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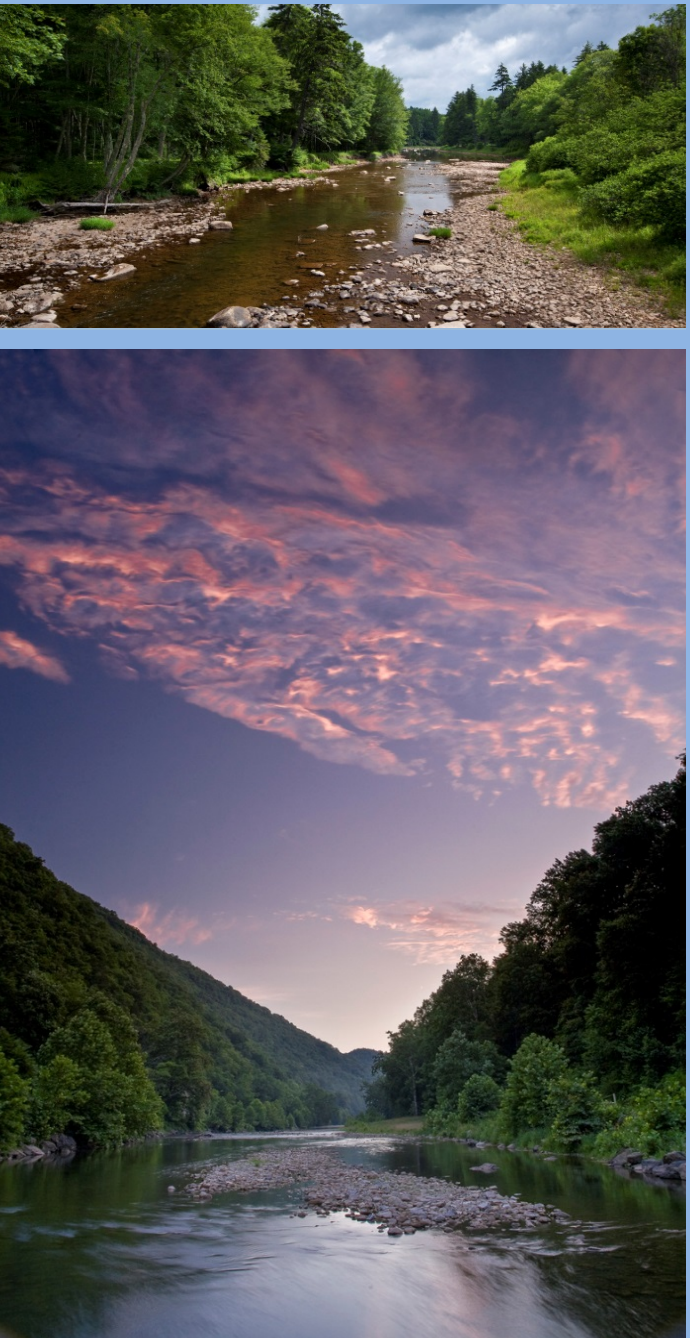
LANDSCAPE CONSERVATION COOPERATIVES

A Stream Classification for the Appalachian Region

The Nature Conservancy Eastern Conservation Science
Arlene Olivero Sheldon, Analie Barnett, and Mark G. Anderson



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Cover photo credits

Top Left: Shavers Fork of the Cheat River at The Conservancy's Upper Shavers Fork Preserve in West Virginia. PHOTO CREDIT: © Kent Mason

Top Right: Confluence of the smaller Tradewater River and the Ohio River in Crittenden County, Kentucky. PHOTO CREDIT: Mark Godfrey © The Nature Conservancy

Bottom Left: Smoke Hole Canyon on the South Fork of the Potomac River in West Virginia. PHOTO CREDIT: © Kent Mason

Small Middle Top: Forest view of the split channel in the upper Rappahannock River above Culpepper in northern Virginia. © Mary Porter

Small Middle Bottom: The south fork of Red Creek flowing through the forest at Dolly Sods Wilderness. in the Allegheny Mountains of eastern West Virginia . PHOTO CREDIT: © Kent Mason

Bottom Right: The Falls of Hills Creek in the Monongahela National Forest in West Virginia. PHOTO CREDIT: © Kent Mason

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Abstract

We developed a hierarchical classification system and map for stream and river systems in the Appalachian Landscape Conservation Cooperative region encompassing parts of 17 states. The product is intended to complement state-based stream classifications by unifying them into a single consistent system that represents the region's natural flowing-water aquatic habitats. The results may be used to understand ecological flow relationships and inform conservation planning for aquatic biodiversity in the region. The classification used six primary attributes to define stream habitats: size, gradient, temperature, hydrology, buffering capacity, and confinement. These variables were identified and agreed upon by a steering committee of stream and river experts representing the states and region. All mapped stream reaches (1:100,000) were tagged with information on each variable based on extensive data compiled, or modeled, for each reach. For each variable, ecologically meaningful class breaks were identified and the variable classes were combined to yield a regional taxonomy. The complete set of types was simplified using recommended prioritization and collapsing rules as follows: headwaters and small rivers were classified based on gradient, temperature, and hydrology (e.g., high gradient, cold, flashy, headwater) and medium to great rivers were classified based on confinement, temperature, and hydrology (e.g., low gradient, warm, unconfined, large river). The simplification identified 62 stream types within the study area.

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1 Background

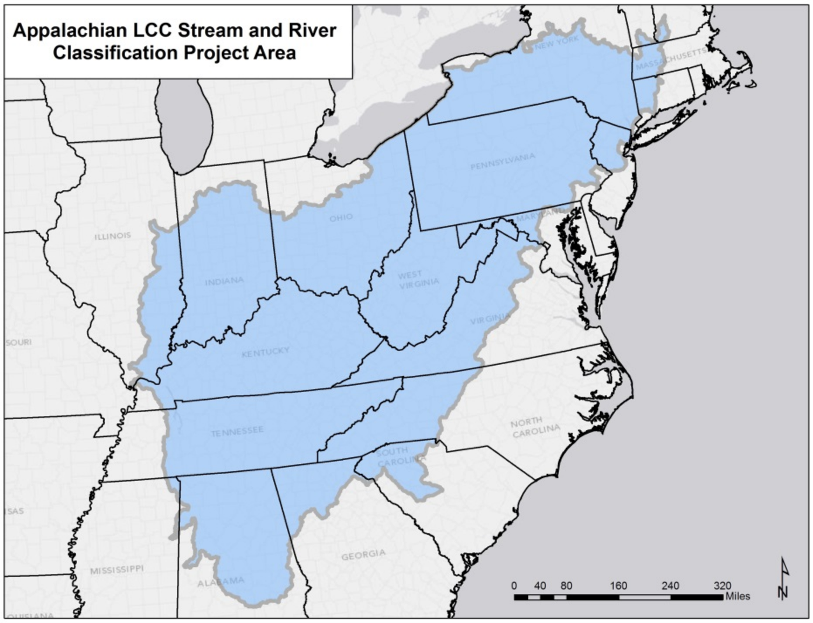
Objective

The objective of this project was to create a mapped classification of streams and rivers in the greater Appalachian Landscape Conservation Cooperative (LCC). Our goal was to base the classification on key variables that structure stream and river natural communities, and that could be mapped consistently across all streams and rivers in the region. The variables and variable classes were identified and agreed upon by a steering committee of stream and river experts representing the states and region. The product was envisioned to represent the natural flowing-water aquatic habitat types across this region in a manner deemed appropriate and useful for building flow ecology relationships and informing other conservation planning tools focused on aquatic biodiversity patterns.

Project Area

The project area included all of the Appalachian LCC boundary plus adjacent area needed to encompass complete watersheds (Map 1-1). This meant expanding the northern and western boundary to include all of the Ohio River Basin as most of the basin was already within the Appalachian LCC. For the eastern and southern boundaries, we included any 8 digit Hydrologic Unit Code (HUC8) watersheds that touched the Appalachian LCC or the Appalachian LCC Marcellus Shale Analysis Project Boundary, another aquatic resource analysis funded by the Appalachian LCC.

Map 1-1. Project area



Classification Process

A steering committee of 41 aquatic ecologists and conservation planners from across the region guided the classification development (Table 1-1). The guidance of the steering committee was critical to ensure we developed a product useful to state and federal agencies and that reflected a local understanding of stream and river ecosystems and their management. The committee members provided specific datasets and gave advice and feedback during the course of the project. We held team webinars throughout the project to solicit feedback regarding the best variables and approaches to develop the mapped stream classification. These discussions highlighted the classification variables that the majority of states currently use, or would like to use, for a regional classification. The team also provided recommendations regarding how the reach-scale stream types should be considered within a hierarchy of larger regional scale planning units including Omernick Ecoregions, Freshwater Ecoregions, Freshwater Ecological Drainage Units, and HUC watersheds. During the initial stages of this project, we also completed a detailed literature review of freshwater classification frameworks (Olivero-Sheldon and McManamay 2014) including taxonomic, environmental, and hydrologic classifications for natural stream and river types.

The literature review and the detailed webinar discussions revealed a high level of agreement among the team regarding the important classification variables. Accordingly, we agreed to focus the reach-scale classification work on the following six primary variables that structure stream and river ecosystems and could be mapped consistently across the region:

- Size
- Gradient
- Temperature
- Hydrology
- Buffering Capacity
- Confinement

The team also provided recommendations regarding how the variables should be simplified and combined into stream and river “types.” The details of the regional and reach-scale classifications are provided in subsequent chapters.

Table 1-1. Project steering committee members and affiliations

Geography	Organization	Name	Email
AL	TNC	Mary Kate Brown	mkbrown@tnc.org
AL	State	Pat O'Neil	poneil@gsa.state.al.us
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Regional	USGS	Nathanial Hitt	nhitt@usgs.gov
Regional	USGS Indiana Science Center	Jeff Frey	jwfrey@usgs.gov
Regional	Oak Ridge National Lab	Ryan McManamay	mcmanamayra@ornl.gov

Base Hydrography Data

The National Hydrography Dataset Version 2 (NHDPlusV2; USEPA 2013), a publicly available 1:100,000 scale GIS dataset, was used as the base hydrography dataset for this project. All resultant classification attributes were linked to the NHDPlusV2 flowline unique IDs (i.e., COMIDs). The flowline units are, in most cases, the vector line between confluences and are thus bounded by confluences or headwater nodes. The NHDPlusV2 linework is geometrically corrected, augmented with names, and provides line (stream), polygon (lake), and local catchment watersheds for each flowline. Moreover, USGS has a maintenance infrastructure to improve the NHDPlus dataset and integrate user updates over time. For example, improvements between Version 1 and Version 2 include better input source data as well as better procedures for building NHDPlusV2 components including improved flow estimates, catchment attributes, and accumulated attributes to enhance the application and utility of NHDPlusV2 (McKay et al. 2012).

Base Flowline Attributes

Over 300 attributes for each NHDPlusV2 flowline were compiled and calculated as part of this project. This includes a set of 50 value-added attributes pre-calculated by USGS and distributed with the NHDPlusV2, along with over 250 local and cumulative attributes calculated by TNC using available soils, geology, landforms, land cover, and other source datasets. Please see Appendix I for a full list of the compiled variables for each flowline, and refer to Appendix II for the methods detailing how the local and cumulative attributes were calculated by TNC.

Literature Review

During the initial stages of this project, we completed a detailed literature review of freshwater classification frameworks (Appendix 4: **Literature Review of Freshwater Classification Frameworks**). The document includes background on taxonomic, environmental, and hydrologic classifications for natural stream and river types. We do not repeat the bulk of this detailed classification background in this report, instead we seek to synthesize and present key ecological concepts justifying the variables chosen and focus on presenting the methods and results of implementing the classification in the Appalachian LCC region. Please consult the full literature review for details regarding approaches to stream classification, particularly the background on hydrologic classification and the environmental geophysical classifications of Frissel (1986), Rosgen (1994), Maxwell (1995) and Higgins (2005) which guided our work.

2 Regional Scale Classification

Stream classifications can be organized on different scales within a watershed or region, from an entire drainage region such as the Ohio River Basin to pools and riffles within a single stream reach. At the regional scale, individual streams fit within several regional classification frameworks: 1) Omernick Ecoregions, 2) Freshwater Ecoregions, 3) Freshwater Ecological Drainage Units, and 4) Hydrologic Unit Code (HUC) watersheds. States within the Appalachian LCC are using all of these frameworks in their freshwater planning. Accordingly, we attributed all stream reaches in the final dataset to each framework because an understanding of these major regional-scale units is important for finer levels of stream classification and management.

Placing the reach classification within a regional classification unit allows consideration of additional variation that is hard to incorporate at the reach-scale alone. This variation can include regional patterns in topography, geology, climate, and larger patterns of network connections. At regional scales, a complex set of historical, environmental, climatic, and ecological factors have interacted to create the current distribution of freshwater biota. For example, due to historical drainage connections during the last glaciation, freshwater species in Mississippian drainages had access to extensive southern refugia and could recolonize northern areas after glaciation. This history has contributed to the large number of freshwater species found in Mississippian drainages in comparison to the lower numbers of species found in similar physical habitats in the northern Atlantic drainages where no portion of the watershed remained habitable during glaciation (Hocutt and Wiley 1986). Thus the individual aquatic species found in any given river or stream habitat will be highly influenced not only by the local physical characteristics of a given reach, but also by the species pool, history, and physical characteristics of the larger region.

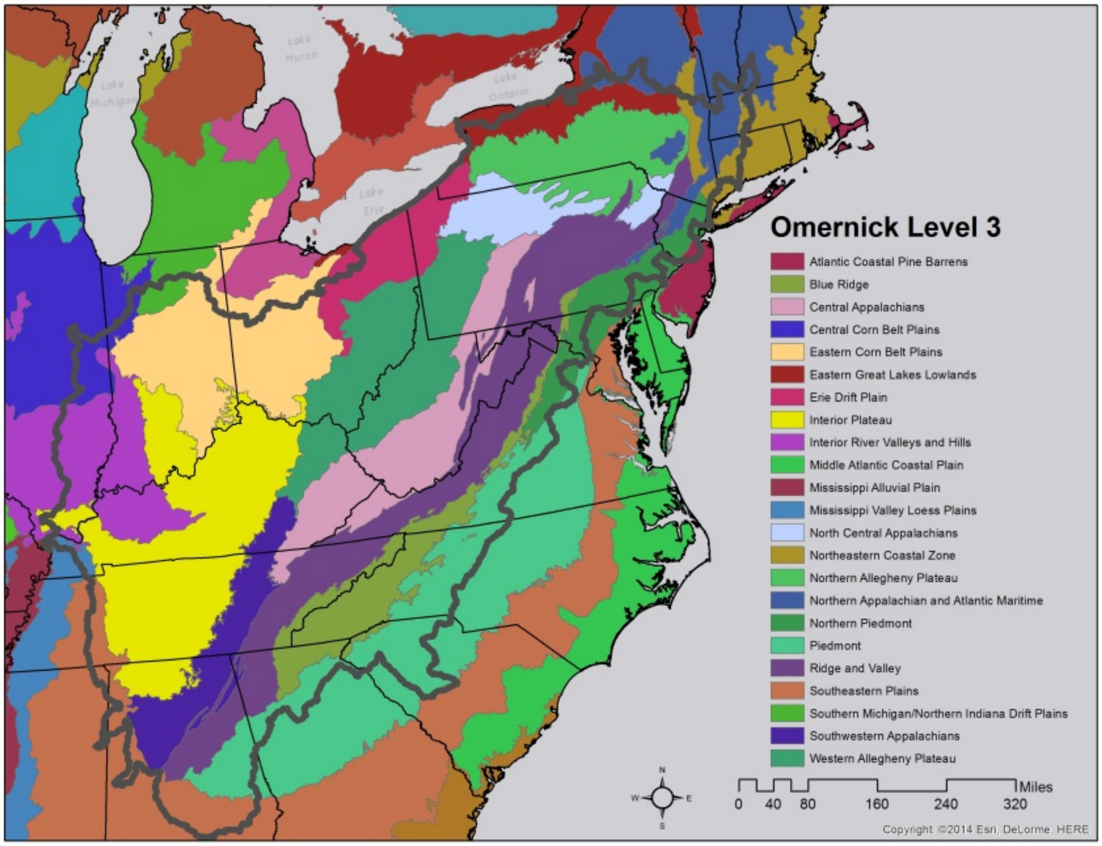
Each of the four regional stratifications is briefly described in the following section:

1. Omernick Ecoregions
2. Freshwater Ecoregions
3. Freshwater Ecological Drainage Units
4. Hydrologic Unit Code Watersheds

Omernick Level 3 Ecoregions

Omernick ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. Omernick ecoregions are based on an analysis of biotic and abiotic phenomena, including geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another. Methods used to define the ecoregions are explained in Omernik (1995, 2004), Omernik et al. (2000), and Gallant et al. (1989). Twenty-three Omernick Level 3 Ecoregions intersect the Appalachian LCC project area (Map 2-2).

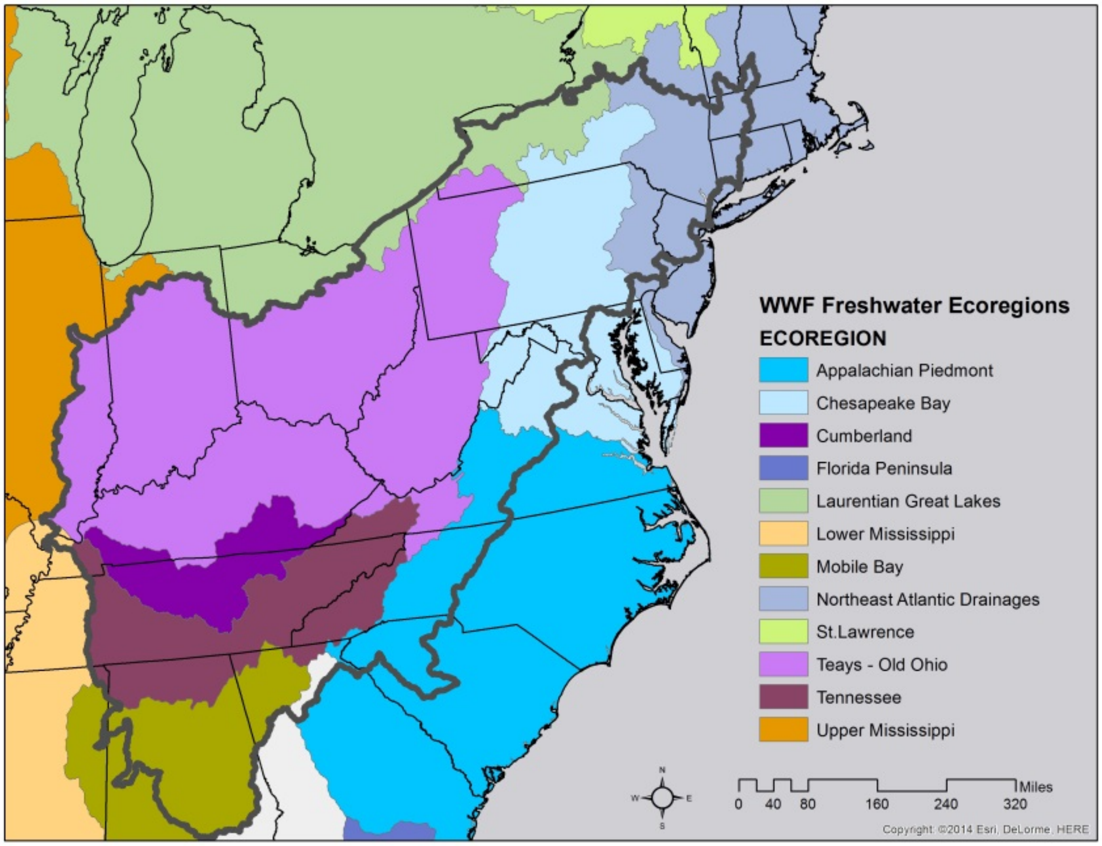
Map 2-2. Omernick Level 3 Ecoregions in the project area



Freshwater Ecoregions

Freshwater Ecoregions of the World (FEOW; Abell et al. 2008), developed by the World Wildlife Fund (WWF) in partnership with TNC and 200 freshwater scientists from institutions around the world, are a global freshwater biogeographic regionalization. These units are based on major drainage basins following patterns of stream connectivity. While the drainage basins cut across terrestrial ecoregions, they are particularly useful for studying aquatic biodiversity patterns which are often limited in their distribution by direct drainage connectivity. Within individual ecoregions there will be turnover of species, however, taken as a whole, a freshwater ecoregion is distinguished by a unique pattern of native freshwater biota resulting from large-scale geoclimatic processes, evolutionary history, and stream connectivity (Abell et al. 2008). The primary Freshwater Ecoregions intersecting the Appalachian LCC project area include the Ohio, Tennessee, Mobile Bay, Appalachian Piedmont, Chesapeake Bay, Northern Atlantic Drainages, and the Laurentian Great Lakes (Map 2-3).

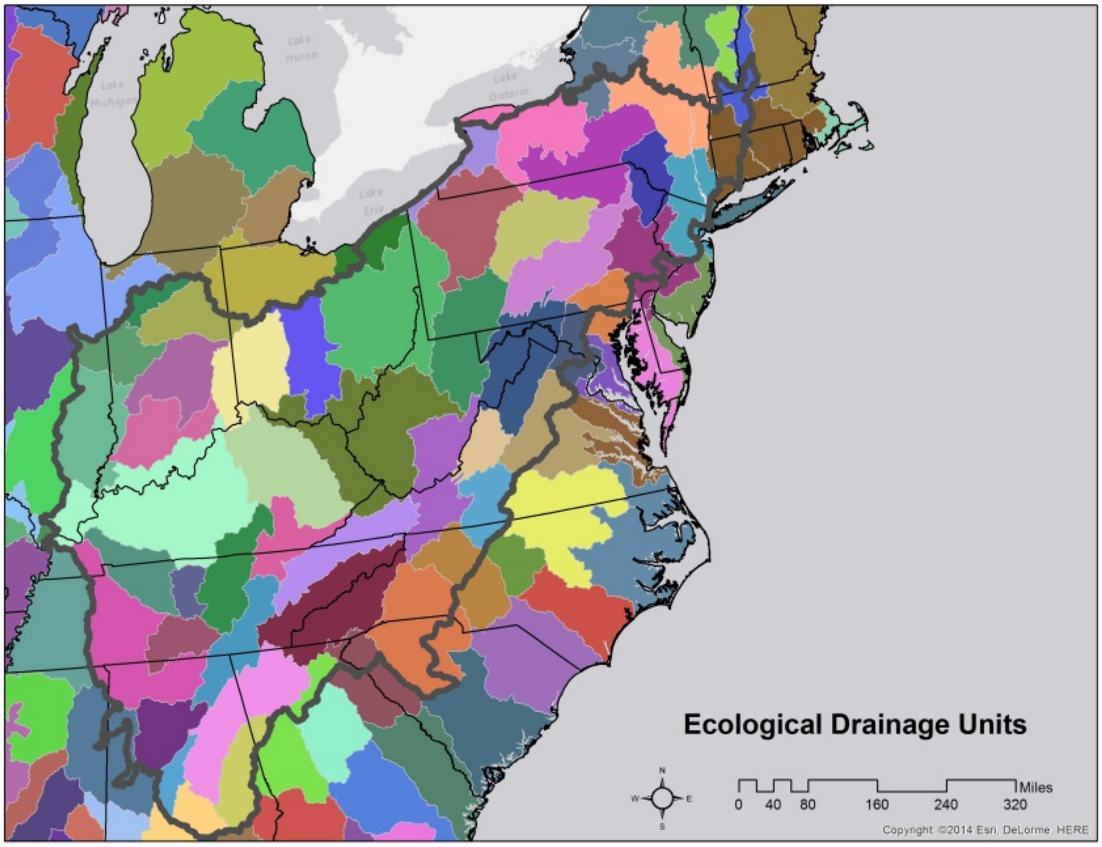
Map 2-3. Freshwater Ecoregions of the World (FEOW) in the project area



Ecological Drainage Units

Ecological Drainage Units (EDUs) delineate areas within Abell et al.’s (2008) Freshwater Ecoregions. They correspond roughly with large watersheds ranging from 3000 - 10,000 square miles. EDUs were developed by aggregating the watersheds of major tributaries (HUC8 scale) that share a common zoogeographic history as well as local physiographic and climatic characteristics. These judgements were made by staff of TNC’s Freshwater Initiative after considering USFS Fish Zoogeographic Subregions (Maxwell 2005), USFS Ecoregions and Subsections (Cleland et al. 2007), and major drainage divisions (Higgins et al. 2005).

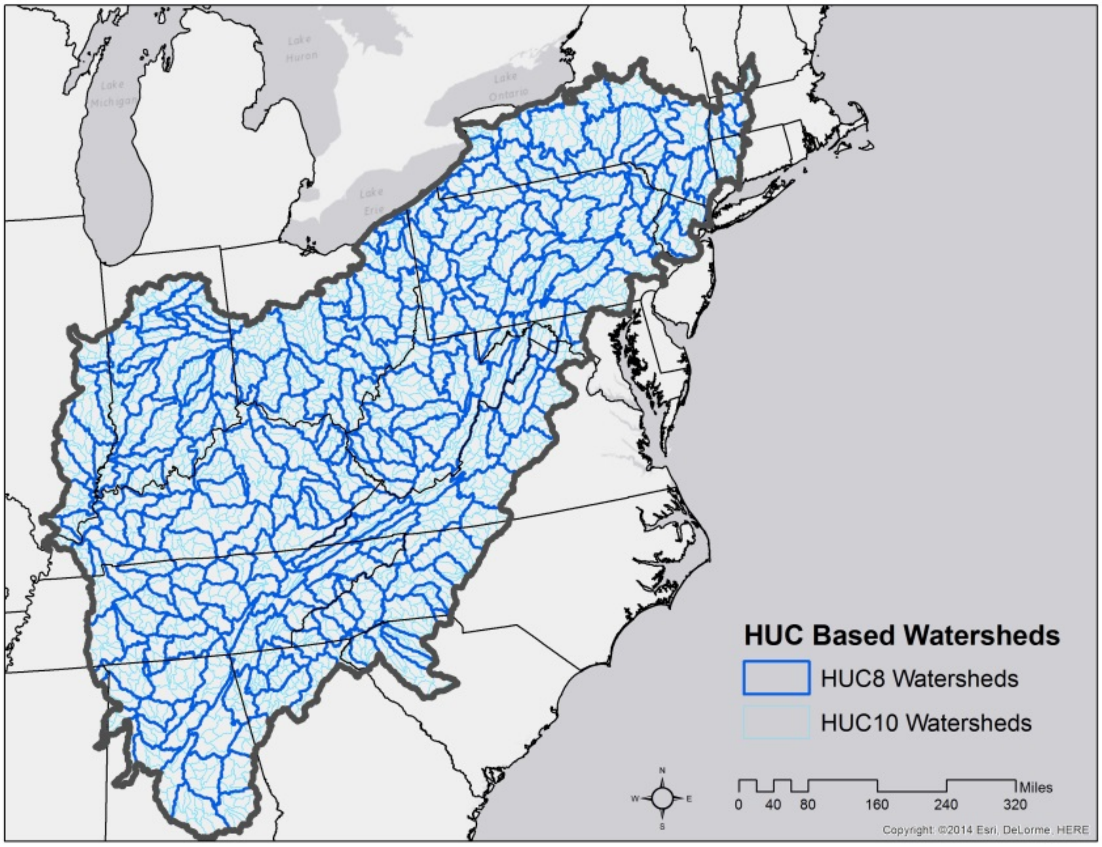
Map 2-4. Ecological Drainage Units (EDUs) in the project area



Hydrologic Unit Codes (HUCs)

The United States is divided and sub-divided into successively smaller hydrologic units (USGS and NRCS 2013). Each hydrologic unit is identified by a unique hydrologic unit code (HUC) consisting of digits based on levels of classification in the hydrologic unit system. The hydrologic units are arranged or nested within each other, from the largest geographic area (HUC2 regions) to the smallest geographic area (HUC12 cataloging units). Hydrologic units are not true watersheds, as defined by an area of land and water bounded such that all surface drainage within the boundary converges to a single point. In contrast, hydrologic units are delineated so as to nest into a multi-level hierarchical drainage system, and may accept water from one or more points outside of the unit's boundary in addition to its internal surface drainage. Many state and federal agencies use HUC units for monitoring and reporting the status of freshwater systems.

Map 2-5. Eight and ten digit Hydrologic Unit Codes (HUCs) in the project area



3 Reach Scale Classification

Reach-scale classification refers to finer-scale patterns of stream channel size, gradient, temperature, hydrologic regime, lateral channel confinement, acidity, and local zoogeographic sources that influence aquatic biological assemblages within a region (Higgins et al. 2005, Maxwell et al. 1995, Rosgen 1994, Frissell et al. 1986). Variation in a stream's size, substrate, gradient, and temperature creates corresponding variations in the biota it supports. The physical factors interact to form a template that shapes the biota (Figure 3-1). For example, a stream in an acidic, high gradient, and cold setting is expected to have low pH, cold, fast moving water, narrow confined channels with step-pool and riffle habitats and bed materials of bedrock, boulders, cobbles, and coarse gravel. In contrast, a stream in a calcareous, low gradient, warm setting would be expected to have high pH, warm, slow-moving water, unconfined and meandering channels with glide-pool and ripple dune habitats and bed materials of sands and silts. The biota adapted to live in these two very different stream settings will vary considerably.

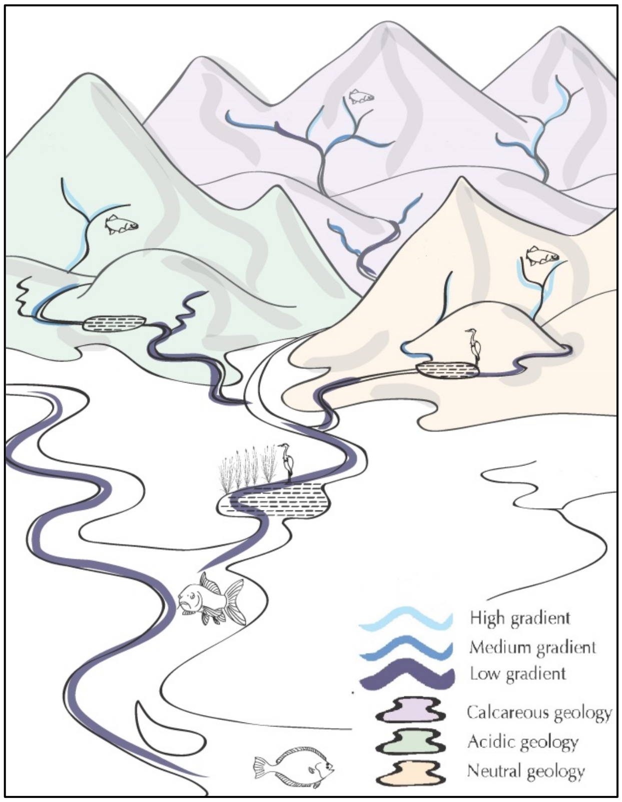


Figure 3-1. This diagram shows different classification variables that can define physical stream habitats: bedrock geology, stream gradient, and stream size.

After literature review and considerable discussion with the steering committee, we identified six variables that strongly influence stream biota at the reach-scale and that could be accurately mapped across the region. These became the basis of our reach-scale classification:

1. Size
2. Gradient
3. Temperature
4. Hydrologiy
5. Buffering Capacity
6. Confinement

The justification for each variable and the methods used to map them are described in the following chapters. All six variables were mapped for every stream and river reach in the region.

4 Size

Ecological Importance

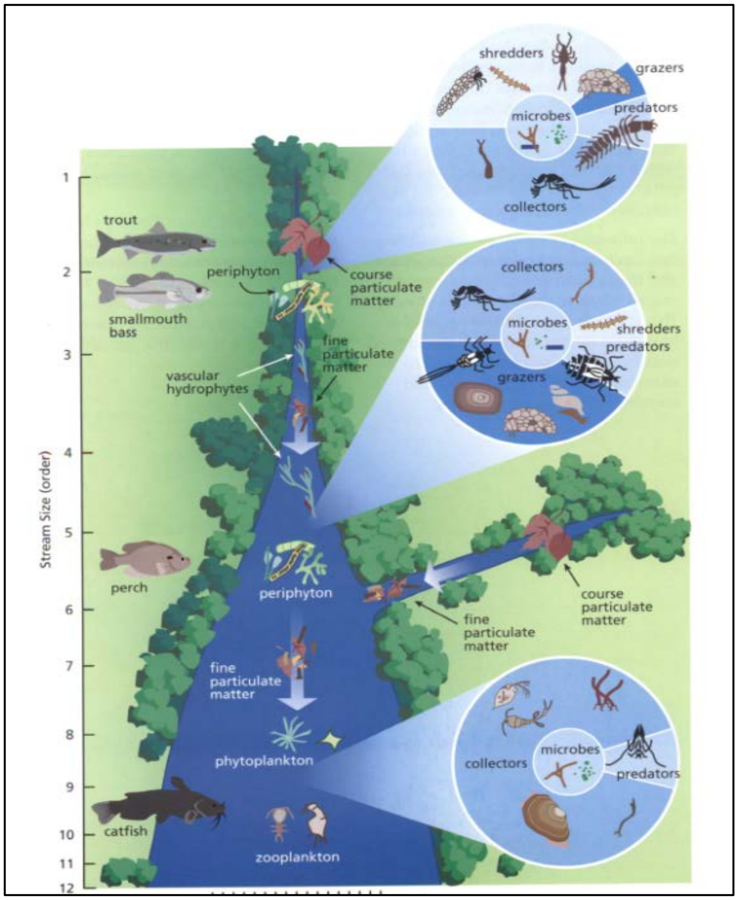


Figure 4-1. River continuum concept (Vanotte et al. 1980)

Stream size has been given the greatest importance in many reach-scale stream classifications because of its strong effect on determining aquatic biological assemblages (Vannote et al. 1980, Higgins et al. 2005). The well-known "river continuum concept" (Figure 4-1) describes how the physical size of a stream relates to major ecosystem changes from small headwater streams to large river mouths (Vannote et al. 1980). In small narrow headwater streams, riparian vegetation shades the stream and coarse particulate organic matter (e.g., leaves and twigs) provides the energy source for a consumer community dominated by plant-shredding insects. As a river broadens at mid-order sites, energy inputs change as sunlight reaches the stream to support significant periphyton production and algae-grazing insects. As the river further increases in size, fine particulate organic matter inputs increase and macrophytes become more abundant as reduced channel gradient and finer sediments form suitable conditions for their establishment. In even larger rivers, the main channel becomes unsuitable for macrophytes or periphyton due to turbidity, fast current, depth, and lack of stable substrates. Production by phytoplankton increases until limited by instream turbidity, and organic matter inputs from outside the stream channel again become the primary energy source as processes such as floodplain scouring increase.

Approach

There are many ways to measure stream size: upstream drainage area, mean annual flow, bankfull width, stream order, or number of first order streams above a given segment. We used upstream catchment drainage area because upstream drainage determines the volume of seasonal floods and large flows which shape the channel size. Upstream drainage area is correlated with the other measures of size, but unlike “stream order” it is independent of the scale of the mapped hydrography and is independent of hydrologic regime or climatic changes. Upstream drainage area was also used to measure stream size in other regional stream classifications covering parts of the Appalachian LCC such as the Northeast Aquatic Habitat Classification system (Olivero and Anderson 2008), the Stream Classification Framework for the Southeast Region (Olivero and Anderson 2013), and the National Fish Habitat Classification (Beard and Whelen 2006).

In GIS, the upstream drainage area for each flowline was available directly from the NHDPlusV2 value-added attributes (USEPA 2013). USGS determined the upstream drainage area for each flowline using a 30 m digital elevation model combined with the national watershed boundary dataset and a flow accumulation algorithm (McKay et al. 2012). Two upstream drainage area variables were available: total upstream cumulative drainage area which accumulates the total value of the area upstream, and divergence-routed cumulative drainage area which normalizes the value by routing a portion of the accumulation down each path of the divergence such that the sum of the portions is 100% of the accumulation. We used the latter because in this method small side channels that diverge from main channels and then reconnect to the main channel are assigned their small local catchment area instead of the full upstream catchment area (e.g., a small side channel reach on the Ohio River is classified as a headwater reach rather than given the full upstream drainage area of the Ohio River). When there is no data on how to apportion an accumulation down divergence paths, the algorithm uses defaults that route 100% of the flow down the main path. As the majority of diversion side channels in the study area had sizes much smaller than the main path, this seemed a reasonable assumption.

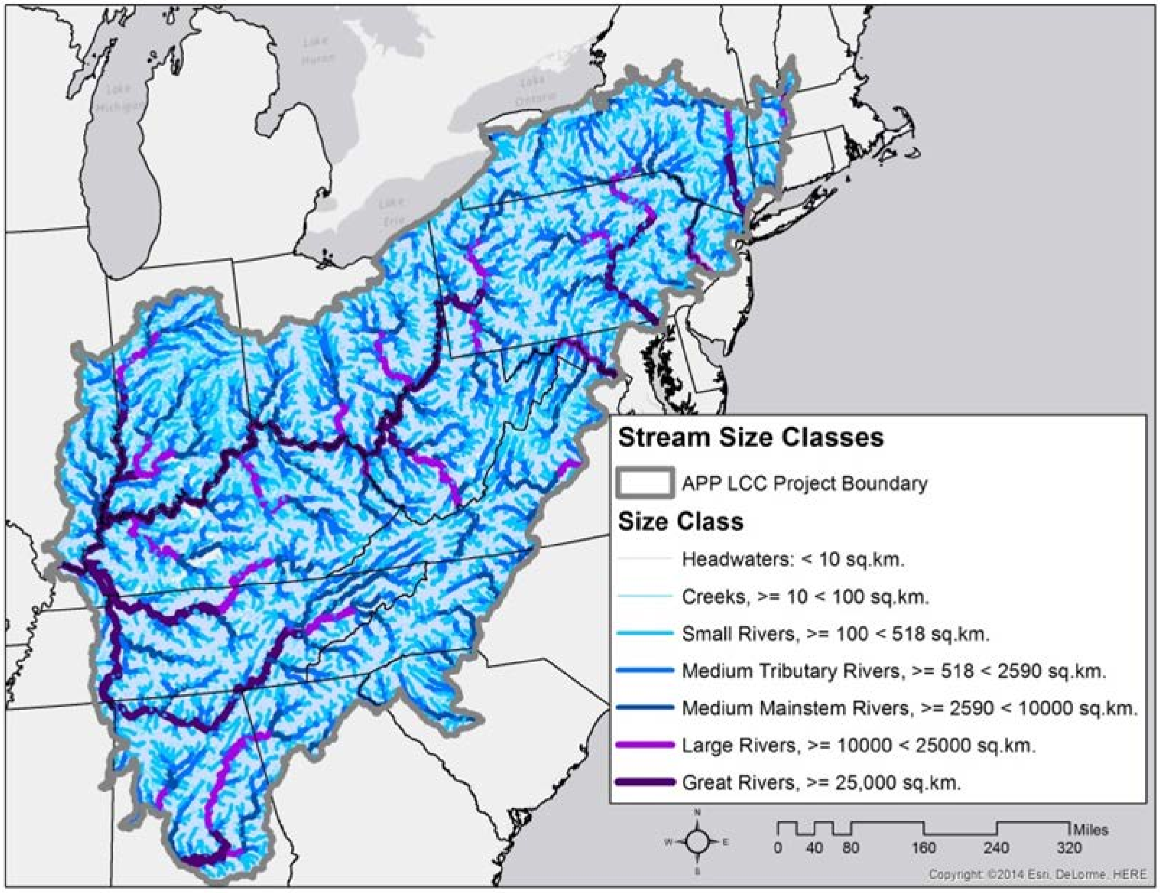
Methods and Results

Size classes and thresholds between classes (Table 4-1; Map 4-1) were developed by studying the following relationships: 1) similarities in size breaks and biological descriptions used in states, 2) the distributions of freshwater species across size classes, 3) relationships between regional patterns and the proposed National Fish Habitat Classification, and 4) consistency with previous stream size classifications covering the project area, specifically the Northeast (Olivero and Anderson 2008) and Southeast (Olivero and Anderson 2013) regions. Our goal was to identify a set of ecologically meaningful size classes and also to develop a system for systematically collapsing them into fewer classes.

Table 4-1. Stream and river size class definitions and hierarchy. This table shows the seven size classes used in the classification and also how these can be collapsed into fewer classes.

Description	Definition: Upstream Drainage Area (sq. km)	Definition: Upstream Drainage Area (sq. mi)	7 Size Classes	6 Size Classes	5 Size Classes	4 Size Classes	3 Size Classes	2 Size Classes
Headwaters	0 < 10	0 < 3.861	11	11	10	10	10	10
Creeks	>= 10 <100	>= 3.861 <38.61	12	12				
Small Rivers	>= 100 <518	>= 38.61 <200	20	20	20	20	20	20
Medium Tributary Rivers	>= 518 <2590	>= 200 <1000	31	30	30	30		
Medium Mainstem Rivers	>= 2590 <10,000	>= 1000 <3861	32					
Large Rivers	>= 10,000 <25,000	>= 3861 <9653	40	40	40	40	40	
Great Rivers	>= 25,000	>= 9653	50	50	50			

Map 4-1. Streams and rivers in the project area mapped by size class.



We used statistical analysis of fish and benthic species to characterize the biota associated with the size classes and to inform how the seven classes could be grouped into a smaller number of classes. Fish species and benthic taxa count data from the National Stream and River Assessment Database (EPA 2013) were compiled for the project area. Sample points were excluded if they were in the "very high" risk of degradation class from the National Fish Habitat Partnership's cumulative disturbance index (Esselman et al. 2011). Taxa occurring in less than three sample sites were also excluded. A total of 286 sites representing 207 fish species, and 288 sites representing 433 benthic taxa were included in the analyses.

We ran a hierarchical cluster analysis in PC-ORD v.5.33 (McCune and Grace 1997) using the Sorenson distance matrix and flexible beta linkage to group the stream size classes by their associated fish species (Figure 4-2) and benthic taxa (Figure 4-3). The distance (objective function) scale indicates the within-group variability and increases as more dissimilar observations and groups are combined in subsequent steps of the classification. The second scale, percent information remaining, shows how much of the information originally in the dataset is lost at each step in the cluster analysis. Groups with low distance values and a high percentage of information remaining (i.e., short branch distance) have more homogenous taxa than groups that are combined later in the classification.

The resultant cluster dendrograms guided our recommendations for how to simplify the seven size classes into a smaller number of classes (Table 4-1). Results of the fish and benthic cluster analyses were similar with some minor differences between the two. Both highlighted an initial major division between rivers (Size classes 20-50) and streams (Size classes 11-12) in terms of their biota. Further splits in the dendrogram indicate differences between larger rivers (Size classes 40-50) from the small to medium rivers (Size classes 20-32). The fish data showed very little differences between medium tributary (Size class 31) and medium mainstem (Size class 32) rivers, suggesting these two sizes could easily be combined. The benthic data showed little difference between small rivers (Size class 20) and the medium mainstem rivers (Size class 32). More weight was given to the fish-based results in determining the collapsing rules as these were simpler and better understood.

Figure 4-2. Hierarchical cluster results showing the relationship between fish species composition and river/stream size classes in the project area. Numbers on the left-hand size of the dendrogram correspond to codes for the size classes (i.e., 11 = headwaters, refer to Table 4-1).

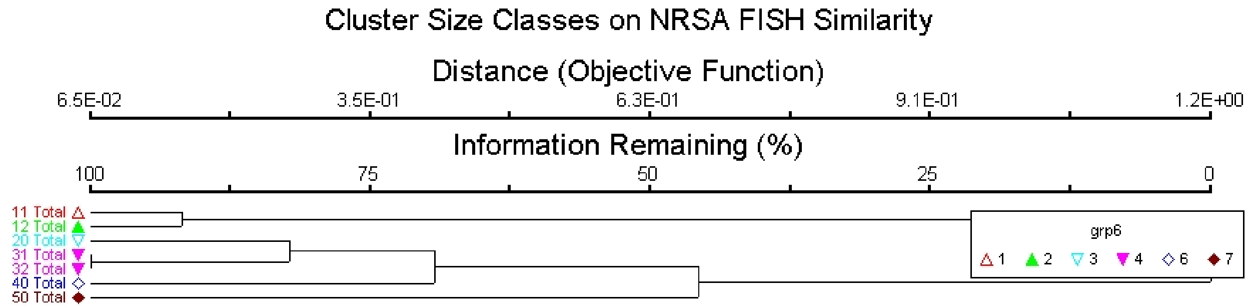
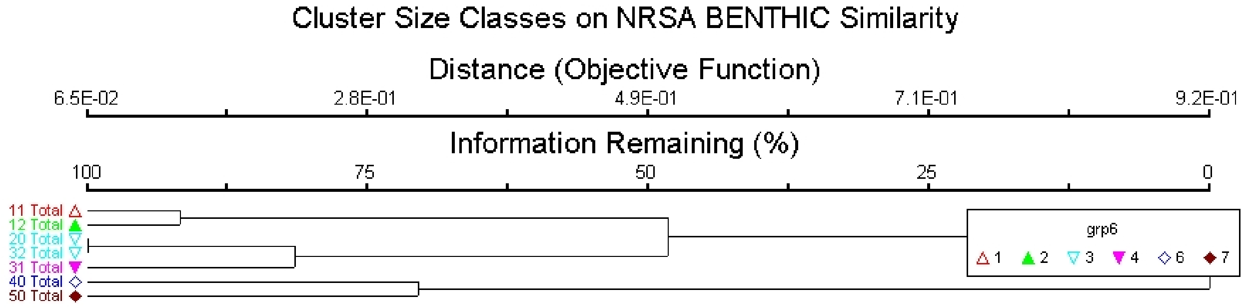


Figure 4-3. Hierarchical cluster results showing the relationship between benthic invertebrate taxa and river/stream size classes in the project area. Numbers on the left-hand size of the dendrogram correspond to codes for the size classes (i.e., 11 = headwaters, refer to Table 4-1).



We used Threshold Indicator Taxa Analysis (TITAN, Baker and King 2010) to identify size thresholds where species distribution changes. We used the recommended default parameters of: a minimum of 5 observations on either side of an environmental change point, 250 random permutations of the taxa data, and 500 bootstraps or new datasets generated by resampling the paired environmental and taxa datasets to calculate the uncertainty and Z metrics. Results highlight a set of significant species where a size threshold could be identified (Figures 4-4 and 4-5). We used the default recommendations from Baker and King (2010) to define "significant" species as those with an indicator p-value < 0.05, purity > 0.95 and reliability > 0.95. Purity and reliability are measures that assess the quality of the indicator response. Purity is the proportion of the bootstrap replicates that have the same direction response (i.e., negative or positive) as the observed response. Reliability indicates the proportion of the bootstrap replicates with p-values for the indicator value score at $\leq$ 0.05.

The analysis is summarized in a chart of individual species and their size thresholds in which the species whose abundance increases as size *decreases* (black) are separated from those whose abundance increases as size *increases* (red). Only significant species are shown and dot symbols are sized in proportion to the strength (Z score) of their threshold (Baker and King 2010). Horizontal lines (solid for decreasing species in black; dotted for increasing species in red) in the figure correspond to the 90% confidence intervals of the threshold change point. Full TITAN results are in Appendix 3 where individual species and threshold values are presented in tabular form and a more readable format.

The TITAN results characterize the patterns of species abundance within the different size classes. Examples of species include:

- **Headwaters and creeks (Sizes 11-12):** Abundance increases with *decreasing* size: Creek Chubsucker, Creek Chub, Brook Trout, Orangethroat Darter, Largescale Stoneroller, and Rosyside Dace.
- **Small rivers (Size 20):** Abundance increases with *increasing* size: Bluegill, Redbreast Sunfish, Spotted Bass, Pumpkinseed, Yellow Perch, Fallfish, Spotted Sucker, Black Crappie, Banded Killifish, Dusky Darter, and White Crappie.

- **Medium tributary rivers (Size 31):** Abundance increases with *increasing* size: Smallmouth Bass, Spotfin Shiner, Common Carp, Channel Catfish, Mimic Shiner, Spottail Shiner, Shorthead Redhorse, Silver Redhorse, and Walleye.
- **Medium mainstem river class (Size 32):** Abundance increases with *increasing* size: American Shad, Gizzard Shad, Blueback Herring, Brook Silverside, Bullhead Minnow, Shield Darter, Satinfin Shiner, and Swallowtail Shiner.
- **Large rivers (Size 40):** Abundance increases with *increasing* size: White Bass, Shortnose Gar, Striped Bass, Grass Carp, Silver Carp, Inland Silverside, and Mooneye
- **Great rivers (Size 50):** Abundance increases with *increasing* size: Freshwater Drum, Flathead Catfish, Longnose Gar, Emerald Shiner, Smallmouth Buffalo, River Carpsucker, Redear Sunfish, and Sauger.

Similar patterns in changing species composition can be found by studying the thresholds for the benthic taxa (Appendix 3).

Figure 4-4. Threshold Indicator Taxa Analysis (TITAN) change points of fish species in relation to stream size (drainage area (km^2)). Black circles represent change points for species associated with small stream size (negative response) while red circles identify species associated with increasing stream size (positive response).

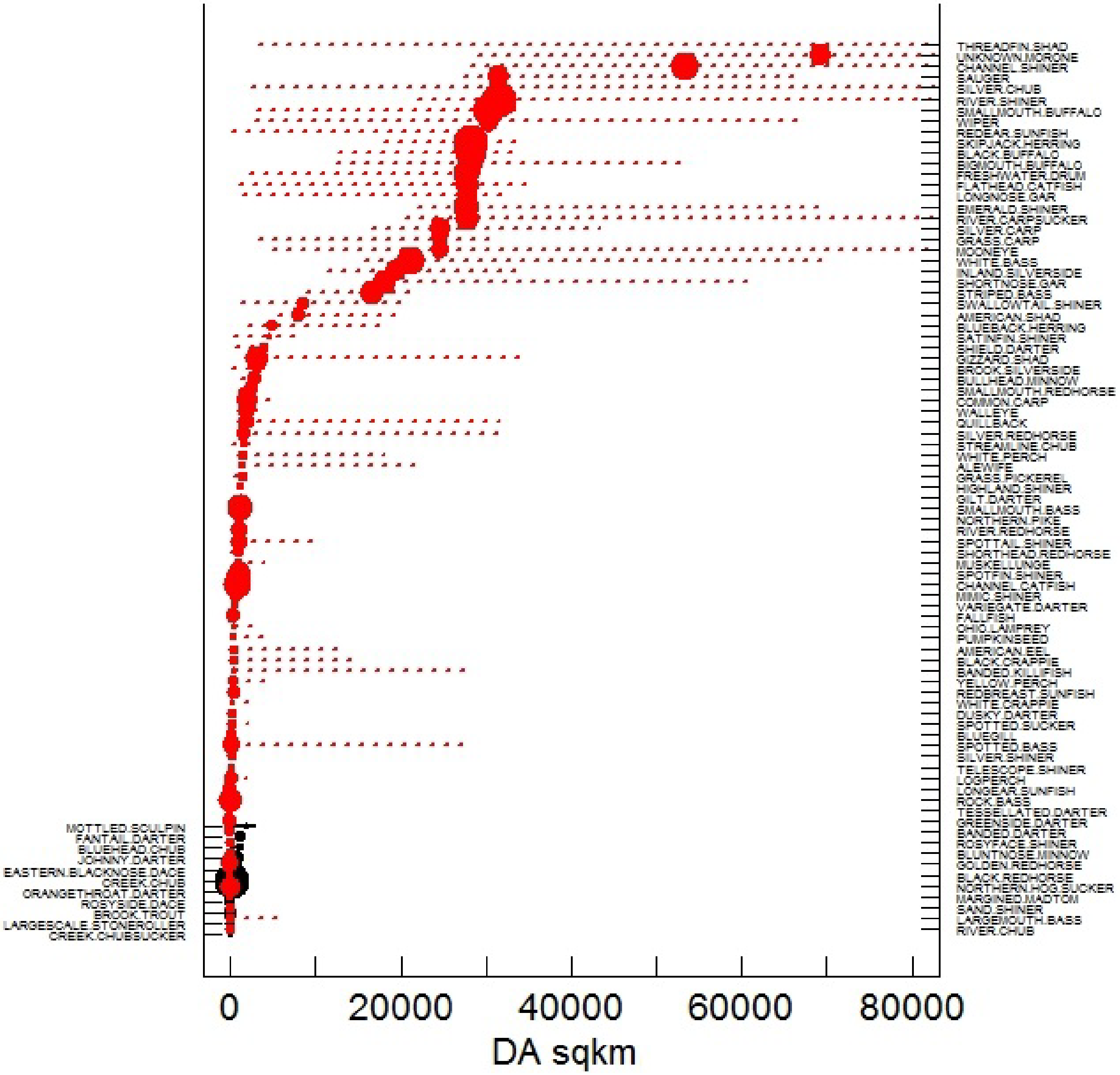
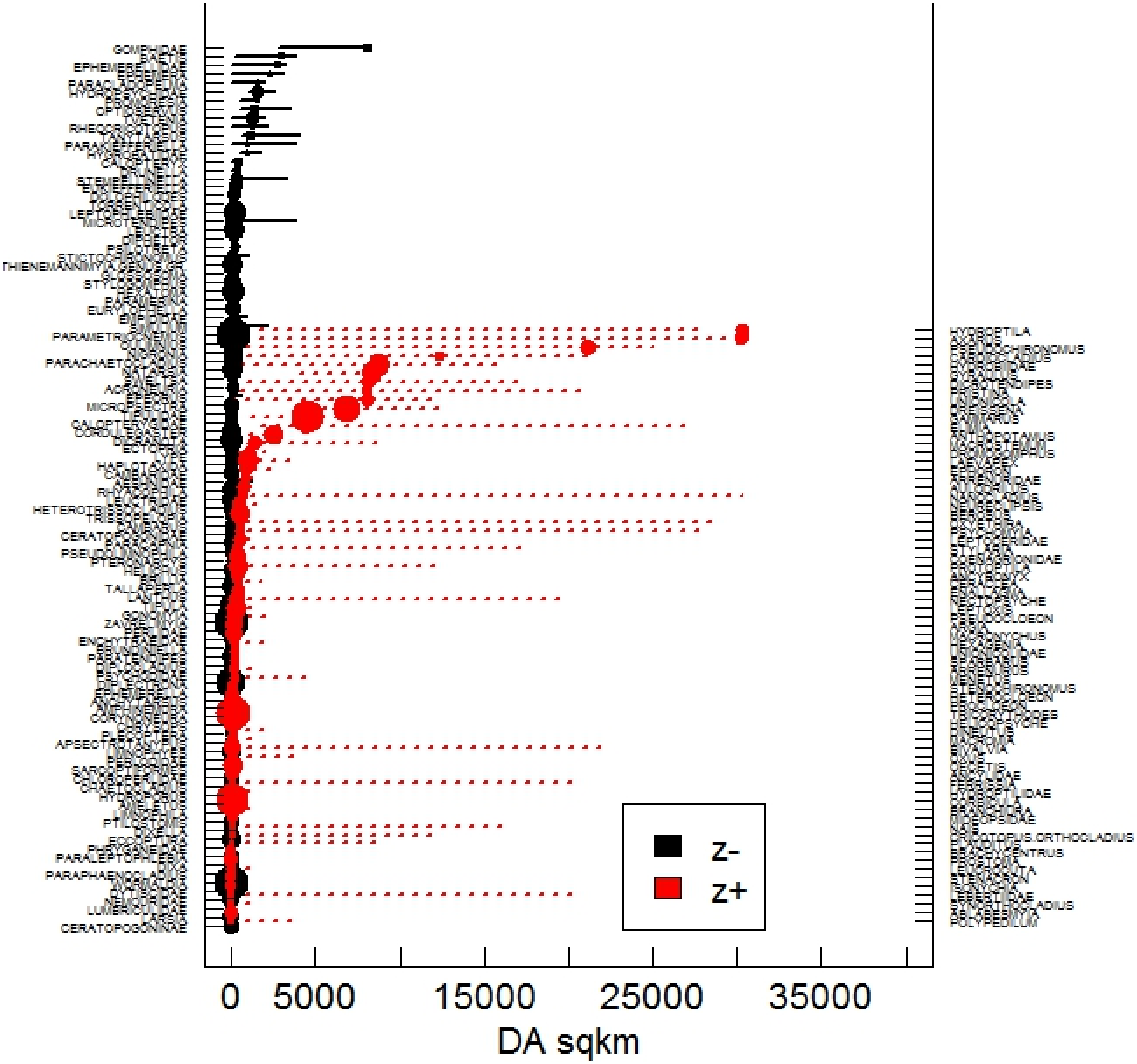


Figure 4-5. Threshold Indicator Taxa Analysis (TITAN) change points of benthic taxa in relation to stream size (drainage area (km^2)). Black circles represent change points for species associated with small stream size (negative response) while red circles identify species associated with increasing stream size (positive response).



