Hydrogeomorphic Functional Assessment Models - Isolated Depressions

Robert P. Brooks, Denice Heller Wardrop, Jennifer Masina Rubbo, Wendy M. Mahaney
Penn State Cooperative Wetlands Center, Department of Geography
302 Walker Building, University Park, PA 16802
and
Charles Andrew Cole, Center for Watershed Stewardship, Pennsylvania State University
227 East Calder Way, State College, PA 16801

INTRODUCTION

Hydrogeomorphic functional assessment models were developed for six regional wetland subclasses in the Commonwealth of Pennsylvania. The following is a description of each of the applicable functions for the specified subclass. This description is made up of six parts which are explained below.

1. Definition and applicability – Briefly defines the function and identifies which subclasses the function should be applied.
2. Rationale for selecting the function – Explains why the function is relevant to the regional subclass.
3. Characteristics and processes that influence the function – A brief literature review describing important characteristics of the function.
4. General form of the assessment model – Identifies what variables are used in the functional assessment model and describes how they are aggregated in the model equation. Additional information about the transferability of functions and variables to different ecoregions can be found in section II.B.3.b.2 (Hydrogeomorphic Model Building Process). Detailed information about the variables can be found in section II.B.3.b.2 (Hydrogeomorphic Variables: Definitions, Rationale, and Scoring).
5. Subclass rigor – Identifies major differences in the assessment model when it is used in a different subclass. Helps the user to understand the importance of correct classification of the wetland for each model.

6. FCI graphs – Each function was calculated for reference wetlands across the state. The final Functional Capacity Index for each function is plotted against our disturbance score. Although there may not be a clear relationship with disturbance, we believe these graphs are valuable in characterizing the functional capacity of the wetlands in our reference collection for use as a comparison with new sites that may be evaluated.

SUMMARY OF FUNCTIONS FOR ISOLATED DEPRESSIONS

Hydrologic Functions

F1 – Energy Dissipation/Short term Surface Water Detention

Not applicable to Isolated Depressions

F2 – Long-term Surface Water Storage

Not applicable to Isolated Depressions

F3 – Maintain Characteristic Hydrology

$FCI = (V_{HYDROCHAR} * V_{HYDROSTRESS})^{1/2}$

F4 – Reserved for alternate hydrology function

Biogeochemical Functions

F5 – Removal of Imported Inorganic Nitrogen

$FCI = (V_{REDOX} + V_{BIOMASS} + V_{ORGMA})/3$

F6 – Solute Adsorption Capacity

$FCI = (V_{HYDROSTRESS}) * [(V_{ROUGH} + V_{REDOX} + V_{ORGM} + V_{TEX})/4$

F7 – Retention of Inorganic Particulates

$FCI = V_{UNOBSTRUC}$

F8 – Export of Organic Carbon (dissolved and particulate)

FCI = $V_{HYDROSTRESS} * (V_{REDOX} + V_{ORGM} + V_{FWD} + (V_{CWD\text{-}BA} + V_{CWD\text{-}SZ})/2) + V_{SNAGS})/5$

Biodiversity Functions

F9 – Maintain Characteristic Native Plant Community Composition

FCI = $[(V_{SPPCOMP} * 0.66 + V_{REGEN} * 0.33) + V_{EXOTIC}]/2$

F10 – Maintain Characteristic Detrital Biomass

FCI = $[(V_{CWD\text{-}BA} + V_{CWD\text{-}SIZE}/2) + V_{FWD} + V_{SNAGS} + V_{ORGMA}]/4$

F11 – Vertebrate Community Structure and Composition

Used HSI models

F12 – Maintain Landscape Scale Biodiversity

FCI = $(V_{AQCON} + V_{UNDEVEL} + V_{SDI} + V_{MFPS})/4$

FUNCTIONAL ASSESSMENT MODEL DESCRIPTIONS

Function 1: Energy Dissipation/Short-term Surface Water Storage

Not applicable to Isolated Depressions

Function 2. Long-term Surface Water Storage

Not applicable to Isolated Depressions

Function 3. Maintain Characteristic Hydrology

Definition and applicability

This function is a supplemental hydrologic function for subclasses not sufficiently covered by the preceding two functions. It assesses subclasses in which the dominant source of water is not flooding related. Sites are assessed by looking at indicators of human alteration of the natural hydrologic regime of the system. This function is assessed for the following regional wetland subclasses:

a. Slopes
b. Riparian Depressions
c. Isolated Depressions

Rationale for selecting the function

Hydrology is one of the defining characteristics of wetlands. However, when compared to wetlands that receive overbank flooding, the hydrology of groundwater and precipitation supported wetlands is very different. As a result, the hydrologic functions the wetlands perform also change. The best way to monitor the hydrology of these systems is through a more quantitative approach, such as the collection of monitoring well data. This is not practical, however, using the rapid assessment approach outlined here. This model uses the presence of hydrologic modifications as an indicator that the hydrologic regime has been somehow altered from reference standard conditions.

Characteristics and processes that influence the function

According to HGM classification methods, wetlands that are primarily supported by groundwater are grouped separately from those that receive water from overland flow (Brinson 1993). These types of wetlands are generally grouped in the depression and slope classes. In Pennsylvania, depression wetlands have been further split into Isolated Depressions and Riparian Depressions. Riparian depressions have a characteristic hydrology that is primarily supported by groundwater. The fact that Riparian Depressions are located in the riparian corridor and have an outlet to a stream separates them hydrologically from Isolated Depressions (Cole et al. 1997). Slopes are groundwater supported systems typically found on an elevational gradient, resulting in a mixture of vertical movement of ground water and horizontal movement of surface water through the system (Cole et al. 1997).

Groundwater flow wetlands are affected by human alterations occurring directly in or adjacent to the wetland and in the corresponding recharge area. Alterations such as ditches or drains, inputs from stormwater culverts, and addition of fill, have the direct effect of causing the wetland to be wetter or drier then what is characteristic of unaltered sites. Riparian Depression wetlands in Pennsylvania with moderate amounts of human disturbance were found to have greater median depth to water and a greater duration of wet conditions then pristine Riparian Depressions (Cole et al. 1997). In surrounding areas, activities that increase the rate or quantity of ground water used, such as irrigation, industrial uses, and uses for private homes may decrease overall levels of groundwater available for wetlands (Novitzki 1989).

Isolated Depressions, many of which are commonly referred to as vernal or temporary pools, are typically supplied by precipitation runoff from a relatively small contributing area. Some receive groundwater inputs, but at rates that do not require an outlet. They often occur in clusters of depressions with members displaying variable rates of drawdown depending on their area, depth and the mixture of precipitation and groundwater. Alterations such as ditches or drains, inputs from stormwater culverts, and addition of fill, have the direct effect of causing the wetland to be wetter or drier then what is characteristic of unaltered sites Alterations of surrounding, vegetated buffers by cutting and operating heavy equipment can change the amount and flow path of waters supporting these wetlands.

