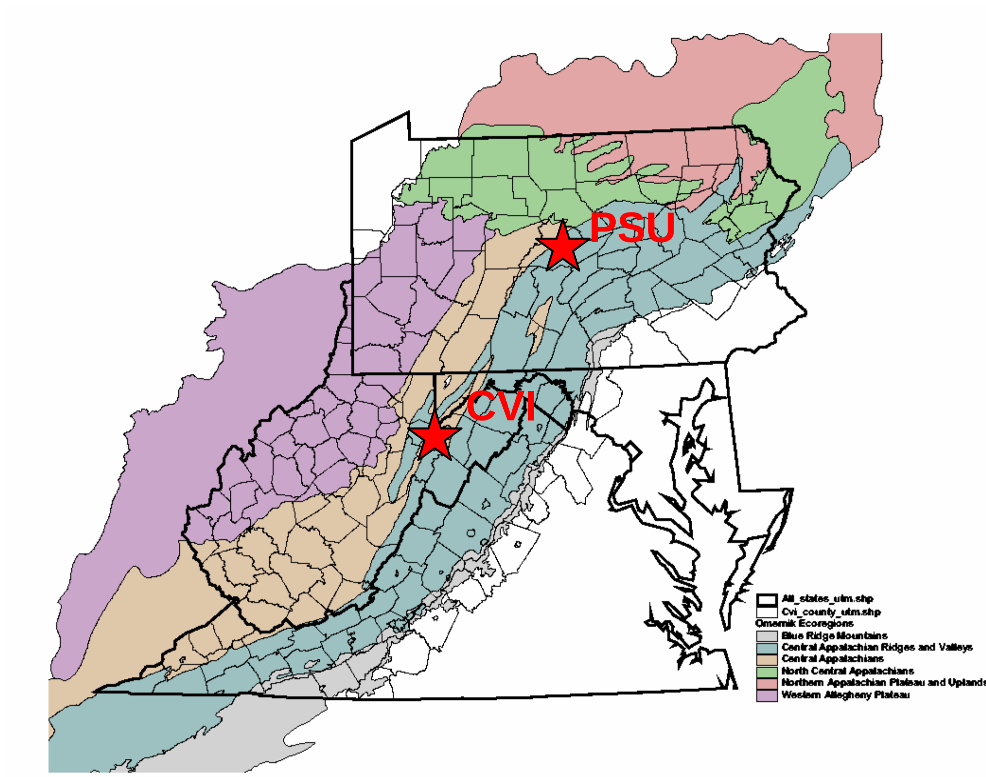
CLASSIFYING AND PRIORITIZING WATERSHEDS FOR PROTECTION AND RESTORATION

An Approach for the Mid-Atlantic Highlands Area



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Classifying and Prioritizing Watersheds for Protection and Restoration:
An Approach for the Mid-Atlantic Highlands Area

EXECUTIVE SUMMARY

Period Covered by the Report: 1 July 2002 – 30 June 2006
Date of Final Report: April 2007
EPA Agreement Number: R830593
Title: Classifying and Prioritizing Watersheds for Protection and Restoration
Investigators: Robert P. Brooks[1], G.P. Patil[2], and George D. Constantz[3]
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Research Category: Development of watershed classification systems for diagnosis of biological impairment in watersheds
Project Period: 1 July 2002 – 30 June 2006

Objective(s) of the Research Project:
To develop a standardized process for classifying and prioritizing watersheds, we proposed to:

- develop a geographically-independent classification system that links watershed characterization and prioritization,
- compile synoptic data for a set of relevant anthropogenic stressors for the region,
- use existing ecological data to validate our watershed classification system, and
- compare the rankings from our models to those of other classification approaches.

Summary of Findings (Outputs/Outcomes):
Natural resource managers need to be able to put watersheds into categories for several reasons, including identifying reference conditions, understanding types of environmental degradation, designing monitoring studies, and narrowing restoration options. In this project, we explored ways to develop and apply a hierarchical, geographically-independent classification of watersheds based on pre-existing environmental data. Our work was focused on the Mid-Atlantic Highlands Area, but has applications elsewhere.

Our approach in this project was to first construct a classification system that characterizes watersheds based on their inherent natural features (climate, soils, topography and hydrology). This resulted in the delineation of nine distinct clusters of watersheds for the region. We then developed an approach to prioritization that classifies watersheds according to human disturbance (primarily expressed through land cover) and their susceptibility to impairment from a variety of stressors, including land use, acidification, impervious cover, and nutrients.

Based on our research products and conversations with potential users, we discovered that the best way to "prioritize" watersheds was to use an interactive process. We produced maps of our nine cluster groups showing their spatial distribution in the region. These maps can be used by managers to recognize where and how their specific watersheds of concern fit into a larger landscape context. We

produced narrative descriptions of the nine watershed clusters that relate their inherent characteristics to their vulnerability of being impacted by a suite of stressors. This approach is preferred to one where researchers impose a prioritization scheme on potential users. This method also allows users to incorporate other information and data that address the invariably unique issues at hand for that single watershed or group of watersheds. Given that we delineated over 2,800 small watersheds in the study area, this seemed to be the most appropriate approach.

We tested the efficacy of our classification system across watersheds in the state of West Virginia, where the best synoptic measure of ecological integrity was available. Using measures of land use in the watershed and riparian corridor, and stream biological integrity, we found that that the nine clusters of watersheds were sufficiently differentiated that they showed variations in vulnerability to human-generated stressors. Vulnerability (ecological resistance) tended to have an inverse relationship with likelihood of land use impacts: high vulnerability watershed classes tended to have relatively low land use impacts, while low vulnerability watershed classes tended to have relatively high land use impacts.

Our recommendations to potential users are to locate watersheds of interest, determine their cluster membership, and then consider their vulnerability to expected stressors. By understanding the inherent characteristics that define each cluster, and considering the watershed's probable response to specific stressors, one can conceptually locate a watershed in the two dimensional space, portrayed in Figure 1 below. When it is necessary to prioritize among multiple watersheds, then the relative location of a watershed in that space will suggest which is most vulnerable and in need of attention first.

We believe this approach is simple for, adaptable to, and useful by managers, because it combines the best available information from scientific investigations with the knowledge and intentions of local stakeholders. Whether comparing among watersheds or varying condition within the same cluster type or across cluster types, this approach should generate a relevant list of prioritized watersheds. To assist users in developing a profile of watersheds of interest, we developed a Watershed Characterization and Prioritization Tool that allows users to graphically locate a watershed and obtain relevant information about its cluster membership and vulnerability. The contemplative process used to locate multiple watersheds in this conceptual space should be most helpful in deciding upon a course of action with regard to prioritizing watershed protection and restoration.

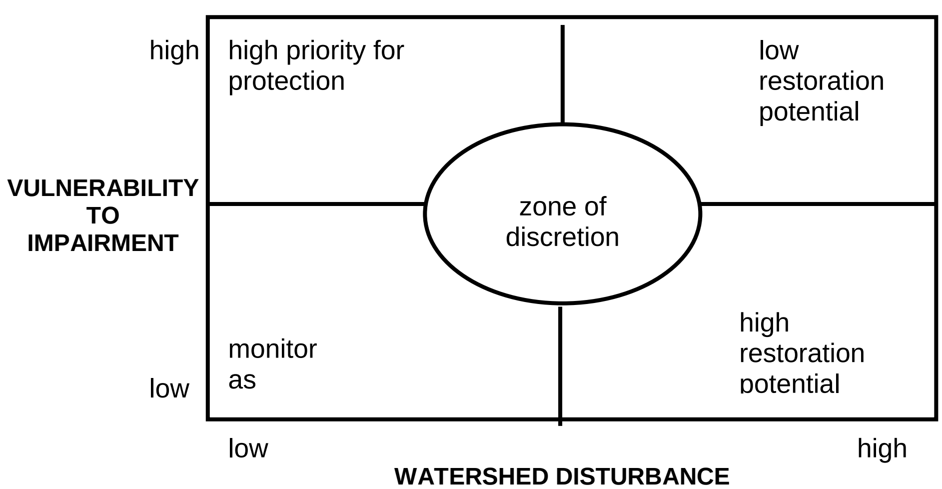

Figure 1. Conceptual framework for prioritizing watersheds for protection and restoration, according to their location in two-dimensional space defined by axes of disturbance and vulnerability to impairment.

Publications/Presentations:

Constantz, G., B. Rashleigh, B. Griscom, and A. McQueen. In prep. Associations between watershed characteristics and benthic macroinvertebrate communities in streams of the Central Appalachian Mountains. 36 ms. pages.

Griscom, B., G. Constantz, A. McQueen, and B. Rashleigh. In prep #1. Influence of elevation on West Virginia Stream Condition Index: vulnerability differences and calibration needs.

Griscom, B., A. McQueen, A. Bayard, R. Brooks, G. Constantz, G. Rocco, and W. Myers. In prep #2. Vulnerability of watersheds to acidification in the Mid-Atlantic Highlands.

Griscom, B., A. McQueen, R. Brooks, W. Myers, G. Constantz, M. Easterling, and J. Bishop. In prep #3. Spatial patterns of land use in the Mid-Atlantic Highlands: Factors affecting avoidance or concentration of human impacts in the riparian zone.

Griscom, B., A. McQueen, W. Myers, G. Constantz, R. Brooks, M. Easterling, G. Rocco, and J. Bishop. In prep #4. Classification of watersheds in West Virginia based on vulnerability of streams to human impacts.

Myers, W., G. P. Patil and Y. Cai. 2006. Exploring patterns of habitat diversity across landscapes using partial ordering. Pp. 309-325 in: R. Bruggemann and L. Carlsen, eds. Partial Order in Environmental Sciences and Chemistry. Berlin: Springer. 406 p.

Myers, W. L., M. McKenney-Easterling, K. Hychka, B. Griscom, J. A. Bishop, A. Bayard, G.L. Rocco, R. P. Brooks, G. Constantz, G. P. Patil and C. Taillie. 2006. Contextual clustering for configuring collaborative conservation of watersheds in the Mid-Atlantic Highlands. Environmental and Ecological Statistics 13 (4): 391-407.

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Classifying and Prioritizing Watersheds for Protection and Restoration: An Approach for the Mid-Atlantic Highlands Area

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SYNOPSIS

Natural resource managers need to be able to put watersheds into categories for several reasons, including identifying reference conditions, understanding types of environmental degradation, designing monitoring studies, and narrowing restoration options. In this project, we explored ways to develop and apply a hierarchical, geographically-independent classification of watersheds based on pre-existing environmental data. Our work was focused on the Mid-Atlantic Highlands Area, but has applications elsewhere.

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Based on our research products and conversations with potential users, we discovered that the best way to "prioritize" watersheds was use an interactive process. We produced maps of our nine cluster groups showing their spatial distribution in the region. These maps can be used by managers to recognize where and how their specific watersheds of concern fit into a larger landscape context. We produced narrative descriptions of the nine watershed clusters that relate their inherent characteristics to their vulnerability of being impacted by a suite of stressors. This approach is preferred to one where researchers impose a prioritization scheme on potential users. This method also allows users to incorporate other information and data that address the invariably unique issues at hand for that single watershed or group of watersheds. Given that we delineated over 2,800 small watersheds in the study area, this seemed to be the most appropriate approach.

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Our recommendations to potential users are to locate watersheds of interest, determine their cluster membership, and then consider their vulnerability to expected stressors. To make this process convenient for users, we produced a Watershed Characterization and Prioritization Tool that helps users locate graphically watersheds of interest and obtain both characterization data and an initial assessment of their vulnerability. By understanding the inherent characteristics that define each cluster, and considering the watershed's probable response to specific stressors, one can conceptually locate a watershed in the two dimensional space, portrayed in Figure S1 below. When it is necessary to prioritize among multiple watersheds, then the relative location of a watershed in that space will suggest which is most vulnerable and in need of attention first.

We believe this approach is simple for, adaptable to, and useful by managers, because it combines the best available information from scientific investigations with the knowledge and intentions of local stakeholders. Whether comparing among watersheds or varying condition within the same cluster type or across cluster types, this approach should generate a relevant list of prioritized watersheds. The contemplative process used to locate multiple watersheds in this conceptual space should be most helpful in deciding upon a course of action with regard to prioritizing watershed protection and restoration.

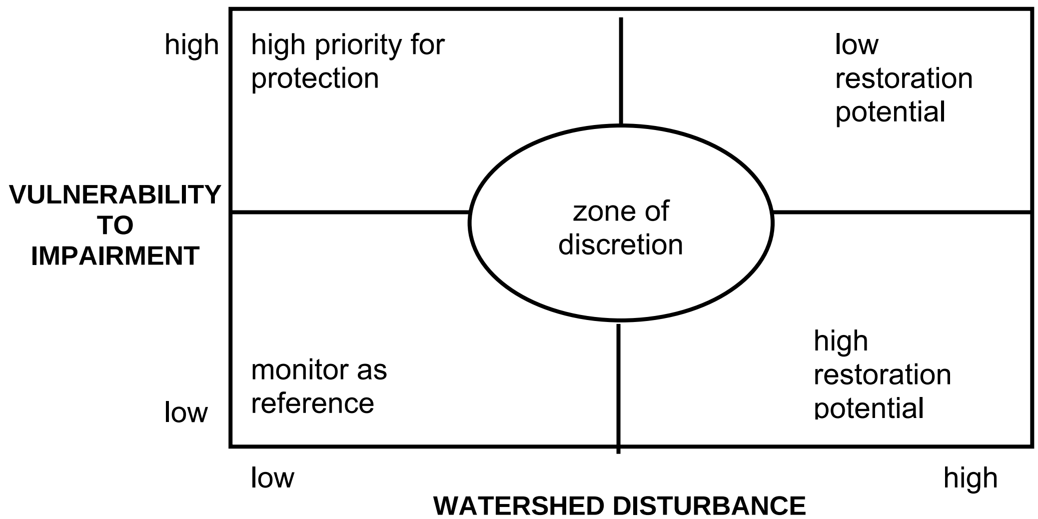

Figure S1. Conceptual framework for prioritizing watersheds for protection and restoration, according to their location in two-dimensional space defined by axes of disturbance and vulnerability to impairment.

Figure S2. Schematic flow chart of watershed characterization and prioritization analyses.

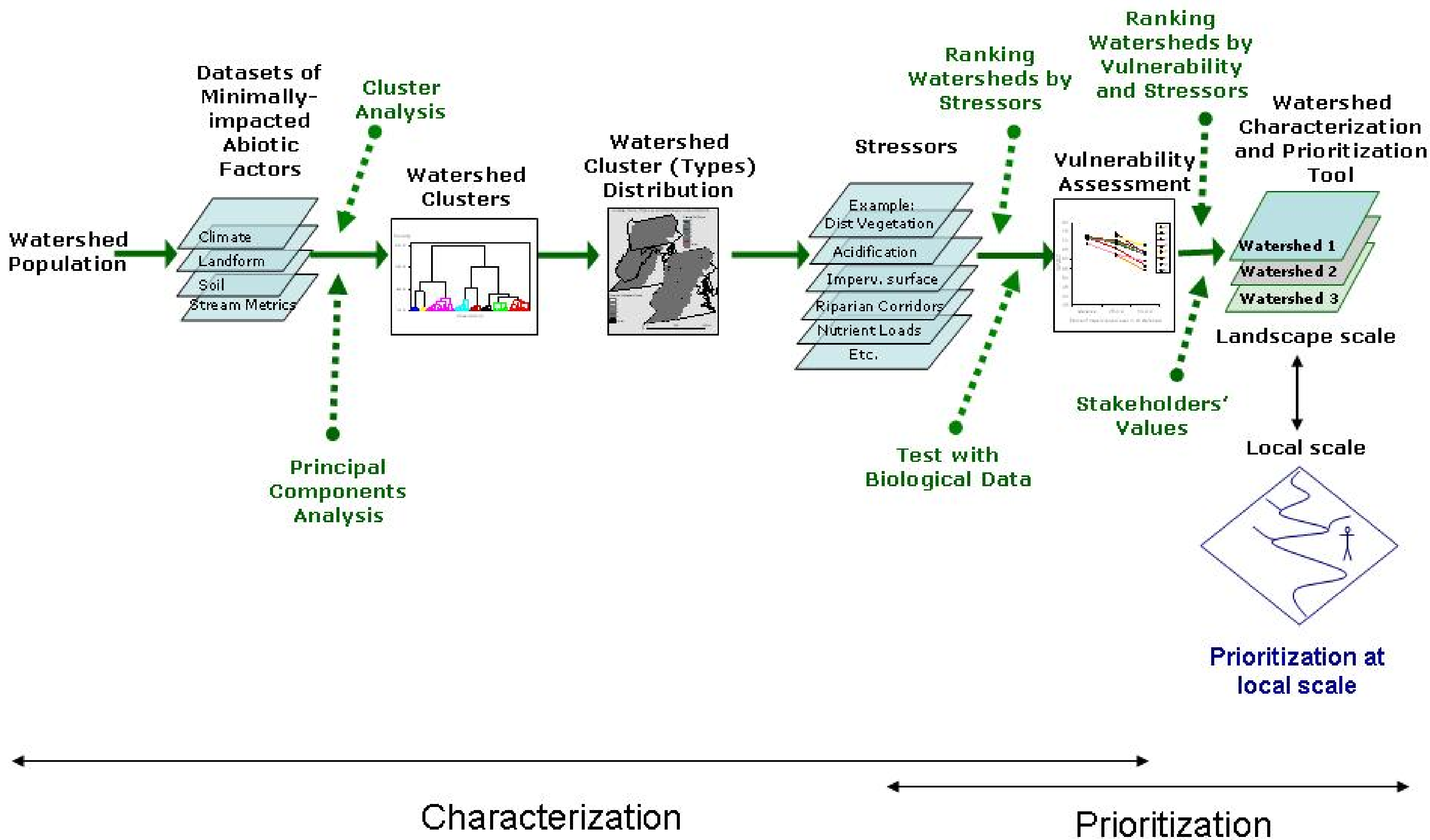

TABLE OF CONTENTS

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Robert P. Brooks and George Constantz, Co-Directors, April 2007

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INTRODUCTION

Rationale and Context

The US Environmental Protection Agency's (USEPA) expressed purpose for a watershed classification system is to "support the design of efficient monitoring strategies, diagnose the causes of biological impairment, and prioritize watersheds for restoration." Such a system should include conceptual models to explain and predict the relationships between land-use activities and the biological conditions within a watershed. Using Characterization and Prioritization models for the Mid-Atlantic Highlands, we developed a classification system that groups watersheds with similar physical characteristics and ecological stressors to provide scientifically defensible information for monitoring and management practices. This will provide managers with efficient tools to prioritize options and defend their decisions.

