Hydrogeomorphic Variables: Definitions, Rationale, and Scoring

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INTRODUCTION

HGM functional assessment models are composed of variables aggregated together to form a mathematical equation. Each variable represents an indicator that is either qualitatively or quantitatively measured at the site. This indicator is given a score from 0-1 called a variable subindex score. The following is a description of all the variables used in our HGM functional assessment models. A summary of each variable and its relevant function can be found in Table 1. The description of each variable includes

1. Definition- A brief description of the indicator used to represent the variable
2. Rationale: A brief explanation, based on literature, describing why the variable is important to the functioning of the wetland.
3. Measurement: How the indicator is measured in the field. For more detailed information about the measurement see our Wetland Sampling Protocol (Section II.B.3.a.)
4. Scoring: The method of transforming the indicator into the variable subindex score.
5. Relevant Functions – Lists where the variables are used.

Table 1. Summary of HGM variables and applicable functions.

Variable	Functions										
	F1	F2	F3	F5	F6	F7	F8	F9	F10	F11	F12
V_{AQCON}											X
$V_{BIOMASS}$				X							
V_{CWD-BA}							X		X		
$V_{CWD-SIZE}$							X		X		
V_{EXOTIC}								X			
V_{FLOODP}	X	X			X	X	X				
V_{FWD}							X		X		
V_{GRAD}	X				X	X	X				
$V_{HYDROCHAR}$			X								
$V_{HYDROSTRESS}$			X		X		X				
V_{MACRO}		X			X	X	X				
V_{MPS}											X
V_{ORGMA}				X	X		X		X		
V_{REDOX}		X		X	X		X				
V_{REGEN}								X			
V_{ROUGH}	X				X	X					
V_{SDI}											X
V_{SNAGS}							X		X		
$V_{SPPCOMP}$								X			
V_{TEX}					X						
$V_{UNDEVEL}$											X
$V_{UNOBSTRUC}$	X	X			X	X	X				

VARIABLE DESCRIPTIONS

V_{AQCON}

1.1 Definition: This variable evaluates the degree of aquatic connectivity within a 1-km radius circle surrounding a site. It is comprised of three indices: presence of the site in the 100-year floodplain (100 FLOOD), stream density index (STR INDEX), and the distance to the nearest NWI wetland (NEAR DIST).

1.2 Rationale: The degree of aquatic connectivity influences the likelihood of species traveling between wetlands and thereby increasing genetic diversity. The greater the degree of aquatic connectivity in the landscape, the more likely species are to move between sites. This may be essential to the survival of species and maintenance of populations in the event of any changes in environmental conditions, natural or human-induced

1.3 Measurement: Used GIS data from 1-km radius circle.

1.4 Scoring: Data for STR INDEX and NEAR DIST were divided into quartiles based on the range of data for all reference sites in a subclass. The value of each variable gets scored based on the quartile it is in. Depending on the subclass, these three indices are totaled and then converted to a subindex score from 0-1. Headwater Floodplains, Mainstem Floodplains, Riparian Depressions and Slopes are first scored on a 0-10 scale using 100FLOOD, STRINDEX, and NEARWET and the scoring categories below. The three scores are totaled and then converted to a score between 0 and 1 by multiplying by 0.1. Isolated Depressions are scored on a scale of 1 – 10 using only NEARDIST. This score is then converted from 0-1 by dividing by 10. Fringing sites are scored on a scale of 0 to 20 using STRINDEX and NEARDIST. This score is then converted to a score between 0 and 1 by dividing by 20.

100FLOOD: (Headwater Floodplains, Mainstem Floodplains Riparian Depressions and Slopes)

- in the 100 yr floodplain = 2
- outside of the 100 yr floodplain = 0

STR INDEX :

Subclass	1st Quartile S	2nd Quartile Score	3rd Quartile Score	4th Quartile Sco
Headwater Flood	<8.5 = 1	8.5-11 = 2	11-13.5 = 3	>13.5 = 4
Mainstem Floodp	<11.75 = 1	11.75-16.5 = 2	16.5-21.25 = 3	>21.25 = 4

Riparian Depress	<9 = 1	9-12 = 2	12-15 = 3	>15 = 4
Slopes	<6.75 = 1	6.75-13.5 = 2	13.5-20.25 = 3	>20.25 = 4
Isolated Depressi	n/a	n/a	n/a	n/a
Fringing	<10 = 2.5	10-14 = 5.0	14-18 = 7.5	>18 = 10

NEAR DIST:

Subclass	1st Quartile S	2nd Quartile Score	3rd Quartile Score	4th Quartile Sco
Headwater Flood	<393.75 = 4	393.75-781.5 = 3	781.5-1169.25 =	>1169.25 = 1
Mainstem Floodp	<260 = 4	260-519 = 3	519-778 = 2	>778 = 1
Riparian Depress	<990.75 = 4	990.75-1942.5 =	1942.5-2894.25 =	>2894.25 = 1
Slopes	<257 = 4	257-510 = 3	510-763 = 2	>763 = 1
Isolated Depressi	<345.75 = 10	345.75-681.75 =	681.75-1017.25 =	>1017.25 = 2.5
Fringing	<129.25 = 10	129.25-255.5 = 7.	255.5-381.75 = 5.	>381.75 = 2.5

1.5 Relevant Functions: Function 12

2.0 $V_{BIOMASS}$

2.1 Definition: This variable provides an estimate of the above-ground vegetative biomass at a site created by combining % cover of the tree, shrub, and herb layers. These components are used as a relative estimate of the ability of the wetland plants to temporarily sequester nitrogen in aboveground biomass.

2.2 Rationale: Plants represent short-term removal of nitrogen, but can account for a large percentage of the removal (16-75% of total removal) (Reddy and D'Angelo 1994). Plant uptake is the dominant NO_3^{2-} sink during the growing season as emergent and submergent macrophytes remove NO_3^{2-} from surface water (Groffman et al. 1992, Weisner et al. 1994). However, this sequestration ability is finite. Over time, plant and microbial pools can become enriched, or saturated, with nitrogen, thus decreasing the nitrogen absorbing capacity (Groffman et al. 1992).