General form of the assessment model

The model for the assessing the maintenance of characteristic hydrology includes the following variables:

Isolated Depressions:

$V_{HYDROCHAR}$: represents characteristic hydrology of groundwater supported systems

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

The general form of the assessment model is:

Isolated Depressions:

$FCI = (V_{HYDROCHAR} * V_{HYDROSTRESS})^{1/2}$

This function is split into two components. The first $V_{HYDROCHAR}$ is representative of site characteristics that would indicate the hydrologic regime. At the time this model was developed, these extensive datasets to describe these characteristics were unavailable for the relevant subclasses. Therefore, the variable was left as a placeholder, to indicate that any available information could be used here. All sites are assumed to receive a score of one for this variable unless other information is available. A typical hydrograph is provided to help define the expected hydrologic regime of each subclass (Figure 1). Deviations from this expected pattern could be used to justify assignment of a score less then one. The second variable $V_{HYDROSTRESS}$ indicates modifications to the hydrology that would cause it to deviate from reference standard conditions. The geometric mean of the two variables is calculated with both variables contributing equally to the final score.

NOT YET AVAILABLE

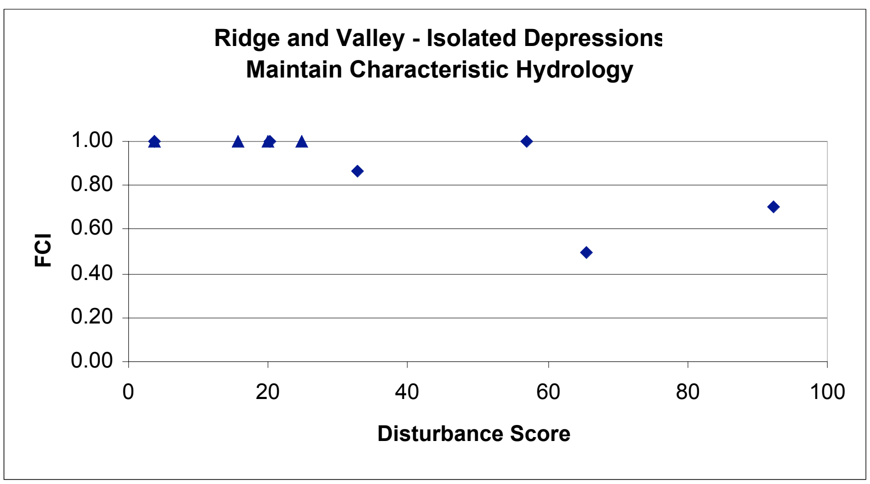
Figure 1. Typical hydrograph for HGM Wetland Subclass - Isolated depression.

Subclass rigor

This function is dependent on subclass classification since it should only be evaluated for non-riverine wetland types. Otherwise, variables that make up the function were calibrated independent of subclass.

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 2 shows the relationship between the functional capacity index and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 2. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 4. Reserved for alternative hydrology function

Function 5. Removal of Imported Inorganic Nitrogen

Definition and applicability

Removal of imported nitrogen is defined as the ability of a wetland to permanently remove inorganic nitrogen through chemical processes or temporarily sequester inorganic nitrogen through the plant community. The function is assessed for the following regional subclasses:

a. Headwater Floodplains
b. Mainstem Floodplains
c. Slopes
d. Riparian Depressions
e. Isolated Depressions
f. Fringing

The assessment of this function incorporates the three basic components of inorganic nitrogen removal. Permanent removal from the system is represented by the amount of organic matter in the soil and the anaerobic characteristics of the soil. Temporary removal from the system is indicated by the plant biomass at the site.

Rationale for selecting the function

Nitrogen is one of the largest non-point source pollutants of stream systems. Often, this nitrogen passes through wetlands before reaching the stream, so the ability of a wetland to remove nitrogen is extremely important to stream water quality. In many countries, agriculture is the biggest non-point source polluter, causing elevated levels of sediment, nutrients, and pesticides (Vought et al. 1994). While the application of fertilizer in general has increased since the 1960's, nitrogen fertilizers have by far been the element with the greatest increase (9 million metric tons) (Crumpton et al. 1993, Vought et al. 1994, Kadlec 2001). Studies show that as much as 50 - 90% of nitrogen fertilizer added to a cultivated crop is transported from the fields in runoff. (Crumpton et al. 1993, Seitzinger 1994). Wetlands play an important role in improving water quality due to their capacity to permanently and temporarily remove nitrogen. Denitrification is the primary process of long-term nitrogen removal from wetland systems

(Davidsson and Stahl 2000). In areas impacted by agriculture, denitrification may remove a significant amount of the nitrogen transported to wetland from fields, thus preventing its movement into streams (Groffman 1994). Research has shown a 90% or more reduction in NO_3^- concentrations in water as it flows through riparian areas (Gilliam 1994).

<u>Characteristics and processes that influence the function</u>

The three main controls on denitrification are: oxygen levels, carbon availability and NO^{2-} supply (Groffman 1994). The majority of inorganic N present in sediments is in the form of NH_4^+ (Bowden 1987). Microbes then transform NH_4^+ to NO_3^-, which is rapidly denitrified in anaerobic zones. Along with the absence of oxygen, a nitrogen pool must be present in the system, usually found in the organic layer. Organic matter is also important in providing a substrate necessary for microbes to perform the process of denitrification. Plant uptake is an additional means of nitrogen removal from the system. Marshes show evidence that nitrogen export is small compared to uptake and internal transformations (Bowden 1987). However, this is considered only temporary removal since the nitrogen taken up by plants will eventually return to the system through leaf litter and other vegetative sources of organic matter.

Anthropogenic impacts often lead to increases in nutrient inputs to nearby wetlands, thus, altering nutrient dynamics within the wetland. Nitrogen fertilizer, one of the more common nutrient inputs in an agricultural setting, enters wetlands through groundwater and surface water runoff (Schlesinger 1997). Vought *et al.* (1994) found that nitrogen transport from fields was primarily in the form of NO_3^- in subsurface flows, where removal occurs mainly via denitrification. Riparian forest retained 89% of total nitrogen inputs as compared to 8% for cropland, and the nitrogen loss from the forest was primarily via groundwater (Peterjohn and Correll 1984). Nitrate was an order of magnitude higher in streams draining agricultural watersheds compared to forested and wetland landscapes (Cronan et al. 1999). Riparian wetlands can retain large amounts of nitrogen originating in upland agricultural areas. Jordan *et al.*. (1993) found that riparian forests retained 70-90% of the total nitrogen inputs from adjacent croplands, most of which occurred within the first 20 m from the forest-field boundary.

