An Assessment of Natural Assets in the Appalachian Region: Water Resources

Prepared for:

Appalachian Regional Commission
1666 Connecticut Avenue, NW
Suite 700
Washington, DC 20009-1068

September 30, 2014
Contract #CO-16812-2010

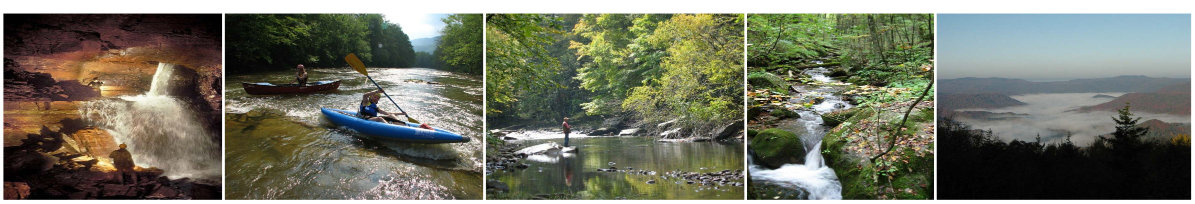
APPALACHIAN REGIONAL COMMISSION

Prepared by:

Downstream Strategies
Fritz Boettner (Project Manager), Evan Hansen, Jason Clingerman, Anne Hereford, Sera Zegre, Roy Martin, and Nate Askins

West Virginia University
Jinyang Deng (Principal Investigator), contributors: James Anderson, Alan Collins, Trevor Harris, Randall Jackson, Frank LaFone, Samuel Lamont, Jacquelyn Strager, Michael Strager, Walter Veselka, and Nicolas Zegre

The Northeast Regional Center for Rural Development
Charles Abdalla and Stephan J. Goetz



West Virginia University | Downstream Strategies | NE RCRD

Table of Contents

Table of Figures

Table of Tables

Abbreviations

AMD	acid mine drainage
ARC	Appalachian Regional Commission
cfu	colony-forming unit
CP	compromise programming
CV	cross-validation
DARE	Driftless Area Restoration Effort
DST	decision support tool
FFFHP	Fishers and Farmers Fish Habitat Partnership
GIS	geographic information system
GWh	gigawatt hour
MCA	multiple criteria analysis
mgd	million gallons per day
mg/L	milligrams per liter
MGLP	Midwest Glacial Lakes Partnership
mL	milliliter
NCDC	National Climatic Data Center
NERCRD	Northeast Regional Center for Rural Development
NFIP	National Flood Insurance Program
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWS	National Weather Service
ORBFHP	Ohio River Basin Fish Habitat Partnership
SARP	Southeast Aquatic Resource Partnership
TRI	Toxics Release Inventory
µS/cm	microsiemens per centimeter
US	United States
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WTP	willingness-to-pay
WVU	West Virginia University

ACKNOWLEDGEMENTS

West Virginia University Regional Research Institute—Randall Jackson

Downstream Strategies—Fritz Boettner (Project Manager), Evan Hansen, Anne Hereford, Sera Zegre, Roy Martin, Nate Askins

West Virginia University Davis College of Agriculture, Natural Resources and Design—Jinyang Deng (Principal Investigator), Alan Collins, James Anderson, Samuel Lamont, Jacquelyn Strager, Michael Strager, Walter Veselka, Nicolas Zegre

West Virginia University Department of Geology and Geography—Trevor Harris, Frank LaFone

The Northeast Regional Center for Rural Development, Pennsylvania State University—Charles Abdalla, Stephan J. Goetz

This project was made possible with funding from the Appalachian Regional Commission. We acknowledge Dr. David Carrier, former senior economist with the ARC, for initiating this project and providing technical guidance, overall project direction, and oversight. Thanks also go to John Cartwright, former director of ARC Regional Planning and Research, and Julie Marshall, ARC economist.

Thanks also go to several research assistants, including: Rogelio T. Andrada II (Ph.D. student, West Virginia University) for data collection and index development related to recreational water access; David Fleming (Ph.D. candidate, The Pennsylvania State University) for his assistance in water value estimation; Arun KC (Ph.D. graduate research assistant, West Virginia University); and Jason Kikel (undergraduate student, West Virginia University).

Many people provided information, comments, and support for this project. American Whitewater—including Mark Singleton (Executive Director), Kevin Colburn (National Stewardship Director), and Ryan Groth—provided whitewater recreation data from the American Whitewater National River Database to help identify the recreational value of waters in Appalachia. The National Park Service—including Sheila L. Lee—provided river data from the National River Inventory that the agency houses.

We would like to thank all the organizations and agencies for submitting water quality data through the United States Environmental Protection Agency STORET database. We offer special thanks to the United States Environmental Protection Agency, Virginia Department of Environmental Quality, Alabama Water Watch, Alliance for Aquatic Resources Monitoring, and Ohio Environmental Protection Agency.