2.3 Measurement:

% tree – Measured by taking the dbh of all trees and saplings in a 11.3 m radius plot centered on plot point in order to calculate basal area. Average basal area per plot is divided by the total plot area to get a % basal area per plot. This percentage was standardized by multiplying by 1000 due to much lower numbers when compared to shrubs and herbs.

% shrub - Recorded the height and radius of the circular projection of cover (crown) for all shrubs and saplings in a 3-m radius plot centered on the plot point. % cover was calculated by using the radius to calculate area and finding an average shrub area per plot. This was divided by the total plot area to get % shrub area per plot.

% herb – Estimates of the percent herbaceous cover within a 11.3-m radius circle centered on sampling plots are made visually and recorded.

2.4 Scoring: Percent cover of herbs and shrubs were added together along with the standardized percent cover of trees. If total biomass is greater then the reference standard average, then the site receives a score of one. Otherwise, divide the total biomass by the reference standard average.

Reference Standard Averages:

Headwater Floodplains

All ecoregions = 224

Mainstem Floodplains

All ecoregions = 188

Riparian Depressions

Ridge and Valley = 234

Allegheny Plateau = 234

Glaciated Poconos, Glaciated Plateau = 146

Piedmont = 234

Slope

Ridge and Valley = 227

Allegheny Plateau = 128

Glaciated Poconos, Glaciated Plateau = 139

Piedmont = 227

Isolated Depression

Ridge and Valley, Glaciated Plateau = 166

Fringing

All ecoregions = 73

2.4 Relevant Functions: Function 5, also used in V_{ROUGH}

3.0 V_{CWD-BA}

3.1 Definition: This variable provides an estimate of the % cover of coarse woody debris on the ground along a transect for a site. Coarse woody debris (CWD) is defined as fallen dead wood.

3.2 Rationale: Coarse woody debris (CWD) is important for both nutrient cycling, and as habitat and food for microbes, invertebrates, and vertebrates (Harmon et al. 1986, Brown 1990, Taylor et al. 1990). CWD also functions to trap sediment and organic matter in a wetland (Harmon et al. 1986). CWD may be exported from a wetland or processed into smaller pieces for utilization by organisms.

3.3 Measurement: Count occurrences of downed woody material that cross transects by the following size classes:

Branches and fallen saplings: 1-12 cm

Trees: >12-40 cm

Large Trees: >40 cm

This number is divided by the length of the transect to calculate a number per meter for each size class. An estimate of coverage of CWD is then calculated by finding the basal area using the midpoint of the two smaller size classes and an average dbh of live trees at the site in the >40cm size class. If there are no live trees >40 cm dbh, then 40 cm is used. This estimate of basal area is totaled for all three size classes.

3.4 Scoring: Sites are scored based on reference standard averages by HGM subclass. If total estimates of CWD basal area are greater then the reference standard average the site receives a score of one. Otherwise, divide the total estimate of CWD by the reference standard average appropriate to the HGM subclass.

Reference Standard Averages:
Headwater Floodplains
All ecoregions = 175
Mainstem Floodplains
All ecoregions = 99
Riparian Depressions
Ridge and Valley = 77
Allegheny Plateau = 77
Glaciated Poconos, Glaciated Plateau = 39
Slopes
Ridge and Valley = 60
Allegheny Plateau = 40
Glaciated Poconos, Glaciated Plateau = 60
Piedmont = 60
Isolated Depressions
Ridge and Valley, Glaciated Plateau = 202
Fringing
All ecoregions = 34

3.5 Relevant Functions: Functions 8 & 10

4.0 $V_{CWD\text{-}SIZE}$

4.1 Definition: This variable is based on the presence of coarse woody debris in three size classes: 1-12 cm DBH, 12-40 cm DBH, and > 40 cm DBH

4.2 Rationale: Not only is the amount of CWD present in a system important, but the size of the CWD present is also an important consideration. CWD provides habitat for amphibians, small mammals and invertebrates (Harmon et al. 1986, Brown 1990). It is likely that different organisms utilize different sized particulates. CWD serves as a long-term nutrient reservoir and as a consistent source of organic material since different sized pieces decompose at different rates. Smaller pieces are likely to be degraded faster and, thus, are readily available nutrient contributors to the system than larger pieces

4.3 Measurement: Count occurrences of downed woody material that cross transects by the following size classes:

Branches and fallen saplings: 1-12 cm
Trees: >12-40 cm
Large Trees: >40 cm

4.4 Scoring: Sites are scored on the presence of CWD in each of the three size classes. Scores are the same across all four HGM subclasses.

3 size classes = 1.0
2 size classes = 0.67
1 size class = 0.33
No CWD = 0.1

4.5 Relevant Functions: Function 8 and 10

5.0 V_{EXOTIC}

5.1 Definition: % of the species list that is made up of non-native plants

5.2 Rationale: Presence of invasive species is often indicative of disturbance at a site (Huenneke et al. 1990, Burke and Grime 1996). Invasive species can have dramatic effects on plant community composition, which often results in alterations to ecosystem properties, such as nutrient and hydrologic cycling (Woods 1997). Many invasive species are opportunistic, aggressive species that can lead to the elimination an entire plant guild or alter the pathway of succession (Walker and Smith 1997, Woods 1997).

5.3 Measurement: A plant list is generated for each site using data recorded in 1 m^2, 3 m-radius, and 11.3-m radius plots. The ratio of native vascular plant species to exotic vascular plant species is calculated to determine % of species present that are not native.