Channelization is a common feature associated with human activity in and around wetlands. This feature may be evident as channels in the actual wetland, or as channels leading into the wetland from the upland. Channelization of wetlands increases annual stream flow yields of nitrogen (Cooper et al. 1986). The channels funnel water rather than spreading it across the wetland (Brown 1988). Channelization also decreases the sinuosity of the river and increases channel gradient, which results in sharper pulses in flow (Brinson 1990). These impacts reduce the frequency and duration of water contact with the wetland soil, which leads to a decrease in opportunity for the wetland to remove nitrogen originating in the upland and an increase in nitrogen entering the stream.

General form of the assessment model

The model for assessing the export of imported inorganic nitrogen includes the following variables:

Isolated Depressions:

V_{REDOX}: presence of redoximorphic features in the upper soil profile
$V_{BIOMASS}$: estimate of amount of plant biomass
V_{ORGMA}: amount of organic matter in the upper soil profile

The general form of the assessment model is:

Isolated Depressions:

$FCI = (V_{REDOX} + V_{ORGMA} + V_{BIOMASS})/3$

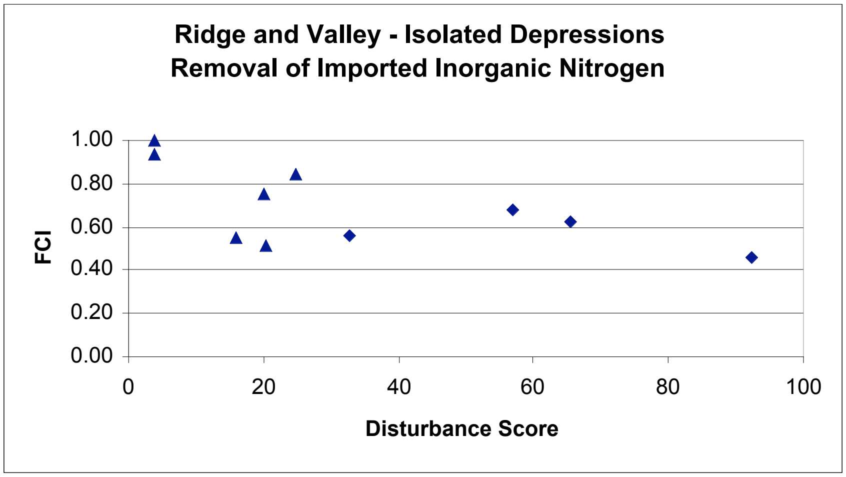
The variables included in this equation estimate the controlling factors for the dominant removal mechanisms. $V_{BIOMASS}$ estimates vegetative uptake of nitrogen, and V_{ORGM} and V_{REDOX} represent conditions that affect denitrification rates. However, the V_{REDOX} variable does not correlate to disturbance so there are no clear relationships to test our ability to accurately measure this variable. At present, there is no evidence that one removal mechanism is more important than the other. Thus, the variables are given equal weight in this equation. Additional information in the future may suggest that one removal mechanism dominates under different conditions, warranting a reconsideration of the equation.

Subclass rigor

This function is assessed for all subclasses using the same function equation for each. The variable $V_{BIOMASS}$ was calibrated based on reference standard conditions, so that sites with the least alteration received the highest scores. For Isolated Depressions, V_{ORGMA} was scored based on reference standard conditions. This method is different than the method used for other subclasses. In Isolated depressions there was an apparent relationship between disturbance and the % organic matter at a site that was not present for other subclasses, therefore it was scored continuously as opposed to categorically. The method of scoring individual variables is discussed futher in Hydrogeomorphic Variables: Definitions, Rationale, and Scoring and the general methods of calibration are discussed further in The Model Building Process. V_{REDOX} showed no relationship with disturbance, and was scored categorically. This variable was calibrated based on conditions that result in higher level of function and is scored the same regardless of subclass. Since two of the three variables that make up this function are specific to subclass, it is important that misclassification errors are avoided when assessing a site for the removal of imported Nitrogen.

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 3 shows the relationship between the functional capacity index and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 3. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 6. Solute Adsorption Capacity

Definition and applicability

This function evaluates the ability of a wetland to permanently remove and temporarily immobilize elements, such as phosphorus, metals, and other imported elements and compounds. Metals include lead, zinc, chromium, etc. Compounds include herbicides, pesticides, etc. Nitrogen, which is considered in Function 5, is not included in this function. Mechanisms for retention include burial, adsorption, sedimentation, vegetation and microbial uptake, and precipitation. This function is assessed for the following regional wetland subclasses:

a. Headwater Floodplains
b. Mainstem Floodplains
c. Riparian Depressions
d. Slopes
e. Isolated Depressions

The procedure for assessing this function is slightly different among subclasses, although all models contain similar fundamental components. The model is split into two components, indicators of changes in hydrology and characteristics that represent water retention at the site allowing the adsorption of solutes to take place. It is in the first component that variables differ among subclasses due to the fact that the hydrology of subclasses is fundamentally different.

Rationale for selecting the function

As pollution due to urbanization and agriculture increases, ponds, lakes and rivers begin experiencing a decrease in water quality. Wetland systems often act as buffers to these water sources due to their ability to filter out contaminants. In many countries, agriculture is the biggest non-point source polluter, elevating levels of pesticides, herbicides and nutrients (Vought et al. 1994). Concentrations of Ca, Mg, NO_3, Cl, SO_4, and suspended solid were up to 1 order of magnitude higher in streams draining agricultural areas compared to forested or wetland areas (Cronan et al. 1999). Phosphorus loads tend to increase with increasing disturbance, with the greatest loading associated with agriculture (Soranno et al. 1996). Riparian areas can remove significant amounts of imported phosphorus. For example, in a floodplain wetland in Sweden, 95% of phosphorus entering the wetland in surface runoff was removed within 16 m (Vought et al. 1994). In North Carolina, approximately 50% of the phosphorus leaving agricultural fields in runoff was removed in riparian areas (Cooper and Gilliam 1987).

Characteristics and processes that influence the function

The primary removal mechanisms for metal and phosphorus are the settling of particles out of the water column and adsorption to organic matter and clay. Phosphorus and metal removal in wetlands is controlled by several factors: adsorption to soil organic matter (SOM) and clay particles, complexation with Fe and Al, adsorption with Fe and Al, vegetation and microbial uptake. Biological uptake of phosphorus and metals is considerably smaller than the other removal mechanisms, and is relatively short-term. Chemical properties, such as pH and redox potential, greatly influence metal and phosphorus retention (Gambrell 1994, Reddy et al. 1998).

Wetlands are usually sinks for metals via three primary mechanisms: 1) precipitation of insoluble salts, 2) sorption of metal ions, and 3) vegetation uptake (Johnston et al. 1990). Detention and transformation of elements depends on SOM content, clay content and type, soil pH, and roughness (Scott et al. 1990). Chemical properties affecting metal retention include the redox potential, pH, SOM, salinity, and Al, Fe, Mn oxide concentrations (Gambrell 1994).