5 Gradient

Ecological Importance

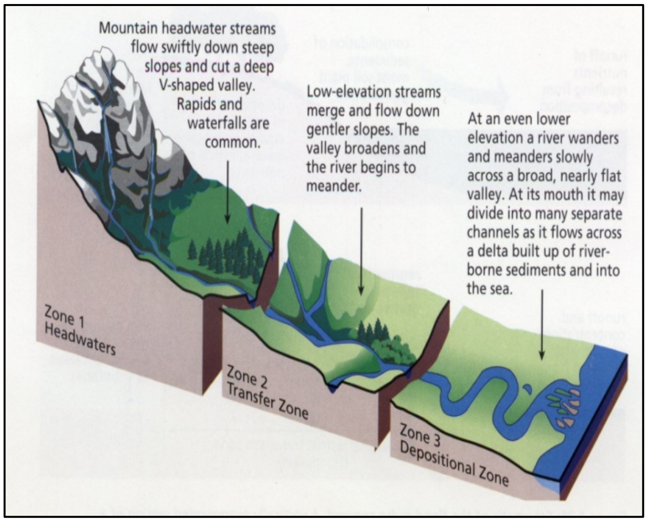


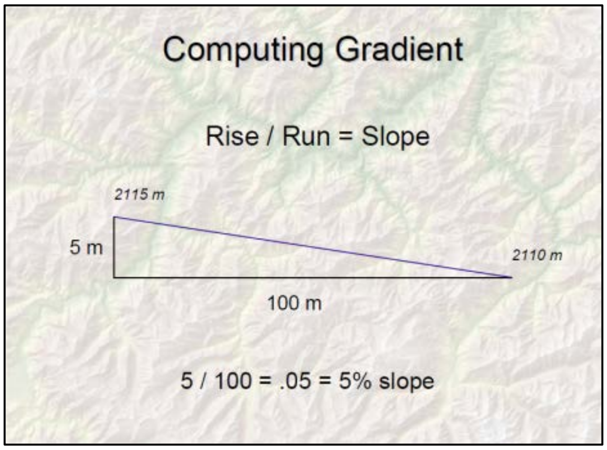
Figure 5-1. Stream gradient diagram (Vanotte et al. 1980).

Stream gradient also influences aquatic communities at the reach-scale due to its influence on stream bed morphology, flow velocity, sediment transport, substrate and grain size (Rosgen 1994, Montgomery and Buffington 1997). For example, high gradient streams have substrates of cobble, boulders and/or bedrock, and are usually highly confined with low sinuosity. They are dominated by cascade to plane-bed channel morphology as opposed to moderate gradient streams that generally have plane-bed channels with some riffle-pool development. In contrast, low gradient systems are dominated by riffle-pool channel morphologies. They typically have substrates of sand, gravel, or cobble; moderate to high sinuosity; and low to no channel confinement with connections to adjacent floodplains in their broader valleys. Very low gradient streams are dominated by ripple-dune channels with very high sinuosity. These rivers have gravel, and finer sediment substrates; alluvial storage and depositional sediment regime, and are relatively unconfined with respect to critical adjacent floodplains (Rosgen 1996, Allan 1995).

Approach

We used “percent slope” as a measure of stream gradient. In the NHDPlusV2, the slope of each flowline was precalculated as rise height over run length (USEPA 2013). The calculations were done using elevation change over the length of each flowline, and specifically using the maximum smoothed elevation attribute minus the minimum smoothed elevation attribute divided by the length of the flowline (see McKay et al. 2012 for details on elevation smoothing algorithm). The final results are a unitless ratio which we multiplied by 100 to display as a conventional “percent slope” value similar to those used by many state programs (Figure 5-2).

Figure 5-2. An example illustrating the calculation of stream gradient



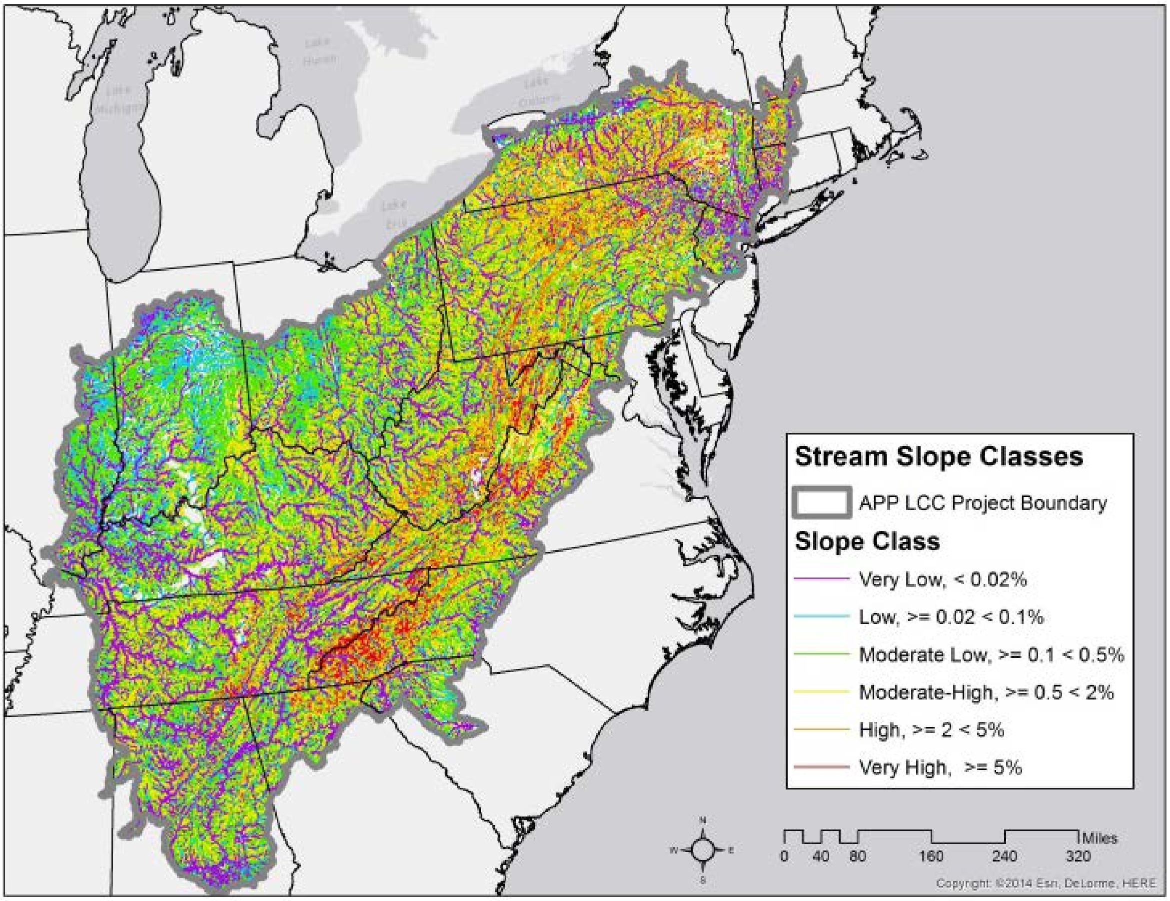
Methods and Results

We identified six gradient classes (Table 5.1, Map 5.1) that matched the classes used in the Northeast Aquatic Habitat Classification system (Olivero and Anderson 2008) and the Stream Classification Framework for the Southeast Region (Olivero and Anderson 2013). The Northeast gradient classes (Table 5-1) were developed by studying breaks used in existing state classifications and review of Rosgen's (1994) five slope classes. These were then tested by examining the relationship of gradient classes to known places in the region and studying rare species distributions across gradient classes. We used a similar approach here, using the species information to characterize the classes and develop collapsing rules for simplifying the six classes by combining the most biotically similar ones.

Table 5-1. Stream gradient class definitions and hierarchy. This table shows the six gradient classes and also how these can be collapsed into fewer classes.

Description	Code	Slope of stream channel * 100	6 Gradient Classes	5 Gradient Classes	4 Gradient Classes	3 Gradient Classes	2 Gradient Classes
Very Low Gradient	1	< 0.02%	1	1	1	1	1
Low Gradient	2	≥ 0.02% & < 0.1%	2				
Moderate-Low Gradient	3	≥ 0.1% & < 0.5%	3	2	2	2	
Moderate-High Gradient	4	≥ 0.5% & < 2%	4	3	3		
High Gradient	5	≥ 2% & < 5%	5	4	4	3	2
Very High Gradient	6	≥ 5%	6	5			

Map 5-1. Streams and rivers mapped by gradient class in the project area



We used statistical analysis of fish and benthic species to characterize the biota associated with the six gradient classes and to inform how the six classes could be grouped into a smaller number of classes. Fish species and benthic taxa count data from the National Stream and River Assessment Database (US EPA 2013) were compiled for the project area. Sample points were excluded if they were in the "very high" risk of degradation class from the National Fish Habitat Partnership's cumulative disturbance index (Esselman et al. 2011). Taxa occurring in less than three sample sites were also excluded. A total of 286 sites representing 207 fish species, and 288 sites representing 433 benthic taxa were included in the analyses.

We ran a hierarchical cluster analysis in PC-ORD v.5.33 (McCune and Grace 1997) using the Sorenson distance matrix and flexible beta linkage to group the stream slope classes by their associated fish species (Figure 4-2) and benthic taxa (Figure 4-3). The distance (objective function) scale indicates the within-group variability and increases as more dissimilar observations and groups are combined in subsequent steps of the classification. The second scale, percent information remaining, shows how much of the information originally in the dataset is lost at each step in the cluster analysis. Groups with low distance values and a high percentage of information remaining (i.e., short branch distance) have more homogenous taxa than groups that are combined later in the classification.

The resultant cluster diagrams guided our rules for how to simplify the six gradient classes into a smaller number of classes (Table 5-1). Results of the fish and benthic cluster analyses were similar. Both highlighted three major divisions in which the two low gradient classes (1-2), the two medium gradient classes (3-4), and the two high gradient classes (5-6), respectively, could be combined to yield three primary groups. Both analyses also indicated that the low and medium classes (1-4) were more similar to each other and the most different from high classes (5-6), when collapsing the classes into two groups. The fish data showed the least difference in species type and abundance between the two lowest classes, while the benthic data showed the least difference between the two medium gradient classes.

Figure 5-3. Hierarchical cluster results showing the relationship between fish species and stream gradient classes. Numbers on the left-hand size of the dendrogram correspond to the gradient classes shown in Table 5-1.

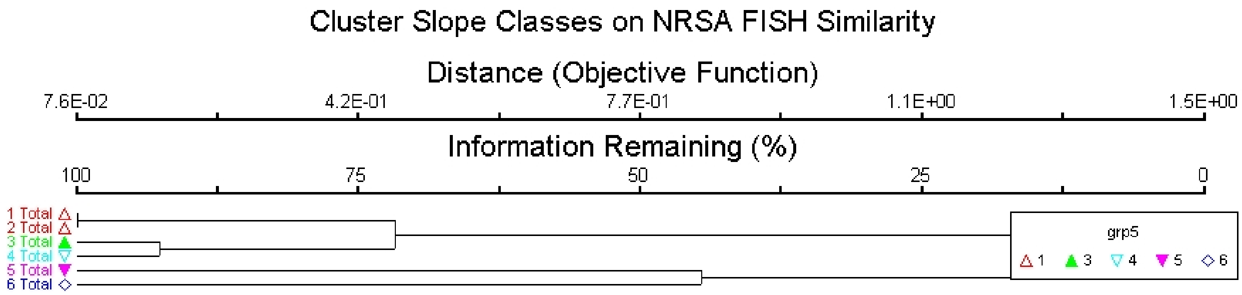
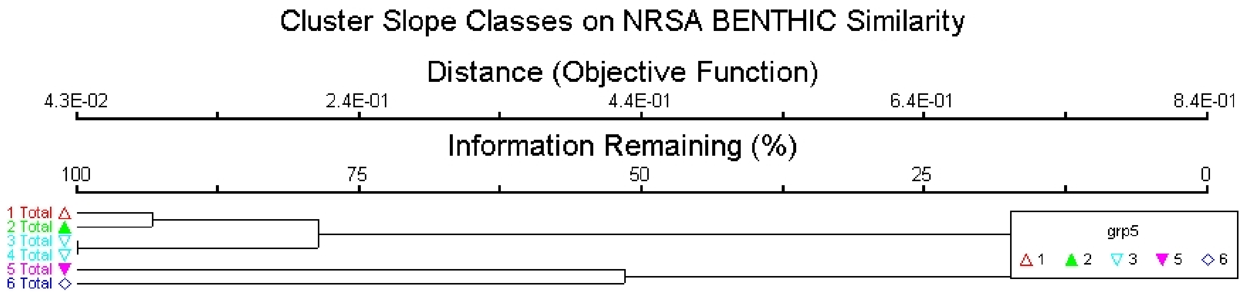


Figure 5-4. Hierarchical cluster results showing the relationship of benthic invertebrate taxa to reach slope classes. Numbers on the left-hand size of the dendrogram correspond to the gradient classes shown in Table 5-1.



We used Threshold Indicator Taxa Analysis (TITAN, Baker and King 2010) to identify gradient thresholds where species distribution changes. We used the recommended default parameters of: a minimum of 5 observations on either side of an environmental change point, 250 random permutations of the taxa data, and 500 bootstraps or new datasets generated by resampling the paired environmental and taxa datasets to calculate the uncertainty and Z metrics. Results highlight a set of significant species where a gradient threshold could be identified (Figures 5-5 and 5-6). We used the default recommendations from Baker and King (2010) to define "significant" species as those with an indicator p-value < 0.05, purity > 0.95 and reliability > 0.95. Purity and reliability are measures that assess the quality of the indicator response. Purity is the proportion of the bootstrap replicates that have the same direction response (i.e., negative or positive) as the observed response. Reliability indicates the proportion of the bootstrap replicates with p-values for the indicator value score at ≤ 0.05.

The analysis is summarized in a chart of individual species and their gradient thresholds in which the species whose abundance increases as gradient *decreases* (black) are separated from those whose abundance increases as gradient *increases* (red). Only significant species are shown and dot symbols are sized in proportion to the strength (Z score) of their threshold (Baker and King 2010). Horizontal lines (solid for decreasing species in black; dotted for increasing species in red) in the figure correspond to the 90% confidence intervals of the threshold change point. Full TITAN results are in Appendix 3 where individual species and threshold values are presented in tabular form and a more readable format.

The TITAN results characterize the patterns of species abundance within the different gradient classes. Examples of species include:

- **Very low gradient** (Class 1, <0.02%): Abundance increases with *decreasing* gradient: White Perch, Threadfin Shad, Wiper, Black Buffalo, Redear Sunfish, Tessellated Darter, Banded Killifish, Skipjack Herring, and Grass Pickerel
- **Low gradient** (Class 2: >= 0.02% to < 0.1%).
    - Abundance increases with *decreasing* gradient: Freshwater Drum, Mimic Shiner, Flathead Catfish, Longnose Gar, Emerald Shiner, Yellow Perch, Spottail Shiner, Black Redhorse, Brook Silverside, Smallmouth Buffalo, Silver Redhorse, Spotted Sucker, River Carpsucker, Walleye, River Redhorse, and Sauger.
    - Abundance increases with *increasing* gradient: Fantail Darter, Johnny Darter, Longnose Dace, Mottled Sculpin, and Bluehead.
- **Low-moderate gradient** (Class 3: ≥ 0.1% & < 0.5%).
    - Abundance increases with *decreasing* gradient: Bluegill, Smallmouth Bass, Northern Hog Sucker, Spotfin Shiner, Largemouth Bass, Longear Sunfish, Greenside Darter, Golden Redhorse, Channel Catfish, Logperch, and Spotted Bass. Over 40 significant benthic taxa also display this pattern.
    - Abundance increases with *increasing* gradient: Creek Chub, Eastern Blacknose Dace, Orangethroat Darter, and Redside Dace as well as more than 15 benthic taxa.
- **Moderate-high gradient** (Class 4: ≥ 0.5% & <2%)
    - Abundance increases with *decreasing* gradient: Rock Bass, Bluntnose Minnow, White Sucker, Striped Shiner, Redbreast Sunfish, and Whitetail Shiner.
    - Abundance increases with *increasing* gradient: Brook Trout and Rosyside Dace and over 50 significant benthic taxa.

- **High gradient** (Class 5: ≥ 2% & < 5%): Abundance increases with *increasing* gradient: Rainbow Trout and benthic taxa including mayflies (Diphetor spp. and Ameletidae spp.); stoneflies (Chloroperlidae, Leuctridae, Perlodidae, Sweltsa spp., Amphinemura spp., Isoperla spp., Peltoperla spp.); and caddisflies (Limnephilidae, Wormaldia spp, Atractides spp.).
- **Very high gradient** (Class 6: > 5%): Abundance increases with *increasing* gradient: Benthic taxa including mayflies (Ephemerella spp., and Drunella spp.); stoneflies (Perlidae, Pteronarcyidae, Tallaperla spp.); and caddisflies (Philopotamidae and Psilotreta spp.). No indicator fish species.

Figure 5-5. Threshold Indicator Taxa Analysis (TITAN) change points of fish species in relation to stream gradient (slope percent). Black circles represent change points for species associated with small gradient (negative response) while red circles identify species associated with an increasing gradient (positive response).

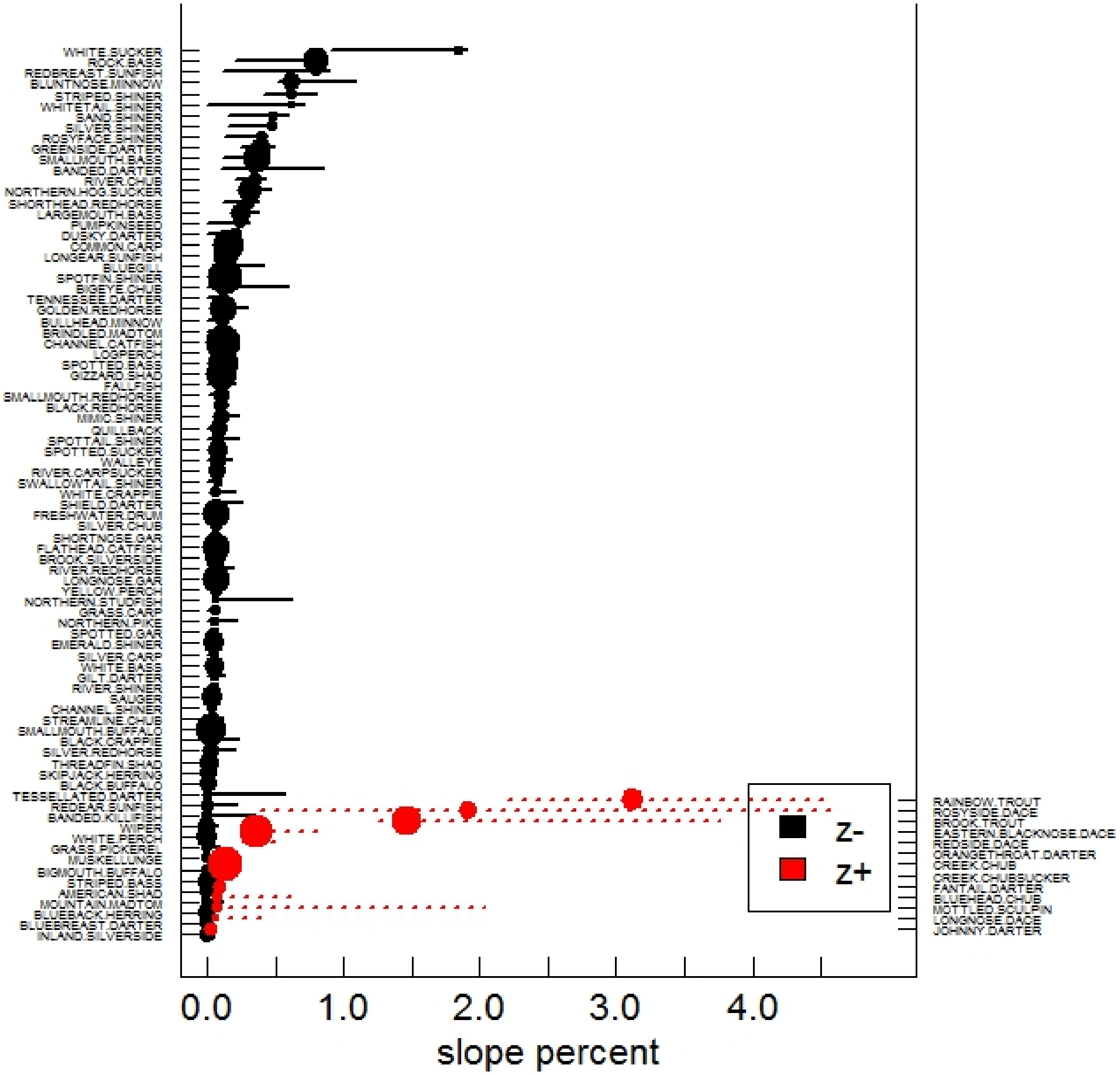
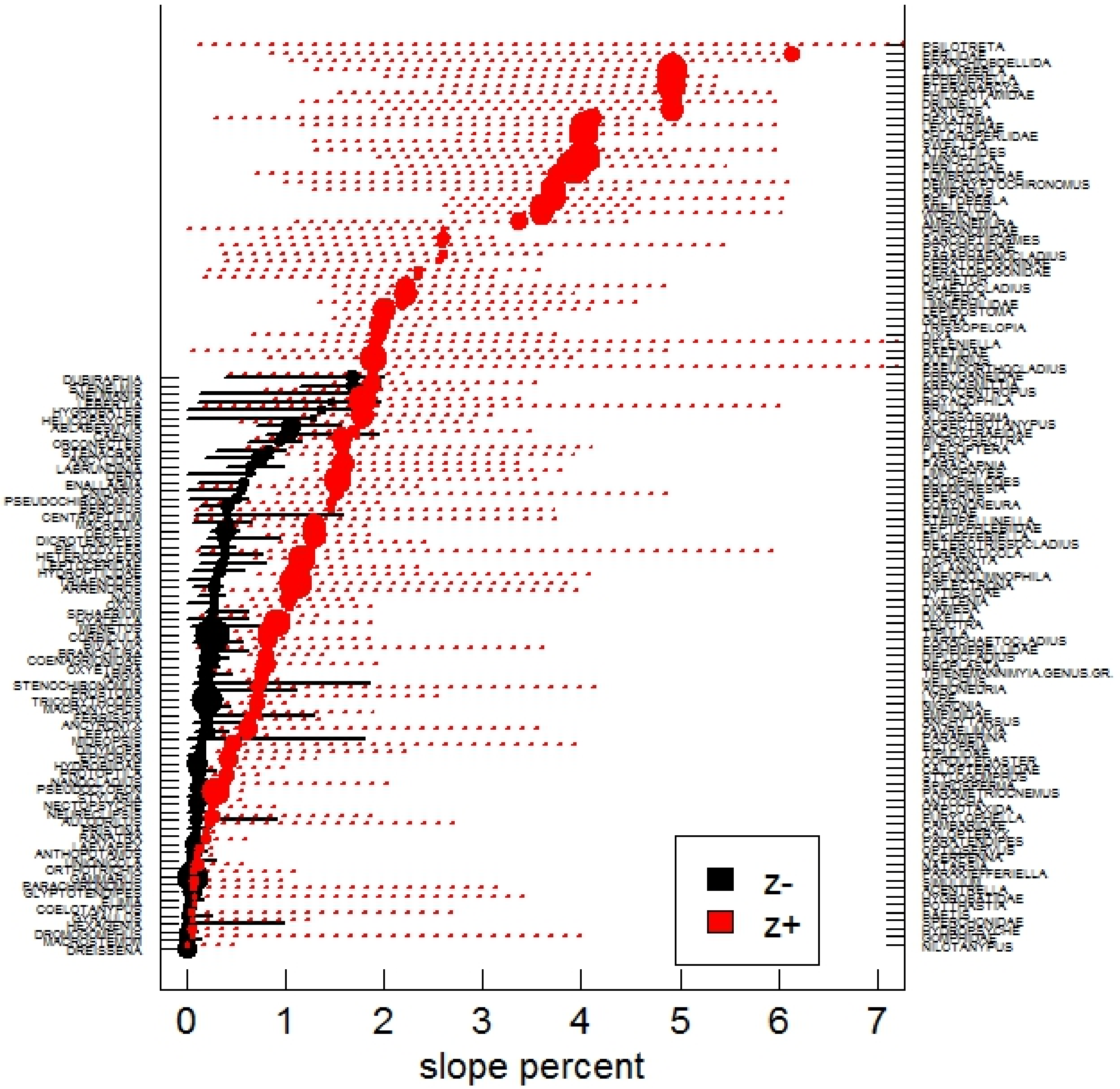


Figure 5-6. Threshold Indicator Taxa Analysis (TITAN) change points of benthic taxa in relation to stream gradient (slope percent). Black circles represent change points for species associated with small gradient (negative response) while red circles identify species associated with an increasing gradient (positive response).



6 Temperature

Ecological Importance

Stream temperatures vary on seasonal and daily time scales, and among locations due to climate, elevation, and the relative importance of groundwater inputs. High elevation areas with low average air temperatures tend to maintain coldwater streams year-round. In low elevation areas, groundwater inflow can also play a role in maintaining cold and cool water streams. Stream temperature has a strong affect on aquatic species assemblages as it sets the physiological limits where many freshwater organisms can persist (Smith and Lavis 1975). Fish species are commonly referred to as cold, cool, or warm water species and many have "lethal limits" of temperatures beyond which they cannot survive (Halliwell et al. 1999). Certain macroinvertebrates have also been classified as cold/cool or warm water taxa (Stamp 2013).

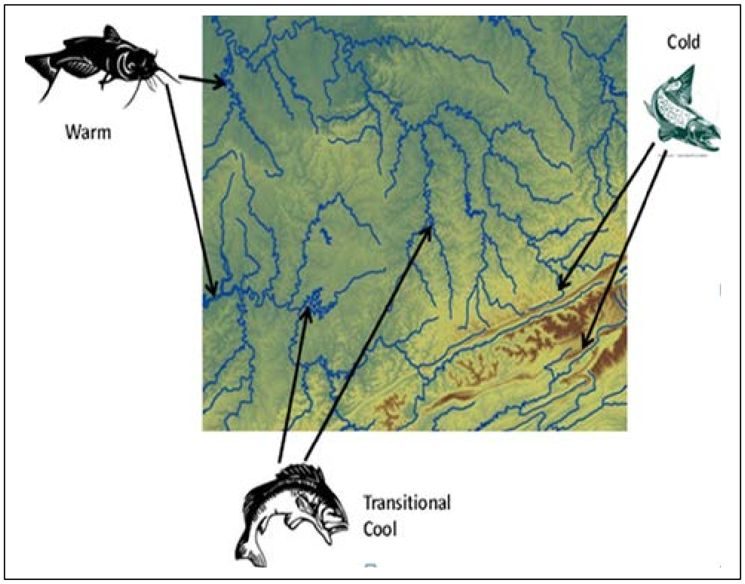


Figure 6-1. Different species inhabit different streams based on the temperature of those streams.

Seasonal changes in water temperature also cue migration, influence growth rates of eggs and juveniles, and can affect the body size and fecundity of adults. Many species that are important in coldwater streams are rare or absent in warmwater streams (Halliwell et al. 1999). Brook Trout, for example, have adapted to specific cold temperature regimes, and are intolerant of even small changes in mean temperatures or lengths of exposure to temperatures above certain limits (Wehrly et al. 2007).

Approach

Our goal was to map the natural mean summer temperature for each reach. That is, the temperature that would occur in the reach if there was no alteration or human impact. Mapping the natural state allows restoration objectives to identify a "natural state temperature goal" for each reach, regardless of current condition. Although there are many temperature parameters that effect aquatic species besides mean summer temperature (for example, temperature in the warmest or coldest month), mean summer temperature is the parameter most often sampled in this region and the one for which we had by far the most data. We used the sampled summer mean temperature data to attribute the flowlines whenever possible. The samples also served as input and validation data for a predictive model we developed to classify the unsampled flowlines.

We obtained summer mean stream temperature data from the following three primary sources:

1) Daren M Carlisle, Ph.D., Ecological Studies Coordinator for the National Water-Quality Assessment Program of the U.S. Geological Survey. The data included mean summer (July-August) stream temperature from USGS gages and the resultant modeled reference summer stream temperatures for these gages as developed in the work by Hill et al. (2013)

2) Yin-Phan Tsang and Dana Infante of Michigan State University in collaboration with the USGS NorEaST: Stream Temperature Data Inventory http://wim.usgs.gov/NorEaST/. This data included mean summer stream temp (July and August) based on average daily temperature of the stream sites if it had at least 30-day records within July and August. The dataset included data from the Connecticut Department of Environmental Protection, Illinois Environmental Protection Agency, Massachusetts Fish and Wildlife, New Hampshire Department of Environmental Services, NY Department of Environmental Conservation, Susquehanna River Basin Commission, graduate work from Tamara Smith, US Forest Service, US Geological Survey, US Geological Survey BRD, West Virginia Department of Environmental Protection, and West Virginia University.

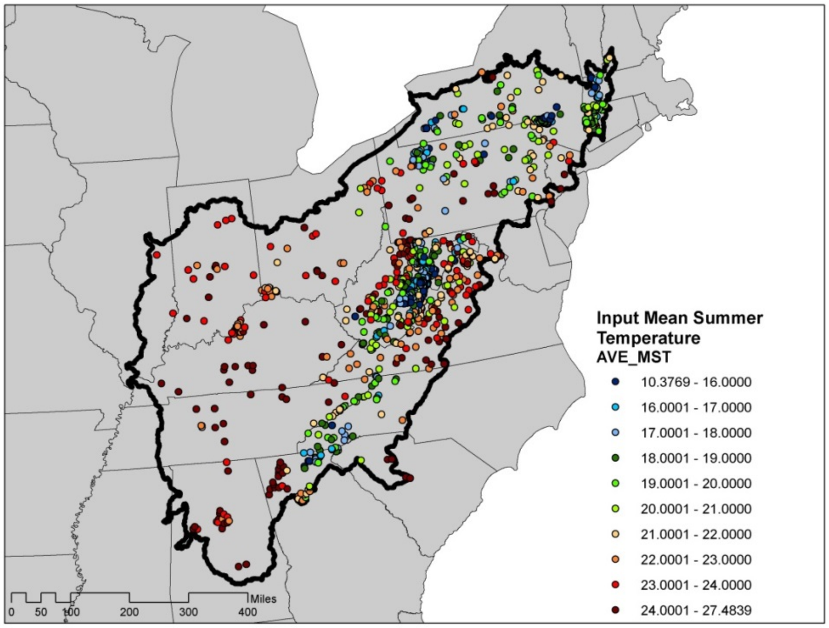
3) Tyrell DeWeber, Ph.D., with the Pennsylvania Cooperative Fish and Wildlife Research Unit at the Pennsylvania State University. This data included mean summer stream temperature (2005-2011, July and August averaged across all years) which he collected as part of his Ph.D. work. It included source data from C. Andrew Dolloff of USFS, Anthony Raburn of GA DNR, Mark Hudy of USGS, and David Thorne of WV DNR.

The above datasets were limited to those points falling within the study area. These were reviewed and spatially joined to the NHDPlusV2 flowlines. We first incorporated all data from Carlisle, followed by non-duplicate data from NorEaST, and finally merged in non-duplicate data from DeWeber. For the Carlisle dataset, all “reference” stream temperatures were used and then for all “non-reference gages,” the predicted reference mean summer temperatures based on Hill et al. (2013) were used. Using these reference predictions provided useful temperature estimates for much of the Ohio River Basin where few if any reference gages were available due to dams or high agricultural impacts. For the NorEaST and DeWeber data, we limited the points to those with more natural conditions to best represent “intact” stream temperatures.

We joined all points to the National Fish Habitat Action Plan (NFHAP) 2010 Risk of Degradation Scores and only used points in the “very low” and “low risk” categories, eliminating points from the “moderate,” “high,” and “very high” categories (Esselman et al. 2011). For the few points missing NFHAP data we applied a screen used by EPA based on 2011 National Land Cover Dataset (NLCD) local and cumulative land use (see Appendix 1 and 2 for description and details) which eliminated a site if it was in disturbance class 4, 5, or 6 (Stamp 2013b). Finally, we wanted to eliminate any site with large dam hydrologic alteration, so we joined the cumulative upstream dam storage based on the 2012 National Anthropgenic Barrier Dataset (NABD) dams (see Appendix 1 and 2 for description and details) to the points and eliminated any point with dam storage > 30% of mean annual flow. In the unusual case where more than one sample point fell on a given flowline, the values were averaged to come up with a single average mean summer temperature for the flowline.

These manipulations resulted in a total of 1081 reaches for which we had an unaltered sample of mean summer temperature. These were used directly to attribute the corresponding stream reaches and were included in our model of predicted natural mean summer temperature: 303 from Carlisle, 571 from NorEaST, and 207 from DeWeber.

Map 6-1. Mean summer stream temperature points selected for use in the project area



Methods and Results

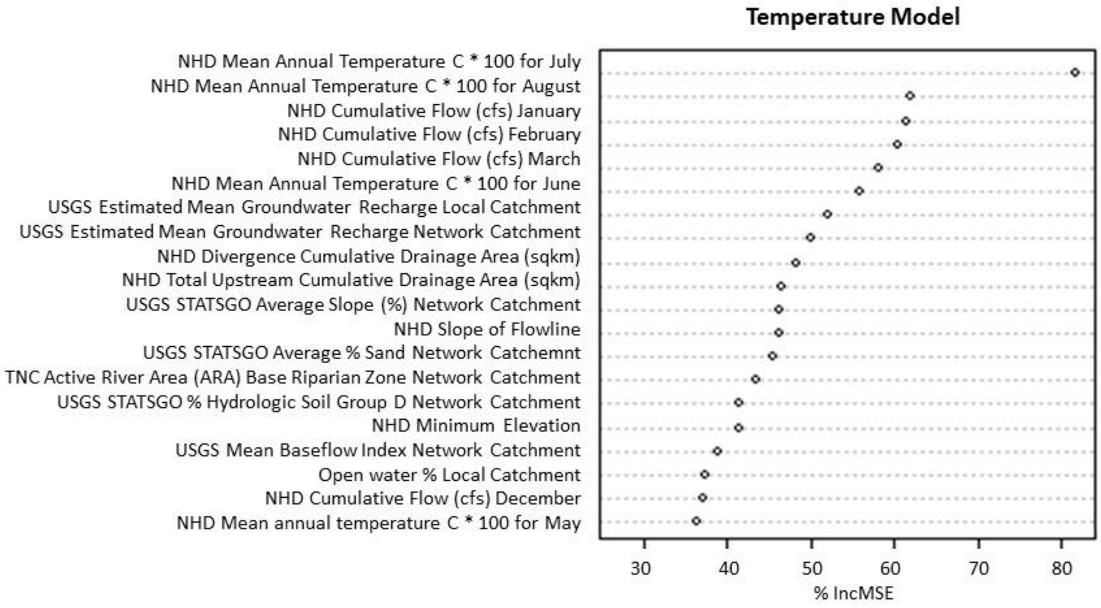
We used the 1081 stream temperature samples with 211 GIS-derived landscape and climate variables to build a continuous predictive model of temperature for all unsampled flowlines in the project area. The predictor variables included a suite of geology, soils, elevation, slope, landform, monthly air temperature, and monthly precipitation data calculated for the local and cumulative upstream network scales. We did not include predictor variables that could be altered by humans or represented anthropogenic alteration such as land cover, dams, or impervious surfaces because our goal was to develop a “reference” model of the expected temperature in an intact stream given its natural physical attributes.

The predictive model was built using the *RandomForest* package (Liaw and Wiener 2002) in R (R Core Team 2014). Random Forest is a machine learning technique that builds hundreds of decision trees to assess the relationship between a response variable and potential predictor variables, returning regression trees for continuous data such as temperature. Random Forest has been shown to be a powerful technique that can handle large datasets, complex data distributions, and correlated variables without a decrease in prediction accuracy and it has built-in approaches that prevent overfitting (Breiman 2001). The algorithm works by first randomly selecting many observations from the data with replacement, a technique known as bootstrapping. The bootstrap samples serve as the training data, and a regression tree is fit to each sample. In each bootstrap sample, approximately 33% of the observations are not used and are referred to as out-of-bag (OOB) data. The OOB data is used for calibration and validation of the trees, and to estimate predictor variable importance. Predictor variable importance is calculated by determining how much prediction error increases when a particular variable is randomly permuted. Prediction error is calculated for each observation using the OOB predictions, and then averaged over all observations (Cutler et al. 2007).

We ran the model using all 1081 stream temperature samples and varied the RF parameters including the number of trees and number of predictor variables used at each split. We selected the final model based on the one with the highest percent variance explained. The final model used 10,000 trees, the default of 70 variables tried at each split, a minimum node size of 2, and sampling with replacement. The final model explained 80.14 percent of the variance in mean summer temperature based on the predictor variables provided.

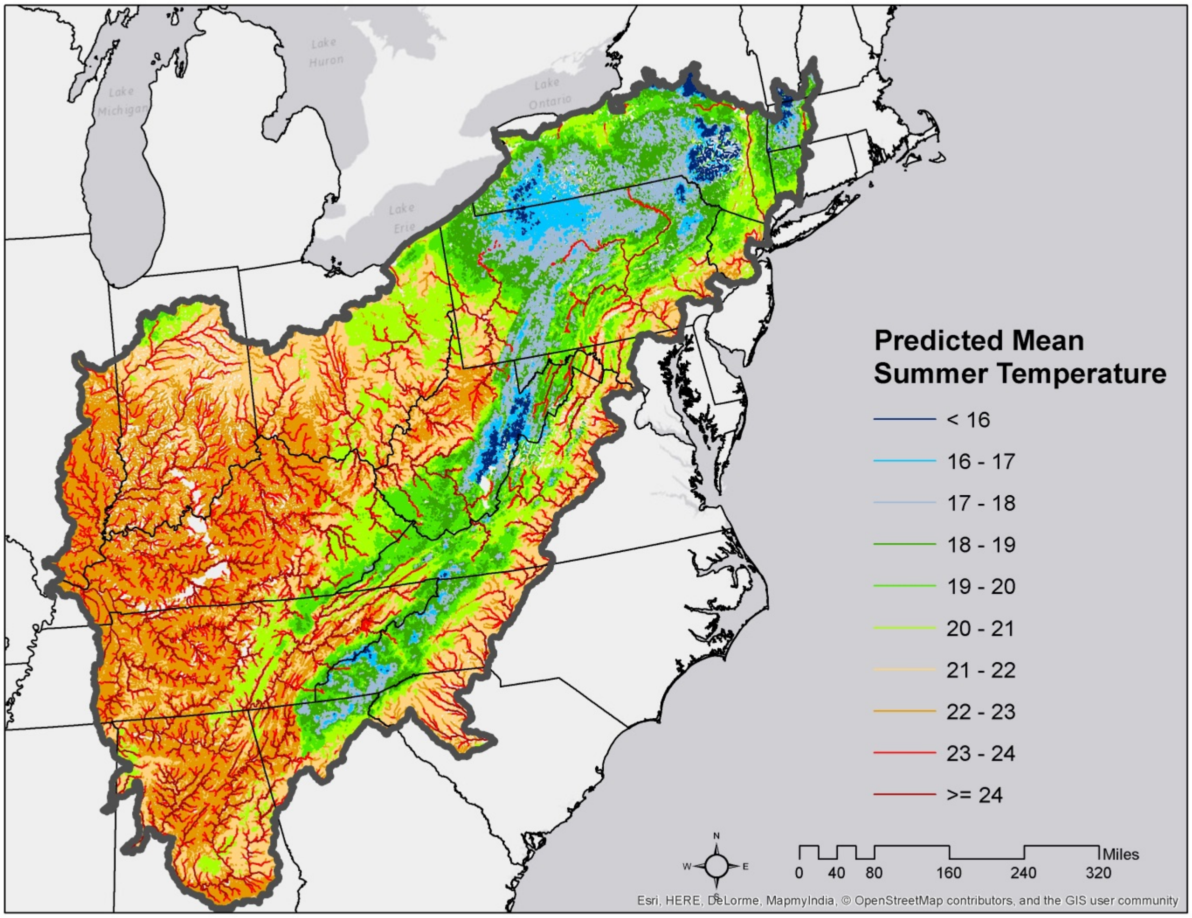
The variable importance plot (Figure 6-2) identifies the variables most important in predicting the temperature values. The top variables related to summer air temperature, stream flow, recharge, drainage area, slope, and sand. The single most important variable was July air temperature as shown by its large effect on the percentage increase in mean squared error, meaning that when this variable was randomly permuted (i.e., filled with random values), the error of the model increased significantly. Other variables in the top five were August air temperature, and cumulative stream flow in the late winter months (Jan, Feb, and March). Many other variables had a small influence on the results including the following: June air temperature, local and cumulative upstream recharge, drainage area, average watershed slope, flowline slope, percent sand in upstream watershed, amount of floodplain, hydrologic soil group D, elevation, and upstream cumulative average baseflow index. These variables make ecological sense as water temperature is directly related to air temperature, except in cases where there is a large amount of cold groundwater inflow. The July and August air temperature variables reflect the large influence of air temperature on water temperature. The remaining variables are related to measures of groundwater. For example, stability of flow in the winter likely indicates places where groundwater inflow keeps flows stable year round. Other variables such as elevation may provide additional measures of locally colder climates, and drainage area represents the importance of these variables for different sized rivers and streams. As a river grows in size, the local cooling effects of groundwater inflows are less influential on the overall temperature given the volume of water originating upstream.

Figure 6-2. Variable importance plot for the RF temperature model. The plot shows each variable on the y-axis ordered from most- to least-important. The x-axis shows the increase in mean square error when that particular variable is randomly permuted.



Applying the above model to all flowlines in the region yielded a continuous map of expected mean summer temperature (Map 6-2). This map reveals core areas of very cold habitat <17^0 C in the mountains of New York and Pennsylvania along with areas of the Central Appalachian mountains in West Virginia, as well as a band of colder habitat < 18^0 C that follows the Appalachian Mountains all the way down to Georgia. More moderate temperatures are found in the mid elevation zones in the eastern part of the study area. Warmer temperatures above 21^0 C dominate in the western parts of the region throughout western Ohio, Indiana, Kentucky, Tennessee, and Alabama as well as on the Atlantic slope footslope fringe (Map 6-2).

Map 6-2. Streams and rivers mapped by mean summer temperature in the project area



Although the continuous temperature model may be used for many applications, for integration into the stream classification, we simplified the continuous temperature values into three ecologically meaningful classes: 1) Cold: < 18^0 C; 2) Cool: $\geq$ 18^0 & <22^0 C; and 3) Warm: $\geq$ 22^0 C. These breaks were based on thresholds used in various state programs along with detailed review of research characterizing fish species association with thermal metrics performed by Yin-Phan Tsang, a research associate at the Center for Systems Integration and Sustainability at Michigan State University (Tsang personal comm. 2/2015).

As part of her ongoing post-doctoral research, Tsang used Threshold Indicator Taxa Analysis (TITAN; Baker and King 2010) to determine temperature thresholds at which fish abundance changes. This draft analysis was based on 2283 paired fish and temperature sites which were analyzed across three regions, the Northern Appalachians, Southern Allegheny Plateau and Coastal Plain, and the Temperate Plains. Using mean summer stream temperature data, the threshold indicator species research highlights three distinct groups of species: 1) species abundance increases as temperature decreases (only cold positive response species); 2) a mixed group containing both species that increase and species that decrease as the temperature decreases (mixed); and 3) species that increase as the temperature increases (only warm positive response species). The breaks of 18 degrees and 22 degrees correspond to changes in fish composition that distinguish three groups (please see forthcoming publications from Tsang for more information and final charts of species by temperature thresholds):

- **Cold (Group 1, < 18^{0}C):** Abundance increases as temperature *decreases*: Brook Trout, Brown Trout, and Slimy Sculpin.

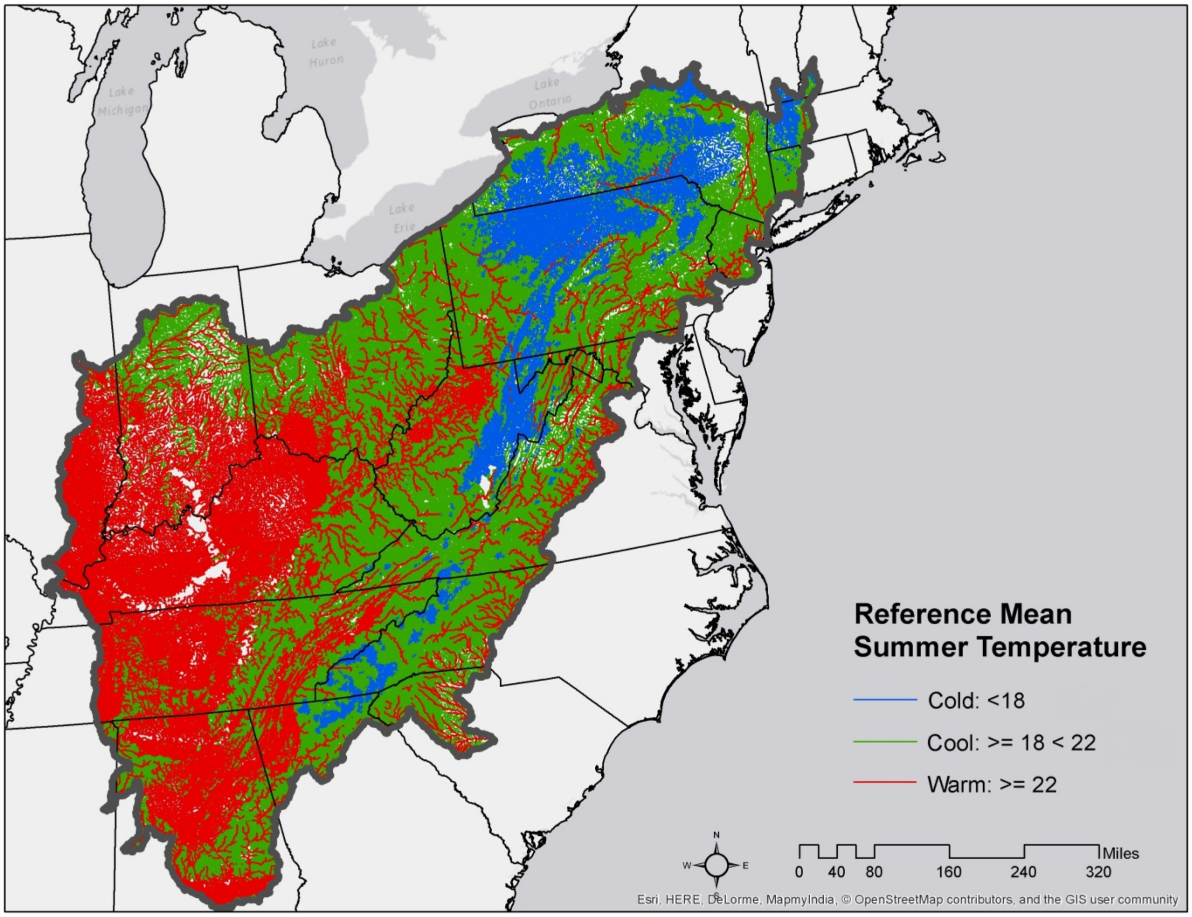
- **Cool (Group 2, 18 - 22^0 C)**

    - Abundance increases as temperature *decreases*: Rosyside Dace, Rainbow Trout, Mottled Sculpin, Eastern Blacknose Dace, Creek Chub, Longnose Dace, Brook Stickleback, Pearl Dace, Fantail Darter, Southern Redbelly Dace, Iowa Darter, White Sucker, and Central Mudminnow.

    - Abundance increases as temperature *increases*: Northern Hog Sucker, Smallmouth Bass, Bluntnose Minnow, Rock Bass, Margined Madtom, Redbreast Sunfish, Spottail Shiner, Northern Pike, Central Stoneroller, Blackside Darter, Horneyhead Chub, Yellow Perch, Banded Darter, Largemouth Bass, Rock Bass, Spotfin Shiner, Bluntnose Minnow, Tessellated Darter, Redfin Pickerel, American Eel, Chain Pickerel, Cutlips Minnow, and Fallfish.

- **Warm (Group 3, > 22^0 C):** Abundance increases as temperature *increases*: Bluehead Chub, Banded Darter, Mimic Shiner, Bluegill, Satinfin Shiner, Spotfin Shiner, Black Redhorse, Longear Sunfish, Channel Catfish, Flathead Catfish, Gizzard Shad, Shorthead Redhorse, Golden Redhorse, Brook Silverside, Smallmouth Buffalo, Kentucky Spotted Bass, Logperch, Walleye, Quillback, Silver Redhorse, Emerald Shiner, Freshwater Drum, and Rock Bass.

Map 6-3. Streams and rivers mapped by temperature class in the project area



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7 Hydrology

Ecological Importance

The hydrologic regime of streams and rivers is a key factor in determining the structure and function of aquatic and riparian ecosystems. A natural flow regime is regulated by five critical components: the frequency, magnitude, duration, timing, and rate of change of flow (Poff et al. 1997, Figure 7-1). The natural variation in stream flow shapes the biological life cycles and reproductive strategies of riverine species (Bunn and Arthington 2002, Poff et al. 1997). The timing and size of flood events structures and maintains riverine habitats (Trush et al. 2000) and floodplain communities (Auble et al. 2005), while also prompting spawning and seasonal migrations of aquatic organisms (Nesler et al. 1988, King et al. 1998). Distinct species assemblages occur in riverine systems across the US as a result of the regional variability in natural hydrologic regimes (Poff 1996, Southwood 1988, Olden and Kennard 2010, Mims and Olden 2012).

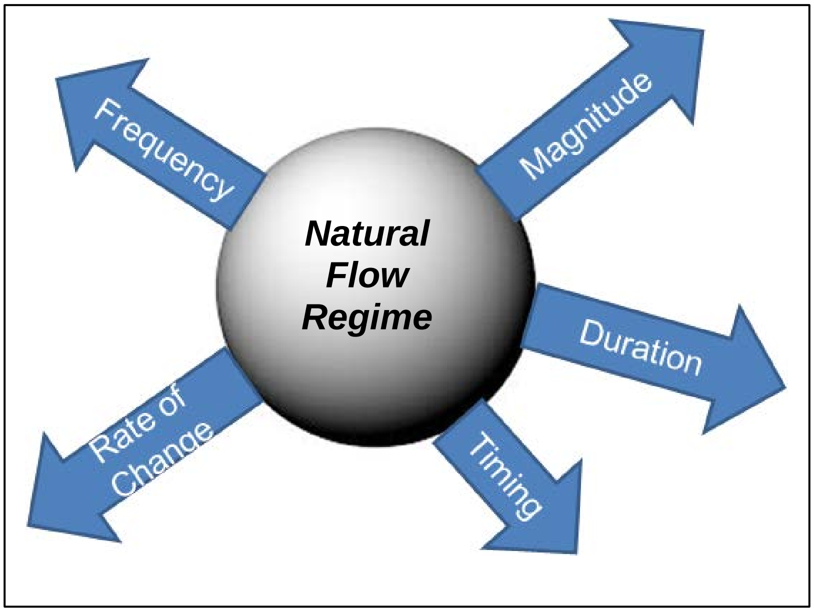


Figure 7-1. The five key components of a natural flow regime (Poff et al. 1997)

While each stream is unique in its hydrologic properties, streamflow exhibits recurring patterns with similar types occurring across the landscape, predisposing river hydrology to classification. As hydrology structures ecological communities and processes, streams and rivers with similar hydrologic characteristics are expected to have similar ecological patterns (Arthington et al. 2006) and also exhibit similar responses to anthropogenic disturbances (Arthington et al. 2006, Poff et al. 2010). A key use of hydrologic classifications is to inform the development of environmental flow standards to protect the natural flow regime of streams and rivers with similar hydrologic characteristics (Arthington et al. 2006, Poff et al. 2010). Enabling managers to implement a more natural flow regime helps protect freshwater biodiversity and ensure the provision of important ecosystem services. Hydrologic classifications are also used to develop flow-ecology responses as ecological reactions to altered flows tend to differ by hydrologic class (Arthington et al. 2006). In addition, a hydrologic classification can provide a baseline for reference conditions to better understand the degree of alteration in a system.