5.4 Scoring: Scoring for V_{EXOTIC} is based on the following thresholds determined from reference standard sites: > 50% exotics receive a score of 0 and < 3% exotics receives a score of one. Values that fall in between these thresholds are scaled using the following equation:

$$1 - (\% \text{ exotics}/50)$$

5.5 Relevant Functions: Function 9

6.0 V_{FLOODP}

6.1 Definition: This variable is presently a placeholder variable for floodplain wetlands and should be developed to represent the characteristic hydrology of floodplain wetlands.

6.2 Rationale: This variable refers to the opportunity for flooding at the site. It takes into account whether the wetland is in the floodplain and whether there is evidence of flooding at the site. This variable can be used to estimate the frequency of flooding of the wetland, since a wetland in the floodplain is more likely to be flooded than a wetland outside of the floodplain.

6.3 Measurement: Possible indicators would include such things as, visual assessment of whether or not the site is experiencing flooding, measurements of bankfull width and floodprone area.

6.4 Relevant Functions: Functions 1,2,6,7, and 8

7.0 V_{FWD}

7.1 Definition: This variable provides a visual estimate of the depth of the litter layer and is taken from HSI models.

7.2 Rationale: Fine woody debris (V_{FWD}) represents material available for decomposition and leaching, thereby indicating a source of available carbon in the wetland for export to streams. Woody debris is a nutritional substrate, provides habitat for microbes, invertebrates, and vertebrates, and is a seedling nursery (Harmon et al. 1986, Brown 1990). The litter layer is an important source of nutrients and helps to provide suitable conditions for plant growth. Leaves decompose faster and are more conducive to mechanical fragmentation than twigs and wood, and so are more readily available for microbial utilization and plant uptake(Brinson 1977, Brinson et al. 1981). The export of fine woody debris provides an important food source for stream fauna. Finer particulates are more susceptible to export from a wetland because they are smaller and lighter than coarse woody debris, and thus move easier with water flow.

7.3 Measurement: Visual estimate of depth of litter layer.

7.4 Scoring: Variable subindices are the same for all four subclasses. Scores are taken directly from HSI models for the woodfrog (see Function 11, woodfrog model variable 3, Brooks and Prosser 1995). The scores below are general guidelines, intermediate scores may be applied at the user's discretion. For example, if there is slightly more than 2.5 cm of litter, but not enough to merit a score of 1.0, a score of 0.7 may be used.

Amount of Leaf Litter	Variable subindex
No leaf litter - bare ground	0.0
Sparse leaf litter: 2.5cm deep	0.5
Abundant leaf litter: >2.5cm deep	1.0

7.5 Relevant Functions: Functions 8 and 10

8.0 V_{GRAD}

8.1 Definition: This variable estimates the elevational gradient using topographic maps.

8.2 Rationale: The gradient of the wetland is important in determining how fast water will move across the wetland from the upland to the stream. Water moves faster over steeper surfaces and may be less affected by the roughness of a site than slower moving water. Slower moving water will allow greater amounts of sediment to settle out of the water column and be deposited on the wetland surface.

8.3 Measurement: For floodplain wetlands 1:24,000 scale topographic maps are used to count the number of contour lines that are crossed by the stream associated with the wetland being assessed. A distance of 1 km upstream and downstream from the site should be evaluated. Since slopes are generally not associated with a stream, contour lines 100 m up-slope and down-slope should be counted for wetlands in the Slope subclass.

8.4 Scoring: This variable is relevant to functions that involve retaining water, therefore, the site with a lower gradient will receive a higher score.

# of topo lines	Variable Subindex
0	1.0
1	0.75

2	0.50
3	0.25
4	0.1
>4	0

8.5 Relevant Functions: Functions 1, 6,7, and 8

9.0 $V_{HYDROCHAR}$

9.1 Definition: This variable is presently a placeholder for a variable that represents the characteristic hydrology of groundwater supported wetlands, such as riparian depressions.

9.2 Rationale: Maintenance of characteristic hydrology is important to the maintenance of many wetland functions. Alterations to hydrology may alter wetland nutrient and contaminant removal, plant community composition, decomposition, and nutrient cycling.

9.3 Measurement: Indicators such as monitoring well data, or visual assessments of the hydrology typical of a non-riverine system may be used here.

9.4 Relevant Functions: Function 3

10.0 $V_{HYDROSTRESS}$

10.1 Definition: This variable is an indicator of hydrologic modifications to a wetland and is derived from the stressor checklist.

10.2 Rationale: Hydrologic modifications to a wetland can impact a wetland by altering its ability to perform functions such as the removal of excess nutrients and contaminants, maintenance of the characteristic plant community and cycling of nutrients.

10.3 Measurement: A count of the number of hydrologic modification indicators from the stressor checklist

10.4 Scoring:

# of Hydrologic Modification Indicators	Variable Subindex
0	1.0
1	0.75
2	0.50
3	0.25
4	0.1
>4	0

10.5 Relevant Functions: Function 3; also used as a subvariable in $V_{UNOBSTRUC}$

11.0 V_{MACRO}

11.1 Definition: This variable estimates the macrotopographic relief of a wetland using the number and size of macrodepressions along a transect. It is used to indicate potential extent and depth of water that can be stored by inundation in pits and/or other depressions.

11.2 Rationale: The presence of macrotopographic depressions indicates the potential for long-term surface water storage. The total volume of macrodepressions in the wetland may be used to estimate relative storage capacity. The ability of a site to slow and retain water for long periods of time influences its ability to remove nutrients and contaminants, process organic materials, and remove particulates from the water column. Macrotopographic depressions include any depression greater than the depression left by a large tree windfall, such as oxbows, meander scrolls and backswamps (Brinson et al. 1995)

11.3 Measurement: Identify and count macrotopographic depressions encountered along transect measured at 1 m intervals to nearest 0.00 m using Abney level (or builder's level, or transit), stadia rod, and 100 m tape. Macrotopographic depressions are defined as depressions that are at least 15 cm deep for 1 m in length along the transect. The length of each macrodepression is totaled per transect, then divided by the total transect length to give the % of transect in macrodepressions.