The degradation of surface waters has spawned responses to remediate both point and nonpoint pollution [e.g., Clean Water Act of 1972 (CWA), Chesapeake Bay Agreement]. Through implementation of the CWA and derivative state laws, "fishable and swimmable" conditions have been restored in some areas. The original intent of the CWA "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" [CWA 1972, Sec. 101(a)] is increasingly addressed as the USEPA encourages states to unify all three categories equally under a watershed umbrella. Threats to life, both human and other, continue to be major issues of concern. In this project, we assumed that the ultimate endpoints of management are to protect, maintain, and enhance both biological integrity and human quality of life in the study area.

The ecological health of a watershed reflects attributes of the transmission, storage, and release of water. The influences of climate, soils, and topography, for example, drive the channel's hydrologic and fluvial geomorphologic processes (Leopold et al. 1964, Lotspeich 1980). These processes in turn affect water quality, flow regime, physical habitat, food and energy sources, and biotic interactions (Karr and Chu 1998), which collectively affect biotic communities. The contributions of each of these factors will likely vary among ecoregions. For example, in the Southwest, groundwater and riparian vegetation may play larger roles in determining watershed condition than in the Adirondacks. To classify watersheds, we must identify the relative contributions of each attribute to the scale of interest which in turn will help managers understand the costs and benefits of management options (Claessen et al. 1994, Bradshaw 1998, Hawkins et al. 2000).

Based on indicators of biotic integrity, many Highlands streams are in poor condition (USEPA 2000a). Both the abiotic (Poff and Ward 1990, Johnson et al. 1997) and biotic (Harding et al. 1998) conditions of an aquatic community are affected by historic and current characteristics of its basin. Within the Highlands, some of the main stressors to local streams are excess sediment, riparian degradation, mine drainage, acid deposition, excess nutrients, and exotic species (USEPA 2000a). Region-wide stressors include loss of riparian habitat, farming in riparian areas and on steep slopes, road crossings, and forest fragmentation (Jones et al. 1997). Most streams are degraded by more than one stressor (Karr 1981, Minshall et al. 1983).

In light of multiple stressors, classification tools are useful to managers. These tools can be geographically dependent or independent, hierarchical or non-hierarchical, incorporate a fixed or sliding scale, and based on structure or function (Detenbeck et al. 2000). Examples of hierarchical, geographically dependent classifications include ecoregions (Omernik 1987, Bryce and Clarke 1996), aquatic regions (Maxwell et al. 1995), and functional groupings (Hawkins et al. 2000). Maxwell et al. (1995) grouped watersheds by indicators of watershed function, including geoclimate, zoogeographic pattern, watershed morphology, and disturbance history. To reveal function in a geographically dependent scheme, The Nature Conservancy developed a nested framework for biotic and abiotic aquatic classification based on two landscape-level regions and two levels of smaller-scale habitat characterization (Lammert et al. 1997).

Geographically independent, hierarchical classifications rely on stream hydrogeomorphic (HGM) structure (Rosgen 1996) and wetland HGM function (Brinson 1993). Imnof et al. (1996) developed a scheme based on physical processes that drive fish abundance. Other examples classify watersheds based on water chemistry and/or temperature (e.g., Richards 1990, Seelbach et al. 1997, Momen and Zehr 1998), and hydrology and geomorphology and/or sediment size (e.g., Whiting and Bradley 1993, Seelbach et al. 1997).

Several *a posteriori* classifications attempt to assess relative risks. For example, one scheme generates a risk index for watersheds based on aerial photos, topographic maps, and rapid bioassessment (Bryce et al. 1999). Another approach maps predicted risk of drought damage due to changes in water withdrawal and soil and groundwater conditions (Claessen et al. 1994).

Ecosystems are also classified by measures of ecological resistance, or the ability of the system to withstand perturbation (Forman and Godron 1986). Resistance, and resilience, which is the ability of a system to return to its original state after a disturbance (Gunderson 2000), are the primary determinants of ecosystem stability. Aquatic systems are dynamic, but if resistance is overwhelmed by disturbance, then its average long-term state changes (Reeves et al. 1995). Poff and Ward (1990) suggested that because stream communities reflect the history of disturbance they are resistant. Others have suggested that resistance is enhanced by material retention (Minshall et al. 1983) or storage capacity (Detenbeck et al. 2000). With these concepts and previous findings in mind, we developed the following objectives for this study.

Objectives and Approach

To develop a standardized process for assessment and restoration, we proposed to:

- develop a geographically-independent classification system that links watershed characterization and prioritization,
- compile synoptic data for a set of relevant anthropogenic stressors for the region,
- use existing ecological data to validate our watershed classification system, and
- compare the rankings from our models to those of other classification approaches.

Our approach was to construct a Characterization Model to classify watersheds based on their inherent natural physical features (climate, soils, topography and hydrology), which eventually resulted in the delineation of nine distinct clusters of watersheds for the region. Also, we had envisioned building a Prioritization Model to classify watersheds according to disturbance (primarily expressed through land cover) and their susceptibility to impairment from a variety of stressors, including land use, acidification, impervious coverage, and nutrients. Based on our research products and conversations with potential users, we discovered that the best way to "prioritize" watersheds was to produce maps showing the geographic distribution of those clusters throughout the region. Using those maps, managers can recognize where and how their specific watersheds of concern fit into a larger landscape context. We produced narrative descriptions of the watershed clusters that relate their characteristics to their vulnerability of being impacted by a suite of stressors. We also produced a Watershed Characterization and Prioritization Tool that helps users locate graphically watersheds of interest and to obtain relevant characterization data and an initial assessment of vulnerability.

This approach is preferred to one of where researchers impose a prioritization scheme on potential users. For example, some managers and users operate at the scale of a single watershed of a single type (e.g., municipalities, watershed associations), whereas others are responsible for larger regions encompassing many watershed types (e.g., regional natural resource managers and biologists, state agencies). Given this disparity of scale, the concerns and questions about vulnerability and restoration will be vastly different. By producing a synoptic classification involving both inherent characteristics and responses to stressors, potential users can apply the results to their best advantage.

To validate our classification system, our intent was to use data on multiple biological taxa to provide a diverse assessment of condition for each watershed. This proved more challenging than initially planned due to the use of disparate methods of both data collection and for the development of indices, and the lack of consistent variables across the entire region. So, as a test of concept, we applied our models to the data from the West Virginia portion of the Mid-Atlantic Highlands (Fig. 1) using a recently developed biological index; however, the process is applicable elsewhere.

Study Area

The USEPA's Request for Application encouraged applicants to develop classifications of understudied areas or well-studied areas that demonstrate a "proof of concept." Opting for a well-studied region, the Mid-Atlantic Highlands Area (MAHA), we proposed to develop a geographically independent system with potentially wider applicability.

The Highlands includes parts of 6 ecoregions and 4 states (Fig. 1), including the state of West Virginia, and the mountainous portions of Virginia, Maryland, and Pennsylvania. Ecoregions have been used to define the study area in terms of natural potential and variability, and response to stressors (Bryce et al. 1999) and are useful in characterizing spatial patterns of water quality (Griffith et al. 1999, Omernik 1995). The Highlands region supports some of the largest tracts and best examples of the Eastern Broadleaf Forest (Riitters et al. 2000). Trees, songbirds, land snails, salamanders, and freshwater mussels are highly diverse (Terwilliger 1991, Ricketts et al. 1999). The Highlands also support many unique natural features, as well as national parks and national forests.

In addition, the Highlands are changing. Population growth threatens natural resources along interstate highways and around urban centers. Mountaintop mining fragments interior forest in

West Virginia and Virginia, and surface and deep mining have led to chronic acid mine drainage in some areas. Invasive species and tree pathogens threaten oaks, beech, hemlock, and pines. Acid deposition, low-level ozone, and toxic ion deposition are also local stressors. Environmental stressors also affect the Highlands' socio-economic health through flooding, unplanned growth, lost economic development opportunities, and loss of farmlands.

In the Mid-Atlantic Highlands, federal agencies such as the USEPA, Natural Resource Conservation Service, U.S. Geological Survey, U.S. Army Corps of Engineers, National Park Service, U.S. Fish and Wildlife Service, and others play regulatory, management, and funding roles that affect over 27 million people (USEPA 2000a). The Highlands' states also regulate, manage, and fund myriad watershed activities. Nearly 300 counties, thousands of local governments, and hundreds of citizens' watershed associations and related groups need a logical system to understand issues, establish ecological and human health goals, tailor management approaches, and target resources for protection and restoration.

The Mid-Atlantic region contains over 25,000 stream miles designated as impaired (USEPA 2000). As required by the Clean Water Act, over 4,000 TMDL restoration plans are needed. A classification system that groups watersheds with similar features and problems would provide a scientifically defensible scheme to develop "off-the-shelf" monitoring and management practices. These methods could then be deployed proactively, potentially improving a stream's condition before TMDL development. For streams that may not receive TMDL remediation due to fiscal constraints, the stream's class would point to best management practices.

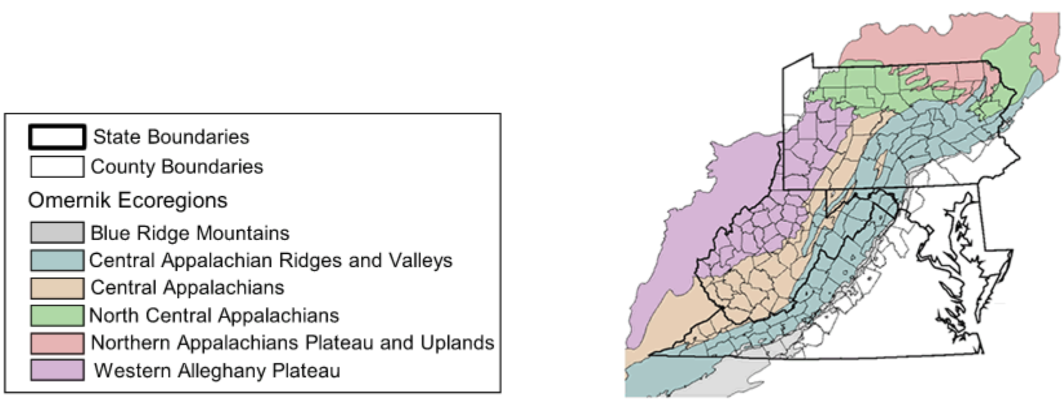


Figure 1a. The Mid-Atlantic Highlands study area includes the mountains and valleys of Pennsylvania, Virginia, Maryland, and West Virginia, plus areas of continuous watersheds.

The Highlands is a desirable region in which to develop watershed classification models because of its available landscape data and multiple, spatially explicit biological datasets. Potentially useful datasets are EMAP (USEPA 2000s) and landscape atlases (Jones et al. 1997), regional indicators of biological integrity (IBIs) such as the Bird Community Index (BCI) (O'Connell et al. 1998, 2000), an IBI for fish (McCormick et al. 2001), and other studies (Pan et al. 1999). Finally, the Mid-Atlantic Highlands Action Program (CVI 2002) has been formulated to encourage restoration activities in the region, including the development of technological and economic stimuli to promote a restoration industry. The availability of this type of tool should enhance the abilities of managers to address the many issues affecting aquatic resources in the region.

Our chosen scale of analysis for this study was that of a 14-digit Hydrologic Unit Code watershed, or "HUC-14" (Seaber et al. 1987). Prior studies and a review of the literature had indicated that this scale was the one at which management decisions are typically made (Brooks et al. 2006b). In the course of compiling a watershed GIS (Geographic Information Systems) layer for use in this project, we found that existing watershed delineations for each state varied widely in the average size of a given HUC unit. For example, watersheds in a HUC-14 delineation in Maryland averaged 3,155 hectares (ha), while in Virginia they averaged 21,749 ha; discontinuities across state boundaries presented additional challenges. We were concerned that computing watershed metrics on units of such disparate size would confound the results of our analyses. Therefore, we made the decision to generate "synthetic" watershed boundaries.

Watersheds were delineated with an automated ArcInfo AML program that used the National Elevation Dataset (USGS 1999a) and the National Hydrography Dataset (USGS 1999b) as inputs. The target size for watershed delineation was set at 17,000 acres, using stream intersections for defining watershed pour points. No watersheds were permitted to be smaller than 3,000 acres or exceed 50,000 acres. This program generated 2,830 watersheds with a mean size of 7,438 ha, a maximum size of 20,125 ha, and minimum size of 1,216 ha. Approximately half of the watersheds thus delineated were hydrologically self-contained (headwaters) while the other half import water from upstream watersheds ("pass-through" watersheds)(Figure 1b).

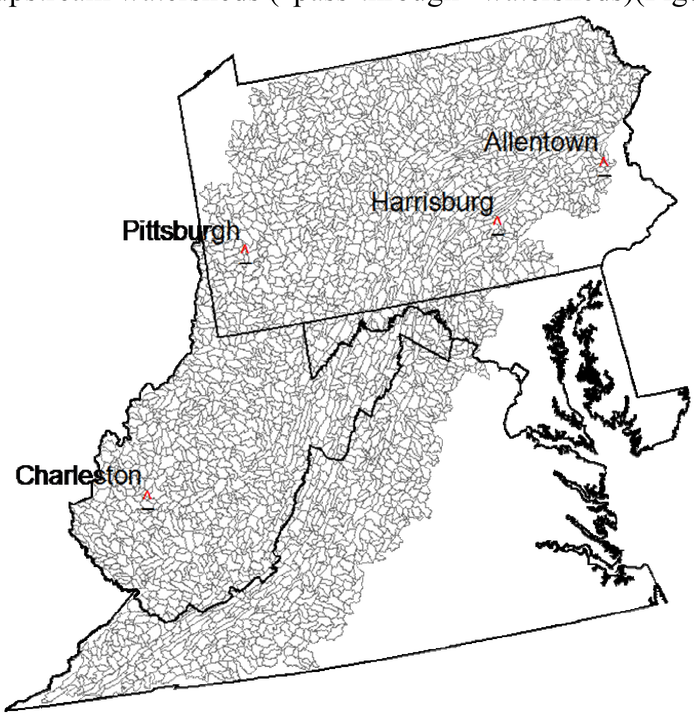


Figure 1b. The 2,830 watersheds we investigated for this study, delineated in grey.

CHARACTERIZATION BASED ON INHERENT ATTRIBUTES OF WATERSHEDS

Dataset Development and Exploratory Analyses

The project team used their combined expertise to develop an initial set of metrics based on expert judgment. These metrics were used to define "inherent" classes of watersheds - that is, watersheds that are expected to respond in a similar manner to anthropogenic stressors. Candidate metrics fell into four categories: landform, soils, climate, and hydrologic characteristics. The full set of potential metrics that was computed and considered is listed in Appendix A.

Cluster analysis (MINITAB 2000) was chosen as the statistical technique for stratifying watersheds into groups with similar characteristics. A detailed account of our clustering can be found in Myers et al. (2006 – see Appendix B, #7). Our initial analyses were conducted with the set of 1297 headwater watersheds alone on the premise that, since the source of water is fully contained within the watershed, the relationship between watershed characteristics and water quality should be more direct (Brooks et al. 2006a).

To prepare the data for cluster analysis we developed a set of "clean and screen" procedures (Myers et al. 2006). We eliminated outliers through examining the results of Principal Components Analysis (PCA) (MINITAB 2000). We also eliminated redundant variables in the dataset using guidance from the results of correlation analysis, parallel coordinate plots, and weighting coefficients for the principal component axes. We had three criteria for choosing among strongly related variables: (1) ease of interpretability, (2) inherent accuracy of the underlying information, and (3) computational tractability. Following the above clean and screen operations, 14 variables each were retained in the landform and soils datasets, 9 variables in the climatic set, and 11 variables in the hydrologic set. These variables are shown in Table 1.

We first performed cluster analyses using each variable set individually. The decision of how many cluster groups to recognize was made by examining both the dendrograms and cluster similarity values, to find the level at which the number of groups increased rapidly. We chose the number of groups just before the point of rapid increase, generally aiming for 5 to 10 groups. These groups were then mapped. We found that groups based on the soils and climate variables showed more highly regionalized spatial patterns than those based landform and hydrologic variables (see Figures 2a-d below).

Next, we explored different methods for combining the variable sets, including (1) simply combining all variable sets, and (2) joint classification of the landform and hydrologic variables, since these two sets of variables were the least regionalized, and had the potential of together providing information that would allow a finer delineation of the broader patterns defined by the climate and soils classifications.

Following the exploratory analyses using the group of headwater watersheds only, we turned to the group of "pass-through" watersheds to investigate their characteristics relative to the variable sets considered. We first conducted clustering using the set of

Table 1. Variables used with cluster analysis to define inherent watershed groups.

Data type	ID	Variable
Phys/topo	area	Watershed area
Phys/topo	elevmean	Mean elevation of watershed
Phys/topo	elevrange	Elevation range in watershed
Phys/topo	slopemean	Mean slope of watershed
Phys/topo	slopemax	Maximum slope in watershed
Phys/topo	mpar	Mean perimeter:area ratio
Phys/topo	mpfd	Mean patch fractal dimension
Phys/topo	ctimax	Maximum compound topographic index
Phys/topo	ctimin	Minimum compound topographic index
Phys/topo	curvemin	Minimum local curvature
Phys/topo	curvemax	Maximum local curvature
Phys/topo	curvemean	Mean local curvature
Phys/topo	flowmean	Mean flow accumulation
Phys/topo	mcnabmean	Mean of Mcnab topographic index
Soil	clay_dwa	Depth-weighted average % clay
Soil	silt_dwa	Depth-weighted average % silt
Soil	PH_dwa	Depth-weighted average pH
Soil	perm_dwa	Depth-weighted average permeability
Soil	awc_100aw	Area-weighted available water capacity
Soil	bd_dwa	Depth-weighted average bulk density
Soil	poros_dwa	Depth-weighted average porosity
Soil	kfacta	USLE erosion k-factor without rocks
Soil	kkfacta	USLE erosion k-factor with rocks
Soil	hsgaa	Area % in hydrologic soils group A
Soil	hsgba	Area % in hydrologic soils group B
Soil	hsgca	Area % in hydrologic soils group C
Soil	hsgda	Area % in hydrologic soils group D
Soil	hsgwa	Area % in hydrologic soils group W
Climate	annff	30-yr average annual frost-free period
Climate	anngdd	30-yr average growing degree days
Climate	jan_mar_pr	30-yr average Jan-Mar precipitation
Climate	apr_jun_pr	30-yr average Apr-Jun precipitation
Climate	jul_sep_pr	30-yr average Jul-Sep precipitation
Climate	oct_dec_pr	30-yr average Oct-Dec precipitation
Climate	tmax_jul	30-yr average max July temperature
Climate	tmin_jan	30-yr average min January temperature
Climate	annsnow	30-yr average annual snowfall
Hydro	sinuos_avg	Sinuosity
Hydro	chan_slp_avg	Mean channel slope
Hydro	sd_ch_slp	Standard deviation of channel slope
Hydro	node_dens	Density of stream network nodes
Hydro	strm1_pct	Stream length % first-order
Hydro	strm2_pct	Stream length % second-order
Hydro	strmlen_tot	Total stream length
Hydro	strmdens_tot	Total stream density
Hydro	strmdns1	Density of first-order streams
Hydro	strmdns2	Density of second-order streams
Hydro	seg_len_avg	Average stream segment length

mainstem" hydrologic variables that were relevant only to this group of watersheds. Our "clean and screen" procedures, described above, were applied to this variable set prior to clustering. The general spatial pattern of the clustering was fine-grained and not highly regionalized, similar to that seen for the headwater watershed group. One interesting pattern observed with the mainstem group of variables was the presence of a cluster group that appeared to represent large river watersheds.

