Hydrogeomorphic Functional Assessment Models – Headwater Floodplains

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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.3 (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 HEADWATER FLOODPLAINS

Hydrologic Functions

F1 – Energy Dissipation/Short term Surface Water Detention

FCI = $(V_{FLOODP} * 0.67 + V_{UNOBSTRUC} * 0.33) * (V_{GRAD} + V_{ROUGH})/2$

F2 – Long-term Surface Water Storage

FCI = $(V_{FLOODP} * 0.67 + V_{UNOBSTRUC} * 0.33) * (V_{MACRO} + V_{REDOX})/2$

F3 – Maintain Characteristic Hydrology

Not applicable to Headwater Floodplains

F4 – Reserved for alternative hydrology function

Biogeochemical Functions

F5 – Removal of Imported Inorganic Nitrogen

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

F6 – Solute Adsorption Capacity

FCI = $(V_{FLOODP} * 0.67 + V_{UNOBSTRUC} * 0.33) * [(V_{ROUGH} + V_{REDOX} + V_{MACRO})/3 + (V_{ORGM}+V_{TEX})/2]/2$

F7 – Retention of Inorganic Particulates

FCI = $(V_{FLOODP} * 0.67 + V_{UNOBSTRUC} * 0.33) * (V_{ROUGH} + V_{MACRO} + V_{GRAD})/3$

F8 – Export of Organic Carbon (dissolved and particulate)

FCI = $(V_{FLOODP} * 0.67 + V_{UNOBSTRUC}\ 0.33) * (V_{MACRO} + V_{REDOX} + V_{ORGM} + V_{FWD} + ((V_{CWD\text{-}BA} + V_{CWD\text{-}SZ})/2) + V_{SNAGS})/6$

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

FUNCTIONAL ASSESSMENT MODEL DESCRIPTIONS

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

Definition and applicability

This function refers to the ability of the floodplain to reduce floodwater velocity and the capacity of the floodplain to temporarily store floodwaters. Energy dissipation is accomplished when the roughness characteristics of the substrate absorb energy from the water as it leaves the channel and passes though the floodplain (Brinson et al. 1995). Short-term surface water detention is the capacity of the floodplain to temporarily store floodwaters, usually for a period of a week or less (Brinson et al. 1995, Ainslie et al. 1999). The dominant sources of floodwater include overbank flow from an adjacent stream channel and upland surface water runoff (Ainslie et al. 1999). This function is assessed for the following regional wetland subclasses:

a. Slopes
b. Headwater Floodplains
c. Mainstem Floodplains

The recommended procedure for assessing this function is composed of two parts. The first estimates how well the floodplain represents the characteristic hydrologic conditions of the subclass and indicators that a change in that regime has occurred. The second part of the function measures the roughness of the substrate along with a representation of the elevational gradient of the surrounding landscape.

Rationale for selecting the function

The physical characteristics of floodplain wetlands are important for assessing the potential of an area to store and manage floodwaters. Wetlands reduce the amount of runoff that reaches the streams by storing runoff from adjoining areas (Demissie and Khan 1993). This desynchronizes water delivery to streams, which decreases the frequency and magnitude of flooding downstream (McAllister et al. 2000). The amount of water stored in wetlands can be quite large. In fact, one acre of floodplain inundated to a depth of 1 foot can store approximately 325,000 gallons of floodwater (Natural Hazards Research and Applications Information Center 1992). Floodplains provide a broad area for floodwaters to spread across, which reduces water velocities, lowers flood peaks, and reduces erosion. Floodplain vegetation retards water flow and small topographic depressions temporarily trap floodwater (Owen and Wall 1989).

Characteristics and processes that influence the function

While precipitation is the driving force in initiating the flooding process, the physical characteristics of the drainage basin, hydrology, and geomorphology of the stream-floodplain ecosystem are the primary factors controlling the concentration, spatial distribution, and dispersal rate of floodwaters (Staubitz and Sobashinski 1983, Scientific Assessment and Strategy Team 1994). Small streams are more influenced by precipitation events and are more unpredictable than larger rivers (Junk and Welcomme 1990, Benke et al. 2000). Although climate and geology are important, they are generally considered to be similar within a given region and wetland type. Differences in landscape-level characteristics, such as upland indicators of disturbance and stream size are important characteristics to consider. Site-level indicators, however, can be utilized when necessary since they tend to be sufficient predictors for functional assessments (Brinson et al. 1995). According to the Riparian Area Management's Proper Functioning Condition Workgroup (1993), riparian-wetland areas are functioning properly when site-level indicators such as: adequate vegetation, landform, or large woody debris is present to dissipate stream energy and improve floodwater retention and groundwater recharge.

Floodplains that rely heavily on overbank flooding are most affected by upstream activities that disrupt their water source. Human activities upstream influence flood frequency and intensity (McAllister et al. 2000). Urbanization creates impervious surfaces and underground sewers, which accelerate the delivery rate of surface water to the stream (Pennsylvania Environmental Council 1973). Channelization, levees, and floodwalls both on-site and upstream destroy riparian habitat, restrict river flow, decrease water elevations at low flows and increase water levels at the same locations during floods (Scientific Assessment and Strategy Team 1994). Channelization funnels water into the stream, rather than allowing water to spread across the wetland and decrease velocity (Brown 1988). This results in a decrease in the ability of wetlands to perform other functions, such as removing sediment and nutrients, and long-term surface water storage (Johnston et al. 1984, Brown 1988, Rheinhardt et al. 1999). Highway embankments remove vegetation, eliminate natural storage areas, and reduce space available for floodwater storage (Owen and Wall 1989). These and other activities often result in channel degradation, which lessens the depth, frequency, duration, and predictability of flooding. The floodplain frequently becomes isolated from the stream channel and no longer has the opportunity to perform this function. In addition, these activities not only impair the performance of this function on-site, but they also reduce the ability of downstream wetlands to dissipate energy and temporarily detain floodwaters.

Considering the constraint of a rapid assessment approach on HGM, many of the characteristics described above are difficult to incorporate into the model. We split the model into two components. The first component represents the flooding regime of the site and how it has been affected by human alteration. The second part of the model examines physical characteristics of the floodplain represented by site roughness and the elevational gradient of the surrounding landscape.

General form of the assessment model

The model for assessing the energy dissipation and short term water storage function includes the following variables:

Headwater Floodplains:

V_{FLOODP}: represents characteristic hydrology of the floodplain

$V_{UNOBSTRUC}$: 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 modifications at the site

V_{GRAD}: elevational gradient of landscape around site

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

The general form of the assessment model is:

Headwater Floodplains:

$FCI = (V_{FLOODP} * 0.67 + V_{UNOBSTRUC} * 0.33) * (V_{GRAD} + V_{ROUGH})/2$

Since classes of wetlands have inherent differences in the way water moves through each, there are slight differences among the variables used for the Riverine Subclasses and the Slope subclass. However, the model was separated into two components for all. The first part represents flooding regime at the site and human alterations to that natural regime. These alterations are looked at in the context of how they cause the present flooding regime to deviate from reference standard conditions. For the Riverine subclasses, the second component of the model is made up of physical characteristics of the floodplain at the site and in the surrounding landscape. V_{GRAD} and V_{ROUGH} have a partially compensatory relationship, with both variables assuming to contribute equally and independently to the level of function. An arithmetic mean was used so that if one of the two variables is zero or does not exist, the function can still be performed to some degree. The first component has a controlling relationship on the second component of the model. Without water flowing through the wetland in some way the function will not occur and the site will receive a score of zero. We incorporated the variable V_{FLOODP} as a space-holder for cases where more information about the present state of the floodplain can be incorporated. Characteristics such as ratio of floodplain width to channel width could be calibrated as this variable. However, information on these characterstics was unavailable during the development of these models. The variable $V_{UNOBSTRUC}$ is added to V_{FLOODP} and both variables weighted. Both variables contribute to this component of the model, however V_{FLOODP} is given a higher weight since it is considered the more important of the two.

<u>Subclass rigor</u>**:**

This function is class specific and is relevant to both Riverine subclasses, Headwater and Mainstem Floodplains. Slope wetlands are also assessed for this function, however different variables are used since Slopes generally do not receive overbank flooding. Along with differences in the overall model components, the variable V_{ROUGH} scoring is dependent on subclasses. Therefore, it is important that the wetland in question is classified accurately to the subclass 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). Figures 1-4 show 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 in each ecoregion.

Figures 1-4. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 1.

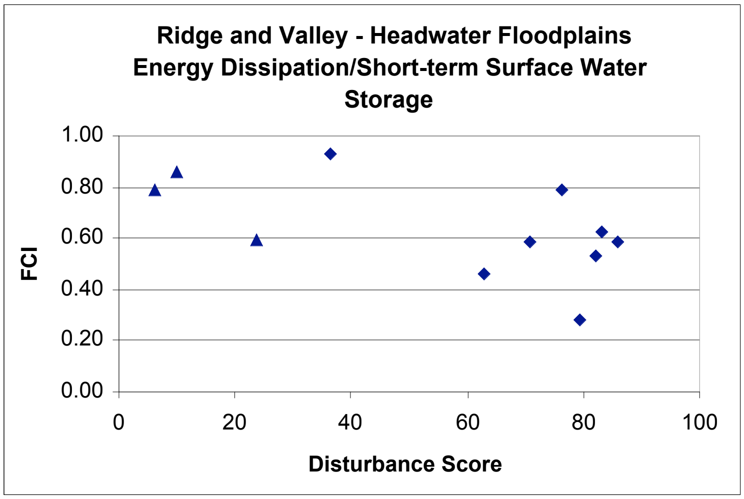


Figure 2.

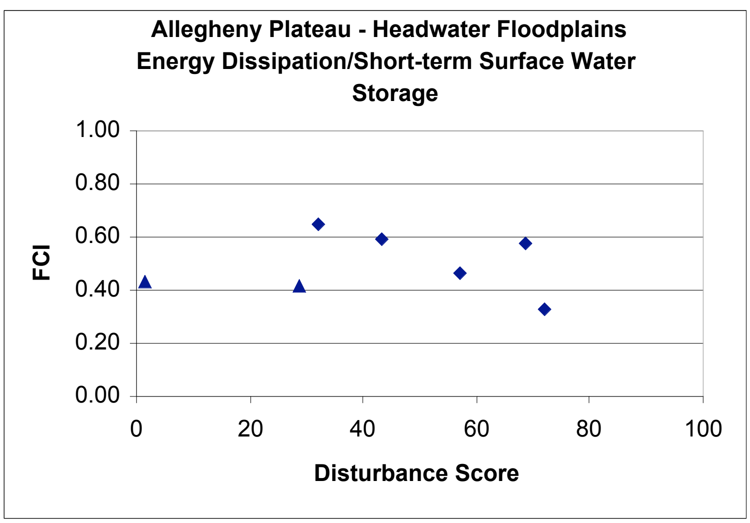


Figure 3.