11.4 Scoring:

% of total transect in macrodepressions	Variable Subindex
≥ 50%	1.0
≥ 25-49%	0.75
≥ 10-24%	0.50
≥ 5-9	0.25
≥ 1-4	0.1
0	0

11.5 Relevant Functions: Functions 2, 6, 7, and 8

12.0 V_{MFPS}

12.1 Definition: This variable represents the mean forested patch size within a 1-km radius circle of a wetland.

12.2 Rationale: Mean forest patch size is a common landscape metric used to represent the level of forest fragmentation found in a given area. As forest patches get smaller, species that require interior forest conditions may be eliminated (O'Connell et al. 2000). Also, as patches become smaller, the amount of edge between forests and non-forest land covers increases which can benefit edge-nesting birds and attract mammalian predators that utilize edge habitats. Thus, reductions in the extent of forest cover are seen as stressors when forest is considered the reference standard for land cover.

12.3 Measurement: Use GIS data from 1-km radius circle.

12.4 Scoring: Subindex scores are not dependent on HGM subclass. These are calculated by dividing the patch size of forested area by 315 which is the patch size in hectares if the site was 100% forested.

12.5 Relevant Functions: Function 12

13.0 V_{ORGMA}

13.1 Definition: This variable represents the % soil organic matter content in the top 5 cm of the soil profile below the litter layer. This variable estimates the abundance of carbon in the soil. Soil organic matter is formed as CWD and FWD decomposes into very fine particles. Snags, CWD, and FWD are eventually respired, physically exported, or incorporated into the soil organic matter pool.

13.2 Rationale: This variable encompasses the availability of carbon as a microbial substrate, provides a relative estimate of the soil nitrogen pool, and correlates with phosphorus and contaminant removal, thereby influencing Functions 5, 6, 8, and 10. The nutrient level of the soil pool influences the growth of the vegetation, and increases with SOM levels. The tissue quality of the vegetation, in turn, influences the utilization rate by microorganisms. Denitrification is a major pathway for the removal of excess nitrogen from a wetland, and is positively correlated to SOM content (Davidsson and Stahl 2000). Several studies have used SOM to predict and measure the phosphorus sorption capacity (Scott et al. 1990, Taylor et al. 1990, Gambrell 1994, Reddy et al. 1999, Bridgham et al. 2001). Soil organic matter has a high capacity to adsorb pesticides and metal ions (Scott et al. 1990, Gambrell 1994). Wetland soils contribute organic carbon to baseflow waters leaving the wetland (Dosskey and Bertsch 1994). Organic soils release more DOC into solution than mineral soils (Dillon and Molot 1997). Flooded, saturated soils cause SOM to accumulate in a wetland (Axt and Walbridge 1999) and recent organic matter (less than 45 years old) is the primary source of DOC (Dillon and Molot 1997, Schiff et al. 1998).

13.3 Measurement: The organic content of the top 5 cm of the soil is determined by lab analysis.

13.4 Scoring:

Headwater Floodplains

Ridge and Valley, Allegheny Plateau, Piedmont =

>6-10 = 1

2-6 or >10-14 = 0.5

Outside of range = 0.1

Glaciated Poconos, Glaciated Plateau =

if %OM is greater then reference standard average then 1, otherwise % OM divided by reference standard average

Reference Standard Average = 46

Mainstem Floodplain

All ecoregions =

>6.75-11.25 = 1

4.5-6.75 or >11.25-13.5 = 0.5

outside of range = 0.1

Riparian Depression

Ridge and Valley, Allegheny Plateau =

>18-30 = 1

6-18 or >30 – 42 = 0.5

outside of range = 0.1

Glaciated Poconos, Glaciated Plateau =

if %OM is greater then reference standard average then 1, otherwise % OM divided by reference standard average

Reference Standard Average = 46

Slopes

Ridge and Valley, Piedmont =

>10.5-17.5 = 1

3.5 – 10.5 or >17.5 –24.5 =0.5

outside of range = 0.1

Allegheny Plateau =

>6-10 = 1

4-6 or >10-12 = 0.5

outside of range = 0.1

Glaciated Poconos, Glaciated Plateau =

if %OM is greater then reference standard average then 1, otherwise % OM divided by reference standard average

Reference Standard Average = 46

Isolated Depressions

Ridge and Valley, Glaciated Plateau =

if %OM is greater then reference standard average then 1, otherwise % OM divided by reference standard average

Reference Standard Average = 31

Fringing

All Ecoregions =

if %OM is greater then reference standard average then 1, otherwise % OM divided by reference standard average

Reference Standard Average = 36

13.5 Relevant Functions: Functions 5, 6, 8, and 10

14.0 V_{REDOX}

14.1 Definition: This variable indicates the presence of redoximorphic features in the upper soil profile, based on mottle and matrix chromas. Redoximorphic depletions, or concentrations, result from fluctuations in oxidation states of elements. When minerals are reduced during anaerobic decomposition, their solubility and mobility increase, causing low chroma redox depletions (Bishel-Machung et al. 1996). When the soils are reoxidized, high chroma redox accumulations are created (Bishel-Machung et al. 1996). The result of periodic flooding is soil with high chroma spots on a low chroma matrix (Bishel-Machung et al. 1996).

14.2 Rationale: This variable estimates the soil moisture conditions and can be used as evidence of long-term surface water storage. This variable is important to many biogeochemical processes, particularly those processes involving nitrogen, phosphorus, and carbon. However, no soil moisture condition is optimal for all biogeochemical processes. Fluctuating water levels create a coupling of nitrification-denitrification, which is optimal for denitrification (Vought et al. 1994) because microbes on the litter immobilize N under aerobic conditions and mineralize N under anaerobic conditions (Bowden 1987). In more stable moisture conditions, saturated anoxic sediments have higher denitrification rates than unsaturated sediments (Seitzinger 1994, Mitsch and Gosselink 2000). Phosphorus sorption maximum is generally greater under aerobic conditions than anaerobic, but anaerobic conditions can cause transformation of Fe and Al to forms with higher phosphorus sorption capacities(Richardson and Craft 1993, Reddy et al. 1998, Bridgham et al. 2001). Anaerobic soils can also increase SOM contents, which increase phosphorus sorption capacity (Axt and Walbridge 1999, Reddy et al. 1999). Heavy metals are generally more immobile under reduced conditions than oxidized conditions (Gambrell 1994).

