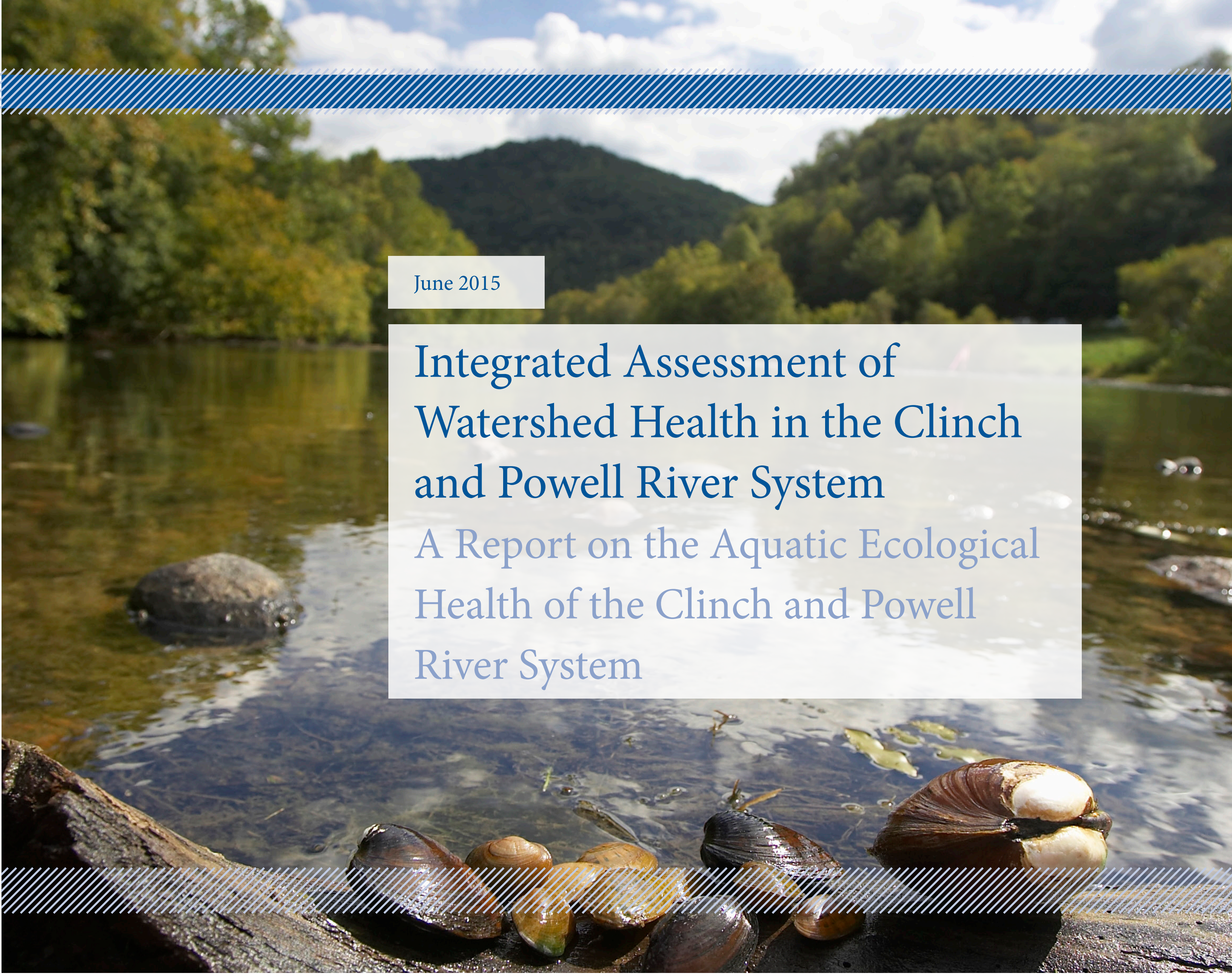

June 2015

Integrated Assessment of Watershed Health in the Clinch and Powell River System

A Report on the Aquatic Ecological Health of the Clinch and Powell River System

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Cover photo: Clinch River; provided by Brad Kreps (The Nature Conservancy)

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Executive Summary

The Clinch and Powell River System in western Virginia and eastern Tennessee is home to one of the most diverse fish and mussel assemblages in North America. Over the past 30 years these biological assemblages have declined and some species have been or are in danger of being extirpated from the river system. Although this river system has experienced significant losses in its biological integrity, remaining healthy portions of the watersheds provide valuable ecological and recreational services such as water purification and fishing. Protection of remaining healthy segments of the stream system is essential to comprehensive ecological and economic management of the Clinch and Powell River System. This study was conducted by the U.S. Environmental Protection Agency (EPA) in partnership with the Clinch-Powell Clean Rivers Initiative (CPCRI), and the results will be used to support the efforts of this organization and others in the region working to protect and restore the river for people and nature.

The purpose of the *Integrated Assessment of Watershed Health in the Clinch and Powell River System* (referred to as "the Assessment") is to characterize the relative health of watersheds in the Clinch and Powell River System to guide future protection, restoration, and education activities. A healthy watershed has the structure and function in place to support healthy aquatic ecosystems. It is characterized as having all or most of these key components:

- Intact and functioning headwater streams, floodplains, riparian corridors, biotic refugia, instream habitat, and biotic communities
- Natural vegetation in the landscape
- Hydrology, sediment transport, fluvial geomorphology, and disturbance regimes expected for its location

This report presents the methods and results of the Assessment and outlines proposed uses of the results. The Assessment applies a *systems approach* that views watersheds and their aquatic ecosystems as dynamic and interconnected systems in the landscape connected by surface and ground water and natural vegetative corridors. Watershed health is quantified at the stream catchment (or subwatershed) scale from existing geospatial datasets and from predictive models derived from field monitoring data collected as part of existing assessment programs. This information is synthesized into several indices that measure aquatic ecological health and combined into a comprehensive index of watershed health.

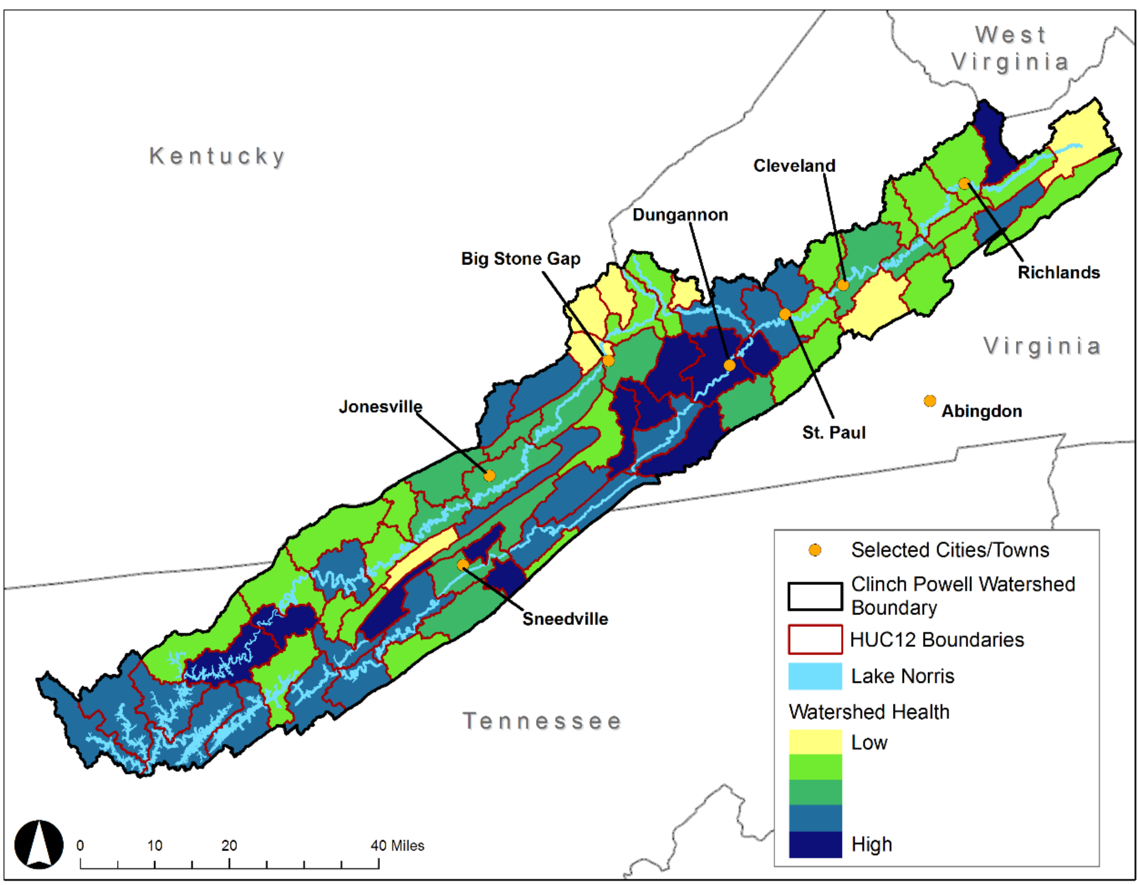
An important facet of the Assessment is that it leverages existing efforts to analyze the characteristics of watersheds and the aquatic ecosystems within them. Several agencies and organizations assess various aspects of watershed health at statewide and regional scales. This project has used disparate datasets to provide a more complete picture of watershed health across the Clinch and Powell River System.

One outcome of the Assessment is a database of watershed health that can be used by CPCRI and other groups involved in watershed protection and restoration planning. The database is intended to help identify healthy watersheds that are priorities for local-scale assessment of protection opportunities. Several immediate uses of the database include outreach and communication and prioritization of restoration and protection areas.

A second outcome is the integrated assessment framework developed by EPA and CPCRI. This framework reflects our understanding of the interconnected nature of the physical, chemical, and biological conditions of aquatic ecosystems; the significance of landscape- and watershed-scale processes on aquatic ecosystem health; and the need to view water bodies as connected parts within a larger system rather than as isolated units. The framework serves as a starting point for the multistate agencies and organizations tasked with protecting the Clinch and Powell River System to collaborate and apply a unified approach rather than undertake disjointed efforts. Over the long term, the existing framework can be updated as data gaps are filled and improved methodologies are identified.

The Assessment resulted in the identification of the relatively healthy portions of the Cinch and Powell River System at the catchment (1-mile square) level, based on metrics characterizing Landscape Condition, Geomorphic Condition, Hydrologic Condition, Water Quality, and Biological Condition. The scores from these six sub-indices were combined to create an overall Watershed Health Index. Results can be presented for each metric, sub-index, or Watershed Health Index at multiple scales (i.e., catchment level or larger watersheds). **Figure ES-1** illustrates the Watershed Health Index at the Hydrologic Unit 12-digit Code to provide a generalized view of watershed health across the entire Clinch and Powell River System. The use of these generalized results and the underlying data are discussed in this report.

Figure ES-1. Overall watershed health aggregated by USGS Hydrologic Unit 12-digit Code.



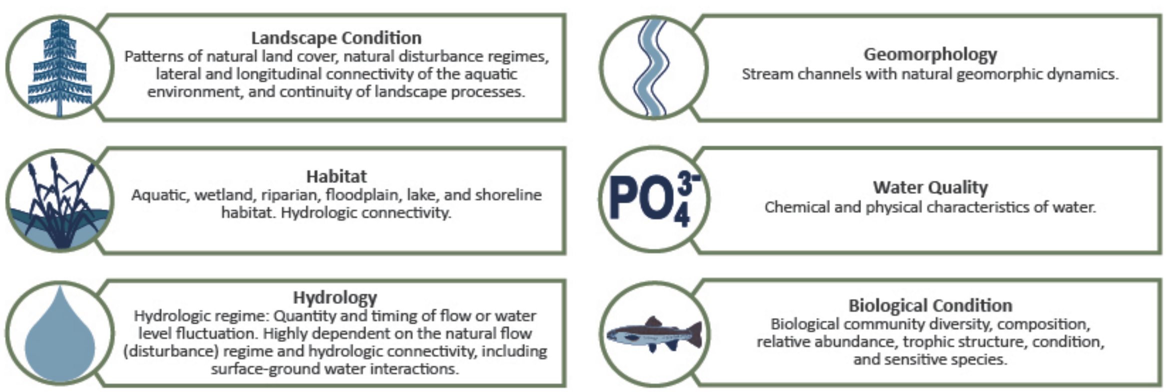
1. Introduction

1.1 Healthy Watersheds

A healthy watershed is one in which natural land cover supports dynamic hydrologic and geomorphic processes within their natural range of variation, habitat of sufficient size and connectivity to support native aquatic and riparian species, and physical and chemical water quality conditions able to support healthy biological communities. Natural vegetative cover in the landscape, including the riparian zone, helps maintain the natural flow regime and fluctuations in water levels in lakes and wetlands. This, in turn, helps maintain natural geomorphic processes, such as sediment storage and deposition that form the basis of aquatic habitats. Connectivity of aquatic and riparian habitats in the longitudinal, lateral, vertical, and temporal dimensions helps ensure the flow of chemical and physical materials and movement of biota among habitats.

The U.S. Environmental Protection Agency (EPA) (2012) conceptualizes watershed health using six distinct but interrelated attributes: 1) Landscape Condition, 2) Habitat Condition, 3) Hydrologic Condition, 4) Geomorphic Condition, 5) Water Quality, and 6) Biological Condition (**Figure 1**). An integrated watershed health assessment should assess the condition of all six of these attributes, though the detail in which they are assessed will vary based on the scale of the assessment (statewide vs. an individual watershed), available data, and available resources.

Figure 1. EPA's six attributes of watershed health.



1.2 Purpose and Objectives of the Assessment

The main goal of this *Integrated Assessment of Watershed Health in the Clinch and Powell River System* (referred to as "the Assessment") is to characterize the relative health of watersheds in the Clinch and Powell River System to guide future protection and restoration activities in the system. The Assessment synthesizes disparate datasets to depict current landscape and aquatic ecosystem conditions throughout the Clinch and Powell River System. It is framed with the recognition that the biological, chemical, and physical processes are interrelated and fundamentally connected to the health of a waterbody and the maintenance of natural watershed processes. By integrating information on multiple ecological attributes at several spatial and temporal scales, this study provides a systems perspective on watershed health. This study was funded by the EPA's Healthy Watersheds Program and was performed in conjunction with The Natural Conservancy (TNC) and the Clinch-Powell Clean Rivers Initiative (CPCRI). The CPCRI is a bi-state watershed protection and restoration effort involving multiple state and federal agencies, research scientists, nonprofit conservation organizations, and industry representatives. More information about CPCRI can be found at http://cpcri.net/.

This report presents the methods, results, next steps, and applications of the Assessment. Readers are asked to consider the following points regarding the scope of the Assessment as they review methods and interpret results:

- The Assessment characterizes *relative* watershed health throughout the Clinch and Powell River System using a collection of metrics that focus on the natural attributes of a watershed and its freshwater ecosystems. No statement on the *absolute* condition of any watershed or water body is made (e.g., attainment of designated uses), and results do not reflect the influence of factors not considered for analysis.

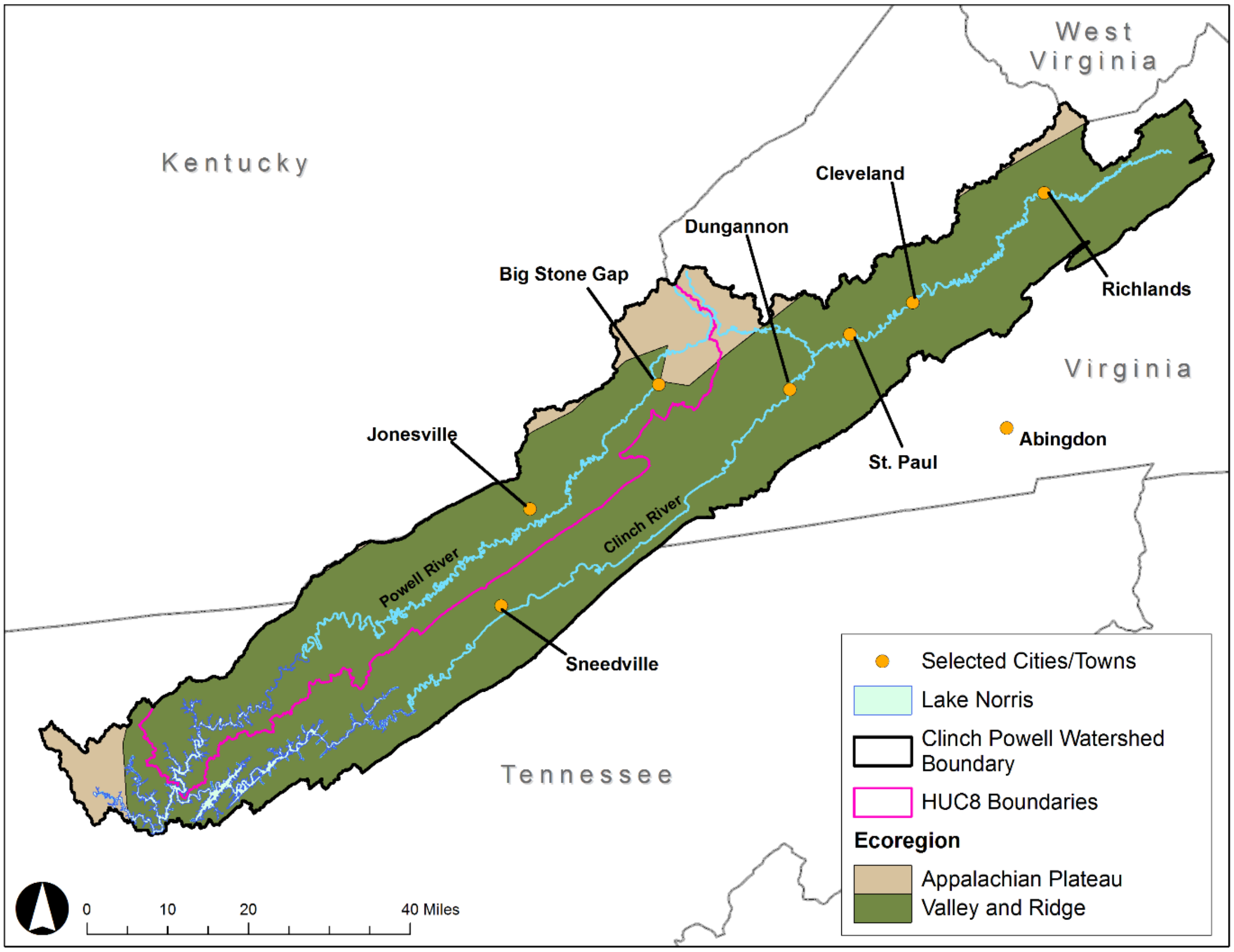
- Data and information on relative watershed health are intended to support a screening-level assessment of protection priorities across broad geographic areas (e.g., statewide or within regional planning units). Assessment data should not supplant in-depth, site-specific evidence of protection priorities, and conclusions drawn for smaller-sized areas should be validated with site-specific information.

1.3 Clinch and Powell River System

The Clinch and Powell River System, upstream of Norris Lake in Tennessee, is one of the last free-flowing sections of the Tennessee River basin. It provides a biological refuge for a large number of aquatic species, particularly rare freshwater mussels. The system begins in the mountains of southwest Virginia and empties into Norris Lake near Tazewell, TN. It has a total drainage area of 1.7 million acres (724,000 ha). Most (95%) of the river system is within the Ridge and Valley Level III ecoregion, while the rest (5%) is in the Appalachian Plateau (**Figure 2**). The Powell River begins in Wise County, VA, and flows 120 miles southwest where it flows into the Powell River Arm of Norris Lake. The Clinch River begins in Tazewell County, VA, and flows approximately 200 miles before reaching Norris Lake.

The Clinch and Powell River System is home to one of the most diverse fish and mussel assemblages in North America, but it has experienced significant ecological degradation associated with past and present coal mining, agricultural activities, and runoff from developed areas (Zipper et al., 2014; Krstolic et al., 2013; Johson et al., 2014; Jones et al., 2014; Ostby et al., 2014). Despite these challenges, the watershed supports more than half of the native fish species currently in the Tennessee River basin, and at least 48 freshwater mussel species inhabit the region including four species that occur only in the Clinch and Powell Rivers. These rivers also provide drinking water for more than 100,000 people, and are popular recreational assets that benefit local communities. Protecting the remaining intact attributes of the Clinch and Powell Rivers' ecosystem and strategic restoration are essential to local economies, citizens' quality of life, and comprehensive management of the Clinch and Powell watersheds.

Figure 2.   Ecoregions of the Clinch and Powell River System.



2. Methods Overview

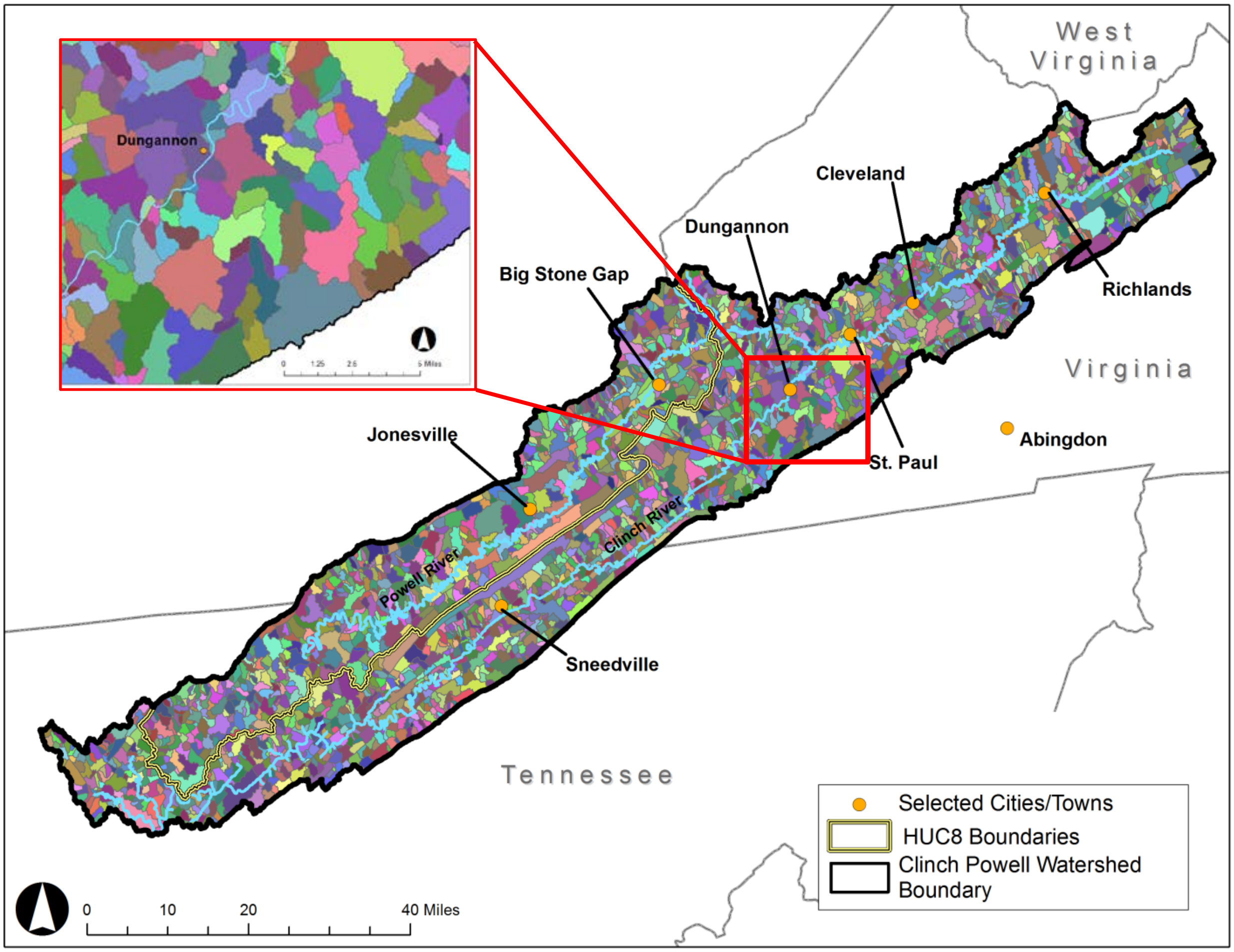
2.1 Description of the Assessment Process

This Assessment was conducted by RTI under the technical direction of EPA's Healthy Watershed Program and in partnership with the CPCRI Technical Team. The first step was to create an inventory of available field monitoring and geospatial data to assess current landscape, geomorphologic, hydrologic, water quality, and biologic conditions throughout the Clinch and Powell River System. Data were gathered directly from the CPCRI Technical Team (e.g., Tennessee Valley Authority, Virginia Department of Environmental Quality, and Virginia Department of Mines, Minerals, and Energy) and other publically available sources such as EPA's Storage and Retrieval Data Warehouse (STORET) and the U.S. Geological Survey's (USGS's) National Water Information System (NWIS). Appendix G provides a complete list of the datasets used in the Assessment. Based on the available data, the technical approach for the Assessment was prepared by RTI and reviewed by the Technical Team. Consensus on the technical aspects of the approach was achieved before implementation. The preliminary results were presented through a series of webinars to the Technical Team where the technical approach was further refined. The final results were presented to the Technical Team at a 2-day in-person meeting in Abingdon, VA. At this meeting, the Technical Team also discussed options for weighting the Watershed Health Index components and potential uses of the Assessment output.

2.2 Spatial Framework

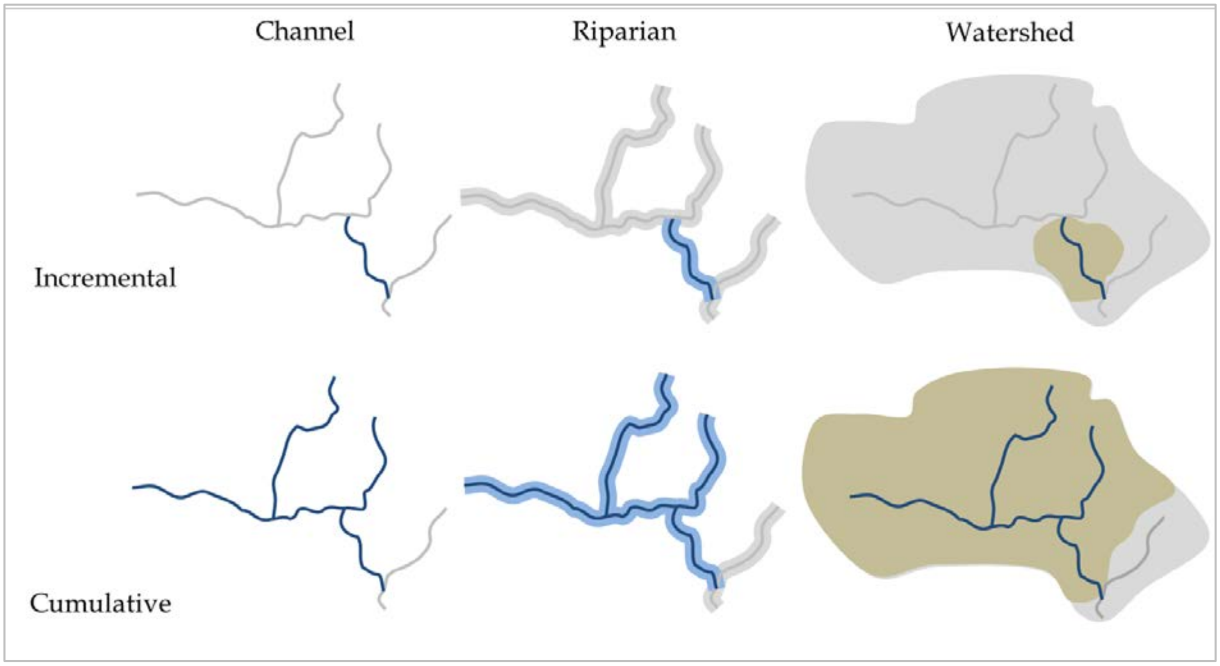
The spatial framework for conducting the Assessment is a network of small stream drainage areas or "catchments" represented in the National Hydrography Dataset Plus (NHDPlus). NHDPlus is a medium-resolution dataset of all stream reaches in the United States and their corresponding catchments. Each NHDPlus catchment represents the direct, or local, drainage area (median size of 0.6 square miles) for an individual stream reach and has a common identifier (COMID) assigned to it in the dataset. A separate table identifies the "from" and "to" COMID for every catchment in the dataset, giving a complete picture of the hydrologic relationships between every catchment in the stream network at the 1:100,000 scale. This information allows for rapid calculations of total upstream watershed characteristics (e.g., drainage area, stream length, land use) for any stream reach in the Clinch and Powell River System. In addition to its analytical benefits, NHDPlus catchments can be rolled up to multiple reporting scales. This allows for flexible reporting of results at scales appropriate for multiple management or communication objectives. NHDPlus version 2 was used for this Assessment. There are 3,131 individual NHD catchments within the Clinch and Powell River System (**Figure 3**).

Figure 3. NHDPlus catchments of the Clinch and Powell River System.
A detailed view of the catchments in the vicinity of Dungannon, VA, is shown in the inset.



Watershed health metrics are quantified on a catchment-by-catchment basis. Calculating most metrics involved summarizing existing geospatial datasets to catchment-specific values. Other metrics were quantified from modeled relationships between stream condition and several landscape variables. These landscape variables describe channel, riparian, and watershed-wide characteristics (e.g., riparian forest cover or watershed area) at both the incremental scale (within catchment boundaries) and cumulative scale (within all upstream catchments) (**Figure 4**). Cumulative values were included due to the potential for upstream conditions to influence the health of a given stream reach. The NHDPlus dataset supports aggregation of incremental-to-cumulative data by storing a unique numeric identifier for each catchment as well as upstream/downstream catchments.

Figure 4. Difference between incremental and cumulative scales for quantifying landscape variables. Variables quantified at the incremental scale summarize conditions within catchment boundaries only. Variables quantified at the cumulative scale also summarize conditions throughout all upstream catchments.



A final note on the spatial framework of the Assessment relates to differences between the scale of analysis and the intended scale of interpretation. Although NHDPlus catchments serve as analysis units, results are not intended to be used to assess the condition of a single catchment. Rather, results should be viewed over broad geographic areas to identify patterns and prioritize watersheds for in-depth, site-specific assessments of protection needs. See Section 5 for more information on the potential uses of the Assessment.

2.3 Watershed Health Metrics and Data Sources

A series of webinars were held with the CPCRI Technical Team in May, June, and July 2014 to identify indicators of watershed health that are most relevant to the Clinch and Powell River System and its stakeholders and for which data were readily available. The discussion was framed around EPA's six attributes of watershed health to ensure that all aspects of watershed health were explored. We explored the use of an ecological flow metric as a surrogate for habitat condition given that insufficient data were available for instream habitat, but we determined that the results were similar to the hydrologic condition assessment. Therefore, the habitat condition attribute was not included in the final assessment. Ecological indicators were calculated for the following attributes: 1) Landscape Condition, 2) Geomorphic Condition, 3) Hydrologic Condition, (4) Water Quality, and 5) Biological Condition (**Figure 5**).

Figure 5. Watershed health metrics used for the Integrated Assessment of Healthy Watersheds in the Clinch and Powell River System.

Landscape Condtion	Geomorphic Condition	Hydrologic Condition	Water Quality	Biological Condition
• Percent Natural Land Cover • Percent Natural Land in ARA	• Lateral Stability • Vertical Stability	• Annual Average 7-Day Minimum Flow • Average Annual 30-Day Minimum Flow • March Median Flow • Winter High Flow Pulse Duration	• Stream Total Suspended Solids • Stream Specific Conductance	• Macroinvertebrate EPT Rating • Fish IBI Rating • Mussel Rating

Landscape Condition was characterized by the extent of natural land cover throughout a catchment and within key floodplain areas such as riparian areas and wetlands. Geomorphic Condition, Hydrologic Condition, Water Quality, and Biological Condition metrics characterize the physical, chemical, and biological attributes of streams and rivers within the Clinch and Powell River System.

Three approaches were used to calculate metrics of watershed health for all catchments within the Clinch and Powell River System. The first approach calculated metric values directly from geospatial data that have representation across both watersheds (e.g., land use, percentage of forest cover, percentage of imperviousness). The second approach used predictions from statistical models that relate landscape characteristics to stream conditions. The statistical models are based on field-collected monitoring data throughout the watershed and modeled estimates of hydrology. Because field-based monitoring data were not available for every catchment in the watershed, statistical models were used to predict conditions in catchments without data. The combination of actual and predicted data was used to rank the relative health of watershed conditions. The third approach, used for hydrologic condition and within selected statistical models, relied on applying a daily rainfall runoff-based streamflow model for both watersheds at the NHDPlus catchment level.

The underlying source of data for Water Quality and Biological Condition Sub-indices are field-based samples collected across the region through various state and federal monitoring programs. Field-based data are not available in each of the 3,131 NHDPlus catchments in the Clinch and Powell River System. The existing monitoring data were used to predict water quality and biological condition in catchments without observed data using statistical regression models. These models quantify relationships among landscape and other catchment characteristics and predict the values of water quality and biological condition for catchments without data. Landscape variables describe land cover, elevation, geology, and stream channel characteristics at both incremental (catchment) and cumulative scales (see **Figure 4**). Other variables, such as sample date and streamflow, corresponding to field data were also used. Landscape and other variables quantified for statistical modeling are presented in **Table 1**.

Table 1. Landscape and other variables used in statistical models

Watershed Land Cover	Percent natural lands, percent forest canopy, percent agriculture, percent disturbed, percent forested land use, percent impervious surface (both within the catchment and cumulative)
Landscape	Fenneman ecoregions, minimum and maximum elevation, K-factor
Geology	Depth to bedrock, dominant rock type
Stream Channel Characteristics	Bankfull conditions (cross-sectional area, width, depth, discharge), sinuosity, average valley width, catchment length, stream type, stream order, channel slope
Sample	Sample date, sample month, sample year
Riparian Area Land Cover	Percent natural lands, percent forest canopy, percent agriculture, percent disturbed, percent forested land use
Catchment Hydrology	Daily flow and previous 5-day flow

Specific methods and statistical modeling approaches are described in the appropriate sections for each Assessment component, and additional information is provided in **Appendix B** (Landscape Condition), **Appendix C** (Geomorphic Condition), **Appendix D** (Hydrologic Condition), **Appendix E** (Water Quality), and **Appendix F** (Biological Condition).

2.3.1 Landscape Condition

Landscape condition is described by the extent of natural land cover throughout a watershed and within key functional zones such as floodplains, riparian areas, and wetlands. Given that accurate land cover data are central to other components in this assessment (e.g., hydrology, geomorphology, water quality, biology), it is critical to use data reflective of current conditions. Two metrics were selected to characterize landscape condition in the Clinch and Powell River System: Percent Natural Land Cover and Percent Natural Land Cover in the Active River Area (ARA). More information on the methods to determine landscape condition are available in **Appendix B**.

Percent Natural Land Cover: The 2011 National Land Cover Database (NLCD; Jin et al., 2013) was used to represent current landscape conditions. The NLCD has a 16-class land cover classification scheme that was applied consistently across the United States at a spatial resolution of 30 m (~100 ft). For this Assessment, these land cover classes were categorized as natural or non-natural for the purpose of calculating Landscape Condition metrics (**Table 2**). In addition to the developed and cultivated crop land classes, shrub/scrub and grassland/herbaceous land cover categories were classified as non-natural because they do not naturally occur in the watersheds and occur only after disturbance or with anthropogenic management (i.e., mowing, grazing, mining reclamation) (Fleming and Patterson, 2012). The amount of natural and non-natural lands for each catchment was calculated and used to assess the relative health of the landscape in each catchment. The area of natural land in the catchment was divided by the total catchment area and multiplied by 100.

Table 2. Classification of natural vs. non-natural lands based on 2011 NLCD categories

HWP Classification	NLCD Description and Classification Codes
Natural	Open water (11); deciduous forest (41); evergreen forest (42); mixed forest (43); woody wetlands (90); emergent herbaceous wetlands (95)
Non-natural	Developed, open space (21); developed, low intensity (22); developed, medium intensity (23); developed, high intensity (24); barren (31); shrub/scrub (52); grassland/herbaceous (71); hay/pasture (81); cultivated crops (82)

Note: Lands being actively mined would likely be classified as barren (31). Reclaimed mined lands would likely be classified as either shrub/scrub (52), grassland/herbaceous (71), or forested (41, 42, and 43).

Percent Natural Land Cover in ARA: The ARA framework is a spatially explicit view of rivers that includes both the channels and the riparian lands necessary to accommodate the physical and ecological processes associated with the river system (Smith et al., 2008). The five components of the ARA are 1) material contribution area, 2) meander belts, 3) floodplains, 4) terraces, and 5) riparian wetlands. The ARA for the Clinch and Powell River System in both Tennessee and Virginia was provided by The Nature Conservancy; however, the material contribution zone and wetland flats were missing for the Tennessee portion. To complete the ARA data layer for Tennessee, the Federal Emergency Management Agency 100-year floodplain was used as a surrogate for the material contribution zone (Barnett, 2013). The area of natural land in the ARA of each catchment was divided by the total area of the ARA in that catchment and multiplied by 100.

2.3.2 Geomorphic Condition

Fluvial geomorphology is the study of the shape of streams; it examines the interactions and relationships between streams and the landscapes through which they flow. Streams are dynamic systems that involve the movement of water through a channel; however, stream channels are subject to a wide variety of forces, both natural and anthropogenic. Geomorphic condition describes how all of these forces and processes, both past and present, affect stream channel formation and evolution. In other words, it indicates whether a stream system is in balance with its environment and able to adjust to changes in the watershed while maintaining its physical, biological, and chemical integrity.

Geomorphic assessments are often completed to determine channel stability and resiliency to watershed- or reach-level disturbances. Channel stability does not mean that the stream will not move on the landscape. Rather, streams in low gradient, alluvial valleys can meander across the landscape, eroding the outside bend and depositing new sediment on the inside of the bend. This form of lateral migration is generally a slow process and the channel dimensions (i.e., width, depth, area) change little even though the stream's position moves. This process is known as dynamic equilibrium. Channel resiliency is the ability of the channel to maintain dynamic equilibrium as disturbances occur in the watershed or along the stream corridor.