Approach and Methods

Our goal was to map the natural hydrologic regimes for each reach, the regime that would occur in the reach if there was no alteration or human impact. The workgroup agreed that the hydrologic classification for the project area should be developed using data from streams with minimal hydrologic disturbance. This provided the ability to model the expected natural class for all ungaged locations rather than the current altered class.

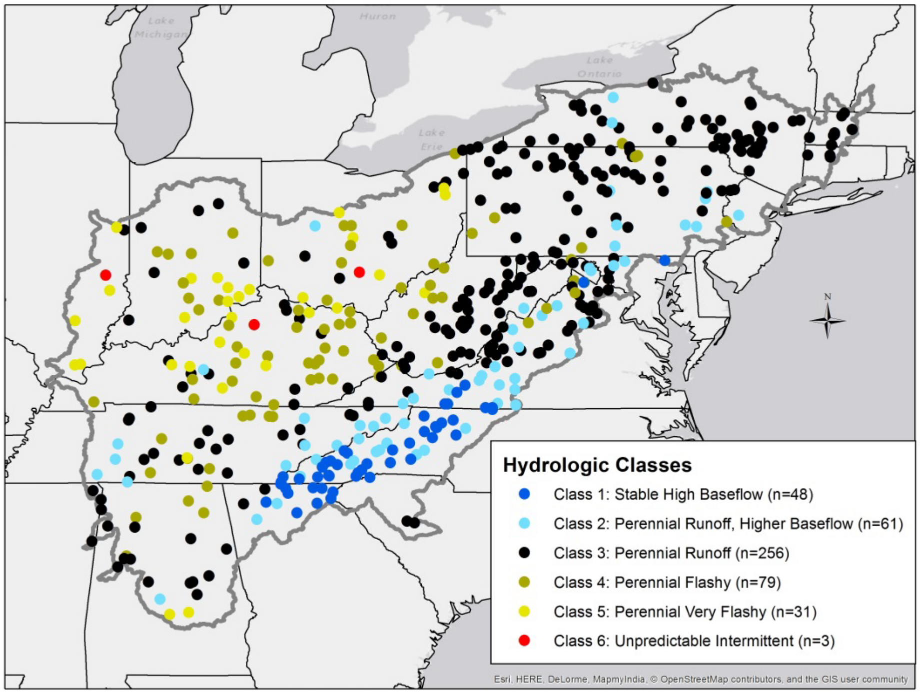
As part of this project, we partnered with Ryan McManamay of Oak Ridge National Laboratory to develop a hydrologic classification of minimally altered and gaged stream reaches in the project area. The next two paragraphs summarize his work. First, gages were identified for which at least fifteen years of stream discharge data was available in the project area. To identify gages on stream reaches with little to no flow alteration, USGS gages were selected that fell into one of three categories: 1) reference, 2) nonreference with minimal hydrologic disturbance, and 3) availability of pre-dam data (McManamay et al. 2014). Reference gages were obtained from the Geospatial Attributes of Gages for Evaluating Streamflow, version II (GAGES II) database developed by Falcone (2011). For details on the approaches used to identify the additional nonreference gages and those with pre-dam regulation streamflow data refer to McManamay et al. (2014). A total of 478 gages in the project area met the standards for minimal flow alteration and were spatially linked to the appropriate NHDPlusV2 reach. Gage data was available for all stream/river size classes except for large and great rivers (Table 7-1).

Table 7-1. The distribution of gages (n=478) for unaltered reaches by stream/river size class in the project area.

Size Class	Size Class Description	Gages (#)
1a	Headwaters	12
1b	Creeks	100
2	Small Rivers	203
3a	Medium Tributary Rivers	148
3b	Medium Mainstem Rivers	15
4	Large Rivers	0
5	Great Rivers	0

Using the gage data, 110 hydrologic statistics were calculated (Olden and Poff 2003) including daily flow variability, number of zero flow days, and seasonal flow. To account for the influence of river size, the magnitude-related variables were all standardized by mean daily flow. The variables were then all log transformed (*x+1*). To address correlation among the hydrologic variables, Principal Component Analysis (PCA) was used to transform the 110 variables into 26 subsets or components of uncorrelated variables. A hierarchical cluster analysis of the 26 components was run using Ward's method to group the gages based on the similarity of their hydrologic variables. The cluster analysis resulted in a total of eight classes at the lowest level of the hierarchy. After reviewing the geographic distribution and the hydrologic characteristics of the eight groups, the workgroup agreed on combining some groups for a total of six hydrologic classes (Map 7-1; Box 7-1). Each of the 478 stream gages was assigned to one of the six final classes.

Map 7-1. Geographic distribution of the six hydrologic classes assigned to unaltered reaches with gage data (n=478) using a cluster analysis of hydrologic characteristics.



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Using the hydrologic classes developed above, we next developed a predictive model of hydrologic class for the ungaged reaches using the 478 classified gages and a suite of GIS variables hypothesized to be related to streamflow regime. The predictor variables consisted of several hundred spatially explicit hydrologic, land cover, geologic, temperature, and soils variables that were calculated for two spatial scales: 1) The NHDPlusV2 local catchments and flowlines and 2) the full drainage area of each NHDPlus flowline. Local variables were calculated for the immediate drainage area of a reach while the network variables were calculated for the full upstream drainage area. The predictive model was built using the *RandomForest* package (Liaw & Wiener 2002) in R (R Core Team 2014). Random Forest (RF) is a machine learning technique that builds hundreds of decision trees to assess the relationship between a response variable and potential predictor variables. A classification tree is used when the response variable is categorical, while a regression tree is used if the response variable is continuous. RF has been shown to be a powerful technique that can handle large datasets, complex data distributions, and correlated variables without a decrease in prediction accuracy and it has built-in approaches that prevent overfitting (Breiman 2001). The algorithm works by first randomly selecting many observations from the data with replacement, a technique known as bootstrapping. The bootstrap samples serve as the training data, and a classification or regression tree is fit to each sample. In each bootstrap sample, approximately 33% of the observations are not used and are referred to as out-of-bag (OOB) data. The OOB data is used for calibration and validation of the trees, and to estimate predictor variable importance. Predictor variable importance is calculated by determining how much predictive accuracy decreases when a particular variable is randomly permuted. For classification trees, the predicted classification of an observation is determined by the majority of OOB votes in the forest, with ties split randomly. Classification accuracies are calculated for each observation using the OOB predictions, and are then averaged over all observations (Cutler et al. 2007).

The six hydrologic classes assigned to the gage data served as our response variable in the RF classification model. In selecting the best model, we adjusted various RF parameters including the sample size of each class, number of trees, and number of predictor variables used at each split, as well as whether to use all variables or simply the most important predictor variables. We initially tried to predict the six hydrologic classes, but the best model had a high overall error rate of 32%, with relatively high misclassification rates for several of the classes. The classification table, also known as the error matrix, indicated how observations were misclassified by the model and was helpful in determining which classes we should consider combining. We experimented with combining the classes that were creating the most confusion in the model and running additional RF classification models. The best four-class model combined the two baseflow classes (1 and 2) into a single class, and combined the perennial flashy classes (4 and 5) into a single class. The overall model error was quite low at 15% and the class errors were evenly distributed with the exception of Class 6 which had only three gage locations.

We then explored whether we could develop a better predictive model of the classes we had combined in the four-class model, hence referred to as subclasses. To do this, we selected Classes 1 and 4 from the four-class model and then developed a model to predict subclasses 1, 2, 4, and 5 using the respective gages and the same set of predictor variables. The resulting subclass model had an overall error rate of 23%, which is still well below the generally recommended 30% threshold. The final step was to use the best four-class model and its best subclass model to predict the hydrologic class of all ungaged stream reaches in the project area. This enabled us to assign two hydrologic classification values to all stream reaches. The first was assignment to one of the four hydrologic classes from the four-class model, while the second was to one of the six hydrologic classes from the four-class model plus its best subclass model.

Results

The characteristics of the six hydrologic classes selected from the hierarchical cluster analysis are described in Box 7-1.

Box 7-1. Descriptions of the six hydrologic classes selected for the project area.

Class 1: Stable High Baseflow: high baseflow index, low variability, high minimum and low flows, low frequency of high flow events, low rise rates
Class 2: Perennial Runoff, Higher Baseflow: among the perennial runoff types, has lower variability, higher minimum and low flows, and lower high flow frequency
Class 3: Perennial Runoff: moderate variability, moderate minimum and low flows, moderate to higher frequency of high flows
Class 4: Perennial Flashy: high variability, may exhibit some intermittency, low minimum and baseflows, high frequency of high flows, and high rise rate
Class 5: Perennial High Flashy: compared to class 4, this class has higher variability, higher intermittency, lower minimum flows, higher high flow frequency, and faster rise rates
Class 6: Unpredictable Intermittent: highest variability, highest intermittency, highest frequency of high flows, and rapid rise rates

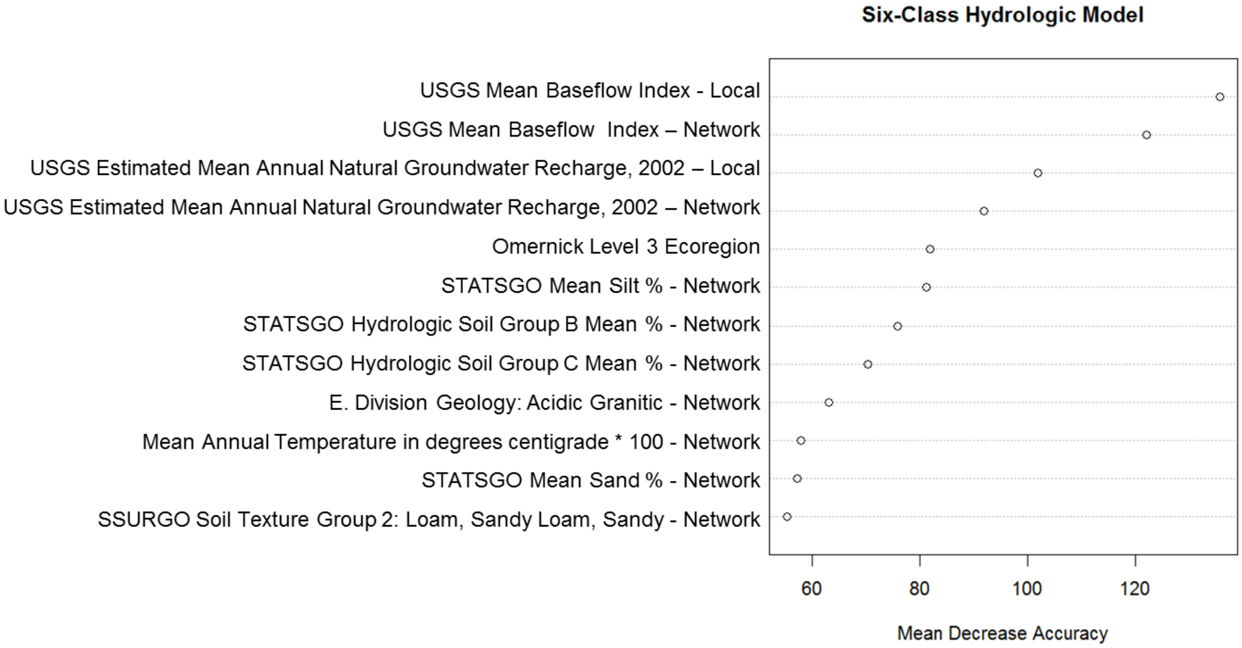
The best six-class model used 50,000 trees, a minimum node size of two, 15 variables at the split for each tree node, and a sample size of 31 for all classes except Class 6 which used a sample size of three. The model had an error rate of 32% with relatively high misclassification rates for Classes 2, 3, and 4 (Table 7-2). In the classification table (Table 7-2), the values in each class column (i.e., Class 1) indicate the number of observations that were assigned to that class by the model for the known class indicated in the "Hydrologic Class" column. For example, of the total 48 Class 1 observations, 42 were assigned to Class 1 and 6 were assigned to Class 2, resulting in a classification error of 12.5% for Class 1. The table also shows that the majority of Class 4 misclassifications were assigned to Class 5 with a handful assigned to Classes 2 and 3.

Table 7-2. Classification table that describes the performance of the best six-class RF model using the 478 gage locations for which hydrologic class was known.

Hydrologic Class	Hydrologic Class Name	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class Error
1 (n=48)	Stable high baseflow	42	6	0	0	0	0	.125
2 (n=61)	Perennial runoff, higher baseflow	10	40	9	2	0	0	.344
3 (n= 256)	Perennial runoff	1	40	169	40	6	0	.339
4 (n=79)	Perennial flashy	0	3	8	50	18	0	.367
5 (n=31)	Perennial high flashy	0	0	0	7	24	0	.225
6 (n=6)	Unpredictable intermittent	0	0	0	0	3	0	1

The top twelve most important predictor variables for the best six-class hydrologic model are shown in Figure 7-2. Variables in the top right corner of the plot are the most important as their removal from the model resulted in the greatest decrease in model accuracy.

Figure 7-2. Variable importance plot for the best six-class RF hydrologic model. The plot shows each variable on the y-axis ordered from most- to least-important. The x-axis shows the mean decrease in classification accuracy when that particular variable is randomly permuted.

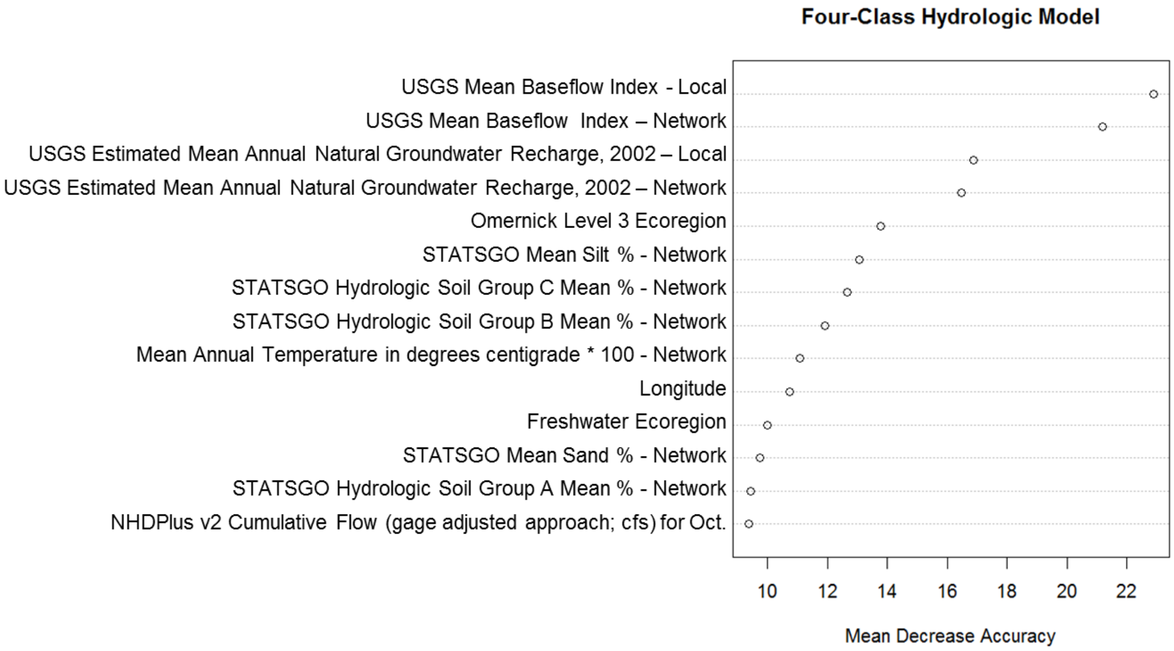


The best four-class model combined Classes 1 and 2 to create a single high baseflow class, and also combined Classes 4 and 5 to create a single perennial flashy class. The model had a low overall error rate of 15% with evenly distributed misclassification rates among all classes except for unpredictable intermittent for which there were only three gage locations. The best-four class model used 1,000 trees, a minimum node size of two, 15 variables at each split, and the following sample sizes: Class 1 = 109, Class 3 = 256, Class 4 = 110, and Class 6 = 3.

Table 7-3. Classification table that describes the performance of the best four-class RF model using the 478 gage locations for which hydrologic class was known.

Hydrologic Class	Combined Classes	Hydrologic Class Name	Class 1	Class 3	Class 4	Class 6	Class Error
1 (n=109)	1 & 2	High baseflow	92	14	3	0	.155
3 (n=256)	3	Perennial runoff	15	220	21	0	.140
4 (n=110)	4 & 5	Perennial flashy	1	15	94	0	.145
6 (n=3)	6	Unpredictable intermittent	0	0	3	0	1

Figure 7-3. Variable importance plot for the best four-class RF hydrologic model. The plot shows each variable on the y-axis ordered from most- to least-important. The x-axis shows the mean decrease in classification accuracy when that particular variable is randomly permuted.

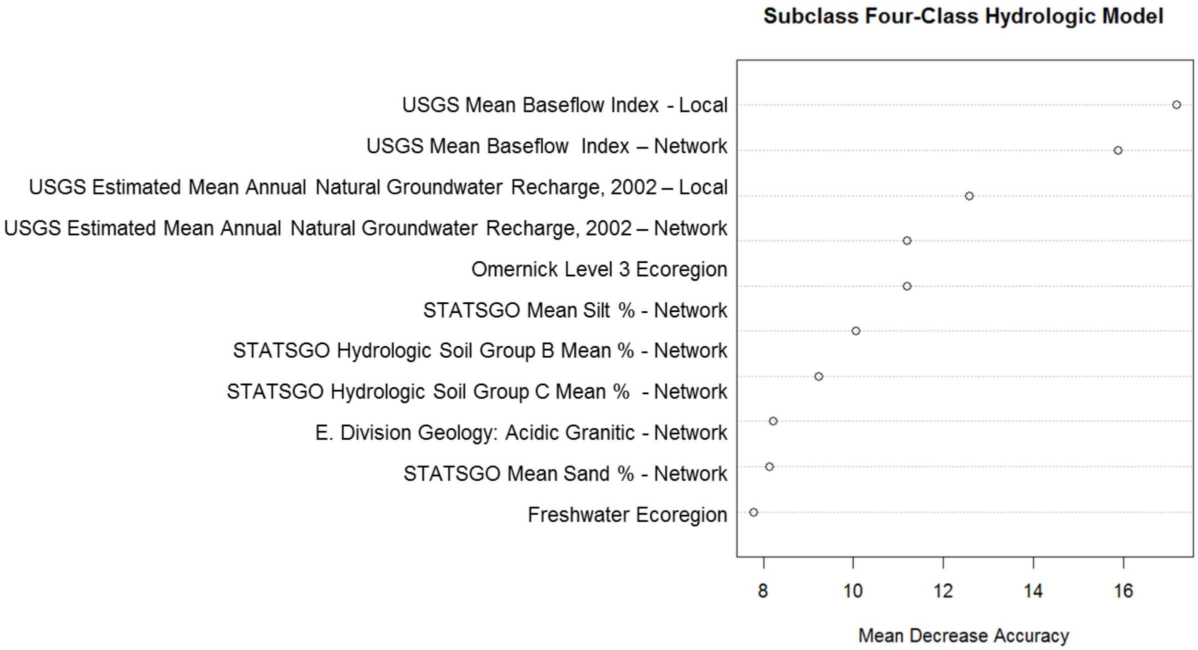


The best subclass model for the four-class model had a relatively low overall error rate of 22.83% with misclassification rates less than 30% for all classes. Of the classes, Class 4 (Perennial Flashy) was the most challenging to predict and was primarily confused with Class 5. The model used 1,000 trees, a minimum node size of two, 15 variables at each split, and the following sample sizes: Class 1 = 48, Class 2 = 61, Class 4 = 79, and Class 5 = 31.

Table 7-4. Classification table that describes the performance of the best subclass model of the selected four-class RF model using the 219 gage locations corresponding to the selected subclasses.

Hydrologic Class	Hydrologic Class Name	Class 1	Class 2	Class 4	Class 5	Class Error
1 (n=48)	Stable high baseflow	41	7	0	0	.145
2 (n=61)	Perennial runoff, higher baseflow	10	48	2	1	.214
4 (n=79)	Perennial flashy	0	6	56	17	.291
5 (n=31)	Perennial high flashy	0	0	7	24	.225

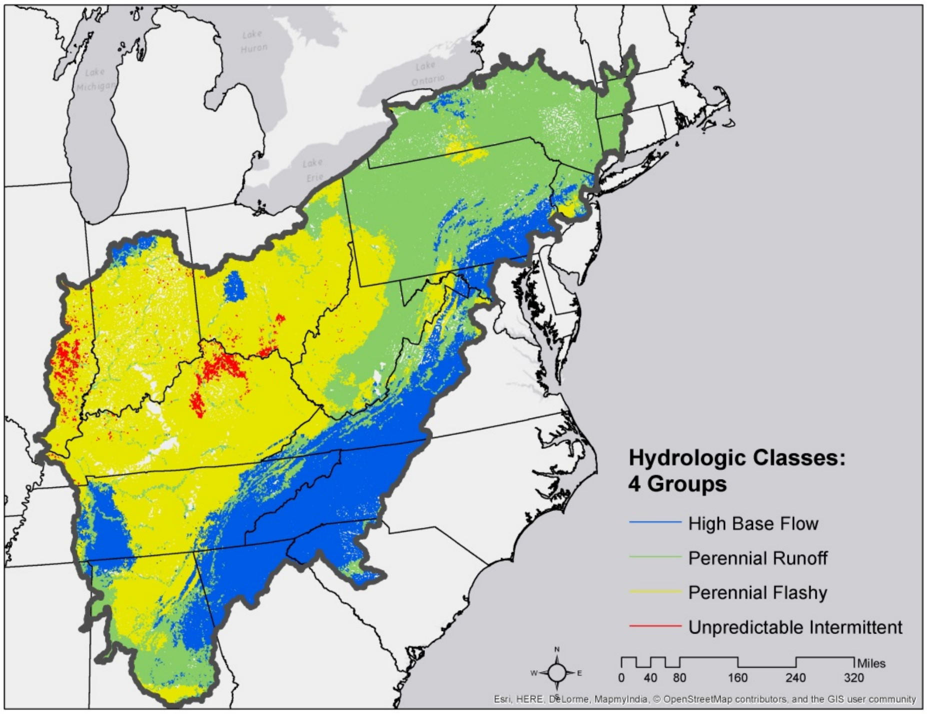
Figure 7-4. Variable importance plot for the best subclass model of the selected four-class model. The plot shows each variable on the y-axis ordered from most- to least-important. The x-axis shows the mean decrease in classification accuracy when that particular variable is randomly permuted.



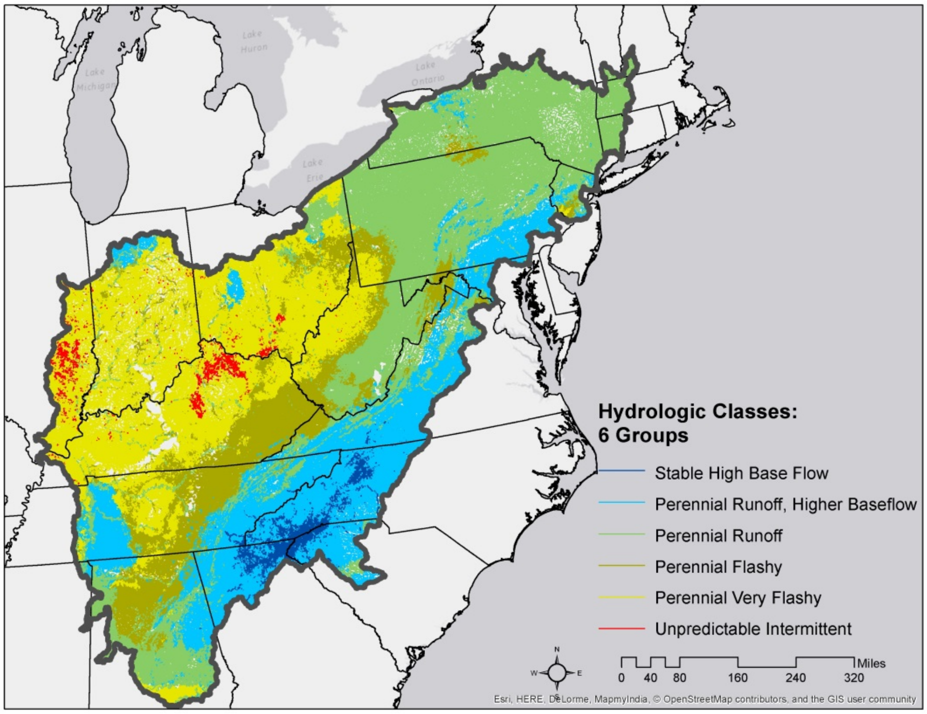
Regardless of the classification model (i.e., four or subclass), the most important variables were consistently related to groundwater. The USGS average baseflow index values at the local and network catchment scales were always the most important predictors of hydrologic class. Omission of these variables resulted in a large decrease in model accuracy for all RF models. USGS estimated average annual groundwater recharge values at the local and network scale were always the third and fourth most important predictors, respectively. Other variables that were important predictors of hydrologic class were Omernick Level 3 Ecoregion, hydrologic soil groups B and C, and STATSGO silt and sand percentages, several of which were also related to groundwater measures.

The best four-class model was used to predict the hydrologic class of all stream reaches in the project area (Map 7-2). The predicted hydrologic class shows distinct geographic patterns with perennial runoff streams largely concentrated in the northern portion of the region and then running along a narrow portion of the Appalachian Mountains into the southern portion of the project area. Unpredictable intermittent streams occurred within an area comprised primarily of perennial flashy streams and rivers. Comparison with the prediction of all six hydrologic classes using the best subclass model and four-class model reveals how the perennial flashy class was further divided into flashy and very flashy classes as well as how the high baseflow class was decomposed into stable and perennial runoff classes. Feedback from the workgroup indicated that the six-class result from combining the best four-class model and its best subclass model (Map 7-3), most accurately reflected the stream systems in participants' respective geographic areas. Thus we selected the results from this combined model for the integration, but both the four-class and six-class assignments are available in the accompanying flowline data package for this project.

Map 7-2. Predicted hydrologic classes (n=4) for all flowlines in the project area using the best four-class RF classification model.



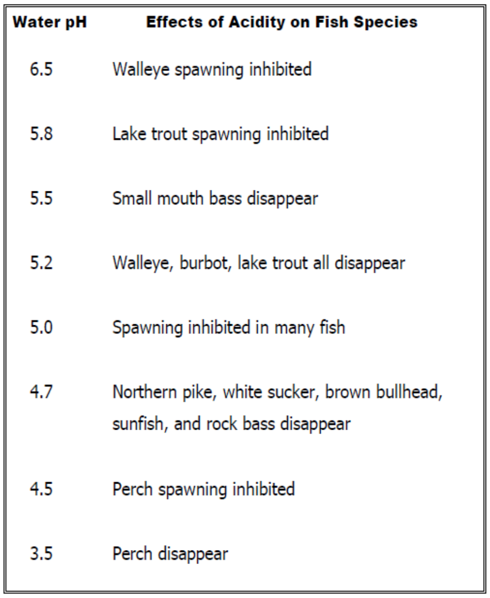
Map 7-3. Predicted hydrologic classes (n=6) for all flowlines in the project area using the best subclass and four-class RF classification models.



8 Buffering Capacity

Ecological Importance

Alkalinity is the water's capacity to resist changes in pH that would make it more acidic. This capacity is commonly called "buffering capacity" as a buffer is a solution to which an acid can be added without changing the concentration of available H+ ions (without changing the pH) appreciably. Alkalinity is commonly measured as mg/l of CaCO3. Waters with high buffering capacity usually have a high pH while waters with low buffering capacity have a lower pH.



Water pH	Effects of Acidity on Fish Species
6.5	Walleye spawning inhibited
5.8	Lake trout spawning inhibited
5.5	Small mouth bass disappear
5.2	Walleye, burbot, lake trout all disappear
5.0	Spawning inhibited in many fish
4.7	Northern pike, white sucker, brown bullhead, sunfish, and rock bass disappear
4.5	Perch spawning inhibited
3.5	Perch disappear

Figure 8-1. Effect of water pH on Fish Species (Olszyk 1980)

Alkalinity is important for fish and aquatic life because it protects against rapid pH changes and helps maintain a higher pH. Aquatic organisms need water pH to be within a certain range for optimal growth, reproduction, and survival. Most aquatic organisms prefer a pH of 6.5-8. Streams with pH levels below five no longer support fish and many other forms of aquatic biota (Allan 1995). The young of most species are also more sensitive to stream acidity. For example, at pH 5, most fish eggs cannot hatch (Olzsk 1980). Not all aquatic species guilds tolerate the same amount of acidity. Frogs, for example, can tolerate a lower pH than clams or snails (EPA 2015; Figure 8-2).

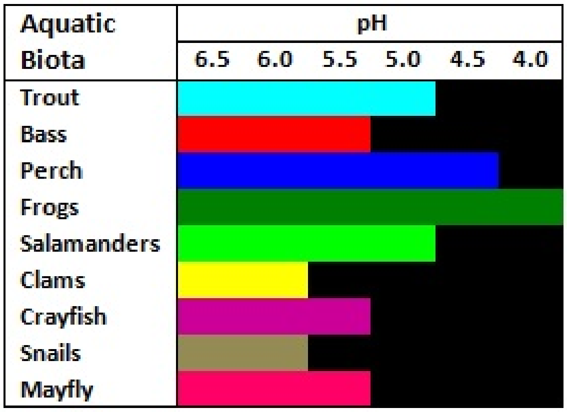


Figure 8-2. pH ranges of fish and other aquatic biota http://www.epa.gov/acidrain/effects/surface_water.html

Alkalinity of natural water is determined by the soil and bedrock through which it passes. The main sources for natural alkalinity are rocks which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates also may contribute to alkalinity. Limestone is rich in carbonates, so waters flowing through limestone regions or bedrock containing carbonates generally have high alkalinity. Areas rich in granites and some conglomerates and sandstones may have low alkalinity (Norton 1980).

Approach

We explored modeling both pH and alkalinity, but we were only able to develop a model with acceptable error rates for alkalinity. The two factors are closely related; however, pH is easily altered by local disturbances while alkalinity is a more stable variable primarily determined by the soil and geology of the surrounding watershed. It is also resistant to changes resulting from biological processes such as decomposition which can alter pH. Alkalinity may provide a better representation of overall water chemistry and ion chemistry than pH, when used at a regional stream classification scale.

Our goal was to map the natural alkalinity that should occur in each stream reach. Even though alkalinity is more resistant to human influence than pH, we removed the most highly altered input points from our sample database.

We obtained alkalinity data from four primary sources:

1) National Rivers and Streams Assessment 2008–2009 (NRSA) A Collaborative Survey U.S. Environmental Protection Agency Office of Wetlands, Oceans and Watersheds Office of Research and Development Washington, DC 20460 EPA/841/D-13/001 February 28, 2013

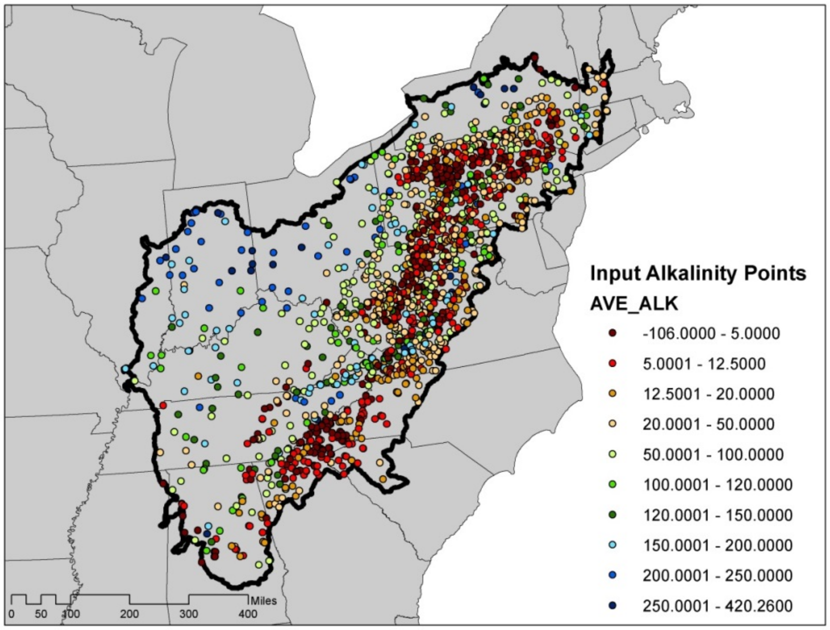
2) Mid-Atlantic Highlands Streams Assessment (MAHA) August 2000. Environmental Monitoring and Assessment Program. National Health and Environmental Effects Washington, D.C. Final Report EPA-903-R-00-015

3) Mid-Atlantic Integrated Assessment (MAIA): Stoddard et al. 2006. State of the flowing waters report. Research Laboratory Western Ecology Division Office of Research and Development & Region III U.S. Environmental Protection Agency

4) National Stream Survey Database Guide (NSS): Mitch et al. 1990. EPN6OO/8-90/055. U.S. EPA Environmental Research Laboratory, Corvallis, Oregon. 92 pp.

We limited the above datasets to those points falling within the study area. Next, we reviewed the points and spatially joined them to NHDPlusV2 reaches, merging them into one dataset. In the unusual case where more than one sample point fell on a given reach, the values were averaged to create a single average alkalinity and pH value for the reach. Acid Neutralizing Capacity (ANC) values were converted to Alkalinity values using the following formula: 1mg/L Alk (as CaCO3) = 20 ueq/L ANC (Brezonik and Arnold 2011). To eliminate samples in extremely altered landscapes, we joined the points to the National Fish Habitat Action Plan 2010 Risk of Degradation Scores and excluded points in the “very high” impact category (Esselman et al. 2011). This removed the most altered sites while still leaving some sites in the Ohio River Basin that were in the “high” impact category. Our final input dataset included 1599 flowlines with 309 from NRSA, 461 from NSS, and 829 from MAHA-MAIA.

Map 8-1. Measured alkalinity points used in the project

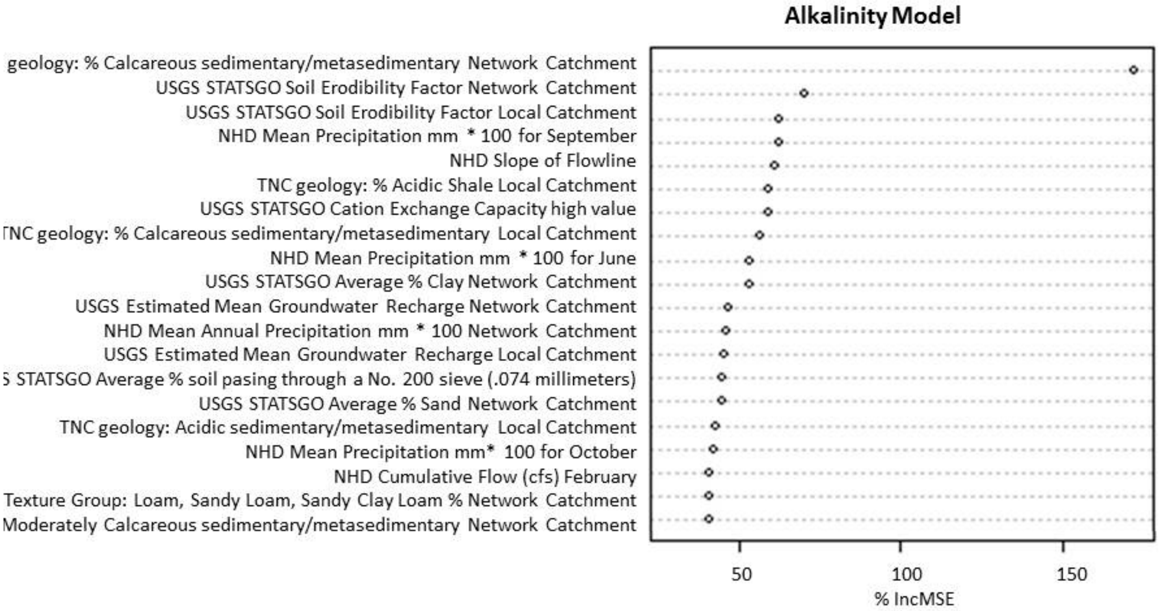


Methods and Results

We used the sample data with 211 GIS variables to build a predictive model of alkalinity for all stream reaches using the methods described for temperature in Chapter 4. We ran the RF model using all 1599 alkalinity samples and varied the parameters including the number of trees and number of predictor variables used at each split. We selected the final model based on the one with the highest percent variance explained. The final model used 10,000 trees, the default of 70 variables tried at each split, a minimum node size of 2, and sampling with replacement. The final model explained 72.67 percent of the variance in alkalinity based on the predictor variables provided.

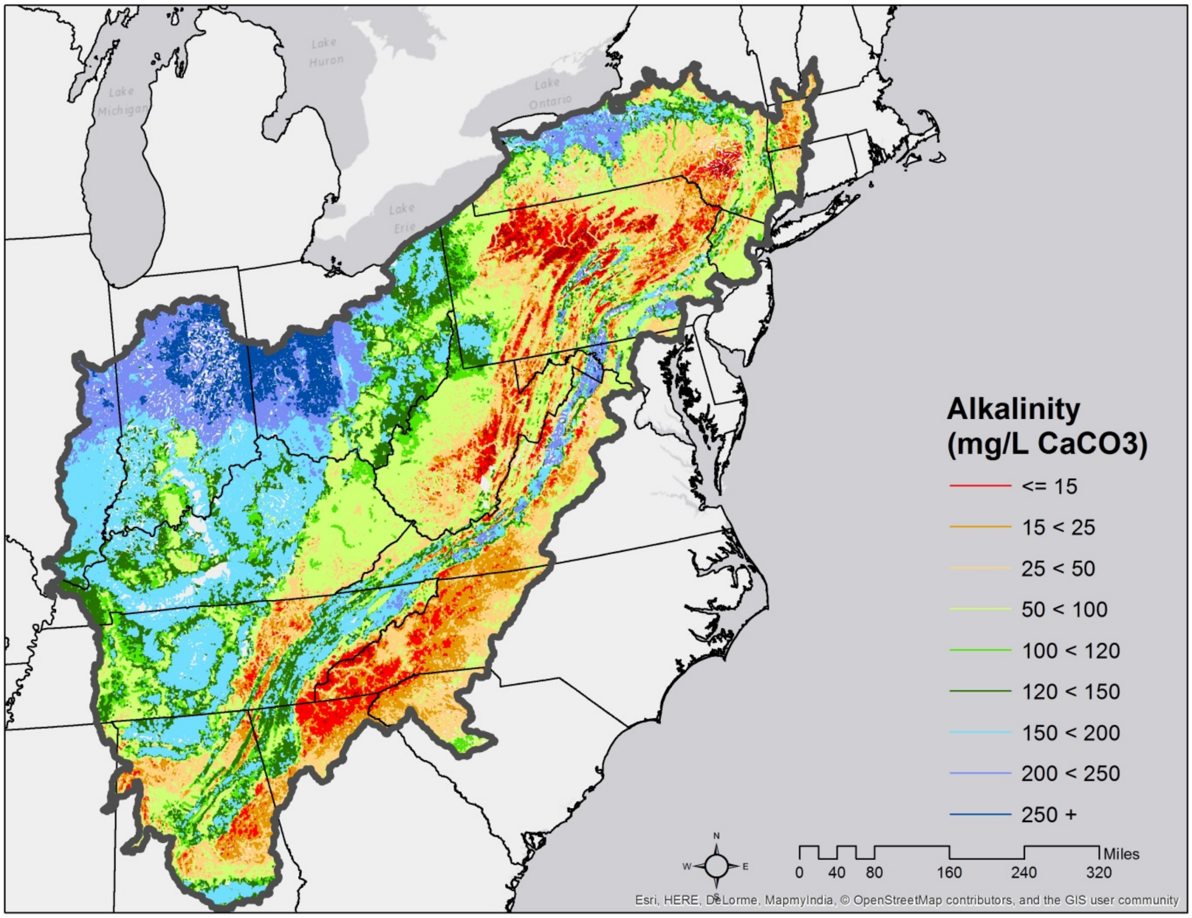
The variable importance table (Figure 8-3) identifies the variables most helpful in predicting alkalinity. The top variables were related to calcareous geology, soil erodibility, rainfall, slope, acidic shale, cation exchange capacity, and clay content. The most important variable by far was the amount of calcareous bedrock geology in the upstream watershed. As Figure 8-3 shows, calcareous bedrock had a huge effect on the percentage increase in mean squared error. If this variable were randomly permuted, the mean squared error of the model increased almost as much as all other variables combined. The next most important variable in the model was upstream watershed soil erodibility. These results are consistent with research that has shown even small amounts of calcareous bedrock in the upstream watershed can exert an overwhelming influence on stream alkalinity and pH. The soil erodibility variables may also indicate that the surficial material and soils may have been derived from calcareous bedrock given calcareous bedrock is more erodible than the acidic bedrock in the region. In the heavily glaciated areas of the Appalachian LCC where bedrock is deeply buried and glacial action may have moved surficial sediments substantially in the past, the presence of surficial material derived from calcareous material may have a higher influence on stream alkalinity than the bedrock.

Figure 8-3. Variable importance plot for the RF alkalinity model. The plot shows each variable on the y-axis ordered from most- to least-important. The x-axis shows the increase in mean square error when that particular variable is randomly permuted.



Applying the above model to all unsampled reaches in the region yielded a continuous map of alkalinity (Map 8-2). This map reveals areas of very high alkalinity and likely higher pH throughout the Ohio Basin in portions of western Ohio, Indiana, Illinois, Kentucky, and Tennessee along with the lower Great Lakes valley area of New York, and a swath of limestone and karst throughout the backbone of the Appalachian Mountains from Pennsylvania to Alabama. The areas with the lowest alkalinity are the high mountains of Pennsylvania, West Virginia, North Carolina, and northeastern Georgia (Map 8-2).

Map 8-2. Streams and rivers mapped by predicted alkalinity values in the project area



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The continuous alkalinity model will be helpful for many applications, but for the stream classification we simplified the continuous alkalinity values into four ecologically meaningful classes. Statistical analysis of the differences in fish and benthic taxa composition related to alkalinity change was used to identify key break points in the continuous distribution of alkalinity values. Fish species and benthic taxa count data from the National Stream and River Assessment Database (US EPA 2013) were compiled for the project area. Sample points were excluded if they were in the “very high” risk of degradation class from the National Fish Habitat Partnership’s cumulative disturbance index (Esselman et al. 2011). Taxa occurring in less than three sample sites were also excluded. A total of 286 sites representing 207 fish species, and 288 sites representing 433 benthic taxa were included in the analyses.

We used Threshold Indicator Taxa Analysis (TITAN, Baker and King 2010) to identify alkalinity thresholds where species distribution changes. We used the recommended default parameters of: a minimum of 5 observations on either side of an environmental change point, 250 random permutations of the taxa data, and 500 bootstraps or new datasets generated by resampling the paired environmental and taxa datasets to calculate the uncertainty and Z metrics. Results highlight a set of significant species where a alkalinity threshold could be identified (Figures 8-4 and 8-5). We used the default recommendations from Baker and King (2010) to define "significant" species as those with an indicator p-value < 0.05, purity > 0.95 and reliability > 0.95. Purity and reliability are measures that assess the quality of the indicator response. Purity is the proportion of the bootstrap replicates that have the same direction response (i.e., negative or positive) as the observed response. Reliability indicates the proportion of the bootstrap replicates with p-values for the indicator value score at ≤ 0.05.

The analysis is summarized in a chart of individual species and their alkalinity thresholds in which the species whose abundance increases as alkalinity *decreases* (black) are separated from those whose abundance increases as alkalinity *increases* (red). Only significant species are shown and dot symbols are sized in proportion to the strength (Z score) of their threshold (Baker and King 2010). Horizontal lines (solid for decreasing species in black; dotted for increasing species in red) in the figure correspond to the 90% confidence intervals of the threshold change point. Full TITAN results are in Appendix 3 where individual species and threshold values are presented in tabular form and a more readable format.

The TITAN results indicated at least four major groups in our study area (Figures 8-4 and 8-5). These groups were supported by patterns in the thresholds of both the fish and benthic taxa. For example, the Low Alkalinity class included a small set of fish species and a large set of benthic taxa that increased with decreasing alkalinity. The Mid Alkalinity class showed many significant responses with a mix of both increasing and decreasing fish and benthic taxa. The High Alkalinity class had a large set of fish and benthic taxa that increased as alkalinity increases and only a few decreasing taxa. The Very High Alkalinity class had a set of fish and benthic taxa that increased with increasing alkalinity but no species that decreased.

Table 8-1. Alkalinity class definitions and hierarchy. The table shows the four class definitions and how the four groups could be simplified to fewer groups.

Description	**CaCO3 concentration**	**4 Alkalinity Classes**	**3 Alkalinity Classes**	**2 Alkalinity Classes**
Low Alkalinity	< 25 mg/l	1	1	1
Mid Alkalinity	≥ 25 & < 50 mg/l	2	2	
High Alkalinity	≥ 50 & < 150 mg/l	3	3	2
Very High Alkalinity	≥ 150 mg/l	4		

Specific species highlighted by the TITAN results were as follows:

- **Low Alkalinity (<25 mg/l CaCO3):** Abundance increases as alkalinity *decreases*: Brook Trout and Rosyside Dace and over 50 benthic taxa. Examples of the benthic taxa in this low alkalinity group include beetles such as Oulimnius spp., Promoresia spp., and Helichus spp.; true flies such as Stempellinella spp., Parachaetocladius spp., Eukiefferiella spp., Limnophyes spp., Tipula spp., and Dicranota spp.; mayfiles of the family Heptageniidae and Leptophlebiidae, Eurylophella spp., and Serratella spp.; stonefiles such as Leuctra spp., and Acroneuria spp.; dragonfiles such as Stylogomphus spp. and dobsonflies such as Nigronia spp.

- **Mid Alkalinity (25-50 mg/l CaCO3)**
    - Abundance increases as alkalinity *decreases*: Bluehead Chub, Rainbow Trout and 30 benthic taxa.
    - Abundance increases as alkalinity *increases*: Bluegill, Smallmouth Bass, Rock Bass, White Sucker, Northern Hog Sucker, Spotfin Shiner, Longear Sunfish, Golden Redhorse, Channel Catfish, Logperch, and Spotted Bass and 11 benthic taxa.
- **High Alkalinity (50-150 mg/l CaCO3):** Abundance increases as alkalinity *increases*: Bluntnose Minnow, Central Stoneroller, Greenside Darter, Striped Shiner, Rainbow Darter, Yellow Bullhead, Shorthead Redhorse, Banded Sculpin, Bullhead Minnow, and Dusky Darter. Sixteen benthic species also exhibit this pattern including beetles such as Dubiraphia spp. and Stenelmis spp.; true flies such as Cryptochironomus spp., Procladius spp., and Chironomus spp.; and mayflies such as Centroptilum spp. and Stenonema spp.
- **Very High Alkalinity (>150 mg/l CaCO3):** Abundance increases as alkalinity *increases*: Creek Chub, Johnny Darter, Sand Shiner, Blackside Darter, Bigeye Chub, Silverjaw Minnow, Fathead Minnow, and Orangethroat Darter. Twenty-one benthic species exhibit this pattern and include snails of the family Lymnaeidae and Physa spp.; clams such as Sphaerium spp.; Beetles such as Peltodytes spp.; true flies including Cladotanytarsus spp., Paratanytarsus spp., Paratendipes spp., Stictochironomus spp., Parakiefferiella spp., Labrundinia spp., and Natarsia spp.; isopods such as Lirceus spp.; and water mites such as Hygrobates spp.

Figure 8-4. Threshold Indicator Taxa Analysis (TITAN) change points of fish species in relation to stream alkalinity (mg/L). Black circles represent change points for species associated with decreasing alkalinity (negative response) while red circles identify species associated with increasing alkalinity (positive response). The shaded ellipses correspond to the classes shown in Table 8-1.

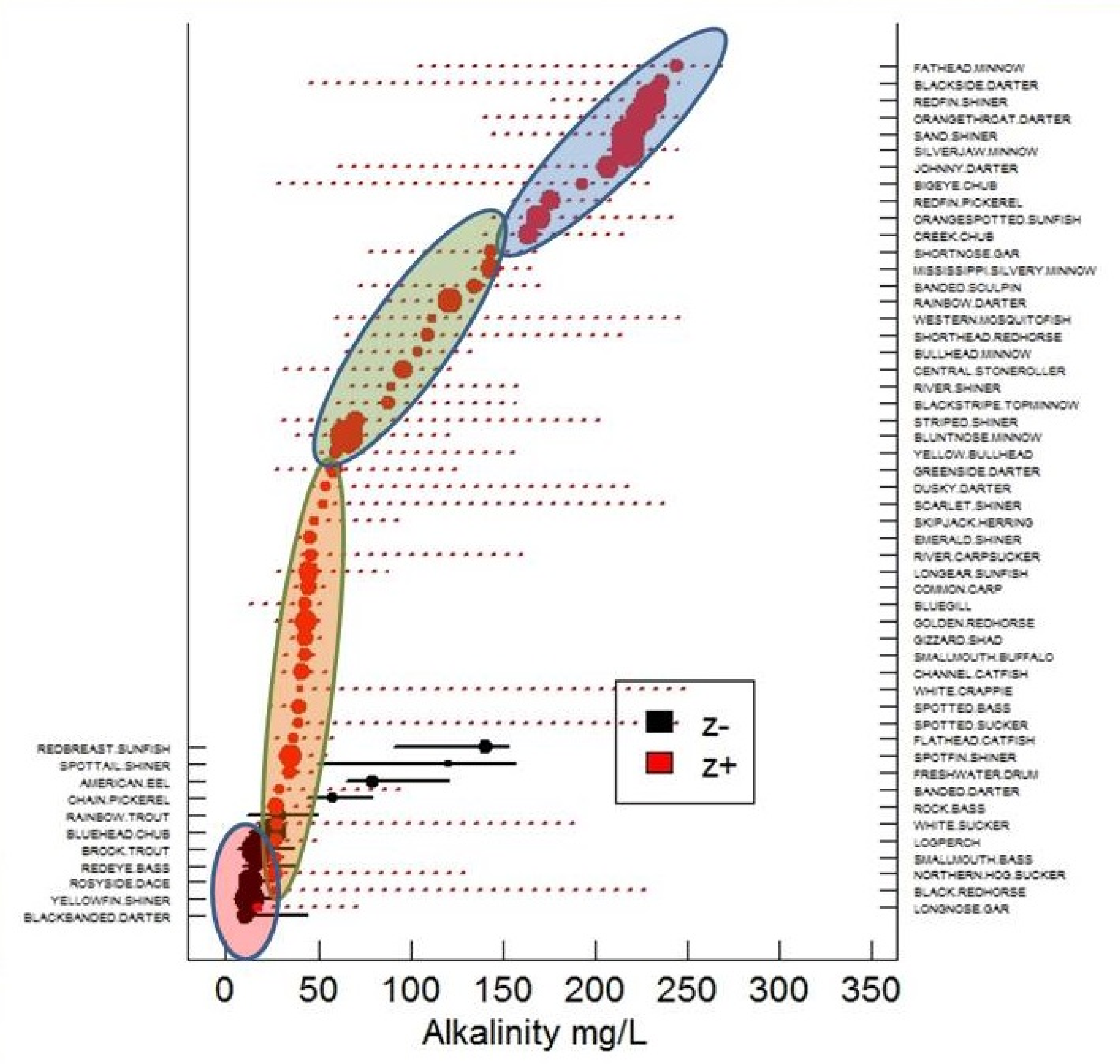
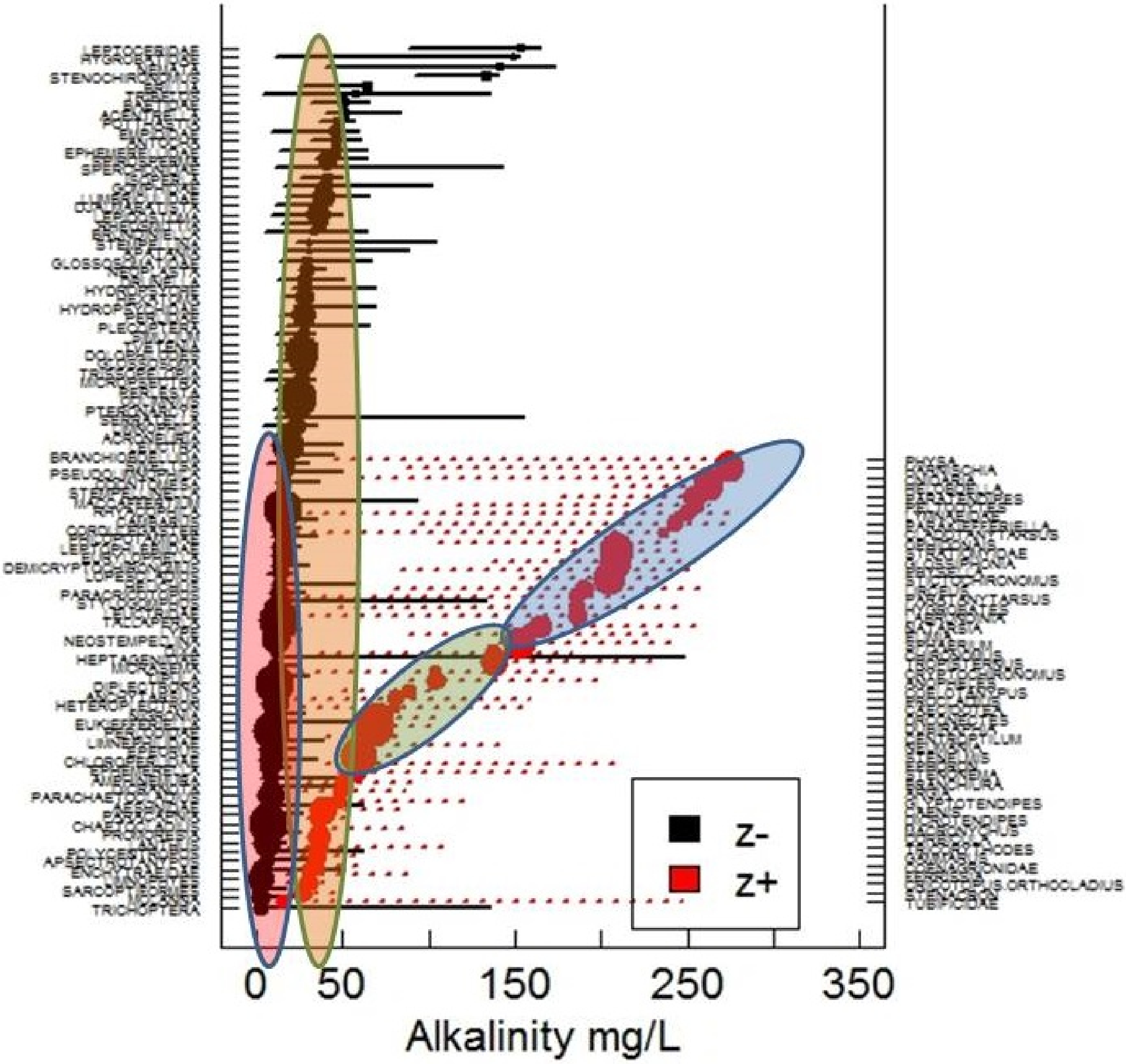


Figure 8-5. Threshold Indicator Taxa Analysis (TITAN) change points of benthic taxa in relation to stream alkalinity (mg/L). Black circles represent change points for species associated with decreasing alkalinity (negative response) while red circles identify species associated with increasing alkalinity (positive response). The shaded ellipses correspond to the classes shown in Table 8-1.