Phosphorus retention is influenced by plant and microbial uptake, sorption to soil particles, sedimentation (sediment-bound phosphorus), and precipitation in the water column with Ca, Al, Fe (Reddy et al. 1999). There is a dominance of geochemical sorption reactions on phosphorus, and unlike nitrogen removal, long-term phosphorus retention is predominantly geochemical rather than biological (Walbridge and Struthers 1993, Bridgham et al. 2001). Long-term removal can be through roots, buried leaves, and sediment deposition (Richardson and Craft 1993). Finer soil particles carry more phosphorus than larger particles, and slower water movement will increase particulate phosphorus settling to the soil surface (Reddy et al. 1999, Mitsch and Gosselink 2000).

The phosphorus removal ability of wetlands is assumed finite (Cooper and Gilliam 1987). After 25 years of receiving sewage effluent, a wetland in Michigan was considered phosphorus saturated (Kadlec and Bevis 1990). In contrast, phosphorus removal in an 11-year-old wastewater treatment wetland was 96%, occurring mainly via burial (Kadlec and Alvord 1989). Part of the ability to retain phosphorus is dependent upon fresh sediment entering the system.

The role of incoming sediment is two-fold; deposition of sediment-bound phosphorus and deposition of fresh soil particles to bind with dissolved phosphorus (Cooper and Gilliam 1987). A large amount of the phosphorus entering and being retained in wetlands is particle-bound. More than 70% of agricultural phosphorus export is particle-bound (Vought et al. 1994). Detenbeck et al. (1993) found that much of the phosphorus transport from urban areas, as well as agricultural areas, is associated with fine particles. As a result, phosphorus retention in wetlands should increase with increasing retention time, as the settling of finer particles increases (Detenbeck et al. 1993). While the residence time in a wetland may be adequate to promote the settling of sediment, much longer times are needed for dissolved elements to settle out of the water column. The residence time of water in an urban-placed riparian depression in Minnesota was sufficient to remove 50% of the sediment-bound phosphorus, but was too short for dissolved phosphorus to be deposited (Brown 1985).

Channelization negatively impacts the ability of wetlands to remove phosphorus by funneling water rather than spreading it across the wetland. Channelization increases loading and runoff, while also decreasing load retention, resulting in increased flow yields of phosphorus into receiving waters(Cooper et al. 1986, Brown 1988).

There is not much information available on metals and other contaminants associated with disturbance, but it is likely that metal, pesticide, and herbicide levels increase with disturbance. All three are likely associated with nearby urban development. Pesticides and herbicides are also likely to be associated with agricultural production in the surrounding watershed.

General form of the assessment model

The model for assessing the solute adsorption capacity of a wetland includes the following variables:

Isolated Depressions:

$V_{HYDROSTRESS}$: indicators of hydrologic modifications at the site

V_{ROUGH}: composite score based on coarse woody debris, microtopography and vegetation

V_{REDOX}: presence of redoximorphic features in the upper soil profile

V_{MACRO}: presence of macrotopographic depressions

V_{ORGMA}: amount of organic matter in the upper soil profile
V_{TEX}: soil texture

The general form of the assessment model is:

Isolated Depressions:
FCI = $(V_{HYDROSTRESS}) * [(V_{ROUGH}+V_{REDOX}+V_{ORGMA}+V_{TEX})]/4$

The assessment models for this function have been split into two primary components representative of alterations to the natural hydrology at the site and residence time of water at the site and soil characteristics. The first component is representative of changes to the hydrologic regime due to human alterations in the system. This hydrologic variable is used as a controlling factor in the Isolated Depression model and is multiplied with the second component.

The second component of each model is representative of variables that indicate the residence time of water at a site and soil characteristics. V_{ROUGH} represents soil characteristics that slow the rate of water moving through the system, therefore, increasing contact time between the soil and water. The variable V_{REDOX} denotes the level of soil saturation, indicating the duration that water and the soil surface are actually in contact with each other, allowing the adsorption of solutes to actually take place. The final variables of the model, V_{TEX} and $V_{ORGM,}$ take into account soil characteristics that promote the adsorption of solutes. V_{ROUGH}, V_{REDOX},V_{TEX} and V_{ORGMA} contribute equally to the level of function and are combined by taking the arithmetic mean.

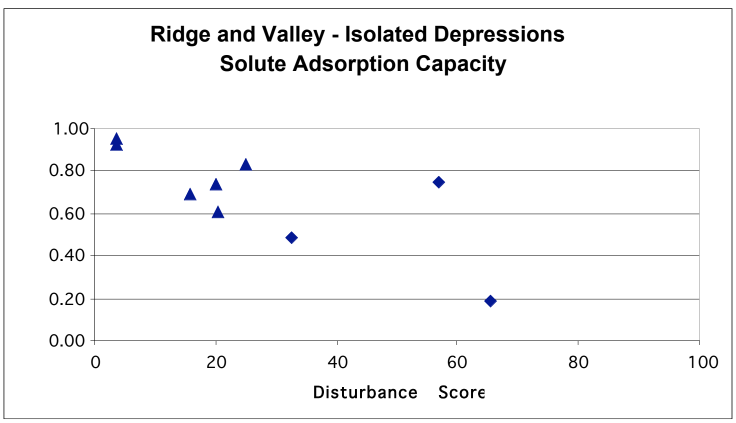
<u>Subclass rigor</u>

The variables and model equations for this function differ depending on the specific subclass. Therefore, proper classification of the wetland is of great importance so that appropriate data can be collected to assess the relevant variables.

Three variables, $V_{HYDROSTRESS}$, V_{REDOX}, and V_{TEX} were calibrated on a categorical basis, with scores given to values that helped the wetland to perform the function at a high level instead of at reference standard conditions. This was due to a poor relationship with disturbance. The variables that did show a response to disturbance were V_{ROUGH} and V_{ORGM}. These were calibrated based on the reference standard conditions of each subclass.

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 4 shows the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 4. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 7. Retention of Inorganic Particulates

Definition and applicability

The retention of inorganic particulates function evaluates the ability of wetlands to remove imported mineral sediments from the water column and prevent them from being carried out of the wetland. This function is assessed for the following regional wetland subclasses:

a. Headwater Floodplains
b. Mainstem Floodplains
c. Slopes
d. Isolated Depressions
e. Fringing

Isolated Depressions differ from other subclasses due to the fact that they are a closed system. Therefore, it is unlikely that sediments entering the system will leave the system. The assessment procedure for this function reflects this by representing sources of sediment that could be detrimental to the natural equilibrium present in these closed systems.

Rationale for selecting the function

Isolated Depression wetlands naturally retain sediments due to the fact that they are closed systems with no outlets. Sediment that enters these systems is primarily from surface runoff from neighboring areas. Some amount of sediment is expected to collect, however, when surrounding land use is altered sources of sediment may increase to a point where the system can no longer maintain a natural equilibrium. This function uses modifications to the surrounding landscape and on-site conditions to indicate changes that could potentially increase the sediment load.