Streams often become unstable because of disturbances in the watershed that change the amount of runoff or sediment that reaches the channel. Watershed and land use changes (e.g., urban development that increases impervious cover, agricultural practices that increase sediment loads, mining that changes upstream hydrology) that cause instability are called indirect disturbances. Streams can also become unstable due to direct changes to the channel like channelization, removal of streamside vegetation, beaver dam and wood removal, valley fills, and mining through streams. These direct and indirect disturbances can cause instability in the vertical dimension, lateral dimension, or both. Geomorphic stability is an important part of overall stream and watershed condition. Unstable channels may increase sediment supply to the stream and downstream waterways, smothering benthic habitats and eliminating the niche spaces where aquatic biota shelter from predators, lay eggs, and forage for food. The subsequent increase in turbidity due to increased sediment supply may reduce primary productivity, increase stress throughout the food web, and change in water chemistry. Other consequences of instability may include threats to human infrastructure and a reduction in natural flood controls.

Geomorphic condition was based on numerous watershed variables to determine the balance of erosive and resistive forces at work within a catchment. Additionally, potential vertical stability and potential lateral stability were evaluated. Few field-based data are available to characterize geomorphology of the watersheds; therefore, geospatial data were used to determine conditions that could be used as a proxy (**Table 3**).

Table 3. List of variables used to determine geomorphic conditions

Variable	Source (and Method)
Bankfull Width	Regional regression equations based on drainage area (Keaton et al. 2005)
Bankfull Depth	
Bankfull Discharge	
Slope	Pre-calculated attribute in NHDPlus
K-factor	Attribute in the Soil Survey Geographic Database (SSURGO)
Depth to Bedrock	Average depth to bedrock along each flowline was calculated using the *Generalized Geologic Map of the Conterminous United States* (USGS, 2005)
Stream Order	Attribute in NHDPlus
Land Cover (Forest, Impervious, Natural Land in Active River Area)	NLCD 2011, ARA NLCD 2011, cumulative NLCD, impervious surface, NLCD 2011 canopy

For this assessment, geomorphic condition for each catchment was characterized in three ways: potential vertical stability, potential lateral stability, and overall geomorphic condition. In each case, metrics were assessed that 1) cause instability through erosional forces and 2) could resist the erosional forces. Because the factors available to evaluate erosional forces were identical for both the vertical and lateral stability assessments, the overall Geomorphic Condition Sub-Index was not calculated using a simple average of these assessments. The CPCRI Technical Team felt that this would give too much weight to the erosive factors in the final sub-index. Instead, the Geomorphic Condition Sub-Index was calculated by averaging the erosive forces within a catchment with the resistive forces for each catchment. Additional information on the methods and results for the determination of the Geomorphic Condition Sub-Index is provided in **Appendix C**.

Vertical Stability

Vertical instability occurs when the streambed lowers in elevation and the channel becomes deeper than it would be naturally. This is a very destructive process. As the stream lowers its bed elevation (incises), it becomes disconnected from the floodplain (or flood-prone area in colluvial valleys). This concentrates the energy in the channel and often leads to lateral instability (streambank erosion). It can take decades, centuries, or even longer for the stream to build a new floodplain at a lower elevation and reestablish a dynamic equilibrium (**Figure 6**). If the streambed is controlled by bedrock, these direct and indirect disturbances may result in lateral instability rather than vertical instability, especially if the riparian vegetation is removed. This can lead to channel aggradation (filling of the channel with sediment) and smothering of aquatic habitats.

Figure 6. Example of a vertically unstable stream channel. The stream is downcutting and becoming increasingly disconnected from its floodplain; high flows from storm events no longer have access to the floodplain, which would have dissipated the increased forces, protecting the channel from excessive erosion.

Photo credit: Brenda Morgan, Versar Inc.

Erosion Factors: Two factors were used to assess the potential for the stream to incise: percent impervious cover and stream power. It is widely accepted that an increase in impervious cover increases the amount of water reaching the channel by runoff and that an increase in runoff often leads to channel erosion, both vertically and laterally. Stream power is a quantitative measure of the stream's ability to do work, typically defined as moving sediment. Stream power is stream flow (discharge) multiplied by the channel slope and the specific weight of water. This value is typically divided by the channel width to create unit stream power so that it can be compared with other stream reaches. For this assessment, we used unit stream power calculated at the bankfull discharge to determine if the valley is considered a high-, medium-, or low-energy valley as defined by Nanson and Croke (1992).

Resisting Factors: High percent impervious cover and high stream power alone do not mean that the streambed will incise because there are other forces that resist erosion. These resisting factors include depth to bedrock, percent forest cover (for the entire land area draining to the catchment), and soil erodibility. Stream beds that are composed of bedrock will not incise, regardless of changes in hydrology (runoff). Bedrock is major form of grade-control for the streambed. As the depth to bedrock increases, the potential for stream incision also increases. The percent of forest cover also mitigates the potential for incision by lowering the volume of runoff from the watershed (opposite to percent impervious cover). Soil erodibility is measured as K-factor and was obtained from the Soil Survey Geographic Database (SSURGO) developed by the Natural Resources Conservation Service. The K-factor represents the susceptibility of soil to erosion and the rate of runoff. Soils high in clay have low K values, about 0.05 to 0.15, because they are resistant to detachment. Coarse-textured soils, such as sandy soils, have low K values, about 0.05 to 0.2, because of low runoff even though these soils are easily detached. Medium-textured soils, such as the silt loam soils, have moderate K values, about 0.25 to 0.4, because they are moderately susceptible to detachment and they produce moderate runoff. Soils with a high silt content are the most erodible. They are easily detached, tend to crust, and produce high rates of runoff. K values for these soils tend to be greater than 0.4. K-factor ranges and classifications were based on research by Jones et al. (1996). Over half of the catchments in the Clinch and Powell River System were characterized as having moderately erodible soils along stream channels based on K-factors.

Lateral Stability

Lateral instability occurs when the streambed migrates laterally across the landscape or experiences changes in channel dimension at an excessive rate, shifting away from a state of dynamic equilibrium (**Figure 7**). In these cases, the pace of change does not allow the stream to maintain its natural shape and relative dimensions. As the stream widens or shifts at an accelerated rate, increased stress to streambanks can undermine deeply-rooted vegetation and the other natural means of channel control, allowing the channel to fill with sediment. It may take many decades for a new, narrower channel to carve through the sediment deposition and establish a new floodplain.

Erosion Factors: Two factors were used to assess the potential for the stream to erode laterally and cause channel widening: percent impervious cover and stream power. It is widely accepted that an increase in impervious cover increases the amount of water reaching the channel by runoff and that an increase in runoff often leads to channel erosion, both laterally and vertically. Stream power is a quantitative measure of the stream's ability to do work, typically defined as moving sediment. Stream power is stream flow (discharge) multiplied by the channel slope and the specific weight of water. This value is typically divided by the channel width to create unit stream power so that it can be compared to other stream reaches. For this study, we used unit stream power calculated at the bankfull discharge to determine if the valley is considered a high-, medium-, or low-energy valley as defined by Nanson and Croke (1992).

Figure 7. Example of a laterally unstable channel. The stream channel is widening and the area of active flow is migrating to the left in the photo, as deposition has occurred to the right.

Photo credit: Brenda Morgan, Versar Inc.

Resisting Factor: High percent impervious cover and high stream power alone do not indicate that the stream channel will widen or migrate at an accelerated rate because other forces resist erosion. In the case of lateral stability, the resisting factor analyzed was percent of natural land cover within the ARA. Vegetation with deep roots, especially near the channel, holds the bank together, thereby reducing the potential for erosion and subsequent stream migration.

2.3.3 Hydrologic Condition

A stream's flow regime refers to its characteristic pattern of flow magnitude, timing, frequency, duration, and rate of change (Poff et al., 1997). Flow regime plays a central role in shaping aquatic ecosystems and the health of biological communities. Altering natural flow regimes (e.g., more frequent floods, prolonged periods of low flow) can reduce the quantity and quality of aquatic habitat, degrade aquatic life, and result in the loss of ecosystem services. To assess hydrologic condition, we can use metrics related to the flow regime to determine which stream segments have current conditions that most closely resemble the natural flow regime and can therefore be assumed to be healthy. Through the use of a hydrologic model, the percentage changes in hydrologic metrics representing the flow regime, rather than absolute values of these metrics, can be quantified to draw conclusions on the relative comparisons of higher condition versus lower condition stream segments across the watershed. These relative comparisons (and rank normalization of the overall condition metric discussed later) alleviate some concerns associated with potential errors associated with simulating an unknown condition (i.e., naturalized streamflow) for which there is no validation data in one case and comparing it to a validated condition in another (i.e., current streamflow).

To assess the current and natural flow regime within each catchment in the watershed, this Assessment used RTI's Watershed Flow and Allocation Model (WaterFALL®) to model long-term catchment scale streamflow. WaterFALL employs an enhanced version of a well-established hydrologic model, the Generalized Water Loading Function (Haith and Shoemaker, 1987), which has been modified to run on the NHDPlus network. WaterFALL functions as an intermediate-level, distributed hydrological model that accounts for spatial variability of the land surface, as well as climatic forcing functions. The watershed model encompasses all major components of the hydrologic cycle using the curve number method for computing runoff and a first-order depiction of infiltration and loss to deep aquifer storage. Enhancements include the representation of human interactions with the natural hydrologic system, allowing for the simulation of altered (current) conditions and routing routines to transport water from upstream to downstream through the catchment network. WaterFALL provides extremely high spatial granularity in its outputs through its distribution across many small NHDPlus catchments, which offers localized sensitivity to geographic variations in land cover and climate across a study region.

The basic methodology for assessing hydrologic condition is as follows:

1. Calibrate and run current condition scenario.
2. Run baseline/naturalized condition scenario.
3. Compute streamflow metrics to characterize flow regime per catchment, per scenario.
4. Assess change in streamflow metrics per catchment.
5. Rank catchments from most natural (i.e., least change) to most impaired (i.e., most change) per metric.
6. Combine ranks into final Hydrologic Condition Sub-Index score per catchment.

As a rainfall-runoff model applied to the NHDPlus hydrologic network, WaterFALL requires catchment-level parameterization of climate, land use, soil, and hydrological parameters in addition to available data on human alterations to the natural hydrologic system. Current conditions modeling was completed first for model calibration and validation purposes.

To characterize current land use, the NLCD 2011 used for the Landscape Condition Sub-Indices was refined to account for hydrologic impacts from coal mining in headwater areas of the basin (e.g., potentially disturbed deciduous forest). Permitting records for mining lands were used to spatially split all land use categories into areas with and without mining influences to create 13 "potentially disturbed" NLCD categories. These categories were classified as having lower infiltration rates (see **Appendix D** for literature that supports this determination).

These revised land use data layers were combined with recent daily climate data and estimates of water use throughout the basin to simulate 10 years of streamflow in the Clinch River and 20 years of streamflow in the Powell River. These simulations allow for model calibration and validation to selected USGS streamflow gages within the basin. To simulate natural conditions, model parameters and climate conditions were held constant, human water uses were removed, and land use conditions were represented by Küchler's Potential Natural Vegetation land cover (Küchler, 1964). Climate conditions were held constant to remove the possible impacts on the flow regime of climate change and instead focus on human alterations that can be managed with adaptation. The resulting modeling scenarios provide daily streamflow time series for all NHDPlus catchments within the Clinch and Powell River System from which hydrologic metrics are then calculated. Details on the WaterFALL modeling calibration and validation are provided in **Appendix D.**

Numerous streamflow characteristics (SFCs) can be generated as potential Hydrologic Condition metrics based on the catchment-level daily time series generated with WaterFALL. The overall objective for selecting metrics was to capture the full range of the hydrologic regime (e.g., timing, magnitude, frequency, duration, and rate of change) in addition to capturing elements of the regime that are important to the ecology of the watershed. Catchments with hydrologic metric values that did not differ greatly (either in positive or negative directions) from values calculated under naturalized conditions were considered to have the highest health condition stream segments.

The CPCRI Technical Team identified some guiding principles and metrics to examine for the hydrologic condition assessment. It is generally accepted that low-flow conditions are most likely to influence water quality parameters because of differences in ion concentrations between healthy and affected reaches within the basin. Additionally, work completed by Ostby (2005) documented that although it is accepted that high flows influence habitat stability, most mussel beds occur where bed stability is high under high flow conditions and shear stress is moderate under low flow conditions. Therefore, for mussels, the stable areas are self-selected. However, there is still the potential for the habitat of other fauna to be affected by changes in high flow duration and magnitude. A study by Knight and others (2011) related ecologically relevant SFCs to fish community structure in the Tennessee River basin. The study identified several SFCs that were significant predictors of fish response in the Valley and Ridge Physiographic Region. The most powerful single predictor for regional fish was variability of flow less than 25% (FL2). Other significant SFCs included variability of March flow (MA26), variability in high-pulse duration (LDH16), and frequency of moderate floods (LFH7).

Using this information and the available data-processing algorithms built into WaterFALL, which did not allow for direct re-creation of the USGS-suggested metrics during the course of this project, the CPCRI Technical Team selected the following metrics to use in defining the hydrologic condition:

- 7-day minimum low flow
- 30-day minimum low flow

- Average winter high pulse duration where high flow is defined as flows above the 75th percentile and winter is defined as the months of December through March

- Average median flow in March where median flow is defined as the 50th percentile

The hydrologic condition of each catchment is evaluated through the absolute percentage change between natural and current conditions for each of these metrics. The absolute change is used to evaluate the metrics because both positive and negative changes are considered to be degrading to the hydrologic regime for the purposes of this assessment. The overall Hydrologic Condition Sub-Index is calculated as the sum of the absolute percentage change for all metrics. This sum per catchment is then rank normalized to present the range of low (largest total percentage change) to high (smallest total percentage change) hydrologic condition across the watershed.

2.3.4 Water Quality

Water quality refers to a suite of physical and chemical parameters present in surface and ground waters. Parameter values are influenced by a complex set of factors that interact across multiple spatial and temporal scales. These factors include stream channel morphology, geology, watershed-scale land use, hydrology, biotic impacts, and other physical, chemical and biological processes. Water quality parameter values in a healthy watershed should fall within the range of naturally occurring variation for that water body. Parameter values that exceed natural variation can have large negative impacts on the physical, chemical, and biological processes that occur in surface waters; these changes can, in turn, alter the fundamental dynamics of aquatic ecosystem health.

Stream water quality data are collected by several organizations in the Clinch and Powell River System. These organizations sample a wide range of water quality parameters. For this Assessment, we focused on parameters that represent natural conditions. Therefore, after considering sample size, spatial and temporal distribution, parameter variability, natural occurrence, and relevance to watershed health, the study team selected two parameters for final modelling to characterize water quality health: stream specific conductance (SC) and stream total suspended solids (TSS) concentrations. Both SC and TSS are influenced by current and legacy land use in the Clinch and Powell River System, and both parameters can influence aquatic biology.

Post-2000 values of TSS and SC were averaged at the catchment scale (**Table 4**). These parameter values were then associated with multiple predictor variables (**Table 1**). Because water quality parameter values can be highly dependent on flow conditions, a range of sample date-specific flow estimates was generated using RTI’s WaterFALL model (see **Appendix D** for more information on this model).

Table 4. Modeled water quality parameters

Parameter	Unit	Number of NHDPlus Catchments with Water Quality Data	Start Date	End Date
Specific Conductance	µS/cm @25C	537	1-Oct-49	7-Aug-14
Total Suspended Solids	mg/L	430	20-Sept-67	8-Jul-14

Exploratory data analysis was used to identify potential relationships between flow and catchment variables and water quality parameter values. Statistical models were then fitted for each parameter to quantify these observed relationships and make water quality predictions for catchments without sample data. More information on the methods for water quality assessment including a list of all predictor variables considered is available in **Appendix E**.

2.3.5 Biological Condition

Biological condition is the most integrative of the six healthy watershed attributes, representing the cumulative effect of all abiotic features of the environment (including historical biogeographic factors) on the communities of organisms within the watershed ecosystem. The cumulative effects may include effects from features that are unknown or impossible to measure. Biological indicators also provide the opportunity to incorporate rare species or assemblages that are important for biodiversity beyond the watershed itself. The use of biological condition indices (such as the Index of Biological Integrity [IBI]) depends critically on the definition of reference condition so that naturally depauperate areas are not viewed as degraded. The best approach to assessing biological condition is to use more than one biological assemblage, in this case benthic macroinvertebrates, fish, and mussels.

Benthic Macroinvertebrates: Benthic macroinvertebrates are the most taxa-rich assemblage in streams and the most commonly used indicator of healthy waters. The presence of generally pollution-intolerant Ephemeroptera-Plecoptera-Trichoptera (EPT) is frequently used to indicate healthy streams. The percentage of EPT families found at 136 sample sites was provided by the Tennessee Valley Authority (TVA) specifically for the Assessment. These sites provided the best coverage of the study area for biological data. A map of sample locations is included in **Appendix F**.

Fish: Fish are the second most commonly used indicator of stream health and provide a good complement to benthic macroinvertebrates, which have different ecological requirements. Fish IBIs developed for the Assessment were provided by TVA from 136 sites nearly (but not exactly) coincident with benthic macroinvertebrate sites. These fish IBIs were based on a modified EPA IBI approach reflecting conditions relative to reference condition (Saylor and Alstehdt, 1990). A map of sample locations is included in **Appendix F.**

Mussels: A qualitative scoring of mussel condition in the Clinch River and its major tributaries was developed by CPCRI based on the best professional judgment of experts in the field (map included in **Appendix F**). Only the river mainstems and major tributaries were scored to reflect appropriate mussel habitats, so these data were not applied to smaller streams within the Clinch and Powell River System. The mussel condition scores were provided for all appropriate catchments in the study area, so no predictive modeling was required.

To characterize biological condition throughout the entire study area for fish and benthic macroinvertebrates, the study team used a range of landscape and other variables to predict macroinvertebrate EPT and fish IBI scores for each catchment in the Clinch and Powell River System (see **Table 1** for a list of variables). Biological condition modeling was performed similarly to the water quality analysis. The first step was a data exploration using correlations between catchment predictor variables and both the benthic macroinvertebrates and fish assemblages to determine which predictor variables to use in the model. Simple linear regression models were examined for significant and intuitive relationships. As described in **Appendix F**, the strongest relationships were combined into multivariable models that best predicted each biological variable independently. The strongest models were evaluated with key model fit parameters and then used to make predictions for all catchments in the watershed.

2.4 Rank Normalization of Metrics

Metrics of watershed health were rank normalized for reporting the metric, sub-index, and final index calculations. Rank normalization transforms one or more variables to a uniform distribution and scale, typically from 0 to 100; this common scale allows for comparisons between variables that may exhibit different units and scales. Rank normalization is also insensitive to outlier or extreme values, which can overly compress a normalized distribution when other normalization methodologies are applied (Mitchell, 2012). Once rank normalized on a common scale, sub-indices were combined to create a multi-metric index representing overall relative watershed health (see **Section 2.5**). Rank normalizing the watershed health metric includes the following steps:

1. Rank all catchments on the basis of raw metric scores:
    - Catchments were ranked in ascending order if higher metric scores corresponded to higher watershed health (i.e., similar to natural conditions)
    - Catchments were ranked in descending order if higher metric scores corresponded to lower watershed health (i.e., high TSS concentrations)
2. Apply the following formula to calculate the catchment's rank-normalized score:

$$Rank\ Normalization = \frac{Catchment\ Rank - Minimum\ Rank}{Maximum\ Rank - Minimum\ Rank} \times 100$$

Rank normalization provides metric scores ranging from 0 to 100 with consistent directionality. Rank-normalized scores are directionally aligned so that higher scores for watershed health metrics and sub-indices correspond to higher watershed health (**Table 5**). The results of each metric and sub-index are displayed in **Appendix A** using colors to depict the final score of each catchment; cool (blue) colors represent better condition and warm (yellow) colors represent lower condition.

Table 5. Original directionality of watershed health metrics

Metric	Original Directionality
Percent Natural Land Cover	Higher values = Higher watershed health
Percent Natural Lands in ARA	
Macroinvertebrate EPT Score	
Fish IBI Rating	
Mussel Condition	
Lateral Stability	
Vertical Stability	
Change in Annual Average 7-Day Minimum Flow[1]	Lower value = Higher watershed health
Change in Annual Average 30-Day Minimum Flow[1]	
Change in March Median Flow[1]	
Change in Winter High-Pulse Flow Duration[1]	
Stream TSS Concentrations	
Stream SC Concentrations	

1. The hydrologic metrics were calculated as the absolute value of the percent change between a naturalized baseline and current conditions experienced in the watershed. Larger changes, whether positive or negative, indicated lower watershed health.

As noted above, rank normalization was not applied to Hydrologic Condition metrics. Instead, only the final Hydrologic Condition Sub-Index was rank normalized based on the sum of the absolute percentage change for all the component metrics. Lower scores correspond to the largest total percentage change and higher scores correspond to the smallest total percentage change across the watershed.

2.5 Multi-metric Index Development

2.5.1 Description

Multi-metric indicators are a powerful tool for reporting aggregate conditions for ecosystems, including healthy watersheds. At the same time, care is required to ensure that multi-metric indicators remain transparent and are not confounded with redundant or spurious information. Weighted scoring schemas should be formulated to address both data validity and ecological importance.

Index scores were aggregated at two levels: the sub-indices (5) and the overall Watershed Health Index. Metrics were first combined into a set of sub-indices based on the groupings previously depicted in **Figure 5**. Each sub-index describes one attribute or component of watershed health: Landscape Condition Sub-Index, Geomorphic Condition Sub-Index, Hydrologic Condition Sub-Index, Water Quality

Sub-Index, and Biological Condition Sub-Index. The Watershed Health Index was calculated from the five watershed health sub-indices to provide an integrated view of landscape and aquatic ecosystem health. The purpose of scoring the sub-indices before calculating the overall Watershed Health Index is to balance the influx of each metric on the overall index score. Without this step, index scores could be biased toward attributes with the higher number of metrics (e.g., Hydrologic Condition).

2.5.2 Calculations

Index and sub-index scores range from 0 to 100 and are calculated based on the weighting of rank-normalized component metrics identified in **Table 6**. Normalization is a customary step in multi-metric index development that standardizes the scale of component metrics (Mitchell, 2012). Rank normalization also standardizes component metric distributions. Standardizing component metric distributions eliminates the potential for any one component metric to dominate index scores as a result of varied scales and distributions. Note, the effects of standardizing the scale and distribution of component metrics are not always positive, particularly when the values of a metric are predominantly in a range considered to be "good" or predominantly "poor." It is also important that rank-normalized scores with lower index and sub-index scores should not be considered impaired or degraded; rather, the condition is lower in score relative to other catchments in the assessment area. If all the catchments in a basin are considered "good" for a given metric, catchments with the lower metric scores will be considered the "least" healthy. Rank normalization can also be problematic when a large number of catchments share the same value of a given metric. The risk of these undesirable outcomes was minimized by choosing component parameters in consultation with the CPCRI Technical Team as well as examining the observed variability of candidate variables; if a parameter was not judged to be indicative of watershed health or exhibited very low variability, the variable was not included in the Assessment.

Table 6. List of metrics and their weighting factors to calculate sub-indices

Sub-indices	Metrics	Weighting
Landscape Condition	Percent Natural Lands	Equal weight
	Percent Natural Lands in ARA	
Geomorphic Condition	Vertical Stability	1st order stream weighting = vertical 75%/lateral 25% 2nd order and higher weighting = vertical 25%/lateral 75%
	Lateral Stability	
Hydrologic Condition	Annual Average 7-day Minimum Flow	Additive
	Annual Average 30-Day Minimum Flow	
	March Median Flow	
	Winter High-Pulse Flow Duration	
Water Quality	Stream Specific Conductance Concentration	Equal weight
	Stream Total Suspended Solids Concentration	
Biological Condition	Macroinvertebrate EPT Score	Equal weight (However, Mussel Condition is not modeled and is only available for a limited number of catchments.)
	Fish IBI Ranking	
	Mussel Condition	

The rank-normalization methodology described in **Section 2.4** provides metric scores that are directionally aligned (i.e., higher rank-normalized scores correspond to higher watershed health). Index scores follow the same directionality:

- High Watershed Health Index scores correspond to high watershed health.

As noted above, index and sub-index scores are calculated by averaging rank-normalized component metrics. These averaged values are also subsequently rank normalized for reporting. This ensures that scores for each index/sub-index range from 0 to 100. Further, rank normalization eases interpretation by providing scores that correspond to percentiles. For example:

- A Watershed Health Index score of 0 corresponds to the lowest condition in the Clinch and Powell River System.
- A Watershed Health Index score of 25 corresponds to the 25th percentile condition.
- A Watershed Health Index score of 50 corresponds to the 50th percentile condition.
- A Watershed Health Index score of 75 corresponds to the 75th percentile condition.
- A Watershed Health Index score of 100 corresponds to the highest condition in the Clinch and Powell River System.

3. Results and Discussion

This section presents the analytical results and maps illustrating scores for the Watershed Health Index and the sub-indices for Landscape Condition, Hydrologic Condition, Geomorphic Condition, Water Quality, and Biological Condition (full-page maps of all sub-indices and metrics are provided in **Appendix A**).

3.1 Landscape Condition Sub-Index

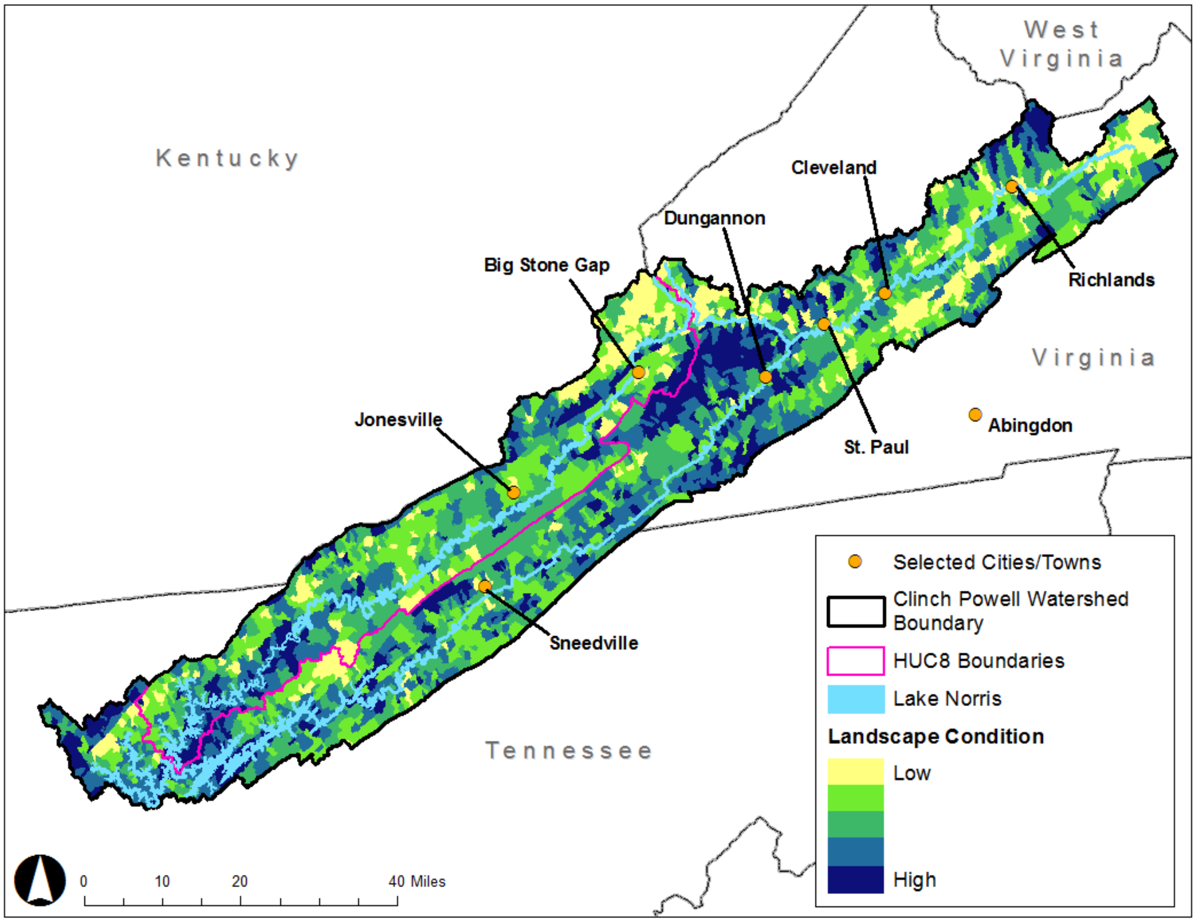
Landscape condition was determined by combining the ranked scores from the two metrics: Percent Natural Land Cover and Percent Natural Land Cover in ARA. Highest ranking areas for the overall Landscape Condition Sub-index are found in some coalfields' stream drainages north of the Clinch River between Richlands and St. Paul, VA (e.g., Weaver Creek, Indian Creek), on National Forest lands located at "High Knob" and along Stone Mountain, and in some areas around Norris Lake (**Figure 8**). Results from the two metrics are available in **Appendix B** illustrating slightly different patterns of landscape condition. For example, Percent Natural Land Cover is higher in the central portion of the Clinch River watershed near Sneedville, TN, and overall rankings are lower in the central portion of the Powell River watershed between Jonesville, VA and Norris Lake. However, the central portion of the Powell River has much higher rankings for Natural Lands in the ARA. The use of these maps could help identify locations of protection and restoration areas in the watershed.

3.2 Hydrologic Condition Sub-Index

The four metrics used to evaluate the Hydrologic Condition Sub-Index provided largely different pictures of hydrologic health that, when combined, allow for an overall estimate of the hydrologic condition across the watershed. With the values of each metric presented as the absolute percentage change, the following intervals were defined to group the catchments into three different general categories of watershed health for mapping and evaluation:

- 0 to 10%: Changes are within model error and there is likely little to no change experienced (presented as blue colors on the metric maps within **Appendix A**).
- 10 % to 30%: Changes are within typical ecological flow metric variation and some change in hydrologic regime is expected (presented as green colors on the metric maps within **Appendix A**).
- More than 30%: Changes are significant and an altered hydrologic regime state is expected (presented as yellow colors on the metric maps within **Appendix A**).

Figure 8. Overall Landscape Condition.



Annual Average 7-Day Minimum Flow: Changes in this short-term low-flow metric ranged from −100% to 5%. Only 23 catchments have experienced significant alteration (lowest health) in this metric, and they are limited to smaller tributaries within the upper reaches of both watersheds. Most catchments have experienced changes that fall within expected model error (highest health), with the exception of just over 200 catchments along the mainstem of the Clinch River and within some of the mined headwater areas.

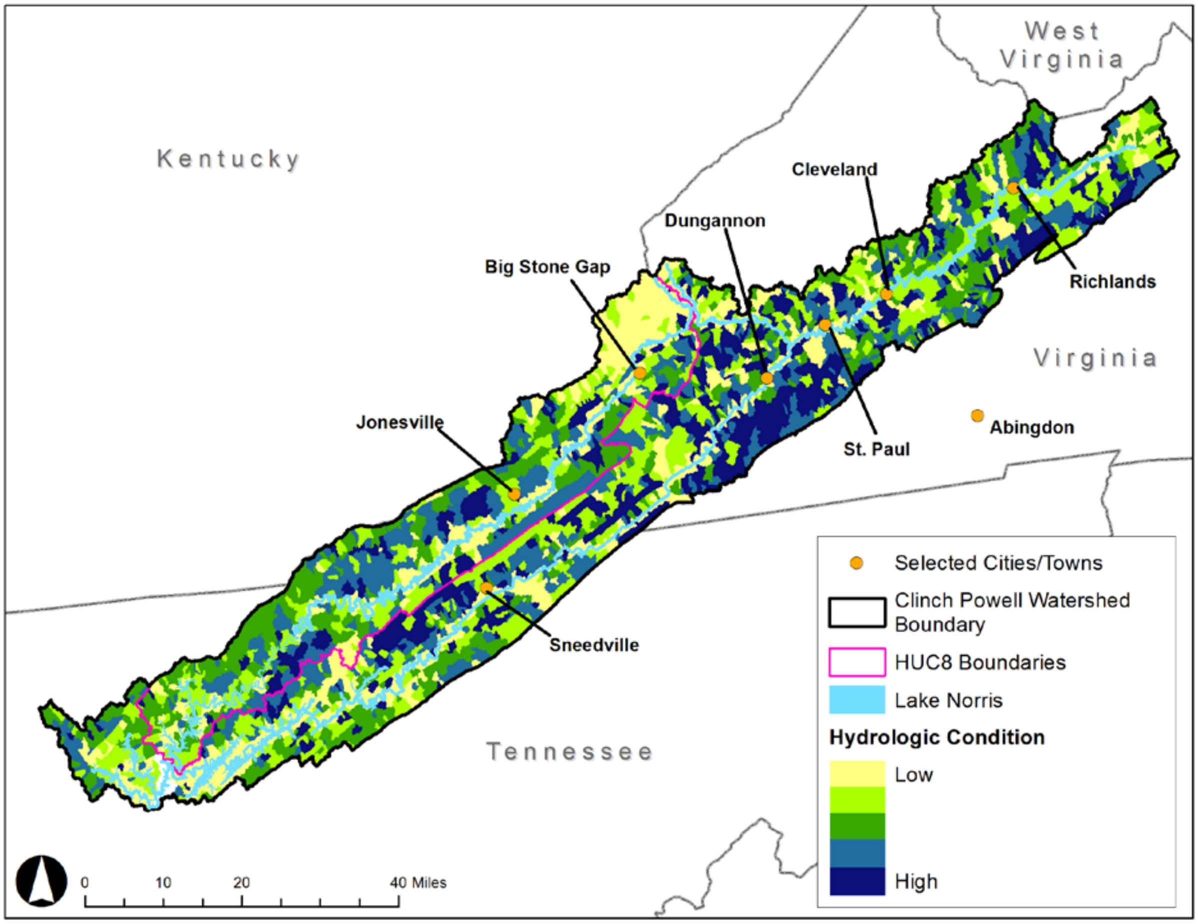
Annual Average 30-Day Minimum Flow: Changes in this longer-term low-flow metric ranged from −94% to 41%. As seen with the other low-flow metric, only a small proportion (n = 29) of catchments have experienced significant alteration and are considered to be of low health condition for this metric. These catchments are again limited to smaller tributaries within the upper reaches of the watersheds but with a greater focus within the mined headwaters of the Powell River. The significant increases (over 30% increase) in the 30-day minimum flow (n = 18) occur within the mined areas of the Powell River, while the significant decreases (over 30% decrease) in this metric (n = 11) occur within the headwater tributaries to the Clinch River. Similarly, catchments with some change expected due to an increase in this metric (10% to 30% change) fall within the mined lands and along the mainstem of the Powell River, while catchments with some change expected due to a decrease in this metric (−10% to −30% change) fall along the mainstem of the Clinch River. However, most of the watershed has experienced little to no change in this metric and therefore is considered to have a high health condition for this metric.

March Median Flow: Changes in the median flow for the month of March ranged from −51% to 6%, although very few catchments have experienced some to significant changes (over a 10% decrease), resulting in average to low health conditions. These changes, all due to a decrease in March median flow, are concentrated within the mined areas of the upper Powell watershed. The majority of the watershed has experienced little to no change in March median flows and therefore is considered to have a high health condition for this metric.

Winter High-Pulse Flow Duration: Changes in the duration of winter high flow pulses ranged from −41% to 50%. Changes in this metric are scattered throughout the watershed and are not focused along the mainstems of the rivers. The majority of the likely significant changes (> ±10% change) experienced in the winter high-pulse duration are due to decreases in the duration (n = 328) as opposed to increases in the duration (n = 74). The areas experiencing the most change were mall, individual headwater catchments that drain ridges, while there were some likely changes within the mined areas of the upper Powell watershed as well.

Overall Hydrologic Condition: The summation of the absolute value in percentage change for each metric results in a range of 0% to 256% change throughout the catchments of the watershed. **Figure 9** displays the rank-normalized overall Hydrologic Condition Sub-Index based on this absolute percentage change using an equal interval division among five categories of health. The areas of lowest hydrologic condition (highest percentage change) fall within the mined areas of the Powell River and along the mainstems of both major rivers. In addition, some of the smaller headwater tributaries that have experienced changes in the winter high-pulse duration are also ranked among the lowest hydrologic condition within the watershed. Areas exhibiting the highest hydrological condition are limited to small headwaters along ridges and are scattered throughout the watershed with the exception of a concentrated area of high hydrologic condition between the Copper and Moccasin Ridges southeast of Dungannon, VA.

Figure 9. Overall Hydrologic Condition.



3.3 Geomorphic Condition Sub-Index

The assessment of geomorphic condition in catchments throughout the Clinch and Powell River System was based on analysis of geospatial data, the selection of factors based on best professional judgment, and knowledge about the physical processes that influence stream channel stability. Because the geospatial data used for this analysis were available for every catchment in the study area, the analysis was able to evaluate the relative geomorphic condition and potential channel stability of each catchment.

Vertical Stability: Vertical stability was less of a concern along the mainstem channel and play a greater role in smaller, headwater streams. The areas along much of the mainstem Clinch and Powell Rivers were highly ranked for potential vertical stability. The map containing the rank-normalized results for this analysis is included in the Map Atlas (**Appendix A**).