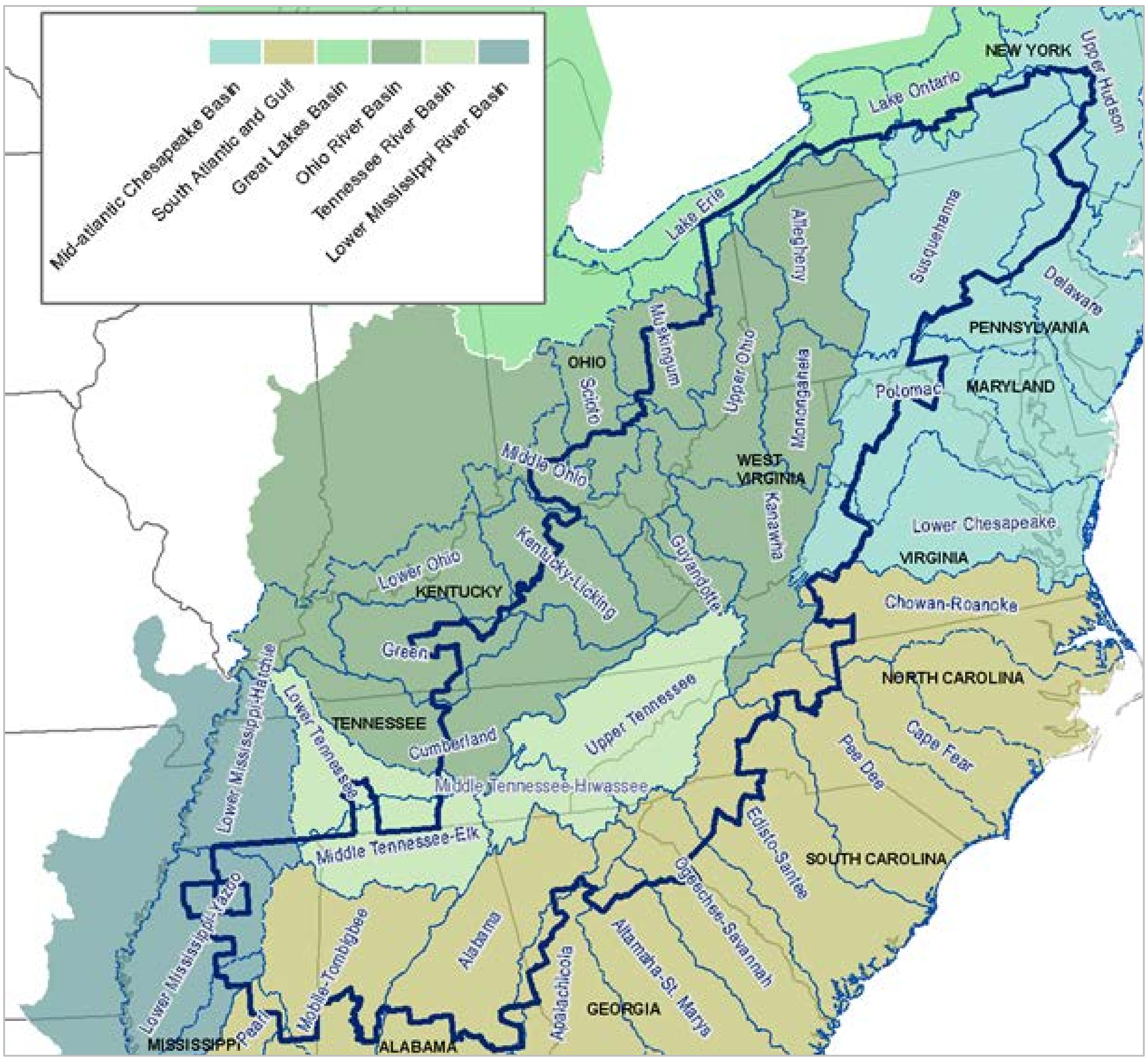
We also thank Pamela Hileman (Northeast Regional Center for Rural Development, Pennsylvania State University), who provided assistance with the stakeholder outreach portions of this project.

Finally, we thank each of the stakeholders who participated in the survey and took the time to provide feedback on this project. We specifically thank Tom Basden (Extension Specialist, Nutrient Management, West Virginia University); Scott Clay (Planner, Mineral County West Virginia); Sam Dennis (Research Associate Professor, Soil and Water Quality, Tennessee State University); Nathaniel Gillespie (Fisheries Scientist and Director of Eastern Lands Protection Project, Trout Unlimited); Dawn R. Hintz (Water Quality Program Specialist, Susquehanna River Basin Commission); Greg Jennings (Professor of Biological and Agricultural Engineering, North Carolina State University); Doug Parker (Mid-Atlantic Water Program, University of Maryland); Colleen Peterson (Executive Director, Greater Cumberland Committee, Cumberland, Maryland); Herbert M. Sachs (Special Projects Coordinator, Maryland Department of the Environment); Earl Smith (Chief, Water Management Division, Interstate Council on Water Policy); Tom Suro (Hydrologist and Engineer, United States Geological Survey); Gary Springston (Water Supply Program Manager, Tennessee Valley Authority); and David Umling (City Planner, City of Cumberland, Maryland).

EXECUTIVE SUMMARY AND KEY FINDINGS

The Appalachian Regional Commission is dedicated to enhancing and promoting the economic viability of Appalachia, a region whose land is 42 percent rural and whose population is 18 percent below the poverty level (Appalachian Regional Commission, 2009a). In 1965, more than 223 counties were rated distressed; today that number is 98, indicating a trend towards recovery (Appalachian Regional Commission, 2009a; 2011). Typically, economies in rural Appalachia have used natural resources for extractive purposes; resources (coal, timber, natural gas, minerals) are harvested and usually shipped out of the region. Water, in contrast, is an "in-place" resource that provides economic, environmental, recreational, health, and cultural benefits. This study quantifies Appalachia's water assets, both in terms of economic development and quality of life.

Figure 1: River basins in the Appalachian region



Water is the lifeblood of all living things, and its quality and availability significantly impact the health of populations, ecosystems, and economies. In Appalachia, water is supplied to many cities and rural communities through six major water basins (Figure 1), which contain thousands of miles of headwater streams. These areas depend upon the wise use, control, and development of water, making it critical to characterize regional water resources in terms of quantity, quality, and value.

While there are many types of water datasets across the United States, it is rare that the information contained within these datasets is homogeneous between regions or states. Datasets of impaired streams have been developed for all states, for example, but each state classifies the data according to its state-specific water quality criteria. Additionally, water resources do not follow political boundaries, nor do they adhere to uniform geographical units. The research team characterized water quality, quantity, and value for the Appalachian region using data and information collected from a variety of sources. Based on available datasets, we synthesized and performed analyses on several key datasets to understand the representative characteristics of Appalachia's water resources. Each summary and analysis in this study lists the specific datasets utilized, the rationale for the methods, and the overall results.

This report examines datasets that vary spatially, temporally, and in their intended application. Among other applications, the data and findings in this report can be used as a blueprint to understand water resources and their relationship to the economy.