Characteristics and processes that influence the function

The predominant delivery mechanism for sediment to wetlands is the flow of water. The source of this water, its direction and magnitude of velocity, and its residence time in the wetland are the primary determinants of sediment deposition in a wetland. The ability of flowing water to transport sediment is dependent upon both the water velocity and the size of the particles being transported (Johnston 1991, Wardrop and Brooks 1998). An increase in the retention time of water in a wetland increases sediment accumulation (Joensuu 1997). Wetlands are known to trap sediment in pristine settings, but accelerated sedimentation can quickly overwhelm the capacity of the wetland to store and process the sediments (Jurik et al. 1994, Wardrop and Brooks 1998, Freeland et al. 1999).

Usually, waterborne sediments flow from the watershed during spring runoff (i.e., periods of high water levels) and spread out across the wetland (Johnston 1993a). The majority of suspended sediment transport may occur during a few, high magnitude events (Heimann and Roell 2000). Storage capacity is an important consideration in evaluating sediment retention (Phillips 1989) and is dependent upon the loading rate and size of the wetland.

Sedimentation alters many wetland characteristics and processes. High sedimentation rates decrease the germination of many wetland plant species by eliminating light penetration to seeds, lower plant productivity by creating stressful conditions, and slows decomposition rates by burying plant material (Jurik et al. 1994, Vargo et al. 1998, Wardrop and Brooks 1998). Sedimentation may also interfere with microbial immobilization (Vargo et al. 1998). Excess turbidity caused by high levels of suspended sediment decreases oxygen levels and photosynthesis rates, impairs the respiration and feeding of aquatic organisms, destroys fish habitat, and kills benthic organisms (Johnston 1993b). Deposition of mineral sediments increases the surface elevation and alters topographic complexity of wetlands, which has hydrologic, biogeochemical, and habitat implications (Ainslie et al. 1999).

Sediment deposition alters the texture of the soil surface. Erosion of sediment from the adjacent upland has often been found to increase the clay content of wetland surface soils (Jones and Smock 1991, Hupp et al. 1993, Axt and Walbridge 1999). Clay particles remain in suspension longest and thus tend to be deposited in floodplains (Jones and Smock 1991, Kleiss 1996). This increase in clay content affects other soil properties, such as the accumulation of Al and Fe (Jones and Smock 1991). This subsequently affects other properties, such as increasing the ability of the wetland to function as a sink for phosphorus (Cooper and Gilliam 1987).

Disturbances impact the sediment loading and retention of wetlands. Hupp et al. (1993) found sedimentation rates to be highest in wetlands located downstream from agricultural and urban areas. Since the onset of agricultural development, a mainstem floodplain swamp in Arkansas has been filling in at an accelerated rate of more than 1 cm yr^{-1} (Kleiss 1996). Accelerated filling may result in premature vegetation changes, decreased floodwater storage capacity, and/or alterations in stream channel migration (Kleiss 1996). Phillips (1989) found that between 14 and 58% of eroded upland sediment is stored in alluvial wetlands and other aquatic environments. As much as 90% of eroded agricultural soil was retained in a forested floodplain in North Carolina (Gilliam 1994). Eighty-eight percent of the sediment leaving agricultural fields over the last 20 years was retained in the watershed of a North Carolina swamp (Cooper et al. 1986). Approximately 80% of this was retained in riparian areas above the swamp and 22% was retained in the swamp itself.

General form of the assessment model

The model for assessing the retention of inorganic particulates in Isolated Depressions includes the following variable:

Isolated Depressions:

$V_{UNOBSTRUC}$: average of the following three variable subindices

V_{RDDENS}: index of road density in a 1km circle surrounding site

V_{URB}: % of 1km radius circle in urban development

$V_{HYDROSTRESS}$: indicators of hydrologic modification at the site

Isolated Depressions:

$FCI = V_{UNOBSTRUC}$

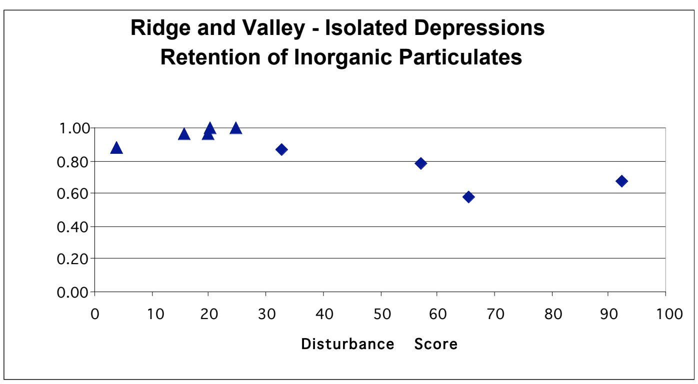
The assessment model for this function contains one variable, $V_{UNOBSTRUC}$. $V_{UNOBSTRUC}$ is a variable composed of the three components: the presence of roads in a 1-km radius circle around the site, the percent urban land use in a 1-km radius circle around the site and on site modifications to the hydrology. Each of these subvariables represents changes to the surrounding land use or to the site that could potentially increase the amount of sediment imported into the wetland.

Subclass rigor

This function is class specific, primarily due to the fact the functional equation differs greatly among subclasses. For Isolated Depressions, this function implies negative changes that can occur when sediments are retained in the system, while for other subclasses the function is looking at sediment retention as a positive influence on downstream areas.

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 5 shows the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 5. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 8. Export of Organic Carbon (Dissolved and Particulate)

Does not apply to Isolated Depressions

Function 9. Maintain Characteristic Native Plant Community Composition (and structure)

Definition and applicability

This function is defined as the ability of a wetland to support native plant species while taking into consideration the presence of invasive species (defined as exotics and native aggressive species). Due to the rapid assessment approach used in the HGM approach, the function looks at the extant plant community as an indicator of a site's ability to maintain characteristic conditions. Since Pennsylvania is historically in a forested region, regeneration of native woody species is used as an indicator of the ability to maintain or develop a characteristic forested plant community.

Characteristic plant community structure is defined as the physical structure of the plant community as it pertains to habitat for wildlife. This includes the presence or absence of three strata: herb, shrub and tree layers. However, plant community structure is difficult to assess independently of plant composition. Therefore, plant community structure has not been included as a direct measure in the function model, but as a modifier to be subtracted from the final score. These deductions should be based on the stressor checklist, and on comparisons of site structural data for each layer, (see appendix for deduction amounts). This function is assessed for the following regional wetland subclasses:

a. Headwater Floodplain
b. Mainstem Floodplain
c. Slopes
d. Riparian Depression
e. Isolated Depression
f. Fringing

The procedure for assessing this function incorporates three characteristics that define the state of the plant community. Species composition and percent invasives represent the quality of the present plant community. Regeneration of the forest community provides an indication that the site is moving toward or maintaining conditions typical of reference standard sites.