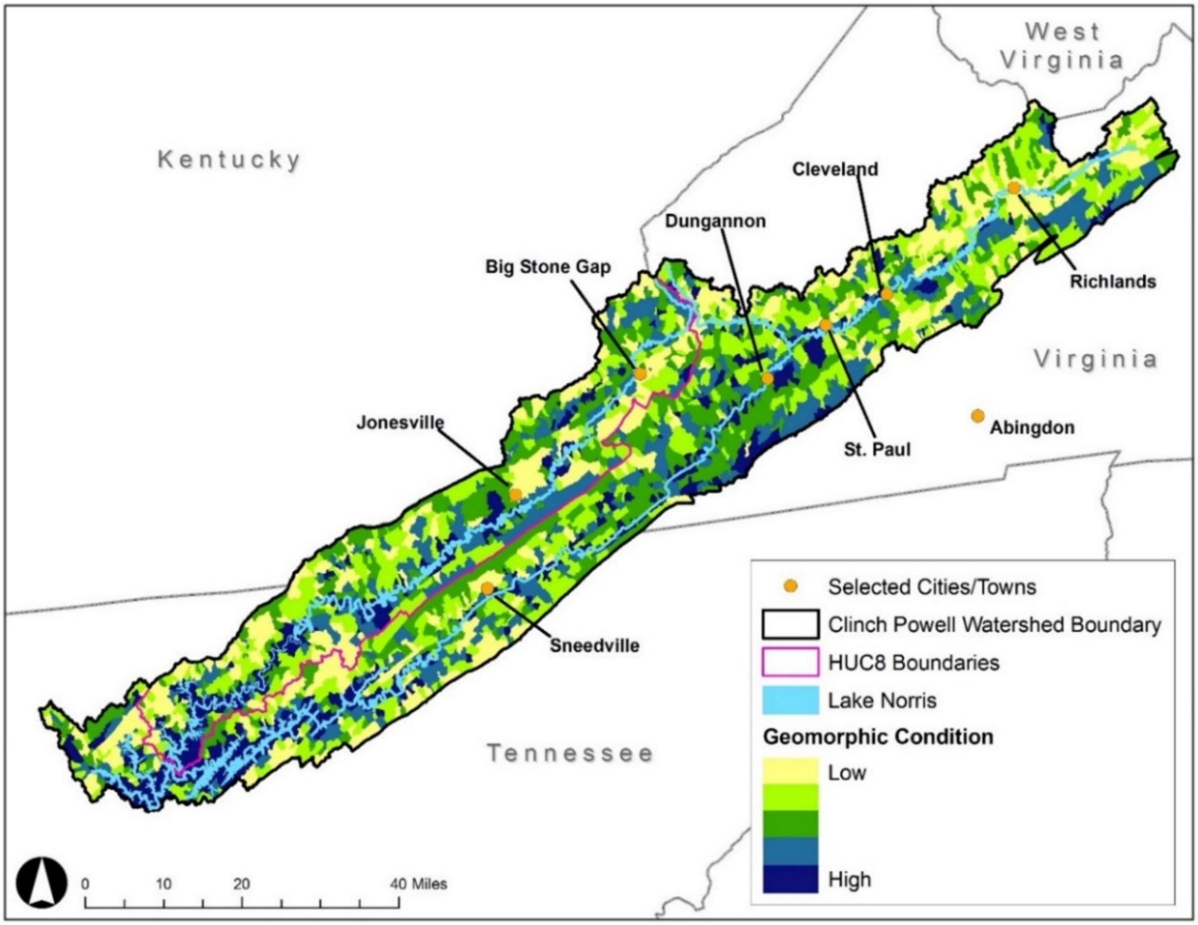
Lateral Stability: Lateral stability was of primary concern along the mainstem river channels. Lateral stability is strongly associated with intact riparian corridors and the downstream reaches of both mainstem rivers; a significant portion of the upstream Powell River was highly ranked for potential lateral stability. The map with rank-normalized results for this analysis is included in **Appendix A**.

Overall Geomorphic Condition Sub-Index: Erosion Factor and Resistance Factor Metric scores were developed through a combination of components of the vertical and lateral stability analyses. The relationship between the erosion and resistance factors, and how they relate to potential geomorphic stability of the catchments is shown in **Figure 10**. A catchment that is rated as being subject to low erosive forces while exhibiting high resistance to possible disturbance would exhibit high overall geomorphic condition and be thought of as both stable and resilient. Catchments along the mainstem rivers were rated as having the greatest potential stability, likely due to geologic characteristics and the greater forces required to reshape these larger channels.

Figure 10. Relationship between erosion and resistance factors used to assess overall geomorphic condition.

There were not strong regional trends or overall spatial relationships indicated by the Geomorphic Condition Sub-Index. This analysis was a first step in developing a way to assess geomorphic stability across a watershed. It was beyond the scope of this project to ground-truth the results of this Assessment; however, this would be an important future step in improving and refining the assessment of geomorphic stream condition. For this assessment, the CPCRI Technical Team decided to include the Geomorphic Condition Sub-Index as a component of the Watershed Health Index, while recognizing that this sub-index requires additional development. The final Geomorphic Condition Sub-Index is a combination of the erosive factors and resistive forces metric scores and is presented in **Figure 11**. Additional information on the erosive and resistive factors is available in **Appendix D**.

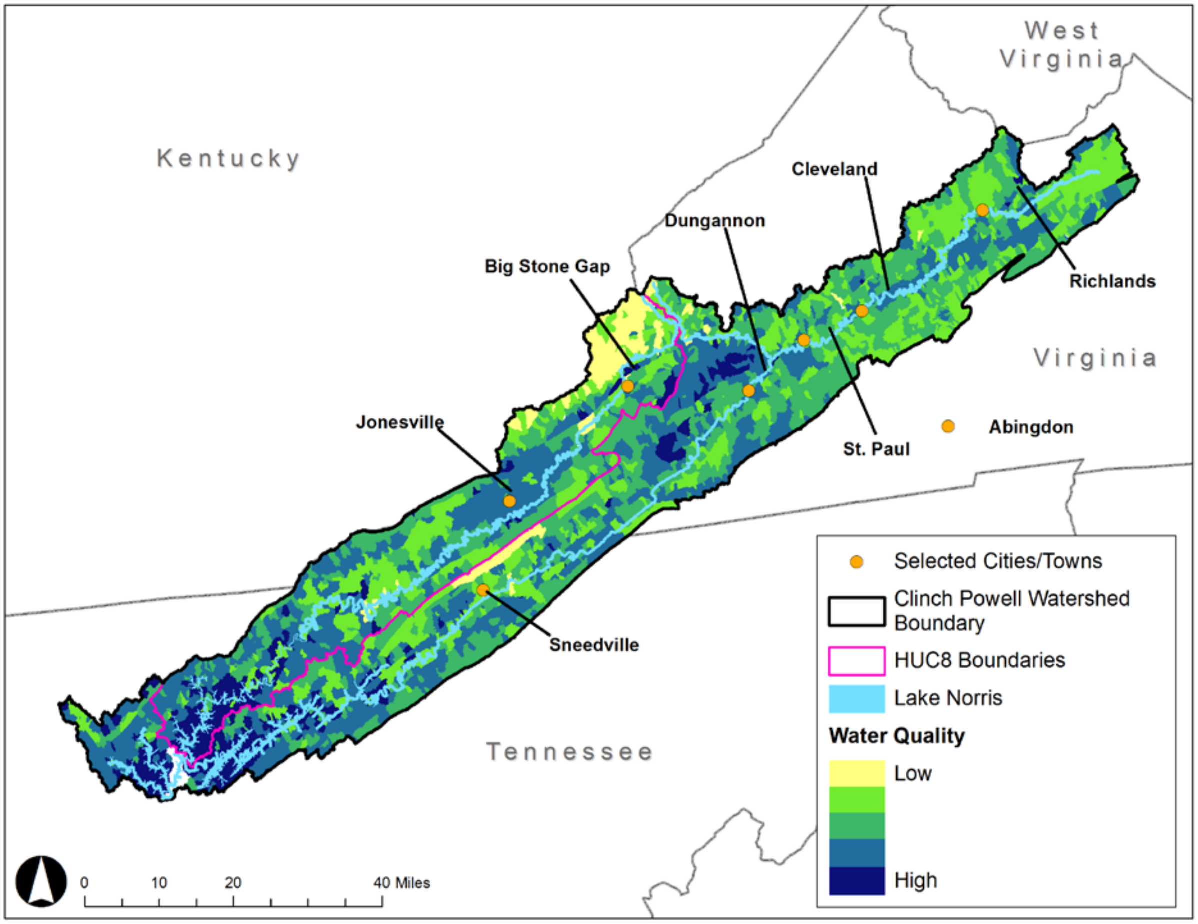
Figure 11. Overall Geomorphic Condition.



3.4 Water Quality Sub-Index

The two metrics used to evaluate water quality produced results that share many spatial trends (**Figure 12**). In general, catchments with higher percentages of mining, agricultural, or developed land use exhibit lower water quality rankings. Heavily mined areas in Upper Powell River tributaries (e.g., Callahan Creek) exhibit the lowest water quality. To compare and combine the two metrics, the predicted parameter values were place on the same numeric scale. Average catchment-scale predictions for SC were scaled on the unit interval (0, 1) using predicted values. Values for TSS were rank normalized on a scale from 0 to 1. For display purposes, the Stream Specific Conductance Metric map displays predictions using literature-based threshold categories and non-normalized parameter values. Additional discussion of the model results can be found in **Appendix E**.

Figure 12. Overall Water Quality Sub-Index.



Stream Total Suspended Solids Concentration: Predicted average catchment TSS values ranged from approximately 1,500 mg/L to values near zero; observed single sample values for TSS ranged from a few observations of greater than 10,000 mg/L to the lower detection limit. Higher predicted average TSS values are associated with surface mining and agricultural activities. Lower predicted average TSS values are associated with catchments that contain higher percentages of forested and natural land covers, especially at the cumulative watershed scale. The map containing the rank-normalized results for the Stream TSS Concentration Metric is included in **Appendix A**.

Stream Specific Conductance Concentration: Predicted average catchment SC values ranged from 1,296 µS/cm to near the lower detection limit; observed single sample values for SC ranged from 8,000 to near zero. Higher predicted average SC values are associated with surface mining and developed land uses and several mainstem segments of the Clinch and Powell Rivers. As with TSS, lower predicted average SC values are associated with catchments that contain higher percentages of forested and natural land covers. The map with the rank-normalized results for the Stream Specific Conductance Concentration Metric is included in **Appendix A**.

Overall Water Quality: Predicted TSS and SC values were rank-normalized and averaged to produce an overall Water Quality Sub-Index score for each catchment (**Figure 12**). The sub-index results exhibit many of the spatial trends evident in the individual metric values (**Appendix A**). Lower Water Quality Condition Sub-Index values are associated with current and legacy surface mining and agricultural land uses. Mainstem Clinch and Powell water quality condition varies relative to these land uses as well as developed area in the valleys (i.e., towns and low-density residential); the cumulative impact of upstream land cover on higher order streams is also influenced by inflows from relatively undisturbed or forested upland regions. These upland regions, apart from mining and agricultural activities, tend to have overall higher Water Quality Condition Sub-Index scores, especially when the upstream drainage area is dominated by forest or other natural land cover.

3.5 Biological Condition Sub-Index

The Benthic Macroinvertebrate EPT Score and Fish IBI Metrics showed similar spatial trends in that the areas with the highest biological condition were located in the areas around Jonesville, VA; the headwaters of both the Clinch and Powell Rivers; and the southernmost portion of both rivers near Lake Norris. Low biological condition was scattered across the watershed for both metrics. Where the Mussel Condition Metric was available, the results showed the lowest biological condition in the headwaters of both the Clinch and Powell Rivers and the highest in the mainstem of the Clinch River.

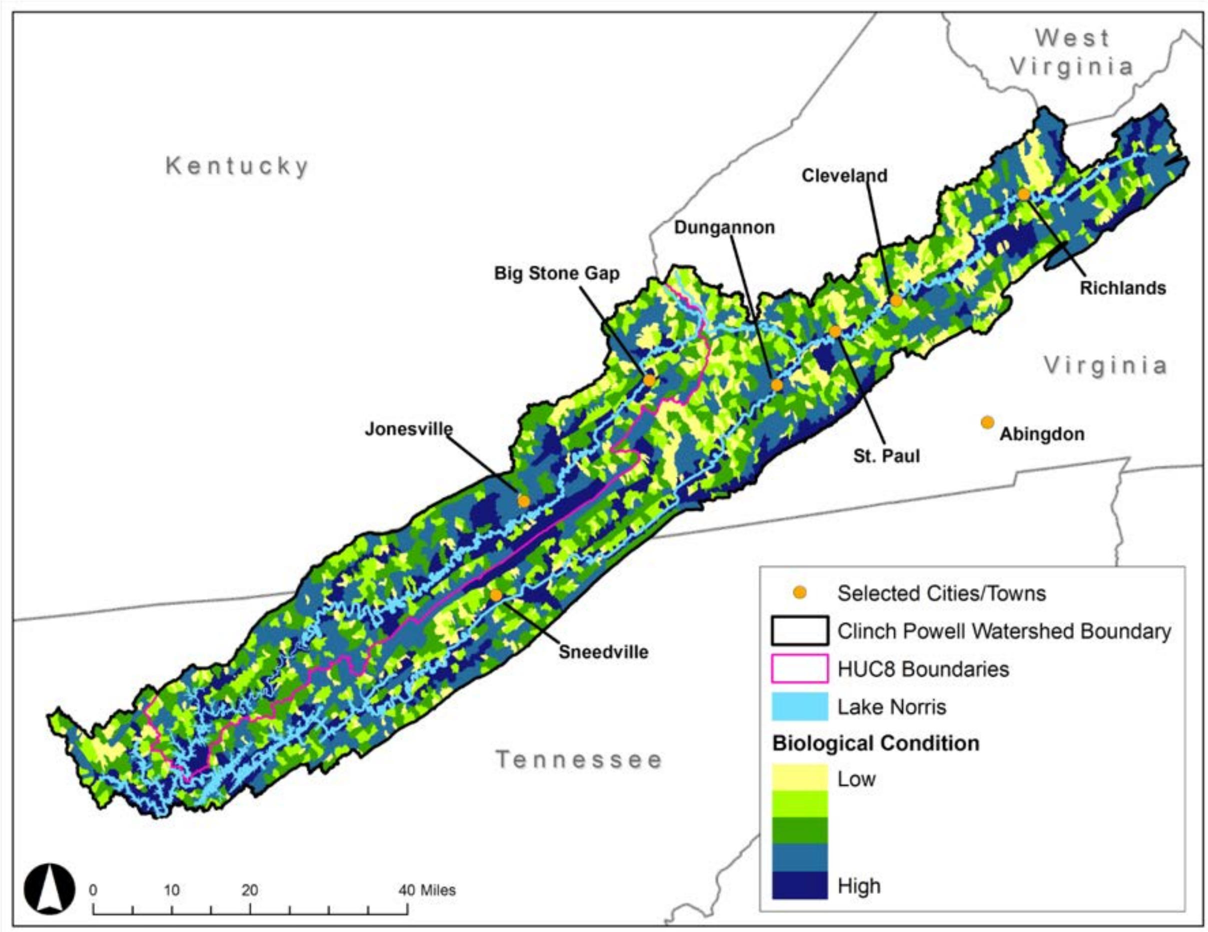
Benthic Macroinvertebrate EPT Score: The strongest model fit for benthic macroinvertebrates includes the following predictor variables: Slope, Percent Forest Area (Cumulative), and Percent Natural Lands in the Active River Area ($r^2 = 0.18$). The map containing the rank-normalized results for this metric is included in **Appendix A**.

Fish IBI Metric: The strongest model fit for the fish IBI includes the following predictor variables: Bankfull Discharge, Percent Forest Area (Cumulative), and Drainage Area. The map containing the rank-normalized results for this index is included in **Appendix A**.

Mussel Condition Metric: Mussel condition scores were provided for 407 catchments located mainly in the Clinch River Watershed. Mussel condition was rated on a scale from 1 to 4 scale, with 1 being poor and 4 being good. Ratings were based on a qualitative assessment of habitat and the existing mussel population. For incorporation of this metric into the overall Biological Condition Sub-Index, the condition scores were assigned corresponding values on a scale of 0 to 1 (i.e., 0.125, 0.375, 0.675, and 0.875).

Biological Condition: Rankings for Benthic Macroinvertebrate EPT, Fish IBI, and Mussel Condition were averaged for each catchment to calculate the Biological Condition Sub-Index (see **Figure 13**). For catchments that did not have mussel data, only the Benthic Macroinvertebrate EPT and Fish IBI Metric rankings were averaged to calculate the sub-index, thus ensuring that catchments for which mussel information was unknown were not downgraded. Results indicated that areas with the highest biological condition include the mainstems of the Clinch and Powell Rivers, generally the Clinch River headwaters, some forested ridges, and limestone/karst-influenced valleys around Jonesville, VA.

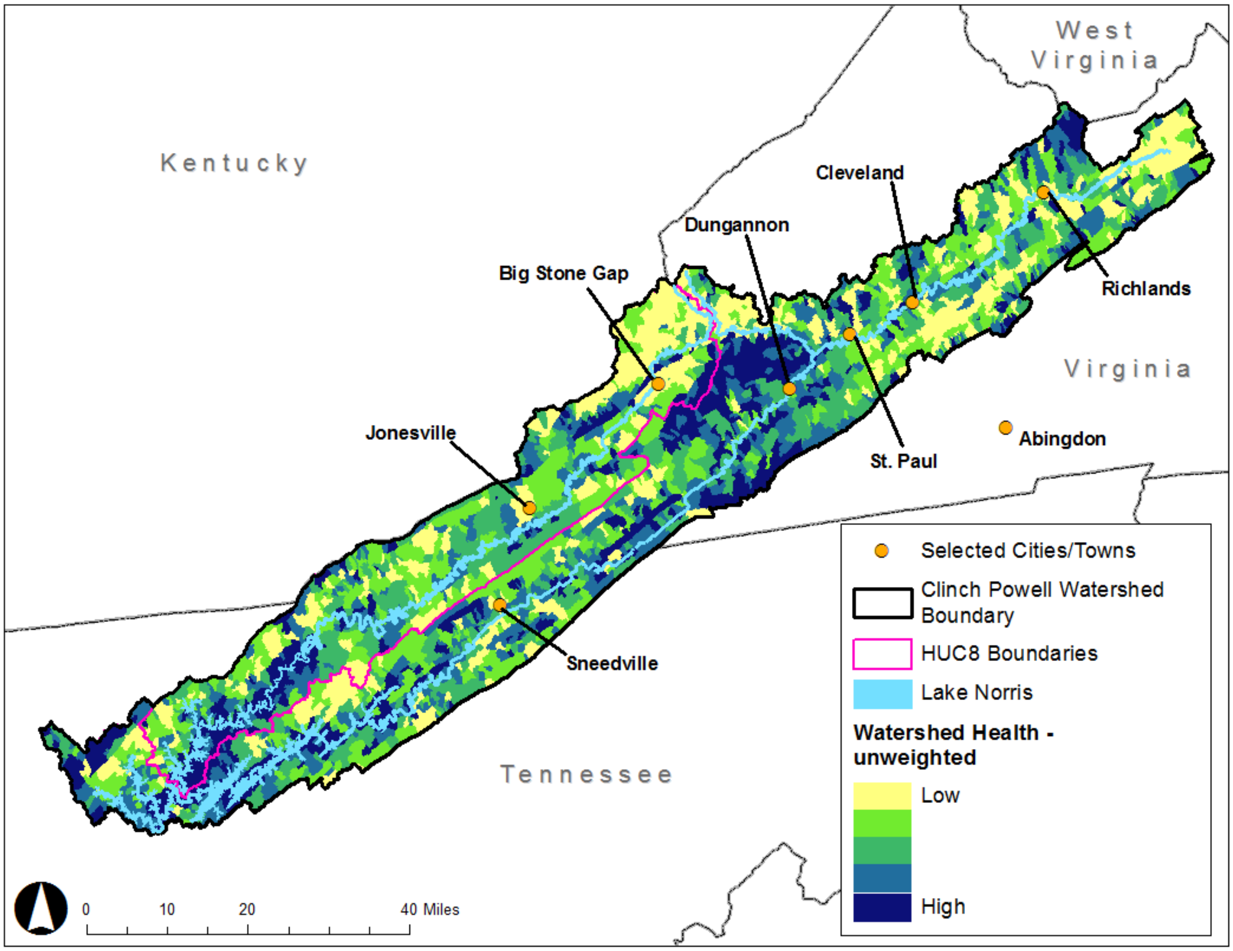
Figure 13. Overall Biological Condition.



3.6 Watershed Health Index

Watershed health scores for the Clinch and Powell River System are presented in **Figure 14**. These results are based on the equal weighting of individual sub-indices for Landscape Condition, Geomorphic Condition, Hydrologic Condition, Water Quality, and Biological Condition. Overall, highest ranking areas are (1) the Indian Creek headwaters of the Clinch River; (2) the "High Knob" section of Wise and Scott Counties; (3) the Clinch River between Dungannon, VA and Sneedville, TN; (4) the Copper Creek watershed in Scott County, VA; and (5) stream drainages near Norris Lake. It should be noted that populations of rare freshwater mussels in the Clinch River downstream of the Guest River in Virginia, as well as in Copper Creek, have seen dramatic declines in recent years. It is also noteworthy that rare mussel populations near Sneedville, TN have been stable to increasing over the same time period. CPCRI partners are separately collecting and analyzing water quality and biological data at a finer scale to better understand the mixed patterns of health in this faunal group of global importance.

Figure 14. Overall Watershed Health Index.



3.7 Correlation Analyses

A correlation analysis between all possible pairings of the watershed health sub-indices was conducted to determine whether there is any relationship between these calculated measures that would ultimately prohibit combining the sub-indices into the Watershed Health Index without redundancy. The potential for correlation exists due to some commonalities in the underlying data used to calculate the metrics used for each sub-index. Component metrics for the Geomorphic Condition, Biological Condition, and Water Quality were quantified from statistical models that relate stream health observations to several landscape variables, including those that describe the amount and distribution of natural land cover in a catchment. Because these same properties are captured in Landscape Condition, there is potential for redundancy between the Landscape Condition Sub-Index and sub-indices derived from modeled metrics.

To assess any correlations, the statistical metric of the squared Pearson's correlation coefficient was used for each unique pairing of sub-indices (**Table 7**). Values for the 10 potential pairings ranged from

0.0001 (Geomorphology and Hydrology) to 0.425 (Landscape and Geomorphology). In addition to the Landscape-Geomorphology pairing, the Landscape-Biology (0.332) and Geomorphology-Biology (0.323) pairings also show low levels of correlation. However, none of these three pairings exhibit correlation values that would restrict the combining of sub-indices in the single Watershed Health Index. For reference, previous thresholds used to indicate correlation among metrics include 0.56 (Emery et al., 2003) and 0.64 (Hering et al., 2006).

Table 7. Square of Pearson's Correlation Coefficient values for each unique pairing of condition indices.

Condition Sub-Index Comparisons	Squared Pearson's Correlation Coefficient
Landscape to Geomorphology	0.425
Landscape to Hydrology	0.020
Landscape to Water Quality	0.032
Landscape to Biological Condition	0.332
Geomorphology to Hydrology	0.0001
Geomorphology to Water Quality	0.048
Geomorphology to Biological Condition	0.323
Hydrology to Water Quality	0.032
Hydrology to Biological Condition	0.004
Water Quality to Biological Condition	0.006

4. Assumption and Limitations

Assumptions were made throughout the assessment process that may impose limitations on using the results for certain watershed protection planning efforts. These assumptions should be recognized by users of the Assessment output and are described below.

Spatial Framework

- The NHDPlus stream network is a medium resolution (1:100,000) representation of water body locations in the Clinch and Powell River System. Although the accuracy of the NHDPlus stream network and catchment delineations were not verified as part of this project, they were determined to be sufficient for regional screening of watershed protection priorities.

- Metric and index scores describe overall or average conditions within a given NHDPlus catchment. Assessment results do not supply information at a resolution finer than the catchment scale (approximately 1 square mile).

Watershed Health Index

- Watershed health metrics were selected on the basis of data availability, data quality, spatial and temporal coverage, and expert judgment of relevance to watershed health. Index scores do not account for aspects of watershed health beyond those represented by selected metrics and the data from which they were derived.

- The 2011 NLCD used in this assessment is assumed to be representative of current landscape conditions. The land use classifications have specific definitions. For example, shrub/scrub is defined as areas dominated by trees generally less than 16 ft (5 m) tall and shrub canopy greater than 20% of the total vegetation canopy. This class includes young trees in the early successional state or trees stunted from environmental conditions. It is not until the tree height is greater than 16 ft (5 m) that the area would be classified as a forest. Because of the transitional state from a disturbance, shrublands are considered non-natural, whereas forest lands are natural lands. The NLCD has a spatial resolution of 30 m or 0.25 acre; therefore, features or land use changes smaller than the minimum mapping unit are not captured.

- Geomorphology describes a dynamic system that is difficult to characterize with static measurements. Typical geomorphic measurements are not available at the catchment scale and there are not enough site-based results to establish statistical models. Available landscape data do not encompass all components of geomorphology.

- The Assessment assumed that lateral and vertical stability are sufficiently representative of geomorphology to characterize the ecosystem. The metrics used for lateral and vertical stability are reliable indicators and are weighted according to stream order. The Assessment assumes that vertical stability is more important in determining the overall geomorphic condition in first order streams, whereas lateral stability is weighted more in streams second order or higher.

- The model parameters derived for using WaterFALL to model the hydrologic regime of present-day streamflows can be applied with acceptable levels of uncertainty to modeling the hydrologic regime of naturalized streamflows. Because there are no observed naturalized streamflow data available for calibration, the present-day calibration parameters must be applied to the naturalized scenario as well.

- Monitoring data and information are not available on all biological components of the ecosystem, ideal reference conditions are not available for all ecoregions and stream types, and the samples are limited in number and distribution along geography and gradient of disturbance.

- In addition to the available and relevant water quality parameters used in the Assessment, there are likely other critical components of water quality that influence the relative health of catchments within the system. For example, CPCRI partners are currently investigating patterns of trace metal concentrations and the influence they may be having on sensitive mussel populations in the river system. However, at this time these data are not spatially distributed enough to be meaningfully included in this Assessment.

- This Assessment assumed that the combination of benthic macroinvertebrates, fish, and mussel assemblage information is representative of the biology of the ecosystem. A total of three components is generally a good number when they have complementary responses to environmental conditions as these do.

- The fish IBI developed by TVA and the EPT benthic macroinvertebrate metrics are reliable indicators of biological condition. Both are well-established general indicators but are not tied to specific references in the study area. The number and distribution of samples is adequate for creating valid models predicting biological condition. This appears to be the case for the entire study area but not for individual ecoregions or stream types.

5. Next Steps and Potential Application of Assessment Maps and Results

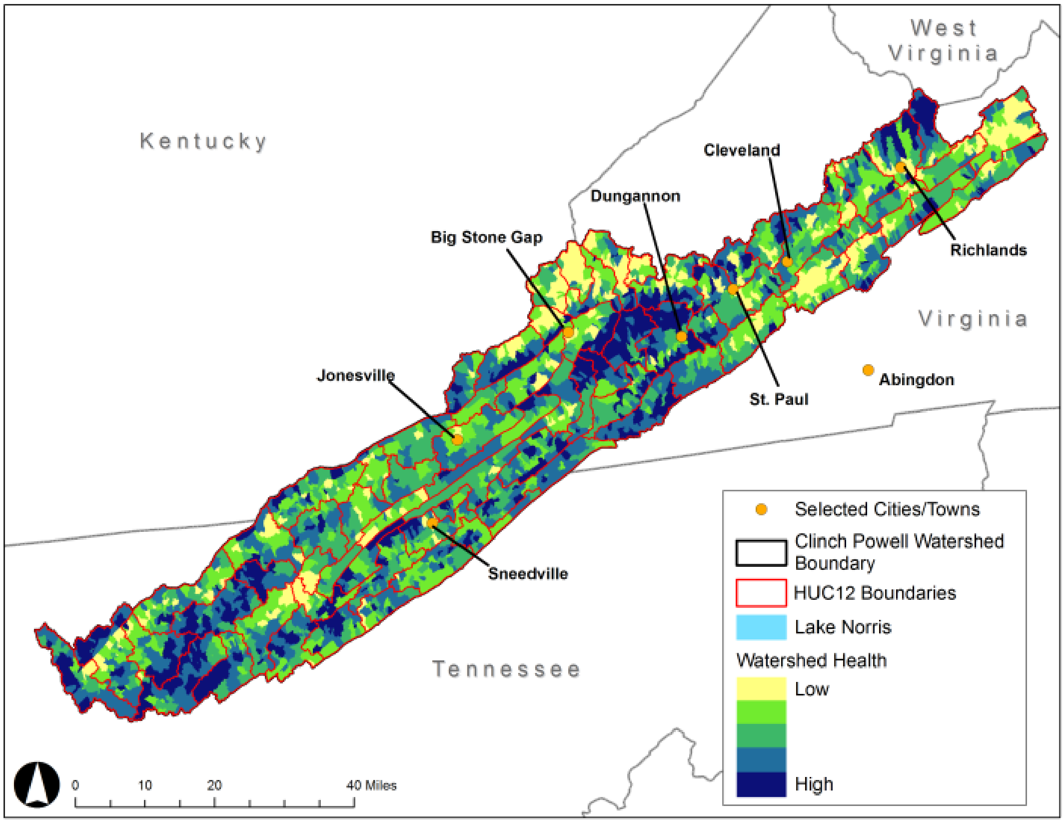
This Assessment integrates disparate datasets to characterize watershed health across the Clinch and Powell River System. Results can be used in a variety of ways to inform efforts to preserve and improve the ecological health of these globally significant waters. For example, the results can be aggregated to HUC 12 watersheds to more easily convey watershed health at different scales (**Figure 15**). The results generated from this Assessment have been provided to the CPCRI and can be used to illustrate results in support of the following uses.

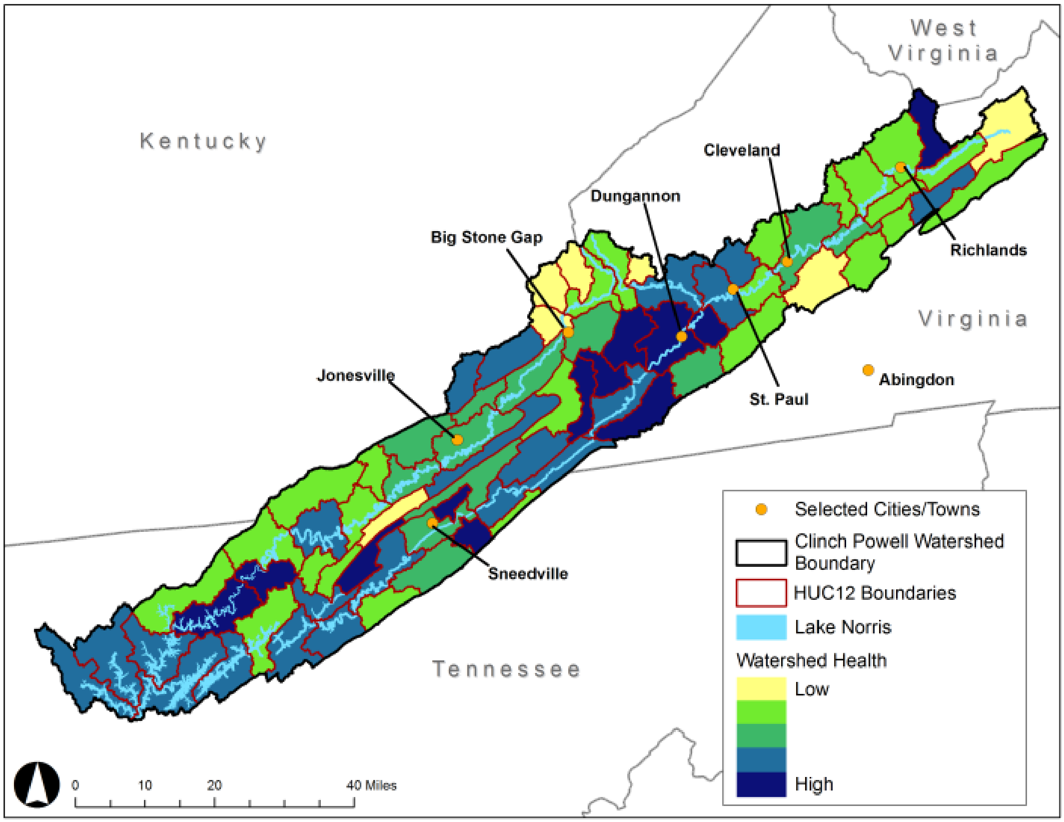
Outreach and Communication: One of the goals of this Assessment is to provide results in a format that fosters communication among both technical and nontechnical audiences. Assessment results are displayed on maps where the condition of aquatic resources is clearly and concisely conveyed on a gradient from unhealthy to healthy. These results can be used as a basis for outreach materials engaging political leaders, planning departments, industry, students, land owners, recreationalists, business leaders, and the general public in a dialogue about needs for watershed protection and restoration. The results can also facilitate communication among groups with similar goals to protect and promote aquatic resources in the Clinch and Powell River System.

Economic Development: The protection, maintenance, and improvement of healthy watersheds support local and regional economic development. Healthy stream systems provide clean drinking water for local communities; support industry, agriculture, and other commercial activities; and provide economically important recreational opportunities for locals and visitors alike. As localities seek to protect the health of citizens, improve water quality, recruit and retain new businesses, attract new residents, and capitalize on the recreational assets of the Clinch and Powell River System, they can use the Assessment results to highlight the unique and special qualities of this river system. Assessment results can be used to promote the region, stimulate financial investments in recreation and other sustainable economic development strategies, and help guide long-range planning efforts.

Strategic Stream Protection: Assessment results sort and rank watersheds according to their relative aquatic condition. The "best-in-class" stream drainages can become candidates for increased protection. Protection of these watersheds could take a variety of forms including but not limited to 1) land or easement acquisition by conservation agencies and qualified nonprofits, 2) special designation by public agencies (e.g., classification as Tier 3 Exceptional Waters under Virginia's Anti-Degradation policy), 3) designation as "avoid" areas in state and federal permitting decisions that require the application of the mitigation hierarchy (e.g., Clean Water Act), or 4) special recognition in county comprehensive plans and land use regulations. Importantly, all of these potential tools require and are dependent on public participation and support.

Figure 15. Overall watershed health (top) and aggregated by USGS Hydrologic Unit 12-digit Code (bottom).





Strategic Stream Restoration: Assessment results can be used to prioritize watersheds and focus restoration efforts on stream drainages that have the best chance of recovery. A variety of tools, programs, and resources can support targeted restoration efforts in high-value watersheds, including but not limited to 1) compensatory mitigation programs, 2) cost-share programs administered by the Natural Resource Conservation Services and local Soil and Water Conservation Districts, 3) the Abandoned Mined Lands Program, 4) U.S. Fish and Wildlife Service Partners Programs, and 5) Virginia/ Tennessee Landowner Incentives Programs administered by state wildlife agencies. Assessment results can be used by agencies administering these programs and, in conjunction with field-based data and local knowledge of watersheds, to direct priorities and take positive management actions based on a holistic understanding of watershed health.

Improved Stream Monitoring and Assessment: The results from this Assessment can inform federal, state, and local aquatic monitoring program integration ensuring representative data collection across a range of watershed conditions. Some of the highest quality watersheds could potentially serve as reference sites. Additionally, the Assessment results can be used to assess the spatial coverage of the existing monitoring programs and sampling locations.

A comprehensive inventory of current data characterizing watershed health was compiled for this Assessment (**Appendix G**). This process identified several data gaps that can be addressed through future research and monitoring efforts. Example gaps include 1) spatially disparate data, and 2) insufficient reach-scale in-stream habitat and geomorphic condition information. Also, hydrologic data exists for only a limited number of sites; therefore, the Assessment had to rely on an approach based on modeled rainfall and runoff to predict flow metrics. Additional research could be conducted to explore flow-ecology relationships. This Assessment focused on stream and rivers; additional assessments are needed to characterize the condition of other aquatic resources such as wetlands, springs, and karst streams. Prioritizing and addressing some of these data gaps could become a focus for CPCRI partners and others working in the Clinch and Powell River System.

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Appendices

Appendix A: Map Atlas

Figure A-1. Landscape Condition Sub-Index.

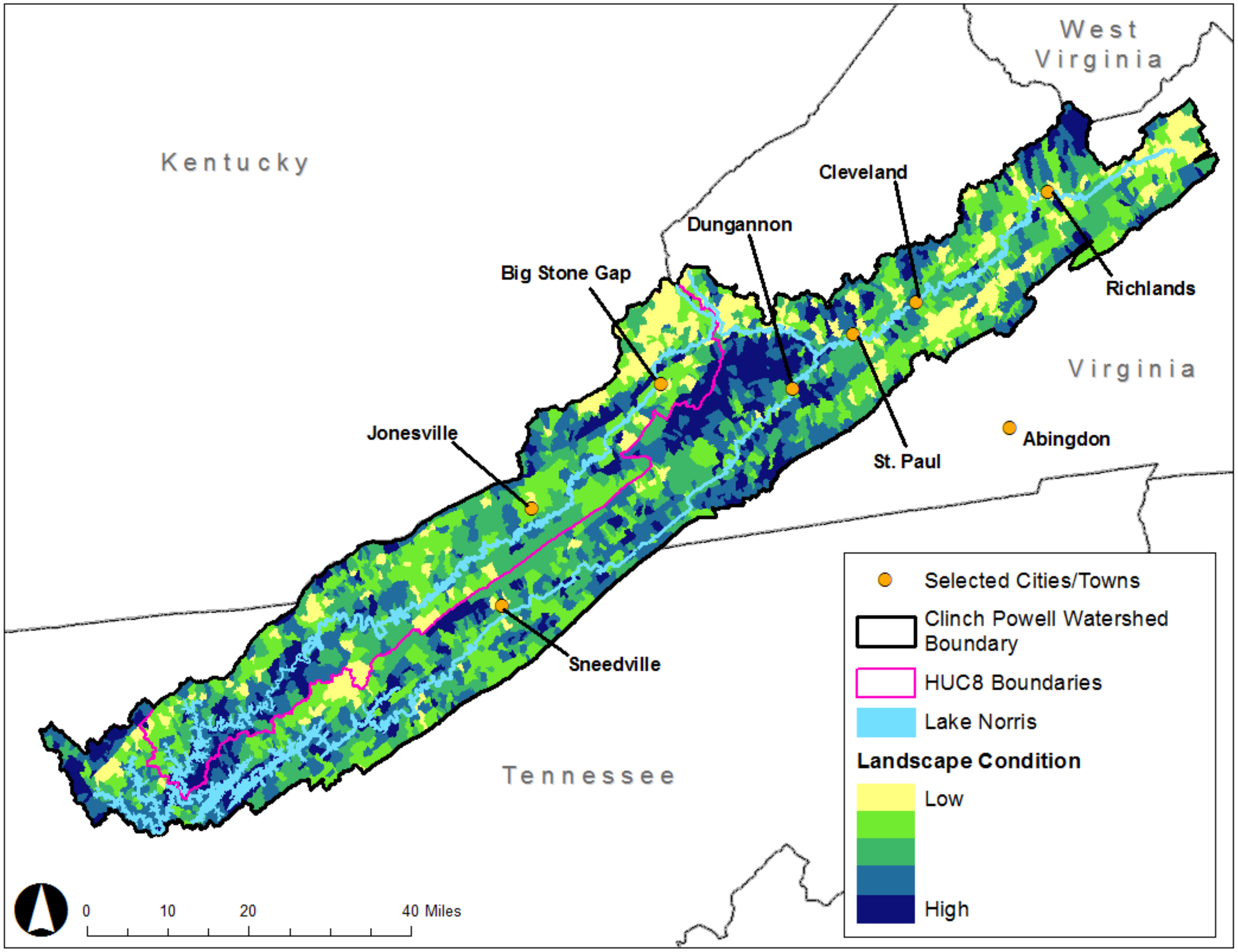


Figure A-2. Landscape Condition Metric: Percent natural land cover.