This study maps water asset metrics and values at the county level for each category of water resources. A geographic information system decision support tool was created to guide the user in assessing water resource conditions. This study and report were developed to enable practitioners across the Appalachian Regional Commission region to better understand their water resources so that they can develop and implement plans that will support a sustainable future.

Table 1: Water assessment components

Quantity	Quality	Value
Water withdrawal and consumption	pH	**Market value**
Surface water withdrawal	Fecal coliform	Agricultural and irrigation consumption
Groundwater withdrawal	Dissolved oxygen	Industrial consumption
Total consumption	Specific conductivity	Domestic consumption
		Thermoelectric consumption
Water sustainability		
Projected water withdrawal change		**Non-market value**
Projected water sustainability risk with climate change		Willingness-to-pay
		Meta-analysis coefficients
Floods		
Surface water quantity		
Mean annual maximum flow		
Percent of headwater streams		

As shown in Table 1, this study assesses and characterizes the water quantity, quality, and value for each county in the ARC region. The water quantity assessment examines, among other things, the quantity of water withdrawn and consumed and each county's propensity to flood. Water quality was assessed by developing a statistical model that predicts several representative water quality parameters for every small watershed in the region. The water value in each county is an economic representation of the market and non-market values of water.

Key findings

The following key findings are organized by asset category.

Water quantity

Human demand for freshwater has tripled since 1950 due to population growth, irrigation, and increased material consumption (Postel and Carpenter, 1997). The region has abundant water resources, providing water for commercial, domestic, and other uses.

- Water quantity in the ARC region was evaluated using five indicators: **water withdrawal and consumption, water sustainability, floods, and surface water quantity**.
- By far, thermoelectric plants withdraw the largest amount of surface water to generate electricity, withdrawing over 29,000 million gallons per day, or 60 percent of the total water withdrawn in the region. However, 98 percent of thermoelectric withdrawals are returned back to surface waters.
- Groundwater withdrawals represent only 4 percent of the total water withdrawals in the region, with a large portion dedicated to drinking water for public or private water supply.
- The ARC region is expected to increase water withdrawals by 92% by 2050, with 48 counties—considering climate change—projected to have a high risk to the sustainability of county water supplies by 2050.
- Since 1978, more than 8 billion dollars was paid in total loss payments due to flooding in Appalachian counties, with nearly 8,000 floods reported from 2000-2010.
- The ARC region is a headwater region, with 65 percent of its streams classified as headwater streams.

Water quality

Water is a key component to sustaining life and is vital to a healthy economy. The Clean Water Act, enacted in 1972, set a goal "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[1] Determining water quality is a complicated process, but the Clean Water Act established water quality standards to identify pristine and polluted waterways.

- For this study, water quality was evaluated by developing peer-reviewed statistical models that predict water quality for every stream segment in the ARC region, using four commonly measured water quality parameters: **pH, fecal coliform, dissolved oxygen, and specific conductivity.**
- Water sampling data were compiled from federal water quality databases and other state and local data providers, which included over 11,000 sample locations with approximately 700,000 records.
- High predicted pH levels occur where the geology is dominated by limestone, and low predicted pH levels occur in forested areas, consistent with acid rain deposition and the low buffering capacities. Areas with low predicted pH levels are also found in pockets of Pennsylvania and West Virginia; these areas are typically associated with active and historic mining of high-sulfur coal, which can be expected to contribute acidity and lower pH. Different levels of pH can have synergistic effects on water quality and could impact aquatic life.
- Large areas of low predicted fecal coliform concentrations correspond with high forest cover and low population, such as National Forests. Higher fecal coliform levels are predicted in areas that are generally urbanized. However, several rural areas see high predicted fecal coliform concentrations, which could be consistent with high incidences of untreated sewage discharges, failing septic

[1] 33 U.S.C. 26 § 1251(a)

systems, or agricultural runoff. Fecal coliform contamination can pose a potential health risk for individuals exposed to polluted water.

- Dissolved oxygen is necessary for sustaining aquatic life. Most of the region shows high predicted dissolved oxygen, particularly in higher elevation and forested areas. Some low dissolved oxygen predictions are found in areas with low slope and warm climates or are due to organic enrichment. Low dissolved oxygen levels in water can stress aquatic life and can result in fish kills.
- Large areas of low predicted conductivity can be observed in areas of high forest cover. High predicted conductivity is found in areas associated with active and historic coal mining. Conductivity is a measurement of a water's ability to carry an electrical current; this parameter is used as a water quality indicator.
- Throughout the region, mountainous and forested counties, and those far from large cities and large rivers, tend to have the best water quality. Counties that exhibit poorer water quality are generally those in mining, agricultural, or urbanized areas.

Water value

Water resources can have both a market and a non-market value. A market value can be placed on the use of water to produce a commodity, such as an industrial process. Non-market values are associated with the value society places on having clean water to drink, recreate in, or fish in.

Market value

An in-depth literature review identified estimates of water value per amount of water consumed. Agriculture is valued 40 dollars per acre-foot, water supply is valued at 100 dollars per acre-foot, industrial uses are valued at 150 dollars per acre-foot, and thermoelectric is valued at 20 dollars per acre-foot.

- The total water market value for the region is estimated at over 1.6 billion dollars per year, with thermoelectric value exceeding 650 million dollars, closely followed by industrial and water supply. Agricultural use was valued significantly less, at over 6.1 million dollars per year.
- Sullivan County, Tennessee has an industrial market value estimated at over 85 million dollars per year. Consumption in this county totaled over 500 mgd—nearly 72 percent of Appalachian-Tennessee's total industrial withdrawal. This consumption is due in part to a large manufacturing base, which employs over a half-million people with an annual payroll exceeding twelve million dollars.
- Typically, water supply value patterns follow population; however, Delaware County, New York is an exception because it provides over 448 million gallons per day to New York City—a value of over 1 billion dollars per year.
- Thermoelectric power generation has the highest water value in the ARC region, with an average county value of over 1.5 million dollars per year.