Since, ultimately, we wanted a classification that included all watersheds in the study area, our next step was to re-combine the headwater and pass-through watershed groups. Furthermore, we also saw no compelling differences between the two subsets of watersheds in their classification, based on the analytical techniques and set of variables used in this study. (This is not to imply that these two types of watershed lack differences, but rather that these differences were not highlighted by the methods used in this study.)

Development of Candidate Classifications

Based on our previous results we conducted the clustering in several different ways: (1) separate clusterings for each variable set, (2) separate clusterings for different pairs of variable sets, including the regional variables (soils and climate), the more localized variables (physical and hydrologic), and the soils and physical variables, and (3) with all variable sets combined. (The hydrologic variables used in these analyses were those that were common to both headwater and pass-through watersheds – i.e., the set of "tributary" variables.) The results of these cluster analyses are shown in Figures 2a – h and Figure 3.

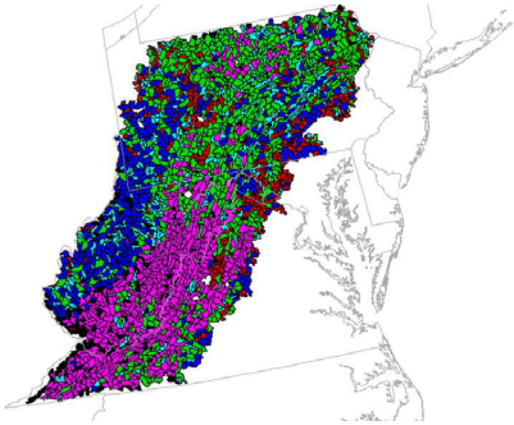
We made the assumption that the cluster groupings with all variables sets considered would yield the best representation of watershed vulnerability to stress. We describe a test of this hypothesis in the Vulnerability section of this report. Ultimately, we chose the nine-cluster version ("AllMet9") to carry forward in our analyses.

Naming of the Nine Clusters

Once watersheds were classified into groups and mapped, descriptive names were assigned to each group (Table 2). Although the groups were delineated based on 48 variables, a smaller subset of variables was chosen to name the groups. The variables chosen are common watershed descriptors that can be related to land use and vulnerability of watersheds, including temperature, precipitation, soil infiltration, soil erosion, soil texture, soil pH, elevation, slope, and stream density. Additionally, the location of each group of watersheds within the Mid-Atlantic Highlands and the geologic processes that contributed to the formation of each group was also considered in the naming process (e.g., Dry Glaciated Northeast).

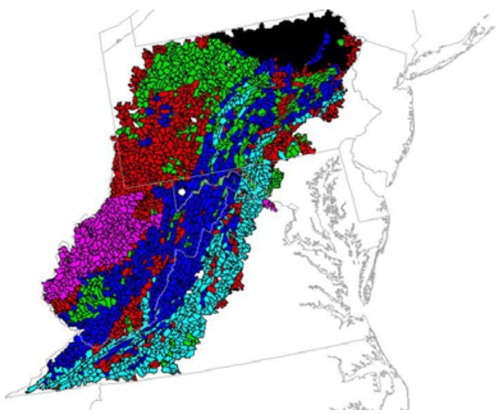
In order to identify which of the previously listed variables differentiated one group from another group, box plots summarizing each variable by cluster were analyzed and named/described accordingly. For example in Figure 4, class numbers 1, 2, and 9 appear to have lower temperatures and class number 6 appears to have higher temperatures compared to the other classes. These low temperatures for classes 1, 2, and 9 and high temperatures for class 6 are reflected in their names and/or descriptions (Table 2). A detailed description of each watershed class is presented later in this report.

Figures 2a-h. Alternative watershed classifications for the Mid-Atlantic Highlands Area. Labels refer to the types of variables included in the cluster analysis.

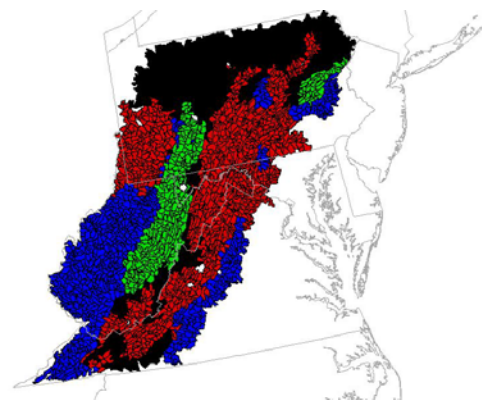


2a - Physical/ topographic variables.

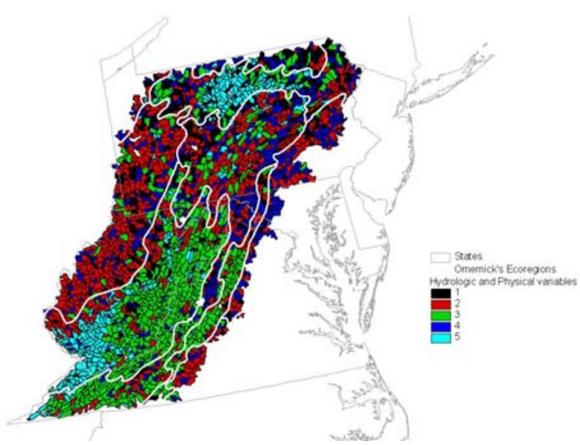
2b - Hydrologic variables.



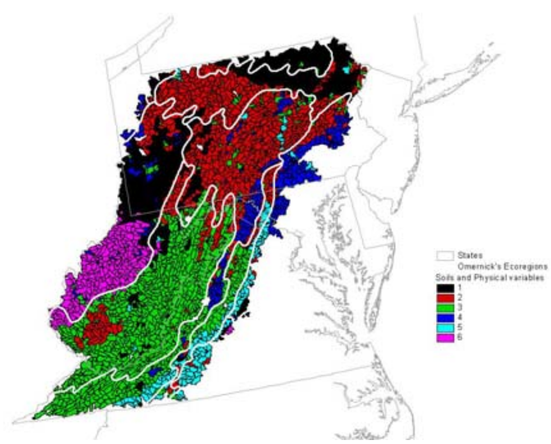
2c - Soils variables.



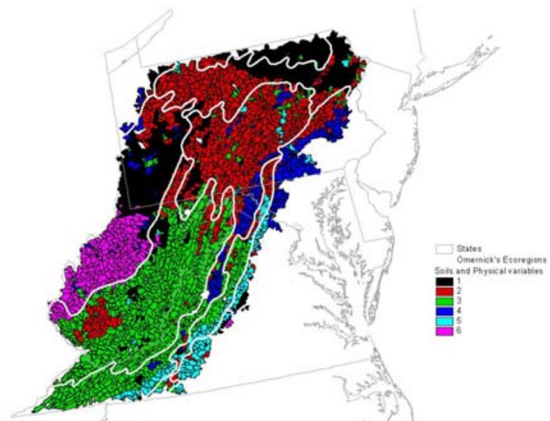
2d - Climate variables.



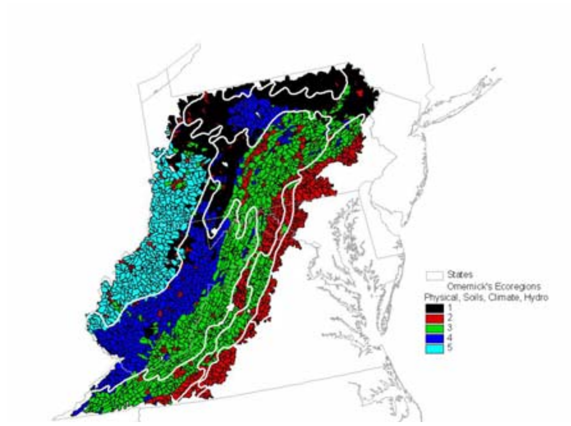
2e - Physical/ topo and hydrologic variables.



2f - Climate and soils variables.



2g - Physical/ topo and soils variables.



2h - Physical/ topo, soils, climate, and hydrol. variables: 5 clusters

Figure 3. Watershed classification using all variable sets (physical/ topographic, soils, climate, and hydrologic), with 9 clusters defined (= "All Met9"). This, ultimately, was selected as the classification that best captured patterns of vulnerability in the Mid-Atlantic Highlands Area. The associated dendrogram is also shown.

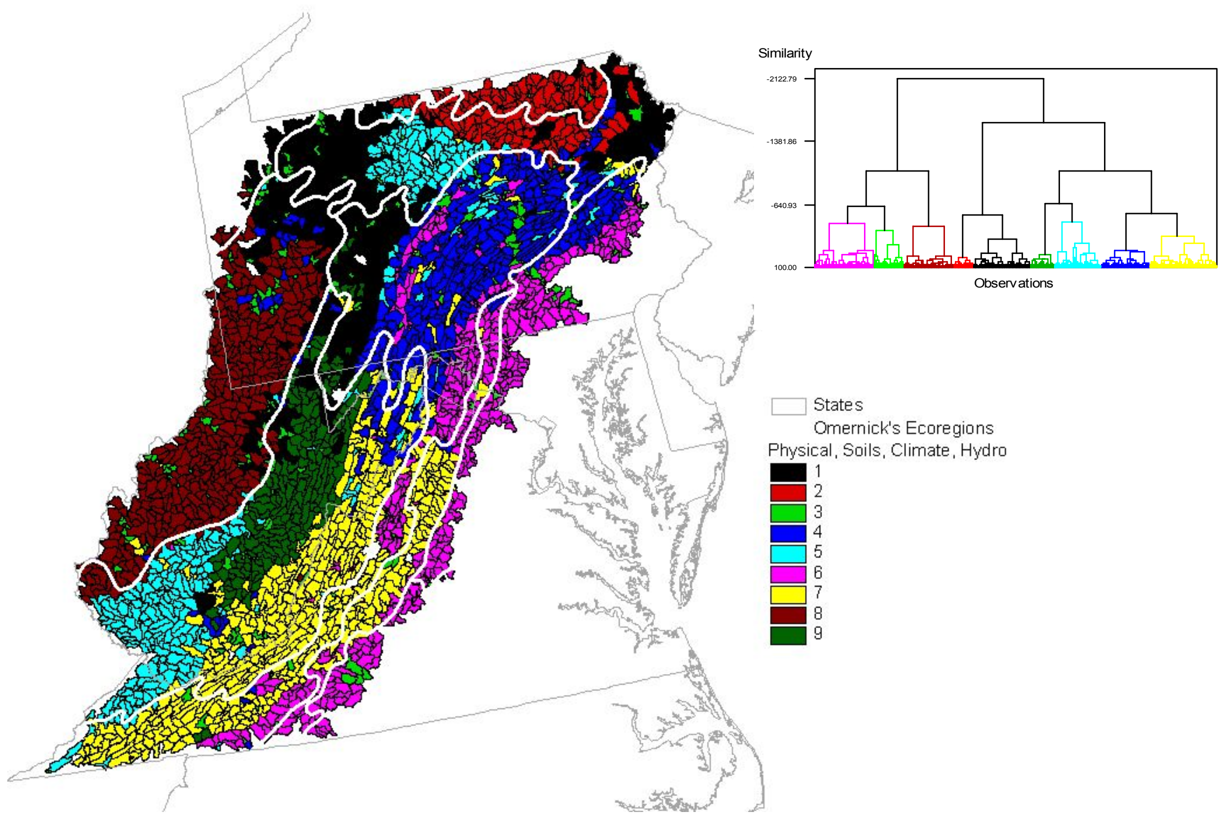


Figure 4. Example of box plot used in cluster naming process.

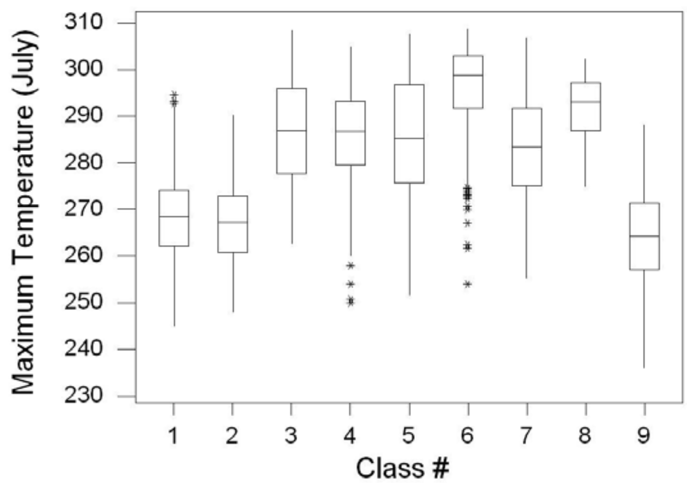


Table 2. Designated names and a brief description of each of the 9 cluster groups shown in Figure 3.

Class No	Name	Description
1	Cold Wet Flats	Climate cold and wet. Landform flat with low soil infiltration
2	Dry Glaciated Northeast	Glaciated. Soils low infiltration, high silt. Climate cold and dry
3	Floodplains	Pass-through watersheds with high percent area in floodplain
4	Moderate Mountains	Watersheds intermediate in all variables.
5	Canyon Lands	Steep, rugged landform with least erodible soils.
6	Fertile Plains	Fertile soils, warm climate, flat and low landform.
7	Steep Dry Mountains	Dry, high elevation range and high stream density.
8	Clay Hills Plateau	Basic, clayey soils and narrow elevation range.
9	High Wet Mountains	High, cold, wet, and steep.

CHARACTERIZATION OF STRESSORS

Our next task was to examine the pattern of stressors in the region. This would allow us, ultimately, to look at the relationship between stressor strength and watershed condition - that is, the “dose-response” relationship. The sensitivity of this relationship can be considered a measure of watershed vulnerability to stress. We compiled a list of potential watershed stressors in the study region, for which synoptic data layers could be formulated. Based on work by Adamus and Brandt (1990), we considered enrichment/eutrophication, biological oxygen demand, contaminants, acidification, sedimentation, turbidity, vegetation alteration, thermal alteration, hydrologic modification, and habitat fragmentation, among others. The goal was to interpret the magnitude of these stressors with existing remotely sensed data. Some were clearly incompatible with remote data, and are more appropriate for site-level investigations.

From this list of potential stressors, candidate stressors were chosen based on the collective expertise of the project team, taking into consideration the availability of suitable GIS layers and other data to describe that stressor. Most of the stressors were derived directly from land cover/ land use, with the exception of acidification and nutrient concentrations in streams, because the former encapsulate long-term and short-term impacts from earth disturbances and land cover conversions. The 1992 National Land Cover Dataset (NLCD, USGS 1999c) served as the primary source for computing values of the land cover-related metrics. Most stressors were developed at the spatial unit of the HUC-14 watershed; however, we also gave some attention to the spatial pattern of stressors within the watershed, comparing riparian zone land use with that of the watershed as a whole. Table 3 presents a list of the stressors examined. Details of GIS data set development and data sources can be found in Griscom et al. (in prep #2, in prep #3 - see Appendix B).

Table 3. List of candidate stressors. The spatial unit for all is the HUC-14 watershed (WS), unless otherwise noted.

Stressor	Abbreviation	Units
Land cover-based, Watershed Scale:		
Impervious Cover	WSIC	%
Disturbed Vegetation	WSDV	%
Disturbed Cover (= IC + DV)	WSDC	%
Landscape Development Index	LDI	Dimensionless
Percent Agriculture	WSAG	%
Percent Mining	WSMINE	%
Land cover-based, Sub-watershed Scale:		
Impervious Cover in Riparian Zone	RZIC	%
Disturbed Veg in Riparian Zone	RZDV	%
In-stream measurements or estimates:		
Acid Neutralizing Capacity	ANC	µeq/L
Nutrients and Total Suspended Solids	N, NO_3, NH_4, P, TSS	Various

Land Cover Stressors - Watershed Scale

Impervious Cover (WSIC)

Impervious cover was defined as anthropogenic land cover types that are not pervious to water (e.g., pavement, roofs). Percentages of impervious cover per watershed were generated using a combination of 1992 NLCD land use data and 2000 U.S. Census Road data. Details of computation are given in Griscom et al., in prep #3)

Disturbed Vegetation (WSDV)

Disturbed vegetation was defined as all other classes of anthropogenic land use that are presumed to be water pervious and, in most instances, are in some form of modified early serial plant regeneration (e.g., agriculture, transitional, lawns, barren).

Disturbed Cover (WSDC)
Disturbed cover includes both IC and DV. According to the literature, IC and DV have very distinct impacts on watershed condition, thus we separated the two for some analyses. However, for the purpose of quantifying the overall proportion of watersheds that has native cover vs. human-impacted cover, they were lumped into a single variable, DC.

Percent Agriculture (WSAG)
Percent agriculture was calculated as the percentage of the watershed in pasture or row crops (NLCD classes 81 (pasture/hay) and 82 (row crops)).

Percent Mining (WSMINE)
Percent mining is defined as the percentage of 1992 NLDC Class 32 (quarries/strip mines/gravel pits) in the watershed.

Land Development Index (LDI)
This index, developed by Brown (2005), is an expression of the intensity of landscape development. Values of LDI were computed using NLCD 1992 land cover data, and coefficients developed by Brown (2005).