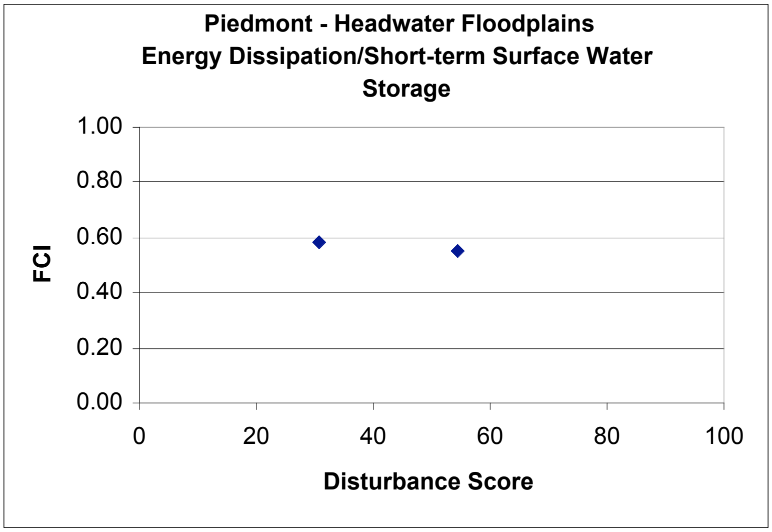
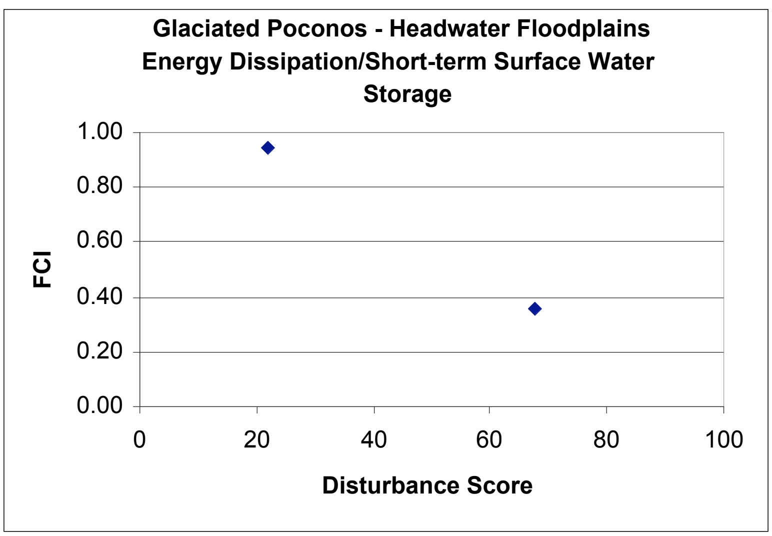


Figure 4.



Function 2. Long-term Surface Water Storage

Definition and applicability

This function is defined as the ability of the wetland to store water for long durations (i.e., periods over one week). The assessment of this function is based primarily on the presence of macro-depressions, soil characteristics, and floodplain characteristics that represent deviations from reference standards. This function is assessed for the following regional wetland subclasses:

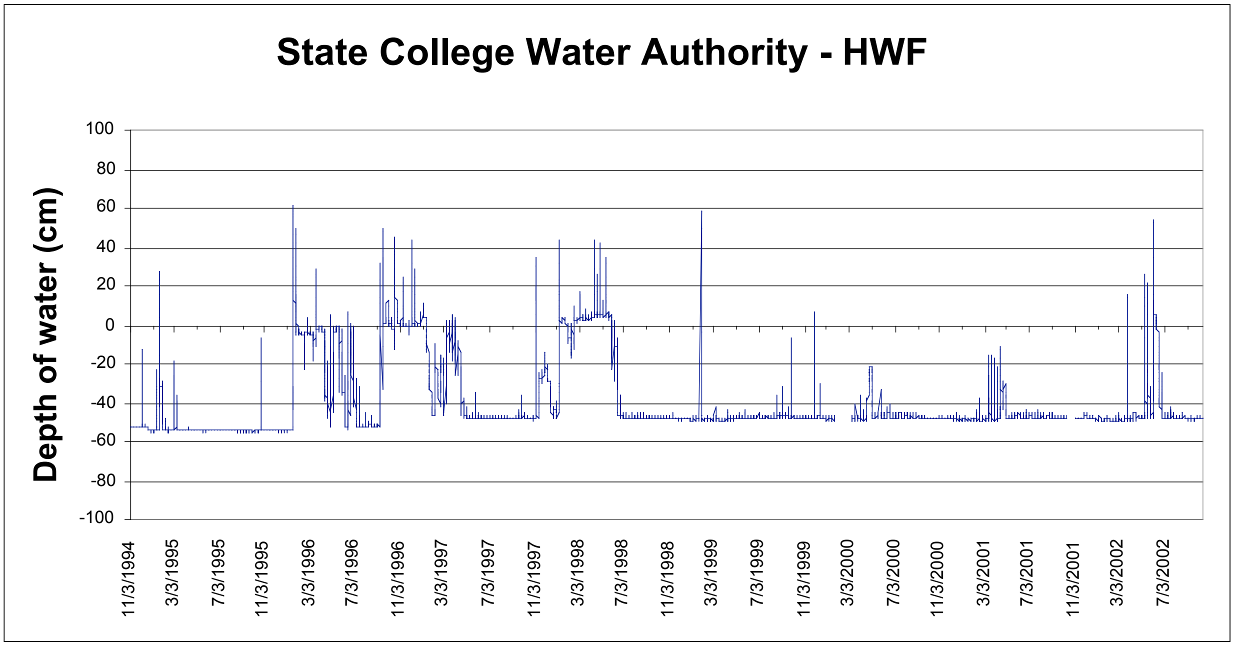
a. Headwater Floodplains
b. Mainstem Floodplains

The recommended procedure for assessing this function is composed of two parts. The first component is identical to the first component in Function 1, and is an estimate of how well conditions in the floodplain represent reference standard conditions of the subclass. The second component of this function differs from Function 1 in that it is made up of variables that represent the ability of a wetland to retain water for long periods of time.

Rationale for selecting the function

Hydrology is considered one of the defining characteristics of wetlands. Water entering a floodplain wetland has several options: it may proceed directly to the stream, be slowed by the roughness of the wetland, or it may be detained for long periods. As with Function 1, the detention of water for long periods of time reduces water velocities, lowers flood peaks, and lessens the effects of erosion. Along with these benefits, it also desynchronizes water flow to prevent flooding and allows groundwater recharge to occur. Most importantly, long-term surface water storage helps to maintain the characteristic hydroperiod of the wetland. Hydroperiod affects just about all components of the wetland community; plant communities, soil processes, nutrient cycling and faunal communities are all influenced by the duration and frequency of inundation (Gosselink and Turner 1978, Carter 1986, Tiner 1998).

Although Function 3 - Maintain Characteristic Hydrology is not used for Headwater Floodplains, we provide a typical hydrograph of the expected hydrologic regime for comparison to other wetland subclasses (Figure 1). Deviations from this expected pattern could be used to justify assignment of a score less then one in any of the hydrologic function.



Typical hydrograph for HGM Wetland Subclass - Headwater Floodplain.

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

Flood storage is a function of the wetland's surface area and depth of flooding (Novitzki 1989). The amount of flooding at a site is dependent on climate, topography, channel slope, soil and lithology (Brinson 1990). Physical characteristics of a site determine the ability of a wetland to retain this excess water. The presence of macrotopographic depressions indicates the potential of a site to retain incoming waters for long periods of time. Features such as oxbows, meander scrolls, and backswamps all constitute macrotopgraphic depressions (Brinson et al. 1995). Low-energy streams and small floodplains often lack these large features (Brinson et al. 1995). Therefore, for the purpose of this model, macrotopographic depressions are defined as areas along a transect that are at least one meter long and one meter deep.

The most effective flood attenuation occurs when there is a high capacity for storage and the soil is unsaturated (McAllister et al. 2000). This allows large amounts of water to be stored on the surface of the wetland and gradually infiltrate into the soil. The depth of soil in a wetland influences the total storage capacity as it influences the amount of seepage that may occur. Deeper soils have a greater water-holding capacity. The ability of wetlands to attenuate floodwaters also depends on the volume and rate of water movement (McAllister et al. 2000). Slowed movement of water by vegetation allows for the recharge of groundwater (i.e. seepage into the soil) (Owen and Wall 1989).

Disturbances may reduce the storage function of a wetland. Channelization increases the rate of runoff, which increases peak flow, and decreases water storage and the residence time of water (Brown 1988). Studies show that increases in water level fluctuation relate directly to increases in runoff from adjacent uplands (Euliss Jr. and Mushet 1996). Human alterations also cause an increase in the amount of sediment transported to a wetland. This may result in the filling of depressions, and hence a reduction in the storage capacity and topographic complexity of the wetland.

General form of the assessment model

The assessment model for the long-term storage of surface water includes the following assessment variables:

Headwater Floodplains:

V_{FLOODP}: represents characteristic hydrology of the floodplain

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

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

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

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

V_{MACRO}: presence of macrotopographic depressions

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

The general form of the assessment model is:

Headwater Floodplains:

$FCI = (V_{FLOODP} * 0.67 + V_{UNOBSTRUC} *0.33) * (V_{MACRO} + V_{REDOX})/2)$

As in Function 1, the model is split into two basic components. The first, which is identical to Function 1, is representative of flooding regime at the site and the human alterations that may affect these patterns. The combination of V_{FLOODP} and $V_{UNOBSTRUC}$, in a cumulative, weighted relationship, again acting as a controlling factor in the model. If the flooding regime is so greatly altered that flooding does not occur at the site, the function cannot be performed and the site receives a score of 0.

The second component consists of variables that represent the storage of water at the site for long periods of time. V_{MACRO} represents the potential for water to be retained at the site for long periods of time, and V_{REDOX} indicates that this is actually happening and causing visible changes in soil characteristics. Both of these variables contribute equally to the functional model and are combined using the arithmetic mean.

Subclass rigor

This function is assessed only for the two riverine subclasses: Headwater Floodplains and Mainstem Floodplains. While Slope wetlands may perform short-term surface water storage, due to their position in the landscape (on a slope) they generally will not store water for long periods of time and this function would not apply. Depression wetlands are usually located in low spots in the landscape, and may be thought of as one large macrodepression. They often retain water until it evaporates or infiltrates into the soil (Novitzki 1989). Examples of this are pothole wetlands, which store and gradually release precipitation and snowmelt (McAllister et al. 2000). Therefore, Riparian Depressions and Isolated Depressions perform the function of long-term surface water detention by nature of their subclass definition, making it unnecessary to assess them for this function.

The variables used in this function were calibrated based on subclass and response to disturbance. Variables that had weak responses to disturbance were scored on a categorical basis, with parameters that contributed to higher levels of function receiving higher scores. These included V_{MACRO}, V_{REDOX}, and $V_{HYDROSTRESS}$, which make up $V_{UNOBSTRUC.}$ The variable $V_{RDDEN,}$ and $V_{\%URB}$ show some relationship with disturbance and were calibrated accordingly, with reference standard sites being the basis for scoring the rest of the sites.

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). Figures 5-8 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 5-8. Relationship of Riparian Depression FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 5.

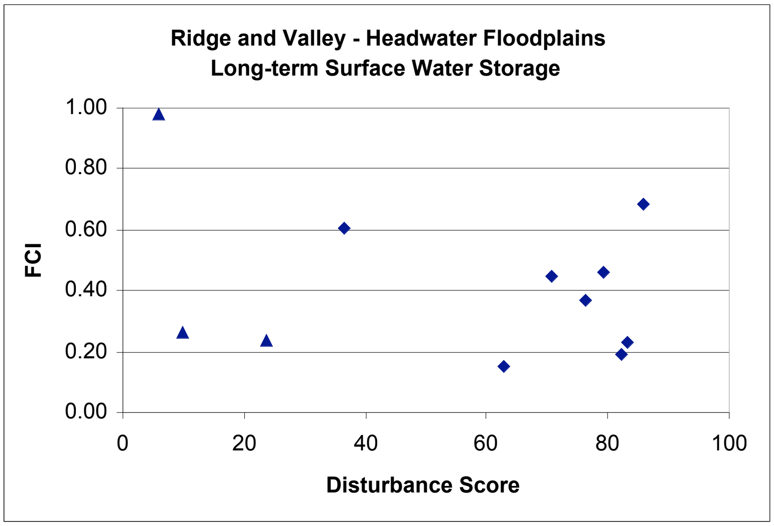


Figure 6.

