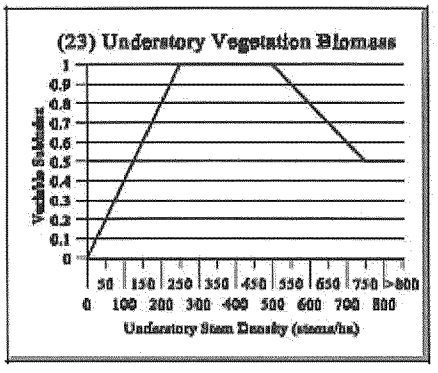

(18) Canopy Tree Biomass
Variable Subindex
Tree Basal Area (square meters/ha)

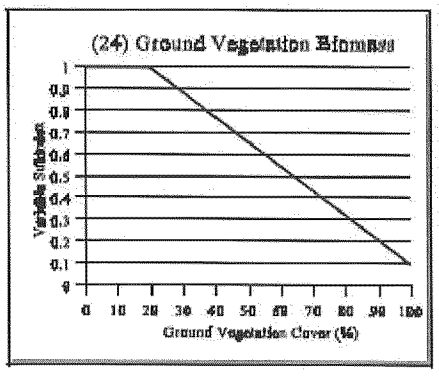

(19) Canopy Tree Density
Variable Subindex
Tree Stem Density (stems/ha)

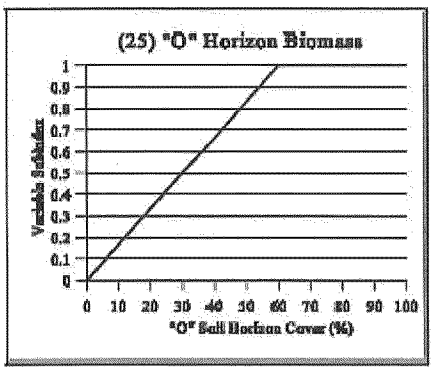

(20) Snag Density
Variable Subindex
Density of Snags (stems/ha)

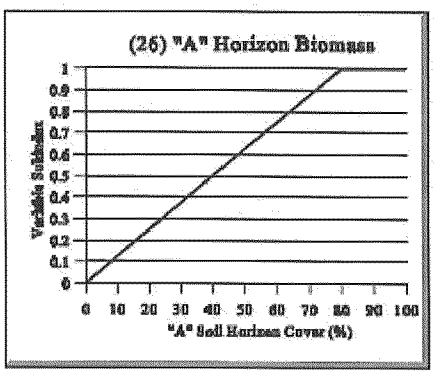

(21) Woody Debris Biomass
Variable Subindex
Woody Debris Volume (cubic meters/ha)

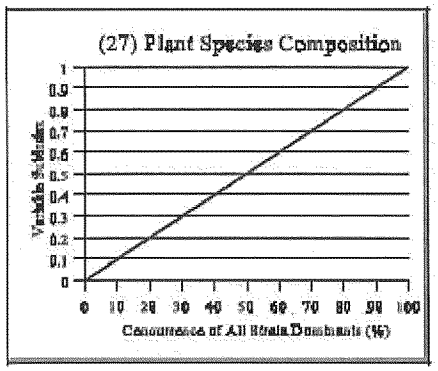

(22) Log Biomass
Variable Subindex
Log Volume (cubic meters / ha)


(23) Understory Vegetation Biomass
Variable Subindex
Understory Stem Density (stems/ha)


(24) Ground Vegetation Biomass
Variable Subindex
Ground Vegetation Cover (%)


(25) "O" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"O" Soil Horizon Cover (%)


(26) "A" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"A" Soil Horizon Cover (%)


(27) Plant Species Composition
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Concurrence of All Strata Dominants (%)