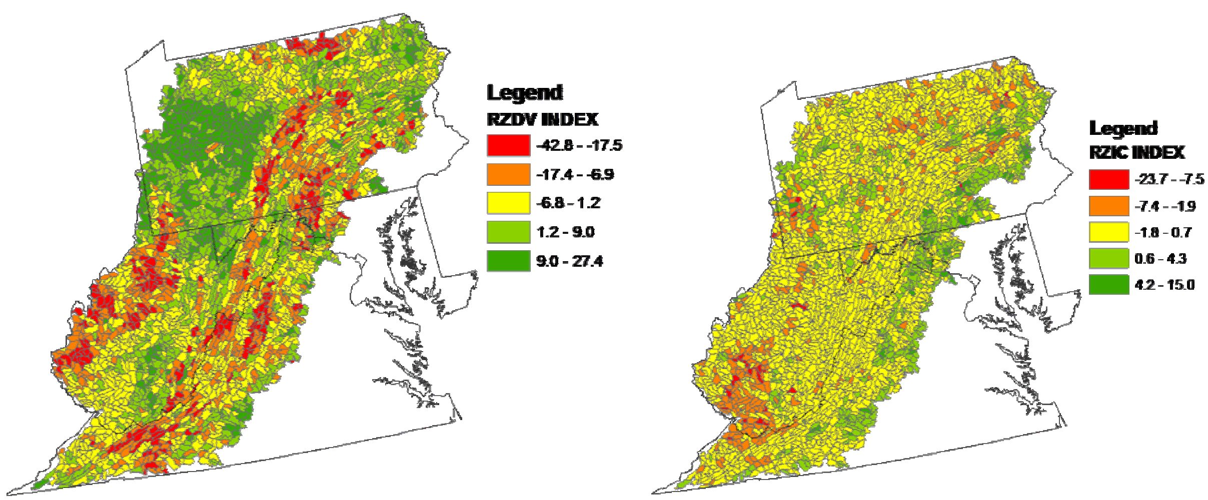
Land Cover Stressors – Sub-watershed Scale

Riparian Zone Indices
A central tenet of conservation biology is that the spatial distribution of land use has implications for landscape ecological integrity (Alberti 2000, Forman 1995). The riparian zone with native vegetation is a landscape element of particular concern as both a zone of high biological diversity and a zone of critical hydrologic function including water purification and flood attenuation, so we focused our pattern analysis on this proximal and essential feature of aquatic resources. We hypothesized that spatial patterns of land use are non-random with respect to the riparian zone, and developed indices that describe the extent to which a given land use type tends to either avoid the riparian zone or prefer the riparian zone. We investigated spatial patterns of two broad categories of human land use: impervious cover (IC) and disturbed vegetation (DV).

We chose to define the riparian zone based on the average width of the floodplain for each stream order (Strahler 1964). Available FEMA Q3 digital floodplain maps were combined with a synthetically generated stream network in GIS to calculate average 100 year floodplain widths. As expected, riparian zone or floodplain width generally increases with stream order.

We developed indices that express spatial distribution of the two land use categories (IC and DV) with respect to the riparian zone independent of the total intensity (proportion) of land use across a watershed. Best-fit curves were identified that explained the highest proportions of variation (highest r^2) in the relationship between percent land use (IC or DV) within whole watersheds (x-axis) vs. percent land use within the riparian zone of watersheds (y-axis). Indices were developed from the residuals of variation in riparian zone percent land use (IC and DV) that was not explained by variation in whole watershed land use. These two indices are termed the "Riparian Zone Impervious Cover (RZIC) Index", and the "Riparian Zone Disturbed Vegetation (RZDV) Index". Thus, the degree to which the indices are above or below zero represents the degree to which land use types (IC or DV) have a spatial distribution with respect to the riparian zone that is different than the central tendency for any given range of land use within watersheds.

On average across the Mid-Atlantic Highlands, we did not detect a tendency for disturbed vegetation to avoid or be concentrated in the riparian zone. In contrast, impervious surface land use classes (IC) tend to be concentrated in the riparian zone: percent IC in the riparian zone is on average about 1.5 times that for watersheds as a whole. Figures 4 a & b show the spatial distribution of these two indices. See Griscom et al. (in prep #3 – Appendix B) for a more complete description of the development of these indices, as well as some related analyses. For example, based on the data results from the above methods, we describe characteristic land use spatial patterns for each inherent class, and identify individual watersheds that represented examples of characteristic land use patterns.



Figures 5a & b. Maps of RZDV and RZIC indices for Mid-Atlantic Highlands Area.

In-stream Stressors: Direct Measurements or Predictions of Water Quality Parameters

Acidification/ ANC

Acidification has a direct and strong impact on the diversity and productivity of aquatic fauna in streams of the Mid-Atlantic Highlands. Atmospheric deposition is considered the largest cause of acidification in this region (Herlihy et al. 1993), followed by acid mine drainage. Although prior studies have made some estimates of the extent of acidification in the region (e.g., Herlihy et al. 1991, Herlihy et al. 1993, USEPA, 1994), we are not aware of any analysis that estimates acidification of stream networks due to both atmospheric deposition and/or acid mine drainage in a spatially explicit manner.

To address this data shortfall we developed regression models that predict stream acid neutralizing capacity (ANC), which indicates degree of stream acidification and vulnerability to further acidification. These predictions are based on watershed characteristics which can influence acidification, including: geology type, area, soil pH, soil texture, depth to bedrock, presence of acid mine drainage, acidity of atmospheric deposition, amount of agriculture, and amount of forest.

Stream ANC is predicted at the pour-point of watersheds 40 – 200 km^2 in size. This size range tends to be relevant to watershed groups in the region, and is at the higher end of the range of stream sizes affected by acidification (Kaufmann et al. 1991, Herlihy et al. 1993). A detailed description of the development of these regression models can be found in Griscom et al. (in prep #2 - Appendix B). Figure 6 presents a map of our estimates of ANC in the study area.

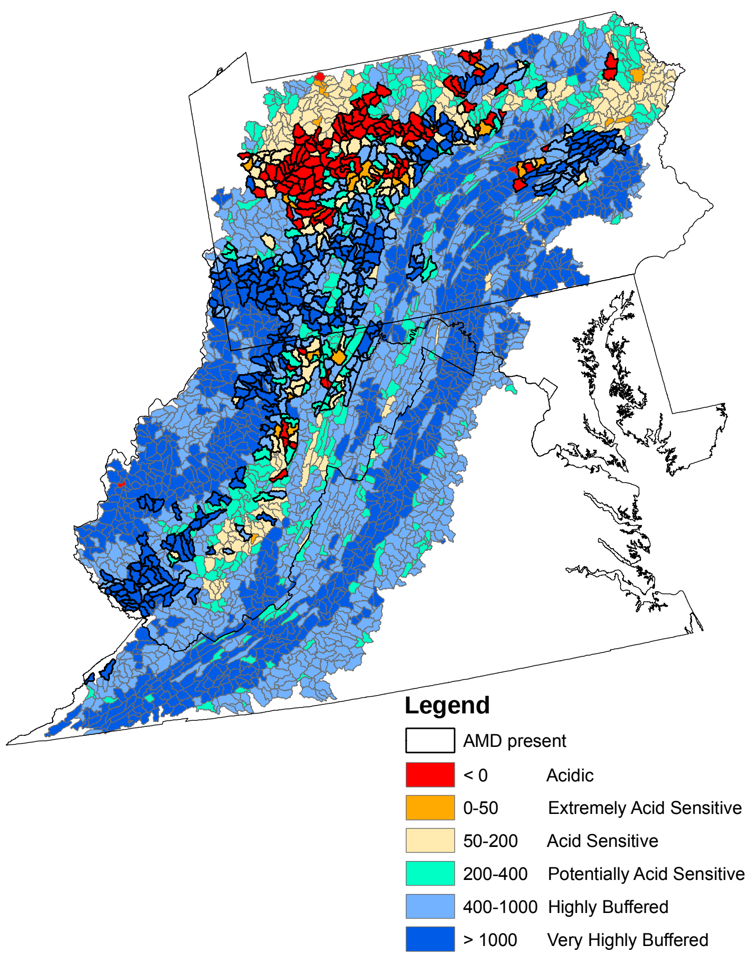


Figure 6. Predicted stream ANC classes (μeq/L) at the pour point of watersheds in the Mid-Atlantic Highlands region. One of the five regression models developed for this study was used for any given watershed, depending upon geology occurring in each watershed and presence/absence of acid mine drainage (AMD).

The predictability of our models is limited by the data limitations of regional datasets used in this analysis, and our estimates are conservative – actual conditions are likely to be more acidic. The map of watershed vulnerability to acidification presented here is intended as a first-cut reference for watershed stakeholders to assess relative condition and vulnerability of their watersheds to acidification. Use of this map should be followed-up with analysis of more detailed local datasets.

Nitrate and other Water Quality Parameters

Excessive nutrients and sediments in surface waters can become significant stressors to aquatic biota and pose risks to human health. Therefore, we considered these as candidates for inclusion in our vulnerability analysis.

Levels of nutrients (total nitrogen, total nitrate, total ammonia, dissolved phosphorus, total phosphorus) and sediments (suspended sediments) in true watersheds were predicted by application of multivariate regression models developed for the Mid-Atlantic Integrated Assessment region by Jones et al. (2001). In their study, models were developed from an initial set of 17 landscape metrics for watershed supporting areas at 148 USGS surface water sampling stations. Atmospheric deposition of nitrate was one of the factors considered in the regression models. Use of land cover models to predict nutrients was considered the preferred method because EMAP water chemistry data were available for only a portion of study watersheds (<600); classification of watersheds in this study was also anticipated to be coarse and broad-scaled.

Predicted values for watersheds containing one or more EMAP stream sampling points were examined to evaluate the correspondence between predicted and observed values (n=896). Efforts were made to compensate for differences between datasets when making the comparisons. We found that our predictions of total nitrogen and total nitrate (Figure 7) were the most highly correlated to EMAP values, while total ammonia correlated the most poorly. The total phosphorus model generally underestimated values. A more detailed description of methods used to estimate water quality parameters for the study region can be found in Rocco et al. (unpublished – see Appendix B).

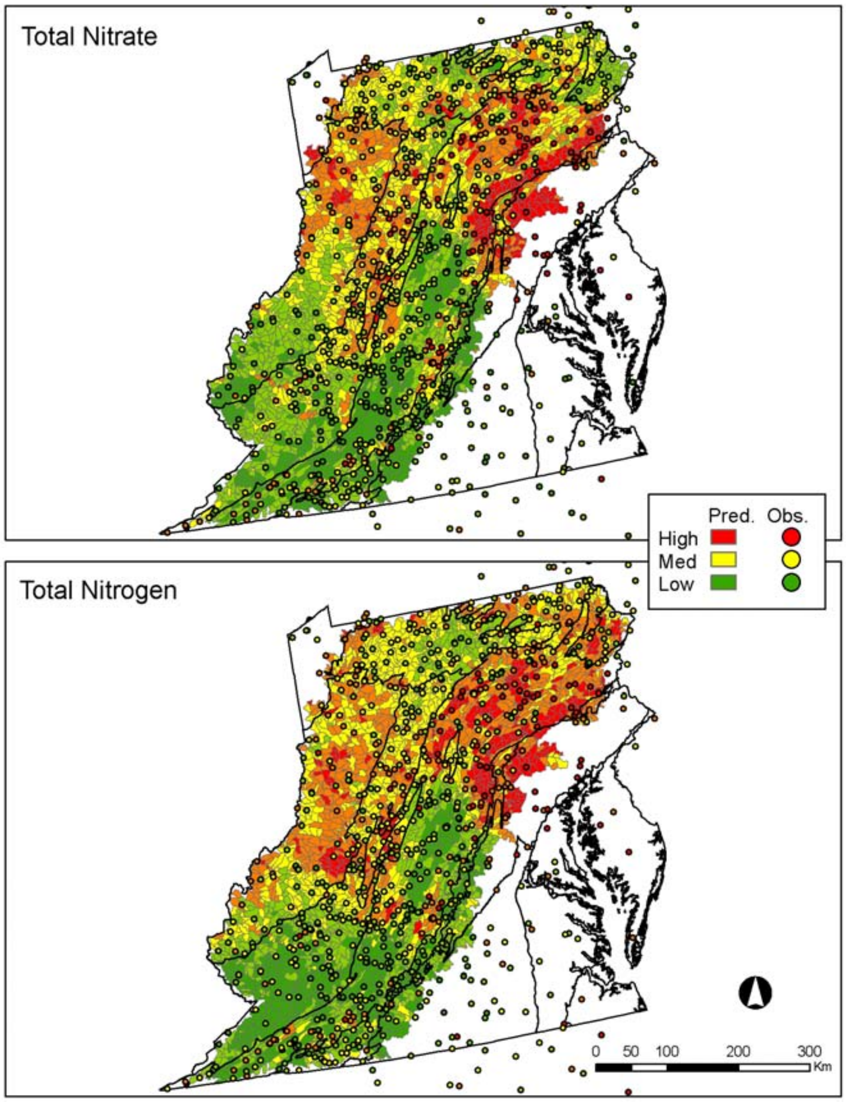


Figure 7. Map showing correspondence between total nitrogen and nitrate predicted from regression models (Predicted Ln Total nitrate (or Total nitrogen) kg/ha/yr) vs. values measured at EMAP sampling points (Observed Ln Total nitrate (or Total nitrogen) μg/L).

STRESSOR CLASS IDENTIFICATION AND CONDITION RANKING

In addition to assessing the vulnerability of watersheds to stress, our conceptual model of prioritization requires an estimate of watershed condition. To that end, this component of the study subdivides the nine inherent watershed classes into stressor subclasses, and ranks those subclasses according to the condition of their aquatic ecosystems.

We used the West Virginia DEP's Stream Condition Index (WVSCI) (Gerritsen 2000) as an index of watershed ecological integrity, or condition. This index is based on diversity and composition of stream invertebrate community, with particular attention to disturbance-sensitive taxa. Prior to analyses, we corrected WVSCI scores for changes due to elevation (Griscom et. al., in prep #1 – Appendix B).

For defining the stressor subclasses, four variables were considered:

(1) The percent cover of impervious cover in a watershed (WSIC).
(2) The percent cover of agriculture in a watershed (WSAG).
(3) The percent cover of mining in a watershed (WSMINE).
(4) Acid Neutralizing Capacity (ANC).

The above variables were selected through exploratory analyses: we first broke down watersheds by impervious cover (IC) and disturbed vegetation (DV), since these were very different types of land cover (different dose-response curves). We next tested for subdivisions of DV (including agriculture and mining) to see if we needed to further refine these subclasses when looking at vulnerability. We found very different dose-response relationship for mining vs. agriculture dominated watersheds. This distinction between mining, and agriculture and impervious cover was also found by Detenbeck et al. (2004).

We also evaluated the water quality variables (e.g., total nitrogen, nitrate) for inclusion in our analysis. However exploratory analyses suggested that these were redundant with other variables (e.g., the land cover-related stressors, and the inherent classes themselves) and there was little additional information gained by their inclusion. Therefore, we did not include these variables in defining the stressor subcategories.

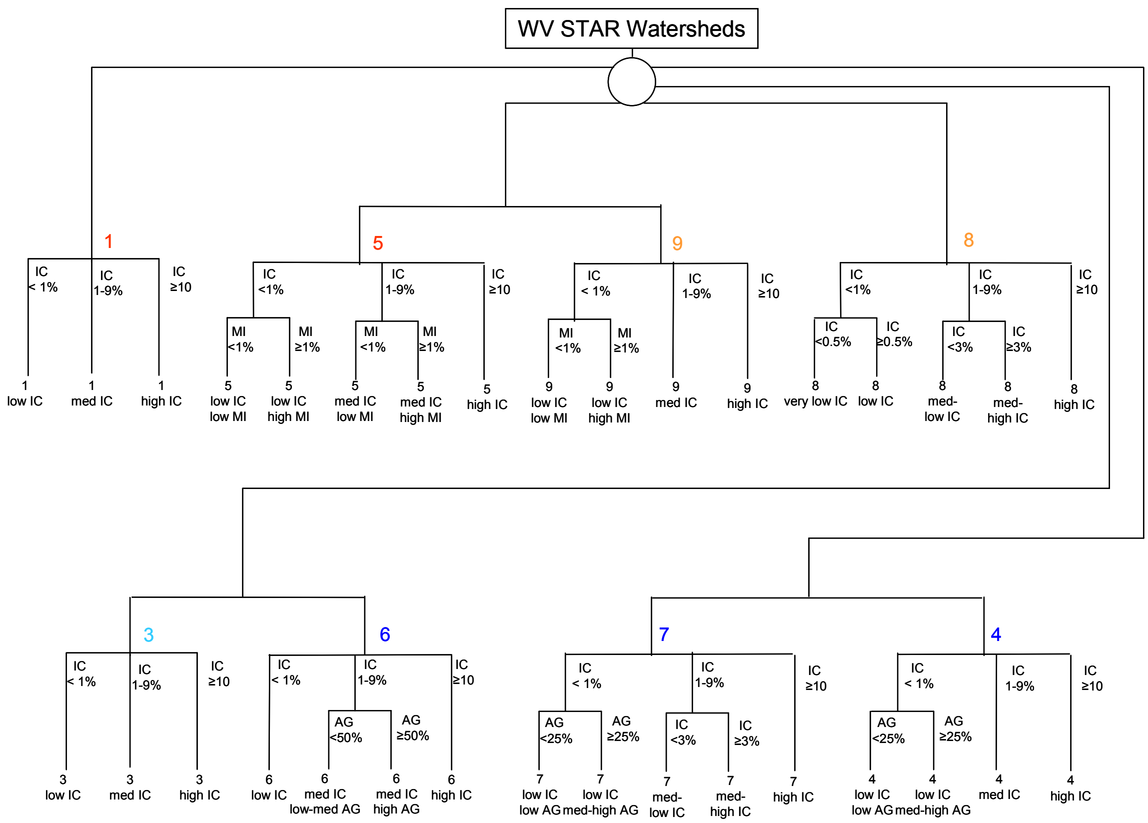
For each of the four variables noted above, tiers or categories were developed based on an extensive analysis of dose-response relationships for each land use type. (One exception is that tiers for ANC are based primarily on literature review, and confirmed by looking at dose-response). One notable finding was a drop-off (e.g., a “threshold” in dose-response curve) in condition (WVSCI score) at much lower levels of both WSIC and WSMINE than expected from review of the literature. Most studies discuss thresholds around 10 or 20 percent IC. We found that although 10 percent was appropriate, the most dramatic drop-off in condition occurred around 0.5 and 1 percent IC, and 1 percent Mining. Table 4 shows tiers for each of the four variables.

Table 4. Tiers used to assign watersheds to stressor subclasses.

	WSIC	WSAG	WSMINE	ANC
Very low	0.0-0.49%	-		
Low	0.49-0.9%	0-24.9%	0.0-0.9%	<50.0
Medium	1.0-9.9%	25-49.9%		
High	10.0-24.9%	$\geq 50.0\%$	$\geq 1.0\%$	≥ 50.0
Very High	$\geq 25\%$			

West Virginia watersheds with one or more WVSCI scores were used for this analysis. Watersheds were first grouped according to their inherent class. Within this grouping, each watershed was assigned to a stressor subclass based on its values for these four variables. Variables were considered in the following order: WSIC, WSAG, WSMINE, ANC. Pairwise differences in mean watershed WVSCI scores among subclasses were then tested using a Kruskall-Wallis rank sum test (non-parametric). If the differences were not significant, the subclasses were lumped together. The resulting subclasses are shown in Figure 8. Mean WVSCI scores were computed for each of these subclasses, and they were ranked accordingly (see Table 5).

Figure 8. Stressor subclasses for nine inherent watershed classes.