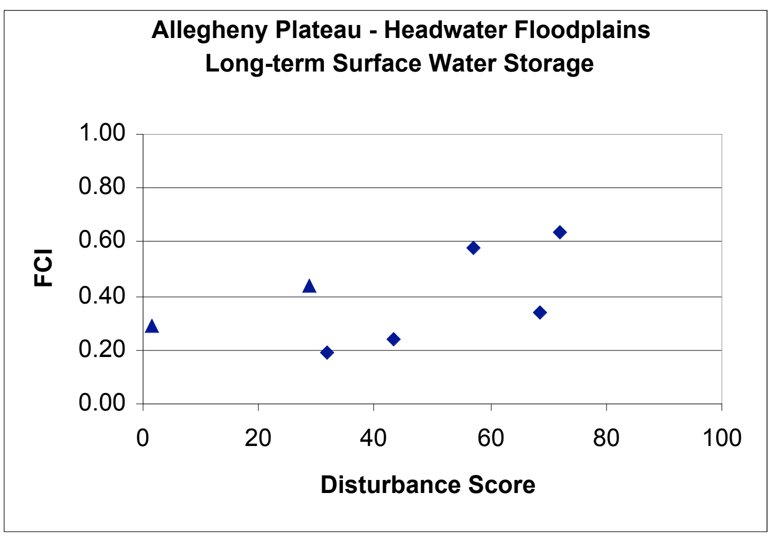


Figure 7.

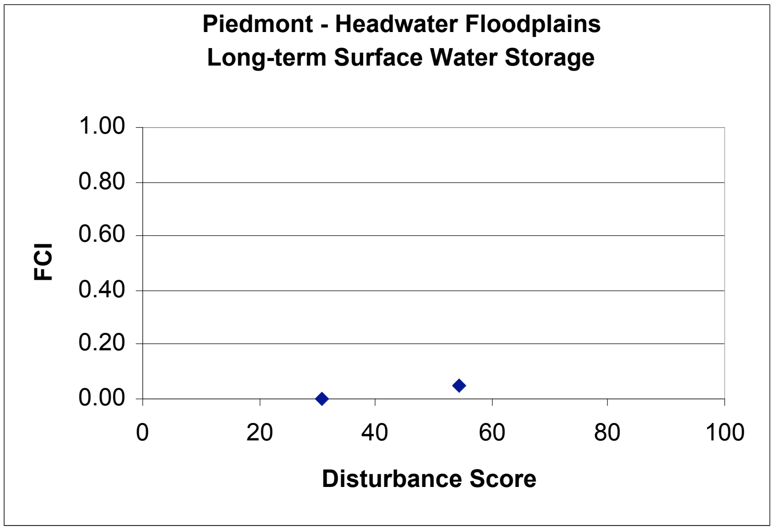
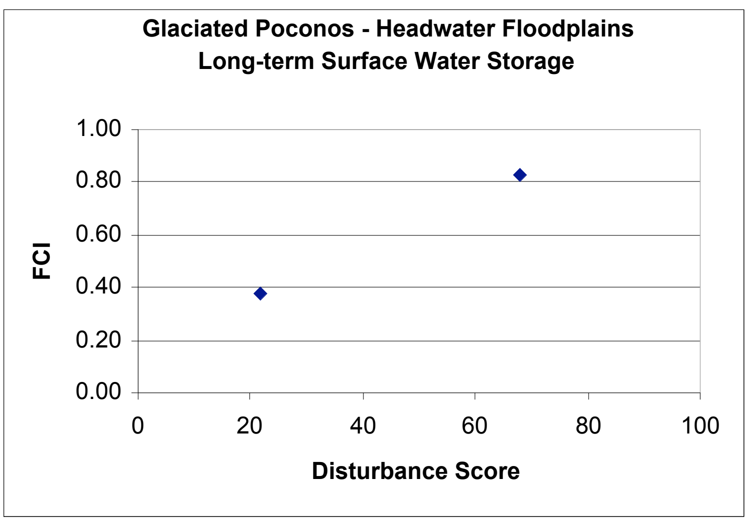


Figure 8.



Function 3. Maintain Characteristic Hydrology

Not applicable to Headwater Floodplains

Function 4. Reserved for alternate Hydrologic 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. Riparian Depressions
b. Isolated Depressions
c. Slopes
d. Headwater Floodplains
e. Mainstem Floodplains
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).

Characteristics and processes that influence the function

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:

Headwater Floodplains:
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:

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

The variables included in this equation estimate the controlling factors for the dominant removal mechanisms. $V_{BIOMASS}$ estimates vegetative uptake of nitrogen, and V_{SORGM} and V_{REDOX} represent conditions that affect denitrification rates. At present, there is no clear 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 a linear relationship with disturbance, so that sites with the least alteration received the highest scores. V_{ORGMA} was scored differently depending on both ecoregion and subclass. For all Glaciated Poconos subclasses, as well as Fringing sites and Isolated Depressions across the state, this variable was scored based on a linear relationship with disturbance and the average of reference standard sites. It showed little response to disturbance and reference standard sites were highly variable in Mainstem Floodplains, Headwater Floodplains, Riparian Depressions and Slope subclasses in all of the other ecoregions. This resulted in a categorical scoring system that was based on deviations from the reference standard average. V_{REDOX} also showed no relationship with disturbance and was scored categorically. This variable was calibrated based on conditions that result in higher level of function.

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). Figures 9-12 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 9-12. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 9.

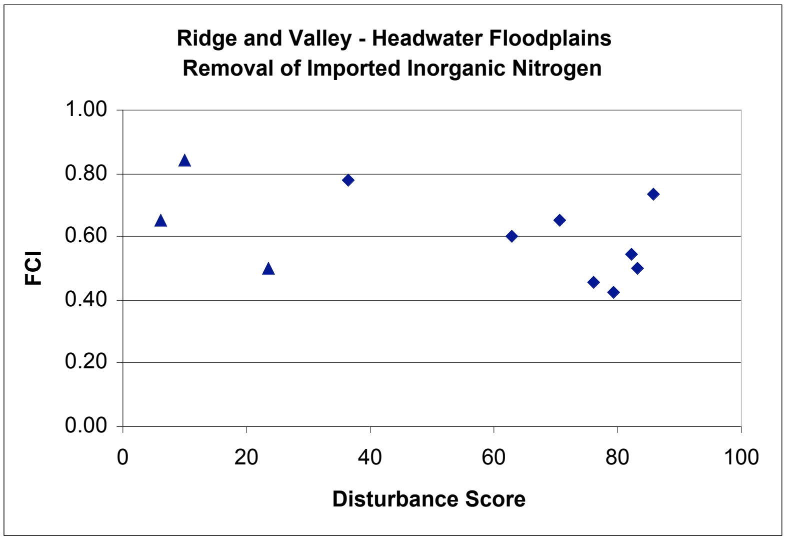


Figure 10.

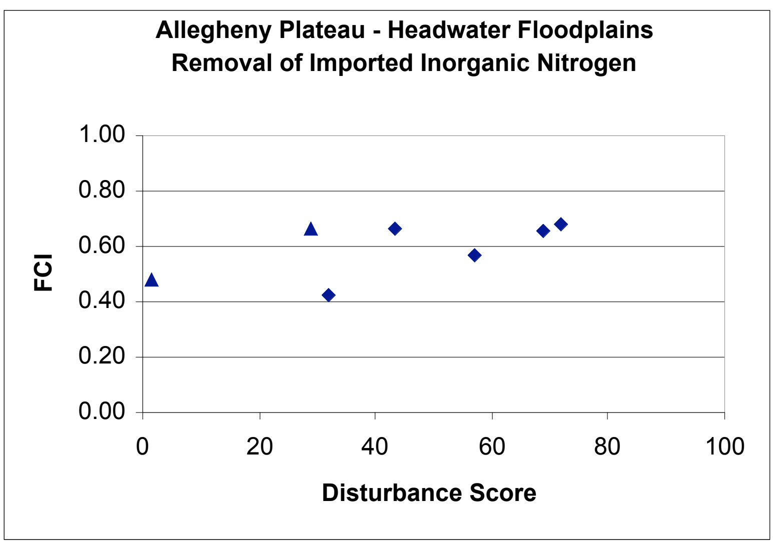


Figure 11.

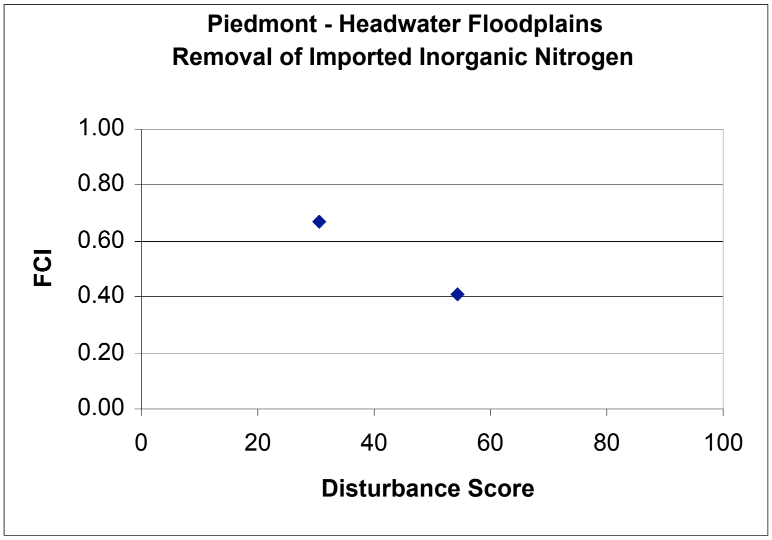
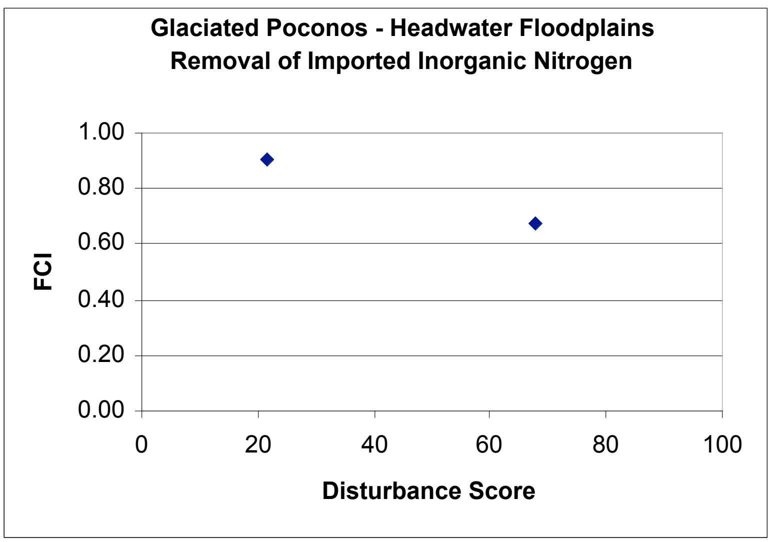


Figure 12.