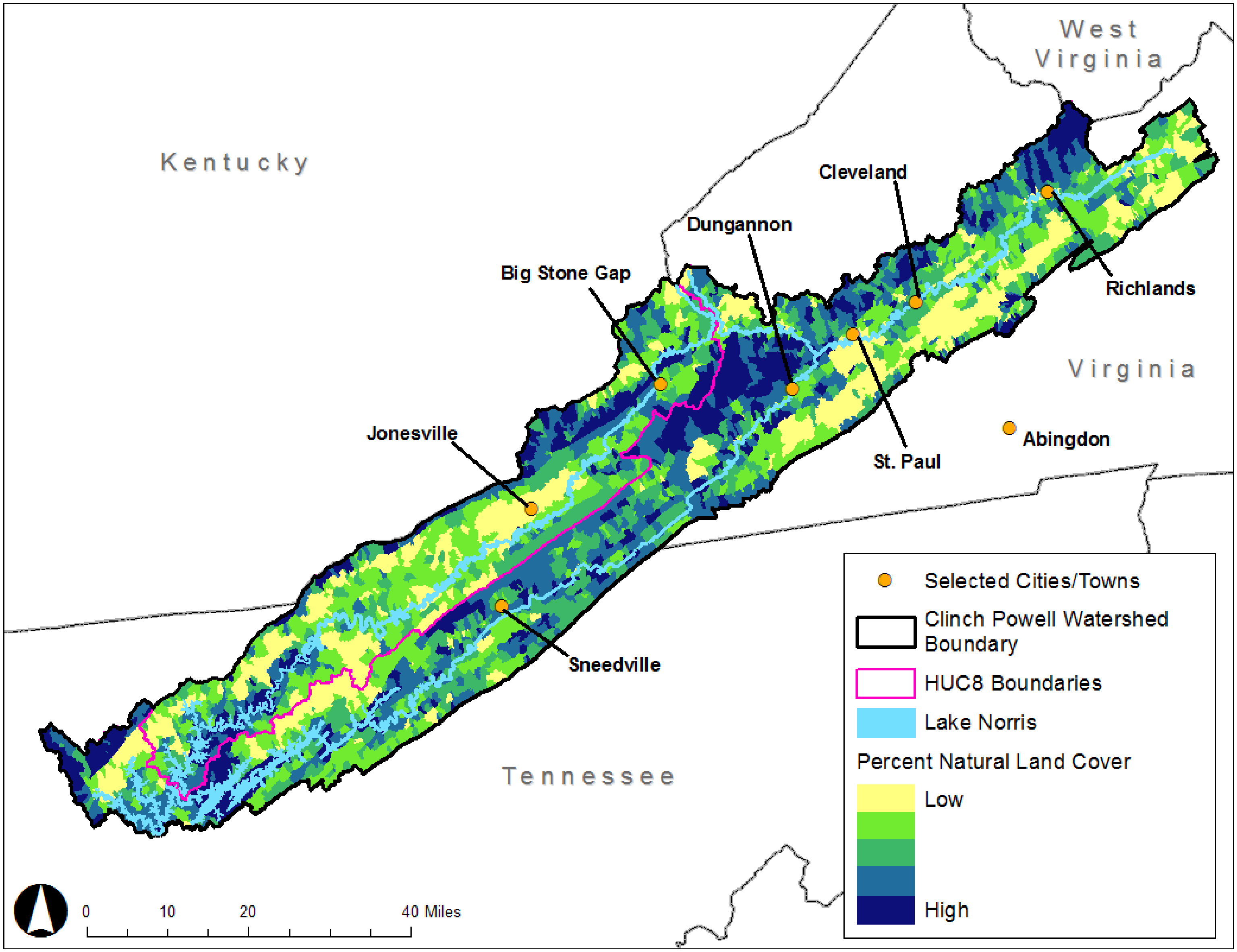


Figure A-3. Landscape Condition Metric: Percent natural land in active river area (ARA).

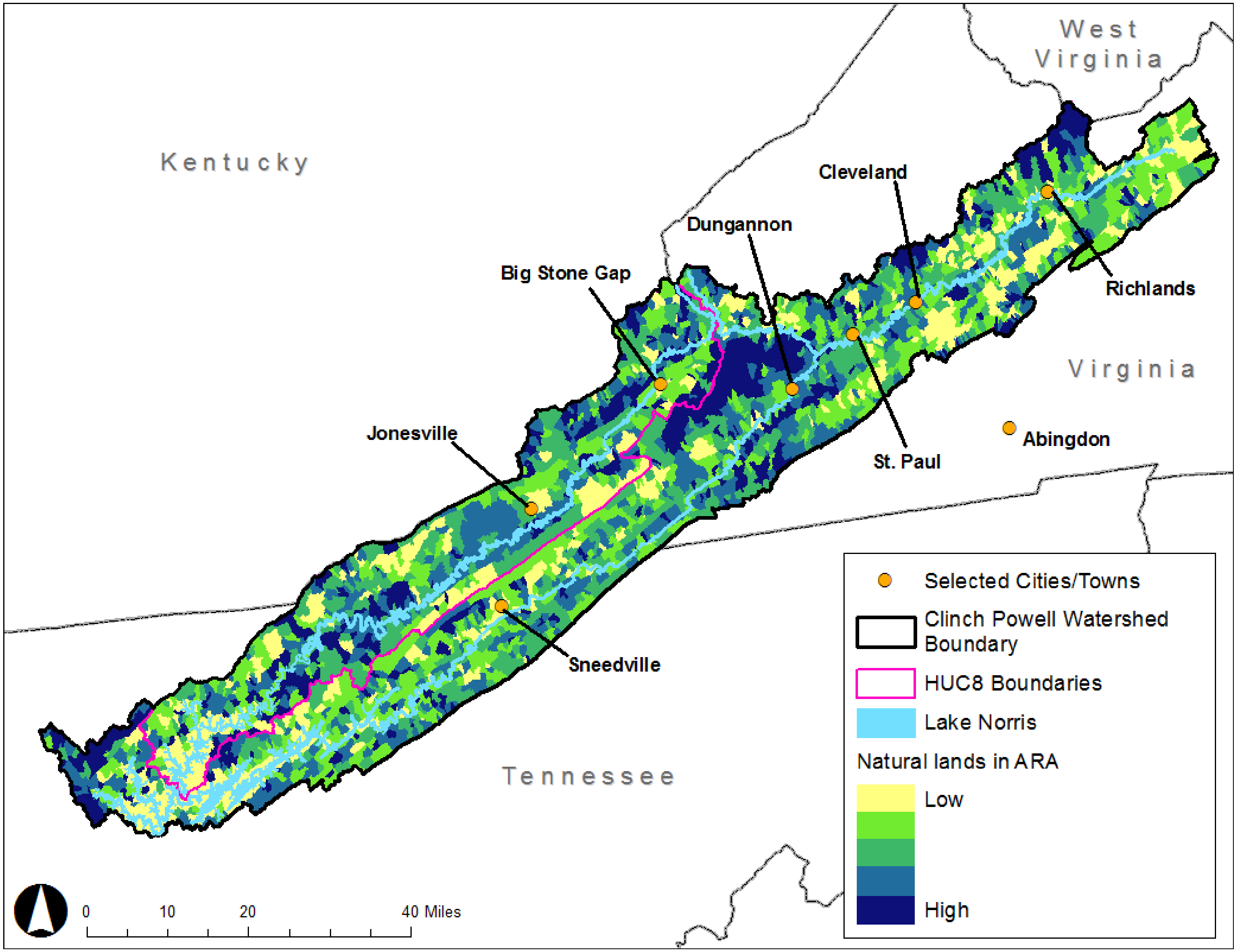


Figure A-4. Geomorphic Condition Sub-Index.

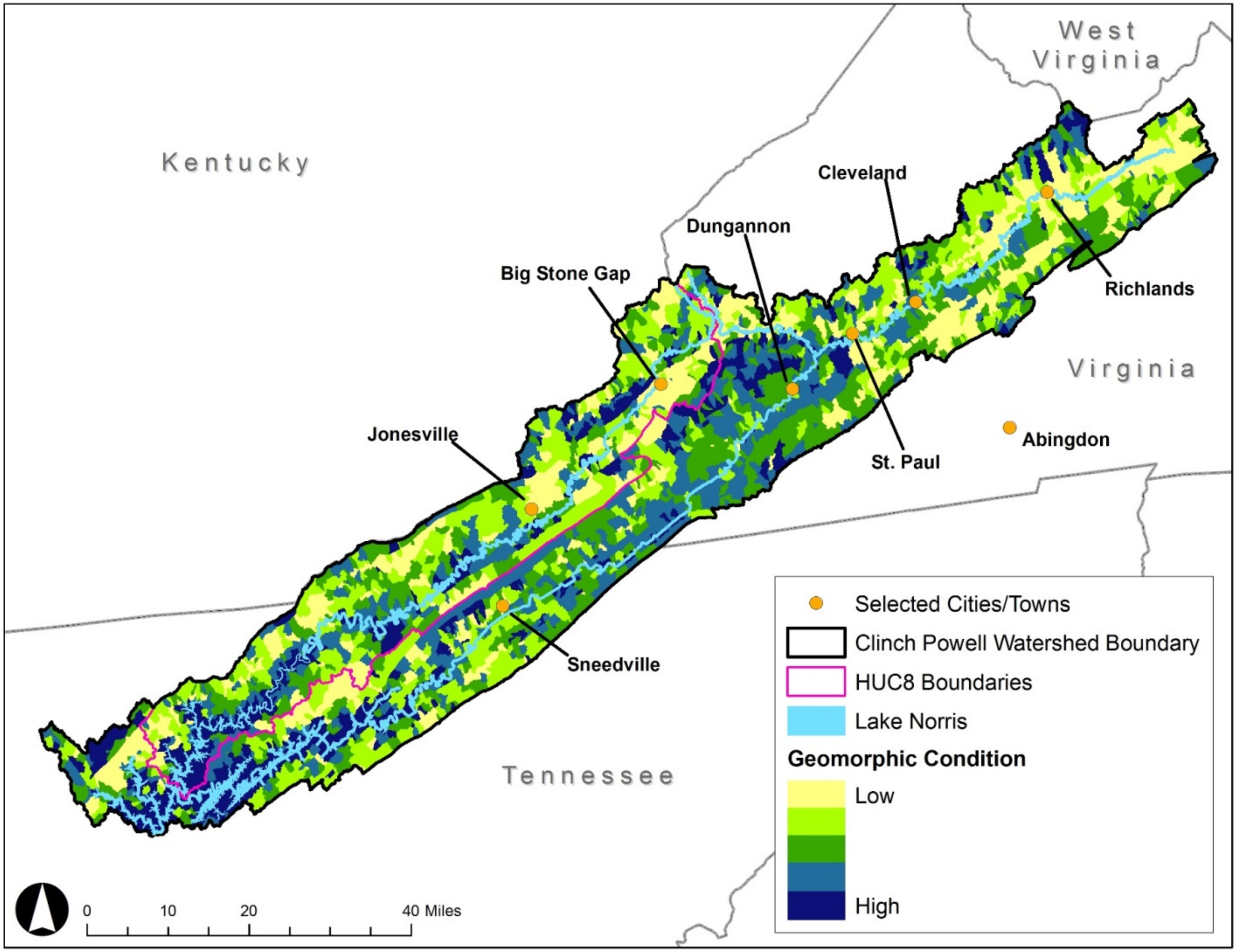


Figure A-5. Geomorphic Condition Metric: Lateral stability.

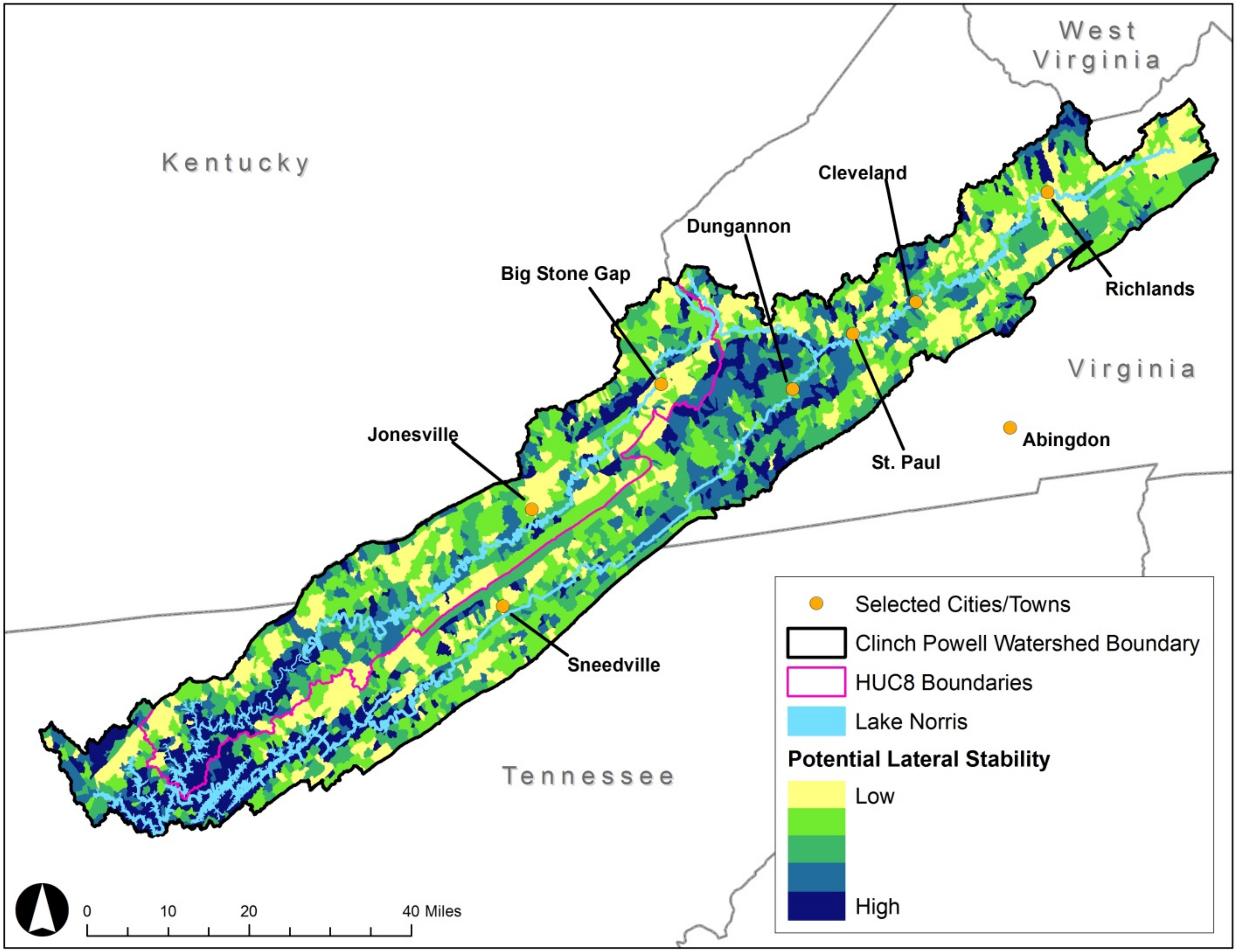


Figure A-6. Geomorphic Condition Metric: Vertical stability.

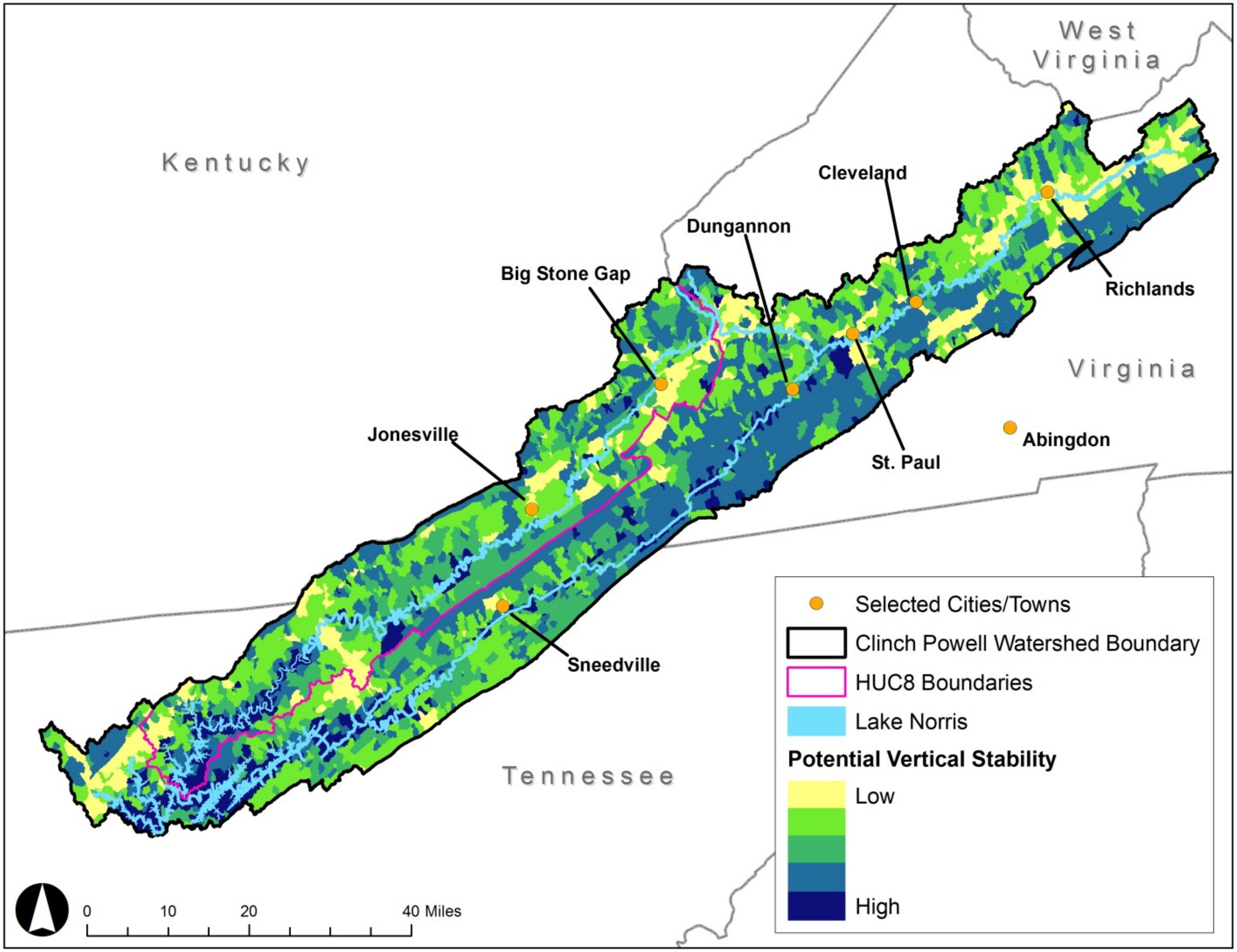


Figure A-7. Hydrologic Condition Sub-Index.

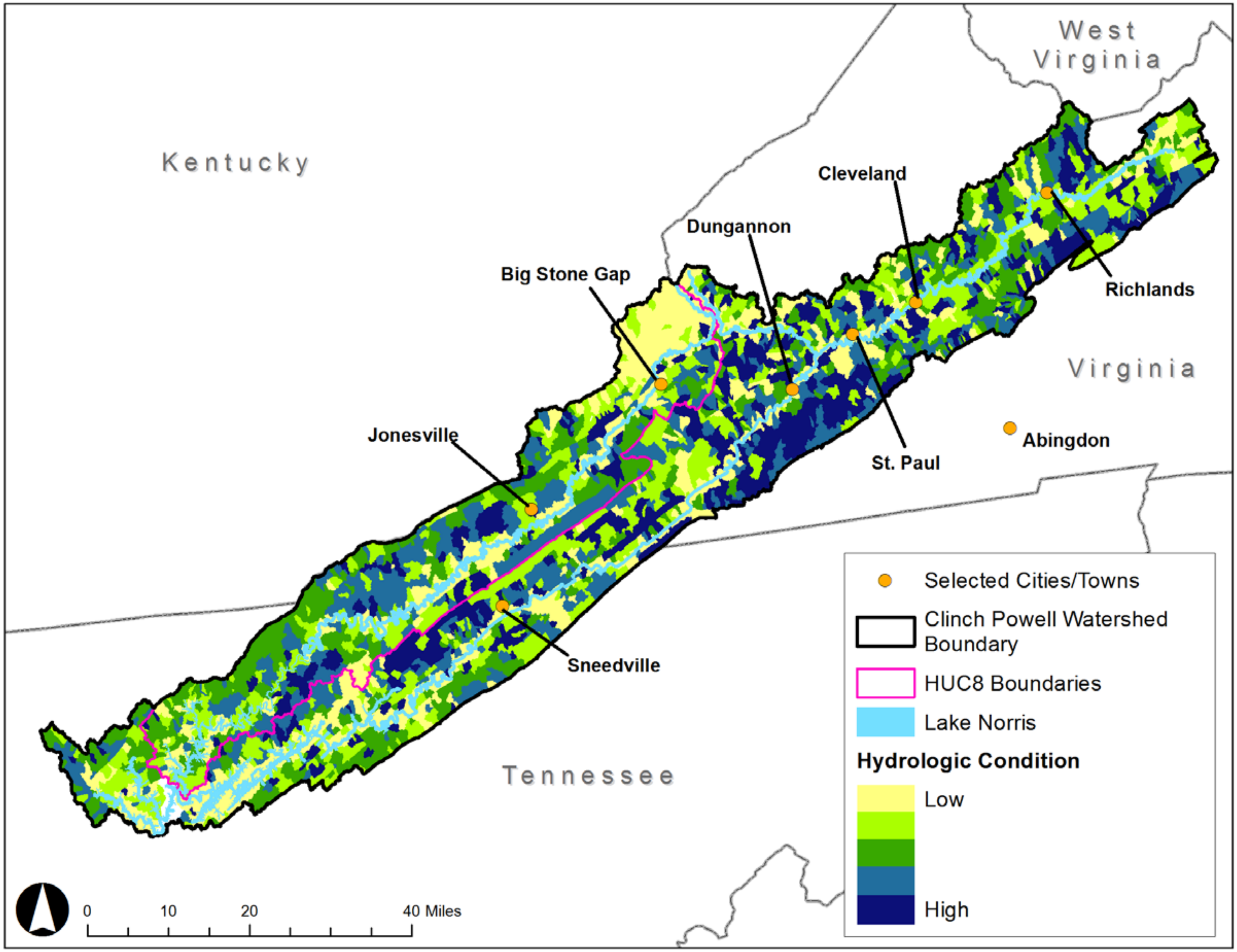


Figure A-8. Hydrologic Condition Metric: Absolute percent change in 7-day minimum flow.

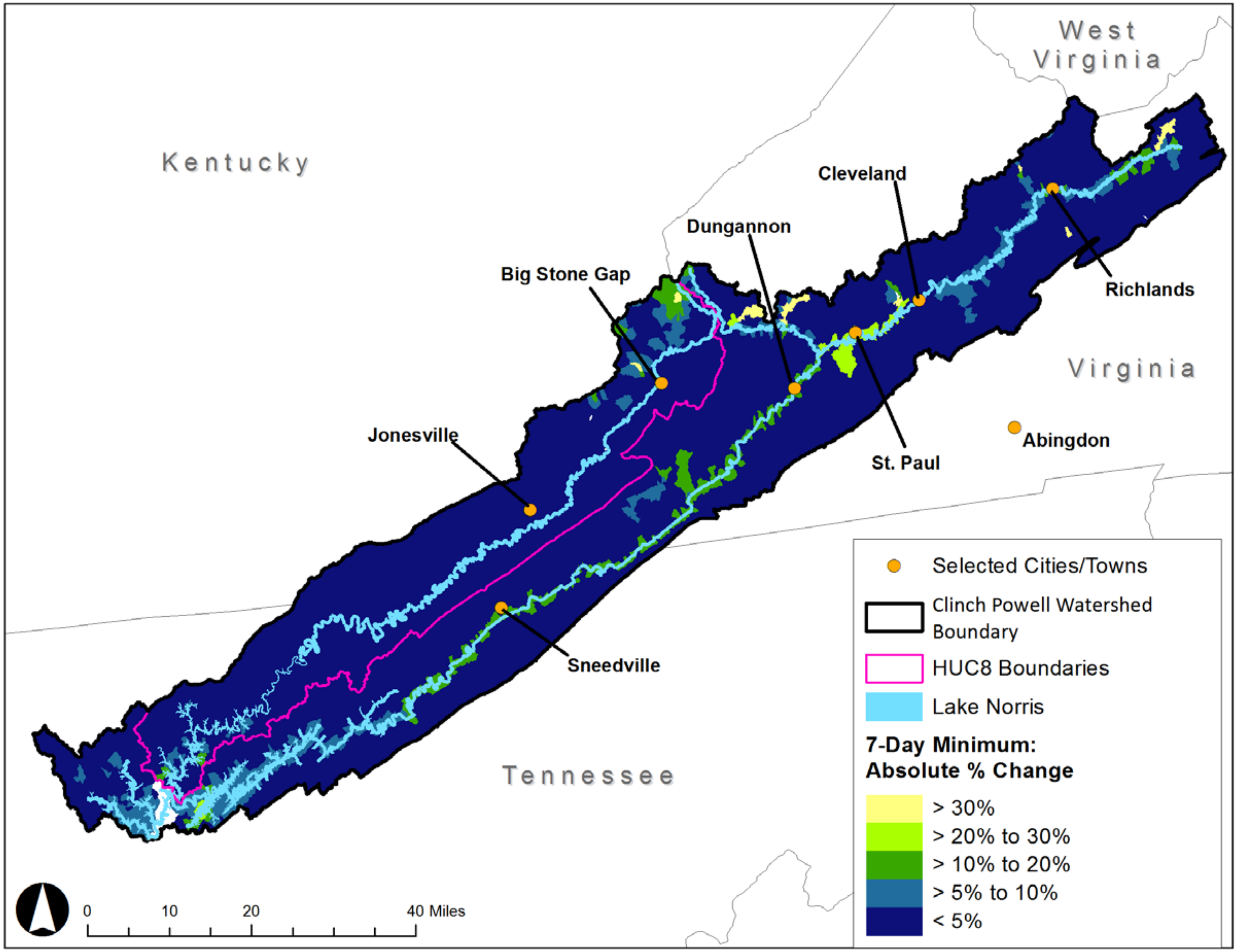


Figure A-9. Hydrologic Condition Metric: Absolute percent change in 30-day minimum flow.

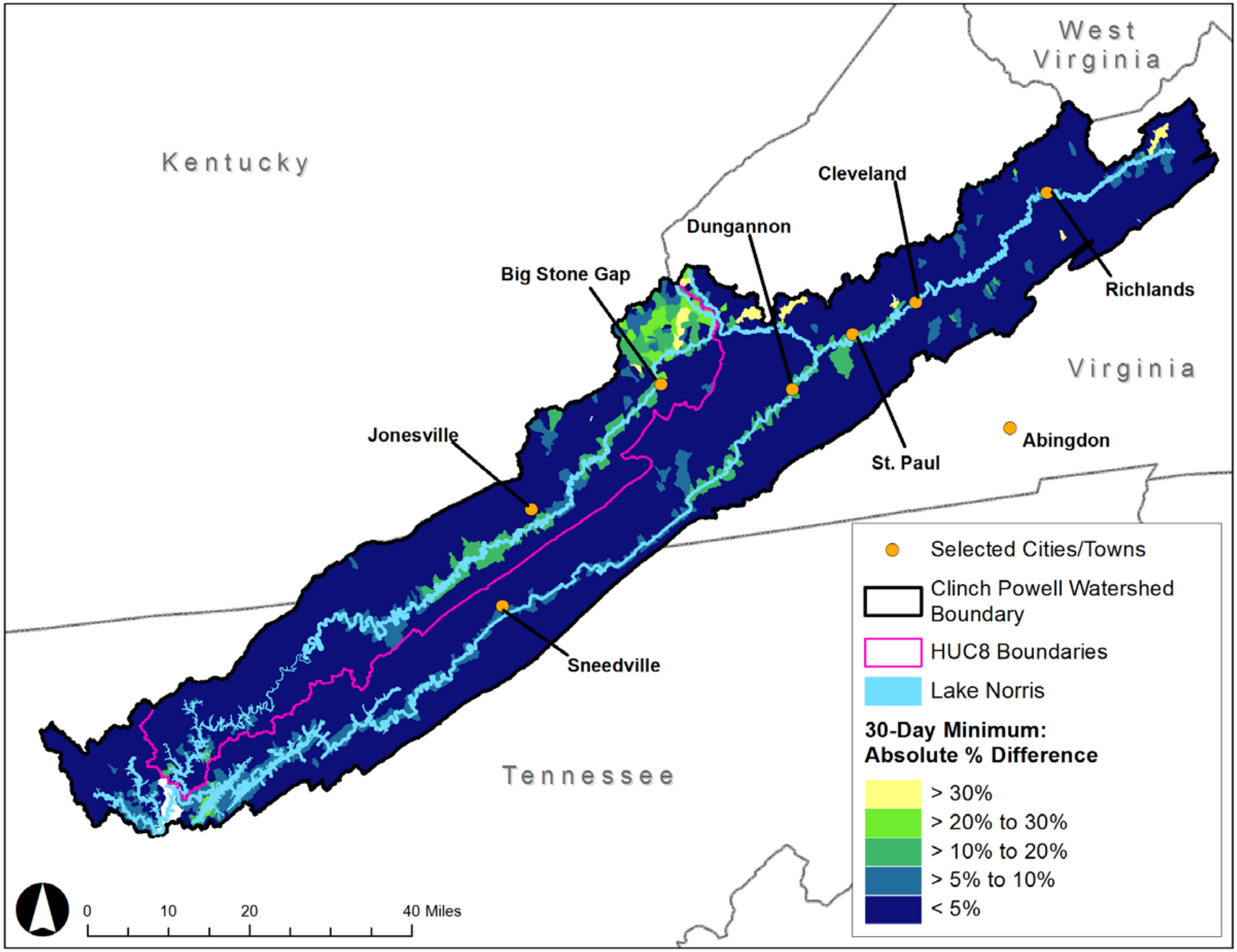


Figure A-10. Hydrologic Condition Metric: Absolute percent change in March median flow.

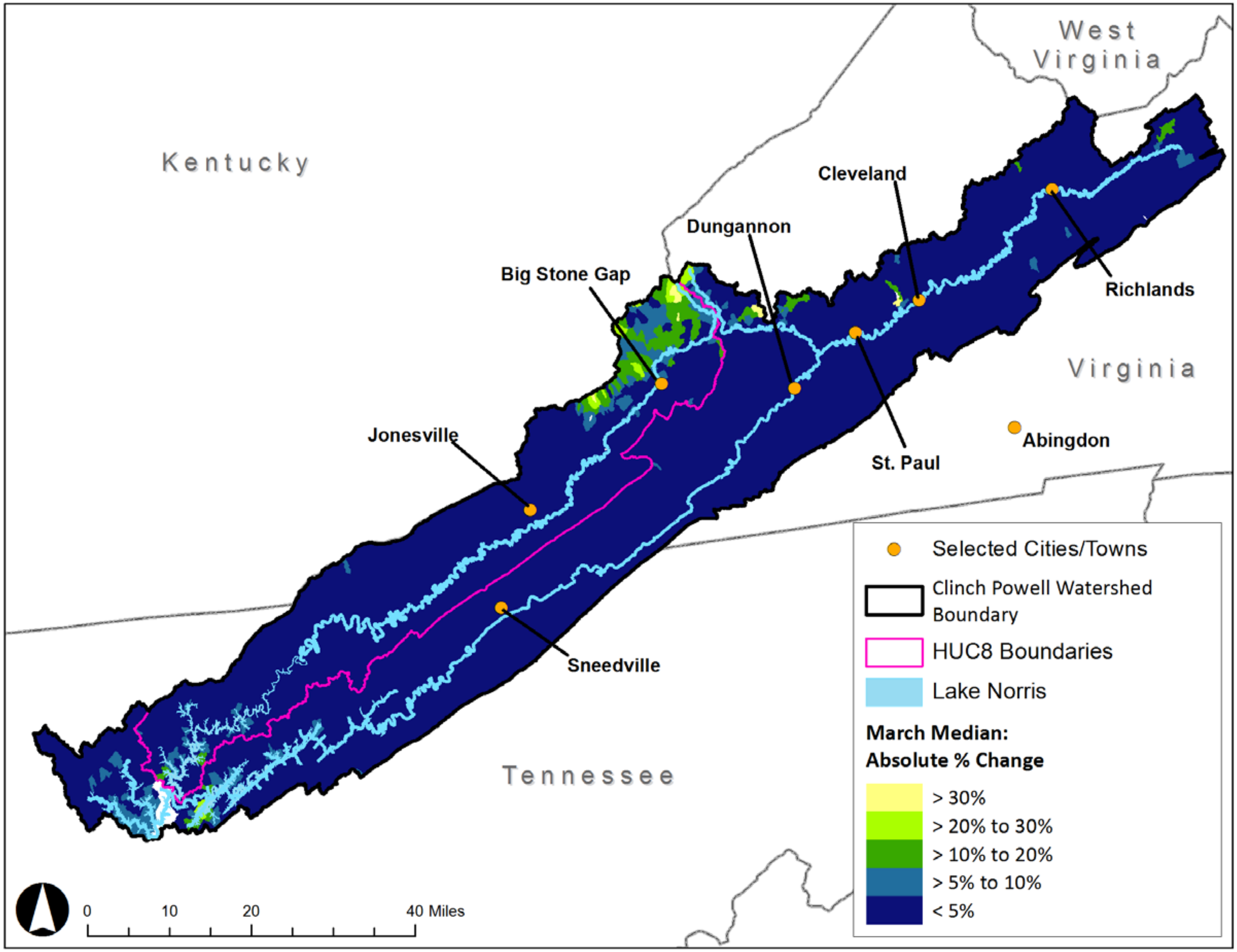


Figure A-11. Hydrologic Condition Metric: Absolute percent change in winter high-flow pulse duration.

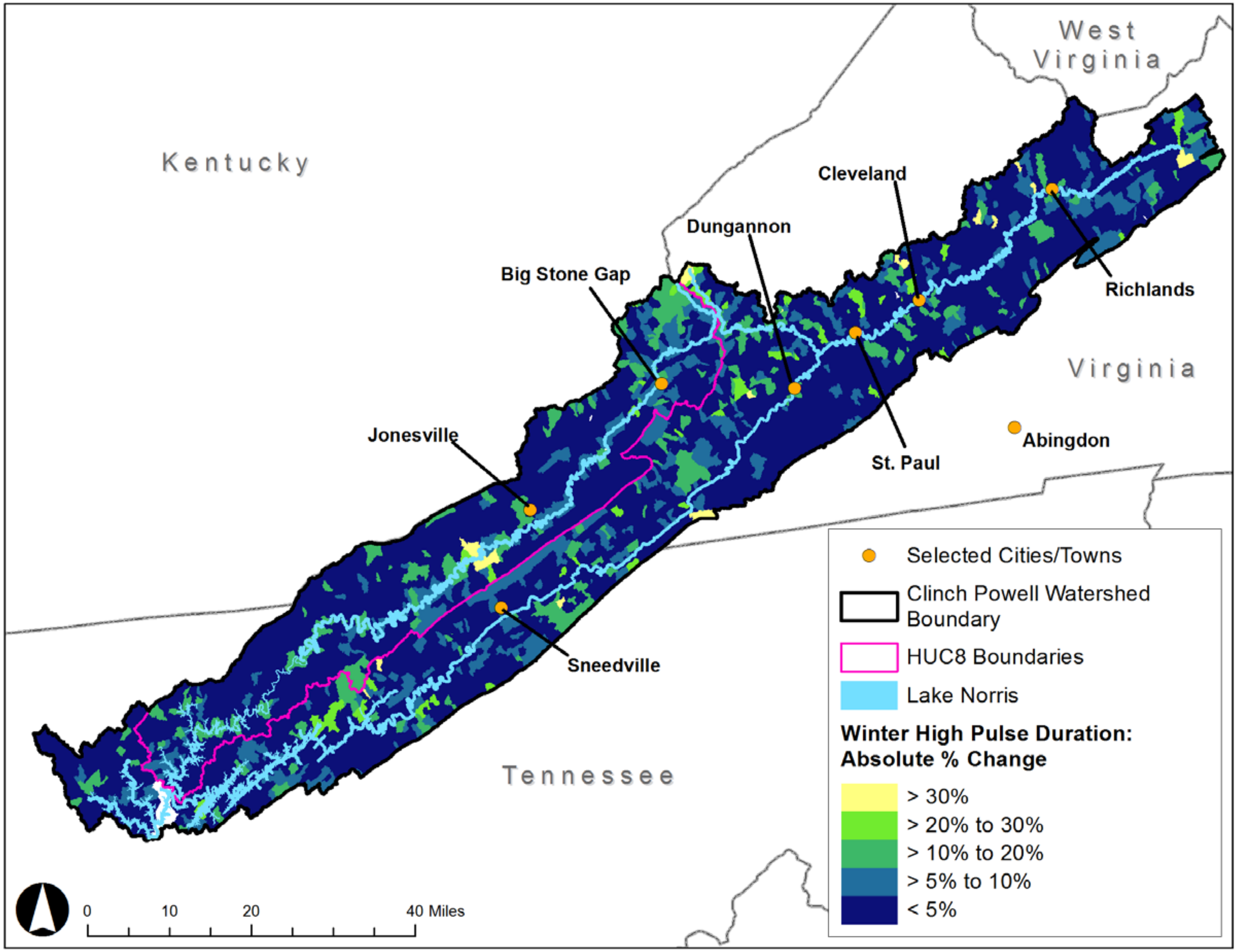


Figure A-12. Water Quality Sub-Index.