All Met-9	Class	Avg WVSCI	WVSCI Biol. Impairment
4	Low IC Low AG	73.96	Unimpaired
9	Low IC Low MI	71.27	Unimpaired
7	Low IC Low AG	69.70	Unimpaired
8	Very Low IC	69.29	Unimpaired
7	Low IC Med-High AG	67.57	Gray Zone
5	Low IC Low MI	66.23	Gray Zone
3	Low IC	65.56	Gray Zone
9	Low IC High MI	64.14	Gray Zone
4	Low IC Med-High AG	63.98	Gray Zone
8	Low IC	63.37	Gray Zone
7	Med IC	63.23	Gray Zone
4	Med IC	63.09	Gray Zone
9	Med IC	62.44	Gray Zone
5	Med IC Low MI	61.46	Gray Zone
1	Low IC	61.42	Gray Zone
5	Low IC High MI	61.34	Gray Zone
8	Med IC Low MI	61.06	Gray Zone
3	Med IC	59.62	Impaired
1	Med IC	55.60	Impaired
5	Med IC High MI	50.44	Impaired
8	Med IC High MI	48.79	Impaired
6	Med IC High AG	46.99	Impaired

Table 5. Stressor subclasses ranked according to average IBI (WVSCI) score. Note: the "impairment" column below is based on cutoffs used in the WVSCI system.

VULNERABILITY OF WATERSHEDS TO HUMAN IMPACTS IN WEST VIRGINIA

Our objective in this component of the study was to illustrate the integration of the information developed earlier in this report - our classification system for watersheds based on inherent characteristics, and our characterization of stressors in the study area - to evaluate the vulnerability of watersheds to loss of stream biological integrity due to human impacts.

Differences in watershed vulnerability are defined here as differences in the response of watershed ecological integrity to increasing human impacts, manifested as different stressor levels within watersheds. For example, “type A” watersheds in Figure 9 demonstrate low vulnerability to human stress, while “type C” watersheds demonstrate high vulnerability.

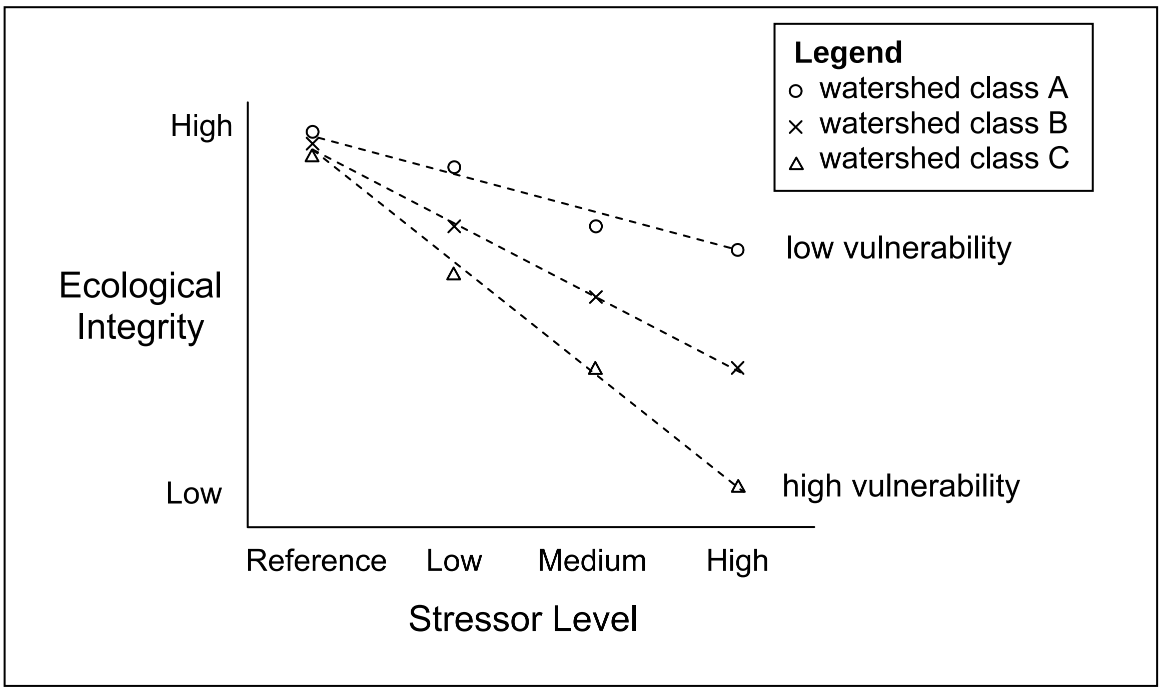


Figure 9. Conceptual diagram of watershed types demonstrating different response of ecological integrity to stressor levels, and thus different vulnerabilities in terms of ecological resistance. Watershed type A has the lowest vulnerability, while watershed type C has the highest vulnerability.

In order to classify watersheds with regard to vulnerability, it was necessary to identify or develop three parameters of the model in Figure 9:

(1) A watershed classification system that identifies classes of watersheds with different vulnerability levels. For this we examined our different inherent classifications described earlier in the report, to see which performed the best.

(2) One or more indices of stressor level. These are described earlier in this report, and some refinements are noted below.

(3) An index of watershed ecological integrity.

We examined various regional and sub-regional datasets for the availability of stream-based indices of biotic integrity or "IBIs", commonly used as a measure of watershed condition. Regional datasets included those collected by the Environmental Monitoring and Assessment Program (EMAP) (US EPA 2000a); state-level datasets included the Maryland Biological Stream Survey (MBSS) (US EPA 1999), the West Virginia DEP's Stream Condition Index (WVSCI) (US EPA 2000b), and Pennsylvania's Surface Water Assessment Program (PA DEP 2004). We found that there were sufficient differences among these programs in their data collection and processing methods that the datasets could not be reliably combined to create a large regional dataset. Therefore, we selected the West Virginia dataset to illustrate our methods, due to the large number of sample sites (n = 4167), and the fact that this state occupies the core of our study area.

The West Virginia DEP's Stream Condition Index (WVSCI) (Gerritsen 2000) is based on diversity and composition of stream invertebrate community, with particular attention to disturbance-sensitive taxa. Prior to analyses, we corrected WVSCI scores for changes due to elevation (Griscom et al., in prep #1 – see Appendix B).

Evaluation of Classification Systems

To test the hypothesis that our nine cluster classification using all variables was indeed the most suitable one for assessing vulnerability, we compared eleven watershed classification systems for their ability to explain variability in vulnerability (as defined in Figure 9). Two of the classification systems compared are commonly used in our region: Physiographic Provinces (Fenneman 1946) and Ecoregions (Omernik 1987). The other nine classification systems were developed as part of this study as described in the next section. All classification systems are based on inherent characteristics of watersheds (e.g., landform, soils, climate), as opposed to human-derived characteristics (e.g., road network, agricultural systems). An exception occurs for Ecoregions, for which human land use patterns were used in addition to inherent characteristics.

To make this comparison we developed indices of vulnerability based on two general indicators of human land use impact intensity: (1) percent of watershed in predominantly anthropogenic land use (referred to as "disturbed cover" (DC)), (2) land development intensity index (LDI) (Brown 2005) within a watershed. Two vulnerability indices were calculated as the difference between actual WVSCI scores and WVSCI scores predicted from stressor levels with the following equation:

$$v_i = msci_i – psci_i$$

Where

- "v_i" is the vulnerability index calculated for watershed "i"
- "$msci_i$" is measured WVSCI score for watershed "i"
- "$psci_i$" is predicted WVSCI score for the stressor level occurring in watershed "i"

The variable "$psci_i$" was calculated for both LDI and DC (as dependent variables) using a robust (MM) regression model. Thus, "class A" watersheds in Figure 9 would generally have positive values for each vulnerability index, "class B" watersheds would generally have values near zero, and "class C" watersheds would generally have negative values.

A non-parametric ANOVA (Kruskal-Wallis rank test – Chi-square statistic) was used to quantify the amount of variability in our vulnerability indices explained by each of eleven classification system for West Virginia. The classification system with the highest Chi-square statistic was selected as the "best" system. We also compared classification systems for variability explained in other variables of interest: (1) land use intensity (DC and LDI), (2) stream condition (WVSCI) and (3) spatial patterns of land use with respect to the riparian zone (Griscom et al., in prep #2 – Appendix B). Ideally the classification system selected would also perform well in explaining differences in these other variables.

		Vulnerability						*Land Use Intensity*						*Spatial Patterns*						*Acidification*			*Condition*			
		WVSCI - LDI			**WVSCI-DC**			**DC**			**LDI**			**RZIC Index**			**RZDV Index**			**stream ANC**			**WVSCI**			
System	No. cat.	Chi-sq	P	Rank	Chi-sq	P	Rank	Chi-sq	P	Rank	Chi-sq	P	Rank	Chi-sq	P	Rank	Chi-sq	P	Rank	Chi-sq	P	Rank	Chi-sq	P	Rank	Mean Rank
All Met-9	8	81.5	**	1	87.8	**	1	285.9	**	1	200.8	**	1	229.1	**	1	192.7	**	4	316.2	**	2	78.1	**	1	1.5
All Met-6	6	76.5	**	2	81.4	**	2	254.2	**	2	171.9	**	2	191.6	**	2	188.1	**	5	285.0	**	4	65.4	**	2	2.6
Ecoregions	6	73.6	**	3	80.7	**	3	229.9	**	3	149.4	**	4	185.1	**	3	125.4	**	6	202.0	**	7	43.5	**	5	4.3
Climate	4	60.9	**	4	68.6	**	4	89.3	**	9	61.2	**	9	152.7	**	4	120.8	**	7	314.9	**	3	40.1	**	6	5.8
Climate-Soil	6	29.4	**	7	29.5	**	7	78.2	**	10	50.5	**	10	85.1	**	7	197.2	**	3	359.6	**	1	46.8	**	4	6.1
Soil	5	25.0	**	8	27.6	**	8	151.5	**	6	122.3	**	6	62.8	**	8	241.2	**	1	250.0	**	5	39.6	**	7	6.1
Phys-Soil	6	10.4		11	10.4		11	188.5	**	4	162.5	**	3	27.8	**	11	220.5	**	2	214.1	**	6	65.3	**	3	6.4
Hydro-Phys	5	34.3	**	6	38.2	**	6	143.8	**	8	98.4	**	8	85.7	**	6	44.8	**	10	85.5	**	9	29.7	**	8	7.6
Provinces	4	39.3	**	5	49.0	**	5	25.2	**	11	6.5		11	102.0	**	5	34.9	**	11	63.9	**	10	21.7	*	9	8.4
Phys	6	15.6	*	9	18.1	*	9	150.4	**	7	119.7	**	7	58.5	**	9	62.7	**	8	141.2	**	8	10.5	**	11	8.5
Hydro	6	15.1	*	10	15.9	*	10	163.3	**	5	127.4	**	5	57.8	**	10	46.6	**	9	26.5	*	11	10.7	**	10	8.8

Table 6. Inherent classification systems are ranked based on explanatory power (as measured by chi-square statistic) for seven different landscape metrics expressing vulnerability, land use intensity, spatial patterns, and stream condition. Vulnerability indices were calculated with respect to disturbed cover (DC) and land development intensity index (LDI). Spatial pattern indices were calculated as tendency of impervious cover (RZIC) and disturbed vegetation (RZDV – dominated by agriculture) to avoid or be concentrated in the riparian zone. Chi-square and P-value results from Kruskall-Wallis Rank Sum test. Significant differences among classes for each variable were found at $P<0.05$ (*) and $P<0.0001$ (**) levels.

Our WVSCI-DC and WVSCI-LDI vulnerability indices generated the same ranking of 11 classification systems based on Kruskal-Wallis chi-square statistic (Table 6). Our "All Met-9" classification system ranked highest; that is, it explained the greatest amount of variability in both WVSCI-DC and WVSCI-LDI vulnerability indices according to chi-square values. Our "All Met-6" classification system ranked the second highest. Climate ranked the fourth highest, and ranked the highest among classification systems using only one category of inherent variables. Our "All Met-9" classification systems also ranked 1st and 2nd for the other variables tested with the exception of the riparian zone disturbed vegetation spatial pattern index (RZDV). Our "Soils" based classification system ranked the highest for RZDV, followed by "Phys-Soil", "Climate-Soil", and then "All Met-9" and "All Met-6" systems.

Ecoregions (Omernik, six subdivisions) was ranked just behind All Met-6 for all metrics with the exception of LDI and WVSCI for which Ecoregions had poorer performance. In particular, Ecoregions demonstrated medium-range prediction of stream condition (WVSCI), which is best predicted by All Met-9 and All Met-6 classification systems.

Comparison of Vulnerability among Inherent Classes

In order to statistically assess vulnerability levels, we used a non-parametric ANOVA (Kruskal-Wallis rank test) to compare median WVSCI score for specified stressor ranges among all inherent classes (All Met-9). We conducted these tests for three stressor parameters: IC, AG, and LDI. DC was not tested due to its low explanatory power for condition (low r2), and similarities to LDI. AG also had a weak relationship with condition, but was retained since it was the primary stressor for one inherent class (Class 6). Water quality variables (e.g., total nitrogen, nitrate) were considered for inclusion; however we found these to have only a weak relationship with condition, likely due to their correlation with other variables already included in the analyses.

Results from the analysis of dose-response curves conducted by Griscom et al. (stressor classification paper manuscript) were used to specify ranges of each stressor parameter as presented in Table 7. LDI ranges were selected based on ranges for IC and AG (Table 7).

Selection of LDI range for each land use intensity class

Land Use Intensity	*Reference*		***Low***		***Medium***		***High***	
Land Cover Type	WSIC	WSAG	WSIC	WSAG	WSIC	WSAG	WSIC	WSAG
Percent Land Cover	0.0-0.4	0.0-12.4	0.5-0.9	12.5-24.9	1.0-9.9	25.0-49.9	10.0-19.9	50.0-74.9
No. watersheds	162		196	140	197	71	6	15
LDI mean	117.3		**141.0**	**147.7**	**161.0**	**191.6**	**288.3**	**267.3**
LDI stdev	9.7		25.5	9.1	32.7	18.5	22.4	25.1
Selected LDI range	na		**130.0 - 154.9**		**155.0 - 224.9**		**225.0-299.9**	

Table 7. Selection of LDI range for each land use intensity class.

Median WVSCI scores were not significantly different for reference watersheds comparing among All Met-9 inherent classes. Median WVSCI scores were significantly different ($P < 0.05$) among inherent classes at low stressor levels for all three stressor parameters (IC, AG, and LDI). Median WVSCI scores were significantly different among inherent classes at medium stressor levels for IC and LDI, but not for AG. Median WVSCI scores were highly significantly different ($P < 0.001$) at both low and medium LDI stressor levels. Due to lack of adequate replication ($n < 3$), mean WVSCI scores were not presented for any inherent classes at high stressor levels, and were not presented (or included in Kruskal-Wallis test) for select inherent classes at medium, low, and reference stressor levels.

Inherent classes 6 and 4 (of All Met-9) were among the three highest mean WVSCI values for a given stressor level – stressor type combination. Inherent classes 5 and 1 had among the three lowest mean WVSCI values for a given stressor level – stressor type combination. Some inherent classes (e.g., 3 and 9) demonstrated variable relative WVSCI levels depending upon stressor parameter. LDI analysis produced results intermediate to that of AG and IC and, unlike AG and IC, had consistent results for low and medium stressor levels. Thus, LDI was selected as the best parameter for ranking vulnerability among inherent watershed classes as presented in Figure 10.

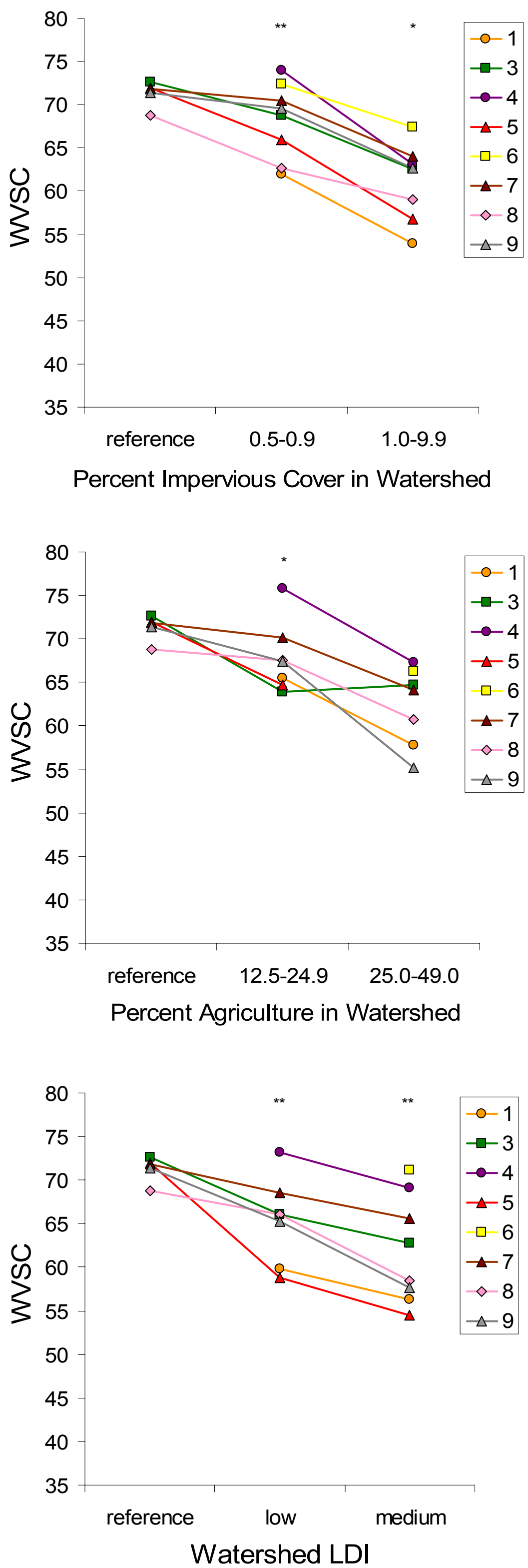


Figure 10. Significant differences were found at P<0.001 (**) and P<0.05 (*) for Kruskal Wallis Rank test comparing median WVSCI among inherent classes for levels of impervious cover (IC), agriculture (AG) and land development intensity index (LDI) as specified in Table 7. Categories with less than three watersheds were considered insufficient replication and were not included in graphs.

No significant difference in stream condition (WVSCI) was identified among watersheds with predicted high (ANC < 50), medium (ANC 50-200) and low (ANC > 200) vulnerability to acidification. Inherent classes 5, 6, 7, and 8 had less than 3 percent of watersheds with predicted ANC < 200. Inherent classes 1, 3, and 4 had 10-15 percent of watersheds with predicted ANC < 200. Inherent class 9 had over 1/3 (37 percent) of watersheds with predicted ANC < 200.

Table 8. ANC vulnerability. Highly significant difference found (P<0.0001) among Allmet-9 classes in median predicted ANC.