Non-market value

Water resources have tremendous value that is not reflected in the use of water to produce a commodity. These non-market values, such as recreational, aesthetic, and cultural values, are evaluated in the non-market value category.

- A meta-analysis—using 49 contingent valuation studies— was performed to determine and place a value on people's perceptions of what clean water is worth to them. A benefit transfer method was applied to estimate a county's mean willingness-to-pay per household for existing surface water quality.
- Across the 420 counties of the Appalachian region, the projected annual mean willingness-to-pay for surface water quality averaged about $8.50 per household.

- The value per household is higher in rural areas, but the number of households has significant influence in the final surface water value.
- Counties in the highest 10 percent for water use valuation were concentrated along major rivers.

1. INTRODUCTION

1.1 About this study and report

This study and report were initiated as part of the long-term research objective developed by the Appalachian Regional Commission (ARC) to understand Appalachia's natural assets. The primary goal is to provide information that will encourage the development and sustainable management of natural assets across the Appalachian region, which requires developing and updating an inventory of natural assets, analyzing their value and usage, assessing their potential contribution to economic development of the region, and creating a framework to assist with planning their best use.

The project team was comprised of several organizations representing the Appalachian region. West Virginia is the only state that is entirely within the ARC service area; hence, the large research team from West Virginia University (WVU). In addition to WVU staff and professors, Downstream Strategies—an environmental consulting company from Morgantown, West Virginia—and Pennsylvania State University's Northeast Regional Center for Rural Development (NERCRD) participated as major contributors to the research. Many experts in water resources and economics were involved throughout this project, providing a well-rounded and representative team.

Merging science and policy can be a tremendous challenge. This study strives to summarize water resource data in a way that is understandable and relevant to policymakers. To enhance the study and its utility, a geodatabase—geographic information system (GIS) data—was created that contains all of the underlying layers and analysis results. These data can be used as a supplement to other research or in customized analysis or mapping projects. In addition to the geodatabase, a GIS decision support tool (DST) was created. The DST is a customized ArcMap GIS software tool that analyzes spatial patterns and creates an environment where users can weigh various decisions that could support or inhibit economic development. The functionality of this tool and technical details are presented in Appendix A. Throughout the report, case studies or scenarios highlight the DST.

"[The present and future economic value of water resources is] perhaps the most important consideration in development of water projects (drinking water, industrial and agricultural, etc.)."

Earl Smith, Chief, Water Management Division, Interstate Council on Water Policy

"There is a need for more quantitative information on the economic value of water for different beneficial uses, [as well as] improved GIS capabilities to access water resource data…and associated analytical tools to summarize and document data."

ARC Water Asset stakeholder

"The organization I represent established an interest in understanding our regional water resources several years ago. To date, we have coordinated a working group of water resource–knowledgeable individuals and have established a working relationship with State offices in Maryland and West Virginia as well as major universities in the area to create a knowledge-based group. Involvement by your firm would enhance our ability to understand our water resources."

Colleen Peterson, Executive Director, Greater Cumberland Committee

1.2 Implications for policy and research

This study attempts to understand water assets in the Appalachian region in order to facilitate water management and planning strategies. This report is not an all-encompassing analysis, but it does contribute toward an ongoing conversation about water resource management. Because of the ever-expanding pressure on water resources, steps should be taken to understand both the positive and negative human influences on these resources. There are many positive relationships between water resources and economic development, including non-economic or quality-of-life benefits.

Appalachia's economy is based on its natural and human resources. Some of its natural resources—for example, its timber, coal, and natural gas—are commodities sold in international markets. Its water resources, in contrast, flow freely and play a more subtle role in Appalachia's economic development.

Understanding the relationship between the region's water resources and its economic development is an important factor to consider. Local leaders and state governments are frequently faced with difficult questions related to clean water standards, water withdrawals, water-intensive industries, and flood control; by clarifying the contribution to health and well-being that clean and plentiful water provides, local and state policymakers can make informed decisions.

It is also important that private sector leaders are fully aware of the impact that Appalachia's water resources can have on their decisions. When deciding where to site new businesses, for example, leaders might consider whether enough water is available to support critical industrial processes for water-intensive industries. Leaders might also consider the proximity of an office to accessible lakes, trout streams, and other recreational assets, which can provide a better quality of life to employees.

This report and its associated data can be used by local and state leaders to develop new policies related to water quality and quantity. It can also be used by economic development officials to attract new businesses, and it can be used by the private sector in business siting decisions.

1.3 How to use the report and data

This report describes the methods and data used to assess the ARC region's water resources. Throughout the document, boxes called "Putting the tool to work" are designed to help the reader identify relevant opportunities, challenges, and actions illuminated by the assessments.

Some of the data are combined or calculated in ways chosen by the research team. However, individuals, agencies, and organizations may want to examine the data without the prescribed calculations. The DST allows users with access to ArcMap GIS software to apply their own priorities or criteria to the water asset data, thus reexamining the counties according to locally important factors.

Putting the tool to work report examples:

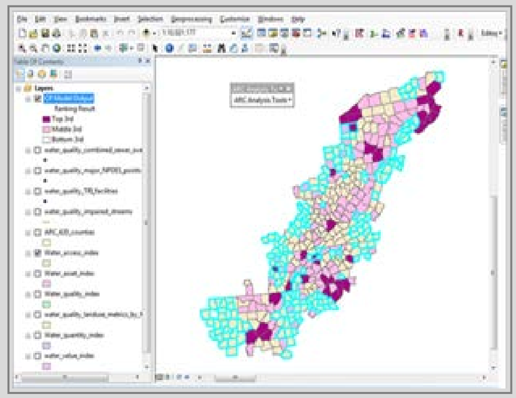
Throughout the document, boxes called "Putting the tool to work" are designed to help the reader identify relevant opportunities, challenges, and actions illuminated by the indices.

Design your own maps using water and economic data

Project GIS datasets can be downloaded from the Downstream Strategies website and used to make maps; examine results; navigate metrics, indicators, and indices; or create additional analyses.