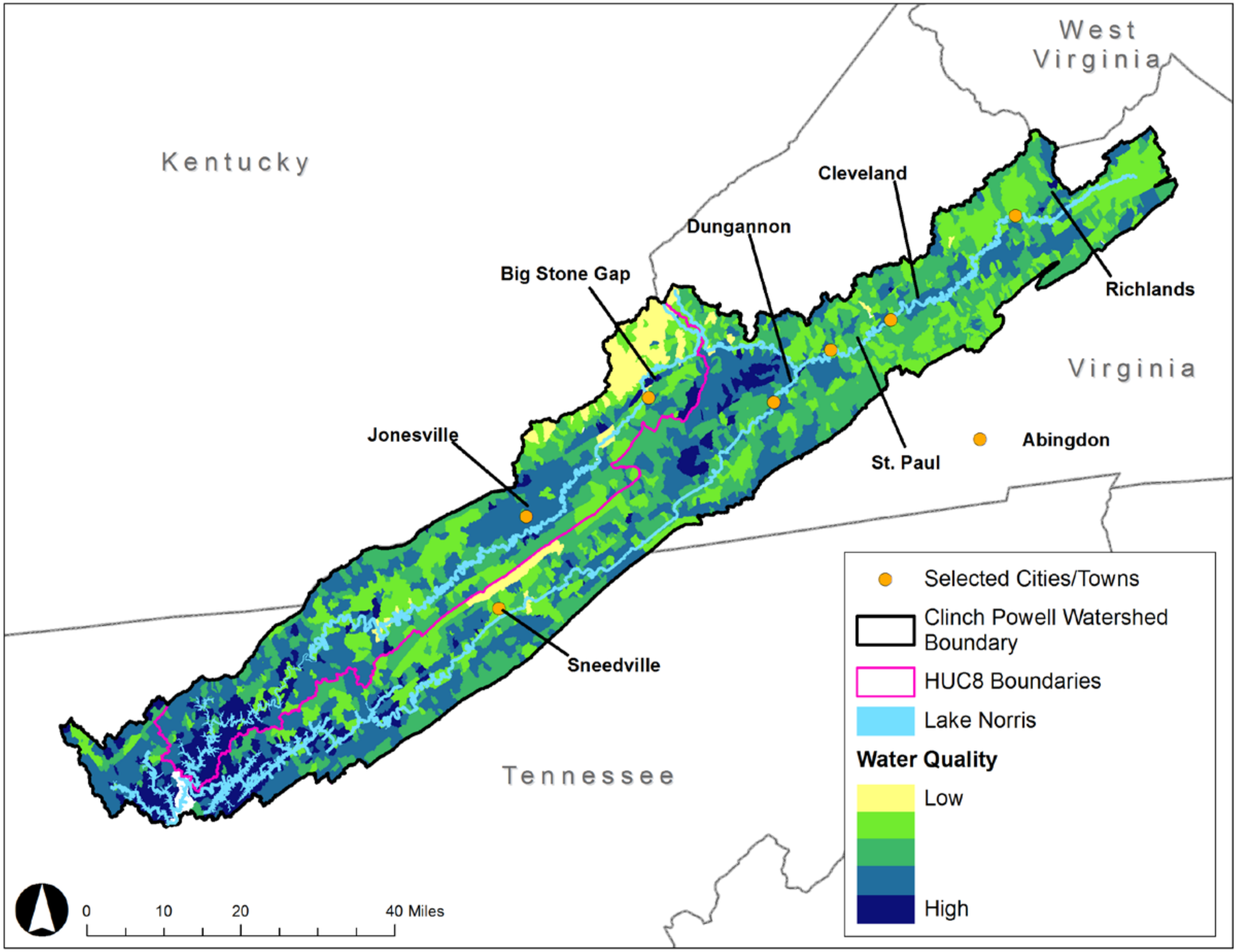


Figure A-13. Water Quality Metric: Stream total suspended solids concentrations.

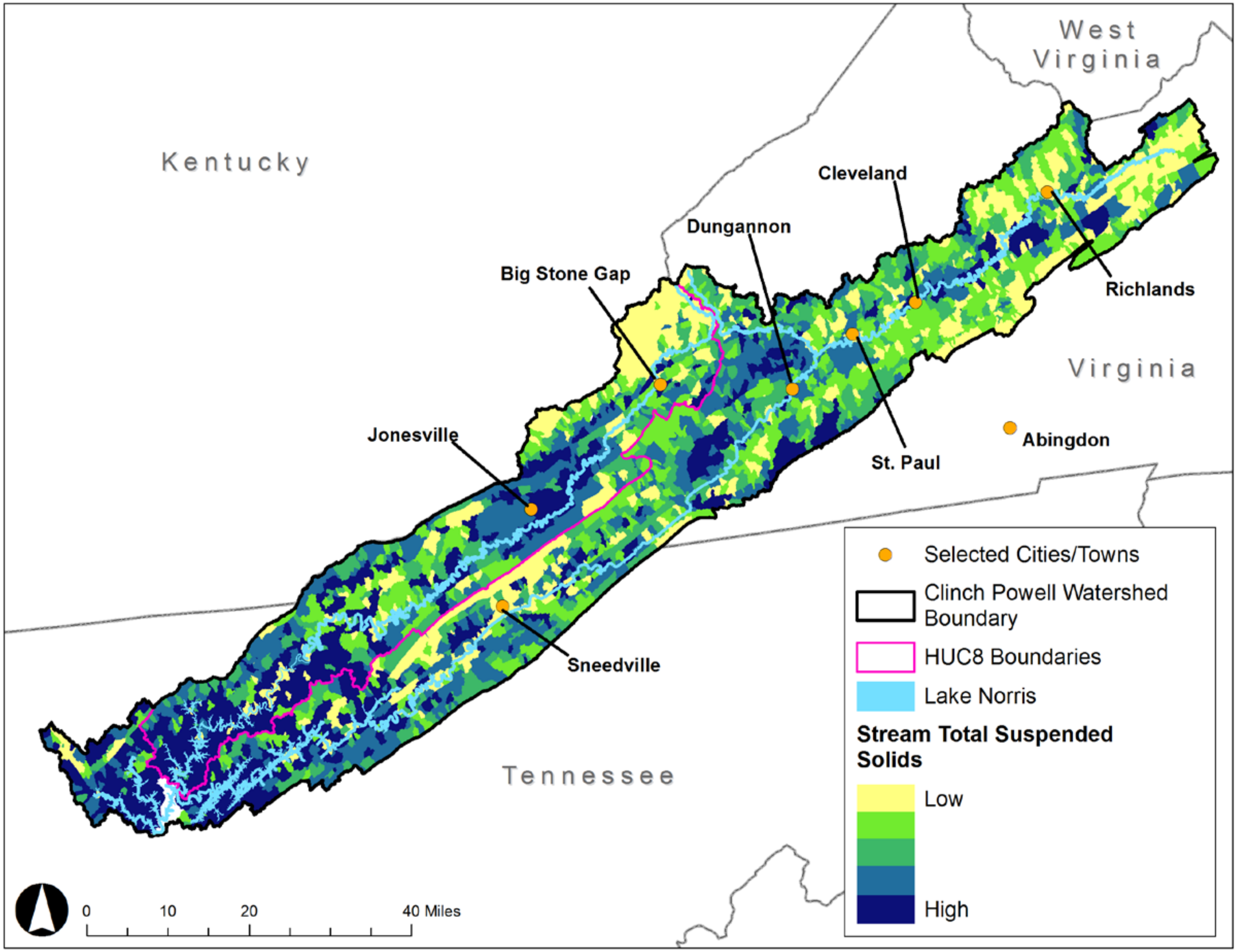


Figure A-14. Water Quality Metric: Stream-specific conductance concentrations.

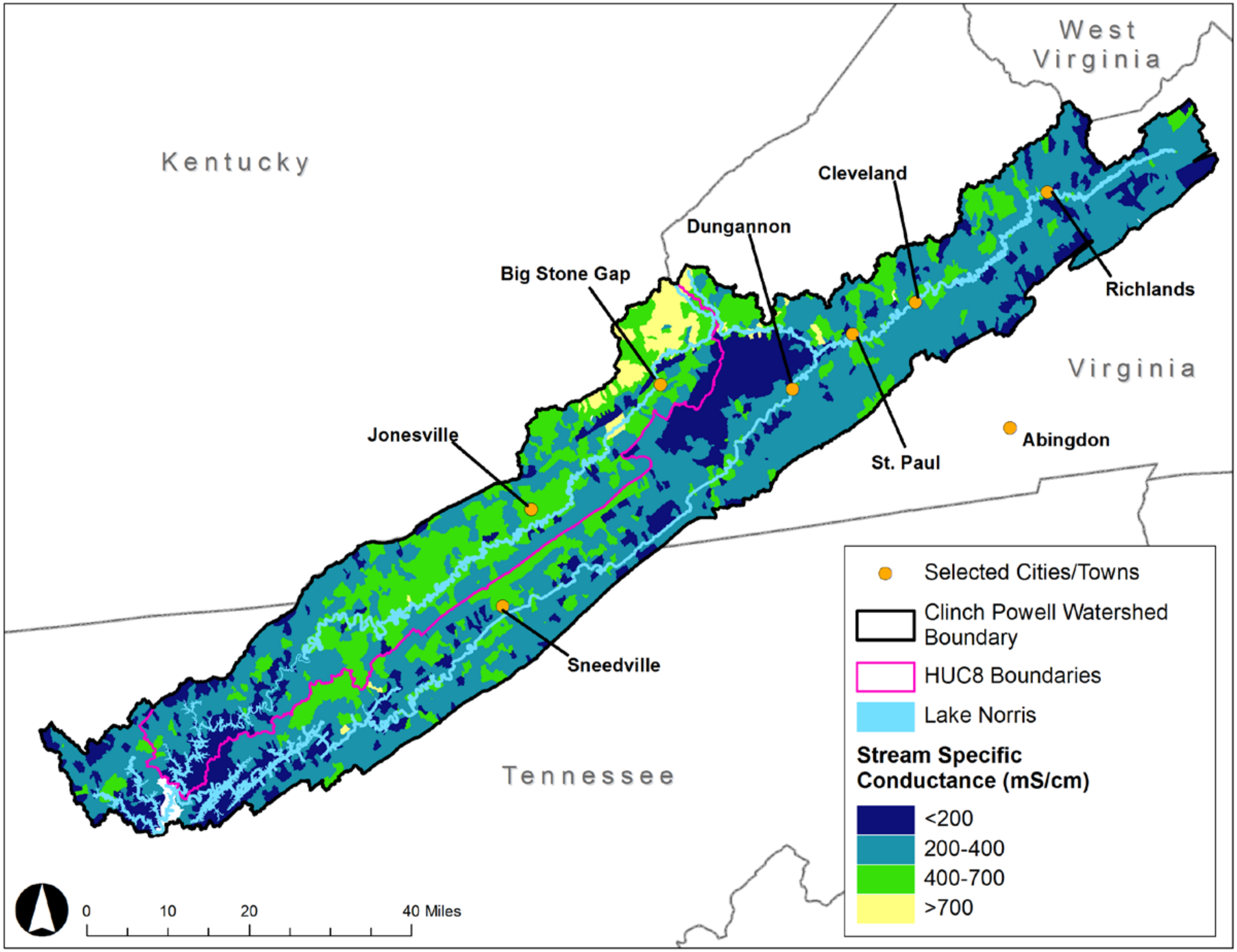


Figure A-15. Biological Condition Sub-Index.

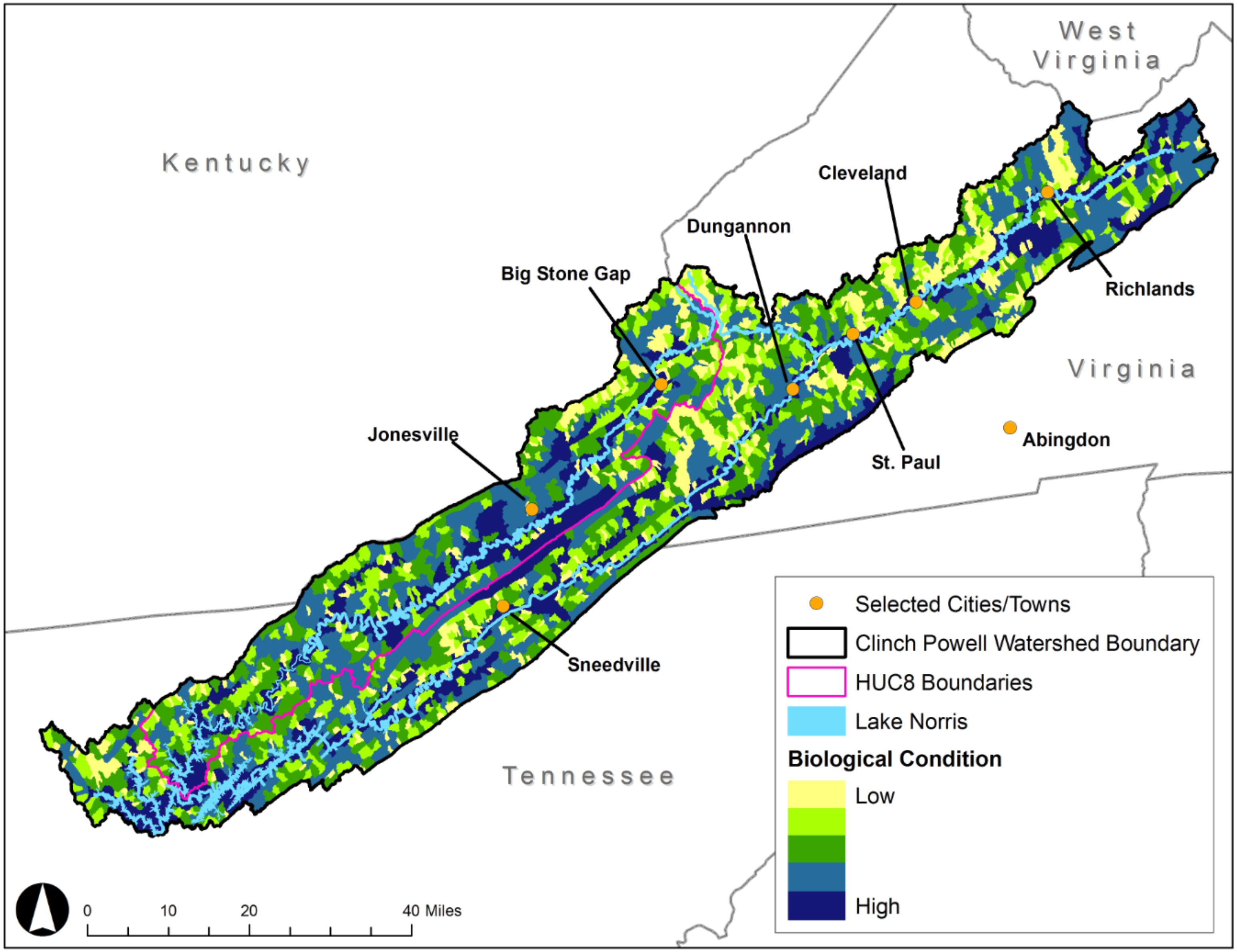


Figure A-16. Biological Condition Metric: Benthic macroinvertebrate Ephemeroptera-Plecoptera-Trichoptera (EPT) rating.

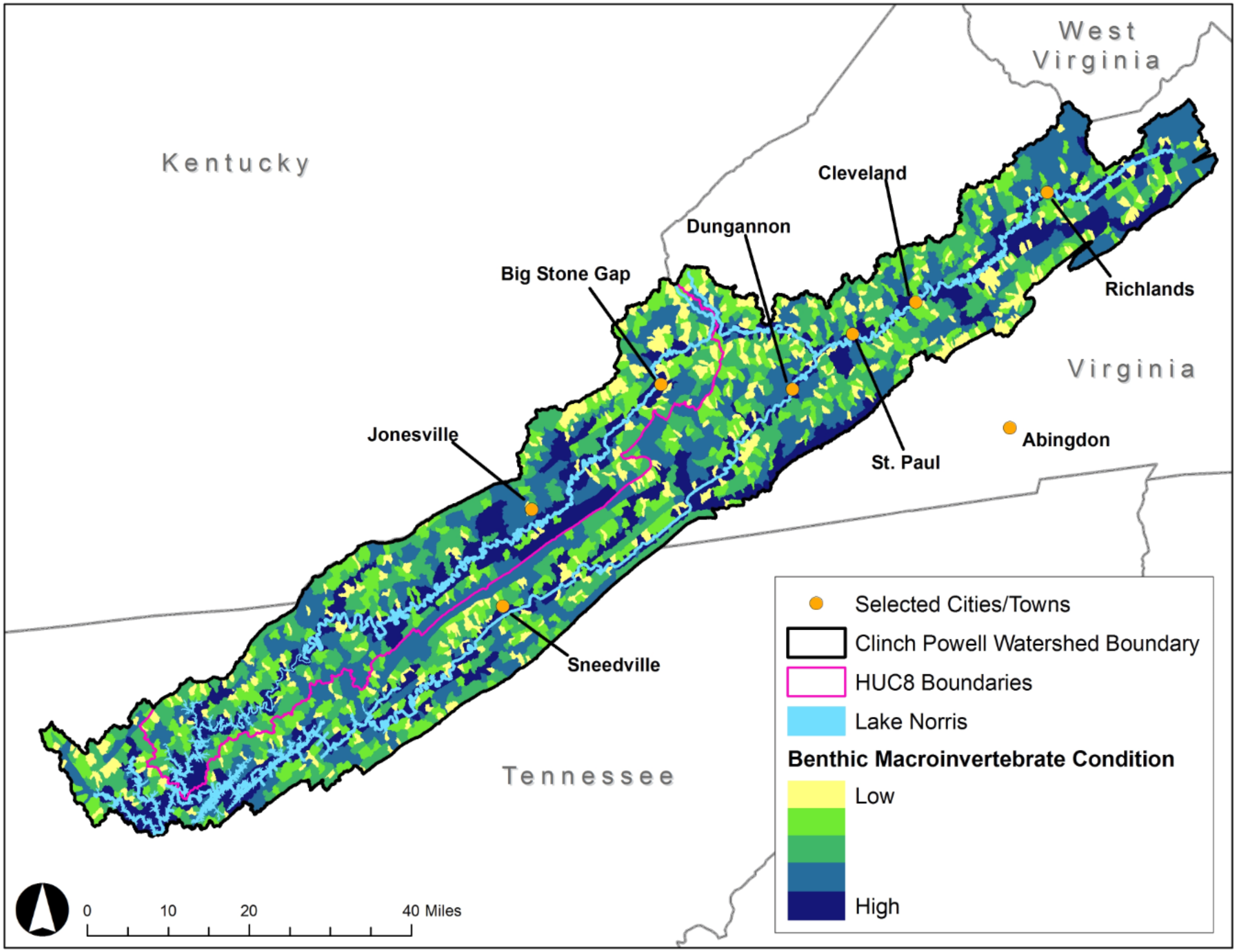


Figure A-17. Biological Condition Metric: Fish Index of Biological Integrity (IBI) rating.

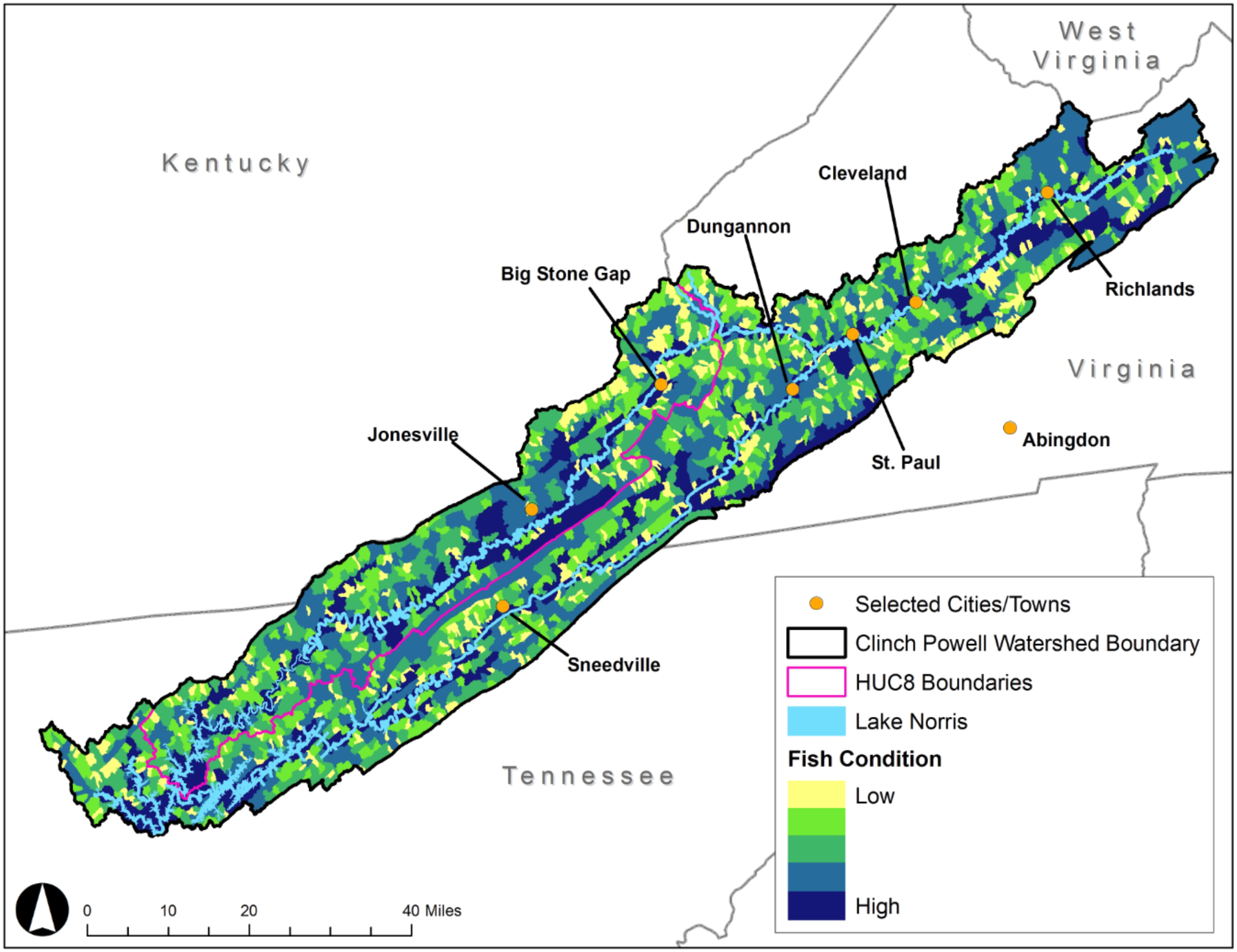
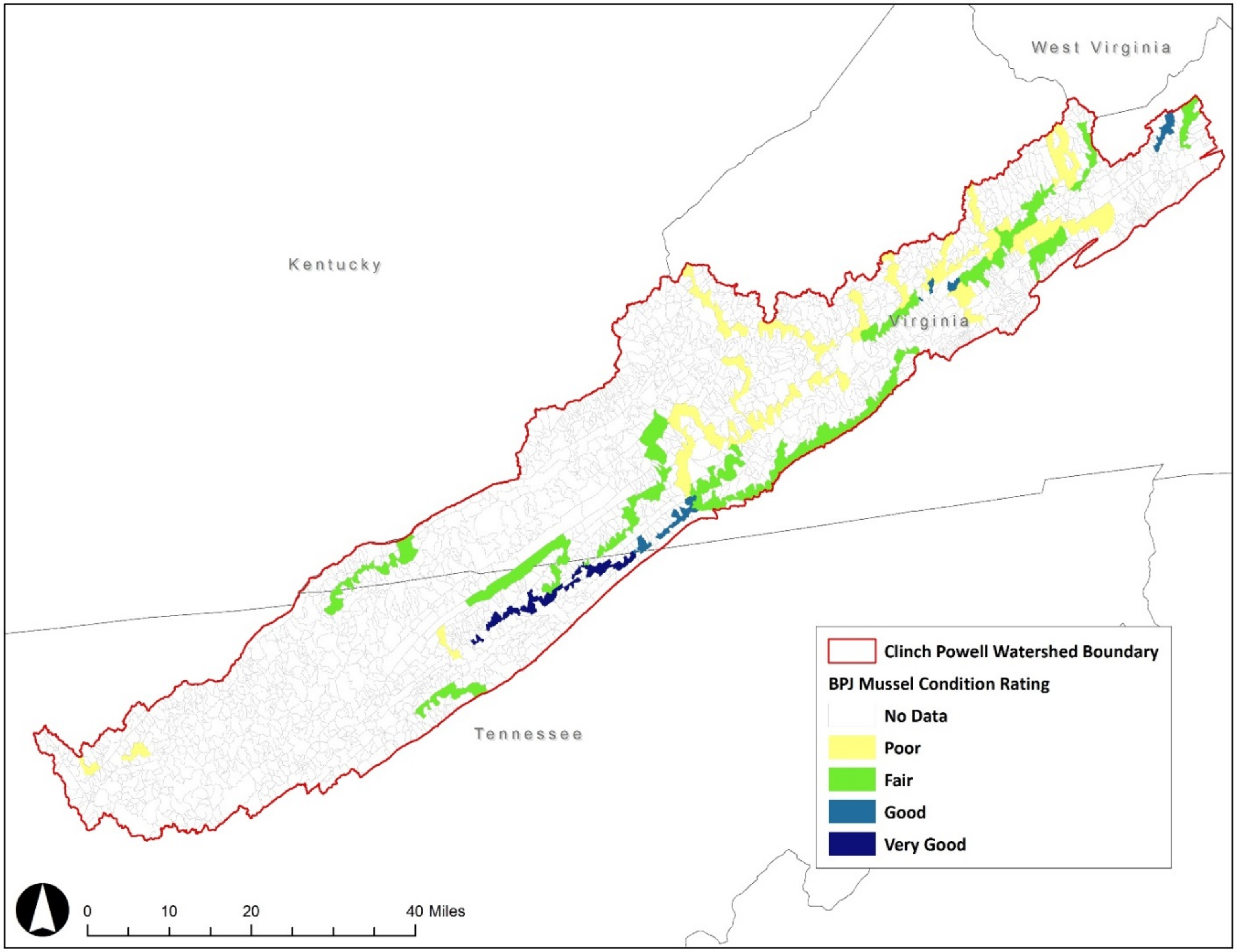


Figure A-18. Biological Condition Metric: Mussel Condition.



Appendix B: Landscape Condition

B.1 Introduction

The Landscape Condition assessment characterizes current land use conditions and determines the departure from natural (e.g., pre-European settlement) landscape conditions. Watersheds with more natural land cover and less impervious surface have been shown to have higher aquatic ecosystem health (EPA, 2012). This appendix presents the methods and data explored to characterize current landscape conditions in the Clinch and Powell River System including methods and data considered but ultimately not used in the Assessment.

B.2 Land Use Classification

The 2011 National Land Cover Database (NLCD; Jin et al., 2013) was used to represent current landscape conditions. The NLCD has a 16-class land cover classification scheme and a spatial resolution of 30 m (~100 ft). The 2011 NLCD updates the previous NLCD that was created in 2006. Additional NLCD products considered in this Assessment include the change in land cover between 2006 and 2011, the percent development imperviousness for 2011, the change in percent development imperviousness change between 2006 and 2011, and the 2011 percent forest canopy. The area-weighted average percentage values for each of these products were calculated for each catchment. These variables were used as landscape predictors in the statistical models for the water quality, geomorphic condition, and biological condition assessments.

The NLCD 16-class scheme provides a coarse characterization of landscape conditions. Additional data and methods were explored to differentiate these classifications into smaller units of natural and non-natural lands. Specifically, the Assessment considered the classification of NLCD categories as natural and non-natural based on the definitions of these categories used by the 2011 NLCD assessment, which are based on the Anderson et al. (1976) system. Further investigation was needed to determine the categorization of the following NLCD categories: herbaceous, shrub/scrub, and barren land. Based on review of the *Natural Communities of Virginia* (Fleming and Patterson, 2012) and discussions with the CPCRI Technical Team, the areas classified in these categories were determined to generally represent lands that have been disturbed from their natural condition and although they may be on the successional path toward a restored natural community, they were considered non-natural lands for this Assessment. Categorization of land cover classes as natural or non-natural is provided in Table 2 of the report.

B.3 Contiguous Natural Lands

The Assessment considered using the percentage of contiguous natural lands (e.g., green infrastructure) in each catchment as a metric of Landscape Condition. Green infrastructure is defined as an interconnected network of natural areas and other open spaces that conserves natural ecosystem functions (Benedict and McMahon, 2006). This network comprises large blocks of natural lands called hubs, which are linked by corridors such as rivers and streams or greenways. To determine the amount of contiguous natural land cover within each catchment, the Landscape Fragmentation Tool (LFT v.2.0) developed by the University of Connecticut (http://clear.uconn.edu/tools/lft/lft2/index.htm) was used. LFT v2.0 is a python script that runs out of ArcToolbox in ArcGIS 9.3 or 10.0. The tool was used to determine the fragmentation of lands classified as natural by lands classified as non-natural. We considered the natural lands contiguous if they were larger than 250 acres (100 hectares). The results were presented to the CPCRI Technical Team. However because of the relative rural nature of the Clinch and Powell watersheds and uncertainty about an appropriate contiguous land threshold, the CPCRI Technical Team decided not to use the amount of contiguous natural lands in the Assessment. Instead, the total percent natural land in each catchment was used as one of the two Landscape Condition Metrics. See Section 2.3.1 in the report for more information.

B.4 Active River Area

The active river area (ARA) framework is a spatially explicit view of rivers that includes both the channels and the riparian lands necessary to accommodate the physical and ecological processes associated with the river system (Smith et al., 2008). The five components of the ARA are (1) material contribution area, (2) meander belts, (3) floodplains, (4) terraces, and (5) riparian wetlands. The ARA for the Clinch and Powell River System in Tennessee and Virginia was provided by The Nature Conservancy. These components are identified through the use of geographic information systems (GIS) techniques. Key input data include the elevation data from National Elevation Dataset (NED), hydrography from the National Hydrography Dataset Plus (NHDPlus, version1), and wetland grid data developed by The Nature Conservancy.

In general, three GIS techniques are used to identify the ARA:

- The riparian habitat modeling approach described by Strager et al. (2000) is used to identify the meander belt, floodplains, and terraces.
- Riparian wetlands can be identified from National Wetlands Inventory and NLCD data. These data are combined with the flow accumulation model based on elevation data to include wetlands formed as the result of high groundwater and overland flow from adjacent wetland areas.
- The third step adds the material contribution areas, which are generally identified as both headwaters areas at the top of watersheds and areas 100 to 200 ft (30 to 60 m) along each side of stream channels not captured in the previous two steps. These areas are identified using elevation data.

Specific information on the methods used to develop the ARA used in this Assessment can be found on The Nature Conservancy Eastern Division Web site at https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/Documents/ED_freshwater_ARA_documentation090813.doc.

B.5 Consideration of Mined Lands

Surface mining represents a major source of land use change in the Clinch and Powell River System. Mountaintop surface mining practices remove the soil and rock over a coal seam (i.e., the overburden) to expose the coal, which greatly alters the natural topography, affects headwater streams, and impairs water quality (EPA, 2011). Reclaiming mined areas involves contouring the land and establishing stable vegetation communities. In the NLCD, mined lands are classified as Barren (NLCD Code 31), which is defined as "areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover." Areas that have been revegetated or reclaimed are included in multiple NLCD categories based on current vegetation (i.e., herbaceous, scrub-shrub, or evergreen, deciduous or mixed forests).

Current mining data from the Virginia Division of Mines, Minerals and Energy's Division of Mined Land Reclamation (DMLR) (https://maps.dmme.virginia.gov/flexviewer/DMLR/) were used to reclassify the 2011 NLCD categories as disturbed due to mining activity. Aerial extent of mining activities is based on the permitted areas of disturbance and is contained within the data layer entitled "CSMO Boundaries." Areas classified as barren and within a permit boundary were considered mining lands (**Figure B-1**). All other land cover classes that occurred within the permitted mine boundaries were classified as "disturbed." This process resulted in the creation of 13 "disturbed" NLCD categories (**Table B-1**).

Figure B-1. NLCD classification of western Virginia shows the barren lands (gray) and CSMO permit boundaries (hatching) (left); active mining activity was determined from the intersection of these layers (shown in light yellow in the right figure).

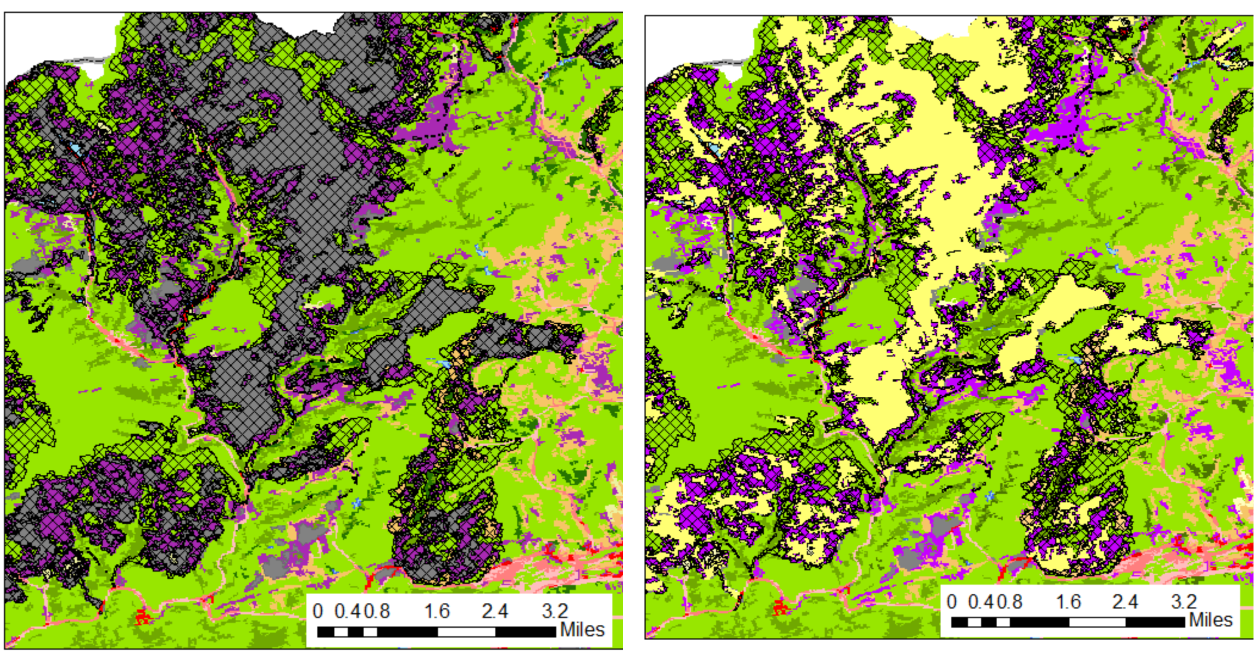


Table B-1. Revised 2011 NLCD categories refined with surface mining permit boundaries.

Original NLCD		Revised Landuse Categories	
Code	Descriptions	Code	Revised Descriptions
11	Open Water	111	Open Water_Disturbed
21	Developed, Open Space	211	Developed, Open Space_Disturbed
22	Developed, Low Intensity	221	Developed, Low Intensity_Disturbed
23	Developed, Medium Intensity	231	Developed, Medium Intensity_Disturbed
24	Developed, High Intensity	241	Developed, High Intensity_Disturbed
31	Barren Land	99	Mined
41	Deciduous Forest	411	Deciduous Forest_Disturbed
42	Evergreen Forest	421	Evergreen Forest_Disturbed
43	Mixed Forest	431	Mixed Forest_Disturbed
52	Shrub/Scrub	521	Shrub/Scrub_Disturbed
71	Herbaceous	711	Herbaceous_Disturbed
81	Hay/Pasture	811	Hay/Pasture_Disturbed
82	Cultivated Crops	-	-
90	Woody Wetlands	901	Woody Wetlands_Disturbed
95	Emergent Herbaceous Wetlands	951	Emergent Herbaceous Wetlands_Disturbed

These revised land use categories due to mining activity were used only for the hydrological condition assessment (see Appendix D). McCormick and Eshleman (2011) has shown that mining activities involve the removal of top soil, compaction of soil, and reconfiguration of hydrological flow path. Therefore, these mine-impacted or disturbed areas were given different runoff coefficients in the Hydrologic Condition assessment. Modeling associated with water quality and biological condition assessments used the revised "Mined" category (shown in **Figure B-1**) to represent current land use conditions. The other "disturbed" land use categories were not included in the models.

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Appendix C: Geomorphic Condition

C.1 Introduction

The descriptive model used to evaluate relative geomorphic condition for this Assessment was developed in consultation with Mr. Will Harman. Mr. Harman is the founder and owner of Stream Mechanics and has 22 years of experience in fluvial geomorphology and stream restoration. Using best professional judgment from Mr. Harman and input from the CPCRI Technical Team, selected stream channel characteristics and landscape conditions (derived primarily from the National Land Cover Database [NLCD] 2011) were used to predict the geomorphic condition of catchments within the Clinch and Powell River System. A simple comparative analysis was used to gauge the relative potential for channel stability and resiliency among the catchments.

Separate analyses were performed for vertical and lateral stability by assessing both the erosive forces at work within a catchment and the resistive capacity of the stream channel. Then elements of the two were combined to determine overall Geomorphic Condition Sub-Index.

C.2 Preparation of Data

Channel characteristics such as bankfull measurements were obtained using regional regression equations based on drainage area (Keaton et al., 2005). Other factors, such as stream slope, K-factor, and depth to bedrock were obtained from the National Hydrography Dataset Plus (NHDPlus), Soil Survey Geographic Database (SSURGO), and U.S. Geological Survey (USGS) datasets. Landscape factors used included the percent impervious cover within a catchment, the percent forest cover of the target catchment and all of the catchments upstream of it, and the percent natural land cover within the active river area (ARA) of a catchment.