Results of a hierarchical cluster analysis of the four alkalinity groups by fish and benthic taxa showed the same dendrogram splits and guided our suggested simplification rules (Figures 8-6 and 8-7). Results of the cluster analyses indicated very little difference between the High and Very High Alkalinity Classes (3-4), suggesting these groups be fused first in a simplification. The Low and Mid Alkalinity Classes (1-2) show some differences, but the dendrogram suggests they be combined as a further simplification step.

Figure 8-6. Hierarchical cluster results showing the relationship of fish species to alkalinity classes. Numbers on the left-hand size of the dendrogram correspond to alkalinity classes in Table 8-1.

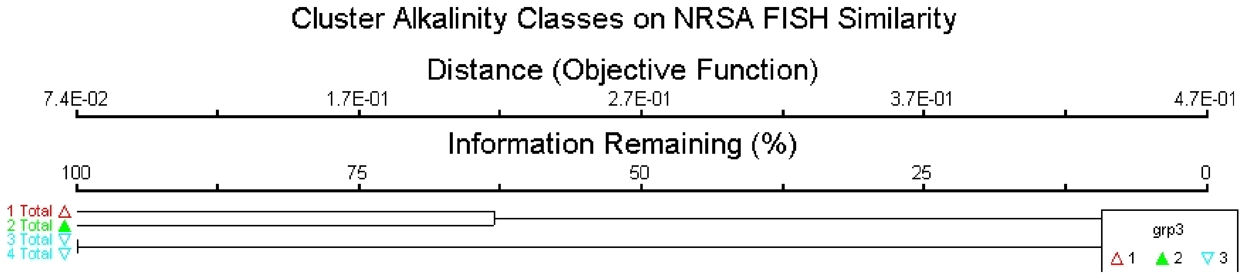
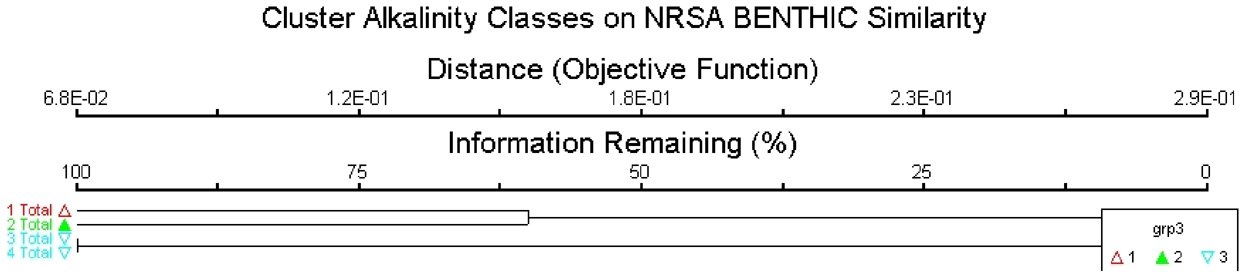
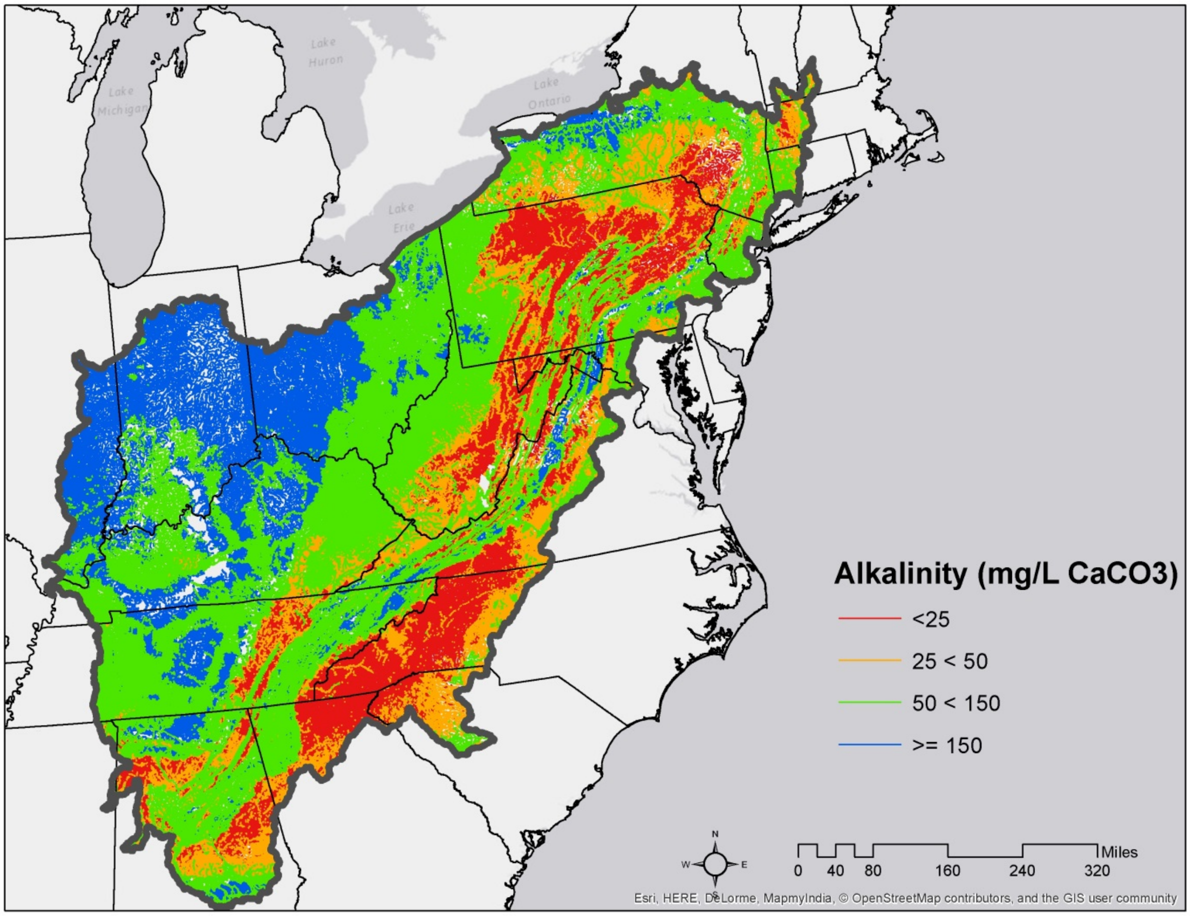


Figure 8-7. Hierarchical cluster results showing the relationship of benthic invertebrate taxa to alkalinity classes. Numbers on the left-hand size of the dendrogram correspond to alkalinity classes in Table 8-1.



Map 8-3. Streams and rivers mapped by alkalinity class in the project area



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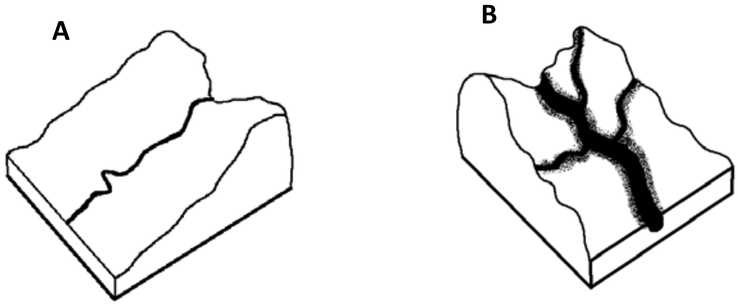
9 Confinement

Ecological Importance

Confinement describes the degree to which bounding topographic features, such as hillslopes, alluvial fans, and river terraces, limit the lateral extent of the valley floor and floodplain along a river (Nagel et al. 2014). Streams and rivers with wider valleys have more area for channel meandering and migration and thus less confinement. The level of confinement affects the development of floodplains and riparian wetlands and the dynamics of floods which are important to formation and maintenance of riparian habitats, biological composition, and ecological function (Hupp and Osterkamp 1985, 1986, Bendix and Hupp 2000, Quinn et al. 2000). The valley flood-prone area is geomorphically dynamic and provides numerous ecological functions critical to water quality, hydrologic processes, sediment regime, and biogeochemical cycling. Larger rivers also often support biota that directly utilize the floodplains for feeding, while smaller streams primarily utilize floodplains for energy dissipation and related sediment regime, water quality, and biogeochemical cycling.

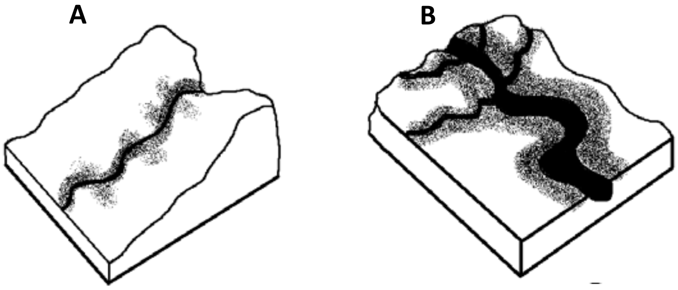
Rivers and their valleys can broadly be classified as confined or unconfined with corresponding differences in their appearance, vegetation, ground water exchange rates, topographic gradient, and stream characteristics. Three types of river valley confinement are described below.

Figure 9-1. Confined: A) Stream to small river and B) Medium-large river *(Image Credits for Figures 9.1-9.3: Inspired by Oregon Watershed Enhancement Board, 1999. Drawn by K. Weaver TNC.)*



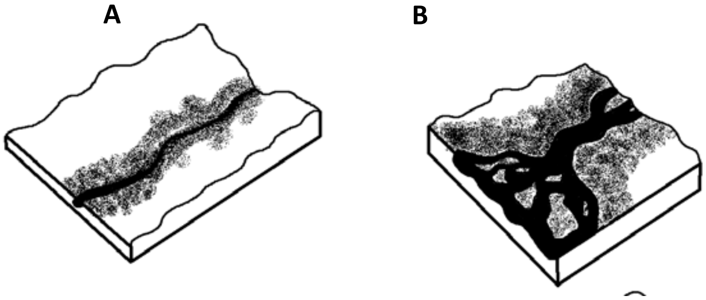
Confined: Narrow valley with little to no opportunity for extensive riparian wetland and floodplain features to develop; occasional small floodplain pockets; low sinuosity, usually relatively steep, high energy transport systems with little sediment storage; frequent bedrock outcrops, high terraces and moderate to steep mountain or hill slopes along the stream banks.

Figure 9-2. Moderately Confined: A) Stream to small river, and B) Medium-large river



Moderately Confined: Moderate width floodplain with wetland and small flood storage pockets throughout; streams have some ability to dissipate energy and access floodplain; slightly to moderately sinuous channels; confined by low terraces and hillslopes; some development of side channels possible.

Figure 9-3. Unconfined: A) Stream to small river, and B) Medium-large river



Unconfined: Nearly continuous wide floodplains; little to no confinement; lower gradient and sinuous channels with active channel migration; complexity of side channels and much variation in accessible floodplain habitats including sloughs, oxbows, wetlands, side-channels, gravel bars, and abandoned channels; important exchange of nutrients, sediments, and organisms during overbank flooding facilitates interactions between terrestrial and freshwater realms with aquatic organisms often feeding and spawning in the floodplains; sediment deposition is prevalent, with extensive alluvial fill; stream banks are composed of fine alluvium and susceptible to bank erosion; fine sediments are typically mobilized during high flow events.

Approach

To develop the confinement metric, we first mapped the floodplain and other components of the Active River Area (ARA). The ARA is a spatially explicit framework for modeling rivers and their dynamic interaction with the land through which they flow (Smith et al. 2008). Key features of the ARA include the meander belt, riparian wetlands, floodplains, terraces, upslope material contribution areas. The ARA is different from, but was calibrated to and compared against the FEMA 100-year floodplain.

Methods and Results

For the project area, we delineated the ARA for each of the seven size classes described in Chapter 4, using a seamless mosaic of 10 m DEM data from the National Elevation Dataset (Gesch 2007, Gesch et al. 2002) as well as stream polylines, waterbody polygons, and stream area polygons from the NHDPlusV2 dataset. We integrated “wetflat” landforms from a 30 m landform model developed for the Eastern US (Anderson et al. 2014, Map 9-1) to identify ARA components that occurred on wetflats and where longer-term storage of water is expected to occur. In addition, we obtained 100-yr floodplain polygons from the FEMA National Flood Hazard Layer (NFHL) in spring 2013 and used this data to inform cost distance threshold selection in the ARA delineation. Any FEMA 100-yr floodplain areas that were not captured by the ARA delineation were gridded at 10 m resolution and merged underneath the ARA components in the final product.

To measure confinement, we used all portions of the ARA except the upslope material contribution zone to represent the flood-prone valley area (Map 9-2). Confinement was quantified by comparing the width of this flood-prone area to that of the open water channel following the guidelines of previous studies (Cupp 1989, Montgomery and Buffington 1993, Moore et al. 1997, Oregon Watershed Enhancement Board 1999, Kline et al. 2004, Bledsoe and Carlson 2012). Higher ratios indicate more floodplain available for channel meandering and migration and thus less confinement.

The width of the ARA flood-prone area was continuously measured using the minimum of the four axes in a series of flow accumulations (N-S, E,W, NE-SW, NW-SE) and/or the maximum inverse Euclidean distance measure. The bankfull width of open water in the channel was estimated for each flowline using 1) the 1:100,000 NHD polygon open water areas, or 2) the open water polygon areas from the 1:24,000 high resolution NHD for rivers and streams. When neither 1 nor 2 was available, bankfull width was estimated using the equations from Faustini et al. (2009).

Each 10 m stream pixel was assigned a confinement ratio and then grouped into one of the three confinement categories based on ratio thresholds developed separately for headwaters to small streams, and medium to large rivers (Table 9-1). Each vector flowline was also assigned to one of the confinement classes based on sampling the 10 m pixel confinement class data along its length to determine the overall dominant confinement class for an entire flowline. The results classify all streams and rivers in the region into one of the confinement classes (Figures 9.3 - 9.4).

Table 9-1. Description of confinement classes

Description	Headwater – Small River Definition: Ratio ARA width to bankfull width	Medium – Large River Definition: Ratio ARA width to bankfull width	3 Confinement Classes	2 Confinement Classes
Confined	0-6	0-2	1	1
Moderately Confined	7-20	3-6	2	2
Unconfined	≥ 21	≥ 7	3	

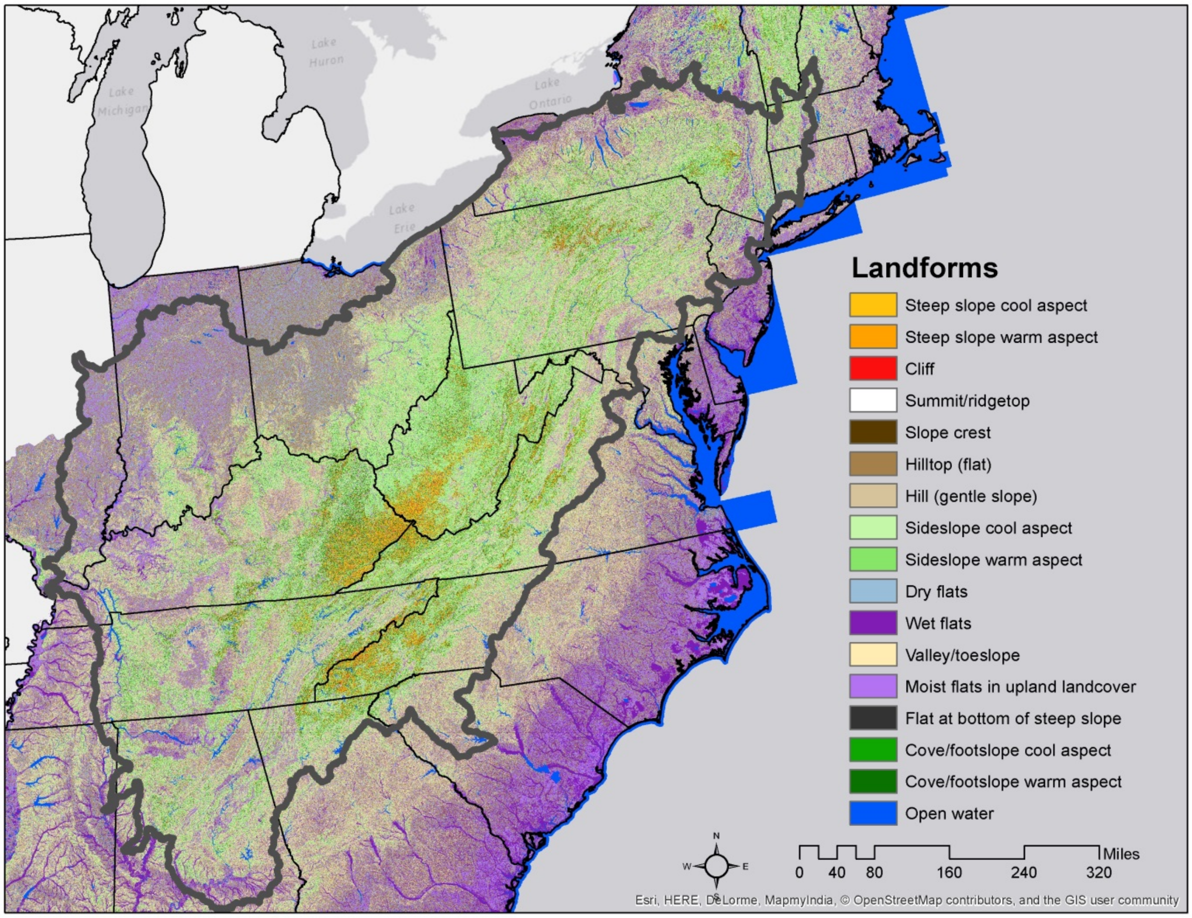
The different floodplain to bankfull width ratio thresholds for medium-large vs. streams-small rivers were developed after studying the results and comparing them to known examples submitted by the steering committee. The thresholds for medium to large rivers conform to those in the literature which suggest that confined rivers have ratios < 2 and become unconfined by ratios > 6 (Kline et al. 2004, Oregon Watershed Enhancement Board 1999, Bledsoe and Carlson 2012). Ratios for smaller streams and rivers were adjusted because our data showed little to no floodplain development below ratios of 6 on streams and small rivers and a lack of wide, continuous floodplains for ratios <20.

The resolution of our DEM-based ARA data is likely a better fit for the larger rivers, and there may be a tendency for the ARA model to overestimate flood-prone width on small streams. Low gradient small headwaters and creeks in this region are often in marshy settings where it is hard to define the "floodplain" because the wetland zone reflects water table and soil drainage more than overbank flooding. Additionally, small infrequently flooded terraces might not be detectable at the 10 m resolution of our data. After careful review with our expert team, we adjusted the thresholds used to define confined, moderately confined, and unconfined systems for streams and small rivers.

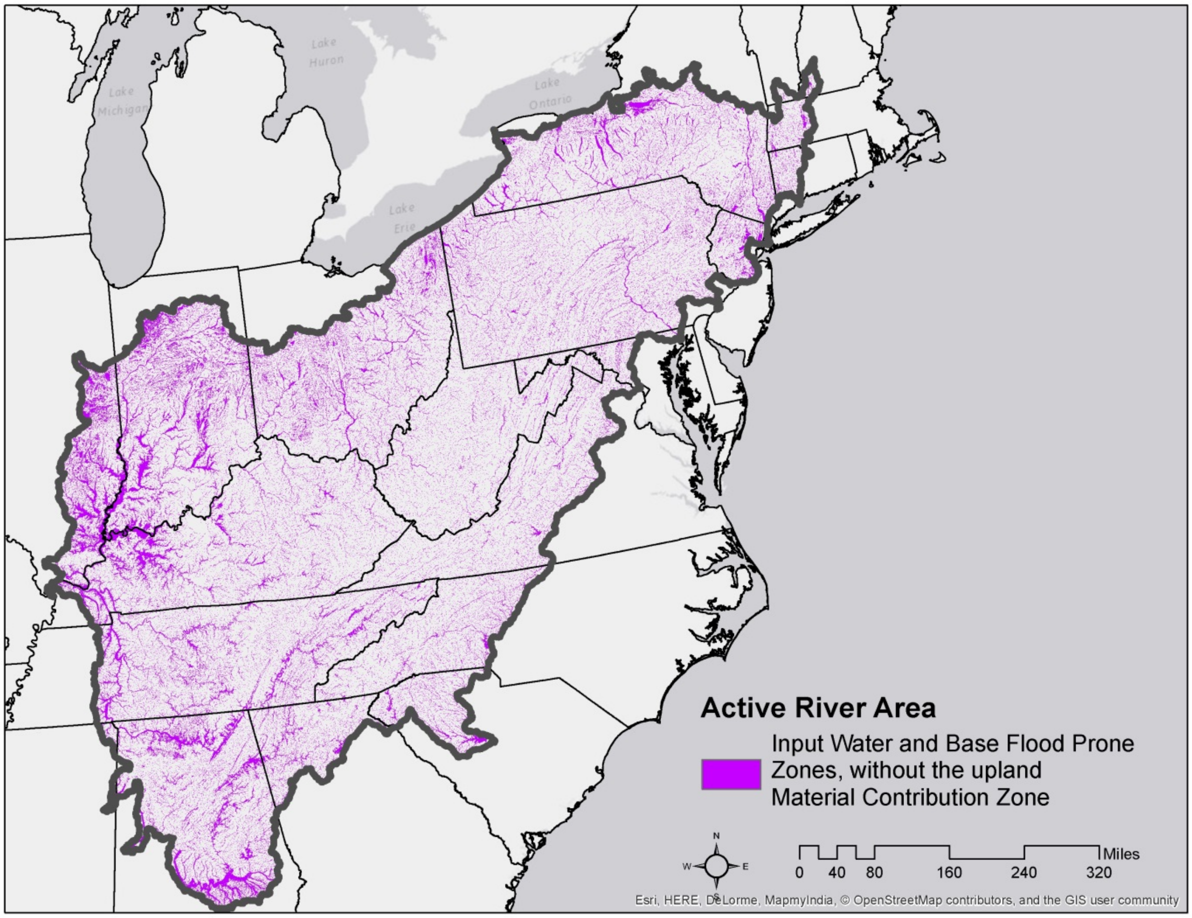
Although every attempt was made to make this regional model as accurate as possible, the floodplain to width ratio is very sensitive to small errors. We had difficulty in measuring the full width of the ARA for rivers that hug one valley margin, which sometimes resulted in these sections having smaller than actual floodplain widths. We also struggled with how to measure and report confinement for our impounded river sections. The impounded lengths often came up as confined because they have little floodplain area currently above water and their "bankfull width, open water measure" represented their current widened reservoir state which has permanently flooded large portions of the original floodplain and often other adjacent areas outside the floodplain. Finally, we smoothed the 10 m raster-based data to the reach-scale and in some cases the systems had variation that was not well represented by the "dominant class." The detailed flowline attribute table indicates the proportion of each flowline classified as confined, moderately confined, or unconfined, and some users may find this information helpful and/or may wish to request the 10 m pixel ratio dataset to study the finer pattern of confinement and where it changes within a single reach.

We encourage all users to also inspect the data and particularly the shape of the floodplain ARA dataset on either side of a given river segment to understand its confinement pattern (Map 9-3, Map 9-4, Map 9-5). This will allow users to see if the river is currently in the middle of the floodplain or has moved significantly to one side or the other of the valley margin. Using the TNC landform dataset (http://nature.ly/TNCResilience), one can also inspect the diversity of wetlands, wetflats, moist flats, and dry flats within the floodplain and see if the floodplain is confined by steep slopes, moderate hillslopes, or gentle hills at its margins (Figure 9.5). We also encourage users to review the flowline attribute table which will indicate whether or not the flowline is within a lake, pond, or reservoir.

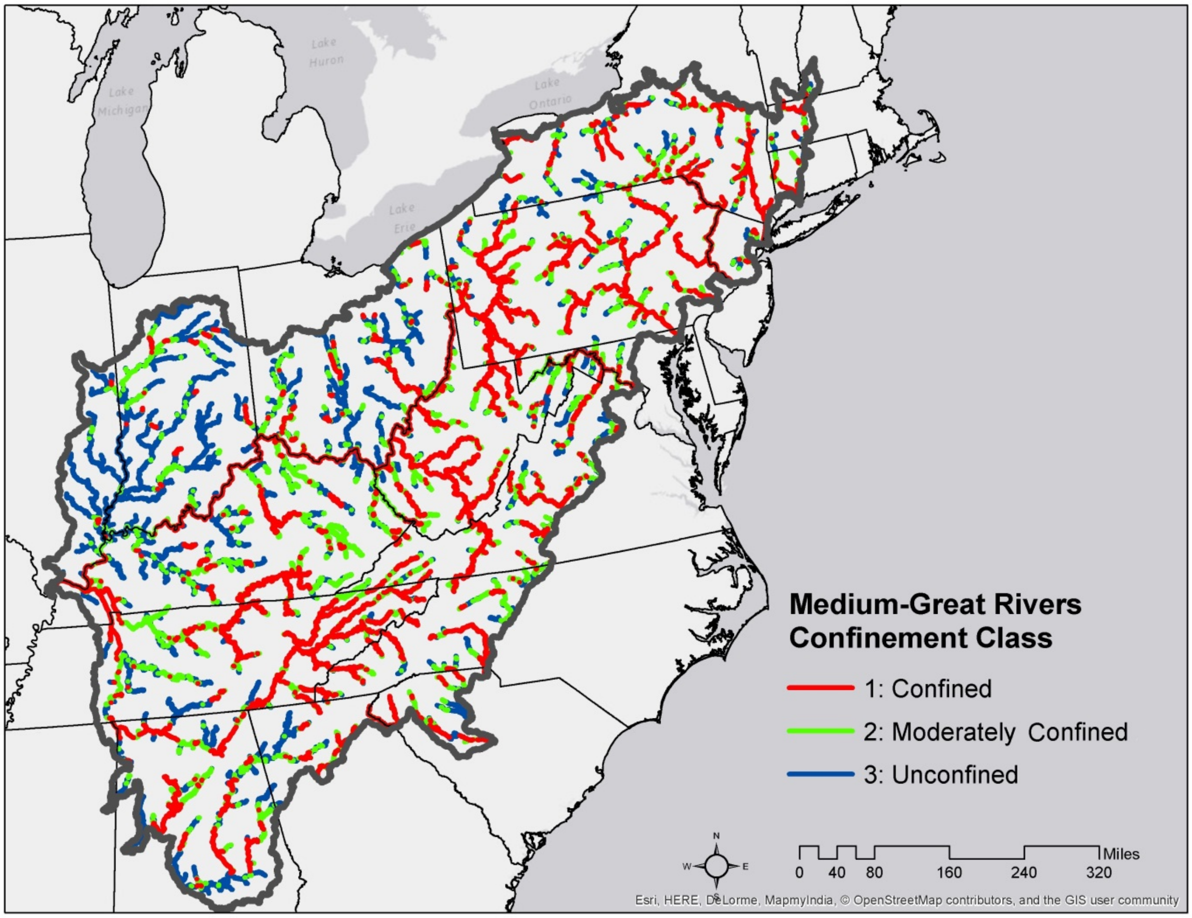
Map 9-1. Landforms



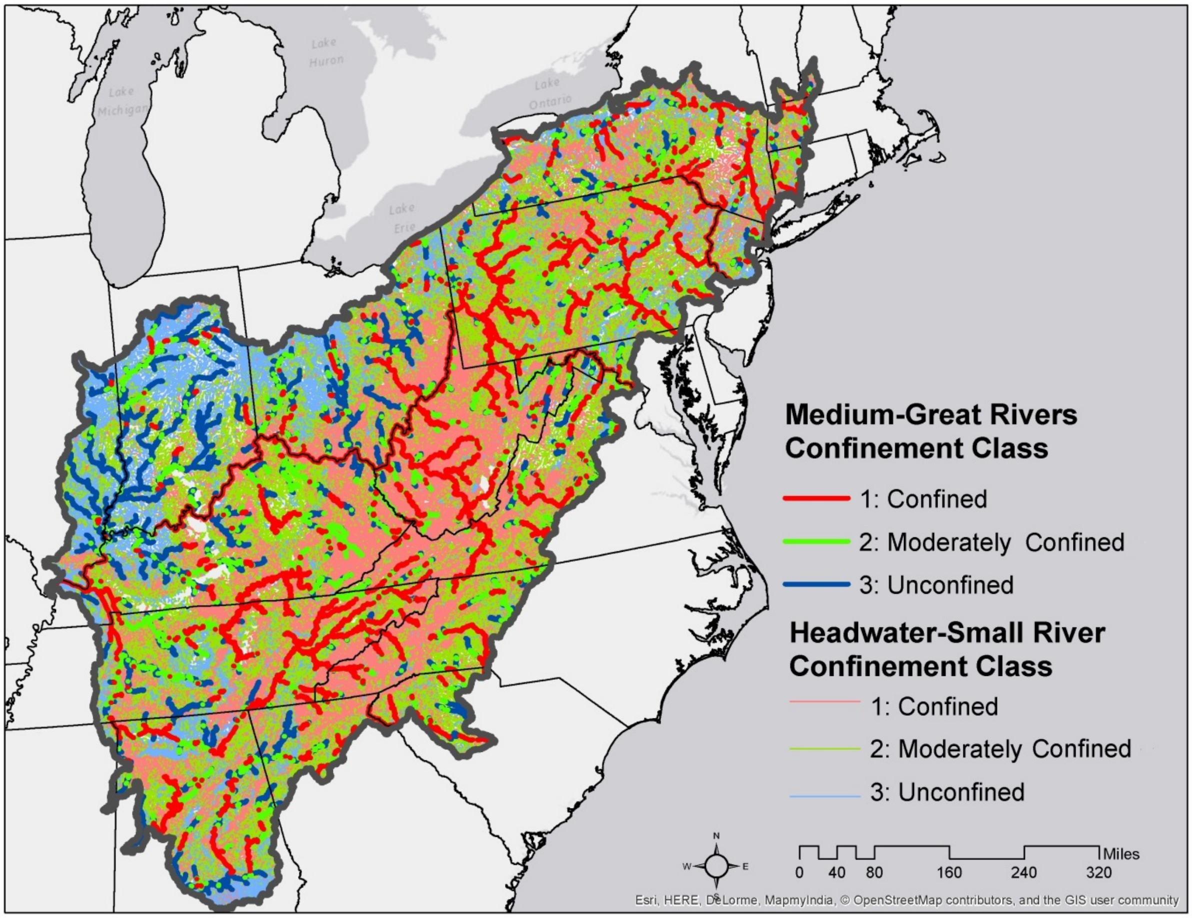
Map 9-2. Active river area



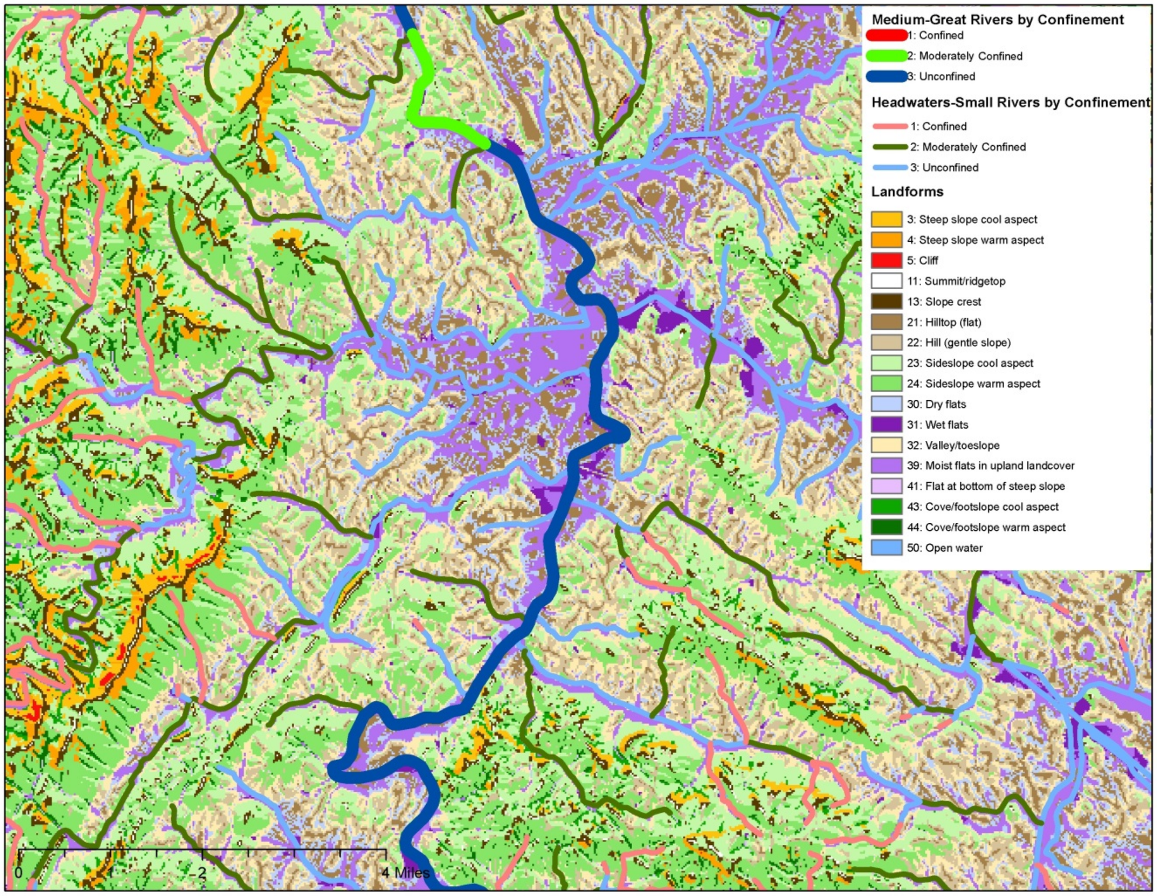
Map 9-3. Medium-great rivers by confinement class



Map 9-4. Streams and rivers by confinement class



Map 9-5. Example of rivers and streams by confinement class with surrounding landforms. French Broad River, medium tributary river, N.C.



10 Combining Variables

Mapping all combinations of the classification variables (size, gradient, temperature, hydrologic regime, alkalinity, confinement) and all their within variable classes (7 x 6 x 3 x 6 x 4 x 3) is neither practical nor necessary for the region. Most users would be overwhelmed with the 2337 resultant types (out of 9072 possible combinations) that occurred in the region when the full set of variables and classes were combined, and many of those types would have no ecological meaning. We wanted to develop a simplified taxonomy that allows users to view this deep database of stream classification attributes in a simpler way to highlight major differences and changes that are most ecologically significant. Below we describe three methods for simplifying the number of types and provide a suggested simplification of types which combines principles of variable prioritization and variable collapsing.

Variable Prioritization

Certain variables can be deemed more important than others in terms of structuring aquatic habitats and biological communities. To see if there were common opinions on this question, we created a questionnaire and polled the steering committee individually. The results indicated strong agreement among the group members. For streams and small rivers the most important variables were gradient, temperature, and hydrologic class. For medium-large to great rivers, the most important variables were confinement, temperature and hydrologic class. We adopted this prioritization in our suggested simplification scheme.

Within Variable Collapsing

Each of the major variables is divided into multiple classes. Although the breaks are useful in many applications, for some applications users may want to group variation within a given variable into a smaller number of classes. In the individual variable chapters, we presented recommended ways of fusing classes that were most similar. Before combining variables together, we suggest reducing the full number of classes using the recommended rules in the specific variable chapters.

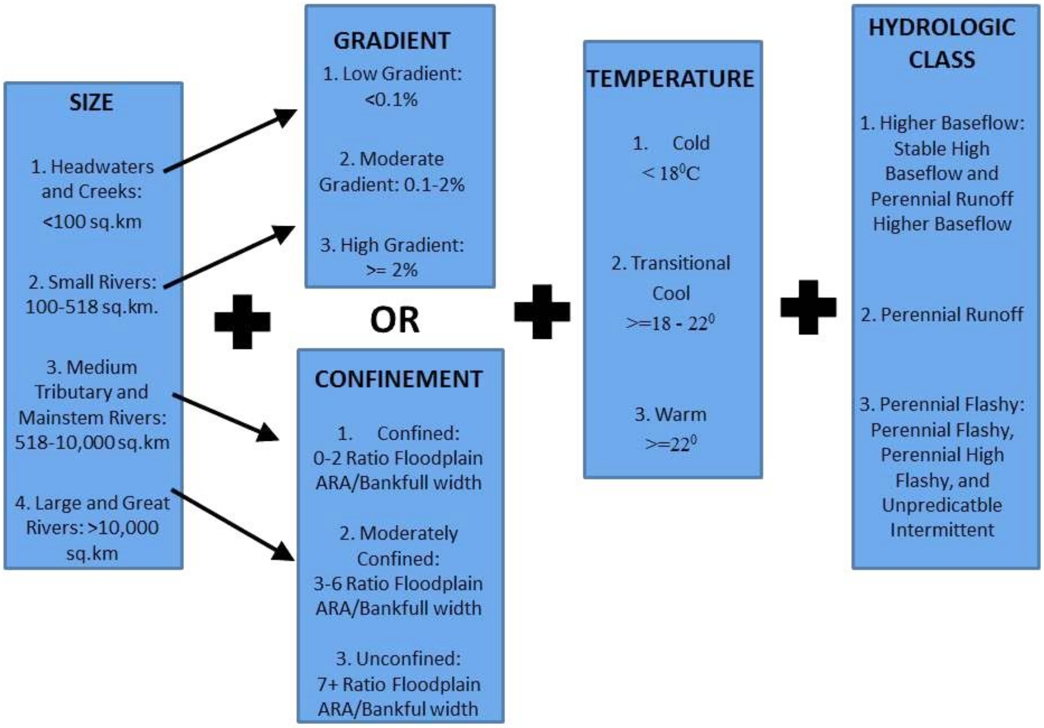
Removing Biotically Insignificant Combinations

Certain combinations of variables are likely to be biologically insignificant or data errors. For example, although larger rivers can occasionally have higher gradient sections and waterfalls, the very few reaches mapped as high gradient large rivers may be potential data errors given the scale of the reach hydrography and DEM. Although team members did not want to eliminate any GIS types until further “on the ground” investigation was done, certain low frequency types should be viewed with skepticism until their unique habitats can be verified.

Simplified Types

We developed a set of simplified types by using principles of variable prioritization and variable collapsing based on recommendations from steering committee members during our questionnaire. The simplified types are based on combining four key variables. For headwaters through small rivers, the variables of gradient, temperature, and hydrologic class were combined. For medium through great rivers, the variables of confinement was deemed more important than gradient, so confinement, temperature, and hydrologic class were combined. The number of classes within the variables of size, gradient, and hydrologic class was reduced by merging classes that were most closely related (Table 4-1, 5-1, Box 7-1) until a smaller number of classes (three or four) for each variable was reached, as recommended by the steering committee. For temperature and confinement, all the original classes were retained. These variables only had three classes to begin with, and all were deemed particularly important for structuring aquatic communities (Figure 10-1.)

Figure 10-1. Simplified types: Description of the four variables combined and their classes



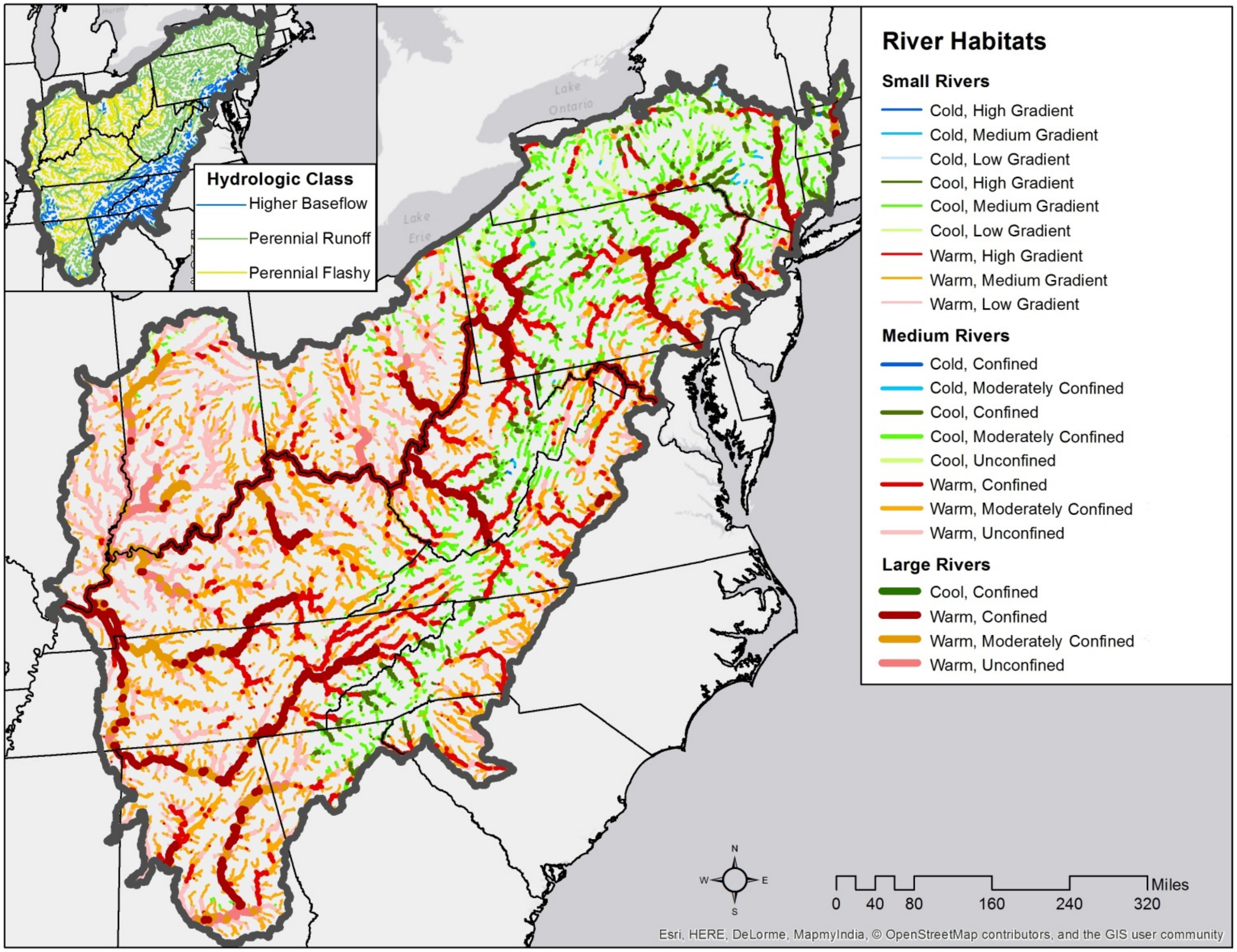
The above simplification resulted in 73 types (out of 108 possible combinations of the simplified classes), with 62 types having > 10 miles in length occurring in the region (Table 10-1, Map 10-1, Map 10-2). The most common types of streams include Perennial Flashy, Warm, Medium Gradient; Perennial Flashy, Cool, Medium Gradient; Perennial Runoff, Cool, Medium Gradient; and Higher Baseflow, Cool, Medium Gradient. The most common types of small rivers include Perennial Flashy, Warm, Low Gradient; Perennial Flashy, Warm, Medium Gradient; Perennial Runoff, Cool, Medium Gradient; and Higher Baseflow, Warm, Medium Gradient. The most common types of medium rivers were Perennial Runoff, Warm, Unconfined; Perennial Flashy, Warm, Unconfined; Perennial Runoff, Warm, Confined; and Perennial Runoff, Warm, Moderately Confined. The most common types of large rivers were Perennial Runoff, Warm, Confined; Perennial Runoff, Warm, Unconfined; Perennial Runoff, Warm, Moderately Confined; and Higher Baseflow, Warm, Confined, Large River.

Table 10-1. Description and miles of simplified types. Note the miles of centerline within lakes, ponds, and reservoirs are reported because many large rivers in this region are defined as "lakes, ponds, and reservoirs" instead of as "rivers" within the NHDPlusV2. Some users may still find these lake, pond, and reservoir mileages useful even though they may have reduced flow and riverine characteristics.

	TYPE_SIMP	Name	Lake/Pond / Reservoir	Stream/ River	Total Miles
1	S10_G2_T3_H3	Perennial Flashy, Warm, Medium Gradient, Stream	544	57,499	58,043
2	S10_G2_T2_H3	Perennial Flashy, Cool, Medium Gradient, Stream	451	53,739	54,190
3	S10_G2_T2_H2	Perennial Runoff, Cool, Medium Gradient, Stream	1,094	43,310	44,405
4	S10_G2_T2_H1	Higher Baseflow, Cool, Medium Gradient, Stream	700	43,496	44,195
5	S10_G3_T2_H1	Higher Baseflow, Cool, High Gradient, Stream	85	29,546	29,630
6	S10_G3_T2_H2	Perennial Runoff, Cool, High Gradient, Stream	87	29,483	29,569
7	S10_G3_T2_H3	Perennial Flashy, Cool, High Gradient, Stream	34	28,920	28,954
8	S10_G3_T1_H2	Perennial Runoff, Cold, High Gradient, Stream	17	19,836	19,853
9	S10_G2_T3_H1	Higher Baseflow, Warm, Medium Gradient, Stream	109	8,318	8,426
10	S10_G1_T3_H3	Perennial Flashy, Warm, Low Gradient, Stream	1,179	6,766	7,944
11	S20_G1_T3_H3	Perennial Flashy, Warm, Low Gradient, Small River	661	6,989	7,649
12	S10_G3_T3_H3	Perennial Flashy, Warm, High Gradient, Stream	56	6,898	6,955
13	S10_G2_T1_H2	Perennial Runoff, Cold, Medium Gradient, Stream	187	5,449	5,636
14	S10_G2_T3_H2	Perennial Runoff, Warm, Medium Gradient, Stream	144	5,413	5,557
15	S20_G2_T3_H3	Perennial Flashy, Warm, Medium Gradient, Small River	35	5,258	5,292
16	S20_G2_T2_H2	Perennial Runoff, Cool, Medium Gradient, Small River	67	4,944	5,011
17	S10_G1_T2_H2	Perennial Runoff, Cool, Low Gradient, Stream	1,785	2,872	4,658
18	S30_C3_T3_H2	Perennial Runoff, Warm, Unconfined, Medium River	54	4,174	4,229
19	S30_C3_T3_H3	Perennial Flashy, Warm, Unconfined, Medium River	37	3,508	3,545
20	S10_G1_T2_H3	Perennial Flashy, Cool, Low Gradient, Stream	581	2,770	3,351
21	S10_G3_T1_H1	Higher Baseflow, Cold, High Gradient, Stream	1	3,057	3,058
22	S30_C1_T3_H2	Perennial Runoff, Warm, Confined, Medium River	839	1,996	2,835
23	S30_C2_T3_H2	Perennial Runoff, Warm, Moderately Confined, Medium River	84	2,639	2,723
24	S40_C1_T3_H2	Perennial Runoff, Warm, Confined, Large River	572	2,014	2,586
25	S20_G2_T3_H1	Higher Baseflow, Warm, Medium Gradient, Small River	20	2,514	2,534
26	S10_G1_T2_H1	Higher Baseflow, Cool, Low Gradient, Stream	1,039	1,479	2,518
27	S20_G2_T3_H2	Perennial Runoff, Warm, Medium Gradient, Small River	27	2,120	2,146
28	S20_G1_T3_H2	Perennial Runoff, Warm, Low Gradient, Small River	249	1,653	1,903
29	S20_G1_T2_H2	Perennial Runoff, Cool, Low Gradient, Small River	359	1,543	1,902
30	S20_G1_T3_H1	Higher Baseflow, Warm, Low Gradient, Small River	285	1,231	1,517
31	S20_G2_T2_H1	Higher Baseflow, Cool, Medium Gradient, Small River	35	1,475	1,510
32	S10_G3_T3_H1	Higher Baseflow, Warm, High Gradient, Stream	9	1,262	1,270
33	S10_G1_T3_H2	Perennial Runoff, Warm, Low Gradient, Stream	413	831	1,245
34	S30_C3_T3_H1	Higher Baseflow, Warm, Unconfined, Medium River	8	1,148	1,157
35	S30_C2_T3_H3	Perennial Flashy, Warm, Moderately Confined, Medium River	61	1,073	1,134
36	S40_C3_T3_H2	Perennial Runoff, Warm, Unconfined, Large River	159	947	1,106
37	S40_C2_T3_H2	Perennial Runoff, Warm, Moderately Confined, Large River	392	706	1,098
38	S10_G1_T3_H1	Higher Baseflow, Warm, Low Gradient, Stream	361	712	1,073
39	S30_C1_T3_H1	Higher Baseflow, Warm, Confined, Medium River	541	529	1,070
40	S30_C2_T3_H1	Higher Baseflow, Warm, Moderately Confined, Medium River	117	853	970

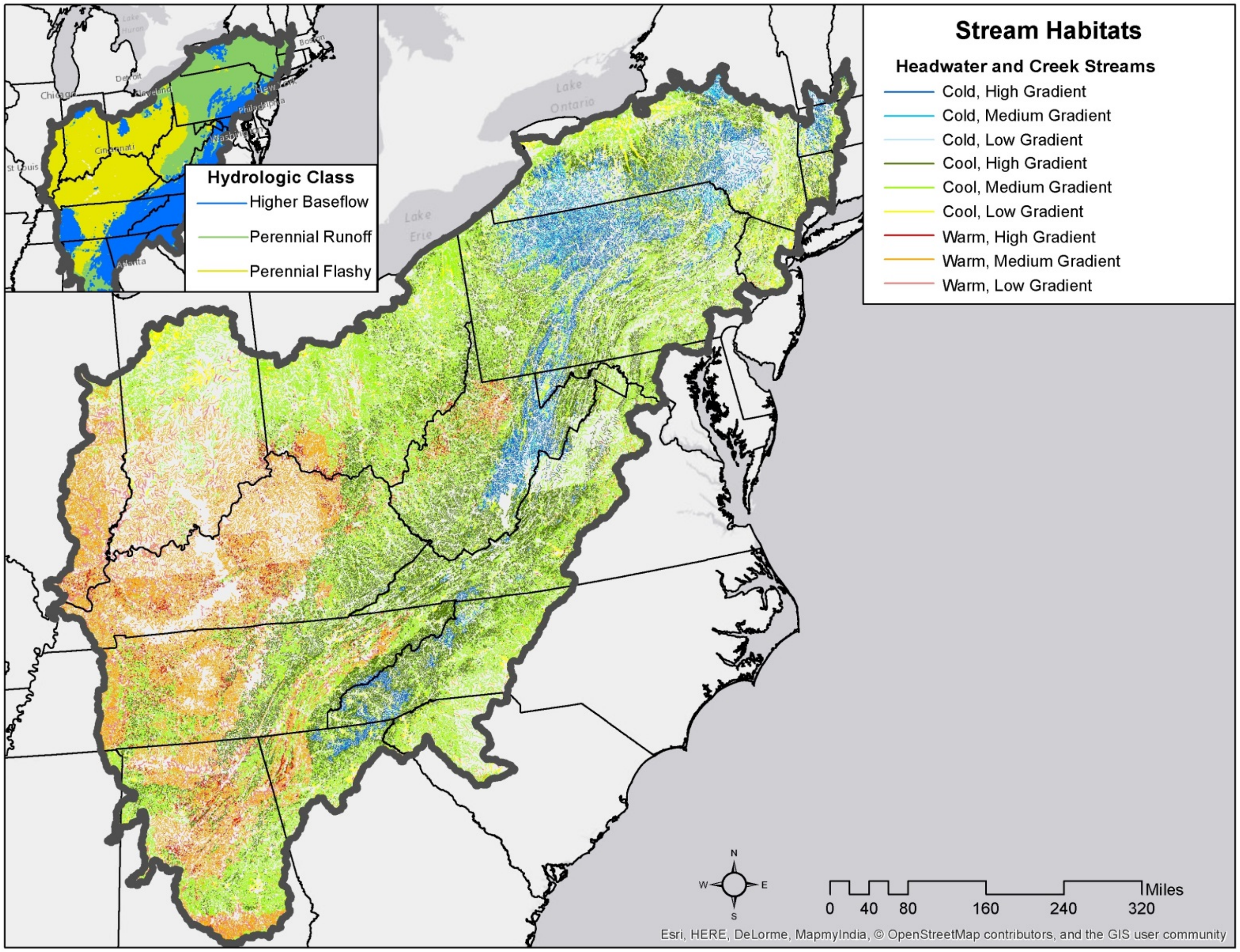
	TYPE_SIMP	Name	Lake/Pond / Reservoir	Stream/ River	Total Miles
41	S30_C3_T2_H2	Perennial Runoff, Cool, Unconfined, Medium River	3	862	865
42	S10_G3_T3_H2	Perennial Runoff, Warm, High Gradient, Stream	10	783	794
43	S30_C2_T2_H2	Perennial Runoff, Cool, Moderately Confined, Medium River	11	641	652
44	S30_C1_T2_H2	Perennial Runoff, Cool, Confined, Medium River	163	445	608
45	S30_C1_T3_H3	Perennial Flashy, Warm, Confined, Medium River	343	186	530
46	S20_G2_T2_H3	Perennial Flashy, Cool, Medium Gradient, Small River	4	505	509
47	S10_G3_T1_H3	Perennial Flashy, Cold, High Gradient, Stream	0	488	488
48	S10_G1_T1_H2	Perennial Runoff, Cold, Low Gradient, Stream	261	88	349
49	S20_G1_T2_H1	Higher Baseflow, Cool, Low Gradient, Small River	105	214	319
50	S20_G1_T2_H3	Perennial Flashy, Cool, Low Gradient, Small River	28	224	252
51	S40_C1_T3_H1	Higher Baseflow, Warm, Confined, Large River	164	83	247
52	S30_C1_T2_H1	Higher Baseflow, Cool, Confined, Medium River	81	158	239
53	S30_C2_T2_H1	Higher Baseflow, Cool, Moderately Confined, Medium River	13	142	156
54	S10_G2_T1_H1	Higher Baseflow, Cold, Medium Gradient, Stream	10	131	141
55	S10_G2_T1_H3	Perennial Flashy, Cold, Medium Gradient, Stream	1	125	126
56	S20_G2_T1_H2	Perennial Runoff, Cold, Medium Gradient, Small River	2	78	80
57	S20_G3_T2_H2	Perennial Runoff, Cool, High Gradient, Small River	4	74	77
58	S20_G3_T2_H1	Higher Baseflow, Cool, High Gradient, Small River	1	57	58
59	S40_C2_T3_H1	Higher Baseflow, Warm, Moderately Confined, Large River	45	13	58
60	S30_C3_T2_H1	Higher Baseflow, Cool, Unconfined, Medium River	0	51	51
61	S20_G3_T3_H3	Perennial Flashy, Warm, High Gradient, Small River	1	26	26
62	S40_C3_T3_H1	Higher Baseflow, Warm, Unconfined, Large River	0	12	12
63	S20_G3_T3_H2	Perennial Runoff, Warm, High Gradient, Small River	0	7	7
64	S20_G1_T1_H2	Perennial Runoff, Cold, Low Gradient, Small River	3	3	5
65	S20_G3_T3_H1	Higher Baseflow, Warm, High Gradient, Small River	0	4	4
66	S20_G3_T1_H2	Perennial Runoff, Cold, High Gradient, Small River	0	4	4
67	S30_C3_T2_H3	Perennial Flashy, Cool, Unconfined, Medium River	0	3	3
68	S20_G3_T2_H3	Perennial Flashy, Cool, High Gradient, Small River	0	3	3
69	S30_C2_T1_H2	Perennial Runoff, Cold, Moderately Confined, Medium River	0	3	3
70	S10_G1_T1_H1	Higher Baseflow, Cold, Low Gradient, Stream	2	0	3
71	S10_G1_T1_H3	Perennial Flashy, Cold, Low Gradient, Stream	1	1	2
72	S40_C1_T2_H2	Perennial Runoff, Cool, Confined, Large River	0	1	1
73	S30_C1_T1_H2	Perennial Runoff, Cold, Confined, Medium River	0	1	1
	Grand Total		14,738	404,382	419,120

Map 10-1. Simplified river types (All four variables could not be combined legibly in a single map color scheme so Hydrologic Class is shown as an inset.)



Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Map 10-2. Simplified stream types (All four variables could not be combined legibly in a single map color scheme so Hydrologic Class is shown as an inset.)



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Appendices

Appendix 1. Attributes Calculated for Flowlines

Table A-1. Variables calculated for NHDPlus v2 flowlines and catchments in the project area.

Variable	Description
ara2367	TNC Active River Area (ARA) base riparian and wetflat zone area (% of local)
ara2367N	TNC Active River Area (ARA) base riparian and wetflat zone area (% of network)
areasqkm	NHDPlus v2 catchment area in square kilometers
awc_avg	USGS STATSGO Average value for the range in available water capacity (fraction)
awc_avgN	Cumulative (network) USGS STATSGO Average value for the range in available water capacity (fraction)
bd_avg	USGS STATSGO Average value for the range in bulk density (grams per cubic centimeter)
bd_avgN	Cumulative (network) USGS STATSGO Average value for the range in bulk density (grams per cubic centimeter)
bfi_avg	USGS Mean Baseflow index
bfi_avgN	Cumulative (network) USGS Mean Baseflow index
caco3h_avg	USGS STATSGO % calcium carbonate high value
caco3h_avgN	Cumulative (network) USGS STATSGO % calcium carbonate high value
caco3l_avg	USGS STATSGO % calcium carbonate low value
caco3l_avgN	Cumulative (network) USGS STATSGO % calcium carbonate low value
cech_avg	USGS STATSGO cation exchange capacity high value
cech_avgN	Cumulative (network) USGS STATSGO cation exchange capacity high value
cecl_avg	USGS STATSGO cation exchange capacity low value
cecl_avgN	Cumulative (network) USGS STATSGO cation exchange capacity low value
clay_avg	USGS STATSGO Average value of clay content (mean percent of catchment)
clay_avgN	Cumulative (network) USGS STATSGO Average value of clay content (mean percent of catchment)
comid	NHDPlus v2 Common identifier (ComID) of NHD Flowline
ct_avg	USGS Mean contact time
ct_avgN	Cumulative (network) USGS Mean contact time
cumEROM_010001	Cumulative Flow from gage adjustment (cfs) January
cumEROM_020001	Cumulative Flow from gage adjustment (cfs) February
cumEROM_030001	Cumulative Flow from gage adjustment (cfs) March
cumEROM_040001	Cumulative Flow from gage adjustment (cfs) April
cumEROM_050001	Cumulative Flow from gage adjustment (cfs) May
cumEROM_060001	Cumulative Flow from gage adjustment (cfs) June
cumEROM_070001	Cumulative Flow from gage adjustment (cfs) July
cumEROM_080001	Cumulative Flow from gage adjustment (cfs) August
cumEROM_090001	Cumulative Flow from gage adjustment (cfs) September

Variable	Description
cumEROM_100001	Cumulative Flow from gage adjustment (cfs) October
cumEROM_110001	Cumulative Flow from gage adjustment (cfs) November
cumEROM_120001	Cumulative Flow from gage adjustment (cfs) December
cumEROM_MA0001	Cumulative mean annual flow from gage adjustment (cfs)
CumPrecip	Mean annual precipitation accumulated down the NHD flowline network. Mean annual precipitation in area upstream of the bottom of flowline in millimeters * 100
CumTemp	Mean annual temperature in area upstream of the bottom of flowline in degrees centigrade * 100
DivDASqKM	NHDPlus v2 Divergence-routed Cumulative Drainage Area, in square kilometers, at the downstream end of the NHDFlowline feature
elevcm_avg	Average elevation (cm) calculated using the NHDPlus v2 NED Digital Elevation Model
elevcm_avgN	Cumulative (network) Average elevation (cm) of the network area calculated using the NHDPlus v2 NED Digital Elevation Model
FWECOREGION	World Wildlife Fund (WWF) freshwater ecoregions
geol_100	TNC Eastern Division geology: acidic sedimentary/metasedimentary (% of local)
geol_100N	Cumulative (network) TNC Eastern Division geology: acidic sedimentary/metasedimentary (% of local)
geol_200	TNC Eastern Division geology: acidic shale (% of local)
geol_200N	Cumulative (network) TNC Eastern Division geology: acidic shale (% of local)
geol_300	TNC Eastern Division geology: calcareous sedimentary/metasedimentary (% of local area)
geol_300N	Cumulative (network) TNC Eastern Division geology: calcareous sedimentary/metasedimentary (% of network area)
geol_303	TNC Eastern Division geology: calcareous deep unconsolidated sediment (% of local area)
geol_303N	Cumulative (network) TNC Eastern Division geology: calcareous deep unconsolidated sediment (% of network area)
geol_400	TNC Eastern Division geology: moderately calcareous sedimentary/metasedimentary (% of local area)
geol_400N	Cumulative (network) TNC Eastern Division geology: moderately calcareous sedimentary/metasedimentary (% of network area)
geol_500	TNC Eastern Division geology: acidic granitic (% of local area)
geol_500N	Cumulative (network) TNC Eastern Division geology: acidic granitic (% of network area)
geol_600	TNC Eastern Division geology: mafic/intermediate granitic (% of local area)
geol_600N	Cumulative (network) TNC Eastern Division geology: mafic/intermediate granitic (% of network area)
geol_700	TNC Eastern Division geology: ultramafic (% of local area)
geol_700N	Cumulative (network) TNC Eastern Division geology: ultramafic (% of network area)
geol_800	TNC Eastern Division geology: deep coarse unconsolidated surficial sediment (% of local area)

Variable	Description
geol_800N	Cumulative (network) TNC Eastern Division geology: deep coarse unconsolidated surficial sediment (% of network area)
geol_900	TNC Eastern Division geology: deep fine unconsolidated surficial sediment (% of local area)
geol_900N	Cumulative (network) TNC Eastern Division geology: deep fine unconsolidated surficial sediment (% of network area)
hga_avg	USGS STATSGO Hydrologic soil group A (mean percent of catchment)
hga_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group A (mean percent of network area)
hgac_avg	USGS STATSGO Hydrologic soil group AC (mean percent of catchment)
hgac_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group AC (mean percent of network area)
hgad_avg	USGS STATSGO Hydrologic soil group AD (mean percent of catchment)
hgad_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group AD (mean percent of network area)
hgb_avg	USGS STATSGO Hydrologic soil group B (mean percent of catchment)
hgb_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group B (mean percent of network area)
hgbc_avg	USGS STATSGO Hydrologic soil group BC (mean percent of catchment)
hgbc_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group BC (mean percent of network area)
hgbd_avg	USGS STATSGO Hydrologic soil group BD (mean percent of catchment)
hgbd_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group BD (mean percent of network area)
hgc_avg	USGS STATSGO Hydrologic soil group C (mean percent of catchment)
hgc_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group C (mean percent of network area)
hgcd_avg	USGS STATSGO Hydrologic soil group CD (mean percent of catchment)
hgcd_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group CD (mean percent of network area)
hgd_avg	USGS STATSGO Hydrologic soil group D (mean percent of catchment)
hgd_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group D (mean percent of network area)
hgvar_avg	USGS STATSGO Hydrologic soil group var (mean percent of catchment)
hgvar_avgN	Cumulative (network) USGS STATSGO Hydrologic soil group var (mean percent of network area)
HUC_10	USGS Watershed Boundary Dataset (WBD) 10 digit Hydrologic Unit Code (HUC 10)
HUC_12	USGS Watershed Boundary Dataset (WBD) 12 digit Hydrologic Unit Code (HUC 12)
HUC_8	USGS Watershed Boundary Dataset (WBD) 8 digit Hydrologic Unit Code (HUC 8)
ieof_avg	USGS Mean Infiltration-Excess Overland Flow, 2002
ieof_avgN	Cumulative (network) USGS Mean Infiltration-Excess Overland Flow, 2002
imp11_per	Percent of the catchment in NLCD 2011 Imperviousness cover
imp11_perN	Percent of the network catchment in NLCD 2011 Imperviousness cover

Variable	Description
incEROM_010001	Incremental flow from gage adjustment (cfs) for January
incEROM_020001	Incremental flow from gage adjustment (cfs) for February
incEROM_030001	Incremental flow from gage adjustment (cfs) for March
incEROM_040001	Incremental flow from gage adjustment (cfs) for April
incEROM_050001	Incremental flow from gage adjustment (cfs) for May
incEROM_060001	Incremental flow from gage adjustment (cfs) for June
incEROM_070001	Incremental flow from gage adjustment (cfs) for July
incEROM_080001	Incremental flow from gage adjustment (cfs) for August
incEROM_090001	Incremental flow from gage adjustment (cfs) for September
incEROM_100001	Incremental flow from gage adjustment (cfs) for October
incEROM_110001	Incremental flow from gage adjustment (cfs) for November
incEROM_120001	Incremental flow from gage adjustment (cfs) for December
incEROM_MA0001	Incremental mean annual flow from gage adjustment (cfs)
IncrPrecipMA	Incremental mean annual precipitation in millimeters * 100
IncrPrecipMM01	Mean precipitation in millimeters * 100 for January
IncrPrecipMM02	Mean precipitation in millimeters * 100 for February
IncrPrecipMM03	Mean precipitation in millimeters * 100 for March
IncrPrecipMM04	Mean precipitation in millimeters * 100 for April
IncrPrecipMM05	Mean precipitation in millimeters * 100 for May
IncrPrecipMM06	Mean precipitation in millimeters * 100 for June
IncrPrecipMM07	Mean precipitation in millimeters * 100 for July
IncrPrecipMM08	Mean precipitation in millimeters * 100 for August
IncrPrecipMM09	Mean precipitation in millimeters * 100 for September
IncrPrecipMM10	Mean precipitation in millimeters * 100 for October
IncrPrecipMM11	Mean precipitation in millimeters * 100 for November
IncrPrecipMM12	Mean precipitation in millimeters * 100 for December
IncrTempMA	Incremental mean annual temperature in degrees centigrade * 100
IncrTempMM01	Mean annual temperature in degrees centigrade * 100 for January
IncrTempMM02	Mean annual temperature in degrees centigrade * 100 for February
IncrTempMM03	Mean annual temperature in degrees centigrade * 100 for March
IncrTempMM04	Mean annual temperature in degrees centigrade * 100 for April
IncrTempMM05	Mean annual temperature in degrees centigrade * 100 for May
IncrTempMM06	Mean annual temperature in degrees centigrade * 100 for June
IncrTempMM07	Mean annual temperature in degrees centigrade * 100 for July
IncrTempMM08	Mean annual temperature in degrees centigrade * 100 for August
IncrTempMM09	Mean annual temperature in degrees centigrade * 100 for September
IncrTempMM10	Mean annual temperature in degrees centigrade * 100 for October
IncrTempMM11	Mean annual temperature in degrees centigrade * 100 for November
IncrTempMM12	Mean annual temperature in degrees centigrade * 100 for December
kfact_avg	USGS STATSGO soil erodibility (k-factor; dimensionless)
kfact_avgN	Cumulative (network) USGS STATSGO soil erodibility (k-factor; dimensionless)

Variable	Description
kfactup_avg	USGS STATSGO soil erodibility factor of uppermost soil horizon (includes rock fragments, dimensionless):
kfactup_avgN	Cumulative (network) USGS STATSGO soil erodibility factor of uppermost soil horizon (includes rock fragments, dimensionless):
lf_03	TNC Eastern Division Landforms: Steep slope cool aspect % of local area
lf_03N	TNC Eastern Division Landforms: Steep slope cool aspect % of network area
lf_04	TNC Eastern Division Landforms: Steep slope warm aspect % of local area
lf_04N	TNC Eastern Division Landforms: Steep slope warm aspect % of network area
lf_05	TNC Eastern Division Landforms: Cliff % of local area
lf_05N	TNC Eastern Division Landforms: Cliff % of network area
lf_11	TNC Eastern Division Landforms: Summit/ridgetop % of local area
lf_11N	TNC Eastern Division Landforms: Summit/ridgetop % of network area
lf_13	TNC Eastern Division Landforms: Slope crest % of local area
lf_13N	TNC Eastern Division Landforms: Slope crest % of network area
lf_21	TNC Eastern Division Landforms: Hilltop (flat) % of local area
lf_21N	TNC Eastern Division Landforms: Hilltop (flat) % of network area
lf_22	TNC Eastern Division Landforms: Hill (gentle slope) % of local area
lf_22N	TNC Eastern Division Landforms: Hill (gentle slope) % of network area
lf_23	TNC Eastern Division Landforms: Sideslope cool aspect % of local area
lf_23N	TNC Eastern Division Landforms: Sideslope cool aspect % of network area
lf_24	TNC Eastern Division Landforms: Sideslope warm aspect % of local area
lf_24N	TNC Eastern Division Landforms: Sideslope warm aspect % of network area
lf_30	TNC Eastern Division Landforms: Dry flats % of local area
lf_30N	TNC Eastern Division Landforms: Dry flats % of network area
lf_31	TNC Eastern Division Landforms: Wet flats % of local area
lf_31N	TNC Eastern Division Landforms: Wet flats % of network area
lf_32	TNC Eastern Division Landforms: Valley/toeslope % of local area
lf_32N	TNC Eastern Division Landforms: Valley/toeslope % of network area
lf_39	TNC Eastern Division Landforms: Moist flats in upland landcover % of local area
lf_39N	TNC Eastern Division Landforms: Moist flats in upland landcover % of network area
lf_41	TNC Eastern Division Landforms: Flat at bottom of steep slope % of local area
lf_41N	TNC Eastern Division Landforms: Flat at bottom of steep slope % of network area
lf_43	TNC Eastern Division Landforms: Cove/footslope cool aspect % of local area
lf_43N	TNC Eastern Division Landforms: Cove/footslope cool aspect % of network area
lf_44	TNC Eastern Division Landforms: Cove/footslope warm aspect % of local area
lf_44N	TNC Eastern Division Landforms: Cove/footslope warm aspect % of network area
lf_50	TNC Eastern Division Landforms: Open water % of local area
lf_50N	TNC Eastern Division Landforms: Open water % of network area
MAXELEVSMO	NHDPlus v2 Maximum elevation (smoothed) in centimeters

Variable	Description
MINELEVSMO	NHDPlus v2 Minimum elevation (smoothed) in centimeters
NFHAB_EDU	National Fish Habitat Action Plan Ecological Drainage Units
nid_stor	2012 National Anthropogenic Barrier Dataset (NABD) calculated field based on the maximum value of Maximum Storage and Normal storage, providing a single storage value (acre/ft) to facilitate database queries. (Source: National Inventory of Dams Data Dictionary). The NHDPlus v2 mean annual flow attribute (gage adjusted) was converted from cfs to acre/ft/year and then used to calculate % of mean annual flow potentially stored behind these barriers.
nid_storN	Percent mean annual flow (gage-adjusted) stored behind dams
nlcd11_ag	NLCD11 Agriculture classes 81 and 82 (% of local area)
nlcd11_agN	NLCD11 Agriculture classes 81 and 82 (% of network area)
nlcd11_dev	NLCD11 Development classes 21-24 (% of local area)
nlcd11_devN	NLCD11 Development classes 21-24 (% of network area)
nlcd11_for	NLCD11 Forest classes 41-43 (% of local area)
nlcd11_forN	NLCD11 Forest classes 41-43 (% of network area)
nlcd11_nat	NLCD11 Natural cover classes 41-43, 52, 71, 90, and 95 (% of local area)
nlcd11_natN	NLCD11 Natural cover classes 41-43, 52, 71, 90, and 95 (% of network area)
nlcd11_wetl	NLCD11 Wetland classes 90 and 95 (% of local area)
nlcd11_wetlN	NLCD11 Wetland classes 90 and 95 (% of network area)
no10_avg	USGS STATSGO Average percent by weight of soil material less than 3 inches in size that passes through a No. 10 sieve (2 millimeters)
no10_avgN	Cumulative (network) USGS STATSGO Average percent by weight of soil material less than 3 inches in size that passes through a No. 10 sieve (2 millimeters)
no200_avg	USGS STATSGO Average percent by weight of soil material lessfs than 3 inches in size that passes through a No. 200 sieve (.074 millimeters)
no200_avgN	Cumulative (network) USGS STATSGO Average percent by weight of soil material lessfs than 3 inches in size that passes through a No. 200 sieve (.074 millimeters)
no4_avg	USGS STATSGO Average percent by weight of soil material less than 3 inches in size that passes through a No. 4 sieve (5 millimeters)
no4_avgN	Cumulative (network) USGS STATSGO Average percent by weight of soil material less than 3 inches in size that passes through a No. 4 sieve (5 millimeters)
om_avg	USGS STATSGO Average value for the range in organic matter content (percent by weight)
om_avgN	Cumulative (network) USGS STATSGO Average value for the range in organic matter content (percent by weight)
OMERNICK_L3	Omernick Level 3 Ecoregion
perm_avg	USGS STATSGO Average value for the range in permeability (inches per hour)
perm_avgN	Cumulative (network) USGS STATSGO Average value for the range in permeability (inches per hour)
rchrg_avg	USGS Estimated Mean Annual Natural Groundwater Recharge, 2002

Variable	Description
rchrg_avgN	Cumulative (network) USGS Estimated Mean Annual Natural Groundwater Recharge, 2002
rckdeph_avg	USGS STATSGO soil thickness (inches) high value
rckdeph_avgN	Cumulative (network) USGS STATSGO soil thickness (inches) high value
rckdepl_avg	USGS STATSGO soil thickness (inches) low value
rckdepl_avgN	Cumulative (network) USGS STATSGO soil thickness (inches) low value
rf30_avg	USGS Mean Annual R-factor, 1971-2000
rf30_avgN	Cumulative (network) USGS Mean Annual R-factor, 1971-2000
sand_avg	USGS STATSGO Average value of sand (mean percent of catchment)
sand_avgN	Cumulative (network) USGS STATSGO Average value of sand (mean percent of catchment)
satof_avg	USGS Average Saturation Excess-Overland Flow, 2002
satof_avgN	Cumulative (network) USGS Average Saturation Excess-Overland Flow, 2002
silt_avg	USGS STATSGO Average value of silt (mean percent of catchment)
silt_avgN	Cumulative (network) USGS STATSGO Average value of silt (mean percent of network catchment)
SLOPE	NHDPlus v2 Slope of flowline (meters/meters) based on smoothed elevations
slope_avg	USGS STATSGO Average Slope (%)
slope_avgN	Cumulative (network) USGS STATSGO Average Slope (%)
Slp_cl	Northeast Aquatic Habitat Classification system slope class (n=6) assigned to each NHDPlus v2 flowline based on NHDPlus v2 slope value
slpdeg_avg	Average slope (degrees) calculated using a slope grid derived from the NHDPlus v2 NED Digital Elevation Model.
slpdeg_avgN	Cumulative (network) Average slope (degrees) of the network area calculated using a slope grid derived from the NHDPlus v2 NED Digital Elevation Model.
slpper_avg	Average slope (%) calculated using a slope grid derived from the NHDPlus v2 NED Digital Elevation Model.
slpper_avgN	Cumulative (network) Average slope (%) of the network area calculated using a slope grid derived from the NHDPlus v2 NED Digital Elevation Model.
ss_1	SSURGO Soil Texture Group: Loamy Sand, Sand % of local area
ss_1N	SSURGO Soil Texture Group: Loamy Sand, Sand % of network area
ss_2	SSURGO Soil Texture Group: Loam, Sandy Loam, Sandy Clay Loam % of local area
ss_2N	SSURGO Soil Texture Group: Loam, Sandy Loam, Sandy Clay Loam % of network area
ss_3	SSURGO Soil Texture Group: Silty Loam, Silty Clay Loam, Clay Loam, Silt % of local area
ss_3N	SSURGO Soil Texture Group: Silty Loam, Silty Clay Loam, Clay Loam, Silt % of network area
ss_4	SSURGO Soil Texture Group: Clay, Silty Clay, Sandy Clay % of local area
ss_4N	SSURGO Soil Texture Group: Clay, Silty Clay, Sandy Clay % of network area
strmdens_avg	Stream density (length of lines (km) / catchment area (km2))
strmdens_avgN	Cumulative (network) Stream density (length of lines (km) / catchment area (km2))

Variable	Description
Sz_cl	Northeast Aquatic Habitat Classification system (NAHC) stream size class (n=7) assigned to each NHDPlus v2 flowline based on upstream cumulative drainage area of the flowline
TotDASqKM	NHDPlus v2 Total Upstream Cumulative Drainage Area, in square kilometers, at the downstream end of the NHDFlowline feature
wtdep_avg	USGS STATSGO Average value for the range in depth to the seasonally high water table (feet)
wtdep_avgN	Cumulative (network) USGS STATSGO Average value for the range in depth to the seasonally high water table (feet)
Xcord	Longitudinal coordinates (centroid) of NHDPlus v2 flowline
Ycord	Latitudinal coordinates (centroid) of the NHDPlus v2 flowline

Appendix 2. Methods to Calculate Flowline Attributes

Summary

Several spatially-explicit datasets (details below) were downloaded, processed, and attributed to the NHDPlus v2 catchments for NHDPlus v2 production units 1-6; a total of 849,800 catchments. From the processed datasets, more than 250 variables were calculated and formatted to be accumulated for the full drainage area of each NHDPlus v2 catchment using the NHDPlus v2 Catchment Attribute and Accumulation Tool (CA3TV2; http://www.horizon-systems.com/NHDPlus/NHDPlusV2_tools.php#NHDPlusV2 Catchment Attribute Allocation and Accumulation Tool (CA3TV2)). An R script was written so that 50 variables at a time could be accumulated simultaneously in the CA3TV2 tool for each NHDPlus v2 production unit in the Eastern US. After the variables were accumulated for all catchments in NHDPlus v2 production units 1-6, the variables were post-processed using different calculations depending on whether the desired metric was an area-weighted percent or an average numeric value. A final spreadsheet of all the local catchment and network drainage (cumulative) was created as well as a spreadsheet with a detailed description of each attribute.

Details

Variable allocation

The following raster grids and datasets were downloaded and processed as described below to calculate selected variables for all NHDPlus v2 catchments in the Eastern US (NHDPlus v2 production units 1-6).

1. USGS Baseflow index: http://water.usgs.gov/GIS/metadata/usgswrd/XML/bfi48grd.xml#stdorder
    a. Resample the grid to 30 m, snap to NHDPlus v2 catchment grids
    b. Run zonal statistics to calculate average: bfi_avg
2. USGS Estimated Mean Annual Natural Groundwater Recharge, 2002: http://water.usgs.gov/GIS/metadata/usgswrd/XML/rech48grd.xml
    a. Resample the grid to 30 m, snap to NHDPlus v2 catchment grids
    b. Run zonal statistics to calculate average: rchrg_avg
3. USGS Basin Characteristics, 2002: http://water.usgs.gov/GIS/metadata/usgswrd/XML/nhd_bchar.xml
    a. Mean Elevation:
        i. Download NED Digital Elevation Model (DEM) from NHDPlus v2 by production unit
        ii. Mosaic grids to create complete elevation grid for each production unit
        iii. Run zonal statistics to calculate mean: elevcm_avg

    b. Mean Slope:
        i. Calculate slope from the NHDPlus v2 NED DEM
            1. Degree
            2. Percent
        ii. Run zonal statistics to calculate mean:
            1. Degree: slopedeg_avg
            2. Percent: slopeper_avg
    c. Stream density (reach length (km) /catchment area (km^2))
        i. All stream reaches were used, regardless of category
        ii. Join flowlines to COMID
        iii. Calculate density = length (km) / drainage area (sq km)

4. USGS Contact Time: http://water.usgs.gov/GIS/metadata/usgswrd/XML/nhd_contact.xml
    a. Obtain grid from Dave Wolock at USGS
    b. Extract grid for project area
    c. Resample to 30 m, snap to NHDPlus catchment grids
    d. Run zonal statistics to calculate average: ct_avg
5. USGS Mean Infiltration-Excess Overland Flow, 2002: http://water.usgs.gov/GIS/metadata/usgswrd/XML/ieof48.xml
    a. Run zonal statistics to calculate average: ieof_avg
6. Mean Annual R-factor, 1971-2000
    a. Download annual R-factor grid from old PRISM site:
        i. http://oldprism.nacse.org/pub/prism/maps/Precipitation/rfactor/U.S./
    b. Define projection using original projection information from metadata (WGS 1972)
    c. Reproject to NAD83 Albers
    d. Resample to 30 m grid, snap to the NHDPlus catchment grids
    e. Run zonal statistics to calculate average: rf30_avg
7. USGS Average Saturation Excess-Overland Flow, 2002: http://water.usgs.gov/GIS/metadata/usgswrd/XML/satof48.xml
    a. Resample the grid to 30 m, snap to NHDPlus catchment grids
    b. Run zonal statistics to calculate average: satof_avg
8. NABD 2012: https://nccwsc.usgs.gov/display-project/51014e04e4b033b1feeb2c26/512cf142e4b0855fde669828
    a. Remove all fields except nid_stor
    b. Run spatial join with NABD 2012 point data and NHDPlus v2 catchments to assign dam storage data to NHDPlus v2 catchments

9. STATSGO variables: http://water.usgs.gov/GIS/metadata/usgswrd/XML/muid.xml
    a. Obtain grid and accompanying INFO files from Dave Wolock at USGS
    b. Extract grid to project area
    c. Resample to 30 m, snap to NHDPlus catchment grids
    d. Join INFO tables to resampled grid
    e. Cation exchange capacity:
        i. high value: cech_avg
        ii. low value: cecl_avg
    f. % calcium carbonate:
        i. high value: cac03h_avg
        ii. low value: cac03l_avg
    g. Average Slope (%): slope_ave
    h. Average value for the range in depth to the seasonally high water table (feet): wtdep_avg
    i. Soil thickness (inches):
        i. high value: rckdeph_avg
        ii. low value: rckdepl_avg
    j. Hydrologic soil group:
        i. Hydrologic soil group A (mean percent of catchment): hga
        ii. Hydrologic soil group B (mean percent of catchment): hgb
        iii. Hydrologic soil group C (mean percent of catchment): hgc
        iv. Hydrologic soil group D (mean percent of catchment): hgd
        v. Hydrologic soil group AD (mean percent of catchment): hgad
        vi. Hydrologic soil group BD (mean percent of catchment): hgbd
        vii. Hydrologic soil group CD (mean percent of catchment): hgcd
        viii. Hydrologic soil group AC (mean percent of catchment): hgac
        ix. Hydrologic soil group BC (mean percent of catchment): hgbc
        x. Soil hydrologic group VAR [hydro group is variable] (mean percent of catchment): hgvar
    k. Soil erodibility (k-factor; dimensionless):
        i. kfact: kfact_avg
        ii. uppermost soil horizon (includes rock fragments, dimensionless): kfactup_avg
    l. Average value for the range in permeability (inches per hour): perm_avg
    m. Average value for the range in available water capacity (fraction): awc_avg
    n. Average value for the range in bulk density (grams per cubic centimeter): bd_avg
    o. Average value for the range in organic matter content (percent by weight): om_avg
    p. Average value of clay content (mean percent of catchment): clay_avg
    q. Average value of silt (mean percent of catchment): silt_avg
    r. Average value of sand (mean percent of catchment): sand_avg
    s. Average percent by weight of soil material less than 3 inches in size that passes through a No. 4 sieve (5 millimeters): no4_avg

STATSGO variables continued

    t. Average percent by weight of soil material less than 3 inches in size that passes through a No. 200 sieve (.074 millimeters): no200_avg
    u. Average percent by weight of soil material less than 3 inches in size that passes through a No. 10 sieve (2 millimeters): no10_avg

10. NLCD 2006 land cover classes: http://www.mrlc.gov/nlcd2006.php
    a. Extract for project area, snap to NHDPlus catchment grids
    b. In ArcGIS, tabulate area of each land cover class in sq meters
11. NLCD 2011 land cover classes:
    a. Download NLCD 2011 land cover grid: http://www.mrlc.gov/nlcd2011.php
    b. Extract for project area, snap to NHDPlus catchment grids
    c. In ArcGIS, tabulate area of each land cover class in sq meters
12. NLCD 2011 Impervious Surface Area
    a. Download NLCD 2011 Percent Developed Imperviousness grid from http://www.mrlc.gov/nlcd11_data.php
    b. Clip the NLCD 2011 impervious grid (.img file) by the Eastern Division mask
    c. SetNull value 127 (no data boundary area in the original file)
    d. Convert the NLCD 2011 Percent Developed Imperviousness values to impervious area (sq meters) as follows:
        i. Multiply each pixel value by 9
            1. For example, a grid cell with a value of 1 was converted to impervious area as follows: grid area = 30 m * 30 m cell = 900 sq meters * .01 = 9 sq meters. 9 * 1 = 9 sq meters of impervious surface in the grid cell.
    e. Project dataset
    f. Run zonal statistics to sum the impervious surface area for all catchments
13. NHDPlus v2 Incremental and Cumulative Flow:
    a. Download all the relevant tables and write R script to process the desired variables
    b. EROM Extension folder
        i. Mean monthly flow
            1. Q0001E in EROM_mm0001, mm is 01 through 12 for January through December (cumulative)
            2. Qincr0001E in EROM_mm0001, mm is 01 through 12 for January through December (incremental). Note that negative incremental flow values can occur.
        ii. Mean annual flow: EROM_MA0001.dbf
            1. Q0001E (cumulative)
            2. Qincr0001E (incremental)
14. NHDPlus v2 precipitation and cumulative precipitation
15. NHDPlus v2 temperature and cumulative temperature

16. NHDPlus v2 monthly temperature
    a. Download all the relevant tables and write R script to process all the desired variables
    b. VPU Attribute Extension folder:
        iii. CumDivTempMM01 – MM12 txt files
            1. IncrTempMM01 – MM12 txt files. Note that negative incremental temperature values can occur.
17. NHDPlus v2 monthly precipitation
    a. Download all the relevant tables and write R script to process all the desired variables
    b. VPU Attribute Extension folder:
        iv. CumDivPrecipMM01 – MM12 txt files
            1. IncrPrecipMM01 – MM12 txt files. Note that negative incremental precipitation values can occur.
18. TNC Eastern Division Geology
    a. TNC's Eastern US Division Conservation Program created a 30 m grid of 10 geology types for the Eastern US using state-based geology datasets and cross-walking geology types into 10 consistent classes.
    b. Tabulate area of each geology class for all catchments
    c. Batch convert resultant INFO tables to dbf files
19. SSURGO Soil Texture
    a. TNC's Eastern US Division Conservation Program processed a 30 m soil texture grid received from USDA SSURGO to create four texture classes
    b. Create grid of texture classes by running Lookup in ArcGIS with the GROUPNUM variable
    c. Tabulate area of the four soil texture classes
    d. Batch convert resultant INFO tables to dbf files
20. TNC Eastern US Division Landforms
    a. TNC's Eastern US Division Conservation Program developed a 30 m grid of 17 landforms for the Eastern US
    b. Tabulate area of each landform for all catchments
    c. Batch convert resultant INFO tables to dbf files
    d. The landform grid does not cover all of Production Unit 4
21. TNC Active River Area (ARA)
    a. TNC's Eastern US Division Conservation Program generated a 10 m grid of the Active River Area for TNC's Appalachian LCC Stream Classification project area.
    b. Resample grid to 30 m and snap to NHDPlus catchment grids
    c. The area of the seven key ARA components was tabulated for each catchment

Prepare allocation files for CA3TV2

In R, prepare input allocation files for each NHDPlus v2 production unit (region) to accumulate in CA3TV2 depending on the attribute type (see *Network* (*Accumulation) Math Details* below) so can simultaneously accumulate 50 variables at a time for each production unit.

1. Production Unit (PU) 01
2. PU 02

3. PU 03N
4. PU 03S
5. PU 03W
6. PU 04
7. PU 05
8. PU 06

Network (Accumulation) Math Details

1. To calculate area-weighted % for each catchment
    a. In R, calculate raw area values (sq meters) if not already present in the source dataset (e.g., NLCD 2011 forest area in sq meters)
    b. In CA3TV2, accumulate (sum) raw values
    c. In R, calculated area-weighted %
        i. (Accumulated sum / accumulated drainage area in sq meters covered by the respective grid) * 100
2. To calculate area-weighted average or high/low value for each catchment
    a. In R, multiply raw value by area (sq meters) of coverage for source dataset
        i. As all variables did not cover the full extent of the catchment, use area of actual data coverage, provided in all USGS datasets and calculate for those metrics that are missing actual data coverage.
    b. In CA3TV2, accumulate (sum) the area-adjusted values
    c. In R, calculated area-weighted value
        i. Accumulated sum/accumulated drainage area in sq meters
3. To calculate cumulative values for NID_STOR variable
    a. Summed NID_STOR (acre-feet) by catchment as some catchments had multiple dams
    b. In CA3TV2, accumulate (sum) the total NID_STOR value
    c. The NHDPlus v2 mean annual flow attribute (gage adjusted) was converted from cfs to acre/ft/year and then used to calculate % of mean annual flow potentially stored behind the NID barriers.

Accumulate variables

In CA3TV2, run total accumulation for each production unit. Append production units 5 and 6 to accumulate together as some catchments in production unit 5 drain to production unit 6.

Post-process accumulated variables

In R, post-process CA3TV2 values as follows:

1. For area-weighted percent
    a. (Accumulated sum / accumulated drainage area in sq meters) * 100
2. For average and high/low values
    a. Accumulated sum/accumulated drainage area in sq meters
3. Create spreadsheet of attribute code descriptions

a. There are 17,072 catchments for which the local catchment value was used as the network (accumulated) value because the catchment does not have an upstream link and thus does not have an accumulated (network) value. This only occurs for sink or coastal catchments. These catchments are identified in the final tables using the following fields:
    i. sink: a value of 1 indicates the catchment is a sink (n = 685)
    ii. coastal: a value of 1 indicates the catchment is on the coast (n=16,387)

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Appendix 3. Fish and Benthic Species by Stream Alkalinity, Gradient, and Size Thresholds (TITAN analysis results)

The following six tables display results from the Threshold Indicator Taxa Analysis (TITAN; Baker et al. 2010) to identify fish and benthic species and assemblage biological responses to stream alkalinity, gradient, and size thresholds developed for the Appalachian LCC stream classification. Each table contains the columns below:

- **Env cp:** environmental change point value for each taxon.
- **Freq:** number of non-zero abundance values per taxon.
- **Grp:** the direction of change where 1 indicates a negative response and 2 indicates a positive response
- **Ind Val:** Indicator species analysis value using the IndVal statistics from Dufrene & Legendre (1997). This value is scaled from 0 to 100% with 100 the highest possible indicator.
- **pval:** probability (p value) that an equal or larger indicator value could be obtained from random data. Calculated as (number of random Ind Vals ≥ observed Ind Val)/ number of permutations
- **z:** Standardization of Ind Val as z scores (mean of individual indicator value / standard deviation of indicator values of permuted samples) to standardize
- **Purity:** Measure that assesses the quality of the indicator response. It is the proportion of the bootstrap replicates that have the same direction response (i.e., negative or positive) as the observed response.
- **Rel 05:** Measure that assesses the quality of the indicator response. Proportion of the bootstrap replicates with p-values for the indicator value score (Ind Val) at ≤ 0.05.
- **Rel 01:** Measure that assesses the quality of the indicator response. Proportion of the bootstrap replicates with p-values for the indicator value score (Ind Val) at ≤ 0.01.

A species may be considered significantly associated to a change point if Ind Val pval < 0.05, purity > 0.95 and reliability > 0.95.

Table A3-1. TITAN benthic indicator species output for the Appalachian LCC alkalinity class. The “A Cls” column indicates the alkalinity class. The “C” column identifies the class of benthic fauna as follows: A = Arachnida; B = Bivalvia; G = Gastropoda; H = Hirudinea; I = Insecta; M = Malacostraca; and O = Oligochaeta.

Target Taxon	C	Order	Family	Genus	A Cls	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Heptageniidae	I	Ephemeroptera	Heptageniidae		1	10.93	183	1	51.82	0.008	3.14	0.98	0.98	0.86
Stempellinella	I	Diptera	Chironomidae	Stempellinella	1	15.51	138	1	51.47	0.004	6.75	1.00	0.99	0.97
Maccaffertium	I	Ephemeroptera	Heptageniidae	Maccaffertium	1	15.51	125	1	39.21	0.008	4.25	0.98	0.96	0.81
Enchytraeidae	O	Enchytraeida	Enchytraeidae		1	2.80	106	1	88.90	0.004	8.32	0.99	0.99	0.97
Leptophlebiidae	I	Ephemeroptera	Leptophlebiidae		1	15.08	76	1	46.94	0.004	11.32	1.00	1.00	1.00
Eurylophella	I	Ephemeroptera	Ephemerellidae	Eurylophella	1	15.08	66	1	47.53	0.004	11.51	1.00	1.00	1.00
Leuctra	I	Plecoptera	Leuctridae	Leuctra	1	17.42	63	1	53.23	0.004	15.92	1.00	1.00	1.00
Nigronia	I	Megaloptera	Corydalidae	Nigronia	1	10.33	60	1	53.98	0.004	11.77	0.99	0.99	0.99
Oulimnius	I	Coleoptera	Elmidae	Oulimnius	1	24.11	59	1	54.47	0.004	18.68	1.00	1.00	1.00
Tipula	I	Diptera	Tipulidae	Tipula	1	10.65	55	1	32.44	0.004	6.40	1.00	0.99	0.96
Polycentropus	I	Trichoptera	Polycentropodidae	Polycentropus	1	5.48	48	1	48.41	0.004	8.61	1.00	1.00	0.99
Trichoptera	I	Trichoptera			1	2.42	46	1	55.37	0.008	7.24	0.99	0.97	0.80
Serratella	I	Ephemeroptera	Ephemerellidae	Serratella	1	23.06	44	1	19.94	0.004	4.51	0.99	0.99	0.78
Rhyacophila	I	Trichoptera	Rhyacophilidae	Rhyacophila	1	15.51	40	1	51.01	0.004	19.03	1.00	1.00	1.00
Acroneuria	I	Plecoptera	Perlidae	Acroneuria	1	17.66	36	1	30.75	0.004	10.91	1.00	1.00	1.00
Parachaetocladius	I	Diptera	Chironomidae	Parachaetocladius	1	8.16	36	1	56.55	0.004	13.80	1.00	1.00	1.00
Dicranota	I	Diptera	Tipulidae	Dicranota	1	8.39	34	1	39.93	0.004	8.54	0.96	0.96	0.96
Eukiefferiella	I	Diptera	Chironomidae	Eukiefferiella	1	8.84	33	1	36.95	0.004	10.10	1.00	1.00	1.00
Limnophyes	I	Diptera	Chironomidae	Limnophyes	1	2.80	33	1	76.77	0.004	13.22	0.99	0.99	0.97
Stylogomphus	I	Odonata	Gomphidae	Stylogomphus	1	13.36	33	1	16.06	0.008	4.01	1.00	0.99	0.85
Diplectrona	I	Trichoptera	Hydropsychidae	Diplectrona	1	10.65	32	1	56.61	0.004	18.75	1.00	1.00	1.00
Sarcoptiformes	A	Sarcoptiformes			1	2.80	32	1	53.55	0.004	8.58	1.00	0.99	0.96
Limnephilidae	I	Trichoptera	Limnephilidae		1	8.72	31	1	30.10	0.004	8.23	1.00	1.00	0.97
Promoresia	I	Coleoptera	Elmidae	Promoresia	1	5.88	31	1	45.34	0.004	9.83	1.00	1.00	1.00
Helichus	I	Coleoptera	Dryopidae	Helichus	1	13.48	30	1	22.43	0.004	7.05	0.97	0.96	0.90
Lype	I	Trichoptera	Psychomyiidae	Lype	1	12.43	26	1	24.84	0.004	8.63	1.00	1.00	0.98
Chloroperlidae	I	Plecoptera	Chloroperlidae		1	8.55	25	1	35.96	0.004	11.21	1.00	1.00	1.00

Table A3-1 *continued*

Target Taxon	C	Order	Family	Genus	A Cls	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Cordulegaster	I	Odonata	Cordulegastridae	Cordulegaster	1	15.34	25	1	28.50	0.004	12.10	1.00	1.00	1.00
Leuctridae	I	Plecoptera	Leuctridae		1	12.86	25	1	37.66	0.004	14.37	1.00	1.00	1.00
Perlodidae	I	Plecoptera	Perlodidae		1	8.84	24	1	54.17	0.004	17.99	1.00	1.00	1.00
Tallaperla	I	Plecoptera	Peltoperlidae	Tallaperla	1	12.86	23	1	46.42	0.004	20.13	1.00	1.00	1.00
Epeorus	I	Ephemeroptera	Heptageniidae	Epeorus	1	8.72	21	1	31.20	0.004	11.32	1.00	1.00	0.99
Branchiobdellida	O	Branchiobdellida			1	17.25	18	1	17.10	0.004	7.68	1.00	1.00	0.99
Micrasema	I	Trichoptera	Brachycentridae	Micrasema	1	10.93	18	1	19.16	0.004	6.54	0.98	0.97	0.95
Molanna	I	Trichoptera	Molannidae	Molanna	1	2.80	18	1	41.77	0.004	9.55	1.00	1.00	0.99
Ephemerella	I	Ephemeroptera	Ephemerellidae	Ephemerella	1	8.55	17	1	27.84	0.004	10.56	1.00	1.00	0.97
Sweltsa	I	Plecoptera	Chloroperlidae	Sweltsa	1	17.25	17	1	18.94	0.004	9.65	1.00	1.00	0.99
Pteronarcys	I	Plecoptera	Pteronarcyidae	Pteronarcys	1	24.11	16	1	17.53	0.004	10.66	1.00	1.00	1.00
Aeshnidae	I	Odonata	Aeshnidae		1	7.84	15	1	19.61	0.004	5.90	0.98	0.97	0.82
Demicryptochironomus	I	Diptera	Chironomidae	Demicryptochironomus	1	14.35	15	1	16.79	0.004	8.39	1.00	1.00	0.94
Paracapnia	I	Plecoptera	Capniidae	Paracapnia	1	7.35	14	1	28.79	0.004	13.29	1.00	1.00	1.00
Dixa	I	Diptera	Dixidae	Dixa	1	11.35	13	1	18.43	0.004	8.84	0.99	0.97	0.88
Philopotamidae	I	Trichoptera	Philopotamidae		1	15.34	13	1	12.79	0.004	6.85	1.00	1.00	0.94
Amphinemura	I	Plecoptera	Nemouridae	Amphinemura	1	8.55	12	1	18.03	0.004	7.31	0.99	0.98	0.93
Lopescladius	I	Diptera	Chironomidae	Lopescladius	1	14.35	12	1	14.06	0.004	8.35	0.99	0.99	0.94
Pseudolimnophila	I	Diptera	Tipulidae	Pseudolimnophila	1	16.18	12	1	14.61	0.004	8.66	1.00	1.00	0.97
Anchytarsus	I	Coleoptera	Ptilodactylidae	Anchytarsus	1	10.53	11	1	18.77	0.004	8.95	1.00	0.98	0.92
Cambarus	M	Decapoda	Cambaridae	Cambarus	1	15.51	11	1	12.87	0.004	7.54	0.98	0.98	0.93
Lanthus	I	Odonata	Gomphidae	Lanthus	1	5.88	11	1	34.87	0.004	13.21	1.00	1.00	0.99
Chaetocladius	I	Diptera	Chironomidae	Chaetocladius	1	6.56	9	1	26.62	0.004	18.45	1.00	1.00	0.99
Limnophila	I	Diptera	Tipulidae	Limnophila	1	22.29	8	1	10.44	0.004	9.19	1.00	1.00	0.98
Apsectrotanypus	I	Diptera	Chironomidae	Apsectrotanypus	1	5.48	7	1	21.08	0.008	7.85	1.00	0.99	0.95
Odontomesa	I	Diptera	Chironomidae	Odontomesa	1	15.79	6	1	7.95	0.004	7.07	1.00	0.96	0.87
Heteroplectron	I	Trichoptera	Calamoceratidae	Heteroplectron	1	10.53	5	1	15.33	0.004	14.06	1.00	0.98	0.91
Neostempellina	I	Diptera	Chironomidae	Neostempellina	1	12.04	5	1	15.15	0.004	15.20	1.00	0.96	0.94
Paracricotopus	I	Diptera	Chironomidae	Paracricotopus	1	13.44	5	1	9.61	0.004	9.18	1.00	0.96	0.86

Table A3-1 *continued*

Target Taxon	C	Order	Family	Genus	A Cls	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Tubificidae	O	Haplotaxida	Tubificidae		1	15.79	223	2	67.88	0.004	4.43	1.00	1.00	0.99
Hydropsychidae	I	Trichoptera	Hydropsychidae		2	27.29	148	1	42.14	0.004	4.22	0.98	0.96	0.82
Simulium	I	Diptera	Simuliidae	Simulium	2	26.90	136	1	47.03	0.004	5.61	0.96	0.96	0.94
Gomphidae	I	Odonata	Gomphidae		2	40.34	123	1	38.74	0.004	5.88	0.99	0.99	0.98
Hydropsyche	I	Trichoptera	Hydropsychidae	Hydropsyche	2	27.49	121	1	36.03	0.004	4.49	0.98	0.97	0.84
Tvetenia	I	Diptera	Chironomidae	Tvetenia	2	26.90	95	1	41.42	0.004	8.67	1.00	1.00	1.00
Lumbriculidae	O	Lumbriculida	Lumbriculidae		2	38.13	72	1	38.56	0.004	11.15	1.00	1.00	1.00
Micropsectra	I	Diptera	Chironomidae	Micropsectra	2	26.47	66	1	37.99	0.004	8.14	0.98	0.98	0.97
Empididae	I	Diptera	Empididae		2	45.26	59	1	23.36	0.004	6.60	0.99	0.99	0.97
Lepidostoma	I	Trichoptera	Lepidostomatidae	Lepidostoma	2	35.90	56	1	38.35	0.004	12.80	1.00	1.00	1.00
Hexatoma	I	Diptera	Tipulidae	Hexatoma	2	27.49	54	1	28.02	0.004	8.93	1.00	1.00	0.99
Antocha	I	Diptera	Tipulidae	Antocha	2	45.26	51	1	21.74	0.004	4.90	0.98	0.97	0.84
Stempellina	I	Diptera	Chironomidae	Stempellina	2	30.64	48	1	17.52	0.008	3.52	0.99	0.98	0.83
Ephemerellidae	I	Ephemeroptera	Ephemerellidae		2	45.26	44	1	20.58	0.004	5.39	1.00	1.00	0.96
Perlidae	I	Plecoptera	Perlidae		2	27.29	43	1	34.19	0.004	12.89	1.00	1.00	1.00
Plecoptera	I	Plecoptera			2	27.29	35	1	16.88	0.004	5.69	0.96	0.96	0.93
Dolophilodes	I	Trichoptera	Philopotamidae	Dolophilodes	2	26.90	34	1	36.22	0.004	16.50	1.00	1.00	1.00
Perlesta	I	Plecoptera	Perlidae	Perlesta	2	25.90	29	1	19.17	0.004	7.27	0.98	0.98	0.97
Sperchonidae	A	Trombidiformes	Sperchonidae		2	40.80	28	1	11.62	0.008	3.97	1.00	1.00	0.77
Glossosomatidae	I	Trichoptera	Glossosomatidae		2	29.14	25	1	14.10	0.004	5.35	1.00	1.00	0.94
Glossosoma	I	Trichoptera	Glossosomatidae	Glossosoma	2	26.90	22	1	24.79	0.004	13.36	1.00	1.00	1.00
Neoplasta	I	Diptera	Empididae	Neoplasta	2	28.35	17	1	13.40	0.004	6.89	1.00	0.99	0.94
Potthastia	I	Diptera	Chironomidae	Potthastia	2	47.47	16	1	9.89	0.004	5.23	0.99	0.97	0.87
Spirosperma	O	Haplotaxida	Tubificidae	Spirosperma	2	41.53	16	1	13.70	0.004	8.95	1.00	1.00	1.00
Apatania	I	Trichoptera	Apataniidae	Apatania	2	30.53	13	1	8.50	0.008	3.37	1.00	0.99	0.86
Drunella	I	Ephemeroptera	Ephemerellidae	Drunella	2	28.01	13	1	12.31	0.004	7.44	1.00	1.00	0.99
Trissopelopia	I	Diptera	Chironomidae	Trissopelopia	2	26.90	12	1	10.55	0.004	6.53	0.99	0.98	0.91
Djalmabatista	I	Diptera	Chironomidae	Djalmabatista	2	38.13	10	1	8.00	0.008	5.15	1.00	0.98	0.88
Rheosmittia	I	Diptera	Chironomidae	Rheosmittia	2	35.90	10	1	10.64	0.004	7.61	1.00	1.00	0.99
Brundiniella	I	Diptera	Chironomidae	Brundiniella	2	33.58	8	1	6.77	0.004	4.67	1.00	0.98	0.87

Table A3-1 *continued*

Target Taxon	C	Order	Family	Genus	A Cls	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Isoperla	I	Plecoptera	Perlodidae	Isoperla	2	40.80	7	1	6.73	0.004	5.18	1.00	0.97	0.90
Cricotopus.Orthocladius	-	NA	NA	NA	2	29.90	199	2	55.31	0.004	5.45	0.99	0.99	0.98
Caenis	I	Ephemeroptera	Caenidae	Caenis	2	38.47	170	2	56.28	0.004	8.02	1.00	1.00	1.00
Dicrotendipes	I	Diptera	Chironomidae	Dicrotendipes	2	36.32	127	2	43.15	0.004	5.67	1.00	1.00	0.99
Corbicula	B	Veneroida	Corbiculidae	Corbicula	2	35.90	106	2	36.31	0.004	6.71	1.00	1.00	1.00
Stenacron	I	Ephemeroptera	Heptageniidae	Stenacron	2	25.96	96	2	37.46	0.004	5.47	1.00	1.00	0.99
Coenagrionidae	I	Odonata	Coenagrionidae		2	34.18	92	2	35.87	0.004	5.89	1.00	1.00	1.00
Tricorythodes	I	Ephemeroptera	Leptohyphidae	Tricorythodes	2	35.90	91	2	30.60	0.004	5.34	1.00	1.00	0.96
Macronychus	I	Coleoptera	Elmidae	Macronychus	2	36.32	72	2	25.60	0.004	4.14	0.99	0.99	0.91
Gammarus	M	Amphipoda	Gammaridae	Gammarus	2	34.54	63	2	24.70	0.004	5.58	0.99	0.99	0.99
Ferrissia	G	Basommatophora	Ancylidae	Ferrissia	2	30.64	58	2	19.49	0.012	3.51	0.97	0.96	0.74
Glyptotendipes	I	Diptera	Chironomidae	Glyptotendipes	2	47.47	22	2	12.43	0.004	4.47	1.00	1.00	0.96
Baetidae	I	Ephemeroptera	Baetidae		3	50.83	111	1	39.56	0.004	6.80	1.00	1.00	0.99
Tribelos	I	Diptera	Chironomidae	Tribelos	3	57.44	72	1	26.56	0.004	4.29	1.00	0.99	0.92
Stenochironomus	I	Diptera	Chironomidae	Stenochironomus	3	132.81	64	1	23.05	0.004	4.86	0.99	0.98	0.87
Nemata					3	141.33	53	1	20.53	0.004	4.09	1.00	1.00	0.89
Acentrella	I	Ephemeroptera	Baetidae	Acentrella	3	50.83	45	1	21.07	0.004	5.19	0.99	0.99	0.95
Hygrobatidae	A	Trombidiformes	Hygrobatidae		3	149.29	39	1	16.16	0.008	3.13	0.99	0.96	0.70
Brillia	I	Diptera	Chironomidae	Brillia	3	63.61	37	1	16.82	0.004	5.25	1.00	0.99	0.95
Dubiraphia	I	Coleoptera	Elmidae	Dubiraphia	3	67.99	173	2	66.44	0.004	11.96	1.00	1.00	1.00
Stenelmis	I	Coleoptera	Elmidae	Stenelmis	3	59.47	164	2	57.89	0.004	10.57	1.00	1.00	1.00
Cryptochironomus	I	Diptera	Chironomidae	Cryptochironomus	3	103.87	135	2	34.74	0.004	3.71	0.99	0.99	0.88
Procladius	I	Diptera	Chironomidae	Procladius	3	80.93	121	2	36.82	0.004	4.88	1.00	1.00	0.96
Chironomus	I	Diptera	Chironomidae	Chironomus	3	137.51	105	2	39.72	0.004	4.85	0.99	0.99	0.90
Argia	I	Odonata	Coenagrionidae	Argia	3	49.55	75	2	27.64	0.004	5.02	1.00	1.00	0.99
Caecidotea	M	Isopoda	Asellidae	Caecidotea	3	79.19	71	2	22.44	0.016	2.94	0.97	0.96	0.67
Centroptilum	I	Ephemeroptera	Baetidae	Centroptilum	3	67.99	65	2	22.64	0.004	5.11	0.98	0.98	0.90
Neumania	A	Trombidiformes	Unionicolidae	Neumania	3	64.13	55	2	20.20	0.004	4.70	0.99	0.97	0.86
Branchiura	O	Haplotaxida	Tubificidae	Branchiura	3	51.25	47	2	20.45	0.004	5.84	1.00	1.00	1.00
Stenonema	I	Ephemeroptera	Heptageniidae	Stenonema	3	57.44	42	2	20.47	0.004	5.36	1.00	1.00	1.00

Table A3-1 *continued*

Target Taxon	C	Order	Family	Genus	A Cls	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Orconectes	M	Decapoda	Cambaridae	Orconectes	3	69.60	34	2	21.10	0.004	9.37	1.00	1.00	1.00
Anopheles	I	Diptera	Culicidae	Anopheles	3	103.87	16	2	10.25	0.004	5.77	1.00	0.99	0.90
Ephoron	I	Ephemeroptera	Polymitarcyidae	Ephoron	3	59.26	12	2	6.60	0.008	3.78	0.99	0.96	0.72
Coelotanypus	I	Diptera	Chironomidae	Coelotanypus	3	88.59	11	2	6.77	0.008	4.17	1.00	0.97	0.82
Tropisternus	I	Coleoptera	Hydrophilidae	Tropisternus	3	137.51	5	2	7.46	0.004	7.83	1.00	0.98	0.88
Leptoceridae	I	Trichoptera	Leptoceridae		4	153.04	60	1	22.74	0.004	3.69	0.96	0.96	0.76
Cladotanytarsus	I	Diptera	Chironomidae	Cladotanytarsus	4	236.09	115	2	45.14	0.016	3.16	0.99	0.98	0.79
Paratanytarsus	I	Diptera	Chironomidae	Paratanytarsus	4	186.41	101	2	41.07	0.004	5.14	1.00	1.00	0.97
Paratendipes	I	Diptera	Chironomidae	Paratendipes	4	253.51	77	2	63.40	0.004	6.55	0.98	0.97	0.91
Stictochironomus	I	Diptera	Chironomidae	Stictochironomus	4	204.07	77	2	56.69	0.004	9.61	1.00	1.00	1.00
Physa	G	Basommatophora	Physidae	Physa	4	274.09	73	2	69.88	0.004	5.87	1.00	0.99	0.97
Parakiefferiella	I	Diptera	Chironomidae	Parakiefferiella	4	242.83	72	2	40.69	0.004	5.10	0.99	0.98	0.89
Hygrobates	A	Trombidiformes	Hygrobatidae	Hygrobates	4	186.41	62	2	28.50	0.004	4.68	1.00	1.00	0.94
Labrundinia	I	Diptera	Chironomidae	Labrundinia	4	186.41	54	2	24.84	0.004	5.33	1.00	1.00	0.99
Natarsia	I	Diptera	Chironomidae	Natarsia	4	164.00	52	2	28.26	0.004	6.92	0.97	0.96	0.91
Lymnaeidae	G	Basommatophora	Lymnaeidae		4	250.16	35	2	30.02	0.012	5.12	0.99	0.98	0.74
Lirceus	M	Isopoda	Asellidae	Lirceus	4	189.61	33	2	21.62	0.004	5.42	1.00	0.99	0.95
Peltodytes	I	Coleoptera	Haliplidae	Peltodytes	4	253.51	32	2	37.44	0.004	5.82	1.00	0.98	0.87
Sphaerium	B	Veneroida	Pisidiidae	Sphaerium	4	152.07	31	2	26.12	0.004	9.50	1.00	1.00	1.00
Cnidaria					4	262.13	26	2	38.73	0.004	6.46	1.00	1.00	0.95
Helobdella	H	Rhynchobdellida	Glossiphoniidae	Helobdella	4	262.13	22	2	38.14	0.004	8.60	1.00	0.98	0.83
Elimia	G	Neotaenioglossa	Pleuroceridae	Elimia	4	158.51	15	2	11.69	0.004	4.92	0.98	0.96	0.82
Harnischia	I	Diptera	Chironomidae	Harnischia	4	274.09	10	2	39.58	0.004	8.73	1.00	0.99	0.88
Ophidonais	O	Haplotaxida	Naididae	Ophidonais	4	209.35	9	2	12.07	0.004	5.96	1.00	0.98	0.90
Physella	G	Basommatophora	Physidae	Physella	4	206.74	6	2	9.47	0.004	7.23	0.99	0.96	0.81
Stratiomyidae	I	Diptera	Stratiomyidae		4	209.35	6	2	13.06	0.004	10.01	0.98	0.98	0.93
Glossiphonia	H	Rhynchobdellida	Glossiphoniidae	Glossiphonia	4	207.61	4	2	9.56	0.004	9.29	0.99	0.95	0.83

Table A3-2. TITAN indicator fish species output for the Appalachian LCC alkalinity class. The "Alk Class" column indicates the alkalinity class.