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

The procedure for assessing this function is slightly different between subclasses, although all models contain similar fundamental components. As in Function 1, the model in split into two components, flooding regime 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 one 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, though, 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 was 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:

Headwater Floodplains:

V_{FLOODP}: represents characteristic hydrology of floodplain

$V_{UNOBSTRUC}$: 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 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:

Headwater Floodplains:

$FCI = (V_{FLOODP} * 0.67 + V_{UNOBSTRUC} * 0.33) * [(V_{ROUGH}+V_{REDOX}+V_{MACRO})/3 + (V_{ORGMA}+V_{TEX})]/2$

The assessment models for this function have been split into three primary components representative of hydrologic regime at the site, residence time of water at the site, and soil characteristics. The first component is identical to the first component in Function 1 and is representative of the hydrologic regime in the system. This is discussed in further detail in the discussion of the assessment model for Function 1. The first part of the model for Headwater Floodplains, takes into account human alterations at the site that may cause the movement of water to deviate from reference standard conditions. These hydrologic variables are used as controlling factors and are multiplied with the remaining two components.

The second component of each model is representative of variables that indicate the residence time of water at a site. V_{ROUGH} and V_{MACRO} both represent physical characteristics at the site 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 soil surface are actually in contact with each other, allowing the adsorption of solutes to actually take place. This component is identical for all subclasses with the exception that V_{MACRO} is left out of the Riparian Depression model. The variables in this part of the equation are considered to contribute equally to the level of function and are averaged together using the arithmetic mean.

The final component of the model takes into account soil characteristics that promote the adsorption of solutes. Greater solute adsorption occurs at higher clay content in the soil and when organic matter is present. V_{TEX} and V_{ORGMA} are considered to contribute equally to the level of function so these two variables were combined by taking the arithmetic mean. The second and third components were combined by taking the arithmetic mean of components two and three.

Subclass rigor

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

Most of the variables in the model equations were calibrated based 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 of these indicators with disturbance. The variables that were calibrated based on a linear relationship with disturbance were: V_{ROUGH} and two components of $V_{UNOBSTRUC}$: V_{RDDENS} and $V_{\%URB}$. The subindex scores remain the same among subclasses for most of the variables with the exception of V_{ROUGH}, and V_{ORGMA}. For these two variables, scores differ between subclasses, which is another reason that accurate site classification is essential.

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). Figures 13-16 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 13-16. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 13.

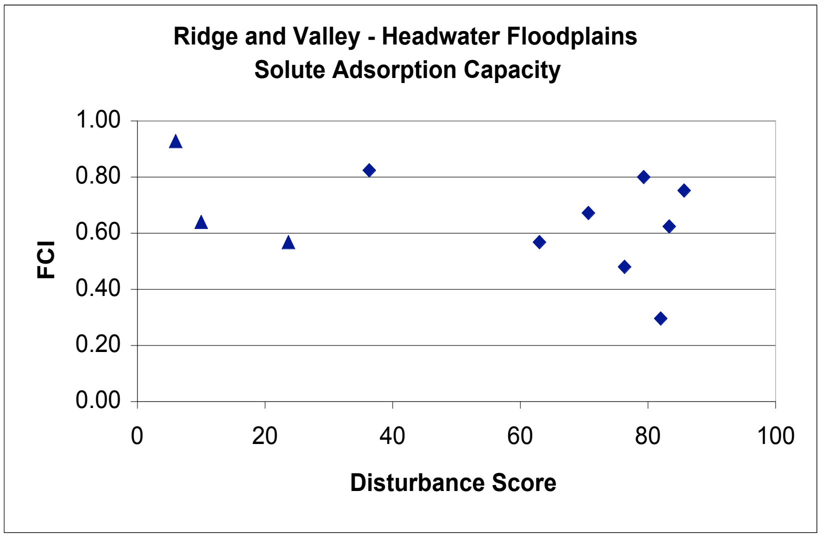


Figure 14.

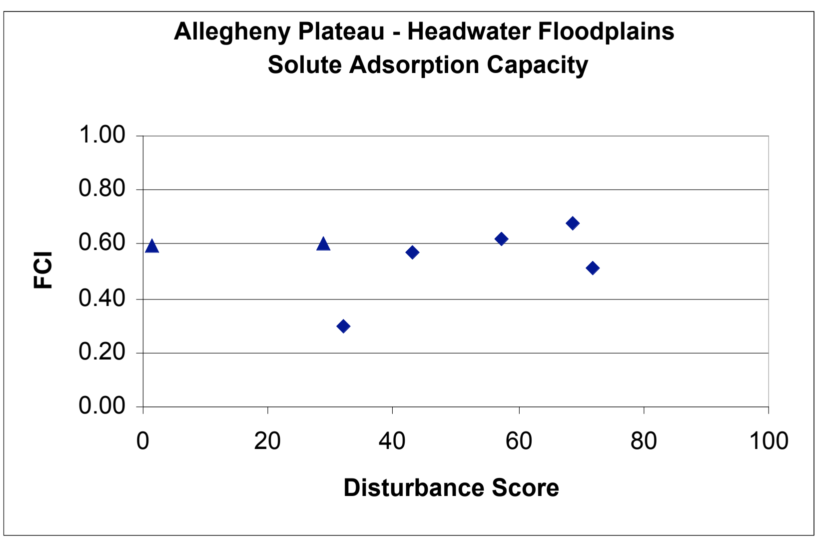


Figure 15.

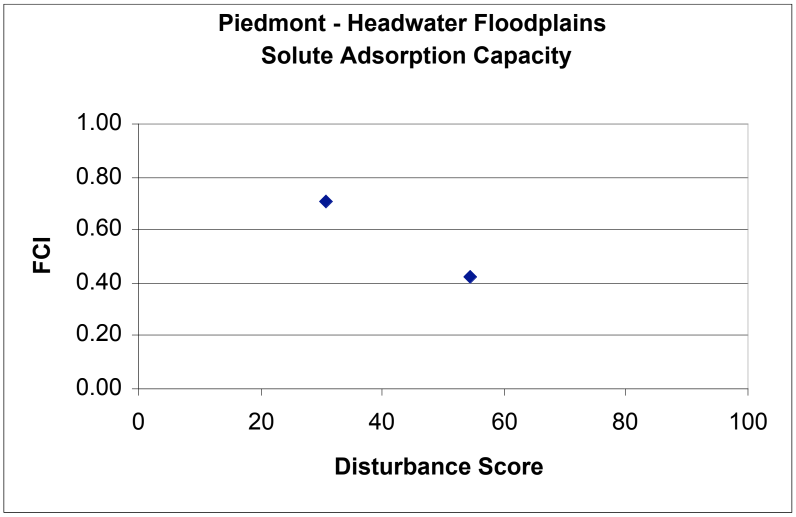
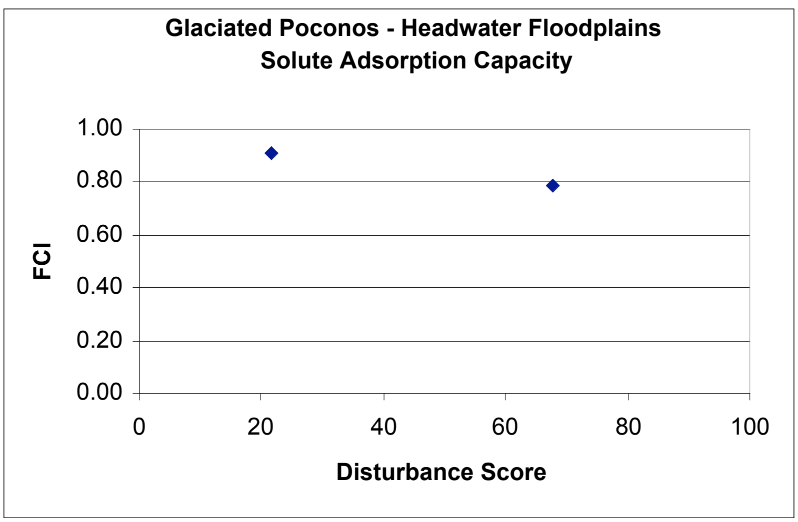


Figure 16.



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

As in previous functions, movement of water through the system is necessary for this function to occur. Therefore, the assessment procedure is split into two parts, with the first representing the hydrologic regime of the system. The second part of the equation represents physical characteristics of the site that aid in the retention of inorganic particulates.

Rationale for selecting the function

Sediment retention in wetlands is beneficial to the water quality of neighboring streams, rivers, and lakes by reducing turbidity, and retaining phosphorus and contaminants that are sorbed to those sediments (Oschwald 1972, Boto and W. H. Patrick 1978, Cooper and Gilliam 1987, Hemond and Benoit 1988, Johnston 1991). If there is little reworking of the sediments, then the deposition of soil particles can be considered a virtually permanent removal (Johnston et al. 1984).

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. A thin sediment layer in a floodplain swamp seems small until the large wetland size is taken into account, and then it becomes a large sink for sediment (Cooper et al. 1987). Molinas *et al.* (1988) stressed the importance of wetland size by crediting water velocity reduction to floodwaters spreading out over a large, flat area, rather than the roughness of the site.

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.

Channelization decreases the sinuosity of the river and increases the channel gradient, which results in sharper pulses of water flow (Brinson 1990). The increase in stream gradient can account for large amounts sediment erosion in the channel (Heimann and Roell 2000). Decreases in flooding frequency and the residence time of floodwaters in wetlands, caused by channelization, impair the ability of the wetland to remove sediment (Johnston et al. 1984). Channelization funnels water rather than dispersing water across wetlands as sheet flow (Brown 1988), thereby reducing the opportunity for sediment removal. Flow rates are higher for channelized flow than for sheet flow, so there is less sediment settling and water infiltration (Castelle et al. 1994).

<u>General form of the assessment model</u>

The model for assessing the retention of inorganic particulates includes the following variables:

Headwater Floodplains:

V_{FLOODP}: represents characteristic hydrology of floodplain

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

V_{MACRO}: presence of macrotopographic depressions

V_{GRAD}: gradient of landscape around site

Headwater Floodplains:

$FCI = (V_{FLOODP} * 0.67 + V_{UNOBSTRUC} *0.33) * (V_{ROUGH} + V_{MACRO} + V_{GRAD})/3$

The assessment models for this function have been split into two components. The first is representative of hydrologic regime and the second represents physical characteristics as the site that would aid in the retention of inorganic particulates. The first component of the equation is discussed in greater detail in previous functions. The second component represents the potential for slowing water movement through the wetland and the ability of the wetland to store water for long periods of time.

For the Riverine subclasses, the variables representative of hydrologic regime are acting as controlling factors for the function. This function cannot occur without overbank flooding which influences the amount and movement of water through the system. Therefore, if the first component equals zero then the entire function will get a score of zero. The second component of the equation is made up of three variables for Headwater Floodplains. V_{ROUGH} and V_{GRAD} represent conditions at the site and in the surrounding landscape that will slow the flow of water, allowing for inorganic particulates to settle out of the water column. V_{MACRO} indicates the potential for water to be stored for long periods of time, increasing the amount of inorganic particulates retained at the site. The variables that make up the second component of this equation in the Riverine subclasses all contribute equally to the level of function and are combined using an arithmetic mean.