Rationale for selecting the function

The structure and composition of vascular plant communities have long been used to characterize wetlands (Cowardin et al. 1979, Mitsch and Gosselink 2000). Plant community composition and structure influences many ecosystem properties, such as primary productivity, nutrient cycling and hydrology (Hobbie 1992, Ainslie et al. 1999). Plant species composition plays an important role in determining soil fertility (Wedin and Tilman 1990, Hobbie 1992). Individual plant species effects on ecosystem fertility can be as or more important than abiotic factors, such as climate (Hobbie 1992). Resource uptake and allocation differs between species, as does tissue quality, and differences in litter quality affects nutrient cycling (Wedin and Tilman 1990, Hobbie 1992). 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). The maintenance of a characteristic plant community can also be related to other HGM functions such as: energy dissipation via roughness, detrital production and nutrient cycling, and biodiversity and habitat functions.

Characteristics and processes that influence the function

Plant communities are highly influenced by human disturbance due to the fact that human alterations generally act as a means of establishment for invasive and aggressive species. Invasive species change competitive interactions, which result in changes in species composition (Walker and Smith 1997, Woods 1997). These changes in species composition often lead to changes in mineral and hydrologic cycling (Woods 1997). Impacts of invasive species include: simple competitive replacement of one or a few native species to the loss of an entire plant guild, modification of one stratum, and a change in plant community structure (Woods 1997). Very little information is available regarding the rates and spatial patterns of species invasion and spread (Higgins et al. 1996). However, it is generally accepted that disturbed sites, both natural and anthropogenic, are more easily invaded (Elton 1958, Mooney and Drake 1986, Huenneke et al. 1990, Burke and Grime 1996). The susceptibility of an indigenous community to invasive species is strongly related to the availability of bare ground and increased fertility (Burke and Grime 1996).

General form of the assessment model

The model for assessing the maintenance of a native plant community includes the following variables:

Isolated Depressions:
$V_{SPPCOMP}$: Adjusted Floristic Quality Assessment Index (FQAI)
V_{REGEN}: regeneration of native tree species
V_{EXOTIC}: percent exotic species

The general form of the assessment model is:

Isolated Depressions:
$FCI = [(V_{SPPCOMP} * 0.66 + V_{REGEN} * 0.33) + V_{EXOTIC}]/2$

To evaluate this function, three metrics that indicate the present state of the plant community, $V_{SPPCOMP}$, V_{REGEN}, and V_{EXOTIC} have been selected. All three variables were calibrated based on characteristic conditions at reference standard sites. In this equation, $V_{SPPCOMP}$ and V_{REGEN} are first considered together in a cumulative interaction. These two components represent the plant community at the present time as well as what the potential canopy tree community may be in the future. $V_{SPPCOMP}$ was weighted more heavily then V_{REGEN} since present conditions at the site are more reliable and relevant than what conditions may be like if the site remains undisturbed. Also, V_{REGEN} only indicates the canopy tree community while $V_{SPPCOMP}$ considers the entire plant community. The variable V_{EXOTIC} is then assumed to be contributing equally and independently to the outcome of the function. The arithmetic mean of the two terms is then calculated to avoid a score of zero if invasive species cover exceeds 50%.

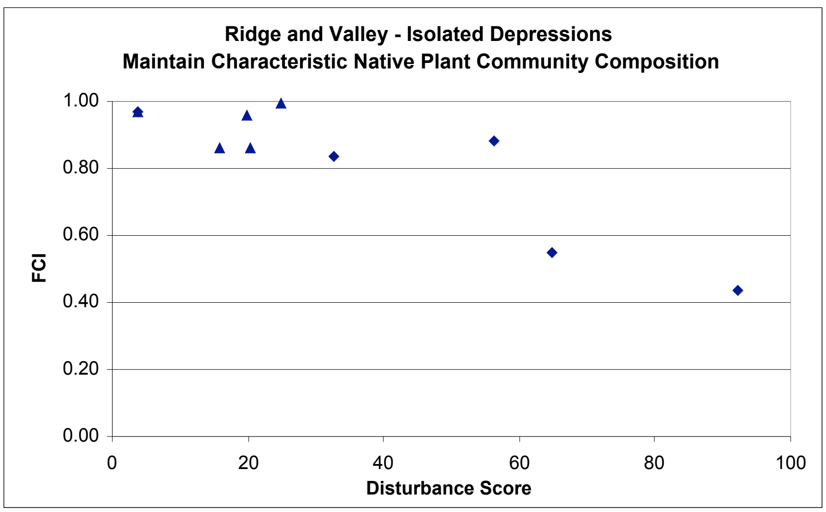
Subclass rigor

This function is assessed for all HGM subclasses, except Fringing sites, using the same function equation. All three variables were calibrated based on reference standard conditions. V_{REGEN} and $V_{SPPCOMP}$ are both scored on reference standard conditions specific to subclass.

V_{EXOTIC} is based on thresholds of % non-native species and is independent of subclass type. Since the majority of variables are scored based on subclass, the classification of the wetland becomes relevant when assessing a site

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 6 shows the relationship between the functional capacity index (FCI) and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 6. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 10. Maintain Characteristic Detrital Biomass

Definition and applicability

Detrital biomass is an important component of wetland ecosystems. It plays a role in nutrient cycling as well as providing habitat and substrate for plant and animal communities. Detrital biomass is represented by snags, down and dead woody debris, organic debris on the forest floor, and organic components of mineral soil, as described in the national riverine model (Brinson et al. 1995). This function compares the amount of detrital biomass present at a site, relative to the reference standard detrital biomass stocks. This model assumes, as did the national riverine model, that detritus standing stocks are proportional to detritus turnover, and can therefore be used to substitute for turnover (Brinson et al. 1995). This function is assessed for the following regional wetland subclasses:

a. Headwater Floodplain
b. Mainstem Floodplain
c. Slopes
d. Riparian Depression
e. Isolated Depressions
f. Fringing

Rationale for selecting the function

For this function, detritus is considered an indicator of the potential decomposition and nutrient cycling rates at a site. Decomposition is a process supplied by the available pool of detrital biomass. Dead wood present at a site is processed into fine particulate organic matter (FPOM) and then further processed and incorporated into organic matter (Bilby and Likens 1979, Jones and Smock 1991). At the same time, these pieces of dead wood provide habitat for numerous invertebrate and vertebrate species. The organic matter derived from vegetation becomes part of the soil matrix and serves two major roles. The first is to provide a substrate for microorganisms that further decompose vegetation and facilitate important nutrient cycling processes such as denitrification. Studies show that organic soil has much greater NO_3^- removal capacity than sandy soils (Davidsson and Stahl 2000). Further, NO_3^- consumption is positively correlated to SOM content (Davidsson and Stahl 2000). Second, organic matter in the soil acts as a growth medium, facilitating regeneration of trees, shrubs and herbaceous plants, which will eventually die and begin the decomposition cycle again. Detritus is important for the maintenance of wetland fertility via decomposition of plant material. Overall, detritus acts as a nutritional substrate, provides habitat for microorganisms, invertebrates, and vertebrates, is a nursery for tree seedlings, and serves as a long-term consistent source of organic material and nutrients (Harmon et al. 1986, Brown 1990, Taylor et al. 1990). For this function, we have focused on the amount of detrital biomass present in the forms of coarse woody debris, dead standing wood, leaf litter, and soil organic matter at a site.