Common Name	Scientific Name	Alk Class	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Brook Trout	Salvelinus Fontinalis	1	17.42	15	1	21.86	0.004	13.09	1.00	1.00	1.00
Rosyside Dace	Clinostomus Funduloides	1	13.39	13	1	20.58	0.004	9.69	1.00	1.00	0.96
Redeye Bass	Micropterus Coosae	1	15.97	9	1	8.67	0.004	5.30	0.99	0.96	0.83
Blackbanded Darter	Percina Nigrofasciata	1	10.53	7	1	12.94	0.008	6.49	1.00	0.96	0.87
Yellowfin Shiner	Notropis Lutipinnis	1	12.04	5	1	13.56	0.004	11.69	1.00	0.97	0.91
Longnose Gar	Lepisosteus Osseus	1	17.42	42	2	17.57	0.004	3.54	0.99	0.99	0.74
Bluehead Chub	Nocomis Leptocephalus	2	25.88	22	1	22.77	0.004	10.91	1.00	1.00	1.00
Rainbow Trout	Oncorhynchus Mykiss	2	28.35	12	1	10.43	0.004	6.19	1.00	0.97	0.91
Bluegill	Lepomis Macrochirus	2	42.95	172	2	52.35	0.004	5.60	1.00	0.99	0.97
Smallmouth Bass	Micropterus Dolomieu	2	26.47	132	2	44.76	0.004	5.08	0.99	0.99	0.95
Rock Bass	Ambloplites Rupestris	2	27.29	130	2	46.15	0.004	6.52	1.00	1.00	1.00
White Sucker	Catostomus Commersonii	2	26.90	121	2	38.21	0.004	4.82	1.00	1.00	0.97
Northern Hog Sucker	Hypentelium Nigricans	2	26.47	116	2	41.80	0.004	6.19	1.00	1.00	1.00
Spotfin Shiner	Cyprinella Spiloptera	2	35.17	109	2	48.77	0.004	9.05	1.00	1.00	1.00
Longear Sunfish	Lepomis Megalotis	2	44.85	95	2	39.09	0.004	8.45	1.00	1.00	1.00
Golden Redhorse	Moxostoma Erythrurum	2	42.95	89	2	37.05	0.004	8.54	1.00	1.00	1.00
Common Carp	Cyprinus Carpio	2	44.85	86	2	35.14	0.004	6.76	1.00	1.00	1.00
Channel Catfish	Ictalurus Punctatus	2	41.53	77	2	29.94	0.004	6.49	1.00	1.00	1.00
Logperch	Percina Caprodes	2	26.90	70	2	30.26	0.004	5.75	1.00	1.00	1.00
Spotted Bass	Micropterus Punctulatus	2	38.94	68	2	26.02	0.004	6.32	1.00	1.00	1.00
Gizzard Shad	Dorosoma Cepedianum	2	42.95	64	2	29.53	0.004	7.11	1.00	1.00	1.00
Banded Darter	Etheostoma Zonale	2	28.73	54	2	21.64	0.004	4.12	1.00	1.00	0.91
Freshwater Drum	Aplodinotus Grunniens	2	34.54	47	2	21.55	0.004	5.34	1.00	1.00	1.00
Flathead Catfish	Pylodictis Olivaris	2	36.32	43	2	16.35	0.004	4.20	0.97	0.97	0.74
Emerald Shiner	Notropis Atherinoides	2	45.75	39	2	19.99	0.004	5.62	1.00	1.00	1.00
Black Redhorse	Moxostoma Duquesnei	2	26.47	34	2	14.96	0.008	3.54	0.99	0.99	0.71
Smallmouth Buffalo	Ictiobus Bubalus	2	42.95	33	2	15.60	0.004	5.38	0.99	0.99	0.96
Spotted Sucker	Minytrema Melanops	2	38.94	30	2	14.69	0.004	4.06	0.98	0.98	0.87
River Carpsucker	Carpiodes Carpio	2	45.75	27	2	14.67	0.004	4.82	1.00	1.00	0.99
White Crappie	Pomoxis Annularis	2	40.12	18	2	8.54	0.012	2.88	0.99	0.96	0.63
Skipjack Herring	Alosa Chrysochloris	2	47.72	15	2	8.20	0.008	3.67	1.00	0.98	0.71
Redbreast Sunfish	Lepomis Auritus	3	140.98	71	1	28.78	0.004	5.65	1.00	1.00	0.99

Table A3-2 *continued*

Common Name	Scientific Name	Alk Class	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Spottail Shiner	Notropis Hudsonius	3	120.43	35	1	13.66	0.012	2.82	0.96	0.95	0.58
American Eel	Anguilla Rostrata	3	79.19	31	1	13.66	0.004	4.69	1.00	1.00	0.97
Chain Pickerel	Esox Niger	3	57.44	12	1	8.08	0.004	4.16	1.00	0.98	0.82
Bluntnose Minnow	Pimephales Notatus	3	65.61	129	2	52.94	0.004	12.78	1.00	1.00	1.00
Central Stoneroller	Campostoma Anomalum	3	95.70	111	2	45.07	0.004	7.65	1.00	1.00	1.00
Greenside Darter	Etheostoma Blennioides	3	58.69	92	2	33.77	0.004	6.76	1.00	1.00	1.00
Striped Shiner	Luxilus Chrysocephalus	3	69.60	76	2	29.71	0.004	7.50	1.00	1.00	1.00
Rainbow Darter	Etheostoma Caeruleum	3	121.57	57	2	32.94	0.004	9.47	1.00	1.00	1.00
Yellow Bullhead	Ameiurus Natalis	3	59.25	57	2	24.61	0.004	5.50	1.00	1.00	0.99
Shorthead Redhorse	Moxostoma Macrolepidotum	3	109.52	32	2	15.96	0.004	5.13	0.98	0.98	0.91
Banded Sculpin	Cottus Carolinae	3	135.11	28	2	17.19	0.004	5.97	1.00	0.99	0.93
Bullhead Minnow	Pimephales Vigilax	3	103.87	19	2	10.48	0.008	3.85	0.99	0.96	0.79
Dusky Darter	Percina Sciera	3	54.21	18	2	9.64	0.008	3.89	1.00	0.99	0.82
Western Mosquitofish	Gambusia Affinis	3	111.37	15	2	9.12	0.008	3.66	0.99	0.96	0.74
Blackstripe Topminnow	Fundulus Notatus	3	88.59	13	2	8.96	0.004	5.71	1.00	0.99	0.97
Scarlet Shiner	Lythrurus Fasciolaris	3	52.31	11	2	6.25	0.016	3.20	1.00	0.97	0.74
River Shiner	Notropis Blennius	3	89.41	8	2	5.72	0.012	3.20	1.00	0.97	0.81
Shortnose Gar	Lepisosteus Platostomus	3	144.18	8	2	7.98	0.004	5.14	1.00	0.97	0.86
Mississippi Silvery Minnow	Hybognathus Nuchalis	3	144.18	5	2	8.06	0.004	8.34	0.99	0.96	0.86
Creek Chub	Semotilus Atromaculatus	4	164.00	122	2	50.86	0.004	8.08	1.00	1.00	1.00
Johnny Darter	Etheostoma Nigrum	4	206.74	53	2	38.52	0.004	8.64	1.00	1.00	1.00
Sand Shiner	Notropis Stramineus	4	217.72	31	2	46.38	0.004	13.02	1.00	1.00	1.00
Blackside Darter	Percina Maculata	4	236.09	28	2	27.20	0.004	7.10	0.98	0.95	0.80
Bigeye Chub	Hybopsis Amblops	4	192.78	27	2	19.20	0.004	5.04	0.99	0.98	0.74
Silverjaw Minnow	Notropis Buccatus	4	217.72	25	2	36.92	0.004	13.08	1.00	1.00	1.00
Fathead Minnow	Pimephales Promelas	4	244.50	19	2	19.34	0.012	5.38	1.00	0.99	0.93
Orangethroat Darter	Etheostoma Spectabile	4	225.80	15	2	28.37	0.004	12.51	1.00	1.00	0.99
Orangespotted Sunfish	Lepomis Humilis	4	169.87	8	2	12.42	0.004	9.67	1.00	0.99	0.95
Redfin Pickerel	Esox Americanus Americanus	4	176.45	8	2	12.26	0.004	8.06	0.99	0.96	0.87
Redfin Shiner	Lythrurus Umbratilis	4	230.64	7	2	22.24	0.004	12.60	1.00	0.99	0.98

Table A3-3. TITAN benthic indicator species output for the Appalachian LCC gradient class. The "G C" column indicates the gradient class. The "C" column identifies the class of benthic fauna as follows: A = Arachnida; B = Bivalvia; E = Enopla; G = Gastropoda; I = Insecta; M = Malacostraca; and O = Oligochaeta.

Target Taxon	C	Order	Family	Genus	G C	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Hexagenia	I	Ephemeroptera	Ephemeridae	Hexagenia	1	0.00	37	1	35.25	0.012	4.17	1.00	1.00	0.80
Gyraulus	G	Basommatophora	Planorbidae	Gyraulus	1	0.00	17	1	11.46	0.004	5.03	1.00	0.99	0.93
Dromogomphus	I	Odonata	Gomphidae	Dromogomphus	1	0.00	11	1	9.85	0.004	6.67	1.00	0.98	0.92
Macrostemum	I	Trichoptera	Hydropsychidae	Macrostemum	1	0.00	9	1	9.94	0.004	6.69	1.00	0.97	0.82
Dreissena	B	Veneroida	Dreissenidae	Dreissena	1	0.00	7	1	11.06	0.004	8.78	1.00	1.00	0.98
Nilotanypus	I	Diptera	Chironomidae	Nilotanypus	1	0.00	25	2	11.11	0.02	3.16	0.99	0.98	0.66
Gammarus	M	Amphipoda	Gammaridae	Gammarus	2	0.05	63	1	42.04	0.004	13.74	1.00	1.00	1.00
Anthopotamus	I	Ephemeroptera	Potamanthidae	Anthopotamus	2	0.07	26	1	16.82	0.004	7.25	1.00	1.00	0.99
Glyptotendipes	I	Diptera	Chironomidae	Glyptotendipes	2	0.05	22	1	20.13	0.004	8.85	1.00	1.00	1.00
Orthotrichia	I	Trichoptera	Hydroptilidae	Orthotrichia	2	0.06	20	1	14.48	0.004	6.98	1.00	1.00	1.00
Unionicola	A	Trombidiformes	Unionicolidae	Unionicola	2	0.06	19	1	12.35	0.004	6.6	1.00	1.00	1.00
Laevapex	G	Basommatophora	Ancylidae	Laevapex	2	0.07	16	1	12.71	0.004	8.25	1.00	1.00	0.99
Parachironomus	I	Diptera	Chironomidae	Parachironomus	2	0.05	16	1	11.34	0.004	5.71	1.00	1.00	0.97
Elimia	G	Neotaenioglossa	Pleuroceridae	Elimia	2	0.05	15	1	9.47	0.008	4.81	0.98	0.97	0.90
Coelotanypus	I	Diptera	Chironomidae	Coelotanypus	2	0.04	11	1	9.77	0.004	6.67	1.00	0.99	0.91
Ranatra	I	Hemiptera	Nepidae	Ranatra	2	0.08	8	1	6.18	0.004	5.22	1.00	0.98	0.92
Simulium	I	Diptera	Simuliidae	Simulium	2	0.07	136	2	46.05	0.004	6.28	1.00	1.00	0.99
Baetis	I	Ephemeroptera	Baetidae	Baetis	2	0.06	131	2	42.53	0.004	4.38	0.99	0.99	0.95
Gomphidae	I	Odonata	Gomphidae		2	0.05	123	2	34.62	0.012	3.41	0.98	0.97	0.86
Hydropsyche	I	Trichoptera	Hydropsychidae	Hydropsyche	2	0.05	121	2	38.48	0.004	5.77	1.00	1.00	0.98
Parakiefferiella	I	Diptera	Chironomidae	Parakiefferiella	2	0.08	72	2	23.61	0.004	4.34	0.98	0.96	0.83
Acentrella	I	Ephemeroptera	Baetidae	Acentrella	2	0.07	45	2	18.56	0.004	4.27	1.00	0.99	0.88
Hygrobatidae	A	Trombidiformes	Hygrobatidae		2	0.06	39	2	17.16	0.012	3.78	0.99	0.98	0.88
Sperchonidae	A	Trombidiformes	Sperchonidae		2	0.06	28	2	12.61	0.004	3.95	0.99	0.99	0.83
Potthastia	I	Diptera	Chironomidae	Potthastia	2	0.06	16	2	8.47	0.004	3.83	0.99	0.97	0.71
Dicrotendipes	I	Diptera	Chironomidae	Dicrotendipes	3	0.38	127	1	45.28	0.004	6.7	1.00	1.00	1.00
Nais	O	Haplotaxida	Naididae	Nais	3	0.27	124	1	38.84	0.008	3.84	0.97	0.96	0.83
Aulodrilus	O	Haplotaxida	Tubificidae	Aulodrilus	3	0.10	123	1	39.85	0.004	5.31	1.00	1.00	0.97
Corbicula	B	Veneroida	Corbiculidae	Corbicula	3	0.25	106	1	53.31	0.004	15.55	1.00	1.00	1.00
Coenagrionidae	I	Odonata	Coenagrionidae		3	0.23	92	1	41.46	0.004	9.52	1.00	1.00	1.00
Prostoma	E	Hoplonemertea	Tetrastemmatidae	Prostoma	3	0.20	92	1	27.7	0.004	4.82	1.00	1.00	0.96
Tricorythodes	I	Ephemeroptera	Leptohyphidae	Tricorythodes	3	0.20	91	1	46.82	0.004	14.14	1.00	1.00	1.00

Table A3-3 *continued*

Target Taxon	C	Order	Family	Genus	G C	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Oecetis	I	Trichoptera	Leptoceridae	Oecetis	3	0.40	87	1	38.06	0.004	9.97	1.00	1.00	1.00
Argia	I	Odonata	Coenagrionidae	Argia	3	0.20	75	1	34.26	0.004	7.71	1.00	1.00	1.00
Macronychus	I	Coleoptera	Elmidae	Macronychus	3	0.20	72	1	34.94	0.004	8.39	1.00	1.00	1.00
Mideopsis	A	Trombidiformes	Mideopsidae	Mideopsis	3	0.15	72	1	23.94	0.004	3.96	1.00	0.99	0.83
Centroptilum	I	Ephemeroptera	Baetidae	Centroptilum	3	0.41	65	1	19.76	0.004	3.1	0.98	0.97	0.65
Stenochironomus	I	Diptera	Chironomidae	Stenochironomus	3	0.20	64	1	18.62	0.008	3.52	0.96	0.95	0.72
Leptoceridae	I	Trichoptera	Leptoceridae		3	0.37	60	1	21.5	0.004	4.51	0.99	0.98	0.88
Nanocladius	I	Diptera	Chironomidae	Nanocladius	3	0.11	59	1	21.16	0.004	4.75	0.97	0.95	0.86
Ferrissia	G	Basommatophora	Ancylidae	Ferrissia	3	0.20	58	1	22.77	0.004	6.15	1.00	1.00	0.99
Hydroptilidae	I	Trichoptera	Hydroptilidae		3	0.32	56	1	22.39	0.004	5.63	0.99	0.99	0.97
Hydrobiidae	G	Neotaenioglossa	Hydrobiidae		3	0.12	53	1	37.3	0.004	9.92	1.00	1.00	1.00
Hyalella	M	Amphipoda	Hyalellidae	Hyalella	3	0.25	50	1	21.27	0.004	4.77	1.00	1.00	0.97
Bivalvia	B				3	0.23	48	1	20.11	0.004	5.75	1.00	1.00	1.00
Branchiura	O	Haplotaxida	Tubificidae	Branchiura	3	0.23	47	1	23.98	0.004	7.75	1.00	1.00	1.00
Menetus	G	Basommatophora	Planorbidae	Menetus	3	0.25	43	1	19.38	0.004	4.88	1.00	1.00	0.99
Nectopsyche	I	Trichoptera	Leptoceridae	Nectopsyche	3	0.11	41	1	25.18	0.004	8.33	1.00	1.00	1.00
Pseudocloeon	I	Ephemeroptera	Baetidae	Pseudocloeon	3	0.11	41	1	21.36	0.004	7.66	1.00	1.00	0.99
Ancyronyx	I	Coleoptera	Elmidae	Ancyronyx	3	0.20	40	1	16.7	0.004	5.63	0.98	0.98	0.97
Pristina	O	Haplotaxida	Naididae	Pristina	3	0.10	34	1	14.08	0.012	3.81	1.00	0.98	0.78
Heterocloeon	I	Ephemeroptera	Baetidae	Heterocloeon	3	0.38	32	1	14.85	0.004	4.18	1.00	1.00	0.96
Peltodytes	I	Coleoptera	Haliplidae	Peltodytes	3	0.38	32	1	13.42	0.004	3.79	1.00	0.98	0.76
Berosus	I	Coleoptera	Hydrophilidae	Berosus	3	0.42	31	1	16.44	0.004	6.85	1.00	1.00	1.00
Sphaerium	B	Veneroida	Pisidiidae	Sphaerium	3	0.26	31	1	14.13	0.004	5.22	0.98	0.98	0.85
Leptoxis	G	Neotaenioglossa	Pleuroceridae	Leptoxis	3	0.20	30	1	16.86	0.004	7.03	1.00	1.00	1.00
Arrenurus	A	Trombidiformes	Arrenuridae	Arrenurus	3	0.28	27	1	14.33	0.004	5.34	1.00	1.00	0.98
Protoptila	I	Trichoptera	Glossosomatidae	Protoptila	3	0.12	22	1	13.26	0.004	7.2	1.00	1.00	0.99
Macromia	I	Odonata	Corduliidae	Macromia	3	0.41	20	1	9.01	0.004	3.74	0.99	0.95	0.73
Triaenodes	I	Trichoptera	Leptoceridae	Triaenodes	3	0.29	19	1	11.66	0.004	4.37	1.00	1.00	0.96
Oxyethira	I	Trichoptera	Hydroptilidae	Oxyethira	3	0.22	17	1	9.97	0.004	3.71	1.00	0.99	0.91
Neureclipsis	I	Trichoptera	Polycentropodidae	Neureclipsis	3	0.11	13	1	8.88	0.004	5.25	1.00	1.00	0.94
Stylaria	O	Haplotaxida	Naididae	Stylaria	3	0.11	13	1	9.21	0.004	4.68	1.00	1.00	0.97
Ephoron	I	Ephemeroptera	Polymitarcyidae	Ephoron	3	0.13	12	1	8.43	0.008	5.61	1.00	0.99	0.94
Oxus	A	Trombidiformes	Oxidae	Oxus	3	0.27	11	1	6.92	0.004	4.43	1.00	0.98	0.93
Didymops	I	Odonata	Corduliidae	Didymops	3	0.15	7	1	5.38	0.004	5.23	1.00	0.96	0.80
Optioservus	I	Coleoptera	Elmidae	Optioservus	3	0.13	122	2	38.66	0.004	5.64	0.99	0.99	0.96

Table A3-3 *continued*

Target Taxon	C	Order	Family	Genus	GC	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Parametriocnemus	I	Diptera	Chironomidae	Parametriocnemus	3	0.28	108	2	66.22	0.004	17.24	1.00	1.00	1.00
Cambaridae	M	Decapoda	Cambaridae		3	0.23	86	2	31.1	0.004	7.24	0.99	0.99	0.98
Paratendipes	I	Diptera	Chironomidae	Paratendipes	3	0.20	77	2	32.21	0.004	7.47	1.00	1.00	1.00
Eurylophella	I	Ephemeroptera	Ephemerellidae	Eurylophella	3	0.25	66	2	31.93	0.004	10.11	1.00	1.00	1.00
Ectopria	I	Coleoptera	Psephenidae	Ectopria	3	0.48	55	2	31.33	0.004	11.29	1.00	1.00	1.00
Natarsia	I	Diptera	Chironomidae	Natarsia	3	0.11	52	2	25.57	0.004	7.89	1.00	1.00	1.00
Antocha	I	Diptera	Tipulidae	Antocha	3	0.28	51	2	22.06	0.008	5.08	0.99	0.97	0.92
Haplotaxida	O	Haplotaxida			3	0.25	48	2	18.07	0.004	4.92	1.00	1.00	0.94
Acerpenna	I	Ephemeroptera	Baetidae	Acerpenna	3	0.12	38	2	17.25	0.004	4.85	1.00	1.00	0.99
Tipulidae	I	Diptera	Tipulidae		3	0.41	38	2	21.35	0.004	8.32	1.00	1.00	1.00
Stylogomphus	I	Odonata	Gomphidae	Stylogomphus	3	0.39	33	2	21.25	0.004	9.93	0.99	0.99	0.99
Calopterygidae	I	Odonata	Calopterygidae		3	0.41	29	2	14.04	0.004	5.21	0.98	0.98	0.92
Calopteryx	I	Odonata	Calopterygidae	Calopteryx	3	0.21	25	2	12.68	0.004	4.56	1.00	0.99	0.95
Cordulegaster	I	Odonata	Cordulegastridae	Cordulegaster	3	0.41	25	2	22.32	0.004	12.64	1.00	1.00	1.00
Spirosperma	O	Haplotaxida	Tubificidae	Spirosperma	3	0.33	16	2	8.25	0.012	3.92	0.98	0.95	0.79
Dubiraphia	I	Coleoptera	Elmidae	Dubiraphia	4	1.68	173	1	59.56	0.004	6.35	1.00	1.00	0.99
Caenis	I	Ephemeroptera	Caenidae	Caenis	4	1.02	170	1	59.22	0.004	7.85	1.00	1.00	1.00
Ablabesmyia	I	Diptera	Chironomidae	Ablabesmyia	4	1.05	168	1	57.96	0.004	9.1	1.00	1.00	1.00
Stenelmis	I	Coleoptera	Elmidae	Stenelmis	4	1.68	164	1	53.66	0.004	6.26	0.99	0.99	0.99
Stenacron	I	Ephemeroptera	Heptageniidae	Stenacron	4	0.83	96	1	34.81	0.004	4.95	1.00	1.00	0.99
Lebertia	A	Trombidiformes	Lebertiidae	Lebertia	4	1.47	92	1	30.63	0.012	3.49	0.97	0.97	0.77
Ancylidae	G	Basommatophora	Ancylidae		4	0.74	78	1	33.07	0.004	8.46	1.00	1.00	1.00
Hygrobates	A	Trombidiformes	Hygrobatidae	Hygrobates	4	1.37	62	1	25	0.004	4.03	1.00	1.00	0.91
Neumania	A	Trombidiformes	Unionicolidae	Neumania	4	1.68	55	1	21.95	0.012	3.62	0.99	0.99	0.72
Labrundinia	I	Diptera	Chironomidae	Labrundinia	4	0.65	54	1	20.37	0.004	5.16	0.99	0.99	0.94
Pseudochironomus	I	Diptera	Chironomidae	Pseudochironomus	4	0.51	46	1	22.13	0.004	4.94	1.00	1.00	1.00
Dero	O	Haplotaxida	Naididae	Dero	4	0.63	41	1	15.76	0.012	3.42	0.98	0.97	0.83
Orconectes	M	Decapoda	Cambaridae	Orconectes	4	0.94	34	1	15.74	0.004	4.46	0.96	0.96	0.84
Helicopsyche	I	Trichoptera	Helicopsychidae	Helicopsyche	4	1.29	28	1	12.12	0.012	2.9	0.96	0.95	0.62
Cnidaria					4	0.53	26	1	11.25	0.008	3.9	0.97	0.96	0.78
Enallagma	I	Odonata	Coenagrionidae	Enallagma	4	0.57	21	1	11.17	0.004	4.54	1.00	1.00	0.96
Thienemannimyia.Genus.Gr.	-	NA	NA	NA	4	0.76	187	2	67.4	0.004	10.58	1.00	1.00	1.00
Stempellinella	I	Diptera	Chironomidae	Stempellinella	4	1.29	138	2	51.44	0.004	6.87	1.00	1.00	1.00
Baetidae	I	Ephemeroptera	Baetidae		4	1.89	111	2	38.81	0.004	4.17	0.99	0.98	0.89
Enchytraeidae	O	Enchytraeida	Enchytraeidae		4	1.68	106	2	52.41	0.004	7.9	1.00	1.00	0.99

Table A3-3 *continued*

Target Taxon	C	Order	Family	Genus	G C	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Tvetenia	I	Diptera	Chironomidae	Tvetenia	4	1.02	95	2	49.95	0.004	11.98	1.00	1.00	1.00
Corynoneura	I	Diptera	Chironomidae	Corynoneura	4	1.47	88	2	40.97	0.004	6.89	1.00	1.00	0.99
Leptophlebiidae	I	Ephemeroptera	Leptophlebiidae		4	1.29	76	2	54.58	0.004	15.41	1.00	1.00	1.00
Elmidae	I	Coleoptera	Elmidae		4	1.47	72	2	30.15	0.004	5.09	0.99	0.99	0.96
Micropsectra	I	Diptera	Chironomidae	Micropsectra	4	1.58	66	2	55.47	0.004	13.44	1.00	1.00	1.00
Leuctra	I	Plecoptera	Leuctridae	Leuctra	4	0.91	63	2	51.85	0.004	17.75	1.00	1.00	1.00
Nigronia	I	Megaloptera	Corydalidae	Nigronia	4	0.70	60	2	36.08	0.004	10.97	1.00	1.00	1.00
Empididae	I	Diptera	Empididae		4	0.68	59	2	26.73	0.004	8.06	1.00	1.00	0.99
Oulimnius	I	Coleoptera	Elmidae	Oulimnius	4	1.89	59	2	57.94	0.004	17.26	1.00	1.00	1.00
Lepidostoma	I	Trichoptera	Lepidostomatidae	Lepidostoma	4	1.99	56	2	57.78	0.004	14.76	1.00	1.00	1.00
Tipula	I	Diptera	Tipulidae	Tipula	4	0.81	55	2	35.8	0.004	12.15	1.00	1.00	1.00
Zavrelimyia	I	Diptera	Chironomidae	Zavrelimyia	4	0.62	53	2	37.9	0.004	12.51	1.00	1.00	1.00
Polycentropus	I	Trichoptera	Polycentropodidae	Polycentropus	4	1.88	48	2	27.02	0.004	6.86	0.97	0.95	0.87
Ephemerellidae	I	Ephemeroptera	Ephemerellidae		4	0.80	44	2	18.53	0.004	4.43	0.97	0.96	0.92
Rhyacophila	I	Trichoptera	Rhyacophilidae	Rhyacophila	4	1.78	40	2	48.24	0.004	17.74	1.00	1.00	1.00
Brillia	I	Diptera	Chironomidae	Brillia	4	1.78	37	2	22.76	0.004	6.37	1.00	0.99	0.98
Acroneuria	I	Plecoptera	Perlidae	Acroneuria	4	0.72	36	2	23.53	0.004	8.9	1.00	1.00	0.99
Parachaetocladius	I	Diptera	Chironomidae	Parachaetocladius	4	0.81	36	2	32.16	0.004	12.55	1.00	1.00	1.00
Plecoptera	I	Plecoptera			4	1.58	35	2	29.16	0.004	9.09	0.97	0.97	0.97
Dicranota	I	Diptera	Tipulidae	Dicranota	4	1.15	34	2	38.58	0.004	17.56	1.00	1.00	1.00
Dolophilodes	I	Trichoptera	Philopotamidae	Dolophilodes	4	1.52	34	2	43.08	0.004	17.1	1.00	1.00	1.00
Eukiefferiella	I	Diptera	Chironomidae	Eukiefferiella	4	1.29	33	2	31.11	0.004	14.6	1.00	1.00	1.00
Limnophyes	I	Diptera	Chironomidae	Limnophyes	4	1.55	33	2	33.17	0.004	11.32	1.00	1.00	1.00
Diplectrona	I	Trichoptera	Hydropsychidae	Diplectrona	4	1.11	32	2	47.45	0.004	21.54	1.00	1.00	1.00
Promoresia	I	Coleoptera	Elmidae	Promoresia	4	1.52	31	2	19.24	0.004	5	1.00	0.99	0.95
Helichus	I	Coleoptera	Dryopidae	Helichus	4	0.76	30	2	20.17	0.004	8.95	1.00	1.00	1.00
Lype	I	Trichoptera	Psychomyiidae	Lype	4	0.72	26	2	16.03	0.004	7.23	0.99	0.99	0.96
Glossosoma	I	Trichoptera	Glossosomatidae	Glossosoma	4	1.78	22	2	32.26	0.004	14.76	1.00	1.00	1.00
Epeorus	I	Ephemeroptera	Heptageniidae	Epeorus	4	1.52	21	2	22.89	0.004	9.62	1.00	1.00	1.00
Paramerina	I	Diptera	Chironomidae	Paramerina	4	0.59	20	2	12.56	0.004	6.11	1.00	1.00	0.96
Diplocladius	I	Diptera	Chironomidae	Diplocladius	4	0.80	18	2	16.51	0.004	10.09	1.00	1.00	1.00
Molanna	I	Trichoptera	Molannidae	Molanna	4	1.15	18	2	17.95	0.004	9.17	0.99	0.99	0.97
Larsia	I	Diptera	Chironomidae	Larsia	4	1.58	17	2	15.88	0.004	8.37	0.96	0.95	0.89
Neoplasta	I	Diptera	Empididae	Neoplasta	4	0.80	17	2	19.58	0.004	13.22	1.00	1.00	1.00
Dytiscidae	I	Coleoptera	Dytiscidae		4	1.11	16	2	11.4	0.004	4.62	1.00	0.99	0.87

Table A3-3 *continued*

Target Taxon	C	Order	Family	Genus	G C	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Paracapnia	I	Plecoptera	Capniidae	Paracapnia	4	1.58	14	2	23.92	0.004	15.17	1.00	1.00	1.00
Dixa	I	Diptera	Dixidae	Dixa	4	1.96	13	2	14.21	0.004	8.55	1.00	1.00	0.98
Diamesa	I	Diptera	Chironomidae	Diamesa	4	1.02	12	2	9.54	0.004	5.44	1.00	0.99	0.91
Heterotrissocladius	I	Diptera	Chironomidae	Heterotrissocladius	4	1.28	12	2	15.76	0.004	9.62	1.00	1.00	1.00
Pseudolimnophila	I	Diptera	Tipulidae	Pseudolimnophila	4	1.15	12	2	15.84	0.004	10.5	1.00	1.00	1.00
Trissopelopia	I	Diptera	Chironomidae	Trissopelopia	4	1.96	12	2	23.49	0.004	13.65	1.00	1.00	1.00
Anchytarsus	I	Coleoptera	Ptilodactylidae	Anchytarsus	4	0.63	11	2	12.09	0.004	8.66	1.00	1.00	1.00
Torrenticola	A	Trombidiformes	Torrenticolidae	Torrenticola	4	1.27	10	2	7.05	0.012	3.56	1.00	0.95	0.70
Dixella	I	Diptera	Dixidae	Dixella	4	0.97	9	2	6.63	0.008	3.83	1.00	0.95	0.77
Apsectrotanypus	I	Diptera	Chironomidae	Apsectrotanypus	4	1.78	7	2	10.24	0.004	9	1.00	0.99	0.94
Goera	I	Trichoptera	Goeridae	Goera	4	1.99	7	2	12.59	0.004	9.37	0.99	0.95	0.85
Pseudorthocladius	I	Diptera	Chironomidae	Pseudorthocladius	4	1.89	7	2	11.36	0.004	9.13	0.99	0.95	0.89
Phryganeidae	I	Trichoptera	Phryganeidae		4	1.89	6	2	8.69	0.008	6.21	1.00	0.97	0.84
Heleniella	I	Diptera	Chironomidae	Heleniella	4	1.92	5	2	9.73	0.004	9.62	0.99	0.97	0.90
Krenosmittia	I	Diptera	Chironomidae	Krenosmittia	4	1.89	5	2	11.63	0.004	11.69	1.00	0.98	0.93
Chironomidae	I	Diptera	Chironomidae		5	2.60	210	2	55.07	0.016	3.4	1.00	0.99	0.91
Ceratopogonidae	I	Diptera	Ceratopogonidae		5	2.33	125	2	52.84	0.004	6.06	1.00	1.00	0.99
Ceratopogoninae	I	Diptera	Ceratopogonidae		5	2.55	97	2	45.91	0.012	5.01	0.98	0.97	0.88
Lumbriculidae	O	Lumbriculida	Lumbriculidae		5	3.73	72	2	57.02	0.004	8.44	1.00	1.00	1.00
Hexatoma	I	Diptera	Tipulidae	Hexatoma	5	4.10	54	2	74.11	0.004	12.96	1.00	1.00	1.00
Sarcoptiformes	A	Sarcoptiformes			5	2.60	32	2	28.79	0.004	8.23	0.99	0.99	0.97
Limnephilidae	I	Trichoptera	Limnephilidae		5	2.18	31	2	27.35	0.004	7.8	0.98	0.98	0.92
Chloroperlidae	I	Plecoptera	Chloroperlidae		5	4.02	25	2	69.22	0.004	18.25	1.00	1.00	1.00
Leuctridae	I	Plecoptera	Leuctridae		5	4.02	25	2	55.25	0.004	17.02	1.00	1.00	1.00
Perlodidae	I	Plecoptera	Perlodidae		5	3.93	24	2	72.23	0.004	22.38	1.00	1.00	1.00
Diphetor	I	Ephemeroptera	Baetidae	Diphetor	5	2.33	17	2	14	0.004	4.73	0.99	0.97	0.85
Psychodidae	I	Diptera	Psychodidae		5	2.60	17	2	12.94	0.004	4.1	0.98	0.95	0.79
Sweltsa	I	Plecoptera	Chloroperlidae	Sweltsa	5	4.02	17	2	34.93	0.004	13.65	1.00	1.00	0.99
Demicryptochironomus	I	Diptera	Chironomidae	Demicryptochironomus	5	3.73	15	2	27.14	0.004	8.15	1.00	0.99	0.97
Atractides	A	Trombidiformes	Hygrobatidae	Atractides	5	4.02	14	2	26.38	0.004	9.07	0.99	0.97	0.83
Paraphaenocladius	I	Diptera	Chironomidae	Paraphaenocladius	5	2.60	14	2	14.37	0.004	6.27	0.99	0.97	0.84
Amphinemura	I	Plecoptera	Nemouridae	Amphinemura	5	3.37	12	2	28.12	0.004	12.21	1.00	1.00	1.00
Cambarus	M	Decapoda	Cambaridae	Cambarus	5	3.73	11	2	33.46	0.004	15.81	1.00	1.00	0.99
Chaetocladius	I	Diptera	Chironomidae	Chaetocladius	5	2.21	9	2	15.08	0.004	13.35	1.00	0.99	0.97
Limnophila	I	Diptera	Tipulidae	Limnophila	5	4.02	8	2	42.27	0.004	20.86	1.00	1.00	0.99

Table A3-3 *continued*

Target Taxon	C	Order	Family	Genus	G C	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Isoperla	I	Plecoptera	Perlodidae	Isoperla	5	2.21	7	2	14.82	0.004	14.73	1.00	0.99	0.96
Ameletus	I	Ephemeroptera	Ameletidae	Ameletus	5	3.59	5	2	20.98	0.004	14.02	0.97	0.96	0.92
Peltoperla	I	Plecoptera	Peltoperlidae	Peltoperla	5	3.73	4	2	23.53	0.004	14.58	0.98	0.98	0.91
Wormaldia	I	Trichoptera	Philopotamidae	Wormaldia	5	3.59	4	2	21.05	0.004	14.91	0.97	0.97	0.89
Perlidae	I	Plecoptera	Perlidae		6	6.13	43	2	79.84	0.004	11.05	1.00	1.00	1.00
Tallaperla	I	Plecoptera	Peltoperlidae	Tallaperla	6	4.92	23	2	67.42	0.004	20.38	1.00	1.00	1.00
Branchiobdellida	O	Branchiobdellida			6	4.94	18	2	40.52	0.004	9.57	1.00	0.99	0.95
Ephemerella	I	Ephemeroptera	Ephemerellidae	Ephemerella	6	4.92	17	2	49.25	0.004	16.64	1.00	0.99	0.99
Pteronarcys	I	Plecoptera	Pteronarcyidae	Pteronarcys	6	4.92	16	2	58.46	0.004	18.29	1.00	1.00	1.00
Psilotreta	I	Trichoptera	Odontoceridae	Psilotreta	6	7.29	14	2	30.21	0.024	4.15	0.98	0.96	0.79
Drunella	I	Ephemeroptera	Ephemerellidae	Drunella	6	4.92	13	2	29.54	0.004	12.94	0.99	0.97	0.89
Philopotamidae	I	Trichoptera	Philopotamidae		6	4.92	13	2	36.82	0.004	10.37	0.96	0.95	0.90
Lanthus	I	Odonata	Gomphidae	Lanthus	6	4.92	11	2	39.33	0.004	15.02	1.00	1.00	0.99

Table A3-4. TITAN indicator fish species output for the Appalachian LCC gradient class. The “Grad Class” column indicates the gradient class.

Common Name	Scientific Name	Grad Class	Env cp	Freq	Grp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Tessellated Darter	Etheostoma Olmstedi	1	0.00	41	1	24.83	0.004	5.11	1.00	1.00	0.92
Redear Sunfish	Lepomis Microlophus	1	0.00	26	1	23.48	0.004	6.28	1.00	1.00	0.99
Banded Killifish	Fundulus Diaphanus	1	0.00	18	1	20.95	0.008	5.44	1.00	0.99	0.92
Skipjack Herring	Alosa Chrysochloris	1	0.01	15	1	15.36	0.004	9.28	1.00	1.00	1.00
Threadfin Shad	Dorosoma Petenense	1	0.01	13	1	16.05	0.004	10.15	1.00	1.00	1.00
Black Buffalo	Ictiobus Niger	1	0.01	10	1	12.50	0.004	9.21	1.00	1.00	0.99
Grass Pickerel	Esox Americanus Vermiculatus	1	0.00	10	1	11.44	0.004	6.07	0.99	0.96	0.82
White Perch	Morone Americana	1	0.00	10	1	31.78	0.004	10.90	1.00	0.99	0.89
Wiper	Morone	1	0.00	10	1	20.35	0.004	9.15	1.00	1.00	0.98
Muskellunge	Esox Masquinongy	1	0.00	9	1	9.18	0.004	5.87	1.00	0.98	0.89
Bigmouth Buffalo	Ictiobus Cyprinellus	1	0.00	8	1	9.67	0.004	6.82	1.00	0.99	0.96
Striped Bass	Morone Saxatilis	1	0.00	8	1	21.72	0.004	9.98	1.00	0.99	0.88
American Shad	Alosa Sapidissima	1	0.00	7	1	9.65	0.004	7.28	1.00	0.99	0.91
Blueback Herring	Alosa Aestivalis	1	0.00	6	1	10.53	0.004	9.75	1.00	0.98	0.92
Mountain Madtom	Noturus Eleutherus	1	0.00	6	1	6.90	0.004	5.61	1.00	0.95	0.75
Bluebreast Darter	Etheostoma Camurum	1	0.00	5	1	7.46	0.004	7.75	1.00	0.96	0.85
Inland Silverside	Menidia Beryllina	1	0.00	5	1	8.20	0.004	8.52	1.00	0.97	0.88
Freshwater Drum	Aplodinotus Grunniens	2	0.06	47	1	39.34	0.004	14.27	1.00	1.00	1.00
Mimic Shiner	Notropis Volucellus	2	0.10	47	1	25.67	0.004	8.13	1.00	1.00	1.00
Flathead Catfish	Pylodictis Olivaris	2	0.06	43	1	31.39	0.004	13.82	1.00	1.00	1.00
Longnose Gar	Lepisosteus Osseus	2	0.06	42	1	32.79	0.004	14.23	1.00	1.00	1.00
Emerald Shiner	Notropis Atherinoides	2	0.05	39	1	30.71	0.004	10.96	1.00	1.00	1.00
Yellow Perch	Perca Flavescens	2	0.06	39	1	23.38	0.004	6.52	1.00	1.00	0.99
Spottail Shiner	Notropis Hudsonius	2	0.08	35	1	19.27	0.004	6.26	1.00	1.00	0.99
Black Redhorse	Moxostoma Duquesnei	2	0.10	34	1	20.72	0.004	7.65	1.00	1.00	1.00
Brook Silverside	Labidesthes Sicculus	2	0.06	33	1	25.09	0.004	11.13	1.00	1.00	1.00
Smallmouth Buffalo	Ictiobus Bubalus	2	0.02	33	1	32.48	0.004	16.07	1.00	1.00	1.00
Silver Redhorse	Moxostoma Anisurum	2	0.02	30	1	21.25	0.004	8.92	1.00	1.00	1.00
Spotted Sucker	Minytrema Melanops	2	0.08	30	1	22.21	0.004	9.91	1.00	1.00	1.00
River Carpsucker	Carpiodes Carpio	2	0.07	27	1	22.04	0.004	9.38	1.00	1.00	1.00
Walleye	Sander Vitreus	2	0.08	27	1	19.62	0.004	8.48	1.00	1.00	1.00
River Redhorse	Moxostoma Carinatum	2	0.06	25	1	17.65	0.004	8.25	1.00	1.00	1.00
Sauger	Sander Canadensis	2	0.04	22	1	20.30	0.004	11.05	1.00	1.00	1.00
Quillback	Carpiodes Cyprinus	2	0.09	21	1	16.03	0.004	9.19	1.00	1.00	1.00

Table A3-4 *continued*

Common Name	Scientific Name	Grad Class	Env cp	Freq	Grp	Ind Val	pval	z	purity	rel05	rel01
Black Crappie	Pomoxis Nigromaculatus	2	0.02	20	1	13.18	0.004	6.03	1.00	1.00	0.95
White Crappie	Pomoxis Annularis	2	0.07	18	1	12.05	0.004	5.77	1.00	1.00	0.99
White Bass	Morone Chrysops	2	0.05	17	1	16.83	0.004	10.16	1.00	1.00	1.00
Northern Studfish	Fundulus Catenatus	2	0.06	16	1	7.91	0.012	3.55	1.00	0.98	0.74
Streamline Chub	Erimystax Dissimilis	2	0.03	14	1	12.42	0.004	6.33	1.00	1.00	1.00
Shield Darter	Percina Peltata	2	0.07	13	1	8.30	0.004	4.69	1.00	1.00	0.93
Northern Pike	Esox Lucius	2	0.06	11	1	7.02	0.004	4.52	1.00	0.96	0.78
Silver Chub	Macrhybopsis Storeriana	2	0.06	10	1	9.09	0.004	6.92	1.00	1.00	0.99
Gilt Darter	Percina Evides	2	0.05	9	1	6.76	0.004	4.46	1.00	0.96	0.83
Swallowtail Shiner	Notropis Procne	2	0.07	9	1	6.89	0.004	4.81	0.99	0.95	0.81
River Shiner	Notropis Blennius	2	0.05	8	1	6.91	0.004	4.88	1.00	0.99	0.92
Shortnose Gar	Lepisosteus Platostomus	2	0.06	8	1	7.27	0.004	5.38	1.00	0.99	0.91
Channel Shiner	Notropis Wickliffi	2	0.04	7	1	7.37	0.004	6.09	1.00	0.98	0.94
Grass Carp	Ctenopharyngodon Idella	2	0.06	6	1	5.61	0.004	5.40	1.00	0.98	0.85
Silver Carp	Hypophthalmichthys Molitrix	2	0.05	6	1	5.88	0.004	5.05	1.00	0.96	0.83
Spotted Gar	Lepisosteus Oculatus	2	0.05	6	1	5.77	0.004	5.07	1.00	0.96	0.84
Fantail Darter	Etheostoma Flabellare	2	0.09	62	2	26.84	0.004	6.65	1.00	1.00	1.00
Johnny Darter	Etheostoma Nigrum	2	0.03	53	2	22.96	0.004	6.65	1.00	1.00	1.00
Longnose Dace	Rhinichthys Cataractae	2	0.06	37	2	15.95	0.004	3.88	0.99	0.97	0.80
Mottled Sculpin	Cottus Bairdii	2	0.08	30	2	14.99	0.004	5.20	1.00	1.00	0.95
Bluehead Chub	Nocomis Leptocephalus	2	0.08	22	2	11.55	0.004	5.54	1.00	1.00	0.98
Creek Chubsucker	Erimyzon Oblongus	2	0.10	10	2	6.21	0.004	3.39	0.99	0.96	0.70
Bluegill	Lepomis Macrochirus	3	0.13	172	1	63.62	0.004	9.39	1.00	1.00	1.00
Smallmouth Bass	Micropterus Dolomieu	3	0.36	132	1	68.36	0.004	14.52	1.00	1.00	1.00
Northern Hog Sucker	Hypentelium Nigricans	3	0.31	116	1	53.12	0.004	12.36	1.00	1.00	1.00
Spotfin Shiner	Cyprinella Spiloptera	3	0.13	109	1	65.75	0.004	17.95	1.00	1.00	1.00
Largemouth Bass	Micropterus Salmoides	3	0.25	106	1	44.49	0.004	9.90	1.00	1.00	1.00
Longear Sunfish	Lepomis Megalotis	3	0.14	95	1	50.11	0.004	12.86	1.00	1.00	1.00
Greenside Darter	Etheostoma Blennioides	3	0.39	92	1	43.70	0.004	10.73	1.00	1.00	1.00
Golden Redhorse	Moxostoma Erythrurum	3	0.11	89	1	47.63	0.004	13.69	1.00	1.00	1.00
Common Carp	Cyprinus Carpio	3	0.15	86	1	54.87	0.004	15.98	1.00	1.00	1.00
Channel Catfish	Ictalurus Punctatus	3	0.11	77	1	52.25	0.004	18.03	1.00	1.00	1.00
Logperch	Percina Caprodes	3	0.11	70	1	43.77	0.004	13.71	1.00	1.00	1.00
Spotted Bass	Micropterus Punctulatus	3	0.11	68	1	42.71	0.004	15.77	1.00	1.00	1.00

Table A3-4 *continued*

Common Name	Scientific Name	Grad Class	Env cp	Freq	Grp	Ind Val	pval	z	purity	rel05	rel01
Gizzard Shad	Dorosoma Cepedianum	3	0.10	64	1	46.13	0.004	15.62	1.00	1.00	1.00
Pumpkinseed	Lepomis Gibbosus	3	0.25	60	1	28.12	0.004	5.63	1.00	1.00	0.99
Banded Darter	Etheostoma Zonale	3	0.35	54	1	23.67	0.004	6.03	1.00	1.00	1.00
River Chub	Nocomis Micropogon	3	0.35	45	1	21.32	0.004	6.83	1.00	1.00	1.00
Rosyface Shiner	Notropis Rubellus	3	0.40	44	1	21.61	0.004	5.30	1.00	1.00	1.00
Fallfish	Semotilus Corporalis	3	0.10	36	1	20.54	0.004	7.76	1.00	1.00	1.00
Shorthead Redhorse	Moxostoma Macrolepidotum	3	0.29	32	1	18.71	0.004	6.39	1.00	1.00	1.00
Sand Shiner	Notropis Stramineus	3	0.48	31	1	14.85	0.004	5.06	1.00	1.00	0.98
Silver Shiner	Notropis Photogenis	3	0.48	29	1	15.26	0.004	5.63	1.00	1.00	1.00
Bigeye Chub	Hybopsis Amblops	3	0.11	27	1	13.35	0.004	3.93	1.00	1.00	0.87
Smallmouth Redhorse	Moxostoma Breviceps	3	0.10	24	1	18.16	0.004	8.63	1.00	1.00	1.00
Bullhead Minnow	Pimephales Vigilax	3	0.11	19	1	14.73	0.004	7.47	1.00	1.00	1.00
Dusky Darter	Percina Sciera	3	0.20	18	1	12.00	0.004	6.58	1.00	1.00	1.00
Brindled Madtom	Noturus Miurus	3	0.11	10	1	6.63	0.004	4.04	1.00	0.95	0.76
Tennessee Darter	Etheostoma Tennesseense	3	0.11	7	1	5.38	0.004	4.80	1.00	0.96	0.81
Creek Chub	Semotilus Atromaculatus	3	0.13	122	2	63.22	0.004	17.04	1.00	1.00	1.00
Eastern Blacknose Dace	Rhinichthys Atratulus	3	0.36	71	2	47.27	0.004	15.64	1.00	1.00	1.00
Orangethroat Darter	Etheostoma Spectabile	3	0.14	15	2	9.44	0.004	4.05	0.99	0.98	0.91
Redside Dace	Clinostomus Elongatus	3	0.36	6	2	5.50	0.008	4.47	1.00	0.95	0.77
Rock Bass	Ambloplites Rupestris	4	0.81	130	1	59.13	0.004	12.76	1.00	1.00	1.00
Bluntnose Minnow	Pimephales Notatus	4	0.62	129	1	51.78	0.004	9.20	1.00	1.00	1.00
White Sucker	Catostomus Commersonii	4	1.84	121	1	45.34	0.004	4.74	0.97	0.97	0.96
Striped Shiner	Luxilus Chrysocephalus	4	0.62	76	1	29.21	0.004	5.45	1.00	1.00	0.99
Redbreast Sunfish	Lepomis Auritus	4	0.80	71	1	28.42	0.004	5.86	1.00	1.00	0.99
Whitetail Shiner	Cyprinella Galactura	4	0.62	21	1	10.29	0.008	3.68	1.00	1.00	0.65
Brook Trout	Salvelinus Fontinalis	4	1.47	15	2	27.51	0.004	14.37	1.00	1.00	1.00
Rosyside Dace	Clinostomus Funduloides	4	1.92	13	2	17.52	0.004	8.58	1.00	1.00	0.98
Rainbow Trout	Oncorhynchus Mykiss	5	3.12	12	2	24.58	0.004	10.47	0.98	0.98	0.92

Table A3-5. TITAN benthic indicator species output for the Appalachian LCC stream size class. The "SC" column indicates the stream size class. The "C" column identifies the class of benthic fauna as follows: A = Arachnida; B = Bivalvia; E = Enopla; G = Gastropoda; I = Insecta; M = Malacostraca; and O = Oligochaeta.