In fact, some metals may become more tightly bound by organics under reduced conditions than in the dry conditions of uplands(Gambrell 1994).

Carbon mineralization is reduced in anoxic conditions, allowing dissolved organic carbon (DOC) to accumulate. However, this relationship exists only up to a threshold, beyond which the system may start to slow DOC production. Carbon adsorption to clays and metals are also reduced in anoxic environments, making more carbon available in the form of DOC. The longer the soil is in direct contact with surface water, the greater the opportunity for soil porewater DOC to mix with surface water(Mulholland 1981, Dalva and Moore 1991). The longer the contact time, the greater the opportunity for soil porewater DOC to diffuse into the water column and drain into the stream.

14.3 Measurement: The direct observation of soil characteristics at soil pits. Chroma of mottles and matrix at 20 cm depths are used as indicators of overall soil moisture conditions at the site.

14.4 Scoring: Five prevalent soil conditions are listed in the table below along with a corresponding "Redox Score". A score of one is given to sites with reduced soil conditions and a score of zero is given to sites with oxidized soil conditions. The remaining conditions are scaled between 0 – 1. The sites are characterized by which soil condition is the majority at each site (i.e., had the highest percentage of all plots). For example, if a site consists of 4 plots, and 3 of the plots (75%) were considered as having fluctuating soil moisture conditions, then the site would be given the corresponding redox score for fluctuating conditions (0.5). If there was no majority at a site, an average was taken. So, if a site had 4 plots, and 2 plots were fluctuating and 2 plots were reduced, then an average of the two conditions was taken (0.5 + 1.0/ 2 = 0.75).

Soil Moisture Condition	Matrix Chroma	Mottle Chroma	Redox Scor
Oxidizing	>2	>2	0.1
	>2	no mottles	0.1
Intermediate Oxidizing	>2	≤ 2	0.25
Fluctuating	≤ 2	>2	0.5
Intermediate Reducing	2	no mottles	0.75
	2	≤ 2	0.75
Reducing	≤ 1	no mottles	1.0
	≤ 1	≤ 2	1.0
	Gley		1.0

14.5 Relevant Functions: Functions 2, 5, 6, 7, and 8b

15.0 V_{REGEN}

15.1 Definition: This variable looks for evidence of regeneration of the dominant canopy species in each stratum.

15.2 Rationale: The reference standard for wetlands in the Ridge and Valley physiographic province is forested, so evidence of regeneration of the dominate canopy species is an important feature to consider when assessing the plant community. The maintenance of plant communities requires that there is replacement of individuals that die with other individuals of that species (Brinson et al. 1995). Species composition in the understory is useful for predicting the future community composition and structure, since the understory of a healthy, stable forest generally contains saplings and seedlings of the forest canopy species (Brinson et al. 1995).

15.3 Measurement: A list of dominant canopy trees was compiled for the Ridge and Valley physiographic province (Appendix A). This list is used to determine the regeneration of the native forest. A regeneration score is then given to each site based on the presence of these tree species in the herb, sapling, and tree layers.

15.4 Scoring: Regeneration scores are determined as follows. A complete absence of canopy trees in any layer is the worst scenario and received the lowest score of zero. Having an individual present in all layers is the best scenario and received the highest score of 7. Any situation in which a representative is present in the tree layer would be ranked higher then any situation in which no trees are present in the canopy layer, due to the fact that adult trees have a greater probability of reproducing than saplings or seedlings. Only having individuals in the sapling layer would receive a higher score than only having individuals in the seedling layer. This is because seedlings have a higher mortality rate then saplings and are less likely to become established. Saplings indicate both successful germination and successful establishment. Having both trees and seedlings together is ranked higher than just trees because there is evidence that the trees are successfully reproducing. Trees and saplings are given a higher score than trees and seedlings because the tree is reproducing and there is successful establishment. This is done for each species at each site. The result is the following scoring system:

None present = 0 (worst)
Seedling = 1
Sapling = 2
Sapling, seedling = 3
Tree = 4
Tree, seedling = 5
Tree, sapling = 6
Tree, sapling, seedling = 7 (best)

The scores for each species are then added together.

Sites are scored based on the avererage regen score for reference standard sites by subclass. If the total regen score is greater then the average, the site receives a score of one. Otherwise, divide the total regen score by the reference standard average appropriate to the subclass.

Reference standard averages:

Headwater Floodplains

All ecoregions = 52

Mainstem Floodplains

All ecoregions = 25

Riparian Depressions

Ridge and Valley = 39

Allegheny Plateau = 39

Glaciated Poconos, Glaciated Plateau = 12

Slopes

Ridge and Valley = 32

Allegheny Plateau = 11

Glaciated Pocoonos, Glaciated Plateau = 32

Piedmont = 32

Isolated Depression

Ridge and Valley, Glaciated Plateau = 24

Fringing

Variable does not apply to Fringing sites

15.5 Relevant Functions: Function 9

16.0 V_{ROUGH}

16.1 Definition: This variable estimates the roughness of a site using Manning's roughness coefficient, a composite weighting score based on flow resistance at the site (CWD, microtopography, and vegetation).