To download data, documentation, or the GIS-based DST, contact the Appalachian Regional Commission.

Create your own scenarios using the GIS decision support tool



This project provides an interactive, GIS-based DST that allows users to prioritize areas for economic development opportunities. The DST integrates spatial data, user input, and a ranking algorithm.

1.4 Data caveats

This study and report were developed to enable practitioners across the region to understand their water resources and to better plan for the future. It examines many different datasets that vary spatially, temporally, and in their intended application. Despite the inherent difficulties in bringing together such a diverse set of data, this study is a comprehensive attempt that catalogs and summarizes water resource data across Appalachia.

1.5 Background

The Appalachian region consists of approximately 205,000 square miles (131 million acres), covering 420 counties in 13 states. It extends more than 1,000 miles, from southwestern New York to northeastern Mississippi, and is home to 24.8 million people (ARC, 2009a).

Many cities and rural communities within and around the region are dependent upon the wise use, control, and development of Appalachian water. This dependence on water resources for economic growth has become increasingly evident in recent decades. Human demand for fresh water has tripled since 1950 because of population growth, irrigation, and increasing material consumption (Postel and Carpenter, 1997). A downsizing of critical Appalachian industries has led to a decline in traditional agricultural, forestry, and mining jobs in many rural areas, leading to a large population migration to urban areas over the past 50 years. According to Freudenberg (1992), employment in traditional farming has dropped about 70 percent from the early 1900s, and employment in other natural resource–dependent industries, such as mining and forestry, has been cut in half.

However, these macro-level economic and social trends are not uniform across all rural areas; the major factors affecting migration patterns across the rural landscape have changed substantially over the last few decades (Nord and Cromartie, 1997). Areas rich in natural assets are more likely to experience substantial population growth than are areas with fewer natural assets. For instance, Johnson and Beale (2002), in a national study of rural counties, report a significant population rebound during the 1990s, with "recreation counties"—those with high tourism receipts and business activity—leading the way with a 20.2 percent population increase compared to a 10.4 percent increase for all rural counties. The economic and population growth patterns in Appalachia also reflect this reality (ARC, 2009a).

Natural assets are not only linked to population growth, but also to economic restructuring and economic well-being (Johnson and Beale, 2002; Shumway and Otterstrom, 2001). For example, Shumway and Otterstrom (2001) report that counties rich in natural amenities experienced dramatic increases in employment in service sectors such as health care, personal services, recreation and entertainment, and professional services.

Water is a necessity for life. The quality of life—human, plant, and animal—is highly dependent upon the quality and quantity of water resources. Water resources have multiple uses with economic, environmental, social, aesthetic, and cultural values. The United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil in 1992, states:

"Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource, and a social and economic good…"

The International Conference on Water and Environment, held in Dublin, Ireland in 1992 concurs:

"Water has an economic value in all its competing uses and should be recognized as an economic good."

Local or regional economic growth depends upon many factors—natural, social, economic, and political. Each factor's contribution to economic growth may vary by county or region in terms of significance and magnitude, challenging researchers to determine the relative importance of each factor at the county or regional level. Water resources have multiple uses, ranging from commodity-type use in the agricultural, industrial, and residential sectors to social and environmental values, including biodiversity, aesthetics, and recreation (Young, 2005). These types of water use and corresponding values may have changed over time across counties in the region. While recognizing the positive contribution of water resources to economic growth, water may also be a threat to the quality of life and community development in the cases of widespread pollution or flooding.

1.6 Literature review

This study's methodologies, framework, data, and approach were chosen based on a literature review. This section highlights regional studies on water as well as methods used in the literature for index development.

The economic contribution of water has been recognized and estimated in many forms, including withdrawals (domestic, irrigation, industrial processing, and thermoelectric power generation) and in-stream use (hydropower, recreation, fish and wildlife habitat, navigation, and waste disposal). Ward and Michelsen (2002), in estimating the values of different uses in the United States (US), found that the national average of water values per acre-foot were 3 dollars for waste disposal, 48 dollars for recreation/fish and wildlife habitat, 146 dollars for navigation, 25 dollars for hydropower, 75 dollars for irrigation, 282 dollars for industrial processing, 34 dollars for thermoelectric power, and 194 dollars for domestic.

Water-related economic activities play an essential role in promoting economic development and growth locally and regionally. For example, in the Texas Gulf Coast Region, the total economic impact (1993-1995 annual average) for commercial fishing activities was estimated at 265.5 million dollars in economic output, 80.3 million dollars in personal income, and 5,558 in job creation (Robinson et al., 1996). In West Virginia, the economic impact of whitewater rafting activities is significant. Based on data collected in 1995 from commercial boaters on the Cheat, New, and Gauley Rivers, total direct expenditures associated with rafting these rivers were approximately 49.4 million dollars, with nearly 43 million dollars within West Virginia (Whisman et al., 1996).

Because of its importance, water has been extensively studied in the literature. An exhaustive literature review is beyond the scope of this study; however, selected studies on natural assets, including water, as specified in the Request for Proposal for this project, are reviewed. In addition, studies on water quality, quantity, and value are reviewed in the corresponding sections.

1.6.1 *United States Army Corps of Engineers (1969)*

One of the most comprehensive studies on water in the Appalachian region was conducted by the US Army Corps of Engineers (1969). This study divides Appalachia into four sub-regions: highlands, northern, central, and southern. It then examines the physical and developmental background, natural and human resources, economic situation, and overall needs related to social development, transportation, education, health, physical environment, and water resources. In addition, development plans for each sub-region were prepared for flood control and prevention, water supply, upstream watershed investigation and development, soil and forest conservation and development, water quality control, fish and wildlife enhancement, general recreation, power, navigation, and economic expansion.