All Met-9 Class	Percentage of WV Watersheds <200 ANC	Mean ANC
1	10.81%	1058.36
3	10.29%	996.09
4	14.29%	657.31
5	1.91%	1095.46
6	0.00%	3567.73
7	2.44%	848.16
8	0.46%	1247.65
9	37.06%	337.65

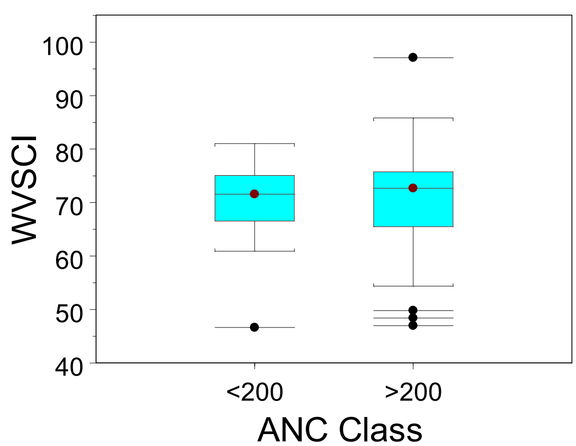


Figure 11. No significant difference (at P<0.05) found between median WVSCI scores of two ANC classes for “reference” watersheds. N=23 <200 ANC, N=132 >200 ANC.

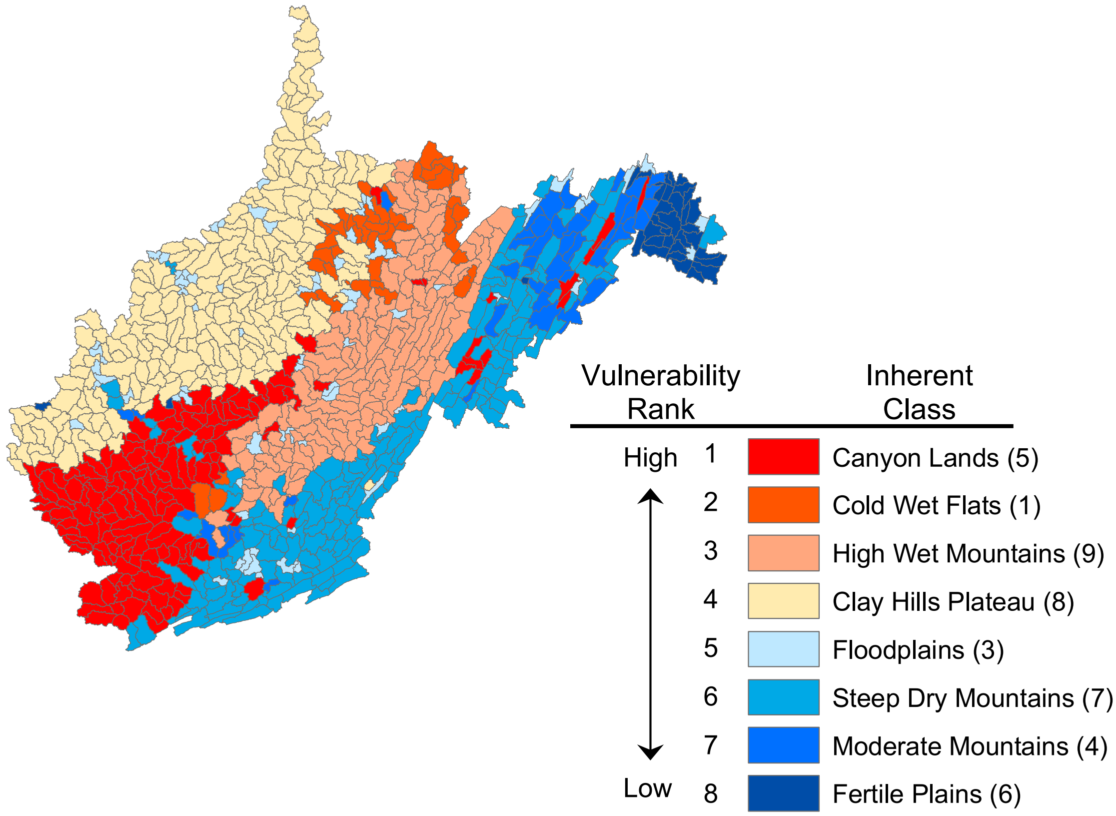


Figure 12. Map of vulnerability to land use impacts for watersheds of the West Virginia.

DISCUSSION & CONCLUSIONS

The "All Met-9" system that takes into account multiple types of inherent landscape characteristics (soils, climate, landform, hydrology) was the best predictor of our vulnerability indices, land use intensity variables, stream condition (WVSCI), and an index of spatial patterns of impervious cover with respect to riparian zone. The "All Met-9" classification system also performed well in predicting the other two stressors tested: ANC, and spatial patterns of disturbed vegetation. Since all the watershed parameters tested (land use vulnerability indices, land use intensity indices, spatial pattern indices, condition index, acidification vulnerability index) were expected to influence our analysis of watershed vulnerability, the "All Met-9" classification was the best system for characterizing watershed vulnerability in West Virginia, and presumably the other states, although only 8 of the 9 watershed types are found in West Virginia. Thus, we projected vulnerability rankings from the analysis in West Virginia to the remainder of the MAHA watersheds for the Watershed Characterization and Prioritization Tool.

Of the three stressor variables used to characterize "dose" in the construction of dose-response graphs (percent impervious cover, percent agriculture, and LDI), we selected LDI for ranking overall vulnerability of watershed classes. LDI generated results intermediate between those for agriculture and impervious cover, as expected since LDI accounts for all anthropogenic land use classes. LDI analysis generated the strongest statistical results (lowest P-values and highest chi-square) for differences between median WVSCI scores among inherent classes at both low and medium stressor levels. LDI also had higher replication since watersheds with multiple primary stressors (e.g., medium agriculture and impervious cover) did not need to be excluded, thus generating a ranking for all eight inherent classes at the medium stressor level. Finally, LDI ranking was consistent at both low and high stressor levels, thus avoiding the need for complicated ranking systems.

Overall, watershed classes of the central wet Appalachian mountains and westward were more vulnerable, while watershed classes of the drier central mountain ranges and east were less vulnerable. Vulnerability (ecological resistance) tended to have an inverse relationship with likelihood of land use impacts: high vulnerability watershed classes tended to have relatively low land use impacts, while low vulnerability watershed classes tended to have relatively high land use impacts. A notable exception to this trend occurred for mining: higher vulnerability watershed classes (e.g., *Canyon Lands* and *High Wet Mountains*) tend to have high levels of mining impacts.

Inherent classes 5 and 1 (Canyon Lands and Cold Wet Flats) were consistently high vulnerability, regardless of the stressor variable used. They also showed the steepest drop in condition between reference and low LDI stressor range, suggesting that thresholds of response to impacts occur at surprisingly low levels of land use impacts for these watershed classes (less than 25% agriculture, and less than 1% impervious cover). Inherent classes 4, 6, and 7 (Moderate Mountains, Fertile Plains, and Steep Dry Mountains), were consistently low vulnerability, regardless of stressor variable used. The remaining inherent classes 3, 8, and 9 (Floodplains, Clay Hills Plateau, and High Wet Mountains), showed more variable results depending upon stressor level and stressor variable; however, the overall pattern as expressed by LDI was that inherent classes 8 and 9 are higher vulnerability, while inherent class 3 is lower vulnerability.

The most successful classification system for differentiating based on predicted ANC was "climate-soil" system. This stands to reason, given that (1) soils influence stream ANC, and are our best proxy for geology, considered the primary driver of stream ANC, and (2) climate classification is the best proxy for atmospheric contributions, another driver of acidification. All met-9 was second best system at differentiating based on predicted stream ANC – primarily identifying class 9 as highly susceptible to acidification. Mean (and median) WVSCI scores were slightly lower for reference watersheds with predicted ANC < 200; however, this difference was not significant. We suspect that this is due, at least in part, to scale issues. Acidification problems tend to occur in small streams, and probably need to measure many streams within each of our study watersheds to address appropriate scale of relationship.

Another method for prioritizing watershed developed, in part, during this project, used partially ordered sets (posets) (Myers et al. 2006). They demonstrated the patterns of partial ordering on watershed ranking, using vertebrate data vs. environmental data. The resultant "rank range runs" allow comparisons among watersheds (or other units) characterized by multiple factors. If unit A is equal or superior to another in its best rank and its worst rank, then it is considered superior (i.e., higher rank order or higher priority rank). A range of ranks produced over a set of multiple factors or indicators yields an objective ranking sequence. Although we did not implement this method over the entire set of MAHA watersheds, we believe that it offers an alternative means to prioritize watersheds, regardless of the criteria selected by managers.

Vulnerability of Watershed Classes

Cold Wet Flats

Watersheds of the *Cold Wet Flats* were ranked second highest vulnerability to loss of stream biotic integrity due to watershed land use impacts. The cold climate and low soil infiltration characteristic of *Cold Wet Flats* may be associated with high vulnerability status identified for this watershed class. Watersheds of the *Cold Wet Flats* are characterized by avoidance of the riparian zone for disturbed vegetation land uses (primarily agriculture) and neutral spatial patterns for impervious cover (Griscom et. al, in prep #3). Thus, disproportionate riparian impacts are not expected to account for elevated vulnerability within watersheds of the *Cold Wet Flats*. Acidification is expected to impact some watersheds: 10 percent of West Virginia's *Cold Wet Flats* watersheds had predicted stream water ANC < 200. Medium and low intensity land use levels are most common in these watersheds.

Floodplains

Watersheds of the *Floodplains* were ranked intermediate-low vulnerability (fourth lowest) to loss of stream biotic integrity due to watershed land use impacts. *Floodplains* watersheds are scattered throughout the West Virginia due to the scattered occurrence of river floodplain systems. Thus, this class includes watersheds with a broad range of climate conditions and biotic communities. These watersheds are, however, expected to have biotic communities adapted to the chronic natural disturbance of flooding. This natural disturbance regime may pre-adapt biotic communities to be relatively tolerant of human impacts. *Floodplains* watersheds have soils with high available water capacity, which may allow water to infiltrate, thus reducing overland flow. Watersheds of the *Floodplains* show a substantial range of land use spatial patterns and no strong overall tendencies of riparian zone concentration or avoidance. While these watersheds tend to be tolerant of land use impacts, they have the highest proportion of watersheds subjected to heavy urbanization, and tend to have relatively high agricultural land use.

Moderate Mountains

Watersheds of the *Moderate Mountains* were ranked second lowest vulnerability to loss of stream biotic integrity due to watershed land use impacts. These watersheds are moderate in most inherent characteristics, but tend to be drier and lower in elevation than most West Virginian watersheds. Other classes tending to have drier climates and/or lower elevations are also low in vulnerability: “steep dry mountains” and “fertile plains.”

Watersheds of the moderate mountains class show a moderate tendency for concentrated disturbed vegetation land use in the riparian zone, yet on average are neutral on impervious surface distribution. While this class is tolerant of human land use impacts, it is subjected to high agricultural land use impacts, second only to the *Fertile Plains* class (Griscom et. al, in prep #3). Acidification is expected to cause problems in some watersheds of the *Moderate Mountains*: 14% of watersheds were predicted to have stream ANC < 200.

Canyon Lands

Watersheds of the *Canyon Lands* were ranked as the highest vulnerability to loss of stream biotic integrity due to watershed land use impacts. This class of watersheds is characterized by extreme inherent characteristics: the steepest slopes, the steepest channel gradient, and the least erodible soils among inherent watershed classes of the Mid-Atlantic Highlands. Stream invertebrate communities are reported to be distinctive and sensitive in *Canyon Lands* watersheds.

Watersheds of the Canyon Lands had the strongest tendency for impervious surface concentrated in the riparian zone. Thus, high vulnerability of these watersheds may be due in part to disproportionate impacts within the riparian zone. Consistent with the challenges to land use, Canyon Lands have the highest proportion of watersheds with low intensity land use (88%). When disturbed vegetation land uses do occur, the highest proportion of that land use category is composed of barren, quarry, and transitional land use classes (28%), generally indicators of mining and logging activities.

Fertile Plains

Watersheds of the *Fertile Plains* were ranked as the lowest vulnerability to loss of stream biotic integrity due to watershed land use impacts; however, the *Fertile Plains* are also subject to the highest level of agricultural impacts, and the second highest level of urbanization (Griscom et. al, in prep #3).

The Fertile Plains class is characterized by fertile soils, warm climate, and relatively flat topography. Fertile Plains watersheds have the highest tendency for impervious surface land uses to avoid the riparian zone, a spatial pattern of land use that may contribute to the relatively low biotic response to land uses quantified at the watershed scale. On the other hand, watersheds of the Fertile Plains tend to have disturbed vegetation land use impacts concentrated in the riparian zone; however, there is high variability in disturbed vegetation land use patterns, and a substantial number of watersheds show avoidance of the riparian zone for all land use types.

Steep Dry Mountains

Watersheds of the *Steep Dry Mountains* were ranked as the third lowest vulnerability to loss of stream biotic integrity due to watershed land use impacts. We were surprised by this result, given (1) the steep slopes and high elevations of watersheds in this class, and (2) the tendency for "disturbed vegetation" land uses to be concentrated in the riparian zone. Like other low vulnerability classes (e.g. Moderate Mountains, Fertile Plains), climate tends to be drier in the *Steep Dry Mountains* than in watersheds to the west. *Steep Dry Mountains* also are not subjected to substantial levels of mining (Griscom et. al, in prep #3). Low and medium land use intensities are common among watersheds of the Steep Dry Mountains, suggesting that topography and other inherent characteristics restrict intensive land use, although not to the same extent as for Canyon Lands and High Wet Mountains.

Clay Hills Plateau

Watersheds of the *Clay Hills Plateau* were ranked as intermediate-high vulnerability (fourth highest) to loss of stream biotic integrity due to watershed land use impacts. There is a tendency towards concentration of land use in the riparian zone (particularly in the West Virginian portion of the *Clay Hills Plateau* region) and this may contribute to higher vulnerability.

High Wet Mountains

Watersheds of the *High Wet Mountains* were ranked as the third highest vulnerability to loss of stream biotic integrity due to watershed land use impacts. Also, the *High Wet Mountains* are the most vulnerable watershed class to acidification*:* over 1/3 of watersheds were predicted to have stream water ANC < 200. Aside from being steep and rugged, watersheds of the *High Wet Mountains* on average have the highest elevation, coldest climate, and highest precipitation of all inherent classes. Like Canyon Lands, the High Wet Mountains generally have low overall land use intensity, and a substantial proportion of disturbed vegetation is comprised of mining and logging related land uses (17%). This land use similarity is consistent with the similarity of inherent characteristics: Canyon Lands and High Wet Mountains are sibling classes according to the cluster analysis dendrogram; however, unlike Canyon Lands, impervious cover land uses do not show a strong tendency towards concentration in the riparian zone (RZIC index was close to zero). Also, unlike Canyon Lands, disturbed vegetation shows a tendency to avoid the riparian zone in the *High Wet Mountains*. This is apparently due at least in part to a shift in landform and other inherent factors that allows mountain tops to be more amenable to land use in the *High Wet Mountains* than in *Canyon Lands*.

Watershed Classification: Description of classes, and vulnerability, as a function of physiographic characteristics throughout the MAHA

The purpose of this section is to provide a narrative description of the watershed cluster types, identify the prominent areas of their distribution, and to discuss their potential vulnerability to a variety of stressors throughout the study area (MAHA), whereas the preceding analyses focused on the vulnerabilities of watersheds in West Virginia. Here, we extend our understanding of those relationships to a broader, regional context. This information should be useful to managers who are using this classification approach to prioritize their watersheds of concern and to locate them on the conceptual diagram that follows. It is anticipated the additional local knowledge will be used to further refine any prioritized order.

Cluster 1 – Cold Wet Flats (black, Figure 13)

Characterization:
Clusters of watersheds throughout the region of this type appear to have little in common, however, there are a few common themes. The climate tends to be relatively cold and wet. Landforms are flat, with low rates of soil infiltration. Glacial and periglacial influences are evident. Watersheds are relatively compact in shape. Clusters appear to occur in physiographical transition zones between ecoregions and geologic features that have moderate slopes (e.g., Allegheny Front, Pocono Plateau slopes into the Delaware River valley, etc. The northern clusters fall primarily in the A and B Climate Zones, which are cold, and possibly moist or at least has discharges of groundwater into streams. The compact shape in northeastern PA can be explained by the glaciated landscape of the northern Pocono Plateau, with relatively flat terrain (not rugged), and wet, but with a poorly developed stream network. In contrast, the cluster along the Venango/Clarion counties border in PA may have some periglacial effects as it is close to the glacial boundary. Also, this area lies between two parallel rivers, the Allegheny and the Clarion, which may restrict the extent of the watersheds, producing a compact shape. Other clusters of this type occur in the Wilkes-Barre/Scranton valley, as well as the Allegheny Front in central PA (Centre and Blair counties). Other clusters appear sporadically in the Allegheny Plateau, which has relatively flat terrain.

Vulnerability to Stressors:
Given the lack of common features of this type, impacts will become apparent at more local scales. For example, the Pocono and Allegheny Front regions may be susceptible to high acidity, whereas, the Venango/Clarion cluster is probably buffered to some extent by calcareous glacial till. Soils tend to moist or wet, which may have reduced historic land conversions, and these conditions appear to have forced human uses away from the riparian corridor toward the base of hills. Farming is present in glaciated northwestern PA, where fertility of glacial tills is fairly high. When land conversion do occur, however, impacts to aquatic resources in watersheds of this type are likely to be substantial and potentially harmful, thus, vulnerability tends to be high.

Cluster 2 – Dry Glaciated Northeast (red, Figure 13)

Characterization:
Watersheds in this cluster have been influenced by glacial and periglacial effects. The climate is cold and relatively dry, although streams can have high accumulation of flow, and wetlands can

be relatively abundant. Rapid responses of streams to precipitation events or spring runoff can result in severe flooding (e.g., Tioga County, PA). Wetlands are less abundant than glaciated regions to the east or west, primarily due to more rugged topography, but are more common than in most unglaciated areas of the Mid-Atlantic region.

Vulnerability to stressors:
Soils have high silt content, and thus, can be vulnerable to erosion. Broader areas of valleys are farmed. There is some mining of gravels of glacial origin in the streams. Acidification is less of a threat here than to watersheds to the east that contain more peat wetlands and coniferous forests.

Cluster 3 – Floodplains (light green, Figure 13)

Characterization:
Watersheds of this cluster are characterized as pass-through types. That is, they represent higher order streams with broad floodplains. When we tried to maintain watershed units of comparable size during the classification process, they were delineated necessarily without their contributing headwaters. Thus, their distribution is scattered throughout the region. Many of these watersheds have been substantially altered through farming in the floodplains, construction of dams, and in some cases, industrialization. Wetter portions of the floodplains may have escaped these conversions.