Subclass rigor**:**

The variables V_{MACRO}, V_{GRAD} and $V_{HYDROSTRESS}$ (which is a part of $V_{UNOBSTRUCT}$), are all scored categorically based on highest level of functioning. The rest of the variables that make up the equation are calibrated based on a linear relationship with disturbance and are scored differently by subclass.

The model for slope wetlands varies substantially from the models for floodplains, especially the first component of the equation, so accurate classification is essential. Slope wetlands use the variable V_{GRAD} to characterize hydrologic regime instead of V_{FLOODP} and $V_{UNOBSTRUC}$.

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). Figures 17-20 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 17-20. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 17.

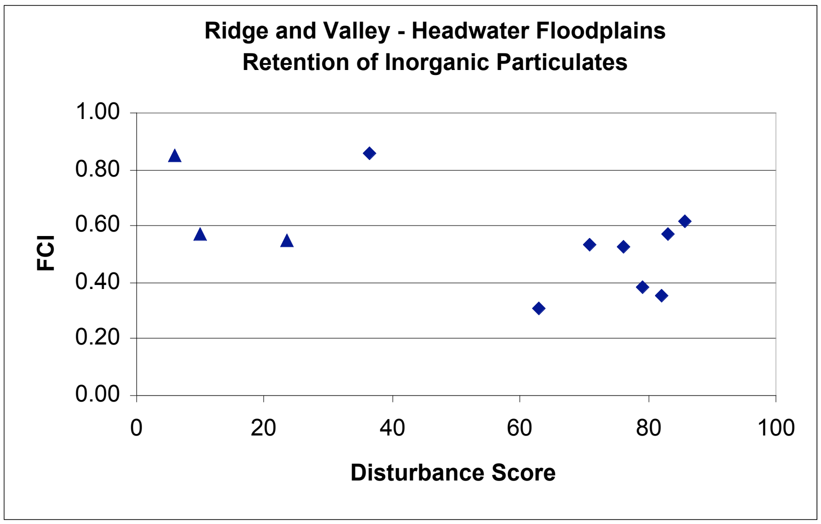


Figure 18.

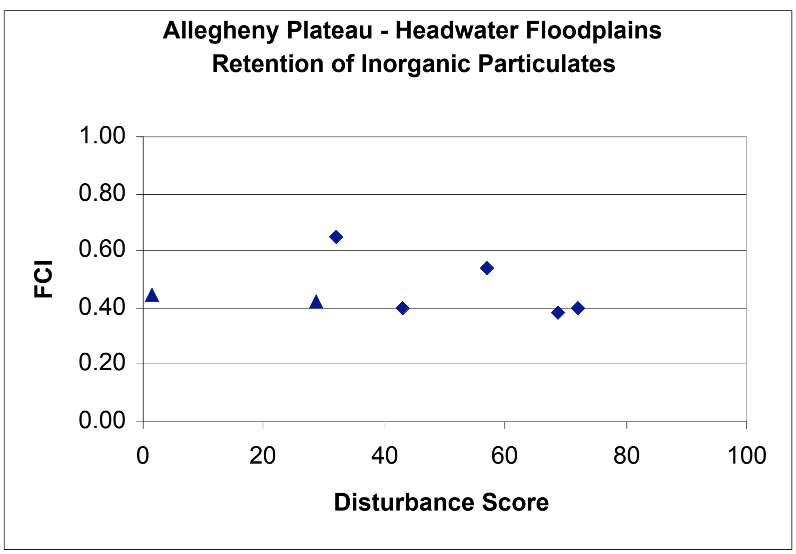


Figure 19.

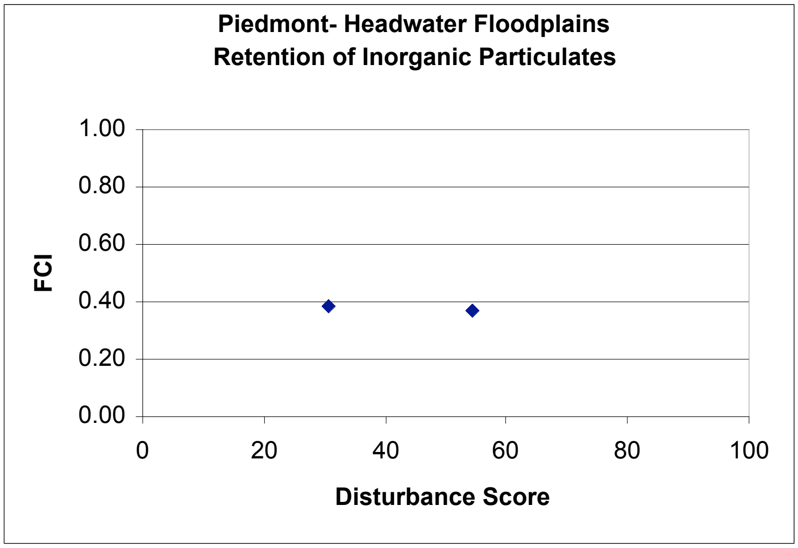
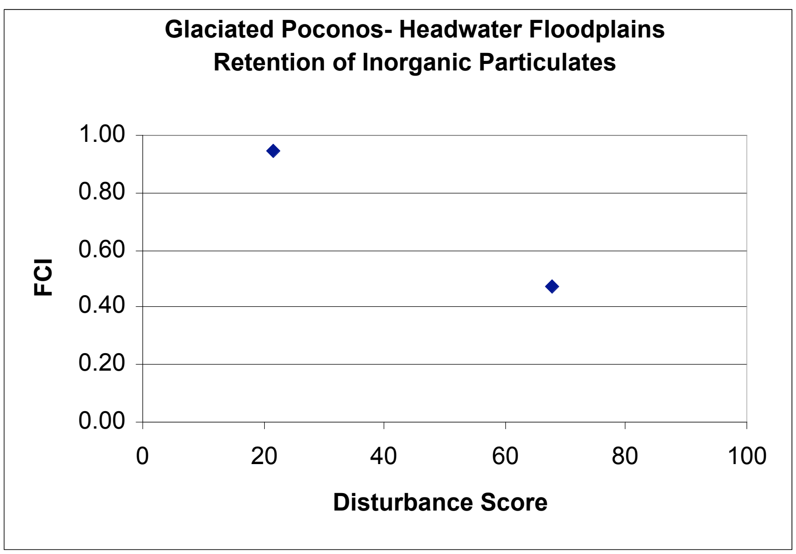


Figure 20.



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

Definition and applicability

This function evaluates the ability of wetlands to export both dissolved organic carbon and organic particulates. The total export of dissolved organic carbon from a wetland consists of three main processes: DOC loss in water leaving the wetland, microbial respiration (CO_2), and photosynthesis. Particulate organic matter includes soil organic matter and leaf litter, as well as sources of particulate organic matter such as coarse woody debris and standing dead trees. Originally, this function was split into two separate functions. However, to avoid redundancy the two functions have been combined. We are assuming that if a site is successfully exporting organic particulates it is likely that it is exporting dissolved organic carbon. This function is assessed for the following regional wetland subclasses:

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

The assessment model for this function is split into two components. Since this function is dependent on water moving through the site, as with previous functions, the first component is representative of the hydrologic regime at the site. The second component has represent residence time of water at the site, availability of organic matter and sources of organic matter. It is in the first component that variables differ among subclasses, reflecting fundamental differences in the hydrology of the different subclasses.

Rationale for selecting the function

Wetlands are a major source of particulate organic matter (POM). Woody debris is a nutritional substrate, provides habitat for microbes, invertebrates, and vertebrates, is a substrate for seedling growth, and serves as a long-term nutrient reservoir, a consistent source of organic material (Harmon et al. 1986, Brown 1990). Particulate carbon is a small fraction of total organic carbon (TOC), but is of a disproportionately higher importance as a food source for fish and invertebrates (Taylor et al. 1990). POM is a nutritional source for stream fauna. Particulate organic carbon (POC) from wetlands contributes substantial amounts of carbon to stream channels (Dosskey and Bertsch 1994). In fact, POC comprises between 24 and 46% of the total organic carbon in streams (Dosskey and Bertsch 1994). Detrital inputs to the stream during peak inundation periods support microbial and macroinvertebrate communities in the stream channel (Smock 1990).

Jones and Smock (1991) referred to floodplain wetlands as integral processing components of low-gradient stream systems. They suggested that most of the coarse particulate organic matter (CPOM) entering floodplains is received, retained, at least partially processed, and then exported in large quantities as a finer form more readily useable by aquatic invertebrate communities(Smock 1990, Jones and Smock 1991). On floodplains, CPOM is processed to fine particulate organic matter (FPOM) and dissolved organic matter (DOM), which may be transported to channels or respired as CO_2 (Bilby and Likens 1979, Jones and Smock 1991).

Dissolved organic carbon (DOC) is composed of humic substances, which are a group of complex organic compounds (fulvic acid, humic acid, and humin) that vary in solubility and molecular weight. DOC originates from recent soil organic matter (less than 45 years old), woody debris, and leaching from stems and leaves. DOC is an intermediary in the decomposition process; it is both produced and consumed (Schiff et al. 1998). The net DOC produced is the balance between these two processes (Schiff et al. 1998). Wetlands contribute large quantities of organic matter to streams, especially in the form of DOC. Dosskey and Bertsch (1994) found that while wetlands made up only 6% of the watershed, they contributed 93% of the total organic carbon flux. The majority of organic carbon is in dissolved form and export may be an order of magnitude greater than particulate export (Bilby and Likens 1979, Naiman 1982). Several studies done in mainstem floodplain systems show that approximately 95% of the annual export to the stream, and up to 93% of the TOC of the stream consisted of DOC (Mulholland 1981, Cuffney 1988).

DOC levels influence the chemical and the biological processes of wetlands. DOC provides energy to microbes, which in turn form the base of the detrital food web in river ecosystems (Dosskey and Bertsch 1994). DOC also plays an important role in the transport and toxicity of metallic ions (Schiff et al. 1990, Dillon and Molot 1997, Schiff et al. 1998) DOC is a strong complexing agent for Fe, Cu, Al, Zn, and Hg (Schiff et al. 1990). Organic acids can have acidifying effects on natural water bodies (Schiff et al. 1990, Dillon and Molot 1997). DOC affects light penetration into water and protects aquatic organisms from damaging UV radiation (Dillon and Molot 1997, Schiff et al. 1998). DOC export to streams influences the carbon cycle of both systems. Although DOC export is small compared to carbon respiration (Schiff et al. 1998), the export of carbon decreases carbon sequestration in the wetland, possibly turning the wetland into a source rather than sink for carbon.

Characteristics and processes that influence the function

The export of organic particulates requires a mechanism of transportation (usually water) and an accessible route (i.e., physical outlets) through which to exit the wetland. It is generally thought that a larger percentage of the fine organic particulates are exported from wetland systems than of the coarse fraction (Jones and Smock 1991), however, medium sized particles frequently exit wetlands due to their lower specific gravity and inherent tendency to float (Benke and Wallace 1990). In fact, Collier Creek, a large frequently inundated floodplain, was an exporter of medium-sized CPOM pieces, such as leaf litter that had been processed into smaller particles (Smock 1990). This trend was not observed in their less frequently flooded site (Smock 1990). Jones and Smock (1991) found that during overbank flow, much of the coarse particulate organic matter moved from the stream channel onto the floodplains, whereas FPOM (the primary size of particulate organic matter that supports invertebrate communities) was exported in large quantities. This was supported by the fact that FPOM comprised 99% of the POM present in the water column of the stream (Jones and Smock 1991).