In this study, water’s role in regional economic development is clearly indicated. For instance, in 1964 there were 74 public or privately owned water companies in a defined region of seven counties in northeastern Pennsylvania: Carbon, Lackawanna, Luzerne, Monroe, Pike, Schuylkill, and Wayne counties, with a land area of 4,427 square miles. On average, 98 million gallons per day (mgd) of water was sold in this region. For the whole Appalachian region, it was estimated that municipal and industrial water use (exclusive of agricultural, mining, and thermal power operations) would be 7,700 mgd for the study year; and to meet the benchmark goals of economic development, these uses would be expected to require approximately 13,300 mgd by 1980, 23,400 mgd by 2000, and 42,200 mgd by 2020.

The Appalachian region is rich in water bodies used for recreation, with 53,000 miles of rivers and streams, 117 man-made reservoirs and natural lakes spanning more than 500 acres, and hundreds of smaller lakes and ponds. Most of the reservoirs and lakes, particularly those near urban centers, are used extensively for fishing, boating, swimming, and other water-dependent activities. Many rivers and lakes that, in the past, were suitable for outdoor recreation have since been severely polluted by a wide range of sources, chiefly industrial and municipal.

The 48,100 miles of fishing streams in Appalachia, when converted to acres at the assumed ratio of four acres per mile, represent approximately 14 percent of the region’s total surface water (or 192,000 acres). Reservoirs constitute about 67 percent (924,500 acres); natural lakes make up about 8 percent (115,900 acres), while farm ponds represent almost 11 percent (153,700 acres). In 1964, an estimated 52.8 million person-days of angling were expended on Appalachia’s 1.4 million surface acres of fishable habitat, which is equivalent to about 38 person-days per surface acre. Total fishing use in Appalachia during 1964 ranged from a low of 23.5 person-days per surface acre in Tennessee to a high of 102.2 person-days per surface acre in Pennsylvania.

There are approximately 89,200 surface acres of usable commercial fisheries habitat in the region, capable of providing 43.9 million pounds of commercial fish annually. This includes reservoirs and lakes that are 1,000 acres or larger. The total commercial fish landings of both fish and shellfish in the region during 1966 were estimated at 10.4 million pounds, valued at 1,283,114 dollars.

A total of 40 units were used for comparing mean and median values for sport fishing opportunities and demand. These values were determined by using 1964 fishing license sales, 1960 population data, and the Appalachian water inventory, which includes natural waters and water development projects completed prior to 1965.

While the 1969 study recognized the positive aspects of water uses in the region, it also acknowledged that regional water quality was polluted to some extent, with the most serious issues being acid mine drainage (AMD) and municipal pollution. It was found that the AMD was generally coincidental with regions that have been, or were presently being, mined and that AMD had polluted approximately 3 percent (5,700 miles) of Appalachia's streams. The worst offending areas were in the old coal fields of West Virginia and Pennsylvania and in a few areas of southeastern Ohio that had been strip-mined for several decades. Water users received 4.2 million dollars annual savings from a 90 percent reduction in AMD. Another widespread problem for much of the region was flooding, which resulted, for example, in average annual damages of 27 million dollars in Water Sub-Region B, which comprises part of New York, Pennsylvania, Maryland, and West Virginia.

1.6.2 *More recent research*

While the study reviewed above examined many aspects of water in the region, several studies have been conducted to look at more specific aspects of water, such as drinking water quality and supply. For instance, the University of North Carolina Environmental Financing Center (Hughes et al., 2005) analyzed the conditions of drinking water and wastewater services in the Appalachian region to assess the available financial requirements and strategies for improving these services, particularly in areas that face chronic economic distress and clear deficiencies. The analyses were carried out at three levels: a regional level, a sub-regional and state level, and a community and system level (case studies).

Several other studies, albeit not focused on water but more on land-use and economic growth, have also been conducted at the regional level in Appalachia. One comprehensive study—Southern Appalachian Man and the Biosphere Cooperative (1996)—examined the ecological conditions (i.e., atmospheric, aquatic, and terrestrial) and the social, economic, and cultural status in the southern Appalachian region comprised of northern Virginia, eastern West Virginia, northwestern South Carolina, northern Georgia, and northern Alabama. Federal and state natural resource agencies within the region cooperated in this assessment. In terms of aquatic resources, the physical setting (i.e., stream density, impoundment acres, major drainages, etc.); effects of human activities on aquatic resources; water quality and associated nonpoint and point sources of pollution; aquatic species; laws, regulations, and programs affecting aquatic resources; and water usage are examined. In addition, the mining impacts by hydrological unit, percent of land area occupied by human activities, and percent of forest cover in riparian zones are mapped.

This study examined four aspects of the social, economic, and cultural status in the region: 1) communities and human influences, 2) the timber economy, 3) outdoor recreation supply and demand, and 4) roadless and designated wilderness areas. To address changes in population and housing in the region, census data from 1970, 1980, and 1990-91 were analyzed. Other data sources included the Census of Agriculture for the last three decades and the US Department of Agriculture Economic Research Service data. Maps displayed averages for the counties in the study area as compared to averages for the seven states in which the southern Appalachian counties reside. In addition, surveys were conducted among organizations and residents to understand their attitudes toward natural resources and the environment.

Another study examines land ownership patterns and their impacts on the Appalachian community based on a survey of 80 counties (Appalachian Land Ownership Task Force, 1981). The study found that only 1 percent of the local population, along with absentee land-holders, corporations, and government agencies, controlled at least 53 percent of the total land surface in the 80 counties; of the 13 million acres of surface sampled, 72 percent was owned by absentee owners. In addition, 7 percent of land was owned by out-of-state owners and 25 percent by owners who resided in the state but outside out of the county of their holdings. Four-fifths of the mineral rights in the survey were absentee-owned. Almost 40 percent of the land in the sample, and 70 percent of the mineral rights, were held by corporations. Indices were developed to illustrate the concentration of ownership of land and minerals.

Finally, the Economic Development Research Group, Inc., Regional Technology Strategies, Inc., and Massachusetts Institute of Technology Department of Urban Studies and Planning (2007) examined five regional growth paths in the Appalachian region; these growth paths are outlined in Table 2.