16.2 Rationale: Vegetation introduces impediments to surface water flow and reduces the energy of storm runoff (Brix 1994). Roughness created by vegetation slows runoff, causing water to deposit sediment and debris (Owen and Wall 1989, Brinson et al. 1995). High vegetation density corresponds to higher effective roughness, flow resistance, and erosion protection of the system (Demissie and Khan 1993, Castelle et al. 1994, Thorne 1998). Heavy vegetation slows flow and provides areas of slack water, allowing more water to seep down through soil and be stored as groundwater (Owen and Wall 1989). Microtopographic complexity increases the tortuosity of flow pathways and reduces average velocity. Microtopographic complexity also increases the gradient of moisture conditions present in a site, which increases the diversity of biogeochemical processes occurring in the wetland (Brinson et al. 1995). Coarse woody debris block flows and modifies flow patterns, accelerating the lateral migration of streams.The slow water flow promoted by roughness increases the residence time of water and promotes the settling of particulates (Brown 1988, Jones and Smock 1991, Joensuu 1997). Roughness slows water movement out of the wetland, increasing retention time and thus increasing the water-soil contact time for dissolved organic carbon (DOC) diffusion.

16.3 Measurement: Complexity of the substrate plays an important role in determining the flow of surface water through the wetland. To characterize this complexity the following sub-variables were used:

$\mathbf{V_{BIOMASS}}$ = sum of the percent basal area of live trees, percent area of shrub cover, and percent cover of persistent herbaceous vegetation

$\mathbf{V_{CWD}}$ = amount of coarse woody debris per standard area

$\mathbf{V_{MICRO}}$ = microtopographic complexity of wetland surface

Calculation of the Manning's roughness coefficient is the basis for quantifying and combining the variables mentioned above. We based our equation on the one suggested by Arcement and Schneider (1989) in their "Guide for Selecting Manning's roughness coefficients for natural channels and Floodplains". The procedure suggested for floodplains used the following equation:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

where:

n = Manning's roughness coefficient

n_b = base value of n for the floodplain's natural bare soil surface, with nothing on the surface

n_1 = a value to correct for the effect of surface irregularities on the floodplain

n_2 = a value for variations in shape and size of the floodplain cross section, assumed to equal zero

n_3 = a value for obstructions on the floodplain

n_4 = a value for vegetation on the floodplain

m = a correction factor for sinuosity of the flood plain, equal to 1.0

(Arcement and Schneider 1989)

We've interpreted the above variables to be represented as follows:

n_b = .03 (suggested value by Arcement and Schneider, 1989, for floodplains)

n_1 = microtopographic variation

n_2 = 0 (assumed for floodplains)

n_3 = Coarse woody debris

n_4 = cover of trees, shrubs, and herbs

m = 1.0 (assumed for floodplains)

This results in the equation: $n = (n_1 + n_3 + n_4)$

This equation uses a composite scoring system to weight variables according to their affect on overall roughness. Vegetation (n_4) gets the highest weight with scores ranging from 0.025 - 0.100, an order of magnitude higher then n_3 and n_1. CWD (n_3) and microtopography (n_1) were weighted comparably, but CWD has a higher maximum score. Microtopography scores ranged from 0.0 - 0.015 and CWD scores ranged from 0.0 - 0.025. The following table should be used to assign appropriate scores for use in Manning's coefficient equation, based on measurements taken in the field.

Table 1. Scores for variables included in Manning's coefficient equation.

	Field Measurement	n value	General Description
n1*	Standard Deviation		
	0 - 0.099	0	Smooth; smoothest, flattest attainable in a given bed material.
	0.1 - 0.29	0.003	Minor; a few rises, dips, or sloughs may be visible
	0.3 - 0.49	0.008	Moderate; more dips and rises, sloughs may be visible
	≥ 0.5	0.015	Severe; many rises, dips and sloughs are visible
* Adapted from Aldridge and Garrett (1973) and Arcement and Schneider (1989)			

	Field Measurement	n value	General Description
n3*	CWD coverage		
	0 - 50	0	Negligible; a few scattered obstructions less than 5% of area
	50 - 200	0.002	Negligible; same
	200 - 550	0.01	Minor; obstructions less than 15% of area
	>550	0.025	Appreciable; obstructions from 15-50 % of area
* Adapted from Aldridge and Garrett (1973) and Arcement and Schneider (1989)			

	Field Measurement	n value	General Description
n4	%herbs + %shrubs + %trees	0.0 – 0.10	This score is same as Variable $V_{BIOMASS}$ resulting score is then multiplied by 0.1 to scale for Mannings coefficient.

16.4 **Scoring:** Sites are scored based on reference standard averages, by HGM subclass. If roughness coefficients for a site are greater then the reference standard average the site receives a score of one. Otherwise, divide roughness coefficient by the reference standard average appropriate to the HGM subclass.

Reference Standard Averages:

Headwater Floodplains

All ecoregions = 0.141

Mainstem Floodplains

All ecoregions = 0.130

Riparian Depressions

All ecoregions = 0.120

Slopes

All ecoregions = 0.120

Isolated Depressions

Ridge and Valley, Glaciated Plateau = 0.129

Fringing

All ecoregions = 0.120

16.4 Relevent Functions: Functions 1, 6, and 7

17.0 V_{SDI}

17.1 Definition: This variable is a composite of the natural log of the Shannon diversity index for eight landscape categories in a 1-km radius circle around the site.

17.2 Rationale: A common landscape metric used to characterize the juxtaposition of land cover patches (as represented by homogeneous clusters of digital pixels) is a diversity measure (Miller et al. 1997). This measure represents the likelihood that a neighboring pixel has the same land cover designation as the pixel being considered. A highly fragmented landscape will have a heterogeneous mix of pixels (representing land cover types). It is comparable to computing species diversity within a community. The measure is sensitive to the number of cover types (or species) occurring in the unit being measured (1-km radius circle). Converting the Shannon Diversity index with the natural logarithm, returns the score to a number related to the number of cover types.

17.3 Measurement: Use GIS data from 1-km radius circle.

17.4 Scoring: The natural log of the Shannon Diversity Index is scaled to a number between 0–1 to develop a variable subindex using the following equation: (8-Natlong SDI)/ 7

17.5 Relevant Functions: Function 12

18.0 V_{SNAGS}

18.1 Definition: This variable reflects the presence of dead standing trees in four size classes that will contribute to particulate organic matter (POM) as it is processed in place or added to the CWD component.