The available stream characteristics were used to calculate the specific stream power (Nanson and Croke, 1992) using the formula:

$$\textit{Specific Stream Power} = \textit{Specific Weight of Water} * \textit{Slope} * \textit{Discharge} \,/\, \textit{Bankfull Width}$$

A simple scoring model was utilized for each factor used in the analysis (**Tables C-1** through **C-6**). Each was scored so that higher point values indicated the factor would have a positive effect on stream resilience and stability (e.g., a lower percentage of impervious cover is less likely to alter the natural flow regime in a catchment and therefore would score more points than a catchment with a higher percentage of impervious cover).

Table C-1. Scores assigned for percent impervious surface in catchment.

% Impervious Surface	Rating	Score
>7%	Very High	0
3–7%	High	2
1–3%	Moderate	5
0.5–1%	Low	7.5
<0.5%	Very Low	10

Table C-2. Scores assigned for specific stream power.

Specific Stream Power	Floodplain Type	Score
>300	High-energy	0
10–300	Medium-energy	5
<10	Low-energy	10

Table C-3. Scores assigned for the cumulative percent forest cover (target catchment and all catchments draining to target catchment).

% Forest Cover (Cumulative)	Rating	Score
>60%	High	10
25–60%	Moderate	6.66
10–25%	Low	3.33
<10%	Very Low	0

Table C-4. Scores assigned for soil erodibility (K-factor) within stream channel.

K-factor	Rating	Score
>0.45	High	0
0.20–0.45	Moderate	5
<0.20	Low	10

Table C-5. Scores assigned for depth to bedrock within stream channel.

Depth to Bedrock (ft)	Rating	Score
>4	Very Low Bed Control	0
3–4	Low Bed Control	2.5
2–3	Moderate Bed Control	5
1–2	High Bed Control	7.5
<1	Very High Bed Control	10

Table C-6. Scores assigned for percent natural lands within ARA for a catchment.

% Natural Lands in ARA	Rating	Score
>75%	High	10
50–75%	Moderate	6.66
25–50%	Low	3.33
<25%	Very Low	0

The factors and weighting used in the vertical stability analysis are presented in **Table C-7**, and the factors used in the lateral stability analysis are presented in **Table C-8**. For the vertical stability analysis, the depth to bedrock along a stream channel is considered to be such a powerful vertical control (Harman, 2014) that regardless of other resistive factors within a catchment, catchments with less than 1 ft of depth to bedrock received the maximum possible resistance sub-score (i.e., the maximum possible points for depth to bedrock, percent cumulative forest cover, and K-factor).

Table C-7. Scoring components of the vertical stability analysis.

Erosion Factors		
% Impervious	50% of Erosion Sub-score	50% of Vertical Stability Score
Specific Stream Power	50% of Erosion Sub-score	
Resistance Factors		
Depth to Bedrock[a]	33% of Resistance Sub-score	50% of Vertical Stability Score
% Forest Cover (Cumulative)	33% of Resistance Sub-score	
K-Factor	33% of Resistance Sub-score	

[a] Catchments with less than 1 ft of depth to bedrock were given the maximum resistance sub-score possible.

Table C-8. Scoring components of the lateral stability analysis.

Erosion Factors		
% Impervious	50% of Erosion Sub-score	50% of Lateral Stability Score
Specific Stream Power	50% of Erosion Sub-score	
Resistance Factors		
% Natural Land in ARA	100% of Resistance Sub-score	50% of Lateral Stability Score

C.3 Preparation of Overall Geomorphic Condition Sub-Index-

Although factors that resist lateral erosion (e.g., riparian vegetation and forested buffers) are different than factors that resist vertical erosion (e.g., bedrock), the forces that lead to erosion are the same (e.g., increased impervious surface leading to altered hydrological regimes). Because the factors used to represent the erosive forces in a catchment were identical between the vertical and lateral stability assessments, factors were combined as shown in **Table C-9**. Based on the experience of the CPCRI

Technical Team, vertical stability was determined to be of greater concern in headwater streams and upstream catchments within the Clinch and Powell River System, while lateral stability was of greater concern in higher order streams and along the mainstem rivers. Using their best professional judgment, the CPCRI Technical Team recommended that resistance factors be additionally weighted according to stream order using a 75%/25% split.

Table C-9. Summary of scoring of erosion and resistance forces.

Erosion Metric		
% Impervious	50% of Erosion Metric	50% of Overall Geomorphic Condition Sub-Index
Specific Stream Power	50% of Erosion Metric	
Resistance Metric–1st Order Streams		
Depth to Bedrock[a]	75% of Resistance Metric	50% of Overall Geomorphic Condition Sub-Index
% Forest Cover (Cumulative)		
K-factor		
% Natural Lands in ARA	25% of Resistance Metric	
Resistance Metric–2nd Order Streams or Higher		
Depth to Bedrock[a]	25% of Resistance Metric	50% of Overall Geomorphic Condition Sub-Index
% Forest Cover (Cumulative)		
K-factor		
% Natural Lands in ARA	75% of Resistance Metric	

[a] Catchments with less than 1 ft of depth to bedrock were given the maximum resistance sub-score possible.

C.4 Consideration of other Approaches

One particular approach that was explored and discarded during the development of the geomorphic condition analysis was the attempt to classify each catchment according to Rosgen stream type, which relies on factors such as lope, sinuosity, and entrenchment (Rosgen, 1996). Rosgen stream type, lettered A through G, groups streams based on valley type and landform. The streams in each category tend to exhibit a similar bed morphology, channel stability, and other characteristics, and so are used as shorthand in stream geomorphology (e.g., a "C" stream type is a low-gradient, meandering, riffle/pool stream with a broad floodplain and is generally considered to be geomorphically stable). Field measurements would typically be used for calculating channel entrenchment ratios. However, field-collected data were extremely limited and suitable surrogates were not found within the available datasets. Without the entrenchment ratio, it was not possible to identify F and G type channels, limiting the usefulness of Rosgen stream types for this Assessment.

Additionally, efforts were made to determine streambed material using knowledge of stream processes and available surface geology data. Predictions of general substrate class size were made based on the geology and stream order of a catchment. However, with only a small pool of pebble count data available to refine and verify these predictions, there was not sufficient confidence in the predictive power of this method to assign estimated substrate class size for all catchments.

Therefore, these two approaches were not used in the assessment methods presented in Section 3.2.3 of the report.

C.5 Model Discussion

Sampling and surveys performed for water quality and stream biota, although not always comprehensive for an area the size of Clinch and Powell River System, typically cover a greater number of locations and can be used to generalize reaches of stream (or even entire catchments) beyond where they occur. Geomorphological surveys are not performed as often or at as many locations, and the type of data collected are extremely site specific. This makes it difficult to apply data collected in one area to other areas or develop broader statistical models based on the types of stream channel measurements that are available. For this reason rather than attempting to use such a very limited dataset to make weak statistical correlations, we used a different approach.

Many of the processes and forces that contribute to channel stability are well known and understood. Based on our understanding of these processes and the available data, best professional judgment was used to select the factors that would approximate the forces that lead to or resist the erosion that influences channel morphology (shown in **Table C-9**). The model for the Geomorphic Condition Sub-Index was developed with the understanding that until ground-truthing of the results can be performed, the primary use of this model was to complement the other Assessment sub-indices and enhance the overall Watershed Health Index results.

One of the strengths of this geomorphic condition analysis is that it was based on data that were available for all catchments within the Clinch and Powell River System. Although localized conditions may lead to conditions in individual catchments that disagree with this Assessment, overall the CPCRI Technical Committee found the results to be a good representation of the relative potential channel stability among all of the catchments.

An erosion factor metric score and a resistance factor metric score were rank normalized and averaged for each catchment in the Clinch and Powell River System to determine the Geomorphic Condition Sub-Index as described in Section 2.4 of the report. Maps of the erosion and resistance factor metric scores are presented in **Figures C-1** and **C-2**. While the erosion and resistance factors were combined to determine the overall Geomorphic Condition, the CPRCI Technical Team wanted to also show the relative ranking of the catchments based on the results of the lateral and vertical stability analyses. These results are illustrated in **Figures A-5** and **A-6**. This analysis is further discussed in Section 3.3 of the report.

Figure C-1. Erosion Factor Metric.

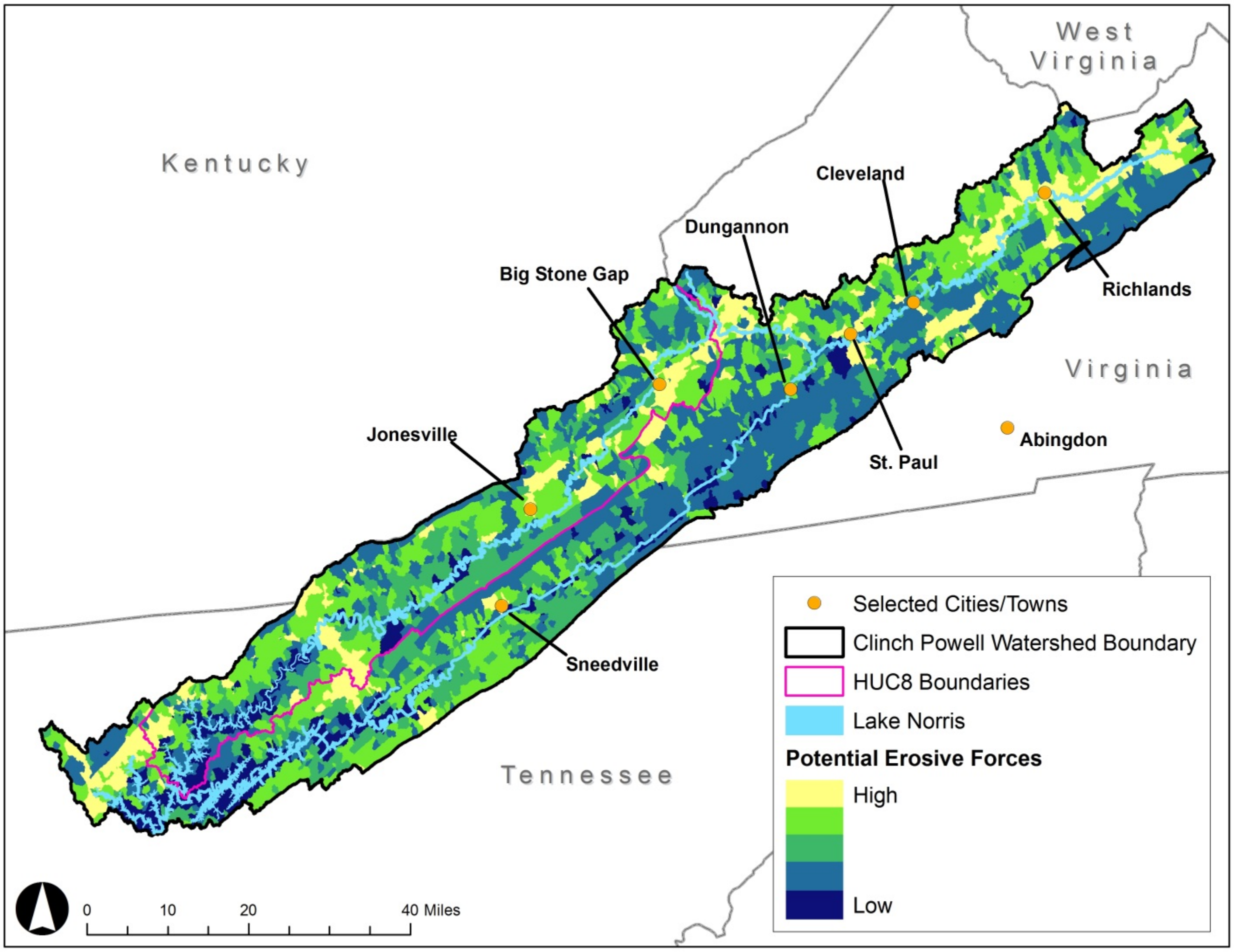
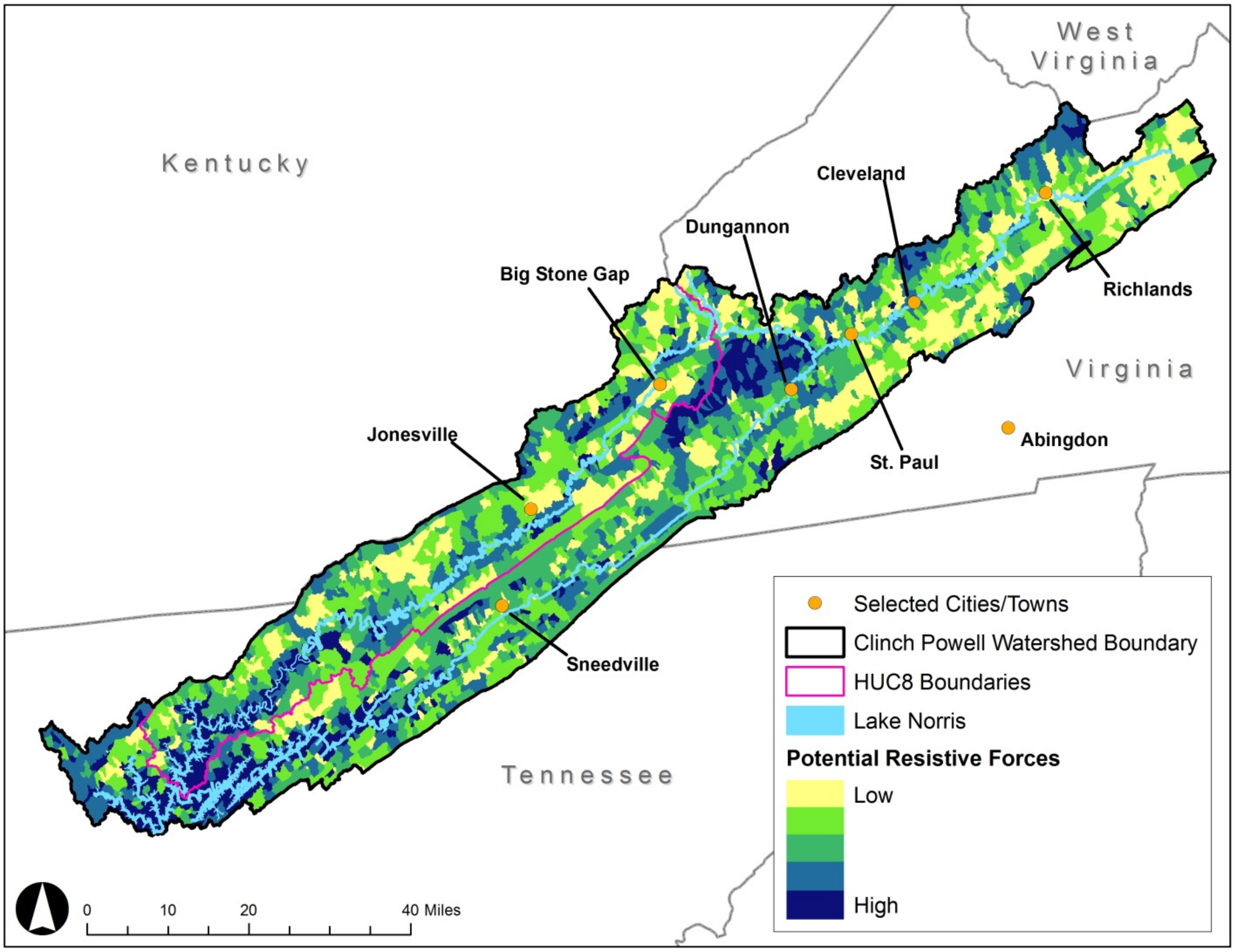


Figure C-2. Resistance Factor Metric.



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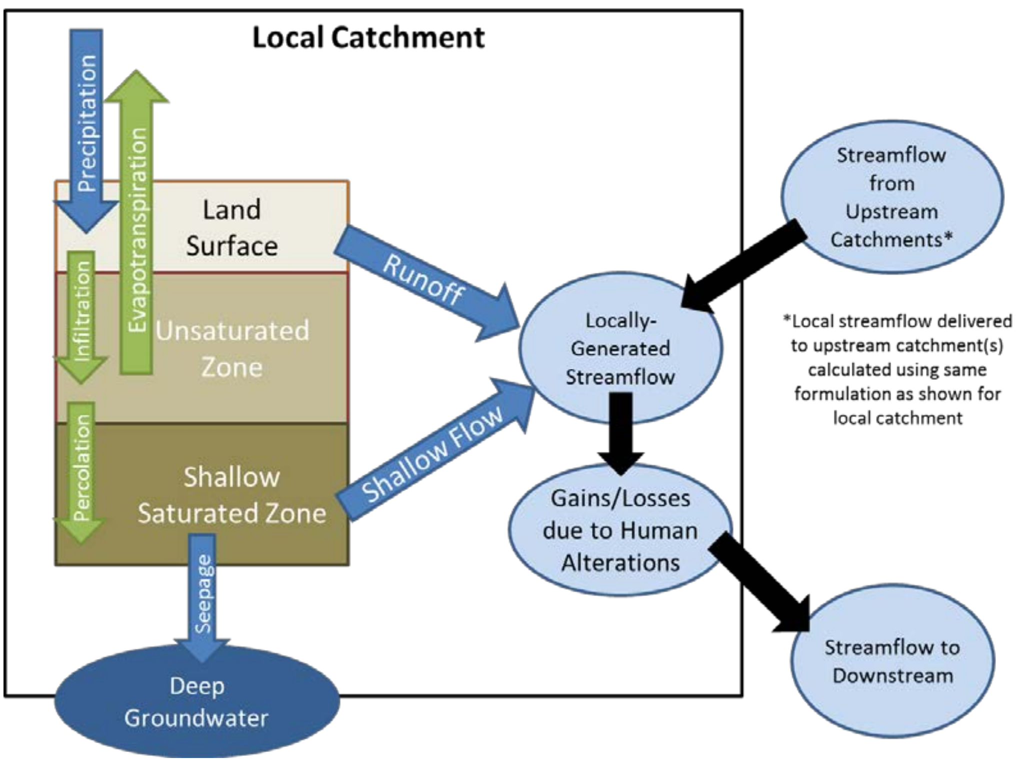
Appendix D: Hydrologic Modeling Descriptions, Calibration, and Validation

D.1 Description

RTI's Watershed Flow and Allocation Model (WaterFALL®) simulates rainfall-runoff processes for each catchment within a watershed, and routes streamflow between catchments, providing a distributed hydrologic model that simulates streamflows for catchments, larger hydrologic units, and full watersheds (**Figure D-1**). The spatially varied, catchment-indexed land use, climate, and soils features that drive the simulation allow for model scenarios related to climate and land use change. WaterFALL also incorporates human interaction on the natural system through water withdrawals/returns and the operation of control structures. Manipulation of these interactions can also be used within scenarios.

Figure D-1. Conceptual framework for WaterFALL.



To simulate rainfall-runoff processes, WaterFALL employs an updated version of a well-established hydrologic model, the Generalized Water Loading Function (GWLF) (Haith and Shoenaker, 1987; Haith et al., 1992). Surface runoff in WaterFALL is computed on a daily basis using the curve number method across each land cover type in a catchment. Discharge from shallow groundwater is computed using a lumped parameter catchment-level water balance for unsaturated and shallow saturated zones controlled by the available water capacity of the unsaturated zone, a recession coefficient providing the rate of release from the saturated zone to the stream channel, and a first-order approximation of infiltration losses to deep aquifer storage simulated using a seepage coefficient. WaterFALL uses the temperature-based Hamon Method (Hamon, 1961) to estimate potential evapotranspiration (PET). The rainfall-runoff mechanisms within WaterFALL are simulated on a daily time step. A full description of WaterFALL can be found in Eddy et al. (submitted). Details pertinent to this analysis are described here.

For all model parameters in WaterFALL, data are either indexed through geospatial processing to the catchment or land use category within a catchment to facilitate the catchment-level streamflow simulations. **Table D-1** describes the level of spatial indexing for the various model parameters. Sources for these data are described in **Table D-2**.

Table D-1. WaterFALL model parameters and definition methods.

Model Parameter	WaterFALL Determination	Applied to
Temperature/precipitation	Georeferenced from 2.5-mile (4-km) grid to catchments using area weighting	Catchment by day
Land use categories	Georeferenced from 100-ft (30-m)grid geospatial layer	Catchment
Curve number	Look-up table based on land use and soil hydrologic group	Land use category
Cover coefficient	Look-up table based on land use category and growing season	Land use category
Soil hydrologic group	Georeferenced to each land use category within a catchment	Land use category
Available water capacity (AWC)	Georeferenced by land use type and soil hydrologic group; calibrated	Catchment
Recession coefficient (Rcoeff)	Georeferenced by land use type and soil hydrologic group; calibrated	Catchment
Seepage rate	Calibrated (starting value based on best profession judgment using watershed geophysical conditions)	Catchment
Start and end dates of growing season	Georeferenced from national geospatial layer of first and last freeze dates	Catchment
Number of daylight hours	Calculated based on latitude of catchment centroid and day of the year	Catchment by day

Table D-2. Data inputs to WaterFALL and the Hydrologic Condition assessment.

Element	Name	Description	Source
Hydrology	The enhanced National Hydrography Dataset (NHDPlus) version 2	NHDPlus is an integrated suite of application-ready geospatial datasets that incorporate many of the best features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), and the Watershed Boundary Dataset (WBD).	McKay et al., 2013
Climate Data	Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group	PRISM dataset AN81d, which provides 2.5-mile (4-km) gridded daily temperature and precipitation covering the continental United States from 1981 through 2012.	Daly et al., 2008
Current Land Use	Modified National Land Cover Database 2011 (NLCD2011)	Land cover dataset refined to include reclaimed and active surface mines. Described in Appendix B.	VA Department of Mines, Minerals and Energy, Division of Mined Land Reclamation (DMLR)
Naturalized Land Use	Potential Natural Vegetation	Potential Natural Vegetation GIS layer based on work by Küchler (1964)	Küchler, 1964
Soils	Soil Survey Geographic (SSURGO) database	Field mapping methods using national standards are used to construct the soil maps in the SSURGO database. Mapping scales generally range from 1:12,000 to 1:63,360; SSURGO is the most detailed level of soil mapping done by the Natural Resources Conservation Service (NRCS).	USDA-NRCS, 2014
Hydrologic Parameters	Sacramento Soil Moisture Accounting (SAC-SMA) Parameters from SSURGO	We adopt 2 of the 11 soil-related parameters estimated for the SAC-SMA model as a starting point for calibrating the available water capacity of the unsaturated subsurface zone (a volumetric measure in cm/cm) and recession coefficient (a dimensionless rate) within WaterFALL. Data are provided on an approximately 2.5 mi x 2.5 mi (4 km x 4 km) grid.	Zhang et al., 2011
Hydraulic Geometry of Streams	Regional (physiographic province) regression equations relating stream cross-section properties to drainage area	Stream cross-sectional area and bankfull depth, width, and discharge estimates are made based on a relationship to cumulative drainage documented for individual physiographic provinces.	Keaton et al., 2005
Water Use Data	Catchment-level monthly average estimates of withdrawals from and discharges to the stream network	Virginia Department of Environmental Quality (DEQ) provided location-specific water use data (both withdrawals and discharges) for the Virginia portions of the watershed resulting in a total of 32 NHDPlus catchments subject to alteration.	Personal communication, Smith, VA DEQ
Streamflow[a]	USGS National Water Information System (NWIS) Stream Gages	Daily streamflow data are downloaded for each gage of interest from NWIS. Gages are examined based on characteristics provided for each in the Geospatial Attributes of Gages for Evaluating Streamflow, version II (GAGES II) dataset and on the daily records.	Falcone et al., 2010

[a] Streamflow values are not used as model inputs but as data for calibration. In some future model simulations, USGS gages may be used as boundary conditions or as representation of control structures/dams in place of model estimations at selected NHDPlus catchments.

As a curve number-based model, WaterFALL requires the specification of different land use components with their corresponding hydrologic soil condition. The impacts of mining have altered the natural topography and removed natural vegetation and soil from the landscape. Therefore, we used mining data to refine the 2011 NLCD barren and revegetated areas as “potentially disturbed” due to mining activity. These methods are described in Appendix B of this report. We verified that there are no active or recent mining activities in the Tennessee portion of the Clinch and Powell River System. Therefore, no changes were made to the NLCD in Tennessee. The curve numbers developed for the land cover classes within the modified NLCD 2011 coverage for use in WaterFALL are provided in **Table D-3**.

The curve numbers derived for use in the WaterFALL modeling effort began with the guidance provided in NRCS document TR-55 (USDA-NRCS, 1986). These curve number assignments by land use category and soil hydrologic group are validated through model calibration.

To modify the curve numbers for reclaimed and active surface mining areas, we reviewed work by McCormick and Eshleman (2011). Their study looked at estimated and calculated/observed curve numbers in a series of small watersheds that had been reclaimed 10 to 30 years ago and originally had low to moderate infiltration (groups C and B/C). They found that observed curve numbers for reclaimed areas were higher (2 to 13 units) than estimated curve numbers from TR-55 guidance. The observed curve numbers ranged from 68 to 92. Other studies cited by McCormick and Eshleman (2011) from Ohio and Pennsylvania provided observed curve numbers for reclaimed mined lands in the range of 83 to 92.

Given the demonstrated increase over TR-55 guidance and the likely impacts of soil compaction within reclaimed areas over natural conditions, we therefore assumed that the disturbed/reclaimed land use categories that were originally in the low to high infiltration categories (groups A, B, and C) would likely behave more like the high runoff potential category (group D) originally estimated using TR-55. (We included a slight increase from 79 to 80 for forest lands.) We also assumed there would be a slight increase in runoff potential for the highest runoff category, which is indicated by increasing the curve number for group D by 4 to 5 units.

Note, most of the Clinch and Powell River System is referenced as groups A and B.

Table D-3. Curve numbers by land use category and soil hydrologic group.

Code	Revised Land Use Description	Soil Hydrologic Group			
		A	B	C	D
11	Open Water	100	100	100	100
21	Developed, Open Space	49	69	79	84
22	Developed, Low Intensity	50	68	79	84
23	Developed, Medium Intensity	59	74	82	87
24	Developed, High Intensity	82	88	92	93
31	Barren Land	77	86	91	94
41	Deciduous Forest	45	66	73	79
42	Evergreen Forest	45	66	73	79
43	Mixed Forest	45	66	73	79
52	Shrub/Scrub	45	57	68	74
71	Herbaceous	49	70	80	87
81	Hay/Pasture	40	64	75	81
82	Cultivated Crops	64	75	82	85
90	Woody Wetlands	100	100	100	100
95	Emergent Herbaceous Wetlands	100	100	100	100
99	Mined	89	92	94	95
111	Open Water_Disturbed	100	100	100	100
211	Developed, Open Space_Disturbed	84	84	84	88
221	Developed, Low Intensity_Disturbed	84	84	84	88
231	Developed, Medium Intensity_Disturbed	87	87	87	91
241	Developed, High Intensity_Disturbed	93	93	93	95
411	Deciduous Forest_Disturbed	80	80	80	85
421	Evergreen Forest_Disturbed	80	80	80	85
431	Mixed Forest_Disturbed	80	80	80	85
521	Shrub/Scrub_Disturbed	74	74	74	78
711	Herbaceous_Disturbed	87	87	87	91
811	Hay/Pasture_Disturbed	81	81	81	85
901	Woody Wetlands_Disturbed	100	100	100	100
951	Emergent Herbaceous Wetlands_Disturbed	100	100	100	100

D.2 Calibration and Validation

Three parameters are calibrated within WaterFALL: the available water capacity (AWC), the runoff coefficient (Rcoeff), and the seepage parameter. The AWC is a physical parameter that varies by soil type and depth. The Rcoeff and seepage parameter are dimensionless rate constants that equate to a rate of water loss to the stream or deep aquifer, respectively, from the saturated subsurface zone. We estimated the values for the two physically based calibration parameters, the AWC within the unsaturated soils and the Rcoeff, to define the release of water from the saturated subsurface zone to the stream, from soils (SSURGO) for the AWC and a combination of SSURGO and land use (2001 NLCD) geospatial data layers as compiled by the National Weather Service (Zhang et al., 2011) for the Rcoeff. The values available for each of these two parameters have a physical basis and are adjusted proportionally, up or down, for a calibration region based on the calibrated multiplier to preserve the physical relationship between the soils and land use properties in the region. We provided a range of values (minimum and maximum) and a starting value for each of these three parameters to WaterFALL to start the calibration algorithm. We have set up a customized version of the Parameter Estimation Tool (PEST) (Doherty and Johnston, 2003) to interact with WaterFALL and calibrate the parameters through an iterative process.

All calibrations were completed with the objective of minimizing the differences in log-transformed daily flows. This objective function gives equal weight to differences in streamflows at the low end of the hydrograph as to the high end of the hydrograph, which often results in better representation of low flows at the expense of potentially underestimating peak streamflows. We use several performance metrics to evaluate the goodness-of-fit for the model. Daily flows were evaluated by an overall volume error (OVE) measure or percent bias and by the Nash-Sutcliffe Efficiency (NSE) (Equations 1 and 2). The OVE quantifies the percent difference in total (summed) daily volume of observations versus model estimates. The NSE ranges from -∞ to 1, where a value of 0 indicates that the model predictions are as accurate as the mean of the observed data. A negative NSE value indicates that the residual variance is larger than the data variance. Both of these daily measures are disproportionately affected by large storm events where the residual (i.e., difference between observation and model) for a single day with peak flow will cause a larger reduction in these quantitative measures than a difference in a day with low flow. Therefore, we also assessed qualitative measures. We balanced the quantitative performance metrics related to daily streamflows by matching overall/seasonal trends in the flow duration curve (FDC), daily hydrograph, and monthly median and mean flows.

$$OVE = \frac{\sum_{t=1}^{n} S_t - \sum_{t=1}^{n} O_t}{\sum_{t=1}^{n} O_t} \times 100$$

EQ 1

$$NSE = 1.0 - \frac{\sum_{t=1}^{N} \left(S_t - 0_t\right)^2}{\sum_{t=1}^{N} \left(O_t - \mu_o\right)^2}$$

EQ 2

where

S_t	=	model simulated flow time series
O_t	=	observed flow time series
μ_o	=	mean (average) of observed flow

Numeric thresholds for evaluating rainfall-runoff model performance were the subject of a recent paper focusing on the Soil and Water Assessment Tool (SWAT; Moriasi et al., 2007), which is similar in its theoretical framework to WaterFALL. Moriasi and others (2007) suggest a "very good" model has a monthly NSE above 0.75 and an OVE less than ±10%, while a "good" model has a monthly NSE between 0.65 and 0.75 and an OVE between ±10% to 15%. Six USGS streamflow gages were available with long-term records for comparing modeled streamflows to observed streamflows (**Figure D-2**). Using the stated performance criteria, 5 of the 6 gages available for calibration provide "very good" models, while one gage is considered "good" (**Table D-4**).

Figure D-2. USGS gages used for calibration and validation in WaterFALL.

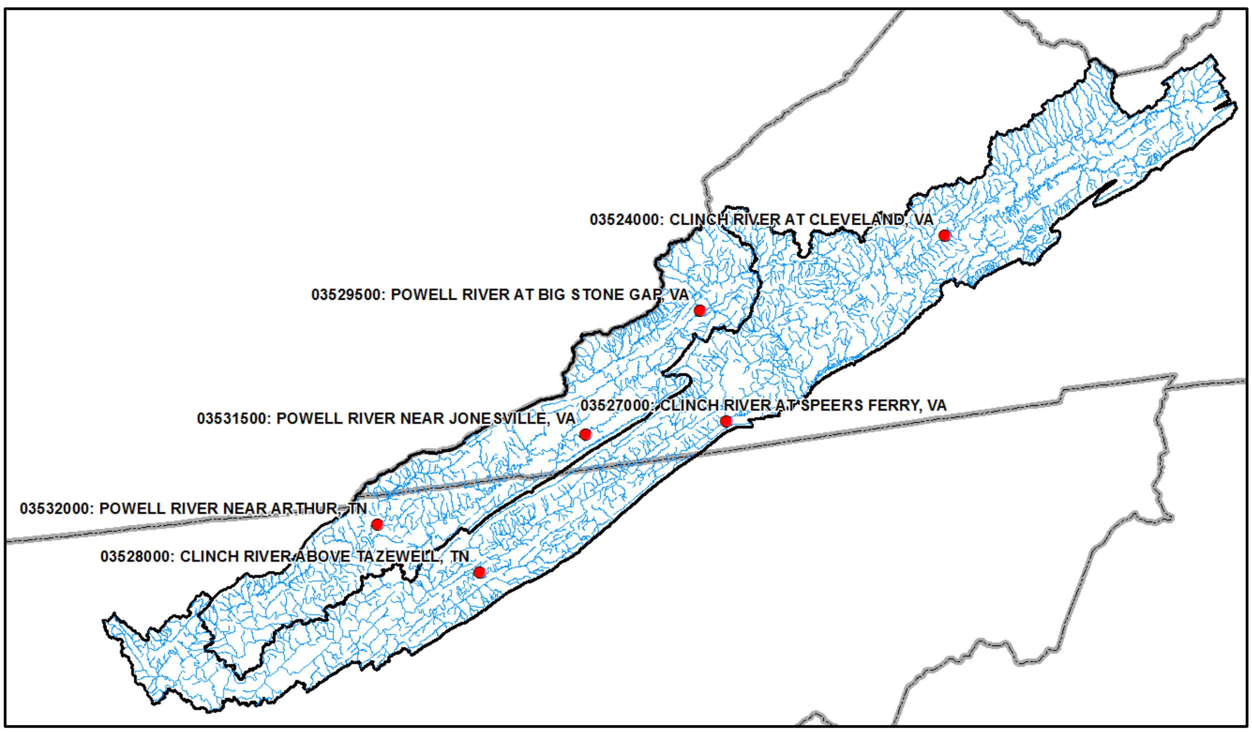


Table D-4. Standard quantitative performance metrics at USGS gages

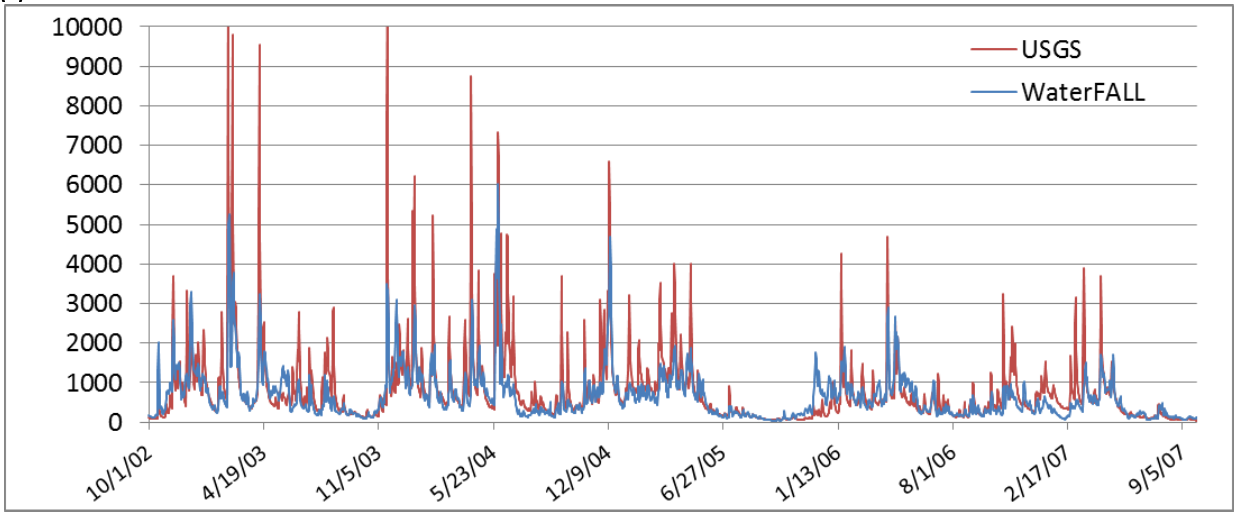
Basin	USGS Gage	NHDPlus COMID	Use	Drainage Area (mi^2)	Daily NSE	Monthly NSE	OVE (%)
Clinch	03524000	14640391	Calibration	533	0.41	0.80	4.4
	03527000	14640581	Validation	1,123	0.50	0.72	−13.0
	03528000	14642349	Validation	1,474	0.47	0.75	−6.7
Powell	03529500	22539070	Validation	112	0.60	0.79	0.1
	03531500	22539818	Calibration	319	0.55	0.82	−1.6
	03532000	22540324	Validation	685	0.41	0.80	4.4

Figures D-3 through D-8 provide qualitative evaluations of the calibration and validation of WaterFALL within the Clinch and Powell River System through daily hydrographs for calibration/validation periods and long-term flow duration curves.

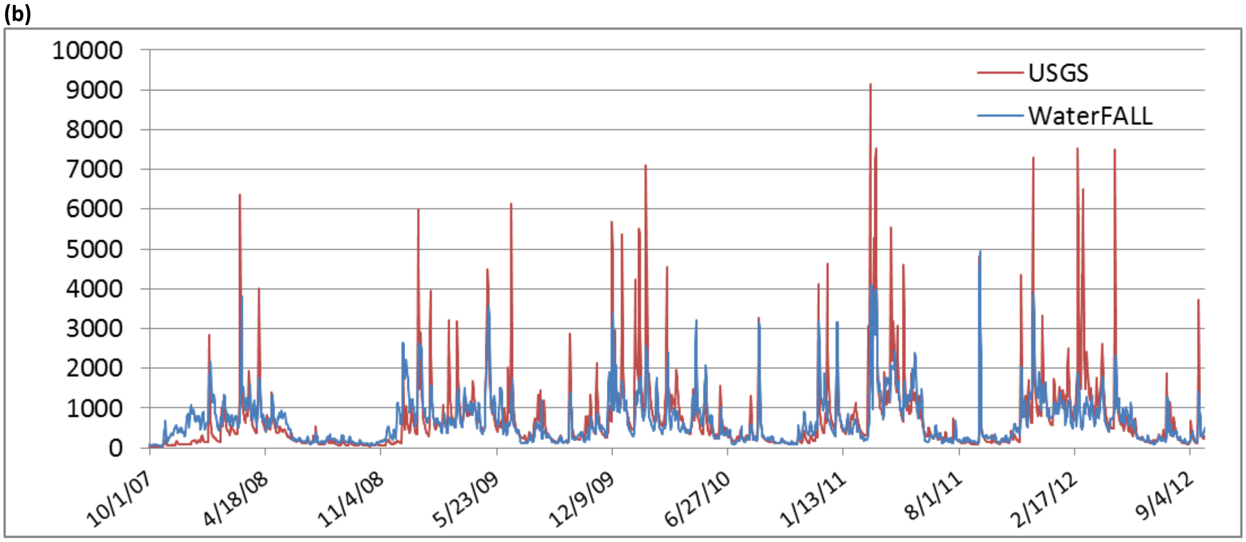
An additional evaluation of model performance that relates more specifically to the objective of this healthy watershed study is an evaluation of the model's calculation of the selected hydrologic metrics. Kennard and others (2010) found that a 20% to 30% difference in calculated observed streamflow characteristics is expected depending on the period of observations used to calculate the metric (i.e., the value of a metric calculated for an earlier period may be up to 30% different from the calculation of the same metric using a later period). This range of uncertainty has been used as a "band of hydrologic uncertainty" to which modeled streamflow characteristics may be compared (Murphy et al., 2013). Table D-5 presents the bias or percent difference in the final flow metrics used in the assessment of the hydrologic condition for the six USGS streamflow gages with available long-term records. Highlighted values indicate those falling outside of Kennard's suggested range of uncertainty. While most of the flow metrics fall within the suggested range of uncertainty, the winter high-pulse duration is more varied for three of the gages, although one gage was simulated exactly (average duration of 11 days) and two others were either within the uncertainty bounds or just outside the range. The three gages farthest outside the range of uncertainty for the winter high-pulse duration were all validation gages and therefore were not calibrated directly.