The rate of particulate matter degradation depends on many factors, including soil moisture levels. According to Bilby et al. (1999), when compared to either fully submerged or terrestrial conditions, wood decays at a much faster rate when periodically wetted and dried, conditions typical of many wetlands. Floodplains had higher decomposition rates for wood than streams (Cuffney 1988). CPOM on dry areas of a streambed undergoes no processing or breakdown, and thus, FPOM formation is low (Bilby and Likens 1979). The breakdown of CPOM into smaller particle sizes influences POM export. Finer particulates are more susceptible to export because they are smaller and lighter and thus move easier with water flow. Heavier or larger pieces need higher water volume and velocity to be moved.

The duration of time between flooding events determines the amount of POM that can build-up. There was a 10-fold variation in FPOC at similar discharge levels in a headwater floodplain, in part because of the variation in duration of dry weather for FPOC to accumulate in the wetland (Bilby and Likens 1979). In winter, there is little biological processing due to low temperatures, so CPOM is able to accumulate. Storage of non-wood CPOM on floodplains increased and peaked in January, and the highest CPOM storage was mainly large pieces >16mm (Smock 1990). FPOM concentrations and export is low during snowmelt because winter decreases the biological breakdown of CPOM and thus formation of FPOM (Bilby and Likens 1979).

Export of DOC is controlled by several factors. The variables used relate to the amount of carbon potentially contributing to the DOC pool, frequency and duration of inundation, and intensity of water flow. The various types of organic carbon present in the wetland are important sources of DOC. Sources of organic matter determine the amount of carbon potentially available for export. Potential DOC production increases with increasing total organic carbon in the system. Long-term surface water storage controls the duration of water contact with DOC sources. The export of DOC from wetlands is affected by the ability of the wetland to store water for short periods of time and control the export volume and rate of the water.

High DOC concentrations found in swamps may be due to: DOC leaching from soil litter during water contact, swamp surface water receiving additional DOC-rich inputs of throughfall and stemflow, low DOC utilization because of the refractory nature of some compounds, and high evapotranspiration rates in wetlands compared to uplands (Marion and Brient 1998). Wetland size and position in the landscape may also be important in terms of surface area for water-soil contact and surface water inflow. The number of wetlands in a watershed has been strongly positively correlated with DOC levels in streams (Mulholland 1981, Dalva and Moore 1991, Dillon and Molot 1997). Disturbances impact many characteristics of wetlands, including wetland productivity and hydrology. Both of which can have an affect on the amount and export of DOC. If a disturbance causes a reduction in the health of the vegetation, the productivity should decrease, resulting in a reduction in the potential amount of DOC available at a site. Human alterations may lower the water table and cause streams to become incised. These changes result in drier, less frequently flooded wetlands. The lack of flood events will lead to lower export opportunities and the dryness will cause carbon mineralization rates to decrease, leading to lower DOC concentrations. Channelization decreases the sinuosity of the river and increases channel gradient, which results in sharper pulses in flow (Brinson 1990). This leads to higher water flow velocities, which can cause more scouring and export of POM, instead of DOC, from the wetland.

General form of the assessment model

The model for assessing the export of organic particulates includes the following variables:

Headwater Floodplains:

V_{FLOODP}: represents characteristic hydrology of the floodplain

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

- V_{RDDENS}: index of road density in a 1km circle
- V_{URB}: % of 1km radius circle in urban development
- $V_{HYDROSTRESS}$: number of hydrologic modification indicators from stressor checklist

V_{MACRO}: presence of macrotopographic depressions

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

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

V_{FWD}: visual estimate of depth of litter layer from HSI models

$V_{CWD\text{-}BA}$: estimate of coverage of coarse woody debris along a transect

$V_{CWD\text{-}SIZE}$: presence of coarse woody debris in three size classes

V_{SNAGS}: presence of dead standing wood in four size classes

The general form of the assessment models is:

Headwater Floodplains:

FCI =

$$(V_{FLOODP}\ 0.67+V_{UNOBSTRUC}\ 0.33) * [(V_{MACRO}+V_{REDOX}+V_{ORGMA}+V_{FWD}+(V_{CWD\text{-}BA}+V_{CWD\text{-}SIZE}/2)+V_{SNAGS})/6]$$

As in previous functions where movement of water through the system is a determining factor on the performance of the function, this function also is split into two major components. The first component is representative of the hydrologic regime of the wetland and is discussed in detail in previous functions. The second component represents the different source of organic matter at the site. V_{ORGMA} and V_{FWD} represent organic matter that is presently available for export. The variables $V_{CWD\text{-}BA}$, $V_{CWD\text{-}SIZE}$, and V_{SNAGS} represent organic matter at the site that will potentially be available in the future as decomposition proceeds. The variables V_{REDOX} and V_{MACRO} represent the residence time of water at the site, which is necessary for the formation of dissolved organic matter. The variables $V_{CWD\text{-}BA}$ and $V_{CWD\text{-}SZ}$ are averaged together since we believe that both are necessary to properly indicate the presence of CWD at the site. Otherwise, the arithmetic mean is taken for all the variables in the second component of the function, since each contributes equally to the overall functioning of the site. This function is very similar among subclasses, with the first component of the equations being the only difference between subclasses.

Subclass rigor

Although the differences in the models appear to be minimal, this function is class specific due to the inherent differences in hydrodynamics among subclasses. Therefore, the first component of the model is different depending on the wetland subclass. The variables V_{FWD}, $V_{CWD\text{-}SIZE}$, V_{SNAGS}, $V_{HYDROSTRESS}$ (which is a part of $V_{UNOBSTRUCT}$), V_{REDOX}, and V_{MACRO} are all scored categorically based on highest level of functioning. V_{ORGMA} was also scored categorically, but with subclass differences. The remaining variables in the equation are calibrated based on a linear relationship to disturbance and are scored differently depending on subclass type. Due to differences in the functional models and the variable scores classification is an important issue when assessing this function.

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). Figures 21-24 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 21-24. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 21.

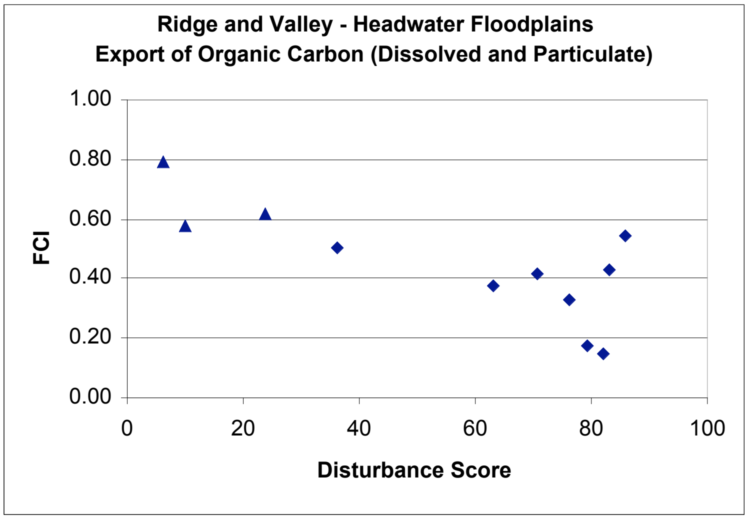


Figure 22.

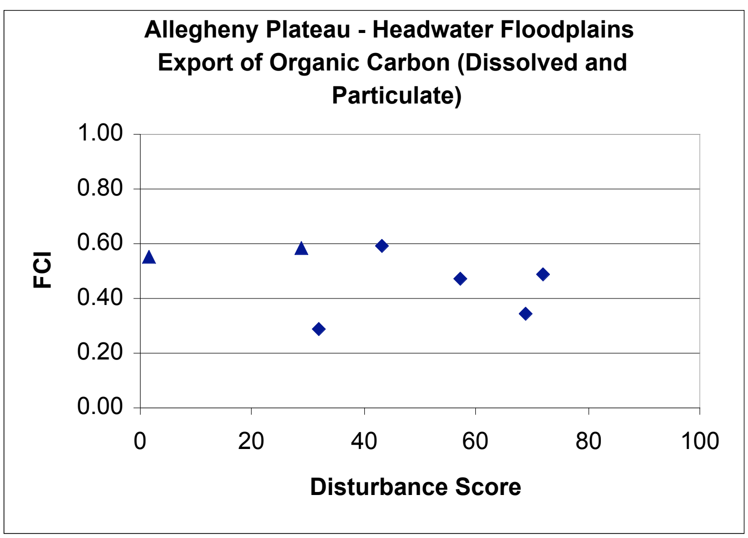


Figure 23.

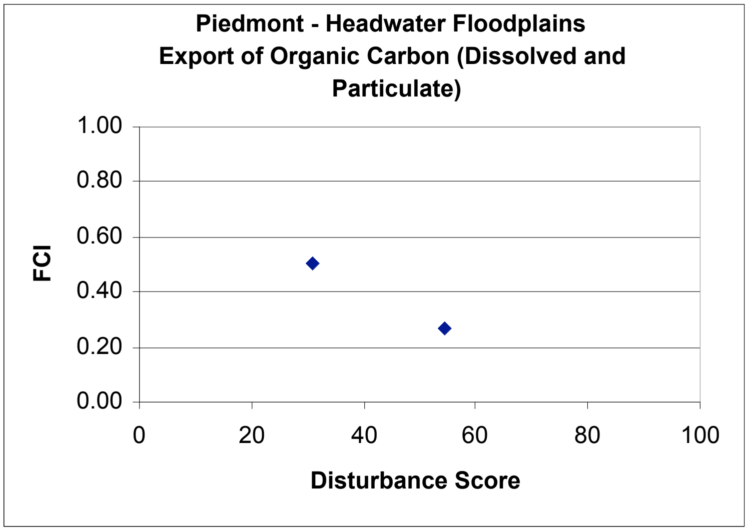
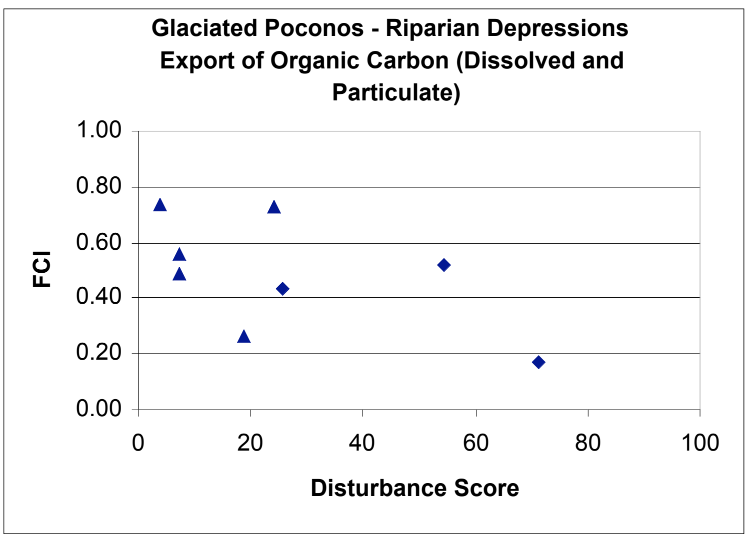


Figure 24.