18.2 Rationale: Like coarse woody debris, snags are important components of the forest ecosystem. Along with acting as a source of detrital matter, they serve as important habitat for numerous vertebrate and invertebrate species (Harmon and Hua 1991). Snags will begin to decompose while standing, but at a much slower rate than fallen debris. The standing dead matter will eventually fall to the ground and be processes as CWD.

18.3 Measurement: Density and dbh of erect dead woody material in 11.3 m radius plot centered on plot point. Snags at each site are divided into four size classes: 0-12cm dbh, >12-28 cm dbh, 28-40cm dbh, and >40cm dbh

18.4 Scoring: Scoring is based on the presence or absense of snags in each of the four size classes. It is assumed that sites with a greater size class distribution are functioning at high levels and receive a high variable subindex score.

# of Size Classes Present	Variable Subindex
3 or 4	1.0
2	0.75
1	0.50
0	0.1

18.5 Relevant Functions: Functions 8, and 10

19.0 $V_{SPPCOMP}$

19.1 Definition: This variable evaluates the species composition of wetlands using an adjusted Floristic Quality Assessment Index (FQAI). The FQAI is used to represent plant species composition. It is weighted richness metric used to assess the natural quality of a system. The basis for this is the coefficient of conservatism (COC), which is a ranking from 0-10 given to each individual plant species present at the site. The COC score is based on the niche breadth of each species, with plants that are conservative or intolerant receiving high scores and plants that can survive in a wide range of conditions, or tolerant, receiving low scores. Exotic species always receive a score of zero.

19.2 Rationale: Plant community composition and structure influences many ecosystem properties, such as primary productivity, nutrient cycling and hydrology (Hobbie 1992, Ainslie et al. 1999). Community composition and structure also influence the habitat quality for invertebrate, vertebrate, and microbial communities (Gregory et al. 1991, Norokorpi 1997, Ainslie et al. 1999). Changes in species composition may influence the ability of a wetland to perform any of these functions.

19.3 Measurement: The FQAI is calculated using the following equation (Andreas 1995).

$I = R/ \sqrt{N}$

where:

I = FQAI

R= sum of the COC scores for native species

N = number of different native species recorded

For our purposes, we adjusted the FQAI for each site to be expressed as the percentage of the maximum potential score. The maximum potential for each site is calculated by first calculating the FQAI score for the site. The FQAI score is calculated again, but this time assuming that all species at the site are native and receive a COC score of 10. This removes any bias that may exist at sites that have low species richness yet are high quality sites. The formula is then changed to:

$$M = \frac{I}{(10 * T/\sqrt{T})} * 100$$

Where:

M = % of the maximum potential score (adjusted FQAI)

I = FQAI for the Site

T = total number of species at the site (natives + exotics)

19.4 Scoring: Sites are scored based on the average adjusted FQAI score for reference standard sites in each subclass. If the adjusted FQAI is greater then the average the site receives a score of one. Otherwise, divide the adjusted FQAI score by the average appropriate to each subclass.

Reference standard averages:

Headwater Floodplains

All ecoregions = 49

Mainstem Floodplains

All ecoregions = 38

Riparian Depressions

All ecoregions = 56

Slopes

All ecoregions = 46

Isolated Depressions

Ridge and Valley, Glaciated Plateau = 49

Fringing

All ecoregions = 44

19.5 Relevant Functions: Function 9

20.0 V_{TEX}

20.1 Definition: This variable determines soil texture using standard field methods. Soil texture acts as a surrogate measure of available pore space, indicating the capacity of the soil to store water.

20.2Rationale: Soil texture influences phosphorus and contaminant retention. Smaller particles tend to bind with phosphorus (Taylor et al. 1990, Reddy et al. 1999, Bridgham et al. 2001). Both phosphorus adsorption and precipitation is associated with clay particles(Walbridge and Struthers 1993). Fine-textured sediments also tend to accumulate more metals than coarse-textured sediments (Gambrell 1994).

20.3 Measurement: Direct observation of soil characteristics in the soil pit at 5 and 20 cm depths. Texture designation is determined by using the appended guide for field characteristics of major textural classes.

20.4 Scoring: Texture designations are converted to scores based on conductivity values presented in Rawls et al. (1982). These conductivity values were standardized to an index between 0-1 by dividing by the conductivity value for the most porous texture class (sand). This is done for each for each plot at a site at both 5 cm and 20 cm depths. The variable subindex was created by reversing these scores so that more porous texture classes would get lower scores, with sand getting a score of zero. An average score was then calculated per site. The resulting subindex scores are:

Soil Texture Class	Variable Subindex
Sand / gravel	0.00
Loamy Sand / Sandy (SAL)	0.40
Silt Loam (SIL)	0.75
Sandy Clay Loam (SA	0.94
Loam	0.96
Silty Clay Loam (SICI	0.96
Clay Loam (CL)	0.98
Clay (C)	0.99
Silty Clay (SIC)	0.99
Sandy Clay (SAC)	0.99
Muck	0.99

20.5 Relevant Functions: Function 6

21.0 $V_{UNDEVEL}$

21.1 Definition: This variable is a landscape-scale variable made up of the average of two sub-variables:

V_{RDDEN} – the density of roads in 1-km radius circle surrounding the wetland

V_{URB} – the % urban development in a 1-km radius circle surrounding the wetland

21.2 Rationale: Human encroachment on wetlands is a major source of stressors on wetlands. Urban development and road density in the landscape surrounding a wetland are good indicators of the extent of human encroachment, and thus the likelihood of stressor impacts on the biodiversity of the wetland. Roads and urban centers can be seen as barriers to the connectivity of wetland systems in the landscape, with potential impacts on species movement between systems.