Figure D-3. 03524000 Clinch River at Cleveland, VA (Calibration Site): (a) Calibration period water years 2003–2007 hydrograph, (b) Validation period water years 2008–2012 hydrograph, (c) Long-term FDC.

(a)



(b)



(c)

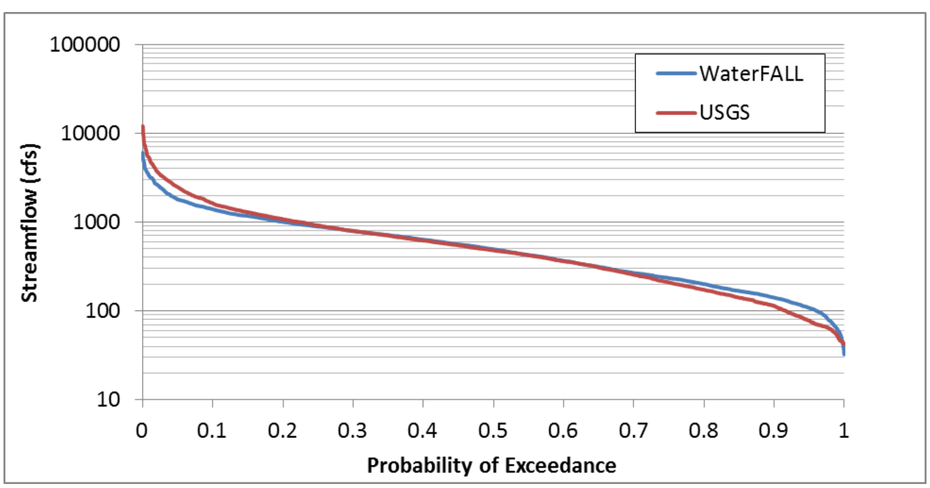


Figure D-4.   03527000 Clinch River at Speers Ferry, VA (validation site).

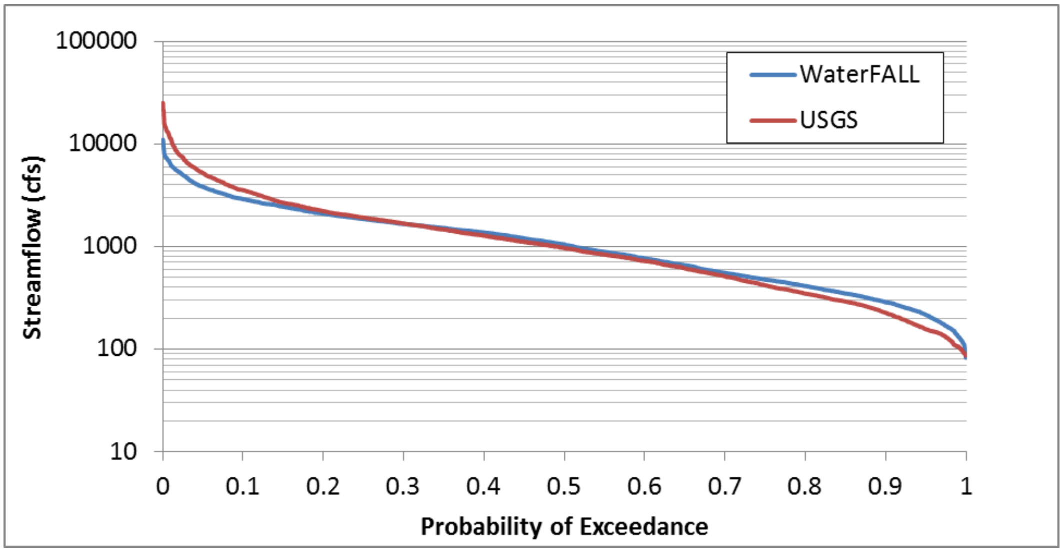


Figure D-5.   03528000 Clinch River above Tazewell, TN (validation site).

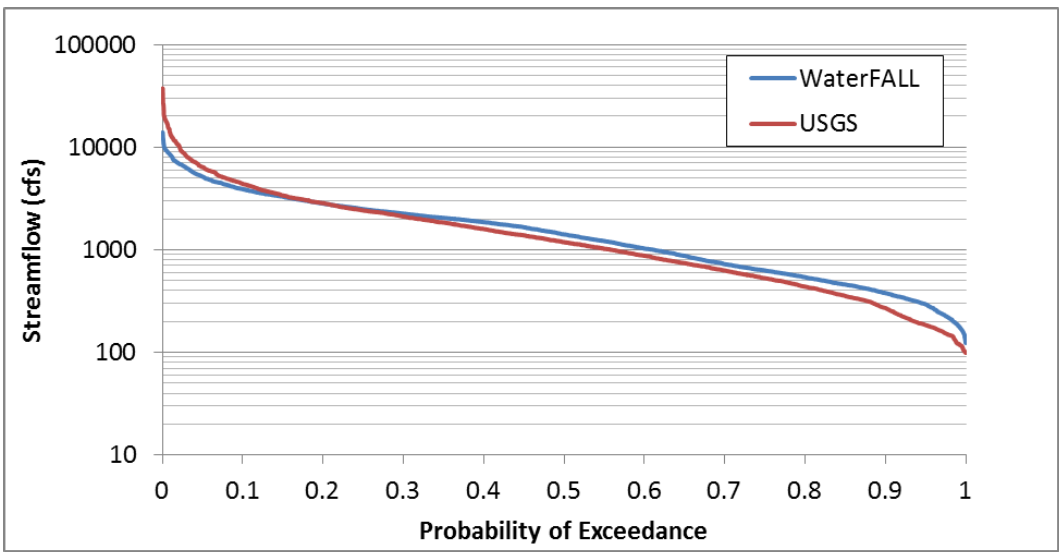
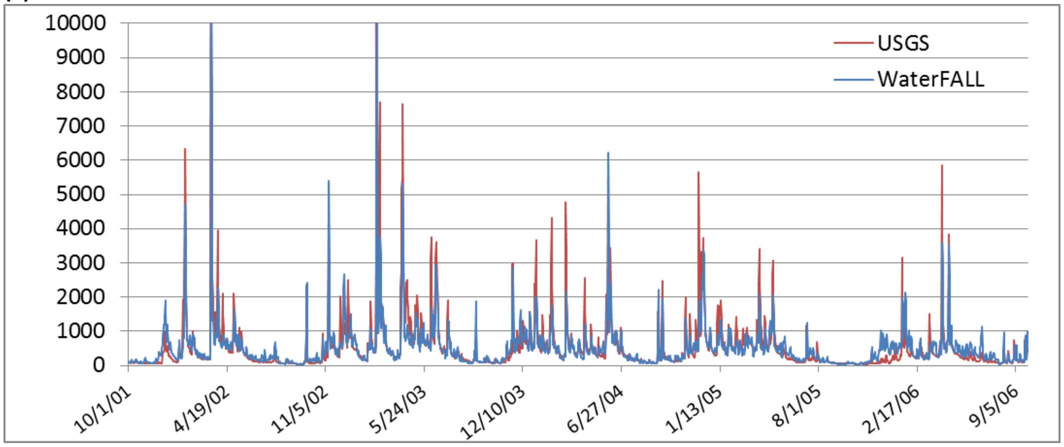
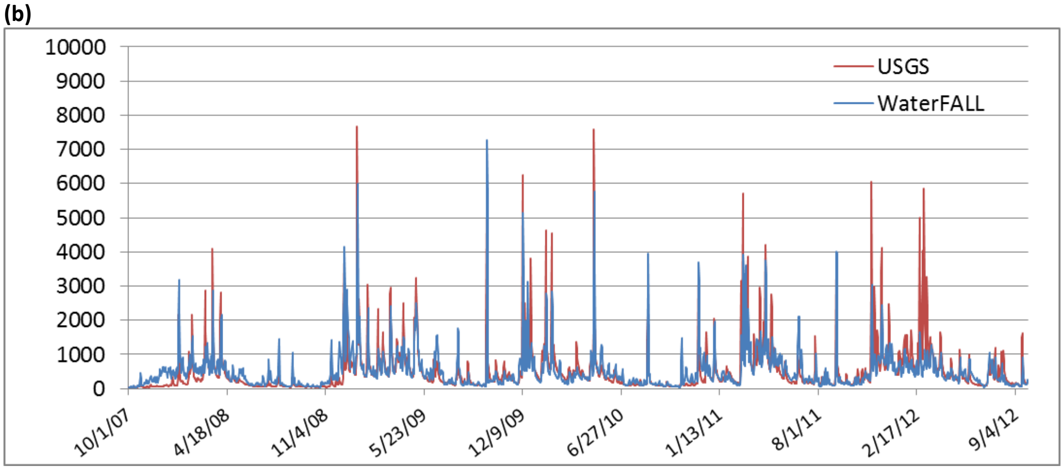


Figure D-6. 03531500 Powell River near Jonesville (calibration site). (a) Calibration period water years 2002–2006 hydrograph. (b) Validation period water years 2008–2012 hydrograph. (c) Long-term FDC.

(a)



(b)



(c)

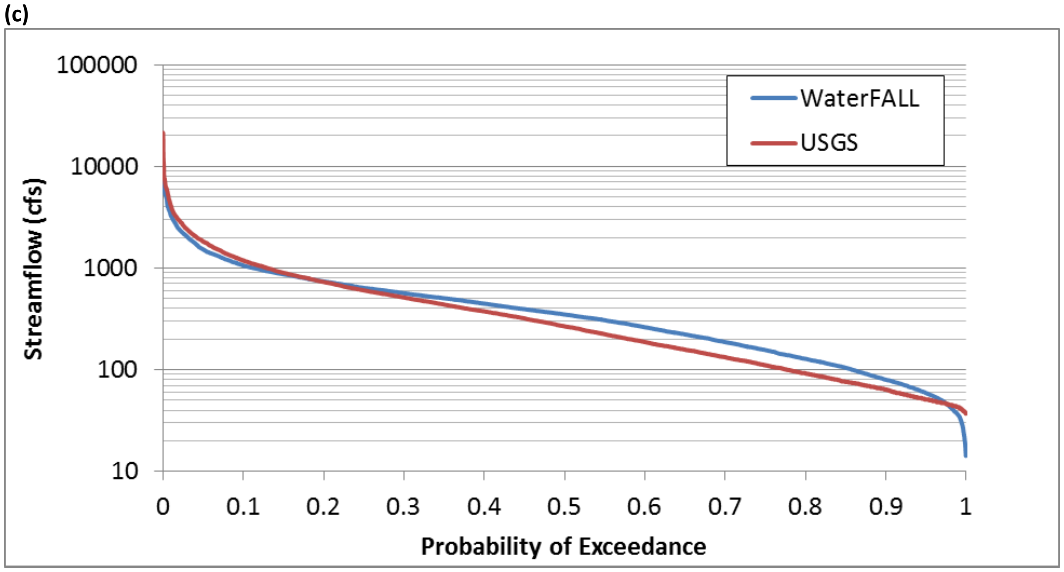


Figure D-7. 03529500 Powell River at Big Stone Gap, VA (validation site).

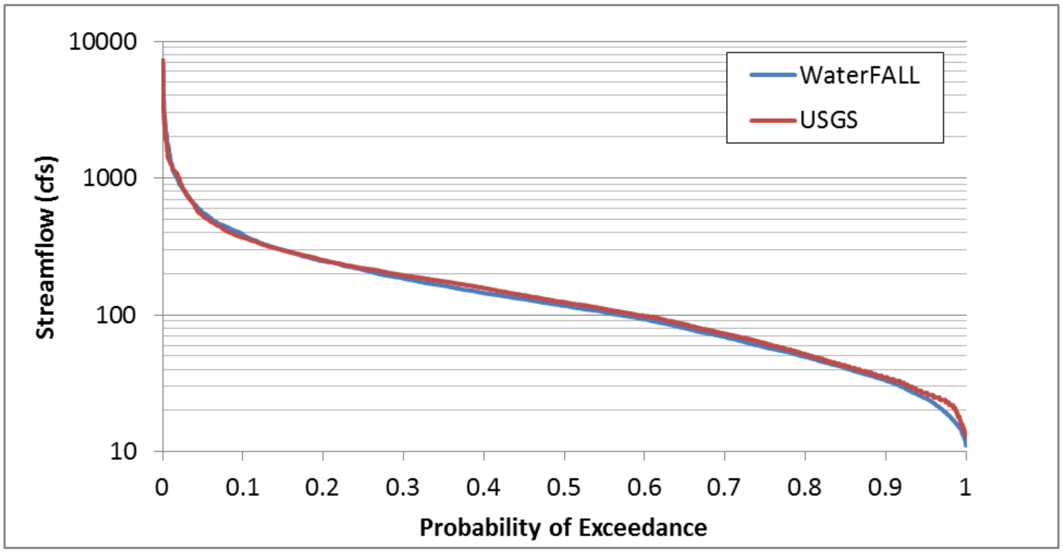


Figure D-8. 03532000 Powell River near Arthur, TN (validation site).

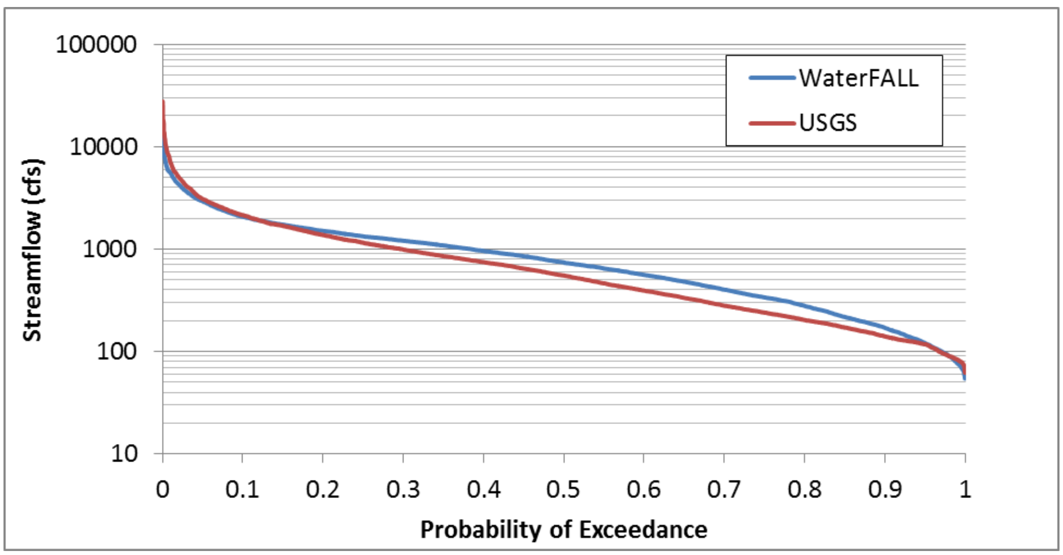


Table D-5. Bias (percent difference) in selected hydrologic metrics at USGS gages (10 to 20 years).

USGS Gage	NHDPlus COMID	Use	Drainage Area (mi^2)	7-Day Minimum Low Flow	30-Day Minimum Low Flow	Average Winter High-Pulse Duration	Average March Median Flow
03524000	14640391	Calibration	533	23	**36**	0	−19
03527000	14640581	Validation	1,123	23	21	**94**	−18
03528000	14642349	Validation	1,474	**33**	28	**129**	−13
03529500	22539070	Validation	112	**−39**	−4	**−47**	−12
03531500	22539818	Calibration	319	−5	**40**	**−33**	−10
03532000	22540324	Validation	685	−14	6	15	7

D.3 References

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Appendix E: Water Quality

E.1 Introduction

Water quality parameter values in catchments without observed data were predicted using a statistical regression approach called multilevel modeling. This modeling framework quantifies relationships between predictor variables and water quality parameters using observed data. The relationships in the fitted model were then used to predict parameter values in catchments with predictor variable data but no observed water quality data.

Multilevel modeling is a form of hierarchical linear regression that differs from classical multiple linear regression in that the approach can correctly incorporate cross-scale interactions or factor variables that occur at different spatial and temporal scales. Cross-scale interactions are explored in this approach by using group-level factor variables. For instance, sample sites may be classed by ecological region under the assumption that sites within the same ecoregion will share commonalities in terms of environmental and ecological response. The impact of group-level factors is formally predicted within the multilevel framework. In this way, multilevel modeling allows for the exploration of factors at the group level that may explain variation in model coefficients (Qian et al., 2010). Because multilevel regression contains classical linear regression as a special case, the approach can also be conceptualized as a linear regression in which model coefficients are allowed to vary based on group membership (i.e., ecoregion assignment) (Gelman and Hill, 2007).

Datasets that contain hierarchical structures and cross-scale interactions are well suited for multilevel regression. Qian (2009) recommends the use of the multilevel approach when:

- The goal of the study is estimation of coefficients
- The data are observational in nature
- Observations can be grouped together by multiple group-level variables (i.e., eco-region, soil group)
- Sample sizes are unbalanced

The ability to explicitly model hierarchical structures can improve understanding of the environmental system under study (Qian et al., 2010. In addition, Gelman (2006) demonstrated that multilevel predictions for hierarchical datasets outperform other predictive methodologies.

The remainder of this appendix describes the data organization and analysis used in the assessment of the Water Quality Sub-Index.

E.2 Data Collection and Organization

E.2.1 Data Sources and Response Variable Selection

Water quality parameters for the Clinch and Powell River System were obtained from the U.S. Environmental Protection Agency's (EPA's) Storage and Retrieval (STORET) system and the U.S. Geological Survey's (USGS's) National Water Information System (NWIS). Data were downloaded from the National Water Quality Monitoring Council's Water Quality Portal (http://www.waterqualitydata.us/). Additional data were also collected from personnel at the Virginia Department of Environmental Quality and the Virginia Department of Mining, Minerals, and Energy. **Table E-1** provides a complete list of sources for the water quality data used in this Assessment.

Table E-1. List of agencies providing data for water quality assessment.

Collecting Agencies
EPA National Aquatic Resource Survey Data
National Park Service Water Resources Division
Tennessee Department of Environment and Conservation
USGS Tennessee Water Science Center
USGS Virginia Water Science Center
Virginia Department of Environmental Quality
Virginia Department of Mines, Minerals, and Energy

A variety of physical and chemical water quality parameters are collected in the Clinch and Powell River System. The complete list of parameters was initially screened to select parameters representative of naturally occurring water quality conditions (i.e., parameters expected to be detectable under natural conditions) (**Table E-2**).

Potential response variables were selected from available candidates after evaluating the following criteria:

- Spatial distribution in watersheds
- Temporal distribution of sample dates
- Variability of parameter values (e.g., mean, median, standard deviation, minimum value, maximum value)
- Statistical distribution of parameter values (e.g., approximately normal, log-normal)
- Relevance to environmental and ecological processes
- Relevance to aquatic biology

Table E-2. List of physical and chemical water quality parameters collected in the Clinch and Powell River System considered for this assessment.

Parameter	Units	Sample Count	Unique XY Coordinates	Forms
Dissolved oxygen	mg/L; %	2,036	268	Concentration; % saturation
Dissolved solids	mg/L; tons/day; tons/ac ft	2,420	246	Total
Suspended solids	mg/L	1,278	480	Total
Orthophosphate	mg/L; mg/kg	226	84	Dissolved; Total
Phosphate	mg/L	387	154	Dissolved; Total
Phosphorus	mg/L; mg/kg/; µg/L	932	256	Dissolved; Suspended; Total
pH		2,173	363	n/a
Ammonia	mg/L; µeq/L; µg/L	630	139	Dissolved; Suspended; Total
Nitrate	mg/L; µeq/L	1,703	201	Dissolved; Suspended; Total
Nitrite	mg/L	297	141	Dissolved; Suspended; Total
Specific conductance	µS/cm @25C	3,817	708	Total
Turbidity	FNU; JTU; mg/L; NTU	1,893	181	Total

Abbreviations: mg/L = milligrams per liter; % = percent; tons/day = tons per day; tons/ac ft = tons per acre foot; mg/kg = milligrams per kilogram; µg/L = micrograms per liter; µeq/L = microequivalents per liter; µS/cm = microsiemens per centimeter; C = degrees Celsius; FNU = Formazin Turbidity Unit; JTU = Jackson Turbidity Unit; NTU = Nephelometric Turbidity Units

Based on the criteria above as well as discussions with members of the CPCRI Technical Team, three response variables were chosen for further analysis: specific conductance, total suspended solids, and dissolved oxygen (**Table E-3**).

Table E-3. Potential water quality response variables.

Parameter	Units	COMID Count
Specific Conductance	µS/cm @25C	537
Total Suspended Solids	mg/L	430
Dissolved Oxygen	mg/L; %	134[a]

[a] Count reflects available data at time of initial modeling; does not include data obtained at later date from Virginia Department of Environmental Quality.

E.2.2 Response Variables

Sample site coordinates were intersected with NHDPlus to match each sample site with a catchment (**Figure E-1**). Sample data were more heavily concentrated in the Virginia portions of the Clinch and Powell River System than in Tennessee.

To more closely capture current land cover conditions, only samples collected on or after January 1, 2000, were retained in the dataset. Non-detect values reported as zero were discarded from the dataset; parameter values reported at the detection limit, which varied depending on reporting agency and analytical method, were retained at the respective limit value. In addition, the following parameter value formats were prepared for statistical testing:

- Retain all post-2000 sample dates
- Retain only the most recent sample date for each catchment
- Retain the post-2000 parameter value mean for each catchment
- Retain the post-2000 mean annual parameter values for each catchment

Catchments with water quality data were also screened against permits in the National Pollutant Discharge Elimination System (NPDES) permit program. Given the characteristic source, fate, and transport mechanisms of specific conductance and total suspended solids and the relative lack of NPDES major permits in the watersheds, it was determined that parameter values were unlikely to be unduly influenced by NPDES discharges.

E.2.2.1 Response Variable Summary and Selection

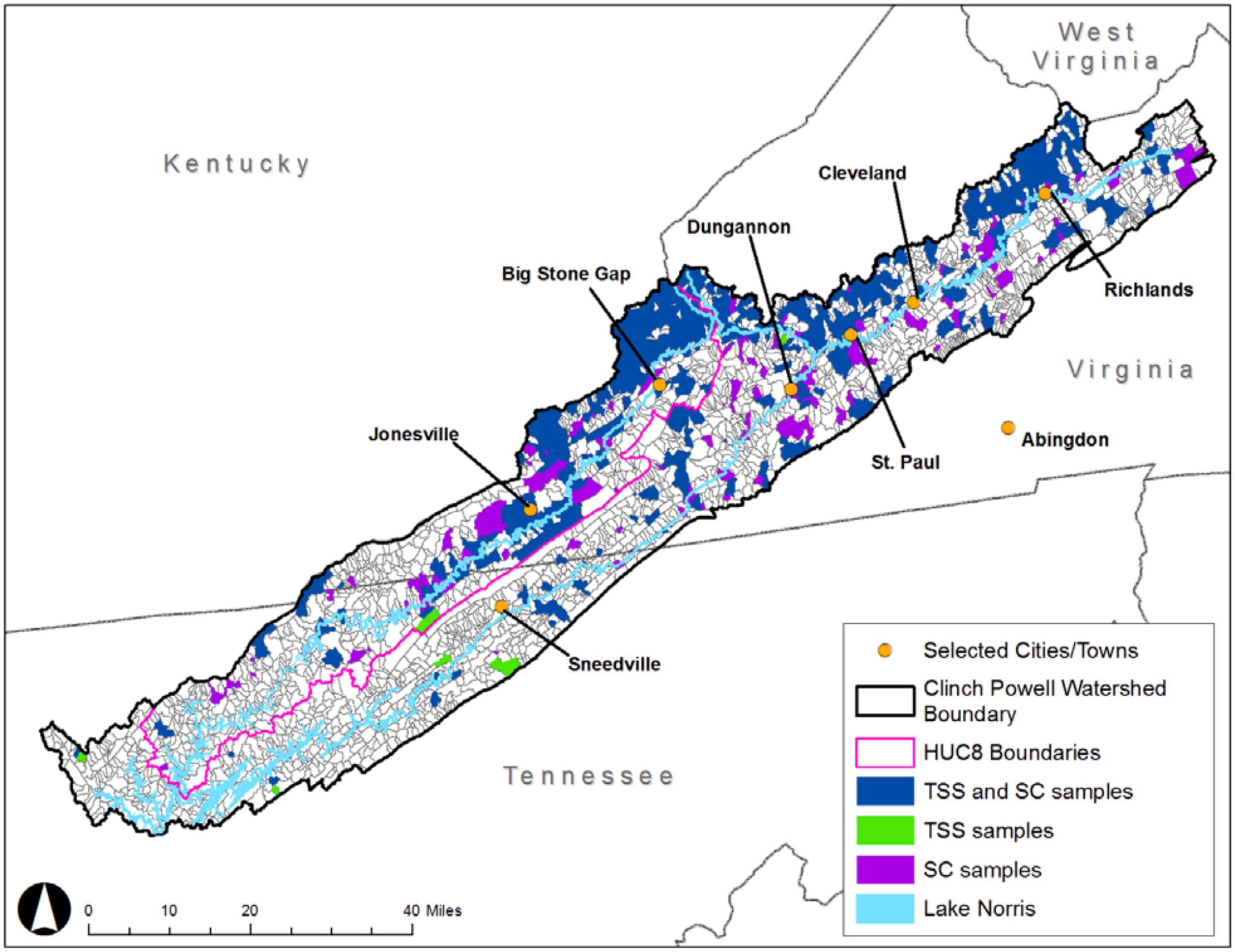
Using the filtering criteria mentioned in Section E.2.1, dissolved oxygen (DO), total suspended solids (TSS), and specific conductance (SC) were selected for initial modeling efforts. **Table E-4** provides summary statistics for post-2000 mean catchment-level parameter values.

Based on discussions with the CPCRI Technical Team, DO was eventually eliminated from the Assessment because it was not regarded as being indicative of watershed health; DO percent saturation levels are generally very high throughout the study area (**Table E-4**). In addition, TSS and SC are regarded as more relevant to environmental and ecological processes, and SC in particular is more likely to negatively impact aquatic biology than dissolved oxygen (Evans et al., 2014).

Table E-4. Summary statistics for modeled water quality parameter values.

Parameter	Unit	Min	25th Percentile	Median	75th Percentile	Max
TSS	mg/L	1	6.3	10.3	16.23	78.7
SC	µS/cm	5	280	372	611	1,768
DO	% saturation	1	83.7	93	100	170

Figure E-1. Distribution of specific conductance (SC) and total suspended solids (TSS) sample sites in Clinch and Powell River System.



E.2.3 Predictor Variables

To characterize and predict water quality parameter values, a range of predictor variables were collected and linked to each catchment in the Clinch and Powell River System (**Table E-5**). Predictor variable selection was based on available data and environmental and ecological relevance. In addition to the variables listed below, all metrics calculated as part of the Hydrologic Condition assessment (Table D-5) were also considered.

Table E-5. Predictor variables used in water quality analysis.

Long Name	Description	Source	Calculated?
Local Area (mi^2)	Drainage area of the catchment in square miles	NHDPlus2	No
Cumulative Drainage Area (mi^2)	Drainage area of the catchment plus the upstream waters	NHDPlus2	Yes
Eco_Region	Fenimni Ecoregion: "Valley and Ridge" or "Appalachian Plateau"—area weighted	USGS	Yes
Bankfull CSA (ft^2)	Bankfull cross sectional area (square feet)	NHDPlus2	Yes
Bankfull Width (ft)	Width of the stream channel at bankfull height	NHDPlus2	Yes
Bankfull Depth (ft)	Depth of the stream channel at bankfull height	NHDPlus2	Yes
Bankfull Discharge (cfs)	Flow condition where the stream channel is filled to bankfull height	NHDPlus2	Yes
Impervious Cover (% across the catchment)	Mean percent impervious across catchment	NLCD 2011	Yes
Length (mi)	Flowline length of the stream channel	NHDPlus2	No
Cumulative Length (mi)	Flowline length of the stream channel within the catchment plus total upstream flowline length	NHDPlus2	Yes
Maximum Elevation NHD (ft)	MaxElevSmo in NHDPlus; maximum elevation (smoothed)	NHDPlus2	No
Minimum Elevation NHD (ft)	MinElevSmo in NHDPlus; Minimum elevation (smoothed)	NHDPlus2	No
Slope (ft/ft)	Slope of flowline based on smoothed elevations; a value of -9998 means that no slope value is available	NHDPlus2	No
Stream Type	Based on slope, classified by Rosgen Stream Type. Slope <2 = Type C, E, Bc; Slope 2–4 = Type B; Slope>4 = Type A	NHDPlus2	Yes
kffact_weighted	An index that quantifies the relative susceptibility of the soil to sheet and rill erosion. Values range from 0.02 for the least erodible soils to 0.64 for the most erodible. Average value for stream length.	SSURGO	Yes
Stream Order	Modified Strahler Stream Order	NHDPlus2	No
Sinuosity	Calculated as the Euclidean distance between the start and end points of a stream segment divided by the length of the stream segment, or shortest path	NHDPlus2	Yes
Average Valley Width (ft)	Average width of the valley per catchment. Calculated using Valley Bottom Mapping Tool and 30-ft (10-m) DEM from the National Map	NHDPlus2; National Map; Goetz, 2001	Yes
Depth to Bedrock (ft)	Average depth to bedrock along the stream segment per catchment; bedrock depth was recorded at points along each stream segment and the average was calculated per catchment	USGS	Yes
Dominant Rock Type 1	Rock type 1 underlying longest piece of the stream segment within the catchment	USGS	Yes
Dominant Rock Type 2	Rock type 2 underlying longest piece of the stream segment within the catchment	USGS	Yes
Tree Canopy (% across catchment)	NLCD tree canopy percentage averaged across the catchment	NLCD 2011	Yes
Land Cover	NLCD 2011 land cover averaged by catchment area	NLCD 2011	Yes

(continued)

Long Name	Description	Source	Calculated?
ARA Land Cover	NLCD 2011 land cover averaged by ARA within each catchment	NLCD 2011; The Nature Conservancy	Yes
Cumulative Drainage Land Cover	NLCD 2011 land cover averaged for total upstream drainage area	NLCD; NHD	Yes
Daily Flow	Daily estimated flow (cfs) on date of water quality parameter sample	WaterFALL	Yes
Daily Flow % Median	Daily estimated flow on date of water quality parameter sample as a percentage of catchment median flow	WaterFALL	Yes
Previous 5-Day Flow	Average previous 5-day flow (cfs) from date of water quality parameter sample	WaterFALL	Yes
Previous 5-Day Flow % Median	Average previous 5-day flow from date of water quality parameter sample as a percentage of catchment median flow	WaterFALL	Yes

E.3 Model Development and Evaluation

The following process was applied to each candidate water quality parameter variable:

1. Spearman and Pearson correlations between parameters and predictor variables were calculated and summarized; the purpose of this step is to identify potential relationships between the response and predictor variables.

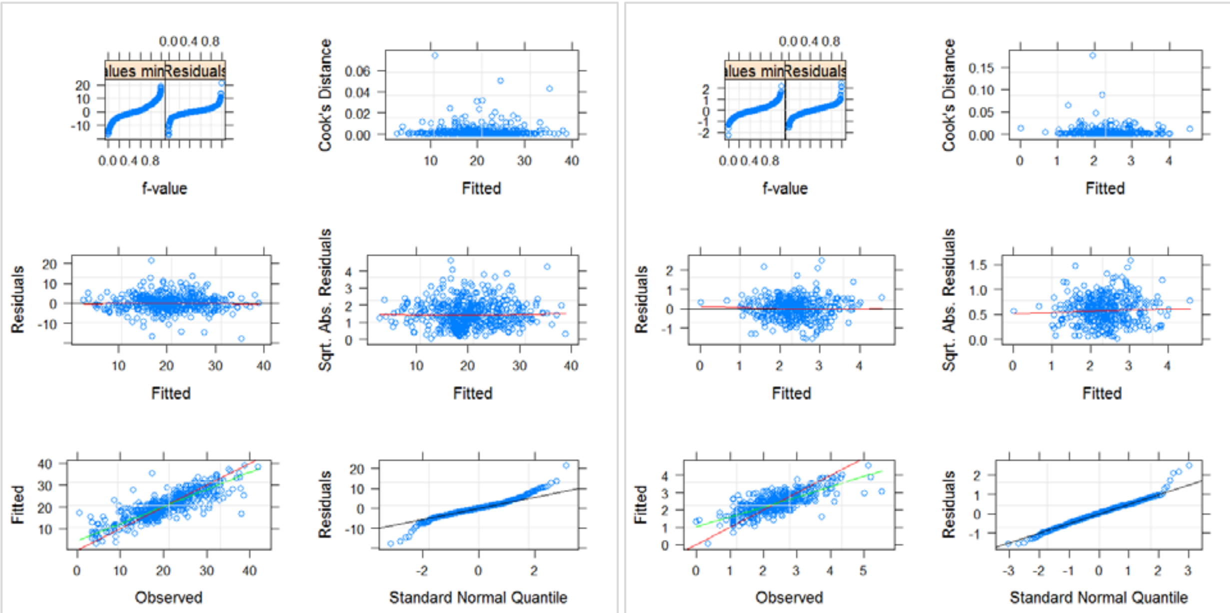
2. Linear models were fit in a stepwise progression for each parameter and predictor variable; the resulting models were evaluated in terms of root mean square error (RMSE) and adjusted r-squared; the purpose of this step is to identify potential relationships between the response and predictor variables in a simple modeling context.

3. A forward and backward step-wise linear regression using both the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) as the model metric was used as a data-mining step to identify potential model formulation.

4. The model identified in Step 3 was then used to estimate a power transformation for the response variable in order to maximize residual normality. A natural log transformation was applied to TSS values and a square root transformation was applied to SC values. The purpose of this step is to help meet key linear regression test assumptions.

5. The stepwise model with the power transformed response was then fit and checked against predictor variables that had been discarded during the stepwise evaluation. The resulting model was then evaluated for key linear model diagnostics, including: residual normality, residual independence, residual variance, linearity, outliers, and influential data points (**Figure E-2**). These steps were undertaken to make sure the application of the chosen model form was justified by the data and that no variables that might increase predictive power were ignored.

Figure E-2. Example diagnostic plot results for initial multiple linear regression models for SC (left) and TSS (right).



6. The model in Step 5 was then used as the starting point for a multilevel model formulation. Model fitting was based on overall fit, explanatory power, physical interpretation, statistical significance of predictor variables, and overall predictive performance.

The multilevel model formulation was then used to make predictions for all catchments without water quality parameter data in the watershed. Predictions were calculated as the mean values per catchment for both total suspended solids and specific conductance.

E.4 Results and Discussion

E.4.1 Total Suspended Solids

A range of predictor variables was useful in explaining observed variation in average catchment scale TSS in the Clinch and Powell River System (**Table E-6**). Model fit was evaluated using a range of approaches. A plot of observed versus fitted values shows the difference between the observed value and what the model predicts as the average value for the catchment; in a perfect model, all the points would fall along the red line (**Figure E-3**). The fitted versus observed plot for TSS shows a clear linear trend with fairly uniform scatter around the reference line.

RRMSE, which is the sample standard deviation of model error, is another common tool for evaluating model fit. The RMSE for the TSS model is 0.507645 on a natural log-scale. Note that RMSE is scale dependent and cannot be used to compare models of different parameters. Another goodness-of-fit (GOF) criteria for model evaluation is the numeric correlation between predicted and observed values. This value is 0.7381159 for the TSS model using the Pearson correlation method. A correlation of “1” corresponds to a perfect model.

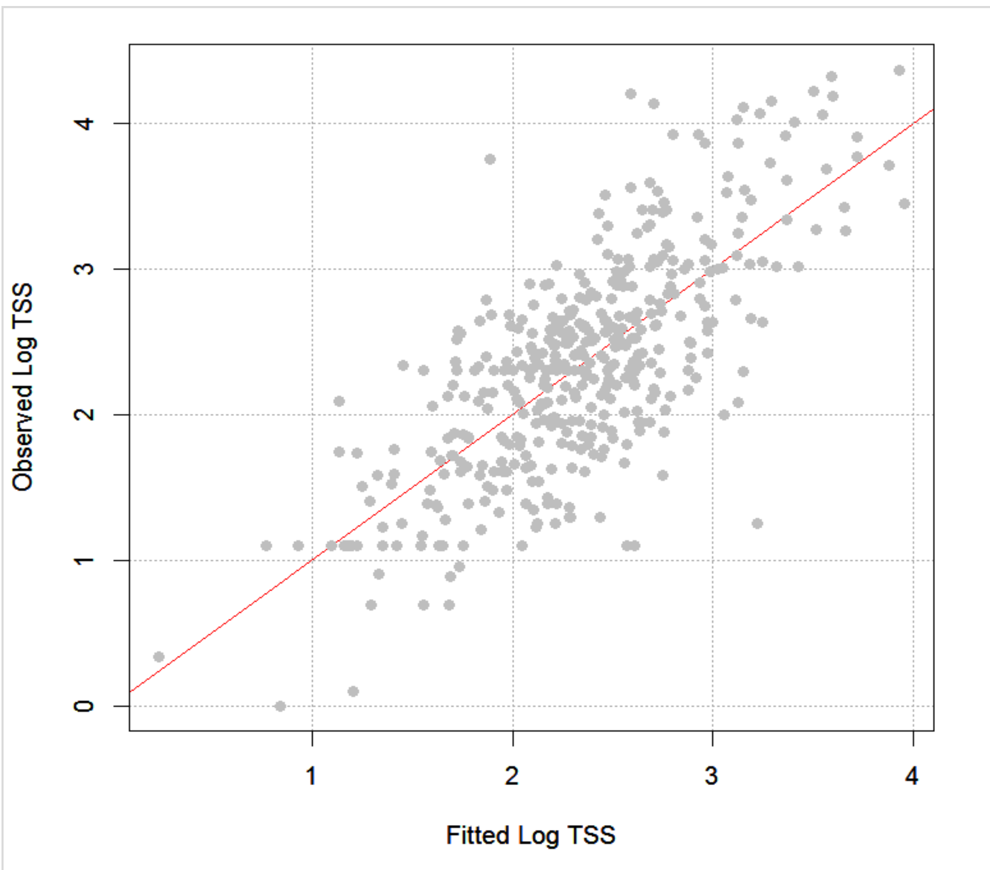
The model results are consistent with the expectation that developed, agricultural, and mining land uses are associated with higher average TSS. Natural and NLCD forested lands are negatively correlated with average TSS concentrations, especially at the watershed (cumulative drainage) scale.