Function 9. Maintain Characteristic Native Plant Community Composition

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 sites ability to maintain characteristic conditions. Since the Pennsylvania is historically 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. This function is assessed for the following regional wetland subclasses:

a. Riparian Depressions
b. Isolated Depressions
c. Slopes
d. Headwater Floodplains
e. Mainstem Floodplains
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 composition of vascular plant communities have long been used to characterize wetlands (Cowardin et al. 1979, Mitsch and Gosselink 2000). Plant community composition 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 also influences 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:

Headwater Floodplains:

$V_{SPPCOMP}$: 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:

Headwater Floodplains:

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

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 the same for all HGM subclasses, except Fringing sites. 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). Figures

25-28 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 25-28. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 25.

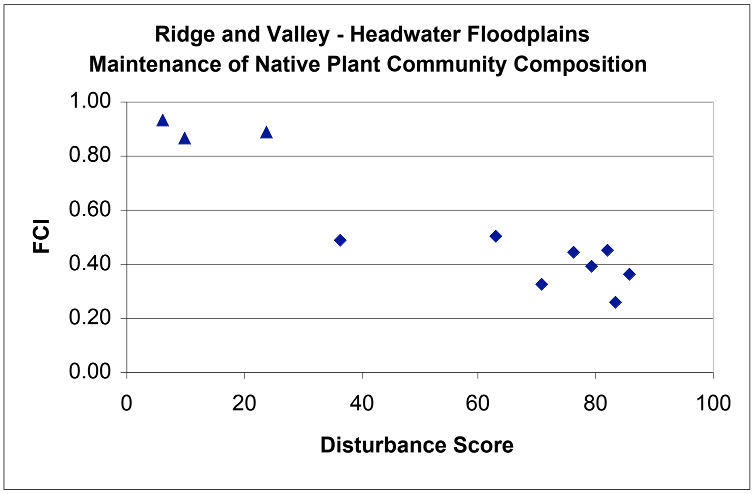


Figure 26.

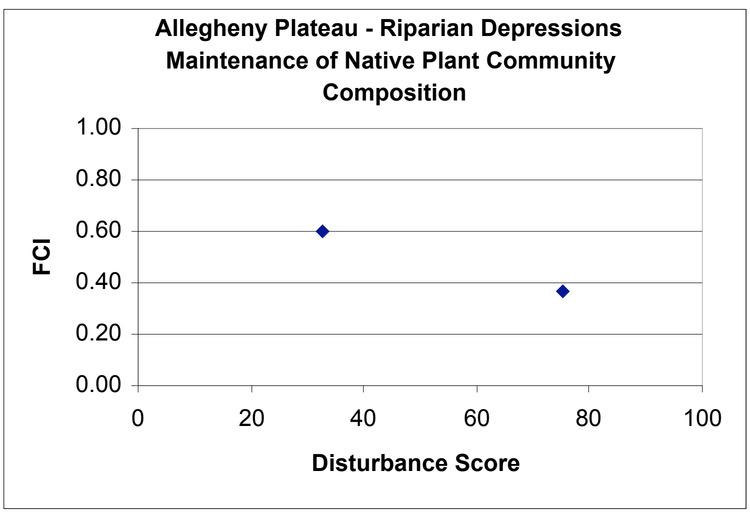


Figure 27.

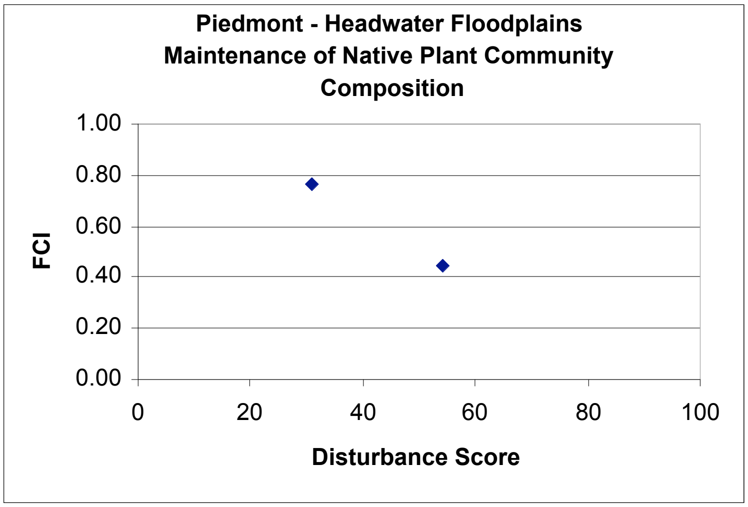
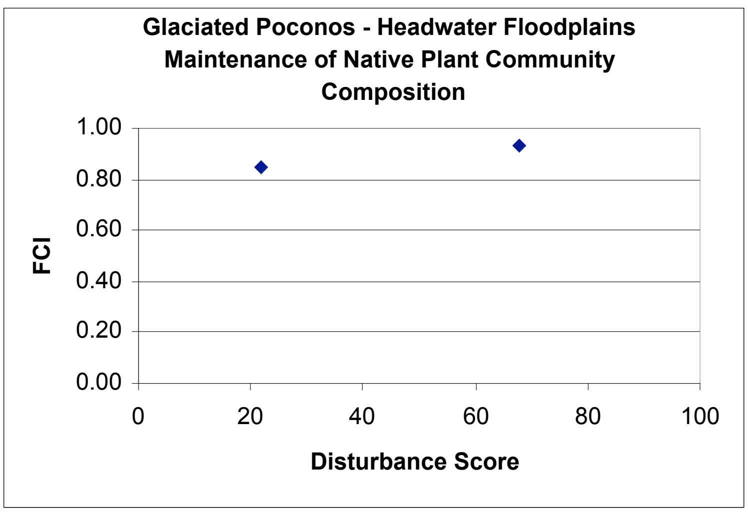


Figure 28.



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

Headwater Floodplains:

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

$V_{CWD\text{-}SIZE}$: 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 is:

Headwater Floodplains:

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

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

Subclass rigor

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} is calibrated based on conditions at sites with the least amount of human alteration. V_{ORGMA} is calibrated based on subclass-specific as well as ecoregion specific methods discussed in detail in Function 5. It is important that a site be classified correctly, due to these differences in scoring.

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). Figures 29-32 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 29-32. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 29.

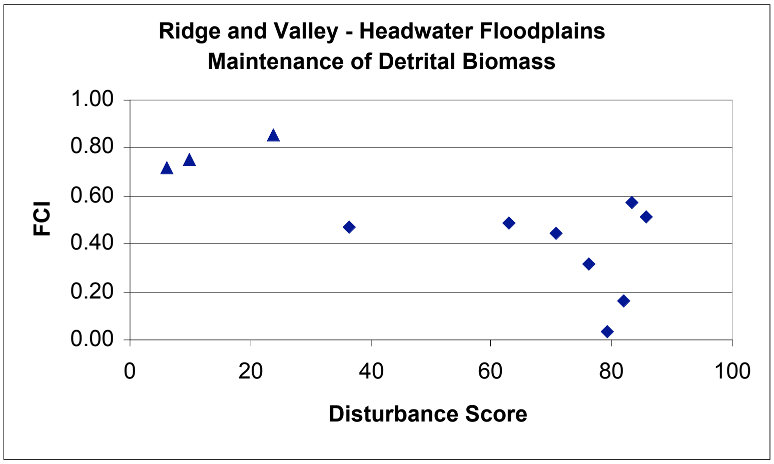


Figure 30.

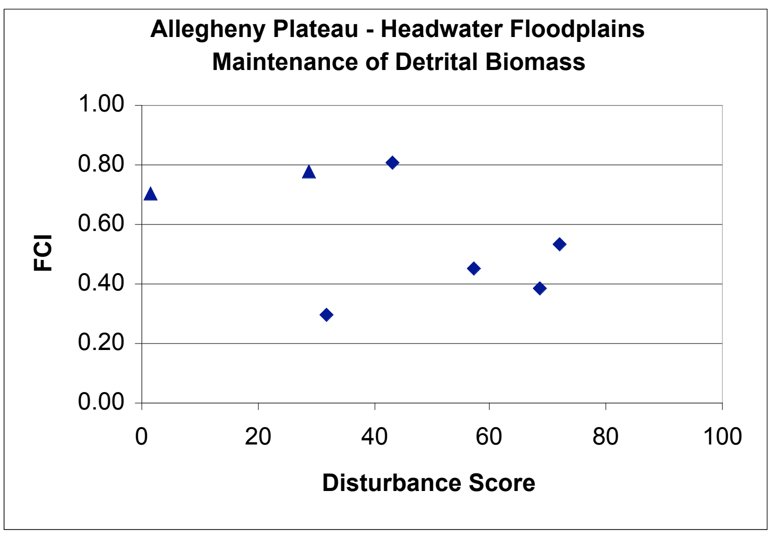


Figure 31.

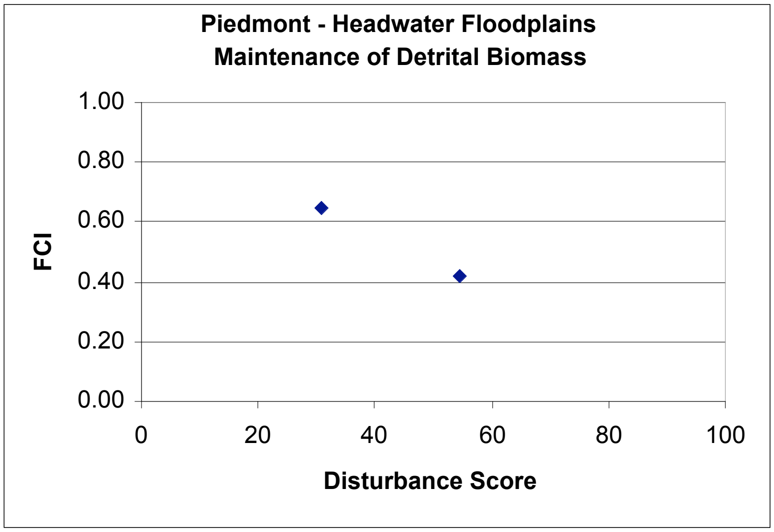
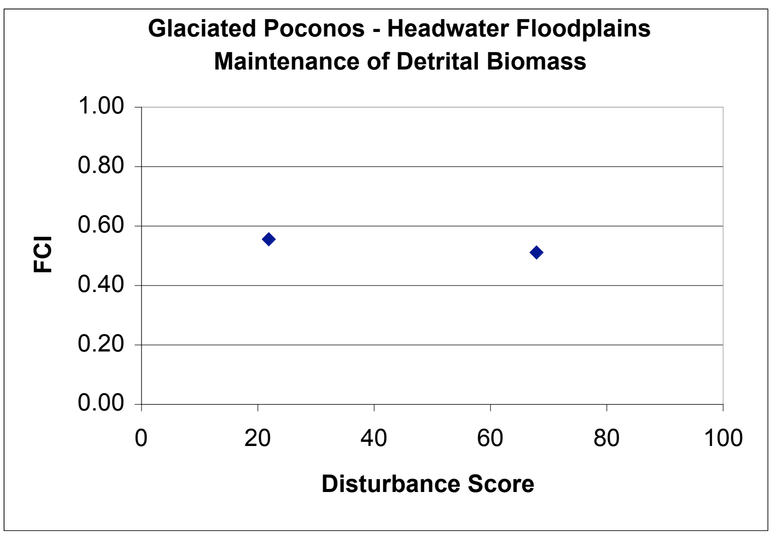


Figure 32.



Function 11. Vertebrate Community Structure and Composition

Definition and applicability

This function is assessed for the following regional wetland subclasses:

a. Riparian Depressions
b. Isolated Depressions
c. Slopes
d. Headwater Floodplains
e. Mainstem Floodplains
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 Section II.B.3.b.2 (Hydrogeomorphic Model Building Process).