Table 2: Appalachian regional growth paths

Growth path	Explanation
Trade center	A growth pattern emanating from a small urban cluster that provides goods and services to the ex-urban communities and rural hinterlands
Agglomeration	Also known as cluster economy, resulting from geographic concentrations of interconnected businesses and institutions that enhance the productivity of the core industries
Supply-chain	Also known as dispersal economy, an economy structure wherein a remote location is chosen over the central metropolitan area to host a node of economic activity (distribution or assembly) that is part of a larger (geographic) production chain
Natural amenity or cultural assets	This path depends on either quality-of-place attracting new households or efforts to actively develop and promote cultural, recreation, and eco-tourism venues and their supporting visitor services
Knowledge assets	This path denotes the growth opportunities leveraged from the collective knowledge embodied in the region, including social capital, technical applications and commercialization, institutional assets (educational and financial), and entrepreneurial start-ups

Source: Economic Development Research Group et al. (2007).

The study presents six case studies of local economic development in Appalachia that range from single counties to multi-county regions: Scioto County, Ohio; Chautauqua County, New York; Pike County, Kentucky; Marion and Monongalia Counties, West Virginia; southeast Tennessee/southwest North Carolina; and Alabama at the state level. The case studies document the local context and history of economic development in these areas in order to illuminate the processes of economic growth and change that have been and are occurring there. All of the case studies focus on non-metropolitan parts of Appalachia.

1.7 Stakeholder involvement

We solicited information and feedback from a variety of stakeholders in an effort to coordinate with outside institutions, as well as to ensure that our focus and efforts are aligned with regional objectives and goals.

We involved stakeholders who represent a wide variety of organizations, including federal and state agencies, interagency councils, universities, and non-profit institutions. An invitation to participate was distributed to over 70 stakeholders identified by the project team as having an important stake in the future of how water resources are used within the region. The invitation letter included project background as well as a request to participate by answering seven open-ended questions.

Respondents included representatives from the following groups:

- City of Cumberland, Maryland;
- Greater Cumberland Committee (Cumberland, Maryland);
- Interstate Council on Water Policy;
- Maryland Department of the Environment;
- Mineral County, West Virginia;
- North Carolina State University;
- State of Arkansas;
- Susquehanna River Basin Commission;
- Tennessee State University;
- Tennessee Valley Authority;
- Trout Unlimited;
- West Virginia University Extension Office;
- United States Geological Survey; and
- University of Maryland Agriculture and Resource Economics.

Stakeholder respondents offered a variety of information concerning informational needs, desired data, and report format, as well as regional water assets and liabilities. In summary, ARC water asset stakeholder respondents' informational needs included the following:

- water availability information for planning purposes,
- information to conserve water resources and special areas,
- monitoring for industrial and other contaminants, and
- evaluation of hydropower.

Data desired by stakeholders included information regarding existing conditions, threatened areas, and areas with potential for improvement or protection. Stakeholders also wanted a report format with the following attributes:

- regional dataset housed in one location;
- improved GIS capabilities to access water resource data and associated analytical tools to summarize and document data;
- long-term projections;
- hard numbers or case studies of examples; and
- online access to water sources, quality, and availability.

Stakeholders identified what they perceived to be the region's top water resource concerns (Table 3).

Table 3: Top water resource concerns in Appalachia identified by stakeholders

Assets	Liabilities
Available data	Hydraulic fracturing concerns
Natural resources	Emerging contaminants
Natural resource use	Mine-related concerns
Natural resource potential	Agriculture concerns
Current research	Development concerns
Conservation	Political and institutional concerns
Partnerships	Availability concerns
Recent innovations	Aging structures
	Future demands

Source: Data from e-mail solicitation to ARC water asset stakeholders in summer 2010.

Responses were shared with the project team during various phases of the project to direct and ground the project. ARC water asset stakeholder respondents offered a variety of information, including informational needs (Table 4), desired data and reports (Table 5), top water assets (Table 6), and liabilities (Table 7).

Table 4: Stakeholder informational needs

Theme	Response
Water availability information for planning purposes	Availability, allocations, quality, protection options, planning
	Potential contribution of water to a region, ownership, usage patterns of water, framework for planning best possible uses
	Estimated sustainable groundwater potential for public water supply and domestic wells at any given location—for planning and permitting process
	Information on water inflows, outflows, and water supplies/demands by state and drainage basin
	More detailed and credible documentation on the quantity and quality of our water supplies and how much of it has already been secured by outside users
	Information and data relating to long term planning (i.e., are current methods of calculation of firm yield of reservoirs accurate when considering climate change?)
	More detailed documentation of water quantity and quality—groundwater sources, in particular
Information to conserve water resources and special areas	Guidance to limit development of sensitive areas along all watersheds—target local county/township leaders, flood plain managers, conservation groups, watershed associations and state regulators
	Guidance for karst and special areas most susceptible to development—target wastewater operators, along with system designers and regulators
	Information related to conservation of water resources
	Irrigation management, private well protection, landscape buffers
Monitoring for industrial and other contaminants	Monitoring of surface stream and river water quality of industrial, agricultural, and emerging wastewater treatment plant contaminants
	Monitoring of ground water extraction for industrial use such as poultry production in the region
	Better documentation of the potential threats to those resources and how they have increased DESPITE a lack of overall growth (through continued expansion of lower intensity land development practices)
Evaluation of hydropower	Evaluation of Federal Lock and Dam system to be adapted to generate hydro power and assist with removal of anthropogenic flotsam
	An economic valuation of small pond development for water storage, fish enterprises, emergency use and small hydro development

Source: Data from e-mail solicitation to ARC water asset stakeholders in summer 2010.