Characteristics and processes that influence the function

Decomposition processes include leaching of soluble material, mechanical fragmentation, and biological decay (Taylor et al. 1990). Decomposition rates are a function of electron-acceptor availability, chemistry of the organic substrate, and the environment (pH, temp, nutrients) (Reddy and D'Angelo 1994). The rate of decomposition depends on soil moisture levels; optimum conditions for decomposition are aerobic with adequate moisture (Brinson et al. 1981, Taylor et al. 1990). Aerobic decomposition is faster and yields more energy than anaerobic decomposition (Brinson et al. 1981, Reddy and D'Angelo 1994). Bilby et al. (1999) found that wood decays at a faster rate when periodically wetted and dried, conditions typical of many wetlands, as compared to fully submerged or terrestrial conditions. Decomposition is generally faster in aquatic than terrestrial landscapes due to increased leaching, fragmentation and microbial activity (Shure et al. 1986). Large pieces of CWD are processed into fine particulate organic matter (FPOM) and then further processed and incorporated into organic matter (Bilby and Likens 1979, Jones and Smock 1991). Organic material may be transported to channels or respired as CO_2 at any stage of the decomposition process (Bilby and Likens 1979, Jones and Smock 1991). Model calculations by Morris and Bowden (1986) found that the greatest change in nutrients occurred in the top 2 cm of soil and observed data showed that organic matter decomposition was faster in the top 5 cm than deeper in the soil. To estimate the potential for nutrient cycling to occur at a site, presence of biomass in each of the variable categories was determined and then either compared to sites with low human alteration or conditions which support high levels of functioning, to determine conditions suitable for nutrient turnover.

General form of the assessment model

The model for assessing the maintenance of characteristic detrital biomass includes the following variables:

Isolated Depressions:

V_{CWD-BA}: estimate of area covered by CWD

$V_{CWD-SIZE}$: presence of CWD in each of three size classes

V_{FWD}: amount of fine woody debris present as fallen leaves and downed twigs <1 cm.

V_{SNAGS}: density of dead standing trees by diameter size class

V_{ORGMA}: amount of organic matter in the top 5cm of the soil

The general form of the assessment model for Isolated Depressions is:

$$FCI = [(V_{CWD-BA} + V_{CWD-SIZE}/2) + V_{FWD} + V_{SNAGS} + V_{ORGMA}]/4$$

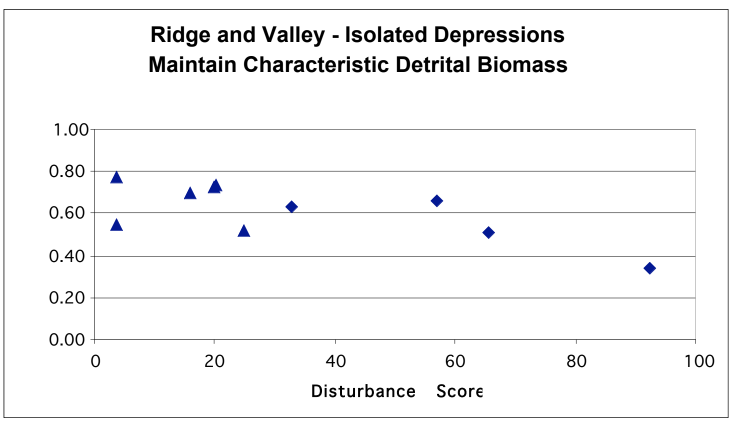
To evaluate this function, four metrics have been selected that indicate the present amounts of detrital biomass: coarse woody debris, dead standing wood, leaf litter, and soil organic matter. We believe that each of these variables represents a different level of decomposition present at the site. In this equation, CWD was split into two categories abundance and size. The arithmetic mean of these two components was taken since each contributes equally to the overall representation of CWD. This CWD expression was then averaged with V_{FWD}, V_{SNAGS}, and V_{ORGMA}. Due to the cyclic nature of decomposition and the fact that each of these variables represents a part of that cycle, each variable is considered equally and independently by calculating the arithmetic mean

<u>Subclass rigor</u>

This function was assessed for all HGM subclasses using the same function equation. Scoring of the variables was the same for all subclasses except for V_{CWD-BA} and V_{ORGMA}. V_{CWD-BA} and V_{ORGMA} are calibrated based on conditions at reference standard sites specific to each HGM subclass. The remaining variables are scored categorically, independent of subclass type, with higher scores given to values that helped the wetland to perform the function at an optimum level.

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 7 shows the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 7. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 11. Vertebrate Community Structure and Composition

Definition and applicability

This function is assessed for the following regional wetland subclasses:

a. Headwater Floodplains
b. Mainstem Floodplains
c. Slopes
d. Riparian Depressions
e. Isolated Depressions
f. Fringing

Rationale for selecting the function

The provision of wildlife habitat is an often cited function of wetlands. Yet, we seldom have resources to census a diverse wildlife community. A commonly used alternative is to assess potential wildlife use with Habitat Suitability Index (HSI) models (USFWS 1980, Morrison et al. 1992, Anderson and Gutzwiller 1994). Thus, for this function, we adopted HSI models as a means to estimate the level of wetland functioning as wildlife habitat.

From the available pool of "blue book" models developed by the U.S. Fish and Wildlife Service (1980) and similar regional adaptations, such as the Pennsylvania Modified Habitat Procedures (Pennsylvania Game Commission 1982), we selected models for common species whose habitat preferences span both the vegetative and hydrologic gradients found in inland, freshwater wetlands typical of the northeastern U.S. We used a standard set of 10 wildlife species to construct a Wildlife Community Habitat Profile (WCHP), that included bullfrog *(Rana catesbeiana)*, muskrat *(Ondatra zibethicus)*, meadow vole *(Microtus pennsylvanicus)*, red-winged blackbird *(Agelaius phoeniceus)*, American woodcock *(Philohela minor)*, common yellowthroat *(Geothlypis thrichas)*, green-backed heron *(Butorides striatus)*, wood duck *(Aix sponsa)*, wood frog *(Rana sylvatica)*, and red-backed vole *(Clethriononmys gapperi)*.

The advantages of using the WCHP method include: 1) selection of species models no longer has to be tailored to each site; 2) comparisons among sites are consistent across the same set of species; 3) visual representation of the wildlife community is produced for each site, and 4) the vegetative diversity inherent in most wetlands is accounted for by using this diverse set of models.