Target Taxon	C	Order	Family	Genus	SC	Env cp	Freq	G rp	Ind Val	pval	z	Purity	Rel 05	Rel 01
Ceratopogoninae	I	Diptera	Ceratopogonidae		11	2.01	97	1	68.11	0.004	9.29	1.00	1.00	1.00
Corynoneura	I	Diptera	Chironomidae	Corynoneura	11	7.11	88	1	35.88	0.004	5.92	1.00	1.00	0.99
Paratendipes	I	Diptera	Chironomidae	Paratendipes	11	9.45	77	1	39.08	0.004	9.74	1.00	1.00	1.00
Lumbriculidae	O	Lumbriculida	Lumbriculidae		11	2.17	72	1	41.05	0.004	5.89	1.00	0.99	0.94
Chrysops	I	Diptera	Tabanidae	Chrysops	11	7.11	36	1	20.70	0.004	6.56	1.00	1.00	0.99
Plecoptera	I	Plecoptera			11	7.11	35	1	18.59	0.004	5.98	1.00	0.99	0.97
Limnophyes	I	Diptera	Chironomidae	Limnophyes	11	6.65	33	1	28.46	0.004	10.86	1.00	1.00	1.00
Diplectrona	I	Trichoptera	Hydropsychidae	Diplectrona	11	7.84	32	1	35.13	0.004	15.87	1.00	1.00	1.00
Sarcoptiformes	A	Sarcoptiformes			11	5.79	32	1	21.16	0.004	7.85	1.00	1.00	0.98
Paraleptophlebia	I	Ephemeroptera	Leptophlebiidae	Paraleptophlebia	11	3.82	27	1	26.21	0.004	8.69	1.00	1.00	1.00
Chloroperlidae	I	Plecoptera	Chloroperlidae		11	5.70	25	1	21.10	0.004	8.86	1.00	1.00	1.00
Perlodidae	I	Plecoptera	Perlodidae		11	5.84	24	1	22.35	0.004	9.54	1.00	1.00	1.00
Diplocladius	I	Diptera	Chironomidae	Diplocladius	11	8.64	18	1	16.96	0.004	9.60	1.00	1.00	1.00
Ephemerella	I	Ephemeroptera	Ephemerellidae	Ephemerella	11	7.84	17	1	11.78	0.004	5.20	1.00	0.99	0.87
Larsia	I	Diptera	Chironomidae	Larsia	11	2.10	17	1	27.15	0.004	9.97	1.00	1.00	1.00
Psychodidae	I	Diptera	Psychodidae		11	8.64	17	1	12.16	0.004	5.91	0.98	0.96	0.89
Dytiscidae	I	Coleoptera	Dytiscidae		11	2.34	16	1	24.37	0.004	10.24	1.00	0.99	0.97
Paraphaenocladius	I	Diptera	Chironomidae	Paraphaenocladius	11	3.05	14	1	13.84	0.016	5.88	1.00	1.00	0.92
Dixa	I	Diptera	Dixidae	Dixa	11	3.39	13	1	20.90	0.004	9.42	1.00	1.00	0.99
Amphinemura	I	Plecoptera	Nemouridae	Amphinemura	11	7.30	12	1	15.79	0.004	11.64	1.00	1.00	1.00
Anchytarsus	I	Coleoptera	Ptilodactylidae	Anchytarsus	11	7.84	11	1	12.74	0.004	9.09	1.00	1.00	0.99
Chaetocladius	I	Diptera	Chironomidae	Chaetocladius	11	5.66	9	1	11.62	0.004	9.50	0.99	0.99	0.96
Dixella	I	Diptera	Dixidae	Dixella	11	4.61	9	1	11.64	0.004	7.73	1.00	0.99	0.92
Limnophila	I	Diptera	Tipulidae	Limnophila	11	5.64	8	1	9.50	0.004	7.41	1.00	1.00	0.96
Ptilostomis	I	Trichoptera	Phryganeidae	Ptilostomis	11	5.61	8	1	11.84	0.004	9.14	1.00	0.99	0.94
Apsectrotanypus	I	Diptera	Chironomidae	Apsectrotanypus	11	6.74	7	1	8.33	0.004	7.30	1.00	0.99	0.92
Hydroporus	I	Coleoptera	Dytiscidae	Hydroporus	11	5.66	6	1	8.24	0.004	8.48	1.00	0.97	0.88
Phryganeidae	I	Trichoptera	Phryganeidae		11	3.94	6	1	9.65	0.004	6.59	1.00	0.97	0.89
Ameletus	I	Ephemeroptera	Ameletidae	Ameletus	11	5.66	5	1	8.33	0.004	7.98	1.00	0.97	0.90
Nemouridae	I	Plecoptera	Nemouridae		11	2.34	5	1	12.58	0.004	10.46	1.00	0.98	0.94
Eccoptura	I	Plecoptera	Perlidae	Eccoptura	11	4.23	4	1	9.09	0.004	10.91	1.00	0.97	0.91
Wormaldia	I	Trichoptera	Philopotamidae	Wormaldia	11	3.05	4	1	14.29	0.004	18.83	1.00	0.97	0.91
Polypedilum	I	Diptera	Chironomidae	Polypedilum	11	2.09	264	2	69.31	0.004	3.73	1.00	1.00	0.96

Table A3-5 *continued*

Target Taxon	C	Order	Family	Genus	SC	Env cp	Freq	G rp	Ind Val	pval	z	purity	Rel 05	Rel 01
Ablabesmyia	I	Diptera	Chironomidae	Ablabesmyia	11	4.11	168	2	54.91	0.004	6.83	1.00	1.00	1.00
Lebertiidae	A	Trombidiformes	Lebertiidae		11	8.64	39	2	16.26	0.004	3.83	0.99	0.98	0.82
Synorthocladius	I	Diptera	Chironomidae	Synorthocladius	11	7.11	21	2	9.86	0.008	3.59	1.00	0.99	0.71
Simulium	I	Diptera	Simuliidae	Simulium	12	68.13	136	1	40.32	0.004	4.54	1.00	1.00	0.97
Ceratopogonidae	I	Diptera	Ceratopogonidae		12	13.44	125	1	45.52	0.004	6.83	1.00	1.00	1.00
Parametriocnemus	I	Diptera	Chironomidae	Parametriocnemus	12	65.39	108	1	66.21	0.004	19.06	1.00	1.00	1.00
Enchytraeidae	O	Enchytraeida	Enchytraeidae		12	10.72	106	1	44.85	0.004	7.73	1.00	1.00	1.00
Cambaridae	M	Decapoda	Cambaridae		12	21.87	86	1	35.55	0.004	9.43	1.00	1.00	1.00
Eurylophella	I	Ephemeroptera	Ephemerellidae	Eurylophella	12	74.84	66	1	29.52	0.004	8.66	1.00	1.00	1.00
Micropsectra	I	Diptera	Chironomidae	Micropsectra	12	35.41	66	1	36.03	0.004	9.05	1.00	1.00	1.00
Nigronia	I	Megaloptera	Corydalidae	Nigronia	12	51.18	60	1	32.37	0.004	11.60	1.00	1.00	1.00
Empididae	I	Diptera	Empididae		12	70.41	59	1	20.49	0.004	5.15	0.96	0.96	0.88
Oulimnius	I	Coleoptera	Elmidae	Oulimnius	12	53.69	59	1	34.83	0.004	11.06	1.00	1.00	1.00
Ectopria	I	Coleoptera	Psephenidae	Ectopria	12	23.77	55	1	27.46	0.004	9.05	1.00	1.00	1.00
Tipula	I	Diptera	Tipulidae	Tipula	12	11.25	55	1	38.01	0.004	13.48	1.00	1.00	1.00
Hexatoma	I	Diptera	Tipulidae	Hexatoma	12	78.42	54	1	31.15	0.004	13.26	1.00	1.00	1.00
Zavrelimyia	I	Diptera	Chironomidae	Zavrelimyia	12	10.97	53	1	49.87	0.004	19.48	1.00	1.00	1.00
Natarsia	I	Diptera	Chironomidae	Natarsia	12	47.61	52	1	30.07	0.004	11.95	1.00	1.00	1.00
Haplotaxida	O	Haplotaxida			12	22.56	48	1	21.67	0.004	6.66	1.00	1.00	0.99
Perlidae	I	Plecoptera	Perlidae		12	10.97	43	1	21.96	0.004	5.96	1.00	1.00	0.97
Rhyacophila	I	Trichoptera	Rhyacophilidae	Rhyacophila	12	18.50	40	1	25.71	0.004	9.80	1.00	1.00	1.00
Tipulidae	I	Diptera	Tipulidae		12	35.41	38	1	19.58	0.004	7.13	1.00	1.00	0.99
Brillia	I	Diptera	Chironomidae	Brillia	12	12.57	37	1	20.05	0.004	6.66	1.00	1.00	1.00
Acroneuria	I	Plecoptera	Perlidae	Acroneuria	12	40.95	36	1	17.99	0.004	6.86	1.00	1.00	0.99
Parachaetocladius	I	Diptera	Chironomidae	Parachaetocladius	12	51.18	36	1	26.56	0.004	10.67	1.00	1.00	1.00
Dicranota	I	Diptera	Tipulidae	Dicranota	12	27.22	34	1	27.32	0.004	13.40	1.00	1.00	1.00
Stylogomphus	I	Odonata	Gomphidae	Stylogomphus	12	86.41	33	1	21.03	0.004	10.14	1.00	1.00	1.00
Helichus	I	Coleoptera	Dryopidae	Helichus	12	13.03	30	1	19.10	0.004	9.27	1.00	1.00	0.99
Calopterygidae	I	Odonata	Calopterygidae		12	33.62	29	1	16.50	0.004	7.35	1.00	1.00	0.99
Lype	I	Trichoptera	Psychomyiidae	Lype	12	23.77	26	1	14.85	0.004	7.48	1.00	1.00	0.99
Cordulegaster	I	Odonata	Cordulegastridae	Cordulegaster	12	29.85	25	1	20.66	0.004	11.31	1.00	1.00	1.00
Leuctridae	I	Plecoptera	Leuctridae		12	15.54	25	1	20.19	0.004	10.73	1.00	1.00	1.00
Tallaperla	I	Plecoptera	Peltoperlidae	Tallaperla	12	12.57	23	1	20.68	0.004	10.41	1.00	1.00	1.00
Glossosoma	I	Trichoptera	Glossosomatidae	Glossosoma	12	89.58	22	1	13.07	0.004	6.04	1.00	1.00	1.00
Epeorus	I	Ephemeroptera	Heptageniidae	Epeorus	12	37.43	21	1	10.52	0.004	3.08	1.00	0.96	0.84

Table A3-5 *continued*

Target Taxon	C	Order	Family	Genus	SC	Env cp	Freq	G rp	Ind Val	pval	z	purity	Rel 05	Rel 01
Paramerina	I	Diptera	Chironomidae	Paramerina	12	78.42	20	1	11.14	0.004	5.67	1.00	1.00	0.96
Sweltsa	I	Plecoptera	Chloroperlidae	Sweltsa	12	44.90	17	1	10.70	0.004	5.68	1.00	1.00	1.00
Pteronarcys	I	Plecoptera	Pteronarcyidae	Pteronarcys	12	13.25	16	1	9.18	0.004	4.58	0.99	0.97	0.89
Aeshnidae	I	Odonata	Aeshnidae		12	21.87	15	1	7.45	0.004	3.85	1.00	0.98	0.81
Paracapnia	I	Plecoptera	Capniidae	Paracapnia	12	13.44	14	1	14.00	0.004	8.30	1.00	1.00	1.00
Heterotrissocladius	I	Diptera	Chironomidae	Heterotrissocladius	12	13.58	12	1	11.88	0.004	9.28	1.00	1.00	1.00
Pseudolimnophila	I	Diptera	Tipulidae	Pseudolimnophila	12	13.31	12	1	10.93	0.004	7.43	1.00	1.00	0.99
Trissopelopia	I	Diptera	Chironomidae	Trissopelopia	12	13.58	12	1	9.71	0.004	5.65	1.00	0.99	0.93
Cambarus	M	Decapoda	Cambaridae	Cambarus	12	13.58	11	1	9.53	0.004	7.52	1.00	1.00	0.99
Lanthus	I	Odonata	Gomphidae	Lanthus	12	12.57	11	1	8.84	0.004	5.36	1.00	0.99	0.96
Brundiniella	I	Diptera	Chironomidae	Brundiniella	12	10.72	8	1	8.13	0.004	6.49	1.00	0.98	0.91
Gonomyia	I	Diptera	Tipulidae	Gonomyia	12	11.06	6	1	6.67	0.004	6.14	1.00	0.96	0.88
Cricotopus.Orthocladius	-	NA	NA	NA	12	43.91	199	2	47.62	0.004	3.33	0.99	0.99	0.89
Nais	O	Haplotaxida	Naididae	Nais	12	57.21	124	2	37.95	0.008	3.70	0.99	0.98	0.82
Corbicula	B	Veneroida	Corbiculidae	Corbicula	12	62.63	106	2	57.14	0.004	16.77	1.00	1.00	1.00
Stenacron	I	Ephemeroptera	Heptageniidae	Stenacron	12	10.72	96	2	34.75	0.004	5.15	0.99	0.99	0.98
Prostoma	E	Hoplonemertea	Tetrastemmatidae	Prostoma	12	24.39	92	2	33.10	0.004	7.13	1.00	1.00	1.00
Oecetis	I	Trichoptera	Leptoceridae	Oecetis	12	68.13	87	2	36.95	0.004	10.26	1.00	1.00	1.00
Ancylidae	G	Basommatophora	Ancylidae		12	68.13	78	2	31.13	0.004	7.55	1.00	1.00	1.00
Isonychia	I	Ephemeroptera	Isonychiidae	Isonychia	12	10.72	75	2	28.76	0.004	5.57	1.00	1.00	0.99
Leucrocuta	I	Ephemeroptera	Heptageniidae	Leucrocuta	12	15.87	65	2	24.46	0.004	5.13	1.00	0.99	0.95
Ferrissia	G	Basommatophora	Ancylidae	Ferrissia	12	68.13	58	2	19.35	0.004	4.18	0.98	0.97	0.81
Hydroptilidae	I	Trichoptera	Hydroptilidae		12	65.39	56	2	23.27	0.004	7.93	1.00	1.00	1.00
Bivalvia	B				12	94.01	48	2	25.94	0.004	9.34	1.00	1.00	1.00
Branchiura	O	Haplotaxida	Tubificidae	Branchiura	12	60.18	47	2	25.61	0.004	8.94	1.00	1.00	1.00
Mideopsidae	A	Trombidiformes	Mideopsidae		12	60.18	43	2	18.69	0.004	5.70	0.97	0.97	0.95
Plauditus	I	Ephemeroptera	Baetidae	Plauditus	12	35.41	30	2	11.62	0.008	3.13	0.99	0.96	0.69
Brachycentrus	I	Trichoptera	Brachycentridae	Brachycentrus	12	32.77	28	2	13.89	0.004	5.40	0.95	0.95	0.93
Oxus	A	Trombidiformes	Oxidae	Oxus	12	81.85	11	2	7.53	0.004	5.85	1.00	1.00	0.96
Thienemannimyia.Genus.Gr.	-	NA	NA	NA	20	103.17	187	1	69.50	0.004	12.11	1.00	1.00	1.00
Microtendipes	I	Diptera	Chironomidae	Microtendipes	20	163.57	158	1	46.22	0.004	5.30	0.99	0.99	0.97
Stempellinella	I	Diptera	Chironomidae	Stempellinella	20	300.66	138	1	46.72	0.004	7.54	1.00	1.00	1.00
Stictochironomus	I	Diptera	Chironomidae	Stictochironomus	20	113.93	77	1	32.57	0.004	6.22	1.00	1.00	1.00
Leptophlebiidae	I	Ephemeroptera	Leptophlebiidae		20	187.15	76	1	41.51	0.004	13.57	1.00	1.00	1.00
Leuctra	I	Plecoptera	Leuctridae	Leuctra	20	163.57	63	1	36.29	0.004	11.77	1.00	1.00	1.00

Table A3-5 *continued*

Target Taxon	C	Order	Family	Genus	SC	Env cp	Freq	G rp	Ind Val	pval	z	purity	Rel 05	Rel 01
Dolophilodes	I	Trichoptera	Philopotamidae	Dolophilodes	20	238.23	34	1	20.39	0.004	8.54	1.00	1.00	1.00
Eukiefferiella	I	Diptera	Chironomidae	Eukiefferiella	20	266.22	33	1	19.32	0.004	7.81	1.00	1.00	1.00
Calopteryx	I	Odonata	Calopterygidae	Calopteryx	20	439.03	25	1	13.67	0.004	5.36	1.00	1.00	0.97
Diphetor	I	Ephemeroptera	Baetidae	Diphetor	20	163.57	17	1	11.18	0.004	5.97	1.00	1.00	1.00
Psilotreta	I	Trichoptera	Odontoceridae	Psilotreta	20	163.57	14	1	8.39	0.004	4.60	1.00	1.00	0.88
Drunella	I	Ephemeroptera	Ephemerellidae	Drunella	20	439.03	13	1	7.98	0.004	3.56	1.00	1.00	0.89
Torrenticola	A	Trombidiformes	Torrenticolidae	Torrenticola	20	211.45	10	1	6.49	0.004	4.43	1.00	0.97	0.82
Procloeon	I	Ephemeroptera	Baetidae	Procloeon	20	113.93	96	2	32.27	0.004	6.20	1.00	1.00	0.99
Coenagrionidae	I	Odonata	Coenagrionidae		20	397.98	92	2	41.65	0.004	9.57	1.00	1.00	0.99
Tricorythodes	I	Ephemeroptera	Leptohyphidae	Tricorythodes	20	113.93	91	2	54.28	0.004	17.96	1.00	1.00	1.00
Argia	I	Odonata	Coenagrionidae	Argia	20	187.15	75	2	37.92	0.004	9.16	1.00	1.00	1.00
Macronychus	I	Coleoptera	Elmidae	Macronychus	20	187.15	72	2	36.95	0.004	9.76	1.00	1.00	1.00
Stenochironomus	I	Diptera	Chironomidae	Stenochironomus	20	131.75	64	2	23.36	0.004	5.86	0.99	0.99	0.94
Leptoceridae	I	Trichoptera	Leptoceridae		20	476.26	60	2	26.04	0.004	6.60	0.99	0.99	0.99
Menetus	G	Basommatophora	Planorbidae	Menetus	20	148.76	43	2	17.74	0.004	4.27	0.98	0.97	0.88
Nectopsyche	I	Trichoptera	Leptoceridae	Nectopsyche	20	300.66	41	2	26.07	0.004	8.87	1.00	1.00	1.00
Pseudocloeon	I	Ephemeroptera	Baetidae	Pseudocloeon	20	211.45	41	2	22.46	0.004	8.49	1.00	1.00	1.00
Ancyronyx	I	Coleoptera	Elmidae	Ancyronyx	20	373.67	40	2	19.20	0.004	7.07	1.00	1.00	0.99
Hexagenia	I	Ephemeroptera	Ephemeridae	Hexagenia	20	187.15	37	2	17.10	0.004	4.92	0.98	0.97	0.92
Heterocloeon	I	Ephemeroptera	Baetidae	Heterocloeon	20	124.07	32	2	20.06	0.004	7.02	1.00	1.00	1.00
Berosus	I	Coleoptera	Hydrophilidae	Berosus	20	496.59	31	2	21.57	0.004	9.95	1.00	1.00	1.00
Leptoxis	G	Neotaenioglossa	Pleuroceridae	Leptoxis	20	266.22	30	2	20.56	0.004	10.41	0.98	0.98	0.98
Helicopsyche	I	Trichoptera	Helicopsychidae	Helicopsyche	20	113.93	28	2	14.73	0.004	6.46	0.99	0.99	0.98
Arrenurus	A	Trombidiformes	Arrenuridae	Arrenurus	20	163.57	27	2	15.43	0.004	6.02	1.00	1.00	0.98
Protoptila	I	Trichoptera	Glossosomatidae	Protoptila	20	397.98	22	2	17.46	0.004	10.09	1.00	1.00	1.00
Enallagma	I	Odonata	Coenagrionidae	Enallagma	20	355.16	21	2	12.35	0.004	6.37	1.00	1.00	0.99
Macromia	I	Odonata	Corduliidae	Macromia	20	103.17	20	2	11.05	0.004	5.74	1.00	0.99	0.95
Unionicolidae	A	Trombidiformes	Unionicolidae		20	187.15	20	2	9.47	0.004	4.34	0.99	0.98	0.84
Oxyethira	I	Trichoptera	Hydroptilidae	Oxyethira	20	496.59	17	2	11.21	0.004	4.52	1.00	0.99	0.92
Ceraclea	I	Trichoptera	Leptoceridae	Ceraclea	20	373.67	13	2	7.39	0.008	4.21	1.00	0.97	0.80
Neureclipsis	I	Trichoptera	Polycentropodidae	Neureclipsis	20	507.63	13	2	10.92	0.004	7.44	1.00	1.00	1.00
Psychomyia	I	Trichoptera	Psychomyiidae	Psychomyia	20	481.51	13	2	7.86	0.008	4.23	1.00	0.99	0.85
Stylaria	O	Haplotaxida	Naididae	Stylaria	20	439.03	13	2	10.40	0.004	5.96	1.00	1.00	0.99
Dineutus	I	Coleoptera	Gyrinidae	Dineutus	20	113.93	11	2	6.75	0.004	4.44	1.00	0.99	0.87
Sparbarus	I	Ephemeroptera	Caenidae	Sparbarus	20	187.15	11	2	7.15	0.008	4.74	1.00	0.98	0.91

Table A3-5 *continued*

Target Taxon	C	Order	Family	Genus	SC	Env cp	Freq	G rp	Ind Val	pval	z	purity	Rel 05	Rel 01
Tanytarsus	I	Diptera	Chironomidae	Tanytarsus	31	1149.66	237	1	56.48	0.004	4.79	0.98	0.97	0.92
Hydropsychidae	I	Trichoptera	Hydropsychidae		31	1539.57	148	1	48.31	0.004	7.57	0.99	0.99	0.99
Optioservus	I	Coleoptera	Elmidae	Optioservus	31	1338.55	122	1	38.28	0.004	4.61	0.98	0.98	0.96
Tvetenia	I	Diptera	Chironomidae	Tvetenia	31	1281.78	95	1	35.08	0.004	7.04	1.00	1.00	1.00
Parakiefferiella	I	Diptera	Chironomidae	Parakiefferiella	31	907.11	72	1	22.23	0.012	3.18	0.96	0.95	0.73
Rheocricotopus	I	Diptera	Chironomidae	Rheocricotopus	31	1183.12	42	1	18.27	0.008	3.08	0.99	0.97	0.78
Hygrobatidae	A	Trombidiformes	Hygrobatidae		31	876.75	39	1	16.10	0.008	3.42	0.97	0.96	0.78
Ephemera	I	Ephemeroptera	Ephemeridae	Ephemera	31	2274.23	34	1	14.01	0.012	3.13	0.99	0.99	0.70
Promoresia	I	Coleoptera	Elmidae	Promoresia	31	1508.84	31	1	13.38	0.004	3.32	0.97	0.97	0.76
Paracladopelma	I	Diptera	Chironomidae	Paracladopelma	31	1558.74	27	1	11.80	0.012	3.35	1.00	0.98	0.69
Aulodrilus	O	Haplotaxida	Tubificidae	Aulodrilus	31	763.78	123	2	43.89	0.004	6.89	0.99	0.98	0.97
Nanocladius	I	Diptera	Chironomidae	Nanocladius	31	763.78	59	2	22.48	0.004	5.93	1.00	1.00	0.95
Anthopotamus	I	Ephemeroptera	Potamanthidae	Anthopotamus	31	2479.13	26	2	23.31	0.004	10.33	0.96	0.96	0.96
Laevapex	G	Basommatophora	Ancylidae	Laevapex	31	1044.44	16	2	16.49	0.004	11.09	1.00	1.00	1.00
Arrenuridae	A	Trombidiformes	Arrenuridae		31	847.13	13	2	8.33	0.004	4.86	0.99	0.96	0.86
Ephoron	I	Ephemeroptera	Polymitarcyidae	Ephoron	31	876.75	12	2	9.22	0.004	7.44	1.00	1.00	0.97
Dromogomphus	I	Odonata	Gomphidae	Dromogomphus	31	1145.79	11	2	8.86	0.004	5.95	1.00	0.99	0.92
Macrostemum	I	Trichoptera	Hydropsychidae	Macrostemum	31	1399.28	9	2	9.59	0.004	7.64	1.00	0.99	0.97
Baetis	I	Ephemeroptera	Baetidae	Baetis	32	2957.71	131	1	41.97	0.004	3.91	0.95	0.95	0.86
Gomphidae	I	Odonata	Gomphidae		32	8051.35	123	1	46.84	0.004	5.01	1.00	1.00	0.99
Ephemerellidae	I	Ephemeroptera	Ephemerellidae		32	2741.98	44	1	18.69	0.004	3.62	0.99	0.99	0.73
Dicrotendipes	I	Diptera	Chironomidae	Dicrotendipes	32	8198.42	127	2	60.64	0.004	7.44	1.00	1.00	1.00
Gammarus	M	Amphipoda	Gammaridae	Gammarus	32	4599.27	63	2	62.05	0.004	17.11	1.00	1.00	1.00
Hydrobiidae	G	Neotaenioglossa	Hydrobiidae		32	8810.41	53	2	52.14	0.004	11.18	1.00	1.00	1.00
Pristina	O	Haplotaxida	Naididae	Pristina	32	8051.35	34	2	22.28	0.004	5.61	0.99	0.98	0.84
Unionicola	A	Trombidiformes	Unionicolidae	Unionicola	32	8051.35	19	2	19.06	0.004	6.82	1.00	1.00	0.99
Gyraulus	G	Basommatophora	Planorbidae	Gyraulus	32	8425.61	17	2	22.63	0.004	11.23	1.00	1.00	0.98
Elimia	G	Neotaenioglossa	Pleuroceridae	Elimia	32	4416.88	15	2	17.86	0.004	8.74	1.00	1.00	0.99
Dreissena	B	Veneroida	Dreissenidae	Dreissena	32	6835.90	7	2	18.14	0.004	13.59	1.00	0.99	0.97
Pseudochironomus	I	Diptera	Chironomidae	Pseudochironomus	40	21162.25	46	2	52.53	0.004	8.74	1.00	1.00	1.00
Cardiocladius	I	Diptera	Chironomidae	Cardiocladius	40	12347.68	23	2	17.15	0.008	4.60	0.99	0.98	0.86
Hydroptila	I	Trichoptera	Hydroptilidae	Hydroptila	50	30248.51	82	2	72.66	0.004	6.16	0.99	0.99	0.96
Axarus	I	Diptera	Chironomidae	Axarus	50	30248.51	6	2	39.08	0.008	7.21	1.00	0.98	0.88

Table A3-6. TITAN indicator fish species output for the Appalachian LCC stream size size class. The "Size Class" column indicates the stream size class.

Common Name	Scientific Name	Size Class	env.cp	Freq	Grp	Ind Val	pval	z	purity	rel05	rel01
Creek Chubsucker	Erimyzon Oblongus	11	5.84	10	1	7.33	0.012	4.00	0.99	0.97	0.80
Creek Chub	Semotilus Atromaculatus	12	94.01	122	1	75.06	0.004	23.34	1.00	1.00	1.00
Brook Trout	Salvelinus Fontinalis	12	20.59	15	1	13.09	0.004	8.45	1.00	1.00	1.00
Orangethroat Darter	Etheostoma Spectabile	12	86.41	15	1	10.84	0.004	5.15	1.00	1.00	0.97
Largescale Stoneroller	Campostoma Oligolepis	12	11.53	14	1	10.58	0.004	5.71	1.00	0.99	0.88
Rosyside Dace	Clinostomus Funduloides	12	57.21	13	1	10.92	0.004	6.91	1.00	1.00	1.00
Rock Bass	Ambloplites Rupestris	12	60.18	130	2	66.57	0.004	17.18	1.00	1.00	1.00
Bluntnose Minnow	Pimephales Notatus	12	47.61	129	2	43.07	0.004	7.16	0.99	0.99	0.99
Northern Hog Sucker	Hypentelium Nigricans	12	37.43	116	2	58.84	0.004	14.90	1.00	1.00	1.00
Largemouth Bass	Micropterus Salmoides	12	15.54	106	2	38.31	0.004	6.47	1.00	1.00	1.00
Longear Sunfish	Lepomis Megalotis	12	68.13	95	2	43.17	0.004	10.29	1.00	1.00	1.00
Greenside Darter	Etheostoma Blennioides	12	53.69	92	2	45.00	0.004	11.30	1.00	1.00	1.00
Golden Redhorse	Moxostoma Erythrurum	12	47.61	89	2	48.81	0.004	13.08	1.00	1.00	1.00
Logperch	Percina Caprodes	12	81.85	70	2	39.14	0.004	11.23	1.00	1.00	1.00
Banded Darter	Etheostoma Zonale	12	53.69	54	2	30.78	0.004	8.80	1.00	1.00	1.00
River Chub	Nocomis Micropogon	12	15.54	45	2	22.86	0.004	7.02	1.00	1.00	1.00
Rosyface Shiner	Notropis Rubellus	12	51.18	44	2	24.35	0.004	6.90	1.00	1.00	1.00
Tessellated Darter	Etheostoma Olmstedi	12	60.18	41	2	17.80	0.004	5.76	1.00	1.00	0.99
Black Redhorse	Moxostoma Duquesnei	12	47.61	34	2	18.59	0.004	6.07	1.00	1.00	1.00
Margined Madtom	Noturus Insignis	12	35.41	33	2	15.07	0.004	4.90	1.00	1.00	0.99
Sand Shiner	Notropis Stramineus	12	35.41	31	2	16.21	0.004	6.52	1.00	1.00	1.00
Silver Shiner	Notropis Photogenis	12	89.58	29	2	16.11	0.004	6.83	1.00	1.00	1.00
Telescope Shiner	Notropis Telescopus	12	86.41	18	2	10.80	0.004	5.86	1.00	1.00	0.99
Eastern Blacknose Dace	Rhinichthys Atratulus	20	334.28	71	1	44.24	0.004	15.08	1.00	1.00	1.00
Bluegill	Lepomis Macrochirus	20	148.76	172	2	61.61	0.004	8.83	1.00	1.00	1.00
Redbreast Sunfish	Lepomis Auritus	20	300.66	71	2	31.90	0.004	9.04	1.00	1.00	1.00
Spotted Bass	Micropterus Punctulatus	20	131.75	68	2	39.06	0.004	14.21	1.00	1.00	1.00
Pumpkinseed	Lepomis Gibbosus	20	481.51	60	2	28.01	0.004	5.21	1.00	1.00	0.99
Yellow Perch	Perca Flavescens	20	334.28	39	2	24.66	0.004	7.63	1.00	1.00	1.00
Fallfish	Semotilus Corporalis	20	488.55	36	2	23.72	0.004	10.47	1.00	1.00	1.00
American Eel	Anguilla Rostrata	20	481.51	31	2	17.96	0.004	6.79	1.00	1.00	1.00
Spotted Sucker	Minytrema Melanops	20	163.57	30	2	19.53	0.004	7.16	1.00	1.00	1.00
Black Crappie	Pomoxis Nigromaculatus	20	476.26	20	2	12.68	0.004	6.34	1.00	1.00	0.99

Table A3-6 *continued*

Common Name	Scientific Name	Size Class	env.cp	Freq	Grp	Ind Val	pval	z	purity	rel05	rel01
Banded Killifish	Fundulus Diaphanus	20	373.67	18	2	10.38	0.004	4.07	1.00	0.99	0.91
Dusky Darter	Percina Sciera	20	187.15	18	2	12.24	0.004	6.52	1.00	1.00	1.00
White Crappie	Pomoxis Annularis	20	187.15	18	2	10.54	0.004	4.66	1.00	1.00	0.97
Variegate Darter	Etheostoma Variatum	20	507.63	12	2	8.33	0.004	5.25	1.00	1.00	0.95
Ohio Lamprey	Ichthyomyzon Bdellium	20	488.55	8	2	6.02	0.004	4.30	1.00	0.98	0.83
Fantail Darter	Etheostoma Flabellare	31	1183.12	62	1	28.82	0.004	7.41	1.00	1.00	1.00
Johnny Darter	Etheostoma Nigrum	31	831.56	53	1	26.37	0.004	9.36	1.00	1.00	1.00
Mottled Sculpin	Cottus Bairdii	31	1894.03	30	1	12.57	0.008	3.12	0.98	0.96	0.71
Bluehead Chub	Nocomis Leptocephalus	31	1183.12	22	1	11.57	0.004	5.17	1.00	1.00	0.98
Smallmouth Bass	Micropterus Dolomieu	31	1159.17	132	2	77.08	0.004	19.07	1.00	1.00	1.00
Spotfin Shiner	Cyprinella Spiloptera	31	924.04	109	2	63.04	0.004	17.35	1.00	1.00	1.00
Common Carp	Cyprinus Carpio	31	2136.69	86	2	63.09	0.004	16.96	1.00	1.00	1.00
Channel Catfish	Ictalurus Punctatus	31	907.11	77	2	55.33	0.004	21.03	1.00	1.00	1.00
Mimic Shiner	Notropis Volucellus	31	648.19	47	2	28.64	0.004	9.26	1.00	1.00	1.00
Spottail Shiner	Notropis Hudsonius	31	958.12	35	2	27.08	0.004	11.71	1.00	1.00	1.00
Shorthead Redhorse	Moxostoma Macrolepidotum	31	958.12	32	2	21.15	0.004	7.89	1.00	1.00	1.00
Silver Redhorse	Moxostoma Anisurum	31	1614.52	30	2	25.30	0.004	11.24	1.00	1.00	1.00
Walleye	Sander Vitreus	31	1930.25	27	2	25.76	0.004	12.37	1.00	1.00	1.00
River Redhorse	Moxostoma Carinatum	31	1071.55	25	2	21.53	0.004	11.97	1.00	1.00	1.00
Smallmouth Redhorse	Moxostoma Breviceps	31	2479.13	24	2	23.54	0.004	11.45	1.00	1.00	1.00
Quillback	Carpiodes Cyprinus	31	1930.25	21	2	20.21	0.004	12.90	1.00	1.00	1.00
Streamline Chub	Erimystax Dissimilis	31	1614.52	14	2	11.62	0.004	6.03	1.00	1.00	0.99
Northern Pike	Esox Lucius	31	1115.35	11	2	10.00	0.004	7.23	1.00	1.00	0.98
Grass Pickerel	Esox Americanus Vermiculatus	31	1352.59	10	2	8.61	0.004	6.69	1.00	0.99	0.95
White Perch	Morone Americana	31	1508.84	10	2	9.34	0.004	6.38	1.00	1.00	0.98
Gilt Darter	Percina Evides	31	1202.38	9	2	6.81	0.004	4.14	1.00	0.97	0.86
Muskellunge	Esox Masquinongy	31	958.12	9	2	6.78	0.004	4.82	1.00	0.99	0.90
Highland Shiner	Notropis Micropteryx	31	1213.33	8	2	7.62	0.004	5.26	1.00	0.98	0.93
Alewife	Alosa Pseudoharengus	31	1508.84	6	2	6.32	0.004	5.60	1.00	0.96	0.84
Gizzard Shad	Dorosoma Cepedianum	32	3024.42	64	2	56.02	0.004	17.21	1.00	1.00	1.00
Brook Silverside	Labidesthes Sicculus	32	3024.42	33	2	22.32	0.004	7.43	1.00	1.00	0.99
Bullhead Minnow	Pimephales Vigilax	32	2883.71	19	2	21.51	0.004	10.82	1.00	1.00	1.00
Shield Darter	Percina Peltata	32	3864.18	13	2	12.30	0.004	6.86	1.00	1.00	1.00
Satinfin Shiner	Cyprinella Analostana	32	4470.83	10	2	7.84	0.008	4.33	1.00	0.96	0.82
Swallowtail Shiner	Notropis Procne	32	8425.61	9	2	13.92	0.004	9.96	1.00	0.99	0.93

Table A3-6 *continued*

Common Name	Scientific Name	Size Class	env.cp	Freq	Grp	Ind Val	pval	z	purity	rel05	rel01
American Shad	Alosa Sapidissima	32	8051.35	7	2	12.97	0.004	10.36	1.00	0.99	0.97
Blueback Herring	Alosa Aestivalis	32	4998.91	6	2	9.25	0.004	7.72	1.00	0.98	0.91
White Bass	Morone Chrysops	40	21162.25	17	2	44.91	0.004	20.29	1.00	1.00	1.00
Shortnose Gar	Lepisosteus Platostomus	40	17991.37	8	2	21.16	0.004	17.47	1.00	1.00	1.00
Striped Bass	Morone Saxatilis	40	16480.80	8	2	23.23	0.004	17.25	1.00	1.00	0.99
Grass Carp	Ctenopharyngodon Idella	40	24715.77	6	2	17.88	0.004	10.97	1.00	0.99	0.94
Silver Carp	Hypophthalmichthys Molitrix	40	24715.77	6	2	22.66	0.004	16.30	1.00	1.00	0.98
Inland Silverside	Menidia Beryllina	40	19501.04	5	2	14.81	0.004	16.32	0.99	0.97	0.95
Mooneye	Hiodon Tergisus	40	24715.77	5	2	17.60	0.004	14.18	0.99	0.98	0.91
Freshwater Drum	Aplodinotus Grunniens	50	27692.37	47	2	74.03	0.004	18.54	1.00	1.00	1.00
Flathead Catfish	Pylodictis Olivaris	50	27692.37	43	2	70.71	0.004	17.98	1.00	1.00	1.00
Longnose Gar	Lepisosteus Osseus	50	27692.37	42	2	66.53	0.004	15.15	1.00	1.00	1.00
Emerald Shiner	Notropis Atherinoides	50	27692.37	39	2	77.66	0.004	19.60	1.00	1.00	1.00
Smallmouth Buffalo	Ictiobus Bubalus	50	30248.51	33	2	81.56	0.004	23.06	1.00	1.00	1.00
River Carpsucker	Carpiodes Carpio	50	27692.37	27	2	55.05	0.004	18.30	1.00	1.00	1.00
Redear Sunfish	Lepomis Microlophus	50	28854.72	26	2	28.80	0.004	7.50	0.99	0.99	0.96
Sauger	Sander Canadensis	50	31434.56	22	2	58.35	0.004	16.88	1.00	1.00	1.00
Skipjack Herring	Alosa Chrysochloris	50	28169.23	15	2	62.49	0.004	25.47	1.00	1.00	1.00
Threadfin Shad	Dorosoma Petenense	50	174446.70	13	2	74.51	0.004	16.28	1.00	1.00	1.00
Black Buffalo	Ictiobus Niger	50	28169.23	10	2	41.91	0.004	23.82	1.00	1.00	1.00
Silver Chub	Macrhybopsis Storeriana	50	31434.56	10	2	30.78	0.004	14.30	1.00	1.00	1.00
Wiper	Morone	50	30248.51	10	2	30.32	0.004	14.33	1.00	1.00	0.99
Bigmouth Buffalo	Ictiobus Cyprinellus	50	28169.23	8	2	31.48	0.004	17.94	1.00	1.00	1.00
River Shiner	Notropis Blennius	50	31434.56	8	2	33.25	0.004	26.17	1.00	1.00	0.99
Channel Shiner	Notropis Wickliffi	50	53367.15	7	2	45.18	0.004	20.31	1.00	0.99	0.98
Unknown Morone	Morone	50	69276.77	4	2	50.00	0.004	16.23	0.98	0.98	0.92

Appendix 4. Literature Review of Freshwater Classification Frameworks

List of Figures and Tables

PART I: Taxonomic and Environmental Classification

Introduction

Identifying aquatic ecosystems requires a classification of stream and lake features into recognizable entities or categories. Although a number of nationally recognized terrestrial community classifications exist, the most accepted being the National Vegetation Classification System (Grossman et al. 1998), currently there is no national or international standard for classifying aquatic communities or ecosystems. Despite the lack of a national aquatic community classification, aquatic ecosystem classifications and frameworks have been developed at a variety of spatial scales. Their goal is often to reflect the distribution of aquatic biological communities. Biological communities may be defined as an interacting assemblage of organisms, their physical environment, and the natural processes that affect them. These assemblages recur across the landscape under similar habitat conditions and ecological processes (Higgins et al. 2005). The methods used to develop aquatic ecosystem classifications vary widely, as do the biotic and abiotic variables considered in the classifications. The classifications generally fall into two broad categories: 1) taxonomic or bio-ecosystem classifications and 2) environmental or geo-physical ecosystem classifications (Rowe and Barnes 1994); however some classifications combine aspects of both.

Taxonomic Classification

Overview

Taxonomic or bio-ecosystem classifications emphasize biological data and are most often derived from analysis of patterns in species presence or abundance data. This species data often focuses on fish or macroinvertebrates which are more widely sampled, but sometimes includes algae, mussels, amphibians, and other freshwater biota. Many examples of taxonomic based classifications using species assemblage data exist at small to medium watershed scales (Bain 1995, Kingsolving and Bain 1993, Lobb and Orth 1991). These studies describe species assemblage patterns within a given small river system or watershed. Examples of taxonomic aquatic community classifications that exist at statewide or other large geographic scales are less common. In the northeast U.S. Appalachian LCC region these large geographic scale taxomonic focused classifications include the Fish Assemblages in the Conterminous USA (Herlihy et al 2006), the Pennsylvania Aquatic Community Classification (Walsh et al, 2007), New York Heritage Aquatic Community Classification (Reschke 1990, Edinger et al. 2002), and the Maryland Department of Natural Resources Aquatic Key Habitats (MD DNR 2012). These classifications are briefly described below.

Applications and Examples

Fish Assemblages in the Conterminous USA (Herlihy et al 2006)

This project compiled a national-scale database of lotic fish assemblages containing 5,951 sample sites from available national and state agency data. Cluster analysis (Bray-Curtis distance) and indicator species analysis were used to cluster the data, identify clusters, and describe them. They developed 12 national clusters of fish assemblage groups that were well described by indicator fish species and predicted using both discriminant function analysis and classification tree analysis. The groups were described qualitatively as associated with streams or rivers of major size classes, nutrient levels, temperature class, turbidity, and substrate. They also examined the relationship of ecoregion, physiography, hydrologic units, and geopolitical boundaries schemes to fish assemblage similarity. Existing schemes captured about half the within-group similarity expressed in biologically derived clusters. Cluster and mean similarity analyses were not strongly influenced by using data subsets that removed nonnative fish species and disturbed sites. This suggests that the underlying mechanisms responsible for controlling fish assemblage patterns at the national scale were fairly robust to the effects of nonnative species and anthropogenic disturbances.

Pennsylvania

The Pennsylvania Aquatic Community Classification Project classified streams and rivers based on community assemblages of macroinvertebrates, mussels, and fish (Walsh et al. 2007). Separate classifications were developed for each of the above 3 taxa groups. The project developed a database of comprehensive aquatic datasets for the state which enabled a large, statewide analysis of existing aquatic biological community survey data. Multivariate ordination and cluster analysis were used to determine initial community groups. Indicator Species Analysis, classification strength, and review by taxa experts helped to refine community types. Final community groupings include 13 mussel communities, 11 fish communities, 12 communities of genus-taxonomy macroinvertebrate communities, and 8 family-taxonomy macroinvertebrate communities. Seasonal influences on macroinvertebrate abundance and basin specificity of fish and mussels were used to define classifications. Datasets within a spring index period were used to classify macroinvertebrates. Three separate basin classifications were necessary to describe mussel communities (Ohio-Great Lakes, Susquehanna-Potomac, and Delaware), while two separate basin classifications were applied to fish communities (Ohio-Great Lakes, Atlantic Basin). Each group is described with a set of community indicator species, a set of species of conservation concern, a general description of the habitat, and habitat threats. By systematically evaluating fish, mussel, and macroinvertebrate communities, this project quantified for the first time these patterns of freshwater biodiversity and gave a better understanding to the composition and natural assemblages found within each of these 3 major freshwater taxa groups. The project also developed a GIS dataset which combined classes of bedrock geology, stream gradient, and watershed size in into physical stream types for each reach in the study area. Models were developed to predict community presence based on the reach and watershed attributes for all mussel, fish, and macroinvertebrate communities. Many of these reach to biological community relationships are many to one.

New York Classification

The New York Heritage Aquatic Community Classification provides another example of a biologically based classification (Edinger 2002).. This classification was designed to be used by biologists in the field to identify aquatic communities. Descriptions of aquatic communities and the indicator and representative biological taxa of these communities were developed by review of literature, species lists compiled from both qualitative and quantitative field surveys, and in some cases interviews with biologists. The New York Heritage Program currently uses this classification to assign each of its aquatic community survey locations to one of these community types. Most communities in the classification have some mapped known occurrence, although no aquatic community is yet comprehensively mapped. The New York classification provides a list of primary organisms used to define the community, and also when possible, main environmental characteristics to help distinguish the community. Riverine systems use fish as the primary organisms and watershed position and stream flow as the environmental characteristics. Community descriptions include dominant species (species with the greatest abundance), codominant species (species with relatively high abundance), and characteristic species (species that are commonly found in the community although not necessarily abundant). Some descriptions also include brief discussions of ecologically important environmental characteristics and disturbance patterns that distinguish the community. A state rarity rank and global rarity rank also accompany the classification based on the estimated number of occurrences and distribution of the community as well as its vulnerability to human disturbance or destruction. The 7 riverine system natural communities include rocky headwater stream, marshy headwater stream, mid-reach stream, main channel stream, backwater slough, intermittent stream, and coastal plain stream.

Maryland Key Riverine Habitats

The Maryland Department of Natural Resources Key Riverine Habitats provides another example of a biologically based classification, although similar to New York it also provides environmental setting descriptions for the types. This classification was developed for the State Wildlife Action plans and provides lists species of greatest conservation need and other wildlife associated with these types. Descriptions of the types and the species associated with them were developed by review of literature and both qualitative and quantitative analysis of field surveys. Community descriptions include rare and common fish, insects, reptiles and amphibians, crayfish, birds, and crustaceans. The description of the habitat includes geographic distributions which are often defined by terrestrial ecoregion or subsection lines, description of the water temperature, stream size, and in some cases slope, geology or soil types that help define these habitats. Each habitat is also described in terms of major threats, conservation actions, and inventory/monitoring/research needs for species of greatest concern. The habitats include coldwater streams, blackwater streams, Piedmont streams, coastal plain streams, limestone streams, highland streams, piedmont riverine, coastal plain riverine, and highland riverine.

Environmental Classification

Overview

Environmental or geo-ecosystem classifications give precedent in classification to environmental or physical factors and emphasize a streams' relationship to its physical environment across a wide range of scales in space and time (Frissel et al. 1986, Rowe and Barnes 1994). Environmental or geo-ecosystem aquatic classifications are based on the assumption that 1) physical factors such as climate and physiography constrain the observed range of aquatic ecological processes and 2) these factors can be used to predict the expected range of biotic community types (Tonn 1990, Jackson and Harvey 1989, Hudson et al. 1992, Maxwell et al. 1995, Angermeier and Winston 1998, Pflieger 1989, Burnett et al. 1998).

Much research has been done to support the relationship between environmental factors and patterns of freshwater biodiversity. For example, large continental aquatic zoogeographic patterns have been shown to be associated with drainage connections changing in response to major climatic and geologic events (Hocutt and Wiley 1986). Regional patterns in geomorphology and climate have also been shown to affect stream hydrology, sedimentation, nutrient inputs, and channel morphology that in turn alter stream form and function and control regional variation in stream systems (Hughes et al. 1994, Minshal 1994, Poff and Allan 1995; Hawkins et al. 2000). Within regions, there are finer-scale patterns of stream and lake morphology, size, gradient, watershed physiography, and local zoogeographic sources that are related to distinct aquatic assemblages and population dynamics (Frissell et al. 1986, Flecker 1992, Rosgen 1994; Maxwell et al. 1995, Angermeier and Winston 1998, Seelbach et al. 1997, Mathews and Robison 1998).

Environmental classifications are often developed within a spatial and temporal hierarchy. The interacting spatiotemporal factors define a system in terms of its potential capacity. Potential capacity is defined as all possible developmental states and all possible performances that a system may exhibit while still maintaining its integrity as a coherent entity (Warren 1979). System potential capacity is a theoretical concept that cannot be fully and directly measured empirically. The concept however provides direction on appropriate variables of classification. It suggests that for a system defined within a given spatiotemporal frame, the variables selected for classification should be those that are most general, invariant, and causal in determining the behavior of the system (Warren and Liss 1983). Classification should thus account for not only the present state and performances of the stream, but also its potential performances over a range of conditions that operate within that spatiotemporal scale (Warren 1979; Warren and Liss 1983).

For the spatial scales, within a regional biogeoclimatic geographic zone, environmental aquatic classifications often use a nested spatial hierarchy of drainage basins from small tributary catchments to largest basins. Smaller scale systems develop within constraints set by the larger scale systems of which they are part. Controlling or constraining environmental variables differ at different locations of the spatial hierarchy. Large watershed scale river systems are controlled by variables related to regional climate and physiography; while at medium scales valley segments and stream reaches reflect variations in geomorphology and mesoclimate; and fine scale channel units respond to variation in features such as substrate size and woody debris that change over periods of months to years (Maxwell 1995). For example, pool/riffle morphology of a reach is largely determined by the slope of the reach and input of sediments and water from the contributing drainage basin. Slope of the reach and pattern of sediment and water discharge are themselves controlled by coarse-scale, long-term variables like climate, lithology and structure, basin topography/area, and paleohydrologic history (Frissell et al 1986).

Temporal variation also significantly affects variation within aquatic ecosystems at every spatial scale. Temporal variation can have both relatively predictable components, such as seasonal variation, along with stochastic components (major geologic events, local invasions, disease, growth, decline of species) (Hawkins et al 2000). The time period over which any given aquatic ecosystem type is likely to persist within a given range of variation will vary, usually with the scale of the system. For example, the time scale of expected continuous persistence of an aquatic system is suggested to be 1-10 years for a pool/riffle system, 10-100 years for a reach system, 10-1,000 years for a segment system, to 1000-10,000 years for a watershed class (Maxwell et al 1995). Understanding the temporal component of potential classification variables can direct users to appropriate stable variables for a given spatiotemporal classification level. For example, as seen across geologic temporal time scales ($>10^5$ year) the slope of stream channel is a changing variable, yet viewed in a time frame of 10-100 years, channel slope is relatively invariant and slope could be considered an independent causal variable that controls on channel morphology and sediment transport at the reach system classification scale (Frissel et al 1986).

In addition to understanding the temporal and spatial hierarchy and appropriate classification variables, classification at any level involves two further steps: 1) delineate the boundaries between systems and 2) describe how the systems that have been delineated are similar or dissimilar by assigning them to some group within the total population based on their origin, development, and potential response to environmental changes. Boundaries between stream systems can be based on geomorphic features that constrain potential physical changes in the stream vertically, longitudinally, and laterally.

Stream system boundaries can be based on catchment areas or drainage divides, basin relief, bedrock faults, and valley developments. Segment systems boundaries could similarly be based on tributary junctions, falls, bedrock, elevation, or other structural discontinuities or factors controlling lateral migration such as valley side slope confinement (Frissel et al. 1986). For example, a stream reach dissecting a terrace with banks composed of gravel alluvium has a different capacity for bank erosion, channel morphology changes, or fish production than an adjacent reach cutting through clay cohesive soils (Frissel et al 1986). The boundary of the two reach systems would thus correspond to the location where bedrock or surficial geology substantially changed. In reality, communities will usually vary continuously on the landscape along ecological gradients which makes defining exact system boundaries extremely difficult; however defining draft boundaries or key factors that can be used to distinguish major transitions is necessary in classification.

Stream size is one of the most fundamental physical factors used to delineate system boundaries in environmental aquatic classification. Catchment drainage area, stream order, number of first order streams above a given segment, and flow volume are all recognized as measures of stream size. Although ecologically significant stream size class breaks may vary numerically between regions, the highly recognized "river continuum concept" provides a qualitative framework to describe how the growth of the physical size of the stream is related to major river ecosystem changes from headwaters to mouth (Vannote et al. 1980). The river continuum concept identifies predicable biotic changes along the longitudinal gradient from source stream to large major river as stream size and position along the longitudinal gradient change. Low order sites are small headwater streams where inputs of coarse particulate organic matter (CPOM) provide a critical resource base for consumer community. As a river broadens at mid-order sites, energy inputs are expected to change as CPOM inputs decrease and sunlight begins to reach the stream bottom to support significant periphyton production. Fine Particulate Organic Matter (FPOM) to the system increases and macrophytes become more abundant as river size further increases, and reduced gradient and finer sediments form suitable conditions for their establishment. In high order sites, the channel gets very large and the main channel becomes unsuitable for macrohphytes or periphyton due to turbidity, fast current, and lack of stable substrates. Autochthonous production by phytoplankton and other instream sources is limited by turbidity. Allochthonous organic matter inputs occurring outside the stream channel are again expected to be the primary energy source as processes such as inputs from the floodplain scouring increase and FPOM imported from upstream systems becomes less important. These changes in energy input along the longitudinal gradient of a stream system have profound consequences for the composition of consumer communities and the functioning of the ecosystem. For example, shredders should prosper in low order streams while grazers will prosper in mid-order streams (Allen 1995). Numerous studies have tested the river continuum concept and used it as a basis for general physical stream classifications across many biomes. (Minshall et al. 1983; Hawkins, Murphy, and Anderson 1982).