21.3 Measurement: Use GIS data from 1 km radius circle.

21.4 Scoring:

V_{RDDEN} – The road density index in a 1 km circle around a site was scored based on reference standard conditions. Thresholds were developed from reference standard site in all HGM subclasses with a road density index of 45 being an upper threshold and road density index of 5 being the lower threshold. Due to the indirect nature of the index (higher road density index signifies lower condition) the variable subindex needs to be reversed. The following method is used to convert the road density index to a variable subindex:

If RDDEN ≤ 5 then 1, if RDDEN is ≥ 45 then 0, otherwise 1- (RDDEN/45)

V_{URB} – this variable was scored based on categories of % urban development in a 1 km radius circle around a site. All HGM subclasses were scored the same using the following variable subindices:

% Urban area	Variable Subindex
0-1	1.0
>1-3	0.75
>3-5	0.5
>5-10	0.25
>10-30	0.1
>30	0

21.5 Relevant Functions: Function 12

22.0 $V_{UNOBSTRUC}$

22.1 Definition: This variable is applied to floodplain wetlands and represents those characteristics that would cause a deviation in floodplain functioning from reference standard. This variable is identical to $V_{UNDEVEL}$ with the addition of the subvariable $V_{HYDROSTRESS}$. This variable is comprised of the average of the three subvariables:

V_{RDDENS} – the density of roads in a 1-km radius circle surrounding the wetland.

V_{URB} – the % urban development in a 1-km radius circle surrounding the wetland.

$V_{HYDROSTRESS}$ – indicators of hydrologic modifications from stressor checklist.

22.2 Rationale: Hydrologic modifications to a wetland can impact a wetland by altering its ability to perform functions such as the removal of excess nutrients and contaminants, maintenance of the characteristic plant community and cycling of nutrients.

22.3 Measurement: Use GIS data from 1-km radius circle.

22.4 Scoring: Scoring for the subvariables V_{RDDENS} and V_{URB} is identical to the scoring described above in $V_{UNDEVEL}$.

$V_{HYDROSTRESS}$ – This subvariable was scored the same for all HGM subclasses based on the number of hydrologic modification indicators identified on the stressor checklist. The following categories were used:

# of Indicators	Variable Subindex
0	1.0
1	0.75
2	0.5
3	0.25
4	0.1
>4	0

22.5 Relevant Functions: Functions 1, 6, 7, 8

FUNCTION 11 SCORING

The FCI for Function 11 is determined using the scores from the HSI models, for more details on the development of these models see section II.B.3.b.2 (HGM Model Building Process). The procedure for determining the F11 score is as follows:

1. For each species in the HSI model determine if the score falls in the range of reference standard sites for each subclass. Ranges are shown in the following table:

HGM Subclass	Bullfrog	Muskrat (Stream)	Muskrat (Marsh)	Meadow Vole	Redwing Blackbird	Common Yellowthroat	American Woodcock	Green-backed Heron	Wood Duck	Wood Frog	Southern Red-backed Vole
Headwater Floodplain	0.00-0.74	0.10-0.70	0.10-0.70	0.64-0.81	0.33-0.82	0.00-0.36	0.10-0.60	0.27-0.67	0.40-0.82	0.56-0.90	0.36-0.67
Mainstem Floodplain	0.20-0.60	0.33-0.67	0.33-0.67	0.40-0.70	0.50-0.70	0.30-0.60	0.40-0.70	0.25-0.50	0.25-0.50	0.25-0.75	0.30-0.60
Slope	0.00-0.97	0.10-0.70	0.10-0.70	0.32-0.72	0.40-0.88	0.25-0.71	0.20-0.37	0.57-0.92	0.15-1.00	0.23-0.89	0.16-0.77
Riparian Depression	0.00-0.60	0.10-0.70	0.10-0.70	0.23-0.79	0.33-0.65	0.24-0.64	0.10-0.50	0.25-0.60	0.22-0.47	0.46-0.80	0.27-0.77
Isolated Depression	0.00-0.80	0.10-0.70	0.10-0.70	0.20-0.78	0.20-0.57	0.00-0.71	0.10-0.45	0.27-0.73	0.23-0.57	0.65-0.90	0.26-0.53
Fringing	0.26-0.93	0.10-0.70	0.10-0.70	0.00-0.69	0.53-0.68	0.32-0.71	0.13-0.55	0.53-0.90	0.30-1.00	0.36-1.00	0.15-0.66

2. Determine the total number of species deviating from the reference standard range.

3. Determine the absolute amount of deviation across all species.

4. Multiply the total number of species deviating by 0.1 and subtract this from 1 to get a preliminary score.

5. This score is then modified depending on the total amount of deviation to get the final function score.

If absolute total amount of deviation is:	Subtract from preliminary score:
>0.5	0.1
>1.0	0.2
>1.5	0.3
>2.0	0.4
>2.5	0.5

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Appendix A. List of tree species used in V_{REGEN}

Abies balsamea
Acer negundo
Acer nigrum
Acer rubrum
Acer saccharinum
Acer saccharum
Acer sp.
Betula allegheniensis
Betula lenta
Betula nigra
Betula papyrifera
Betula populifolia
Betula sp.
Carya cordiformis
Carya glabra
Carya ovata
Carya sp.
Carya tomentosa
Catalpa sp.
Fagus grandifolia
Fraxinus americana
Fraxinus nigra
Fraxinus pennsylvanica
Fraxinus quadrangulata
Fraxinus sp.
Juglans cinerea
Juglans nigra
Juglans sp.
Larix laricina
Larix sp.
Liriodendron tulipifera
Magnolia acuminata
Nyssa sylvatica
Picea abies
Picea glauca
Picea rubens
Picea sp.
Pinus banksiana
Pinus resinosa
Pinus rigida
Pinus sp.
Pinus strobus
Pinus virginiana
Platanus occidentalis
Prunus serotina
Quercus alba
Quercus bicolor
Quercus coccinea
Quercus palustris
Quercus prinus
Quercus rubra
Quercus sp.
Quercus velutina
Salix nigra
Tilia americana
Tsuga canadensis