Subclass rigor

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

Figures 33-36 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 33-36. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 33.

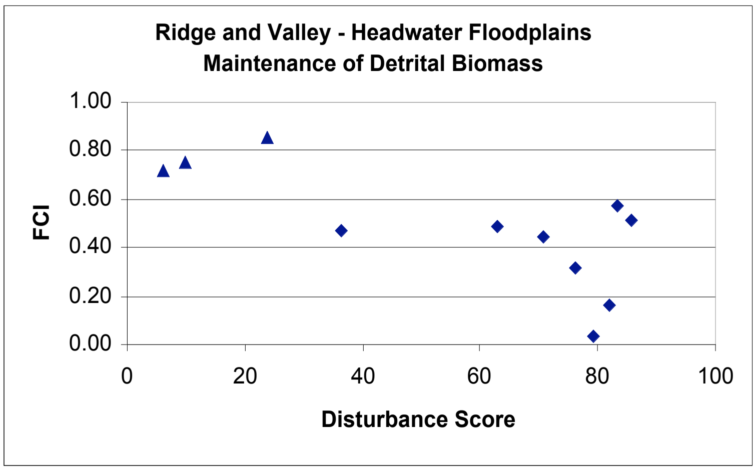


Figure 34.

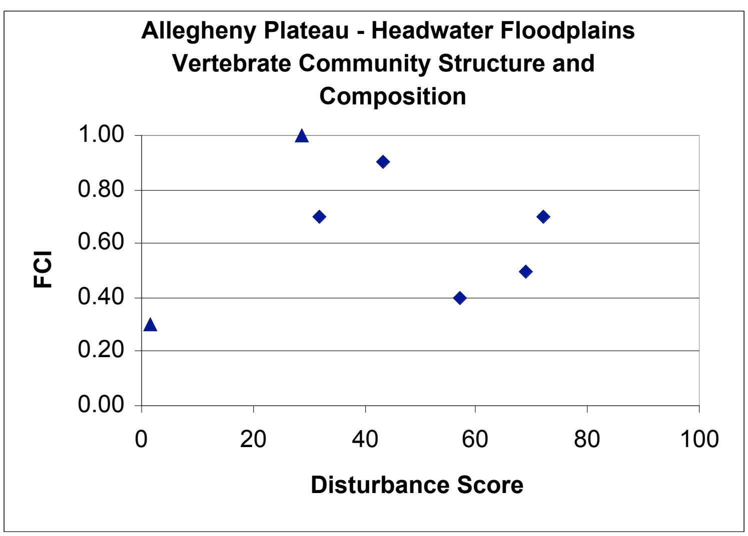


Figure 35.

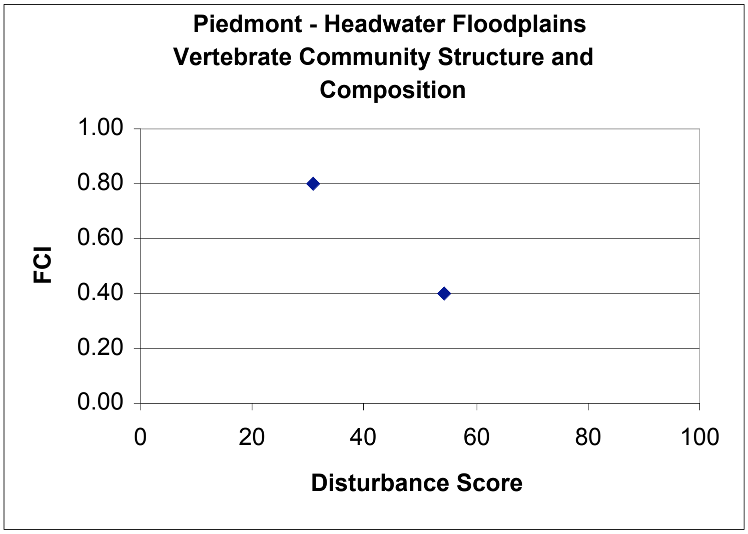
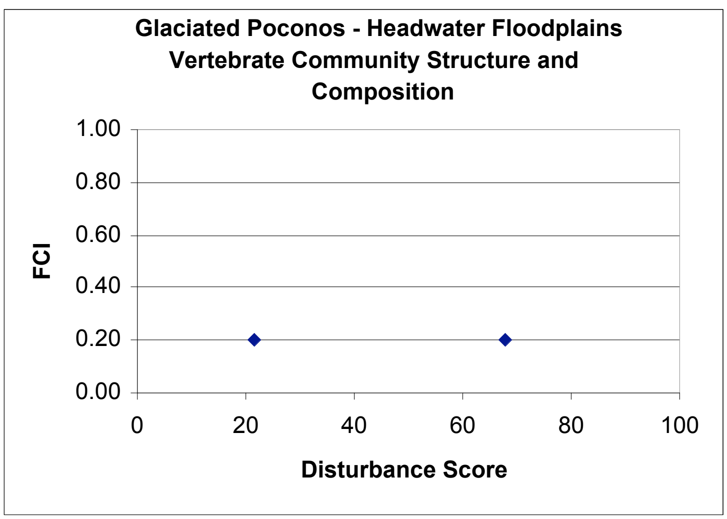


Figure 36.



Function 12. Maintain Landscape Scale Biodiversity

<u>Definition and applicability</u>

This function is assessed for the following regional wetland subclasses:

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

Headwater Floodplains:

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:

Headwater Floodplains:

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

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 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). Figures 37-40 show the relationship between the FCI and the degree of human alteration at the site, illustrating the how well the model responds to human disturbance for each ecoregion.

Figures 37-40. Relationship of Headwater Floodplain FCI and disturbance for sites in the Ridge and Valley, Allegheny Plateau, Piedmont, and Glaciated Poconos. _ = Reference Standard Sites

Figure 37.

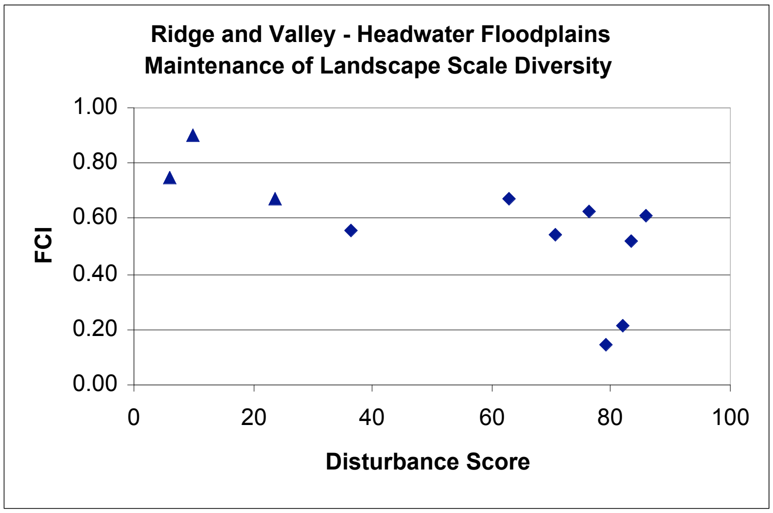


Figure 38.

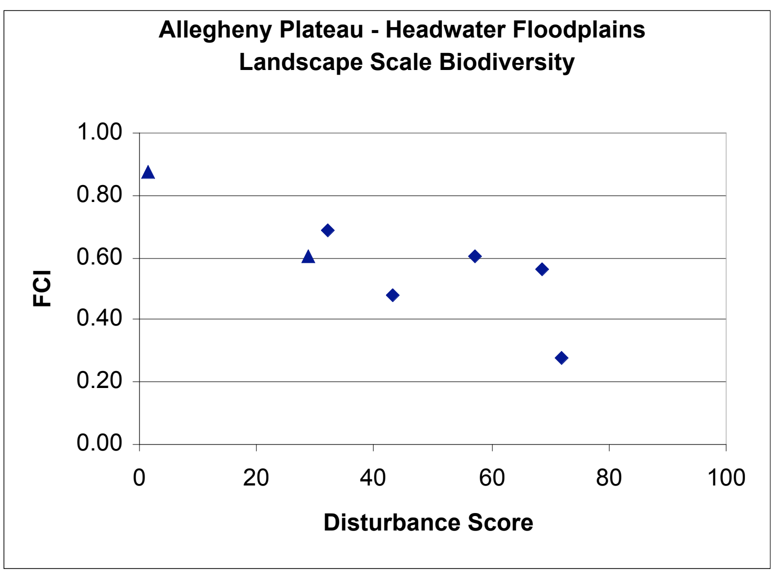


Figure 39.

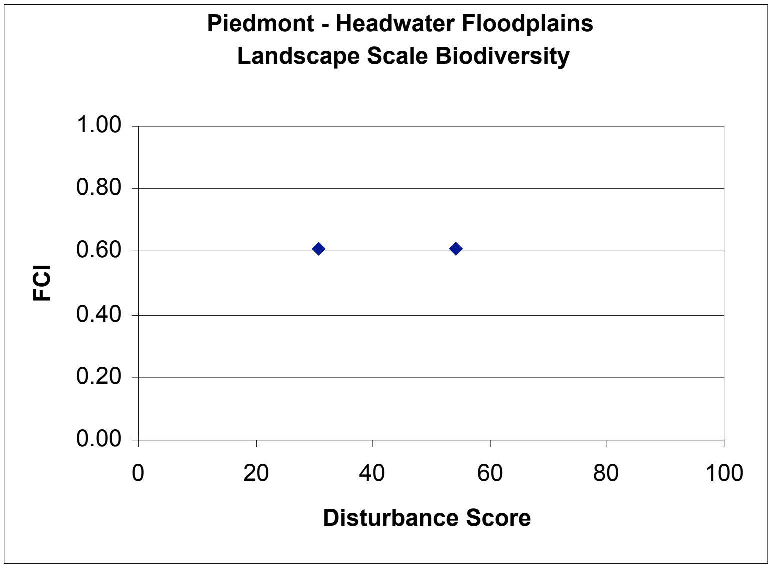
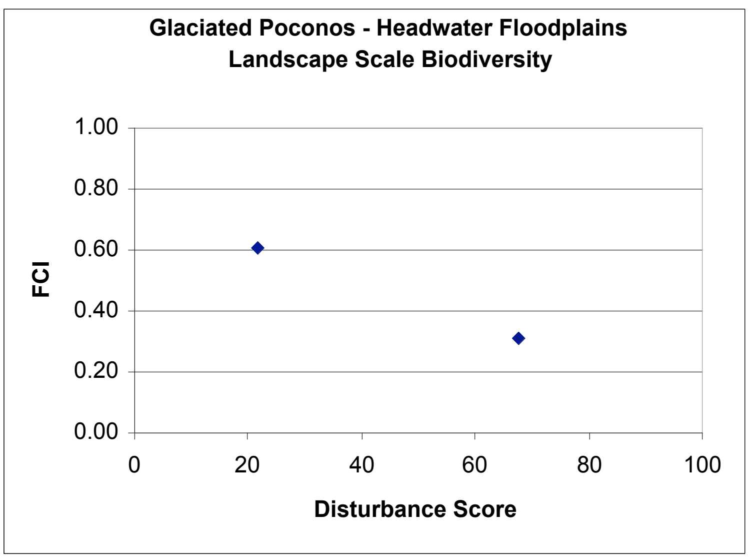


Figure 40.



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