In addition to a measure of stream size, stream morphology has been integrated into many aquatic classifications to define system boundaries and classification types. Stream morphology characteristics of slope and sinuosity for example strongly affect hydrologic processes such as water and sediment yield, flow duration, and magnitude and frequency of floods. Straight, meandering, and braided physical stream patterns were used in an early classification by Leopold and Wolman (1957). Schumm (1963) delineated a reach classification based on channel stability (stable, eroding, or depositing) and mode of sediment transport (mixed load, suspended load, and bedload) based primarily on channel slope and then integrated a measure of size in channel dimension (Schumm 1977). Culbertson et al. (1967) used depositional features, vegetation, braiding patterns, sinuosity, meander scrolls, bank heights, levee formations, and floodplain types in a classification. Khan (1971) developed a quantitative classification for sand-bed streams based on sinuosity, slope, and channel patterns. Montgomery and Buffington (1997) proposed a reach-scale morphological classification for mountain stream channels that reflects the typical downstream progression of channel bedforms that occurs as stream gradient and bed material size decrease. Rosgen (1994, 1996) developed a comprehensive and widely used hierarchical stream classification system based on geomorphic variables including slope, sinuosity, width-to-depth ratio, and substrate size.

Many environmental aquatic classifications have been implemented nationally and internationally and serve as a surrogate measure of aquatic biodiversity potential (Van Sickle and Hughes 2000, Oswood et al 2000, Waite et al. 2000, Sandin and Johnson 2000, Rabeni and Doisy 2000, Marchant et al 2000, Feminella 2000, Gerritsen et al 2000, Hawkins and Vinson 2000, Johnson 2000, Pan et al 2000, Bryer 2001, Smith et al 2002). Components of environmental classifications such as regionalization and use of stream size and temperature classes have also been used widely in bioassessment (Karr et al.1986, Hughes et al. 1994, Hawkins et al. 2000,, Frimpong and Angermeier 2010). Descriptions of major environmental classification frameworks that could be applicable to the Appalachian LCC Region are provided below and include the conceptual frameworks of Frissel, Rosgen, Maxwell, and Higgins, as well as examples of several applications of the Higgins approach.

Frissel

Frissel defines an environmental classification framework where stream systems are hierarchically organized on successively lower spatial-temporal levels into the following classes: stream system, segment system, reach system, pool/riffle system, and microhabitat systems (Frissel et al. 1986). Frissell's classification framework includes stream morphology and size as key classification variables, but suggests a variety of additional key physical structuring factors depending on the spatio – temporal hierarchy of the classification. Frissel suggests that larger regional scale stream system classifications should be defined by the watershed's biogeoclimatic region, geology, topography, soils, climate, channel shape and slope, and network structure. Frissell's smaller spatial scales systems of segments, reaches, and pool-riffles types are defined by distinguishing more local morphological characteristics. For example, segment systems are defined by channel floor lithology, channel floor slope, position in the drainage network, valley sideslopes, soil association, and potential climax vegetation. Frissell's pool/riffle systems are defined by bed topography, water surface slope, substrates immovable in < 10 year flood, and bank configuration (Frissel et al. 1986).

Rosgen

Rosgen's classification of natural rivers (Rosgens 1994, 1996) was developed using data from 450 rivers throughout the U.S, Canada, and New Zealand and is driven by stream morphology at each spatiotemporal scale. Stream pattern morphology is directly influenced and can be described by eight major variables including channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size (Rosgen 1994, 1996). Theoretically, a change in any one of these variables sets up a series of channel adjustments that leads to a change in the others, resulting in channel pattern alterations that influence aquatic habitats and thus aquatic species distributions (Rosgen 1994, 1996).

The Rosgen classification is divided into 4 hierarchical levels. Level 1 is a broad geomorphic characterization integrating the landform and fluvial features of valley morphology with channel relief pattern, shape, and dimension. It depends on lithology, landform, soils, climate, depositional history, basin relief, valley morphology, river profile morphology, and general river pattern. It uses measurements of cross-section morphology, longitudinal profiles, and plane view morphology to classify rivers into 9 broadly defined stream type categories. Examples of these categories include Aa+: very steep, deeply entrenched debris transport systems, A: Steep, entrenched, cascading, steep/pool high energy/debris transport systems, B: Moderately entrenched, moderate gradient, riffle dominated channel with infrequently spaced pools, C: Low gradient meandering point-bar riffle/pool, alluvial channels with broad floodplains, or D: Braided channels with very wide channel and eroding banks (Rosgens 1994, 1996). Level 2 adds a morphological description that subdivides the initial stream types based on discreet slope ranges and dominant channel material. It depends on field measurements of channel patterns, entrenchment ratio, width/depth ratio, sinuosity, channel material, and slope. Level 3 is based on more detailed information including measurements of depositional patterns, meander patterns, confinement features, flow regime, debris occurrence, channel stability index, and bank erodibilty among others. Level 4 further subdivides the previous levels by finer scale variables such as sediment transport rates, bank erosion rates, aggradation/degradation processes, fish biomass, aquatic insects, and riparian vegetation.

Maxwell

In 1995, the USFS adopted the Hierarchical Framework of Aquatic Ecological Units (Maxwell et al. 1995) classification framework based on the principles of Rosgen, Frissel, and other geo-ecosystem classifications (USFS 2001). To date, this framework has been applied at a handful of state and sub-state level sites by the USFS (USFS 2001). This multiple scale framework is linked with terrestrial systems and complements the USFS hierarchy of terrestrial ecological unit classification developed in 1993. The USFS terrestrial and aquatic frameworks jointly classifies the stable (biophysical) components of terrestrial and aquatic ecosystems into a limited number of discrete units that, at any given scale, are mappable and distinguishable from one another by differences in various structural or functional characteristics, and biological and physical potentials (USFS 2001). In the USFS framework, separate information themes are developed for factors considered more transient such as current vegetation, wildlife, and fish distributions, road densities, insect infestations, and land use.

The USFS Hierarchical classification outlines the following 10 hierarchical classification mapping units: Subzone, region, subregions, river basins, subasins, watersheds, subwatersheds, valley segments and lakes, stream reaches and lake zones, and channel units and lake sites (Table 1). Subzones to Subbasins are defined at scales of 1:2,000,000+ by the physical features of regional climate, regional geology, river networks, and basin boundaries in combination with fish families and unique aquatic assemblages. Watershed and subwatershed types are defined a scale of 1:100,000 where physical features such as watershed boundaries, stream networks, geomorphology, and local climate define the map unit type according to the local geoclimatic, zoogeographic setting and morphological features. Valley segments are defined at a scale of 1:24,000 and reflect the valley geomorphology, climatic regime, and hydrologic regime. Stream reaches are defined at a scale of 1:12,000 and reflect channel morphology bedform/materials, bank condition, and woody debris. Channel units are defined at a scale of 1:1000 and reflect detailed habitat features, depth patterns, and debris patterns. The distinguishing physical features, disturbance patterns, biotic processes, and approximate persistence time of each spatial scale are defined in the table below.

Table 1: USFS Hierarchical Framework of Aquatic Ecological Units (Maxwell et al. 1995)

Mapping Scale	Riverine Patterns	Physical features	Disturbance pattern	Biotic processes	Approx. time for change/years
1:2,000,000	Subzones to Subbasins	Basin boundaries, river networks, regional climate, regional geology	Tectonics, glacial cycles	Speciation/ extinction	>10,000
1:100,000	Watersheds, Subwatersheds	Watershed boundaries, stream networks, geomorphology, local climate	Local uplift, folding/faulting, flood cycles	Genetic variation	1,000-10,000
1:24,000	Valley Segments	Valley geomorphology, climatic regime, hydrologic regime	Valley filling, channel migration, stream incision	Population demographics	100-1000
1:12,000	Stream Reaches	Channel morphology, bed form, materials, bank conditions, woody debris	Peak flows, Sediment transport	Population dynamics	10-100
1:1,000	Channel Units	Habitat features, depth patterns, debris patterns	Hydrolics, Scour and deposition, bedload sorting	Behavior patterns	1 - 10

Higgins

In 1998 The Nature Conservancy (TNC) Freshwater Initiative Program integrated classification concepts from Maxwell, Rosgen, Frissel, and others to define a geo-ecosystem environmental hierarchical aquatic classification framework for use in its ecoregional planning effort. This standard classification framework can be implemented at ecoregional scales and emphasizes environmental gradients of climate, elevation, landform, and geology that are known to shape aquatic ecosystems at several spatial scales and influence the physical habitat diversity (Higgins et al 2005). The classification framework is based on four key assumptions about the connection between habitat structure and biological communities. (Higgins et al. 2005) 1) Large-scale physiographic and climatic patterns influence the distribution of aquatic organisms and can be used to predict the expected range of community types within these large zones (Tonn 1990, Jackson and Harvey 1989, Hudson et al. 1992, Maxwell et al. 1995, Angermeier and Winston 1998, Pflieger 1989, Burnett et al. 1998); 2) Aquatic communities exhibit distribution patterns that are predictable from the physical structure of aquatic ecosystems (Schlosser 1982, Tonn 1990, Hudson et al. 1992); 3) Although aquatic habitats are continuous, we can make reasonable generalizations about discrete patterns in habitat use (Vannote et al. 1980, Schlosser 1982, Hudson et al. 1992); and 4) By nesting small classification units (Aquatic Ecological Systems, macrohabitats) within the large climatic and physiogrpahic zones, we can account for community diversity that is difficult to observe or measure (taxonomic, genetic, ecological, evolutionary context) (Frissell et al. 1986, Angermeier and Schlosser 1995)

TNC has classified freshwater ecosystems in over thirty ecoregions in the U.S. and Latin America using these methods. The WWF, Aquatic GAP and others are also adopting TNC's methods for regional conservation planning (Higgins et al. 2005). The classification framework uses four hierarchical spatial scales: 1) Zoogeographic Region, 2) Ecological Drainage Unit 3) Aquatic Ecological System, and 4) Macrohabitat. Zoogeographic Subregions describe continental patterns of freshwater biodiversity. These units are distinguished by patterns of native fish distribution that are a result of large-scale geoclimatic processes and evolutionary history. For North America, TNC adopted the freshwater ecoregions developed by the World Wildlife Fund (Abell et al. 2000). Ecological Drainage Units (EDU's) delineate areas within a zoogeographic subregion and correspond roughly with large watersheds of 6-8th order major river systems (~3000-10,000 sq. miles). EDUs are hypothesized to account for the variability within zoogeographic sub-regions due to finer-scale drainage basin boundaries and physiography. Aquatic Ecological Systems (AES) are defined within an EDU as networks of streams and associated lakes and wetlands that occur together in similar geomorphological patterns, are tied together by similar ecological processes or environmental gradients, and form a robust cohesive and distinguishable unit on a map. AES can be defined at multiple sub-scales within an EDU to represent for example types of 1) headwater to small river systems, 2) medium sized river systems, and 3) large river systems. Macrohabitats are the finest scale unit of classification and define stream reach types or lake types. Macrohabitats are based on abiotic variables known to structure aquatic communities at this reach or lake scale and that can be modeled in a GIS (Table 2). These variables include factors such as stream or lake size, gradient, general chemistry, flashiness, elevation, and local connectivity. The macrohabitat model is based on work done by Seelbach et al.1997, Higgins et al. 1998, and Sowa et al. 2005 Macrohabitats are relatively homogeneous with respect to energy and nutrient dynamics, habitat structure, and position within the drainage network. The physical character of macrohabitats and their associated biological composition are a product of the immediate geological and topographical setting and the transport of energy and nutrients through the systems (Higgins et al. 2005). The driving processes, measurable variables, and GIS datasets used to define macrohabitats are listed in Table 2.

Table 2: TNC Aquatic Classification Framework: Reach-Scale Macrohabitat Ecosystem Attributes, Model Variables, and Spatial Data

Ecosystem Attribute	Modeled Variable	Spatial Data
Zoogeography	1) Region 2) Local Connectivity (to lake, wetland, ocean, large river, etc.)	1) Ecological Drainage Unit 2) Hydrography
Morphology	1) Size (drainage area) 2) Gradient	1) Hydrography 2) Hydrography and DEM
Hydrologic Regime	Stability/Flashiness and Source	Hydrography, Physiography, Geology
Temperature	1) Climatic Zone 2) Elevation	1) Ecological Drainage Unit/Ecoregions 2) DEM
Chemistry	Geology and Hydrologic Source	Geology

Applications and Examples

Freshwater Biodiversity Conservation Assessment of the Southeastern United States (Smith et al. 2002)

This project developed a stream classification as part of The Nature Conservancy's efforts to identify the most important areas for freshwater biodiversity conservation in the southeastern United States. The project covered four large freshwater ecoregions: Tennessee-Cumberland, Mississippi Embayment, South Atlantic, and Mobile Bay and was funded by the Charles Steward Mott Foundation. The project implemented a hierarchical classification of aquatic ecosystems using the Higgins classification approach to define and map the communities and ecosystems in the landscape. This classification helped planners identify "coarse filter" targets, which are large-scale ecosystems that capture multiple levels and types of biodiversity, including untracked common species, communities, and ecological processes. The classification systems was not meant to replace detailed data on the distribution and status of species and communities, but provided conservation planners with a tool to help deal with incomplete information.

Within the freshwater ecoregions, the project delineated Ecological Drainage Units (EDUs). EDUs facilitate evaluation of targets in the set of sub-regional ecological and evolutionary settings they occur. EDUs were defined as groups of watersheds (8-digit U.S. Geological Survey Hydrologic Units) within aquatic ecoregions with similar patterns of zoogeographic sources and constraints, physiography, drainage density, hydrologic characteristics and connectivity. Identifying and describing EDUs stratified basins into smaller units for more accurate evaluation of patterns of freshwater biodiversity, promoted consideration of sub-regional differences in freshwater species pools, and guided conservation goals for targets across their environmental ranges.

Aquatic ecological systems were then mapped within EDUS. Aquatic ecological systems are rivers, streams, and lakes with similar geomorphological patterns tied together by ecological processes (e.g., hydrologic and nutrient regimes, access to floodplains) or environmental gradients (e.g., temperature, chemical and habitat volume), and form a distinguishable unit on a hydrography map. To identify aquatic systems, the project employed an approach developed by the Freshwater Initiative of The Nature Conservancy (Higgins et al. 1998, Groves et al. 2000) that uses a physically-based classification mapped in a Geographic Information System (GIS) to define the environmental patterns of freshwater ecosystems. While the systems defined by the same set of attributes may occur in several EDUs, they identified these system types as distinct because the context of each EDU is distinct. Aquatic system classification and delineation involved: 1. Determine physicochemical habitat variables that define environmental gradients and influence species distributions: stream size, gradient, elevation, downstream connectivity, and bedrock and surficial geologic characteristics (as they relate to hydrologic regime, water chemistry,stream and river geomorphology, and dominant substrate material; Seelbach et al. 1997). 2. Acquire and develop GIS data layers of these habitat variables or other data layers that can be used to model these variables and attach them to the EPA Rf3 1:100,000 stream reaches. 3. Determine classes for these variables that correspond to ecologically meaningful breaks in environmental gradients and attribute each stream reach with a value for the variables. 4. Classify the types of ecosystems by identifying all distinct combinations of physicochemical attributes. 5. Map aquatic systems by assigning system types to stream reaches at the small watershed scale. Aquatic systems of each size category were further distinguished by patterns in the other classification variables including Elevation, Gradient, Downstream Connection type, and Bedrock and Surficial Geology Classes . The detailed class breaks are shown in Table 3

Table 3: Reach Classification Attributes from Freshwater Biodiversity Conservation Assessment of the Southeastern United States (Smith et al. 2002)

Category	Range of Values
Size	Link magnitude
Headwater	1-10
Creek	11-100
Small River	101-1000
Medium River	1001-2500
Large River	>2500
Elevation	Meters
Low	<300
Moderate	301-900
High	>900
Gradient	Rise/Run
Low	<0.01
Moderate	0.01-0.05
High	>0.05
Downstream Connections	Link magnitude
Streams	<100
Small and Medium Rivers	101-2500
Large Rivers	>2500
Lakes	NA
Ocean	NA
Embayment	NA
Bedrock and Surficial Geology	Recent river alluvium, Gravels, Sands, Mixed sands, silts, clays, Noncalcareous clays, Calcareous clays, Pleistocene terrace, Pleistocene valley-train, Loess, Marsh deposits, Loose limestone, shell, Alkaline sedimentary, Moderately alkaline mixture, Fissile shales, Erodible acidic sedimentary, meta-sedimentary, Resistant acidic sedimentary, meta-sedimentary, Erodible acidic, intermediate igneous, metaigneous, Resistant acidic, intermediate igneous, metaigneous, Erodible mafic igneous, meta-igneous, Resistant mafic igneous, meta-igneous

Virginia's Comprehensive Wildlife Conservation Strategy. (Waida 2006)

The Virginia Department of Game and Inland Fisheries (VDGIF) developed an aquatic habitat classification for use in the Comprehensive Wildlife Conservation Strategy. The methods used in this classification follow the basic structure of The Nature Conservancy aquatic community classification (Higgins et al. 2005) and the Missouri Resource Assessment Program's Aquatic GAP study (Sowa et al. 2005). The classification has been applied to riverine habitats only.

There were multiple goals of this classification effort. One was to provide a means to describe and catalog the diversity of stream habitats in Virginia. The second was to provide a dataset that can be used to describe species-habitat associations and predict species distributions at the stream reach level. The stream reach classification was also used to group all species of greatest conservation need into assemblages with similar patterns of habitat use.

This habitat classification is hierarchical and is based on an understanding of how habitat influences the composition and distribution of biological communities. The EDU dataset was used in this strategy to describe a layer of habitat classification within ecoregions, and as a unit of organization for the species of greatest conservation need and their habitats. The stream reach classification was the next level of the hierarchy applied. For the purposes of this classification, reaches were defined by confluences recognizing that stream habitats are continuous and most breaks we apply are artificial and/or subjective. The dataset used to depict streams was the USGS National Hydrography Dataset, or NHD. The reaches were then attribute with key variables related to size, gradient, elevation, and downstream connectivity. The key continuous variables they were divided into meaningful class categories. Stream temperature had been identified as another important factor to predict species distributions. However, it is difficult to predict in a landscape scale classification and attempts to assign temperature categories (cold vs. warm) based on some threshold elevation proved unsatisfactory so this variable was not included in the final classification. The classification used five categories for size, six categories for connectivity, and four categories for gradient as shown in the table below.

Table 4: Aquatic habitat classification categories used for continuous variables

Category	Range of values
Size:	Link magnitude:
Large river	> 999
Small river	200 - 999
Large stream	50 - 199
Stream	3 - 49
Headwater	1 and 2
Connectivity	Downstream link magnitude:
Connected to large river	> 999
Connected to small river	200 - 999
Connected to large stream	50 - 199
Connected to stream	3 - 49
Connected to headwater	2
Disconnected	Null and [Disconn] field=1
Gradient	Rise over run (m/km):
Very low	</= 4
Low	4 - 15
Moderate	15 - 40
High	> 40

A Framework for Assessing the Nation's Fish Habitat, National Fish Habitat Science and Data Committee (Beard and Whelan. 2006)

This framework defines aquatic habitat as a hierarchy of different attributes at several spatial and temporal scales corresponding to patterns of dominant ecological processes that affect fish distributions. For this national assessment and synthesis, it was critical that habitats were 1) classified and represented as mapped units at several different spatial scales, and 2) that the units were classified and mapped with relative consistency across the United States, given data limitations. By fulfilling these criteria, the units could be the basis for regional and national assessment and synthesis regarding their condition, and the type and severity of threats to them. (Beard and Whelen 2006). For this classification, the first major delineation in habitat was between inland and coastal habitat. Inland habitats are defined as waters above the head of tide. For inland habitats, the Higgins et al (2005) classification scheme was selected.

A simplified, consistent framework for the NFHAP was needed to allow the implementation of the assessment in a timely manner so the national framework was started at the landscape ecosystem level. The recommended simplified approach following was to initially use catchment size, average system gradient, and drainage network position. This differentiated true headwater stream and lake complexes from those that are small but are connected directly to large mainstem rivers. This established an initial national framework to characterize freshwater landscape ecosystems by size and stream power. Further refinement of size categories and all of the other attributes for a more detailed macro/meso habitat classifications can be conducted in the future by Fish Habitat Partnerships to better reflect more meaningful ecological breaks. Landscape ecosystems of different sizes were nested within Ecological Drainage Units (EDUs) (Higgins et al. 2005; Sowa et al. 2005, 2007). EDUs are nested within larger Freshwater ecoregions. EDUs were created using 8-digit USGS Hydrologic Unit Codes (HUCs), and 6-digit HUCs in Alaska, and are used to distinguish regional landscape and climate patterns that influence broad ecosystem characteristics such as lake and stream density, morphology, hydrology, temperature, and nutrient regimes.

Northeast Aquatic Habitat Classification and Map. (Olivero and Anderson, 2008)

This project developed a standard reach-scale Northeastern Aquatic Habitat Classification (NAHCS) and GIS map for 13 northeastern states (ME, NH, VT, MA, RI, CT, NY, PA, NJ, DE, MD, VA, WV, and DC.) for the Northeast Association of Fish and Wildlife Agencies (NEAFWA). Stream and river flowlines were taken from the NHD Plus V1 1:100,000 dataset.

This classification and GIS dataset was designed to consistently represent the natural aquatic habitat types across this region in a manner deemed appropriate and useful for conservation planning by the participating states. This product was not intended to override state classifications, but was meant to unify state classifications and allow for looking at aquatic biodiversity patterns across the region. The NAHCS habitat classification was based on the biophysical aquatic classification approach of Higgins et al. 2005 and used four primary classification attributes that are key to structuring aquatic habitats at the reach-scale. These variables include size (7 classes), gradient (6 classes), geology (3 classes), and temperature (4 classes) (Table 5). Ecologically meaningful class breaks within each of the four variables were developed and the resultant variables and classes combined to yield a regional taxonomy with 259 stream types. These types could be further nested within larger stratifications such as Ecological Drainage Unit and Freshwater Ecoregion.

Table 5. Variables and Classes used in Northeast Aquatic Habitat Classification System

Size Class	**Description**	**Definition (sq.mi.)**
1a	Headwaters	0<3.861
1b	Creeks	>=3.861<38.61
2	Small Rivers	>= 38.61<200
3a	Medium Tributary Rivers	>=200<1000
3b	Medium Mainstem Rivers	>=1000<3861
4	Large Rivers	>=3861<9653
5	Great Rivers	>=9653
Gradient Class	**Description**	**Definition (slope of stream channel (m/m) * 100)**
1	Very Low Gradient	<0.02%
2	Low Gradient	>= 0.02 < 0.1%
3	Moderate-Low Gradient	>= 0.1 < 0.5%
4	Moderate-High Gradient	>=0.5 < 2%
5	High Gradient	>=2 < 5%
6	Very High Gradient	>5%
Geology Class	**Description**	**Definition (index based on cumulative upstream geology; only applied to size 1a, 1b and 2 rivers)**
1	Low Buffered; Acidic	100-174
2	Moderately Buffered; Neutral	175-324
3	Highly Buffered; Calc-Neutral	325-400
Temperature	**Estimated Natural Temperature Regime**	**Definition**
1	Cold	Complex rules; see CART analysis and final rules on Temperature Metadata worksheet
2	Transitional Cool	
3	Transitional Warm	
4	Warm	

The full reach types could be simplified using recommended prioritization and collapsing rules. Providing the detailed types and recommended collapsing rules allowed the data to serve flexible and multiple purposes for the uses. For example, the detailed stream types have most recently been simplified for a regional assessment to 58 regional types and 23 major regional types in the Northeast Habitat Guides: A Companion to the Terrestrial and Aquatic Habitat Maps (Anderson et al 2013a) and the Northeast Geospatial Condition Assessment (Anderson et al 2013b). In this simplification, the full 259 reach types were collapsed to 58 types based on using simplified size (4 classes), gradient (3 for headwaters/creeks, 2 for rivers), geology (3 classes for headwaters through small rivers), temperature (3 classes), and tidal classes. For the general audience of the habitat guide, the 58 types were further collapsed into 23 major types. The 23 major types were created by merging the geology classes for headwaters through small rivers and merging the gradient classes for medium to large rivers. The simplified types were described in terms of their environmental setting, commonly associated fish species, associated rare species, and coded with summary condition information relating to impervious surfaces, dams, and riparian conditions.

New York Freshwater Blueprint (White et al. 2011)

The project goal was to develop GIS datasets that identify the locations and status of critical freshwater targets (habitats and species) in New York. The Northeast Aquatic Habitat Classification (NEAHC) System GIS datasets were used to develop a classification system for this project (Olivero and Anderson 2008). The NY Blueprint combined classes within each variable to simplify the NEAHC to reduce the number of aquatic habitat types in the study area. It derived collapsing rules within a variable from the NEAHC dataset once the Blueprint Team decided on parameters to use. The Blueprint Team relied heavily on the freshwater assessment of the Upper Delaware River basin as a model for determining how to simplify the NEAH classification. The NY Blueprint Team decided to use a size, gradient, geology, temperature, and tidal designation to assign unique types, however each type was not necessarily defined as differing in each of these 5 primary variables. For example, headwaters were split by gradient, geology, temperature and tidal class, however large rivers were lumped into only tidal and non-tidal types (not split by gradient, geology, or temperature). The Blueprint Classification used five size classes headwaters and creeks, small rivers, medium tributary rivers, medium mainstem rivers, and large rivers. It used three classes for gradient on headwaters and creeks, two gradient classes on small to medium rivers, and no gradient classes for large rivers. It used two geology classes on headwaters through small rivers and no geology classes for all medium and large rivers. It used two temperature classes for headwaters through medium rivers and no temperature classes for large rivers. It added a tidal designation to all segments. Combining these classes yielded 44 unique types which were used in the NY Freshwater Blueprint assessment.

Stream Classification Framework for the SARP Region (Sheldon and Anderson 2013)

The objective of this project was to develop some basic stream classification attributes for the entire Southeast Aquatic Resources Partnership (SARP) region (17 states) and to provide more detailed attributes in the eastern section of the SARP geography (9 states: AL, FL, GA, KY, NC, SC, TN, WV, VA) where additional data and modeling capacity was available. The final product was a mapped dataset of information linked to the NHD Plus medium resolution hydrography that can be used to classify stream reaches. The results of this work contribute to SARP’s overall objective to develop a river classification framework database consisting of a hierarchical set of hydrologic, morphologic, and biotic parameters for NHDPlus river segments which can be used to identify ecologically similar types of rivers within the region according to the needs of the user. All reaches were attributed with stream size, gradient, freshwater ecoregion, and EDU. Reaches in the eastern section of the SARP geography were attributed with the additional attributes of baseflow index, bedrock geology, soils, surrounding landforms, landcover, and a modeled hydrologic class.

Conclusion

Many existing stream classifications fall into two major types, taxonomic or physical environmental classifications. Taxonomic based classifications provide descriptive information regarding aquatic species distributions and assemblage structure. By measuring the presence and abundance of taxa at a given location and time, these classifications emphasize the resident current biota and focus on the biotic expressions (taxa) that have resulted from the variety of interacting spatial, temporal, and biotic factors at the site. Biologists and managers often find taxonomic classifications easy to understand and useful in management, such as in biomonitoring, as these classifications depend upon readily identifiable biological entities that can be sampled and monitored at sites. However, taxonomic based classifications have been criticized because previous research has shown that classifications using strictly biological data or data about one type of organism, such as fishes, macroinvertebrates, or mussels, rarely represent the complexity inherent in aquatic communities (Higgins et al. 2005). For example, stream systems are extremely dynamic and their biological species composition can vary widely seasonally and over short temporal scales due to changes in environmental factors. The high temporal variation makes it difficult for researchers to obtain comprehensive collection data at sampling station or compare data collected at different times. Existing biological classifications of stream communities are also almost always based on data collected from wadable streams, that biases their representation of ecological diversity in terms of stream size, gradient, and scale. Historic data on distribution and abundance are rarely taken into account and the future evolutionary potential created by underlying environmental diversity is usually not considered in taxonomic classifications. In addition, biological classifications are not easily applied to map comprehensively all streams and rivers community types across a state or larger geographic area given lack of biological sampling in every stream and river.

Physical environmental classifications emphasize a stream's relationship to its physical environment. Physical factors have been shown to constrain the observed range of aquatic ecological process and biotic communities and are used as classification variables in these classifications. The classification variables often include measures of climate, physiography, bedrock and surficial geology, channel width, depth, and gradient, bed form, and bank conditions (Maxwell et al.1995, Frissel et al 1986, Rosgen 1994, Argent 2002). Environmental classifications are often designed within a spatial and temporal scale hierarchy. For example, a number of environmental classifications recognize a sequential spatially nested hierarchy of a small scale pool/riffle system units, reach level, reach systems, stream systems or subwatersheds, watersheds, subbasins, and subzones (Maxwell et l.1995, Frissel et al 1986, Higgins et al 2005). At any point in the hierarchy, the potential capacity or development of a smaller scale systems develop within the constraints set by the larger scale systems of that they are a part. For example, geology and climate factors associated with very large scale subbasins and subzones constrain the development of reach level physical habitat and biological structure through their large-scale controls on chemistry, hydrology, and sediment delivery (Hawkins et al 2000). The temporal scale or time during which a type at a given spatial scale units are thought to continuously persist within a given range of variation defining their type will also vary. Smaller spatial levels of aquatic systems, such as a reach's arrangement of pools and riffles, are much more temporally dynamic than larger scale systems that are often only significantly altered after major geologic and climate processes occurring over much longer time frames. At any spatial or temporal scale, the variables selected for classification should be those physical entities that are most general, invariant, and causal for the given frame of time and space (Warren 1979, Warren and Liss 1983, Frissel et al 1986).

Both taxonomic and environmental classifications can provide useful approaches to structuring the continuum of aquatic biodiversity patterns that exist on the landscape. Use of one over the other can depend on the availability of comprehensive taxonomic sample data for the entire study area, the desire to comprehensively classify every aquatic feature (even those without collection sites), the desire to include physical habitat parameters as a surrogate to address unknown/unsampled aquatic biodiversity, and the desire to include the ecological and evolutionary context of the system in a structured hierarchical manner. Some classifications are beginning to combine aspects of both taxonomic and physical environmental classifications. For example, a number of taxonomically derived biological classifications attempt to relate assemblage structure to the underlying physical habitat parameters (Langdon et al 1998, Reschke 1990). Many environmental classifications are also beginning to describe their classes with biological entities (Van Sickle and Hughes 2000, Oswood et al 2000, Waite et al. 2000, Sandin and Johnson 2000, Rabeni and Doisy 2000, Marchant et al 2000, Feminella 2000, Gerritsen et al 2000, Hawkins and Vinson 2000, Johnson 2000, Pan et al 2000, Walsh et al. 2007, MD DNR 2012) or use physical classification variables to model and broadly map predicted habitat for certain species (McKenna and Johnson, 2011, White et al. 2011,)

PART II: Hydrologic Classification

Introduction

Hydrology varies extensively across regions, continents, and the globe (Kennard et al., 2010b; Haines et al., 1988), yet streams display reoccurring patterns in their streamflow (Acreman and Sinclair, 1986; Burn and Arndell, 1993; Poff et al., 1997). By their very nature, streamflow regimes are also multi-dimensional. The hydrologic signature of streams is measured by five key components: the magnitude, duration, frequency, timing, and rate of change of flow events (Poff et al. 1997). These repeatable multivariate patterns naturally predispose streams to hydrologic classification. However, the question remains, “Why do we care about classifying streams by their hydrology?” According to Melles et al. (2012), classifications depict our current state of knowledge about a subject area. In fact, classifications provide the structure and relationships within and among groups of objects (Sokal, 1974). These relationships provide a foundation for drawing inferences about the principles that govern relationships among different classes and how to interpret unclassified objects (Sokal, 1974). Thus, the best approach to characterize streamflow regimes is to classify them. Hydrologic classifications not only provide an understanding of how different streams operate, but also how they structure ecological communities. Riverine organisms have developed life history strategies adapted to the natural variation in stream flow regimes (Bunn and Arthington, 2002; Poff et al. 1997). The natural timing and magnitude of flooding establishes the template on which riverine habitats are created and then maintained (Trush et al. 2000), structures floodplain riparian communities (Auble et al. 2005), and provides behavioral cues for the initiation of spawning and seasonal migrations for fish (Nesler et al. 1988; King et al. 1998). Studies have suggested that hydrology forms the habitat template (Schlosser 1987, 1990) or hierarchical filter (Jackson and Harvey, 1989; Tonn, 1990; Poff, 1997), which organizes tradeoffs among adaptive strategies for fish and macroinvertebrates. The wide range of natural flow conditions across the US continent (Poff, 1996) exerts different selective pressures that shape life history and reproductive strategies and result in regionally distinct river assemblages (Southwood 1988; Olden and Kennard 2010; Mims and Olden 2012).

With regard to river systems, stream classifications and their use in management have a fairly long history (Horton, 1945; Strahler, 1957; Pennak, 1971; Rosgen, 1994). However, the development of hydrologic classifications for use in environmental flow management has greatly expanded in recent years. In fact, hydrologic classifications have become so popular that Olden et al. (2012) compiled a literature review strictly on the subject. One of the primary justifications for developing hydrologic classifications is to provide a means for developing environmental flow standards to support the preservation of freshwater biodiversity and ecosystem services (Arthington et al., 2006; Poff et al., 2010). With growing water demands, infrastructure, and development (Poff et al., 2003), river managers are faced with a need to protect the key aspects of the natural flow regime. However, managing for the specific needs of every river is not only challenging, but also unlikely. Competing social, economic, political, and ecological demands on water typically result in simple and static flow rules that ignore the complexity of flow variability responsible for sustaining river systems (Arthington et al., 2006). For many states found within the APP LCC region, the practice of making environmental flow recommendations (e.g., water withdrawal criteria) has been to apply statewide criteria, treating all river types in a similar way. Obviously, this is inadequate for protecting the variability in flow regimes that support aquatic biodiversity. One practical approach to providing environmental flow standards is to form classes of rivers with similar hydrologic properties across regions from which standards for managing flow needs can be developed (Poff, 1996; Arthington et al., 2006). Classifications alleviate some of the complexity of environmental flow management by consolidating hydrologic variation into management units and managing for groups of streams rather than for the uniqueness of individual water bodies. The assumption is that rivers that behave similarly in terms of their hydrology should share similar patterns in ecology (Arthington et al., 2006) and respond similarly to a given anthropogenic stressor (Arthington et al., 2006; Poff et al., 2010). The latest paradigm in environmental flow science is the development of the Ecological Limits of Hydrologic Alteration (ELOHA) framework (Poff et al., 2010), whose central design is based upon placing streams into hydrologic classes to provide a context for generalizing hydrologic disturbances, assembling and testing hypotheses regarding ecological responses to hydrologic disturbance, and lastly, developing environmental flow standards. In essence, hydrologic classes form the template for developing relationships between flow alteration and ecology (Poff et al., 2010). Comparisons of ecological patterns between natural and hydrologically altered streams within each class yield flow-ecological response relationships, which provide the basis for environmental flow standards (Arthington et al., 2006).

Major Approaches to Hydrologic Classification

According to Olden et al. (2012), two major approaches to hydrologic classification are available. *Deductive* techniques use regional boundaries, such as ecoregions, or environmental variables to infer areas of similar hydrologic regimes, whereas *inductive* techniques use hydrologic data (either from stream gages or synthesized data) directly to inform and create classifications (Olden et al., 2012). In situations where hydrologic information is lacking, deductive approaches may be advantageous; however, these approaches have several assumptions: 1) features in the landscape adequately represent hydrologic variability, 2) the actual number of hydrologic classes and thus, total hydrologic variation, is already known, or 3) the structure of environmental variables in predicting hydrology is already known (Olden et al., 2012). In addition, deductive approaches often only include best professional judgment as criteria (e.g., such as using watershed boundaries) and may not accurately represent or predict streamflow patterns (McManamay et al., 2012b). By comparison, inductive approaches utilize the available hydrologic information (i.e. stream gages) and classification techniques that group streams according to similarities in hydrologic metrics (Olden et al., 2012). Then, various predictors, including climate and features of the landscape, are used to understand differences among streamflow classes. The hierarchical importance of different predictors in discriminating amongst classes is extremely important and depends on the spatial extent of the hydrologic classification (McManamay et al. 2012b). However, the hierarchical importance of these predictors is not known unless direct hydrologic observations are used in classifications. For these reasons, inductive approaches to hydrologic classifications are the recommended technique to support environmental flow standard development where sufficient observational data are available (Poff et al. 2010).

Within the last 2 decades, the majority of approaches to hydrologic classification (including approaches within the APPLCC) have used inductive methods (Table 1). Inductive approaches to hydrologic classifications have been created at multiple scales including states (Kennen et al., 2007; Turton et al., 2008; Henriksen and Heasley, 2010; Liermann et al., 2012), regions (Monk et al., 2006; Sanborn and Bledsoe, 2006; Chinnayakanahalli et al., 2011; McManamay et al., 2012a), continents (Kennard et al., 2010b; McManamay et al. 2013), and the world (Haines et al., 1988). However, one noteworthy example of a deductive approach was the creation of Hydrologic Landscape Regions (HLRs) by Wolock et al. 2004. HLRs were created by compiling information on landscape characteristics known to influence hydrology (climate, topography, and soil characteristics). These variables were summarized within > 12,000 catchments across the conterminous US and then used in a hierarchical clustering procedure to produce 20 different hydrologic-landscape classes. The purpose of HLRs were to stratify sampling designs for studies assessing nutrient loading (e.g., USGS NAQWA), with the rationale that study sites should represent the diversity of background hydrologic conditions (since hydrology influences nutrient loading). As noted above, a major assumption of such deductive approaches is that the selection and structural importance of landscape characteristics are already known and adequately explain variation in hydrology. However, McManamay et al. (2012b) showed that HLRs did a poor job of explaining hydrologic variation in the Southeast.

Inductive Hydrologic Classification Process

The inductive hydrologic classification process can be described as a 3-step procedure, symbolized by CCC: 1) Compile reference condition hydrologic information, 2) Compute statistics that summarize hydrologic information, and 3) Cluster streams according to similarities in hydrologic statistics.

Compile hydrologic information: One common approach in hydrologic classification is screening gages for inclusion in a final 'reference' dataset (Olden et al., 2012). Because hydrologic classifications form the starting point for developing environmental flow standards, great care should be taken in selecting streams that represent the "baseline" or "reference" hydrologic condition. These reference streams are used for classification, but also they become important for measuring the degree of hydrologic alteration in areas of disturbance. Hence, if the baseline becomes contaminated with non-reference conditions, then some portion of the "natural" hydrologic variation inferred from classes is likely spurious, with the result that an adequate appreciation of how streams should function in their natural or, in the least, semi-natural state is lost. However, ensuring high data quality standards often comes at the expense of losses in hydrologic information, which may limit sample sizes of representative gages (McManamay et al. 2013). Hence, conclusions regarding the true nature of hydrologic variability may be limited by sample sizes (e.g., largest streams are likely to be the most disturbed – thus, large rivers are missing from the analysis). In summary, careful selection of gages must be made in consideration of two major points: 1) Tradeoffs exist between sample size and sample quality (i.e., the representativeness of "natural" streamflow), and 2) Size dependent sample bias may occur due to fewer gages that represent minimally altered conditions as drainage area increases.

The screening process typically includes evaluating landscape disturbances upstream of each gage, the hydrologic record length, and the extent of overlap among hydrologic records (Olden et al., 2012). Because most hydrologic classifications are constructed from natural streamflow patterns, the standards for inclusion can be quite strict and exclusive (Poff, 1996; Kennard et al., 2010a; Olden et al., 2012), which may limit the sample size and variation represented in the final dataset. Thus, high-data-quality standards often come at the expense of losses in hydrologic information. The period of record (POR) needed for each stream gage is also important, as changes in climatic regimes will be reflected in hydrology. Thus, short PORs may cause incorrect classification, especially if including drought years or extremely wet years. Kennard et al. (2010a) recommends that at least 15 years of record is suitable for estimating hydrologic variables that are used to detect differences in the spatial variation, such as flow classifications. In addition, at least 50% overlap among all PORs is needed to ensure different classes are not an artifact of different climatic regimes.

Compute hydrologic statistics: Over 200 different hydrologic statistics are available to summarize stream flow. Statistics typically represent either measurements of one of the five key flow components (magnitude, frequency, duration, timing, and rate of change) or variation in one of the key flow components. Olden and Poff (2003) describe 171 different hydrologic statistics supported within the existing literature, including 94 magnitude indices, 14 frequency indices, 44 duration indices, and 9 rate of change indices. Hydrologic indices were subdivided into a total of 9 subcategories where magnitudes were divided into average (n = 45), low (n = 22) and high (n = 27) categories, frequency into low (n = 3) and high (n = 11) categories, and duration into low (n = 20) and high (n = 24) categories. The set of indices reported by Olden and Poff (2003) included the Indicators of Hydrologic Alteration (IHA), the most commonly used set of hydrologic metrics in streamflow analyses (Ricther et al. 1996; Olden and Poff 2003). IHA variables include 33 individual metrics and 33 associated measures of variation. Indices not included in Olden and Poff's assessment included commonly-used percentile flows from flow-duration curves(1%'tile-95%'tile) and indices protecting withdrawal limits, such as 7Q10 (the lowest 7-day average flow that occurs on average once every 10 years). However, these indices are likely captured in other metrics because of the high colinearity among hydrologic indices.

Because streamflow is a multivariate concept, the use of single hydrologic indices in characterizing streamflow regimes has been criticized because of either over simplification or being ecologically irrelevant (e.g., Poff, 1996; Richter et al.,1996, 1997). However, stream ecologists are now faced with the difficult task of selecting from among >200 hydrologic indices to characterize streamflow regimes (Olden and Poff 2003). In addition, hydrologic indices are highly redundant, i.e. many indices convey the same information because of mulit-colinearilty among metrics. Besides the need to simplify the logistics of characterizing streamflow regimes, selecting a subset of non-redundant hydrologic metrics is important to avoid the deleterious effects of multi-colinearity, such as biases in classification results and failure to identify the most meaningful patterns in data. Redundancy may bias classifications by providing more weight to variables with higher colinearity (i.e. more representation by redundant variables in clustering algorithms). One approach to identify and remove redundant variables includes examining correlation matrices among variables and removing those with highest correlation values, in favor of metrics that are more interpretable. An alternative and more robust approach is to use Principal Components Analysis (PCA) to reduce the redundancy in the dataset while also identifying variables that explain the most variation in streamflow regimes. Olden and Poff (2003) used this exact process to identify redundant patterns among 171 hydrologic indices and select the indices that explained predominant patterns in streamflow variation. However, one of their main conclusions was that the 66 IHA indices explained the majority of variation in streamflow regimes represented by all 171 indices. Thus, selecting the IHA variables for characterizing streamflow regimes would be a simpler alternative to running PCA analyses and then selecting subsets of variables. In addition, the variables are supported by scientific literature. If PCA is used, another simpler alternative is to use the principal component scores themselves (as opposed to variables with highest loadings) in future clustering procedures. This avoids the complication of selecting metrics.

Besides ensuring that hydrologic metrics are not redundant, there is a need to ensure that hydrologic metrics are "ecologically relevant". The term, "ecological relevance (ER)", when related to hydrology, places additional emphasis on indices that supposedly explain more variation in ecological patterns (e.g., fish assemblage structure). However, ER has been used quite loosely to justify the arbitrary selection of metrics due to preference, opinion, prior use, or simplicity. However, to date, very few studies have specifically addressed which hydrologic indices (out of >200) explain the most variation in ecological patterns, either related to natural or altered streamflows (Carlisle et al. 2011). Kennen et al. 2008 evaluated the ecological relevance of almost 80 hydrologic metrics in New Jersey streams using a series of steps: 1) conducting a PCA filtering out the metrics that were redundant and keeping those explaining the most variation, 2) Employing multiple linear regression models to identify the remaining subset of hydrologic variables driving differences in invertebrate assemblages across a disturbance gradient. In a similar approach, Knight et al. (2008) selected a subset of 16 hydrologic indices (out of 90 total) that best represented multivariate patterns in fish assemblages in the Tennessee River Basin. For obvious reasons, determining the ecological relevance of hydrologic metrics should be conducted at the same spatial scale in which the hydrologic classification will be developed.

Many software packages are now available to calculate hydrologic indices. The Indicators of Hydrologic Alteration are available from The Nature Conservancy (Richter et al. 1996; TNC 2010). In addition, the Hydrologic Index Tool (HIT) software is provided by the U.S. Geological Survey (USGS) and calculates the 171 variables used in Olden and Poff (2003), which also includes the IHA variables (Henriksen et al. 2006). The USGS also provides StreamStats, an online web-interface that provides up to 1264 different indices, which vary according to state (USGS 2014). Most states only provide <50 indices.

Cluster streams according to similarities in hydrology: Because multiple variables are selected to represent streamflow regimes, multivariate statistics are required to appropriately create hydrologic classes through ordination or clustering. Unfortunately, an exhaustive list of clustering procedures is available and the selected approach can have dramatic influences on the clustering outcome. Olden et al. (2012) provides a good overview and identifies five major types of classification techniques: 1) ordination, 2) hierarchical, 3) partitional, 4) fuzzy clustering, and 5) Bayesian probabilistic clustering. For more detailed discussion of clustering approaches, see Everitt et al. (2001). Ordination techniques include principal components analysis or non-metric multidimensional scaling. While these approaches are convenient for allowing visual examination of similarities or dissimilarities among the data, they require manually separating classes based on visual patterns. The remaining four procedures are clustering procedures that produce groups of observations.

Hierarchical classifications have been the most widely used in and include two major approaches: 1) the agglomeration approach, which starts with each stream gage and combines into the most similar groups until only one gage is left, or 2) the divisive approach, which splits larger clusters into smaller ones until all stream gages have been separated. At least seven different algorithms are available to produce hierarchical classifications and while each differs in their pros and cons, describing all algorithms in detail is well beyond the scope here. The similarity among hierarchical classifications, however, is that smaller classes are nested within the larger classes that they comprise, which create a dendogram/tree-like structure. For most hierarchical applications, Olden et al. (2012) recommend using Ward’s hierarchical classification because it is a space-conserving method, which means it balances distances between and within clusters proportionally that best represents the structure of the original data. In addition, this approach removes any relationships between the clustering solution (i.e., number of clusters) and group-size (we cannot assume that equal numbers of stream gages should be represented among groups).

In contrast to hierarchical classifications, partitional clustering techniques seek equal distinction among clusters rather than seeking clustering solutions represented by hierarchy. Partional approaches initiate with a random group of clusters where euclidean distances are measured from each observation to each cluster centroid (Olden et al. 2012). Observations with similar distance measures create new cluster centroids. The mean distance values from the previous iteration are used in subsequent iterations to create new clusters, until no changes occur in the observations. This approach is considered more efficient for larger datasets, because, unlike hierarchical approaches, the dissimilarity matrix among all observations is not needed. However, partitional approaches are sensitive to the initiation of the clustering algorithm and thus, the order of the dataset can influence the outcome. Partitional approaches also require the user to pre-define the number of clusters, whereas the number of clusters in hierarchical approaches is typically determined following the procedure by examining the dendrogram. However, in both cases, plots of the sum-of-squared distances (SSD) versus the number of clusters can be used to determine the most parsimonious solution. The number of groups in which SSD is minimized is typically used to determine the most parsimonious solution. At least four different partitional approaches are available and include k-means, k-median, k-modes, and k-medoids (Olden et al. 2012). Among approaches, k-means is the most widely used approach.

Both hierarchical and partitional approaches, in their raw form, are considered hard clustering procedures. Thus each observation is assigned to a given cluster under the assumption there is well defined boundaries between clusters and each observation fits neatly within its corresponding class (Olden et al. 2012). However, this is rarely found in nature and many streams tend to share overlap (in some regard) with multiple classes. Fuzzy clustering is a technique that uses ordination, along with hierarchical or partitional clustering solutions, to simultaneously assign probabilities of membership for all clusters to each observation. This provides an indication of strength of membership for a given stream to its assigned class, but also provides a mechanism to exclude only high-probability streams or identify no-analogue or novelty streams.

One of the main obstacles in clustering, especially with hydrologic data, is that the number of clusters and the multivariate shape of the clusters are unknown. Unfortunately, the choice of the number of clusters and distance measure/algorithm used is subjectively made by the user and this will certainly influence cluster solutions. However, Bayesian mixture modelling (BMM) presents an approach to overcome some of these obstacles. BMM models the observed data as a finite number of component distributions (number of clusters) (Gelman et al. 2004). Mixture modeling refers to probabilistic modeling where subpopulations are represented within an overall population; thus, subpopulations refer to hydrologic classes. The Bayesian approach models the number of clusters, the parameters describing each cluster (shape, orientation, etc.), and membership of each stream to a cluster as completely probabilistic. The approach produces multiple classification scenarios and the most parsimonious solution is presented that has the highest probability of correctly describing the data (Gelman et al. 2004; Olden et al. 2012). Only two studies, Kennard et al. (2010b) and McManamay et al. (2013), have used the BMM approach and created continental classifications for Australia and the United States, respectively.

Examples of Inductive Hydrologic Classifications overlapping with APP LCC

Based on our knowledge, at least 10 different inductive hydrologic classification efforts spatially overlapping with the APP LCC region have been publicized; however, only 6 are available in published materials, either as peer-review journal articles or reports. Four of the efforts were conducted for the conterminous or continental US. The first hydrologic classification for the conterminous US was produced by Poff and Ward (1989) and later expanded by Poff (1996), who documented 10 dominant streamflow types of varying intermittency, perennial flows, and timing in 806 streams (Figure 1).

Over two decades of US Geological Survey (USGS) streamflow gage information has become available since Poff (1996) produced his hydrologic classification (latest gages used were from 1986). Recently, McManamay et al. (2013) created an updated classification for the US (including AK and HI) and Puerto Rico using 2618 reference condition stream gages in a hierarchical bayesian clustering method (mentioned previously). Fifteen hydrologic classes were represented across the US, with many showing similarities to classes created by Poff (1996) (McManamay et al. 2013). One similarity in the approaches by Poff (1996) and McManamay et al. (2013) is that streamflow patterns were not influenced by river size, either through careful selection of metrics or by standardizing magnitude-related metrics; thus, in both cases, classes tended to show high regional affiliation.

Archfield et al. (2013) also recently completed a US hydrologic classification using 7 fundamental daily streamflow statistics (FDSS) in a Ward's hierarchical clustering procedure. Several classification solutions were created from 2 to 8 nested classes. The novelty of the approach was the development of the FDSS, hydrologic indices representative of moments of the streamflow distribution. However, one of FDSS was mean daily flow; thus, the resultant river classification was heavily biased by river size and failed to show any distinct regional affiliation (one of the main conclusions of their analysis).

As opposed to multivariate clustering approaches, Environmental Flow Specialists produced a hydrologic classification for the continental US and Puerto Rico using a 'multi-univariate' approach (EFS 2013). The approach consists of a decision-tree design where multiple individual hydrologic variable thresholds are used to categorize streams into a series of classes, regardless of the reference condition of the gages. The approach is convenient in that the classification approach is easy to follow; however, the selection of hydrologic metrics and their threshold values to create classes are somewhat subjective and do not rely on natural patterns among streams. Mean daily flow is used to segregate classes based on size rather than standardize for river size.

Other efforts have been at the regional or state-wide level. McManamay et al. (2012a) conducted a stream classification for an 8-state region of the southeast using 66 hydrologic statistics for 292 streams. Using a k-means clustering procedure, six flow classes showing regional affiliation were isolated that ranged from extremely stable to highly variable to intermittent. Konrad et al. (2013) developed a hydrologic classification for the Southeastern Aquatic Resources Partnership (SARP) region based on the seasonality of streamflow regimes (using monthly flow estimates) and 13 carefully selected metrics (based on discussion/expert review). In both of the above cases, magnitude-related metrics were standardized by mean daily flow; thus classes showed a high degree of regional affiliation. State-specific classifications within the APPLCC region have been conducted for New Jersey, Pennsylvania, and North Carolina. Kennen et al. (2007) classified 94 "least impaired" streams into 4 groups using 70 hydrologic indices within an average-linkage hierarchical clustering procedure. Using a k-means clustering approach, Henriksen and Heasley (2010) developed a hydrologic classification for 163 unaltered streams in North Carolina. Seven classes emerged, six of which were perennial and varied in stability and timing and one of which showed signs of intermittency. Five hydrologic classes were developed for Pennsylvania using 136 reference streams (Apse and DePhilip 2009).

Prior to clustering streams, hydrologic metrics must be selected that explain the maximum variation in the data, but are also non-redundant. As stated previously, this can be achieved using PCA to determine which variables explain the majority of the variation and then correlation analysis can be used to remove redundant variables. At least three of the regional/state-level studies above used PCA followed by correlated metrics to reduce the predictor dataset. McManamay et al. (2012a) reduced 171 metrics to 66, Kennen et al. (2007) reduced 171 metrics to 70, and Henriksen and Heasley (2010) reduced 108 to 61 indices. In most cases, 60-70 indices (out of 171 total) seem to be a consistent number of non-redundant, hydrologic statistics that explain the majority of variation in streamflow patterns. While some metrics are consistently used (e.g., specific monthly flows), the sample of metrics used in each analysis vary on a case-by-case basis depending on the hydrologic variation present within a given region.

Conclusion

The approach to hydrologic classification will vary depending on the objectives. If the objective is to describe patterns in streamflow, then an inductive approach is recommended. Because stream classifications are mean to represent the natural “baseline”, building classifications using the best reference streams is also recommended. The choice of metrics is also pivotal in any clustering analysis; however, again, if describing natural patterns in flow variation is the objective, then selecting non-redundant metrics that describe the majority of variation is best. Alternatively, simply using scores from PCA can be an efficient and preferred alternative. Similar to choosing metrics, the selection of a clustering procedure can also have consequences on the final outcome. Because most managers desire simplicity and nested organization, a Ward’s hierarchical approach may be best and is recommended by Olden et al. (2012), at least as the best approach when using hierarchical methods.

Despite the intense growth of hydrologic classifications, comprehensive testing of hydrologic classifications in generalizing patterns of disturbance and establishing environmental flow standards, one of the central precepts behind creating streamflow-based classes (Arthington et al., 2006; Poff et al., 2010), has not been fully addressed. Furthermore, with regard to ecological patterns, the predictive capacity of hydrologic classifications has received little attention (but see Monk et al., 2006; Chinnayakanahalli et al., 2011). The utility of any classification system lies, in part, on its ability to stratify analyses and generalize patterns in disturbance. Thus, the full utility of hydrologic classifications will not be realized until they can be used to enhance our understanding of the ways in which flow regimes influence the structure and function of stream ecosystems.

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