Vulnerability to stressors:
The river channels in some watersheds of this type served as transportation corridors, which in turn attracted commerce and industry. These areas tend to have the highest concentration of urban lands uses in the region studied (e.g., Pittsburgh, Williamsport). Issues related to management will be tied to concerns about flooding of economic property, brownfield development, and transportation infrastructure (e.g., highways, bridges). Some opportunities for restoration of forested floodplains may occur.

Clusters 4 & 8 - Moderate Mountains and Clay Hills Plateau (dark blue and brown, respectively – Figure 13)

Characterization:
Although these two regions are distinct, they have similar topographic, watershed, and use characteristics, and thus, are discussed together. These features tend to be moderate is many respects, relative to other watershed types – moderately large, moderately rugged, and with moderate flow accumulation in streams. The plateaus of western WV/southwestern PA (Cluster 8 – rust) are associated with Climate Zones C and E, where mining is not prevalent, but these have low to moderate levels of agricultural use (Detenbeck et al. 2004). The plateau is probably eroding toward the Ohio River resulting in a high drainage density. This condition may presuppose these watersheds to relatively high rates of erosion and sedimentation. In the PA Ridge and Valley (Cluster 4 – blue), associated with Climate Zone C, the watersheds encompass farmlands in the narrow valleys and lower slopes, but are forested on the ridges. In VA, there is a linear cluster located on the southeastern slopes of the Blue Ridge. Relief is moderate, but less steep than the higher elevation mountains to the west.

Vunerability to stressors:
For these watersheds in Clusters 4 and 8, there are no major obstacles to use by humans, so all kinds of uses are present; agriculture, land development, road building, etc. Thus, both the likelihood of stressor occurrence and the resultant degradation from all stressors, except acidification, are likely to be moderate to high. For these same reasons, riparian corridors are subject to the same stressors. Stressors can be proximal to streambanks. Disturbed vegetation is likely to proliferate in these areas. Natural vegetation is expected to be fragmented due to the wide distribution of uses. The base of these ridges may consist of colluvium from eroded slopes producing soils of moderate agricultural value. There also may be sources of water produced along topographic breaks in slope and geologic contacts. Given that this type of watershed is common and widely-distributed, and because it is fairly vulnerable to a variety of stressors, implementation of a generic array of BMPs is probably warranted.

Cluster 5 – Canyon Lands (turquoise, Figure 13)

Characterization:
The Deep Valleys of PA and Southern Coal Counties of WV characterize these watersheds. In the south the land tends to be in private ownership, contrasting with north which is primarily in public ownership (state forest and state game lands). This type subsumes the Appalachian Plateau portion of western Virginia. These lands are not conducive to past or current agricultural uses, and thus, agriculturally generated nutrients and sediments are not a threat. Some of these valleys collect and store water for municipal water authorities and private water companies, so extra caution should be taken when evaluating potential impacts by stressors in these areas.

Vulnerability to Stressors:
Rock strata are generally oriented horizontally, which may restrict movement and infiltration. Oil and gas deposits are present in both north and south, with an emphasis on coal in the south. These energy extraction activities can lead to fragmentation by access roads, and potential contamination of headwaters, which ultimately discharge into the larger valley rivers, with inherent impacts. Drilling and excavation can potentially lead to aquifer contamination. Hillslopes are vulnerable to erosion from land clearing activities (e.g., logging, land development) leading to high sediment loads. Creation of impervious surfaces exacerbates runoff into streams. Linear invasion of disturbed vegetation along transportation and river corridors is likely, although less so for smaller streams. Land development activities are proportionally low, so it may be less likely to see disturbed vegetation encroaching outside riparian and transportation corridors. With the steep terrain, the tendency will be to locate development proximal to rivers out of necessity, with inherent impacts. This also intensifies the vulnerability of human settlements to unstable slopes and severe flooding. Plateaus could potentially support development, but encroachment and addition of impervious surfaces could lead to impacts. The mountain top mining activities of southern West Virginia present a unique challenge to protect and/or restore vital headwater systems. In general, aquatic resources in this watershed type show high vulnerability to stressors. The cumulative impacts of large-scale land clearing and topographic alterations will be significant in this sub-region.

Cluster 6 – Fertile Plains (pink, Figure 13)

Characterization:
This cluster is concentrated in the eastern Ridge and Valley region and into the western portion of the Piedmont region, but can occur sporadically throughout as the pass-through portions of other watersheds. Thus, they are not superimposed on any particular physiographic province. Elongated, trellis drainage patterns with short stream segments, that are mostly first order, are common. With regard to climate zones, there is some concentration of this watershed type in D and E zones; both feature mild, moist, mesic and hilly, but not steep conditions. Soils are fertile, which has supported agricultural uses for hundreds of years.

Vulnerability to Stressors:
Valley locations will tend to neutralize any acidity. Concentrations of this watershed cluster occur in the Great Valley of PA (Allentown, Reading, Lancaster), Fredrick and Hagerstown in MD, Fairmont and Clarksburg in WV, Lexington and Stanton portions of the Great Valley along I-81 corridor in VA. Another linear group lies in the valleys along Laurel and Chestnut ridges in southwestern PA, extending to the Fairmont/Clarksburg cluster. Along the northcentral PA-NY border, there are farmland valleys associated with the glaciated Genessee River basin with similar characteristics. Similar watersheds can be found scattered throughout the region in smaller, narrower valleys, such as the Allegheny River in western PA, and valleys in the northern reaches of the Ridge and Valley in PA. A few are present in western WV presumably small farmland valleys entering the Ohio River along the state border.

Floodplains are broad due to high sinuosity, allowing for extensive human uses along the mainstems, less so for the tributaries. This type of watershed supports significant agriculture, the highest proportion in the study area, and has suitable sites for industrial development, railroad yards, and storage facilities. These floodplains will be dominated by alluvial soils, which can unstable, subject to erosion, incision, undercutting and slumping of streambanks. When coupled with crops or livestock, these soils will be vulnerable to nutrient and sediment loads that degrade water quality. Activities tend to be proximal to streambanks, and within the riparian corridor. There are potential opportunities for establishing BMPs for riparian corridor protection and fencing.

The headwater stream portions of these watersheds are short, of moderate gradient, and of low sinuosity reaches. A good example would be the hollows along the Allegheny Front in central PA. These hollows may provide water supplies from spring and groundwater discharges, and could be vulnerable to poor logging practices (e.g., sedimentation, streambank erosion, channel destabilization). There may be secondary roads, old railroad beds, and sparse to moderate residential development in these areas. Impacts could include flashy runoff into these streams, which in turn could alter the structure of larger rivers at confluences. These confluences might be characterized by a transition in stream bed load and materials from cobbles to alluvial sediments. These headwaters are potential vectors for disturbed vegetation and invasives, but the problem is assumed to be moderate. Acid impacts may occur selectively in the higher elevations of these headwaters, but are unlikely to severely affect the mainstems.

Cluster 7 – Steep Dry Mountains (yellow, Figure 13)

Characterization:

Watersheds in this cluster tend to have a large elevational range. Stream densities are high, with headwaters emanating from the hills. Their steepness tends to preclude many land uses. These watersheds tend to be drier than those found further west, so flow rates from streams are modest.

Vulnerability to stressors:
Land cover conversions have been modest, constrained by steep slopes. Agriculture is generally confined to the narrow valleys, placing it proximal to riparian corridors. Watersheds in this type appear to tolerate land use conversions. The relative steepness and lower fertility may have discouraged development of intensive land-altering activities. Vulnerability is ranked relatively low, and mining is not a major threat. BMPs should be given high priority, especially along streams to minimize potential impacts.

Cluster 9 – High Wet Mountains (dark green, Figure 13)

Characterization:
Concentrated in eastern WV and western VA, these watersheds are associated with the ridges of the eastern Allegheny Plateau, Ridge and Valley, and Blue Ridge. They originate in the highest elevations of the region, often accumulating significant flow through a high drainage density. Due to past land uses, they are primarily forested today. These watersheds appear to be dominated by Climate Zones C and D, which can produce drought prone or mesic conditions, respectively, but in general, watersheds of this type receive high rates of precipitation and contain moist soils. High degrees of soil saturation and wetland occurrence can occur in some watersheds.

Vulnerability to Stressors:
Acid sensitivity is expected to be significant due to high elevations, and with a likelihood of poorly buffered geology (e.g., sandstone and shale). If forested, stress associated with high nutrient concentrations is not anticipated, unless it comes from concentrated land development (e.g., stormwater and septic systems). Erosion and sedimentation problems are expected due to land clearing, especially with clear-cutting and any road development. It is expected that small amounts of impervious cover (<5%) will contribute to flashy hydrologic regimes, with resultant stream incision.

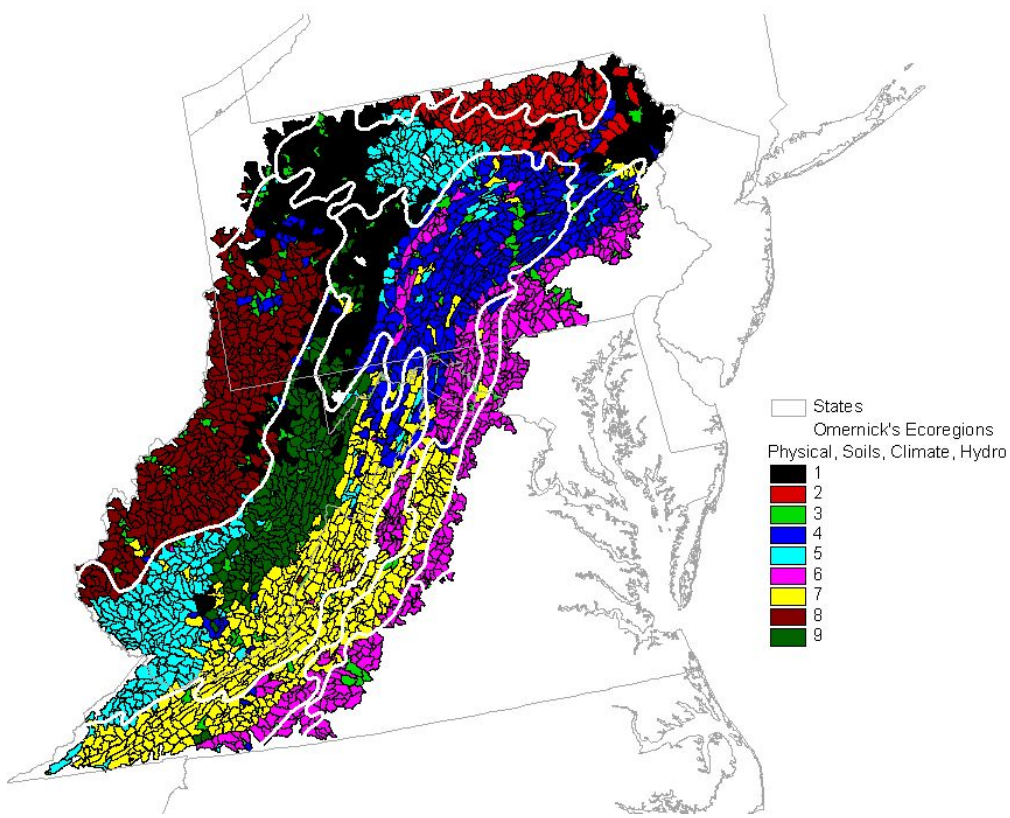
Where non-forested cover types are predominant, there may be an increased risk of flooding damage along the larger rivers (e.g., Tioga and Bradford counties in northeastern PA). Based on Detenbeck et al. (2004), the impervious coverage in the WV and VA portions tends to be less than 1%, however, development of second homes may be increasing in this region, which could be a cause for concern. Also, according to Detenbeck et al. (2004), agriculture does occur with some frequency in some of these WV and VA watersheds. It is suspected that agricultural land uses would occur on the lower slopes and in the associated hollows of these watersheds, and thus, there is potential for runoff of excess nitrogen, phosphorus and sediment from these fields into receiving streams.

Many of these watersheds, both in public and private holdings, currently have mature deciduous forests as the primary cover. If managed sustainably, they should remain fairly resilient to most stressors. Use of Best Management Practices for forestry and land development would provide substantial protection for aquatic ecosystems in these watersheds.

Areas of non-forest cover, and particularly along larger rivers and small streams, could serve as sources and vectors for spread of invasive plants. Riparian corridors without natural vegetation may be threatened by invasives and exotics. We predict that impervious cover is less associated with riparian corridors in this type than in others, because there are more options for land development in these larger watersheds.

By way of comparing our classification system to others, during the characterization process we found that the geographic dispersion of watershed types matched, to some extent, the available ecoregional classification, although we found recognizable subclusters of watersheds within those delineated ecoregions. We found that the nine-cluster classification system based on inherent, natural, physical features, developed for this project, aligned best with biological measures of stream integrity.

Figure 13. Our nine-cluster classification is shown below for reference (repeated from Fig. 3)



Recommendations for Applying Watershed Classification Approach

Our recommendations to potential users are to locate watersheds of interest, determine their cluster membership, and then consider their vulnerability to expected stressors. By understanding the inherent characteristic that compose each cluster, and considering its probable response to specific stressors, one can conceptually locate a watershed in the two dimensional space portrayed in Figure 14 presented below. When it is necessary to prioritize among multiple watersheds, then the relative location of a watershed in that space will suggest which is most vulnerable and in need of attention first. Although not developed during this project, a third axis to the diagram could incorporate aspects of technological and economic feasibility. Sometimes, even after a problem is properly assessed and diagnosed, its solution may be outside the realm of known technological treatments and available funds. At this point, perhaps other watersheds considered to be in a high priority category can be addressed. Based on our collective experience and interaction with stakeholders, we recognize that some of the more intangible, subjective aspects of professional judgment should definitely remain as part of any prioritization scheme. In this manner, a collaborative decision informed by science, policy, and local knowledge, can be made with resultant solutions implemented with an increased probability of success.

We recommend a prioritization approach that incorporates summary measures of condition and overall assessments of human disturbance (Figure 14). The x-axis of this conceptual model is a composite index of overall anthropogenic disturbance. That is, what is the current, assessed condition of the watershed(s) under consideration? The human disturbance gradient should combine landscape metrics (e.g., proportional land cover, LDI, riparian corridor) and site-specific data on stressors as available (e.g., fragmentation, acidification, influence of mining, etc.; Adamus and Brandt 1990, Karr and Chu 1998, USEPA 2000a). Best professional judgment or a quantitative measure of condition (e.g., Brooks et al. 2006a) should be used to place a watershed along this gradient from reference (least impaired) to severely impaired. The y-axis is used to assess how vulnerable a watershed is to observed or expected stressors. This axis can be regarded as “vulnerability to impairment.” As was found in this study, most watershed cluster types that are already impacted by land cover conversions, often have high ecological resistance or tolerance of future disturbance (e.g., cluster types: Moderate Mountains (4), Fertile Plains (6)), whereas cluster types demonstrating high vulnerability may show less conversion and impairment to date (e.g., Canyon Lands (5), Cold Wet Flats (1)). The high vulnerability of these latter watershed types implies that when landscape conversion or other types of stressors are present, then ecological condition declines rapidly.

We believe this approach is simple for, adaptable to, and useful by managers, because it combines the best available information from scientific investigations with the knowledge and intentions of local stakeholders. Whether comparing among watersheds or varying condition within the same cluster type or across cluster types, this approach should generate a relevant list of prioritized watersheds. The contemplative process used to locate multiple watersheds in this conceptual space should be most helpful in deciding upon a course of action with regard to prioritizing watershed protection and restoration.

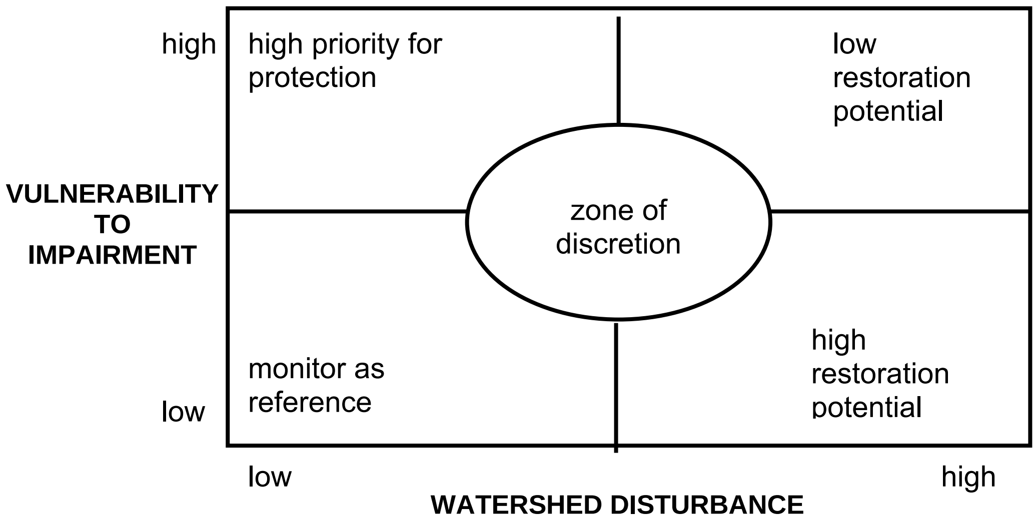


Figure 14. Conceptual framework for considering a watershed's vulnerability and potential for restoration given it's inherent characteristics and current condition. Users of this classification system are encouraged to consider where in this two-dimensional space they would place the watersheds of interest.

STAKEHOLDER COMMUNICATION

Meetings with Stakeholders

As part of this project, CVI coordinated three meetings with stakeholders. These included:

- On 12 Oct 2005, in State College PA, the PSU-CVI team met with representatives of Trout Unlimited, the Coldwater Heritage Partnership, and the PA Fish & Boat Commission to present an outline of our project.
- On 19 Jan 06, in Harrisburg PA, the research team met with fisheries biologists and program managers of the several resource agencies and conservation organizations in the Mid-Atlantic to present an overview of the project, alternate classifications based on inherent characteristics and stressors, and examples of watersheds prioritized for restoration. Feedback was solicited in a structured session.
- On 14 Jul 06 in Pleasant Gap PA, the CVI members presented a more advanced version of our watershed classification to members of the PA Fish & Boat Commission.

At these meetings, we solicited two general kinds of comments: (1) critical evaluations of our watershed classification scheme and (2) a conjecture of whether they might use it in their natural resources management programs. After each stakeholder meeting, all comments were discussed during the following all-hands team work sessions, and recommendations were implemented where feasible. Some additional details of these meetings are provided in Appendix C. Overall, the stakeholders' collective comments have placed us in a stronger position for applying and advocating the uses of our watershed classification system.