Table E-6. Predictor variables used to model average TSS concentrations

Land Cover	NLCD 2011 (Low*/Medium*/High Developed*, Forest*, Crops*, Mining*), ARA NLCD 2011 (Mining*, Crops*), Cumulative NLCD (Mining*, Forest*, High Developed*), NLCD 2011 Canopy, Catchment Natural Lands*
Geology	Dominant Rock Type I , Dominant Rock Type II*
Channel/ Hydrology	Bankfull CSA*/Width*/Depth*/Discharge*, Sinuosity, Catchment Area*, Cumulative Drainage Area*, Slope*
Hydrologic	Average Flow as % Median*, Average 5-day as % Median*, Min. 7-day Annual*, Min. 90-day Annual*

* Indicates statistical significance at the standard 0.05 threshold.

Figure E-3. Predicted versus observed plot for TSS model. Note natural log scale. RMSE is 0.507 on a natural log scale. The Pearson correlation between fitted and observed values is 0.738.



Predicted average catchment TSS scores are shown in the **Figure A-13** in **Appendix A**. The predicted TSS values were rank normalized and displayed from low to high health levels (i.e., higher TSS values are lower aquatic health).

E.4.2 Specific Conductance

A range of predictor variables was useful in explaining observed variation in average catchment scale SC in the Clinch and Powell River System (**Table E-7**). Model fit was evaluated using a range of approaches. A plot of observed versus fitted values shows the difference between the observed value and what the model predicts as the average value for the catchment; in a perfect model, all the points would fall along the red line (**Figure E-4**). The fitted versus observed plot for SC shows a general linear trend with slightly increasing error as parameter values increase.

The RMSE for the SC model is 4.800915 on a square-root transformed scale. The numeric Pearson correlation between predicted and observed values is 0.7353454 for the SC model.

The SC model results indicate that mining land use in the cumulative drainage area is positively correlated with higher average SC parameter values. Agricultural land use, which is frequently found to be positively correlated with SC, was positively correlated in the model but did not achieve statistical significance and did not improve predictive performance when included. As with TSS, forested and natural lands at various spatial scales were negatively correlated with average catchment scale SC values.

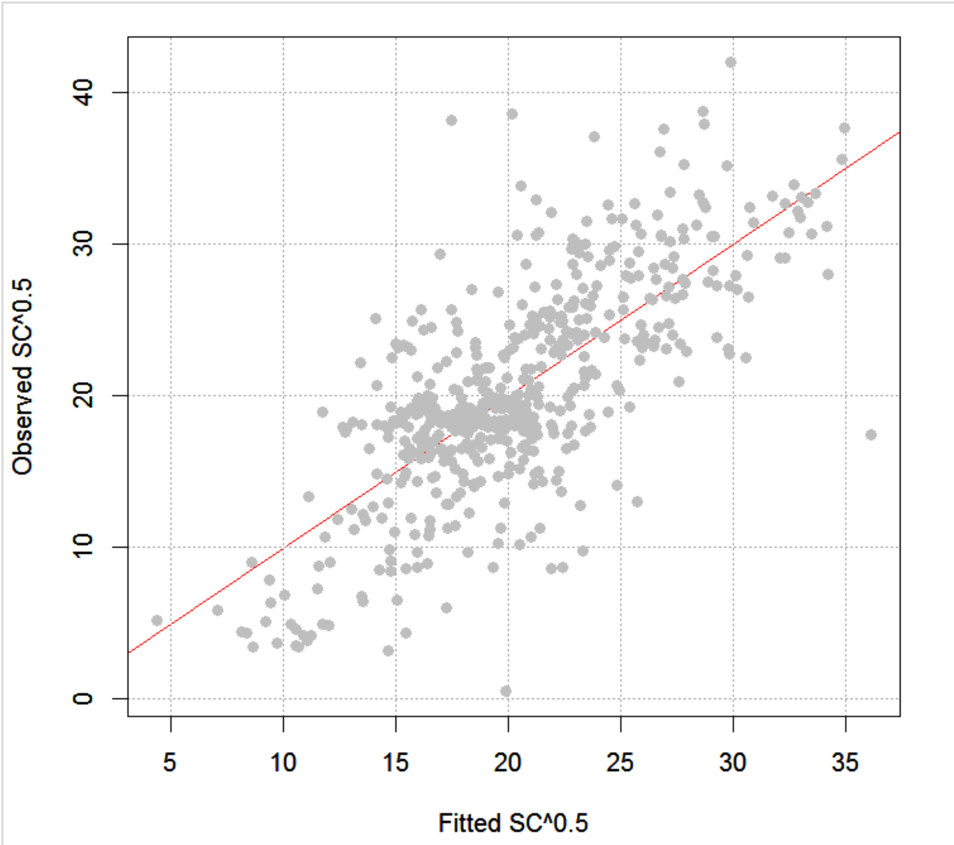
Predicted average catchment SC scores are shown in **Figure A-14** in **Appendix A**. In contrast to TSS, predicted SC values are displayed using a series of thresholds derived from peer-reviewed literature on SC in the Clinch and Powell River System as well as ecoregion-specific nutrient and salinity category criteria used in U.S. EPA's Wadeable Stream Assessment (Evans et al., 2014; EPA, 2007). These sources cite values of less than 200 µS/cm as indicative of reference conditions, with values in the 300–500 µS/cm range capable of producing negative biological impacts (Evans et al., 2014; EPA, 2007).

Table E-7. Predictor variables used in SC model

Land Cover	ARA NLCD 2011 (Mining), Cumulative NLCD (Mining*, Forest*), NLCD 2011 Canopy, Catchment Natural Lands*
Geology	Dominant Rock Type I*, Dominant Rock Type II*, Eco-Region
Channel/ Hydrology	Bankfull Width*/Depth*, Avg. Valley Width*
Hydrologic	Min. 30-day Annual*

* Indicates statistical significance at the standard 0.05 threshold.

Figure E-4. Predicted versus observed plot for SC model. Note square-root transformation. RMSE is 4.8 on square-root scale. The Pearson correlation between fitted and observed values is 0.735.



E.5 References

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Appendix F: Biological Condition

F.1 Introduction

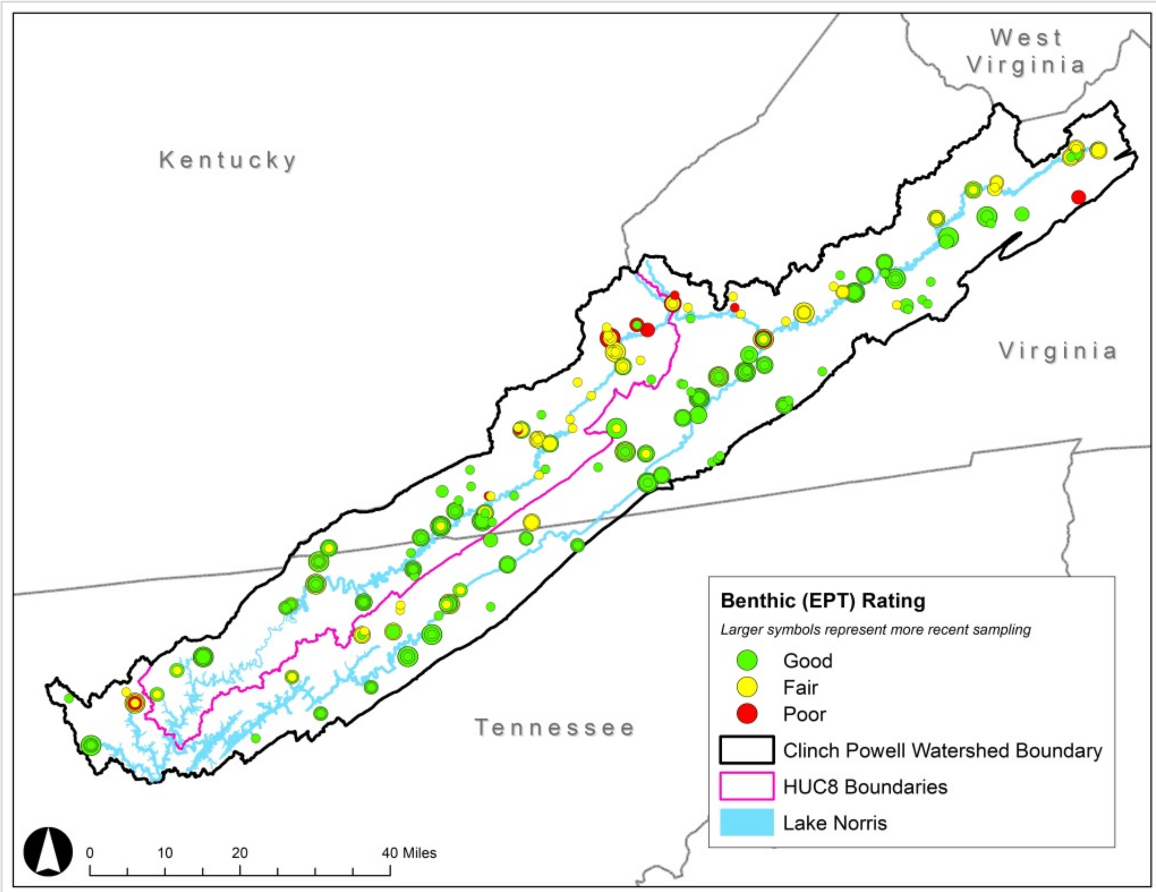
Landscape and other variables were used to predict biological condition of catchments within the Clinch and Powell River System. For this analysis, a multivariable model was used to attempt to assess the relationship between a number of predictor variables and the independent variable.

Separate models were developed for benthic macroinvertebrates and fish. In addition, an expert assessment of mussel condition in the Clinch River and its major tributaries was used as a third metric of Biological Condition in the catchments where this information was available. The results of these three metrics were combined into one Biological Condition Sub-Index.

F.2 Preparation of Response Data

Benthic macroinvertebrate data were obtained from the Tennessee Valley Authority (TVA) for 136 sites in the Clinch and Powell River System. Data were collected from 1994 to 2012. Using data that is several decades old is not ideal for assessing current conditions, but all data were included in the model to increase the size of the sample and improve predictions. The percentage of Ephemeroptera-Plecoptera-Trichoptera (EPT) taxa was reported at each site. EPT are generally the taxa most sensitive to disturbance in stream systems. Each sampling site was associated with an NHDPlus catchment for the purposes of linking the data to predictor variables (**Figure F-1**).

Figure F-1. Benthic macroinvertebrate sample locations in the Clinch and Powell River System.

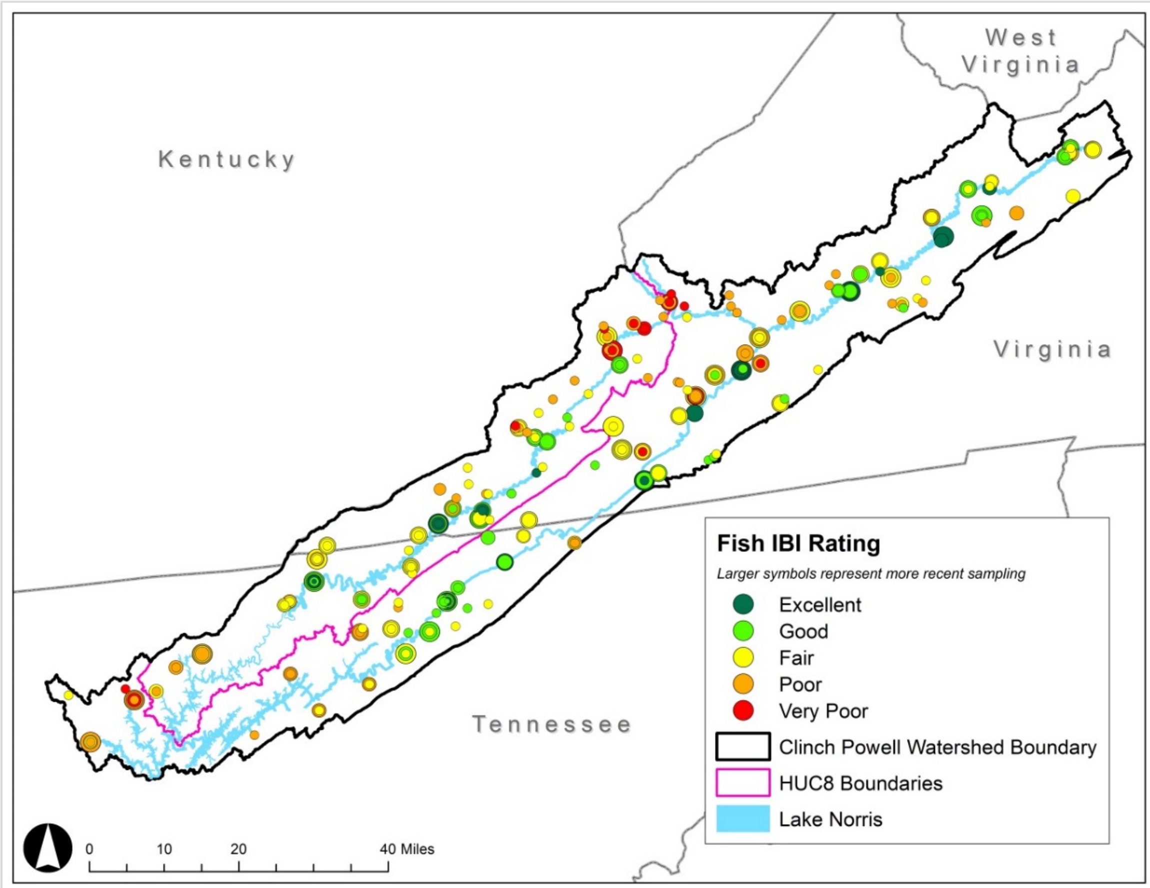


Fish data were also obtained from the TVA for 136 sites in the watershed. These data were also collected from 1994 to 2012. A fish Index of Biotic Integrity (IBI) was calculated for each site based on a modified EPA IBI (Saylor and Alstehdt, 1990). IBIs were scored on a 12 to 60 scale and were assigned narrative ratings as follows:

- Excellent: 58–60
- Good: 48–52
- Fair: 40–44
- Poor: 28–34
- Very Poor: 12–22

Each site was associated with a catchment for the purposes of linking the data to predictor variables (**Figure F-2**).

Figure F-2. Fish IBI sample locations in the Clinch and Powell River System.



The distribution of biological sampling sites by ecoregion (**Table F-1**) and size class (**Table F-2**) was evaluated to determine if separate models were feasible and appropriate for these different stream types.

Table F-1. Biological samples in the Clinch and Powell River System by Omernik Level 4 ecoregion.

Omernik Ecoregion	Benthic EPT	Fish IBI
Southern Limestone/Dolomite Valleys and Low Rolling Hills	84	84
Southern Shale Valleys	3	3
Southern Sandstone Ridges	7	7
Southern Dissected Ridges and Knobs	3	3
Dissected Appalachian Plateau	37	37
Cumberland Mountain Thrust Block	2	2

Table F-2. **Biological samples in the Clinch and Powell River System by stream size class.**

Cumulative Drainage Area (mi^2)	Benthic EPT	Fish IBI
< 50	104	104
<50–<100	6	6
<100–<500	20	20
≥ 500	6	6

F.3 Preparation of Predictor Data

Predictor variables were selected from a suite of landscape and other variables, similar to the water quality analysis (see **Appendix E**). Specifically, variables fell into four different categories:

- Landform: examples include Cumulative Drainage Area, Maximum Elevation, August Max Temperature, and January Mean Precipitation
- Geology: examples include Percent Clay, Percent Silt, and Percent Sand
- Channel Form: examples include Slope, Bankfull Discharge, Sinuosity, Mean Canopy Cover, and Mean Groundwater Discharge
- Land Cover: Percent Disturbed Area, Percent Forest, Percent Agriculture, Impervious Cover, Mined Lands, Percent Natural Lands, Percent Active River Area (ARA, and Road Length (all variables were examined at both the local and cumulative scales)

F.4 Model Development

The first step in model development was to examine the relationship between the response data (percent EPT taxa or fish IBI) with the predictor variables. Regression relationships were used to choose the most significant and intuitively meaningful variables for use in the model. **Figures F-3** and **F-4** show the strongest relationships for the percent EPT taxa metric and the fish IBI, respectively. The R^2 values are rather low; it is likely that the natural variability in biological data is more apparent in this study area, which has a smaller range of anthropogenic degradation than typically assessed with this method. The need to apply an indicator, such as EPT, that is not tied to a specific reference condition also creates more variation in the data.

Because of the small sample sizes, it was decided not to divide this analysis by either ecoregion or drainage area. For example, the relationship between bankfull discharge and fish IBI score was significant in the Ridge and Valley ecoregion (R^2 = 0.32; similar to the overall R^2 of 0.28) and was similar but not significant in the Appalachian Plateau as a result of a low number of samples.

Figure F-3. Regression relationships between select predictor variables and the percent EPT taxa in the Clinch and Powell River System.

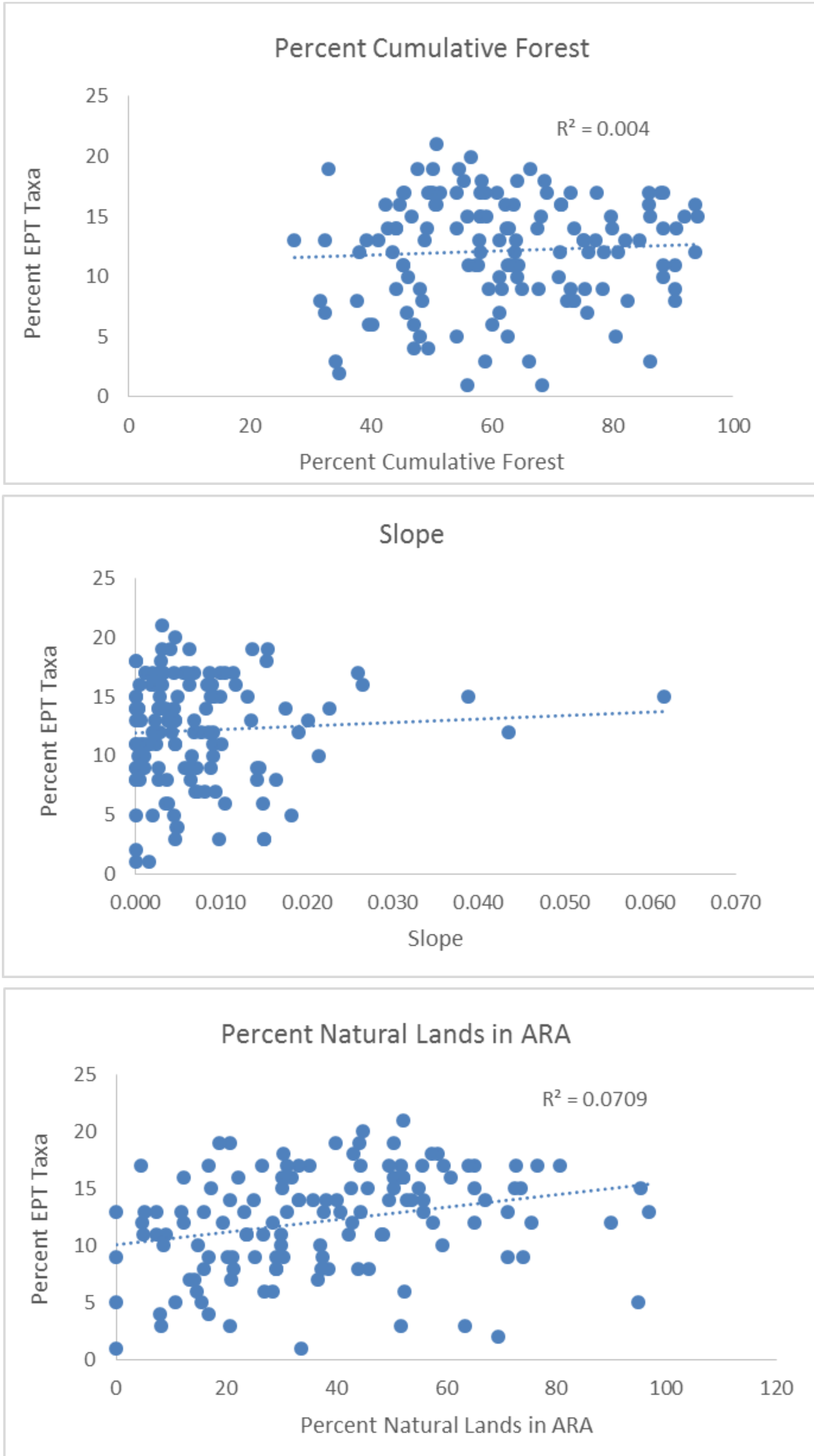
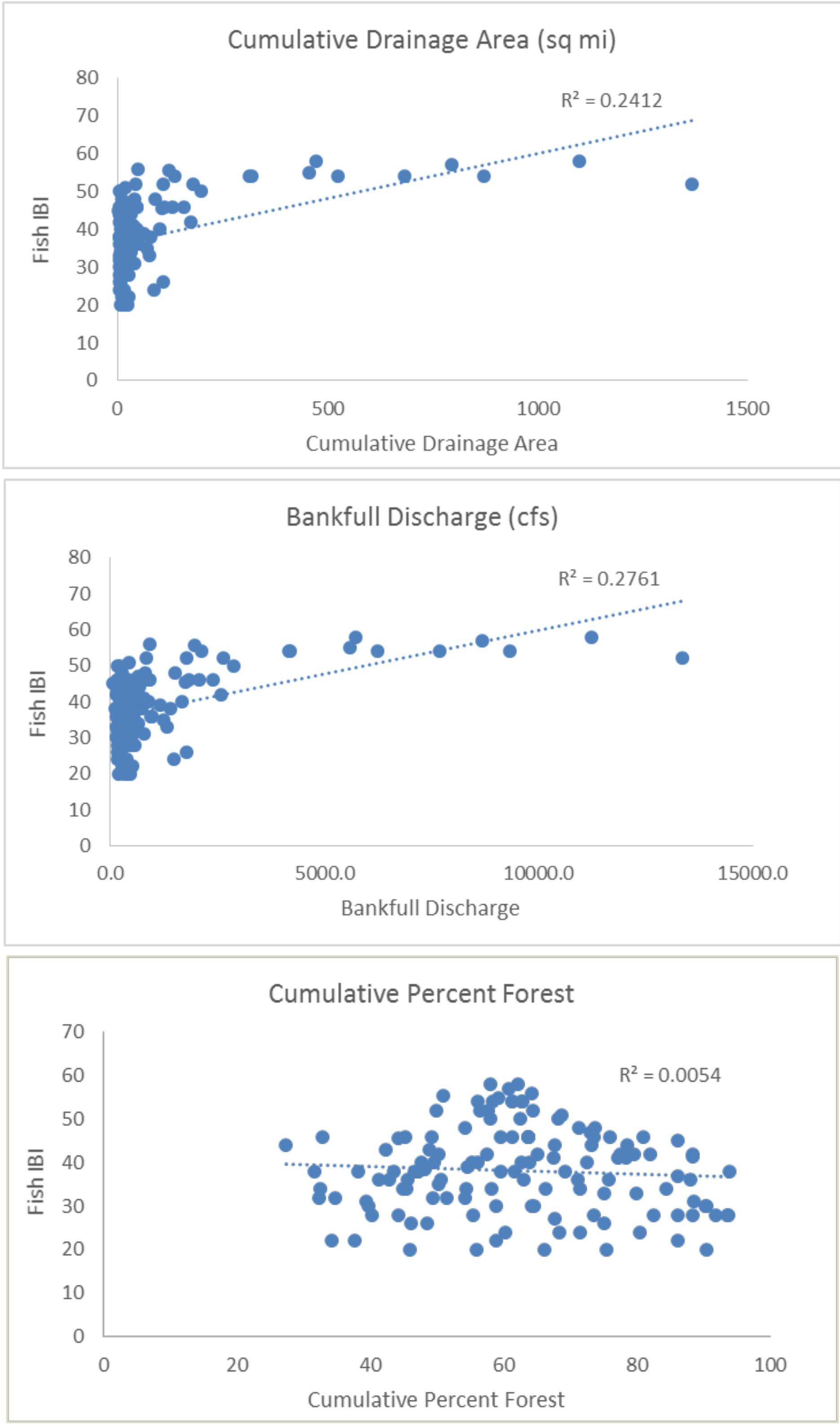


Figure F-4. Regression relationships between select predictor variables and the Fish IBI in the Clinch and Powell River System.



While many of the relationships to fish IBI scores were not significant, the strongest relationships were included in the final model. The most reliable variables for each metric were combined in a multivariable equation as follows (symbol following predictor variable indicates direction of the relationship with the response variable):

Benthic Macroinvertebrate EPT:

- Slope (+)
- Percent Cumulative Forest Area (+)
- Percent Natural Lands in ARA (+)

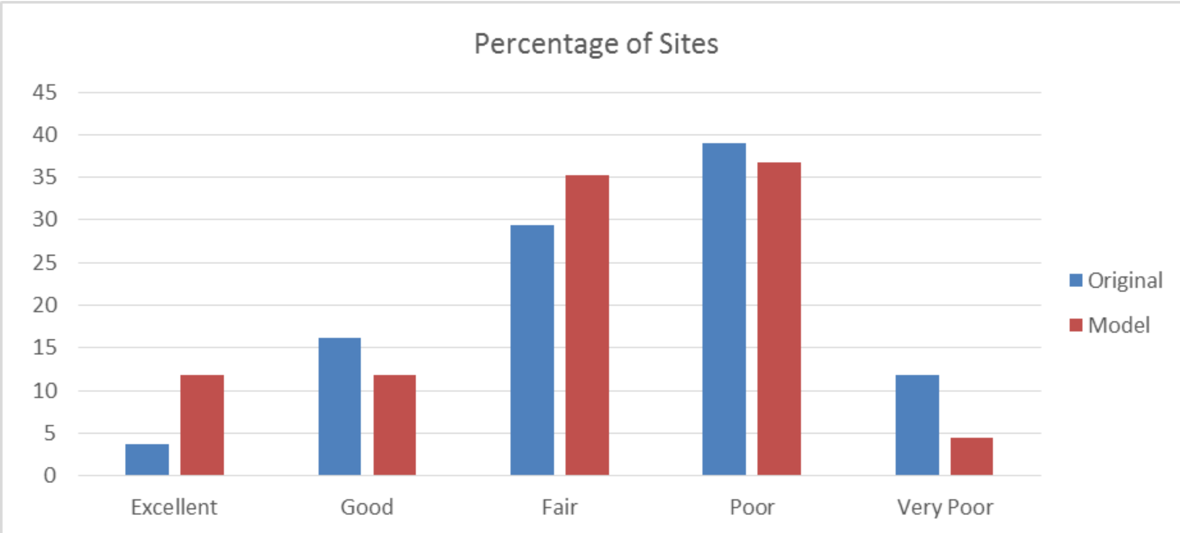
Fish IBI:

- Bankfull Discharge (+)
- Percent Cumulative Forest Area (+)
- Cumulative Drainage Area (mi^2) (−)

F.5 Model Evaluation

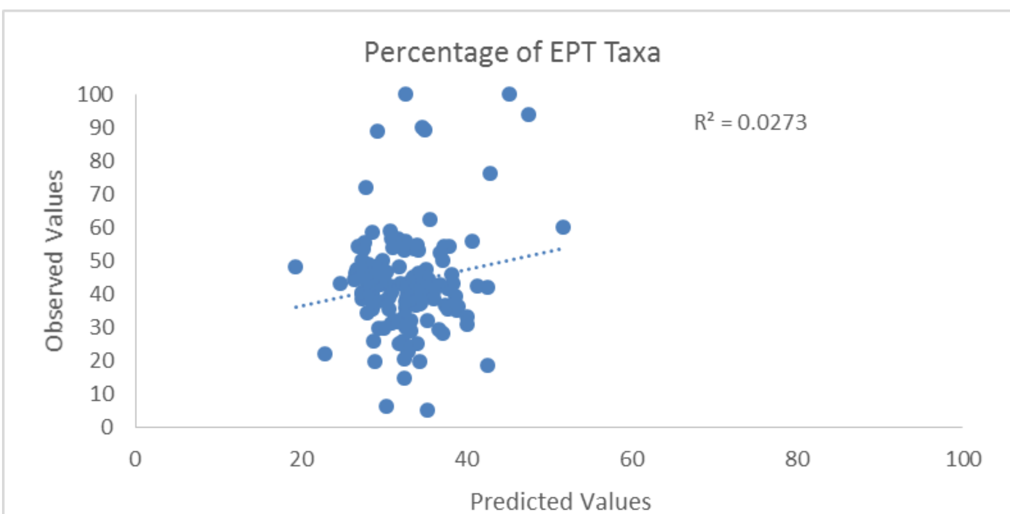
The Root Mean Squared Error (RMSE) of the fish IBI model is 7.74. This number is the standard deviation of the unexplained variance in the model and assumes that the predicted values differ by as much as 7.74 IBI units from the observed values. In most cases (85% of the time), this indicates that the actual IBI score may vary, but that the narrative rating will remain the same. The model predicting fish IBI was evaluated by calculating the predicted value for each of the 136 sites that had an observed value. Each site was then placed into the narrative rating category used by the TVA. Overall, many of the sites scored in similar categories (**Figure F-5**).

Figure F-5. Fish IBI narrative ratings for the observed (original) fish IBI values compared to the predicted fish IBI values for 136 sites sampled in the Clinch and Powell River System.



The RMSE for the percentage of EPT taxa was 14.07. Narrative ratings were not available for this metric, so a regression of the predicted values versus the observed values was generated (**Figure F-6**). In general, the predicted values were less than the observed values, especially as the observed values approached 100. The RMSE and model fit reflect the lack of predictor variables that predict the most degraded benthic macroinvertebrate conditions.

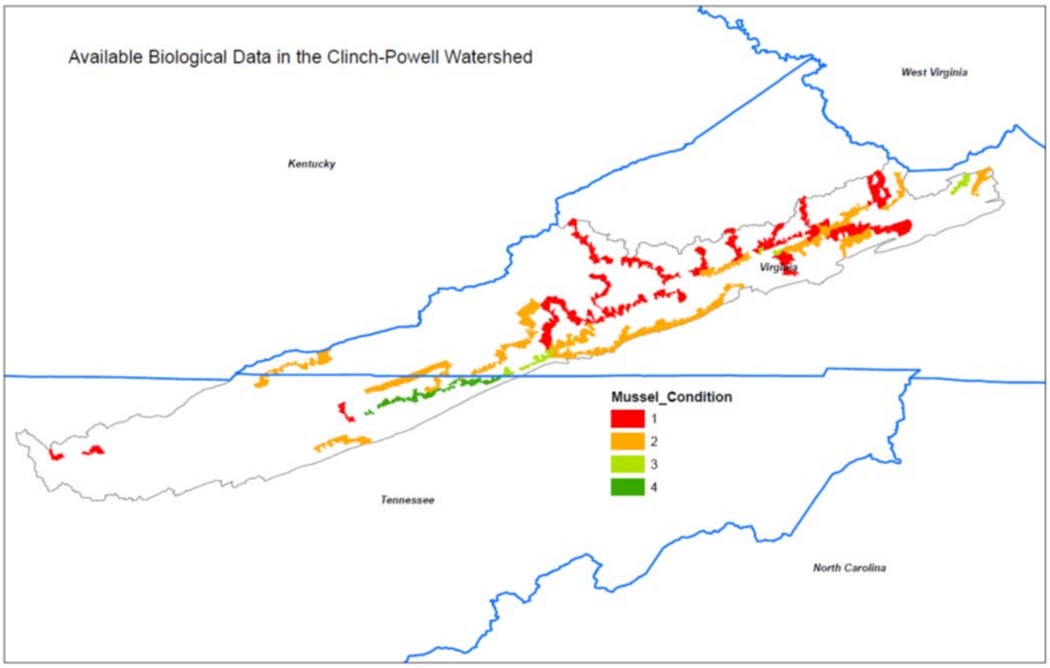
Figure F-6. Observed vs. predicted values for the percentage of EPT Taxa for 136 sites in the Clinch and Powell River System.



F.6 Mussel Condition

Mussel condition in the Clinch River and its major tributaries was rated on a 1 (poor condition) to 4 (high condition) scale by the best professional judgment of experts in the area based on local knowledge of areas that still contain mussels versus areas that should contain mussels but from which they are extirpated (Beatty, 2014; **Figure F-7**). The mussel data were used to characterize catchments in which the samples were collected. No attempt was made to predict or model mussel condition for streams where data were not collected.

Figure F-7. Mussel Condition class in the Clinch and Powell River System.



Mussel scores were provided for 407 catchments. For the purpose of calculating the Biological Condition Sub-Index, ranks based on the midpoint of the category based on a 100-point scale (**Table F-3**) were assigned to catchments with mussel data, which were then averaged with rankings for benthic macroinvertebrates and fish.

Table F-3. Ranking of Mussel Condition metric.

Mussel Condition Score	Ranking
4 (Very Good)	0.875
3 (Good)	0.675
2 (Fair)	0.375
1 (Poor)	0.125

F.7 Summary

Benthic macroinvertebrate, fish, and mussel condition scores were rank normalized and averaged for each catchment in the Clinch and Powell River System. The average score was then rank normalized to determine the Biological Condition Sub-Index. The resulting maps of the individual metrics, as well as the overall Biological Condition Sub-Index, are included in **Appendix A**. Overall Biological Condition ranked highest in the Powell watershed in the vicinity of Jonesville, VA, the upstream reaches of the Clinch River, and in the southernmost portion of the watershed in Tennessee near Norris Lake. "Low" Biological Condition was spread throughout the watershed, but seemed to be concentrated mainly in the upper reaches of the Powell River.

F.8 References

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Appendix G: Data Sources

This table summarizes data that were used in the Assessment.

Element	Name	Description	Source
Current Land Cover	National Land Cover Dataset (NLCD)	The NLCD has a 16-class land cover classification scheme that was applied consistently across the United States at a spatial resolution of 30 m (100 ft).	Jin et al., 2013
Riparian Zone	Active River Area (ARA)	The ARA framework is a spatially explicit view of rivers that includes both the channels and the riparian lands necessary to accommodate the physical and ecological processes associated with the river system.	Smith et al., 2008
Riparian Zone	Federal Emergency Management Agency (FEMA) Floodplain	The FEMA 100-year floodplain was used as a surrogate for the material contribution zone in the ARA.	FEMA
Geology	Generalized Geologic Map of the Continental United States	This dataset contains polygons representing the areal extent of major geologic units in the United States. The data depict the geology of the bedrock that lies at or near the land surface.	USGS, 2005
Hydrology	National Hydrography Dataset (NHDPlus) version 2	NHDPlus is a medium-resolution dataset of all stream reaches in the nation and their corresponding catchments. This information allows for rapid calculations of total upstream watershed characteristics (e.g., drainage area, stream length, land use) for any stream reach in the Clinch and Powell River System.	McKay et al., 2013
Climate Data	Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group	PRISM dataset provides gridded daily temperature and precipitation covering the continental United States from 1981 through 2012.	Daly et al., 2008
Mined Land Use	Surface Mine Permit Boundaries	Aerial extent of mining activities based on the permitted areas of disturbance.	VA DMME, 2014
Naturalized Land Use	Potential Natural Vegetation	Potential Natural Vegetation GIS layer based on work by Küchler (1964).	Küchler, 1964
Soils	Soil Survey Geographic (SSURGO) database	Field mapping methods using national standards are used to construct the soil maps in the Soil Survey Geographic (SSURGO) database. Mapping scales generally range from 1:12,000 to 1:63,360.	USDA-NRCS, 2014
Water Use Data	Catchment-level monthly average estimates of withdrawals from and discharges to the stream network	Virginia Department of Environmental Quality (DEQ) provided location-specific water use data (both withdrawals and discharges) for the Virginia portions of the watershed resulting in a total of 32 NHDPlus catchments subject to alteration.	Personal communication, Smith, Virginia DEQ

(continued)

Element	Name	Description	Source
Streamflow	National Water Information System (NWIS)	Daily streamflow data are downloaded for each gage of interest from NWIS. Gages are examined based on characteristics provided for each in the Geospatial Attributes of Gages for Evaluating Streamflow, version II (GAGES II) dataset and on the daily records.	Falcone et al., 2010
Physical, Chemical, and Biological Data	EPA's Storage and Retrieval (STORET) and USGS's National Water Information System (NWIS)	National database that includes data from EPA, National Park Service, Tennessee Department of Environmental Control, U.S. Geological Survey, and Virginia Department of Environmental Quality.	National Water Quality Monitoring Council, 2014
Water Quality Data	Virginia Department of Environmental Quality	Additional water quality data not available through the Water Quality Portal.	Unpublished data.
Water Quality Data	Virginia Department of Mining, Mineral, and Energy	Additional water quality data not available through the Water Quality Portal.	Unpublished data.
Macroinvertebrate, Fish, and Mussel Population Data	Tennessee Valley Authority (TVA)	Data from TVA provides complete coverage across the project area using consistent methods.	Unpublished data.

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