Characteristics and processes that influence the function

Variables and calibration procedures for this function were conducted independently from the process used for the other functions. The process used is described in the HGM Model Building module (II.B.3.b.2). The actual models used, originally produced by Brooks and Prosser (1995), are presented as part of the section on sampling protocols (II.B.3.a.).

General form of the assessment model

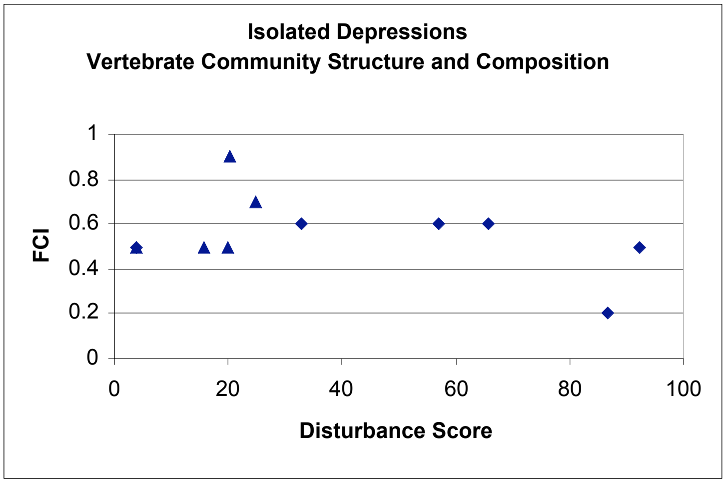
The FCI scores for this function are calculated by using scores from Habitat Suitability Index (HSI) Models calculated for 10 common wetland species. (Brooks and Prosser 1995). FCI scores are based on HSI model scores at reference standard sites across subclasses and the amount of deviation from these reference standard conditions. The actual method for calculating FCI scores is discussed further in The Model Building Process.

Subclass rigor

HSI models and FCI scores are calculated identically across HGM subclasses. Therefore, this function is rigorous to misclassification issues.

Figure 8 shows the relationship between the functional capacity index (FCI) and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 8. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

Function 12. Maintain Landscape Scale Biodiversity

<u>Definition and applicability</u>

This function is assessed for the following regional wetland subclasses:

a. Headwater Floodplains
b. Mainstem Floodplains
c. Slopes
d. Riparian Depressions
e. Isolated Depressions
f. Fringing

<u>Rationale for selecting the function</u>

The strong influence of the surrounding landscape on a wetland's ability to perform a function has become increasingly evident (e.g., Gibbs 1993, Wardrop and Brooks 1998, O'Connell et al. 2000). To capture this factor, all variables for this function were based on measurements taken in a 1-km radius circle centered on each reference wetland. We have found that that distance incorporates stressors occurring in the landscape, but does not extend beyond the geomorphic setting for most wetland types in the ecoregions of Pennsylvania.

In the eastern U.S., we consider forested land cover to be the reference condition for most types of freshwater wetlands (e.g., Brooks et al. 2004). One way to characterize the extent of forest in the landscape matrix is by mean forest patch size (Forman 1995), so we used a variable derived from the forest patches within the circle. Connectivity among aquatic habitats has been shown to affect both faunal (e.g., Gibbs 1993) and floral communities, so we combined the best available synoptic data to construct that variable; 100-year floodplain, stream density, and nearest wetland. Similarly, urban development typically has negative impacts of aquatic communities (e.g., Karr and Chu). We represented that stressor with variables that characterize the proportion of urban land and road density. F12 integrates multiple stressors that potentially affect the way a wetland performs many of its functions.

General form of the assessment model

The model for assessing the maintenance of landscape scale biodiversity includes the following variables:

Isolated Depressions:

V_{AQCON}: degree of aquatic connectivity in a 1-km radius circle surrounding site. Composed of a combination of three indices: presence in 100-year floodplain, stream density index, and distance to nearest NWI wetland.

$V_{UNDEVEL}$: landscape variable made up of the average of two sub-variables:

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

V_{URB} - % of 1-km radius circle in urban development

V_{SDI}: natural log of the Shannon diversity index of eight landscape categories in the a 1-km radius circle around the site

V_{MFPS}: mean forested patch size within a 1-km radius circle

The general form of the assessment model is:

Isolated Depressions

$FCI = (V_{AQCON} + V_{UNDEVEL} + V_{SDI} + V_{MFPS})/4$

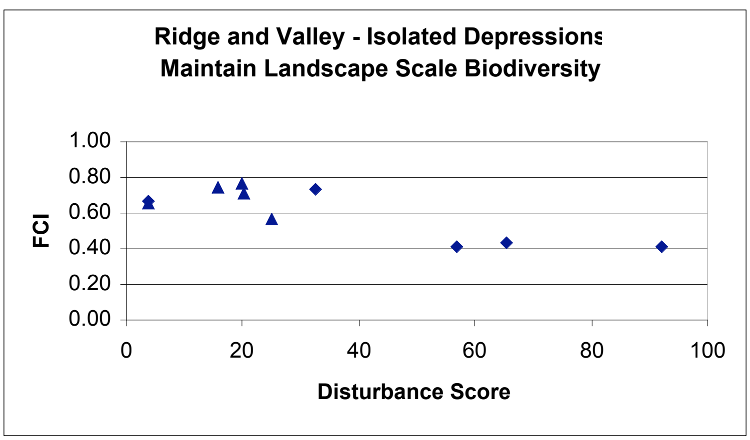
To evaluate this function, variables were chosen that represent the condition surrounding a wetland at a landscape scale. All indicators were based on measurements taken in a 1-km radius circle surrounding the site. Two of the variables, V_{AQCON} and $V_{UNDEVEL,}$ were composites of other indicators in the 1-km radius circle. All variables were considered to contribute equally to the function and the arithmetic mean was taken. Although F12 is not identical to the human disturbance score generated for each wetland, it contains similar elements. For example, both values will score higher when the landscape circle contains more forest. Thus, when examining the figures, it is important to realize that we expect to see some correlation between the two scores because they represent different ways to express the condition of the landscape.

Subclass rigor

This function is assessed for all HGM subclasses using the same function equation. All variables were calibrated based on reference standard conditions. Each variable also has the same scoring criteria, regardless of HGM subclass. Therefore, this function is very robust to misclassification issues.

The ability of a function to reflect disturbance is directly related to the ability of the individual variables to predict disturbance, which depends on the method of calibration used for each variable. The different methods of variable calibration and details on individual variable scores are discussed in section II.B.3.b.2. (Hydrogeomorphic Model Building Process). Figure 8 shows the relationship between the functional capacity index (FCI) and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance.

Figure 8. Relationship of Isolated Depression FCI and disturbance.



_ = Reference Standard Sites

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