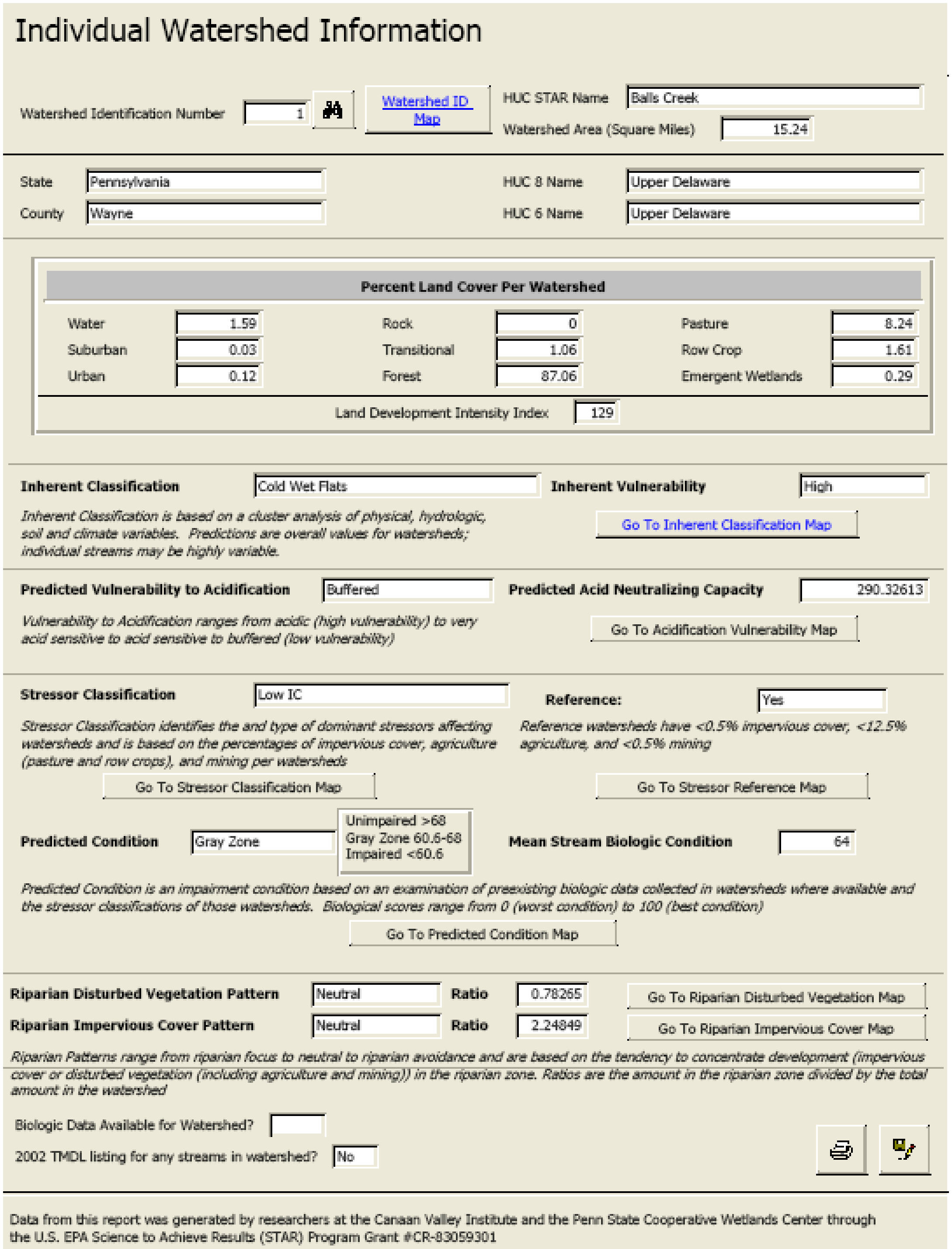
STAKEHOLDER TOOL

A prototype of a watershed visualization tool was developed as part of this project. This tool is referenced in Appendix B and can be found on the CD included with this report. In its current form, it consists of:

(1) a "zoom-able" JPG-format map of the study area, showing HUC-14 watersheds (including a reference number), streams, and county boundaries, and

(2) a database in Microsoft Access, referenced by watershed number, that provides a formatted version of much of the information generated by this project. An example watershed record is shown in Figure 15.

The database is searchable and can be linked to the watershed cluster map, providing easy assess to this information. Users can locate their watersheds to graphically zooming on the watershed map provided until the ones of interest are identified (one at a time). Once selected, the database is queried and produces a form listing the characteristics and predicted vulnerability of those watersheds according to the nine cluster types developed during this project. Then, stakeholders can locate their watersheds of interest in the two-dimensional prioritization space shown in Figure 13. At this point, best professional judgment should be used to further understand the vulnerabilities of the watersheds of interest and to devise an appropriate management, restoration, or protection approach to conserve the aquatic resources observed or predicted to occur in those watersheds. As stated previously, management decisions should be tied to the spatial scale of concern (e.g., several watersheds vs. an entire state or ecoregion) and the intended use of the information (e.g., planning development projects, targeting restoration areas, etc.).



Individual Watershed Information

Watershed Identification Number: 1 | Watershed ID Map

HUC STAR Name: Balls Creek

Watershed Area (Square Miles): 15.24

State: Pennsylvania

County: Wayne

HUC 8 Name: Upper Delaware

HUC 6 Name: Upper Delaware

Percent Land Cover Per Watershed

Water	1.59	Rock	0	Pasture	8.24
Suburban	0.03	Transitional	1.06	Row Crop	1.61
Urban	0.12	Forest	87.06	Emergent Wetlands	0.29

Land Development Intensity Index: 129

Inherent Classification: Cold Wet Flats

Inherent Vulnerability: High

Inherent Classification is based on a cluster analysis of physical, hydrologic, soil and climate variables. Predictions are overall values for watersheds; individual streams may be highly variable.

Go To Inherent Classification Map

Predicted Vulnerability to Acidification: Buffered

Predicted Acid Neutralizing Capacity: 290.32613

Vulnerability to Acidification ranges from acidic (high vulnerability) to very acid sensitive to acid sensitive to buffered (low vulnerability)

Go To Acidification Vulnerability Map

Stressor Classification: Low IC

Reference: Yes

Stressor Classification identifies the and type of dominant stressors affecting watersheds and is based on the percentages of impervious cover, agriculture (pasture and row crops), and mining per watersheds

Reference watersheds have <0.5% impervious cover, <12.5% agriculture, and <0.5% mining

Go To Stressor Classification Map

Go To Stressor Reference Map

Predicted Condition: Gray Zone

Unimpaired >68
Gray Zone 60.6-68
Impaired <60.6

Mean Stream Biologic Condition: 64

Predicted Condition is an impairment condition based on an examination of preexisting biologic data collected in watersheds where available and the stressor classifications of those watersheds. Biological scores range from 0 (worst condition) to 100 (best condition)

Go To Predicted Condition Map

Riparian Disturbed Vegetation Pattern: Neutral **Ratio** 0.78265 | Go To Riparian Disturbed Vegetation Map

Riparian Impervious Cover Pattern: Neutral **Ratio** 2.24849 | Go To Riparian Impervious Cover Map

Riparian Patterns range from riparian focus to neutral to riparian avoidance and are based on the tendency to concentrate development (impervious cover or disturbed vegetation (including agriculture and mining)) in the riparian zone. Ratios are the amount in the riparian zone divided by the total amount in the watershed

Biologic Data Available for Watershed?

2002 TMDL listing for any streams in watershed? No

Data from this report was generated by researchers at the Canaan Valley Institute and the Penn State Cooperative Wetlands Center through the U.S. EPA Science to Achieve Results (STAR) Program Grant #CR-83059301

Figure 15. Example information page available for each watershed in the study area, using a Microsoft Access database developed specifically for this project.

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APPENDIX A. Full set of candidate metrics computed for the Mid-Atlantic Highlands Area, and considered for inclusion in the Characterization Model.

Variable Name	Description
PHYSICAL/ TOPOGRAPHIC VARIABLES	
AREA	area of watershed
PERIMETER	perimeter of watershed
ELEVMIN	minimum elevation in watershed
ELEVMAX	maximum elevation in watershed
ELEVMEAN	mean elevation in watershed
ELEVRANGE	elevation range in watershed
SLP-MIN	minimum slope in watershed
SLP-MAX	maximum slope in watershed
SLP-MEAN	mean slope of watershed
MSI	mean shape index
AWMSI	area weighted mean shape index
MPAR	mean perimeter to area ratio
MPFD	mean patch fractal dimension
AWMPFD	area weighted mean patch fractal dimension
CTI_MIN	compound topographic index - minimum
CTI_MAX	compound topographic index - maximum
CTI_MEAN	compound topographic index - mean
CURVMIN	minimum local curvature
CURVMAX	maximum local curvature
CURVMEAN	mean local curvature
FLOWMIN	minimum flow accumulation
FLOWMAX	maximum flow accumulation
FLOWMEAN	mean flow accumulation
BOLMIN	minimum bolstad concavity/convexity index
BOLMAX	maximum bolstad concavity/convexity index
BOLMEAN	mean bolstad concavity/convexity index
FDIRMIN	minimum flow direction (degrees)
FDIRMAX	maximum flow direction (degrees)
FDIRMEAN	mean flow direction (degrees)
MCNABMIN	minimum McNab topographic index
MCNABMAX	maximum McNab topographic index
MCNABMEAN	mean McNab topographic index
SOILS VARIABLES	
RVOL_AW (L1-L11)	rock fragment volume, area weighted, for each of 11 soil layers
SAND_AW (L1-L11)	sand percentage, area weighted, for each of 9 soil layers
CLAY_AW (L1-L11)	clay percentage, area weighted, for each of 10 soil layers
SILT_AW (L1-L11)	silt percentage, area weighted, for each of 11 soil layers
PHAW (L1-L11)	pH, area weighted, for each of 10 soil layers
PERMAW (L1-L11)	permeability, area weighted, for each of 11 soil layers
AWC_100AW	available water capacity in top 100 cm, area weighted
AWC_150AW	available water capacity in top 150 cm, area weighted

AWC_250AW	available water capacity in top 250 cm, area weighted
BDAW (L1-L11)	bulk density, area weighted, for each of 11 soils layers
POROS_AW (L1-L11)	porosity, area weighted, for each of 11 soils layers
ROCKDEPMA	depth to bedrock, area weighted
KFACTA	Universal Soil Loss Equation (USLE) *k*-factor, without rocks
KFFACTA	Universal Soil Loss Equation (USLE) *k*-factor, with rocks
HSGAA	% Hydrologic Soil Group A in watershed
HSGBA	% Hydrologic Soil Group B in watershed
HSGCA	% Hydrologic Soil Group C in watershed
HSGDA	% Hydrologic Soil Group D in watershed
HSGWA	% Hydrologic Soil Group W (Water) in watershed
PIA_AW (L1-L11)	plasticity index, area weighted

CLIMATE VARIABLES

ANNFF	length of freeze-free period, 30-year average
ANNGDD	annual growing degree days, 30-year average
ANNPRECIP	annual precipitation, 30-year average
ANNSNOW	annual snowfall, 30-year average
ANNTMEAN	average of "ANNTMAX" and "ANNTMIN" variables
ANNTMAX	maximum daily temperature, 30-year average
ANNTMIN	minimum daily temperature, 30-year average
JAN_MAR_PR	Jan - Mar precipitation, 30-year average
APR_JUN_PR	Apr - Jun precipitation, 30-year average
JUL_SEP_PR	Jul - Sep precipitation, 30-year average
OCT_DEC_PR	Oct - Dec precipitation, 30-year average
TMEAN_JAN	mean Jan temperature, 30-year average
TMEAN_FEB	mean Feb temperature, 30-year average
TMEAN_MAR	mean Mar temperature, 30-year average
TMEAN_APR	mean Apr temperature, 30-year average
TMEAN_MAY	mean May temperature, 30-year average
TMEAN_JUN	mean Jun temperature, 30-year average
TMEAN_JUL	mean Jul temperature, 30-year average
TMEAN_AUG	mean Aug temperature, 30-year average
TMEAN_SEP	mean Sep temperature, 30-year average
TMEAN_OCT	mean Oct temperature, 30-year average
TMEAN_NOV	mean Nov temperature, 30-year average
TMEAN_DEC	mean Dec temperature, 30-year average
TMAX_JUL	maximum Jul temperature, 30-year average
TMIN_JAN	minimum Jan temperature, 30-year average

HYDROLOGIC VARIABLE SET (for all watersheds)

SINUOUS_AV	average sinuosity
CHAN_SLP_A	average channel slope
SD_CHAN_SL	standard deviation of channel slope
TNODE_DNS	density of stream network nodes
STRM1_PCT	% of 1-3 order streams that are 1st order
STRM2_PCT	% of 1-3 order streams that are 2nd order
STRMLEN_TO	total stream length

STRMDENS	total stream density
STRMDENS1	density 1st order streams
STRMDENS2	density 2nd order streams
SEG_LENGTH	average stream segment length

HYDROLOGIC VARIABLE SET (for "pass-through" watersheds only)

INORD	iInitital stream order
PRORD	stream order at pour point
ORDINC	order increase
FAC_MAX	maximum flow accumulation
FWA_INELEV	flow weighted average input elevation
PRELEV	pour elevation
MSRELIEF	mainstem relief
MS_LENGTH	mainstem length
LWA_SIN	length weighted average sinuosity
MSMINGRAD	mainstem minimum gradient
MSMAXGRAD	mainstem maximum gradient
MSMNGRAD	mainstem mean gradient
ORD1ND	density of 1st order stream nodes
ORD2ND	density of 2st order stream nodes
ORD3ND	density of 3st order stream nodes
ORD4ND	density of 4st order stream nodes
ORD5ND	density of 5st order stream nodes
ORD6ND	density of 6st order stream nodes
ORD7ND	density of 7st order stream nodes
ORD8ND	density of 8st order stream nodes

APPENDIX B. Publications, draft manuscripts, and a prototype of a stakeholder tool developed as part of this study.

Publications and Draft Manuscripts

Constantz, G., B. Rashleigh, B. Griscom, and A. McQueen. In prep. Associations between watershed characteristics and benthic macroinvertebrate communities in streams of the Central Appalachian Mountains. 36 ms. pages.

Griscom, B., G. Constantz, A. McQueen, and B. Rashleigh. In prep #1. Influence of elevation on West Virginia Stream Condition Index: vulnerability differences and calibration needs.

Griscom, B., A. McQueen, A. Bayard, R. Brooks, G. Constantz, G. Rocco, and W. Myers. In prep #2. Vulnerability of watersheds to acidification in the Mid-Atlantic Highlands.

Griscom, B., A. McQueen, R. Brooks, W. Myers, G. Constantz, M. Easterling, and J. Bishop. In prep #3. Spatial patterns of land use in the Mid-Atlantic Highlands: Factors affecting avoidance or concentration of human impacts in the riparian zone.

Griscom, B., A. McQueen, W. Myers, G. Constantz, R. Brooks, M. Easterling, G. Rocco, and J. Bishop. In prep #4. Classification of watersheds in West Virginia based on vulnerability of streams to human impacts.

Myers, W., G. P. Patil and Y. Cai. 2006. Exploring patterns of habitat diversity across landscapes using partial ordering. Pp. 309-325 in: R. Bruggemann and L. Carlsen, eds. Partial Order in Environmental Sciences and Chemistry. Berlin: Springer. 406 p.

Myers, W. L., M. McKenney-Easterling, K. Hychka, B. Griscom, J. A. Bishop, A. Bayard, G.L. Rocco, R. P. Brooks, G. Constantz, G. P. Patil and C. Taillie. 2006. Contextual clustering for configuring collaborative conservation of watersheds in the Mid-Atlantic Highlands. Environmental and Ecological Statistics 13 (4): 391-407.

Rocco, G. Unpublished. Modeling of Nutrients for the Watershed Classification Project.

Prototype of Stakeholder Tool

Map of Study Area showing HUC-14 watersheds (including watershed reference number), streams, and counties.

Database (Microsoft Access) of selected watershed information, by watershed reference number

APPENDIX C. Summary of Meetings with Stakeholders.

As part of this project, CVI coordinated three meetings with stakeholders. From these state officials, nonprofit conservation groups, and other potential users, we solicited two general kinds of comments, (1) critical evaluations of our watershed classification scheme and (2) a conjecture of whether they might use it in their natural resources management programs.

On 12 Oct 05 at State College PA, the PSU-CVI team met with representatives of Trout Unlimited, the Coldwater Heritage Partnership, and the PA Fish & Boat Commission. After we outlined our project, they offered the following comments:

- Delete “buffer” from the term “Watershed Storage Buffer Categories.”
- More completely define “ANC,” the acronym we use for acid neutralizing capacity. What is it? Characterize it chemically. Is it always correlated with pH?
- Consider forecasting changes in a watershed’s class to reflect expected land development changes.

The first two seek clarifications, while the last suggests a task unattainable with present data.

On 19 Jan 06 in Harrisburg PA, the research team met with fisheries biologists and program managers of the PA Fish & Boat Commission. Our presentation included an overview of the project, alternate classifications based on inherent characteristics and stressors, and examples of watersheds prioritized for restoration. In a structured session, we solicited their advice on high-priority questions, most useful tools, and most relevant scales. Stakeholders offered the following suggestions:

- Use a different color to indicate forest land cover.
- Come to a consensus on the terms vulnerability, dose, and stressor.
- To distinguish cold- and warm-eater fisheries, try including water temperature.
- To support the protection of instream flows, include stream discharge volumes in our classification.
- Integrate PA’s 303(d) list into our watershed classification process.
- Evaluate the relationship between Rosgen’s stream classes and our watershed classes. Test this with a subset of stream reaches that have been classified by the Rosgen classes.
- For nitrate, phosphate, and pH, use EPA’s STORET water-quality database to evaluate our watershed classes.
- Consider using Strager’s decision-support system in the prioritization phase of our process.
- Try to overlay the PA categories of protection and our prioritization maps.
- They liked the tiered steps we used to identify reference watersheds.

We consider these comments to be mainly substantive, going to the core of how to improve our scheme's usefulness. Where appropriate, we incorporated some of these suggestions.

Lastly, on 14 Jul 06 in Pleasant Gap PA, the CVI members presented a more advanced version of our watershed classification to members of the PA Fish & Boat Commission. Although they felt it might be useful for statewide program managers, it seemed to offer little to within-state regional restorationists because the scale of our data was too coarse. Because of the scale of pre-existing datasets, we classified watersheds of 10,000 to 50,000 acres each. The stakeholders stated that our product did not provide enough within-watershed data to allow prioritization of restoration sites within individual watersheds.

After each stakeholder meeting during all-hands team work sessions, all comments were taken seriously. As you can infer, some recommendations (e.g., definitions) were easily implementable, others (e.g., using finer-scale data) were not. Overall, the stakeholders' collective comments have placed us in a stronger position for applying and advocating the uses of our watershed classification system.