Table 5: Data and reports desired by stakeholders

Theme	Response
Existing conditions	Quantity and quality of our water supplies and how much of it has already been secured by outside users
	Mapping well locations, depths, volumes and water quality with interpolation in between known data points to give a better understanding of what is available
Threatened areas	Areas at high risk for water withdrawals in the future
	Watersheds at high risk for Marcellus Shale impacts
	Areas with low buffering capacity to attenuate effects of acid deposition
	Water resources damaged by flood recovery areas (dredged and channelized)
	Documentation of the potential threats to those resources
	Areas with depleted, impaired, or lack of riparian cover
	Water resources with dissolved oxygen impairment
	Water resources exhibiting temperature regime impairment
Areas with potential for improvement or protection	Areas of groundwater recharge
	Spring resources
	Water resources with potential for trout restoration
	Eco-tourism potential
	Areas with high potential for AMD remediation
Report format	A report that could take advantage of myriad existing data sets
	A regional dataset housed in one location
	Watershed-scale report pertaining to pollution impairment
	Improved GIS capabilities to access water resource data (e.g., water supply, demands, wastewater discharges, precipitation) and associated analytical tools to summarize and document data
	Long-term projections
	Hard numbers or case studies of examples, not a modeling effort that runs what-if scenarios
	Online access to water sources, quality, availability

Source: Data from e-mail solicitation to ARC water asset stakeholders in summer 2010.

Table 6: Top water assets in Appalachia identified by stakeholders

Theme	Response
Available data	Available water quality and quantity data for the Susquehanna River
Natural resources	Quality of water resources
	Our groundwater quality and quantity
	Water for aquatic habitat
	Existing eastern brook trout populations
	Reasonable annual rainfall rate near 40 inches per year
	Our headwaters streams that have very high quality, quantity, and temperature for multiple use
	Rainfall and topography that allow for expanded use of small catchment impoundments
Natural resource use	Water for recreation
	World class fisheries and whitewater recreation
	Water for agriculture
	Water for municipal use
	Clean drinking water
	Relatively low cost of water supplies relative to surrounding growth areas
	The overall benefits that the river system brings to stakeholders of Tennessee River Basin (e.g., substantial navigational capabilities, readily available water for municipal and industrial growth, low-cost electricity, increased recreational opportunities)
	Our river systems are navigable due the Corps lock and dam system that could be adapted to provide zero-carbon power
	Patterson Creek and New Creek watersheds have a total of 40 flood control structures, of which 29 are located within the County
Natural resource potential	North Branch water resource potential if withdrawals were permitted
	Capacity in available public water supplies
	Recreational potential of Jennings Randolph Lake and over 50 miles of shoreline on the North Branch of the Potomac
	Extensive untapped resource potential
	Proximity to urban areas with high growth and limited supplies (not from perspective of selling or diverting our water resources, but from the perspective of tapping into a growth-constrained engine for our own growth and economic revitalization)
	Current capacity, perceived water quality, unanticipated rapid growth (also a threat)
Research	WVU study underway of the limestone aquifer along the length of Knobley Mountain
Conservation	Subwatersheds identified by Trout Unlimited's CSI as protection priorities
	CSI-directed restoration priorities
Partnerships	Linkages to local decision-makers
	Availability, cost, quality, ability to manage and state water law
	Recent media regarding water quality in the US
Recent innovations	New and effective wastewater technologies
	Knowledge of innovations in water quality protection

Source: Data from e-mail solicitation to ARC water asset stakeholders in summer 2010.

Table 7: Top water liabilities in Appalachia identified by stakeholders

Theme	Response
Hydraulic fracturing concerns	Marcellus Shale/hydraulic fracturing
	Potential consumption and contamination of water capacity and untapped supplies by Marcellus Shale interests
	Emerging interests in hydrofracking process related to natural gas extraction (need to know what we have to feed this interest)
	Oil and gas well development on ground water
Emerging contaminants	Emerging contaminants such as estrogen and other chemicals passed through wastewater treatment plants and dropped back into surface streams and river systems
Mining-related concerns	Mercury in the water column
	Surface mining impacts on stream water quality
Agriculture concerns	Nonpoint source runoff from farms and agriculture
	Agriculture, nitrogen, phosphorus, and sediment losses to surface streams
Development concerns	Ill-advised and implemented mountain home development
	Aquatic organism passage blockages on private lands and at public road crossings
	Potential threat of exploitation and diversion of water resources by outside high-growth urban areas with limited water capacity
	Potential impacts of continued low-intensity, consumptive land development practices despite the lack of growth (from a perspective of both contamination and inefficient use of land and water supplies)
	Raw sewage direct deposited into surface streams from low-income residents and failed/failing septic systems (800-pound gorilla that never gets any attention)
Political and institutional concerns	Linkages to local decision-makers
	Knowledge of innovations in water quality protection
	Minimal knowledge of existing ground water resources
	Availability, cost, quality, ability to manage and state water law
	Lack of local financial resources to properly care for and manage water resources
	Jennings Randolph and other surface supplies are vulnerable to terrorist activity
Availability concerns	Extended drought
	Availability, impact of climate change, agricultural use, other consumptive uses, environmental impacts of low flows
	Water shortages in high-density areas that could appeal to use our water
Aging structures	29 aging flood control structures
Future demands	Reliance on surface water for much of the county's public water supply
	Potential cost of accessing and developing untapped water resources
	Competing demands between water resources and economic development have the potential to hinder advances in both arenas

Source: Data from e-mail solicitation to ARC water asset stakeholders in summer 2010.

2. WATER QUANTITY

Cities and rural communities within and around the region are dependent upon the wise use, management, and development of Appalachian water resources. This dependence on water for economic growth has become increasingly evident in recent decades. Human demand for freshwater has tripled since 1950 due to population growth, irrigation, and increased material consumption (Postel and Carpenter, 1997). Many factors must be considered to gain an understanding of water quantity within a county and across the region. The Appalachian region is comprised of the headwaters of many major waterways; headwaters are important because they are critically linked to the quality and quantity of water resources downstream (Alexander et al., 2007).

As shown in Figure 1 (above in Chapter 1) and Figure 2, the region's streams flow toward eight major drainages and ultimately reach the Gulf of Mexico, Chesapeake Bay, and Atlantic Ocean. The region has abundant water resources, providing water for commercial, domestic, and other uses. As a headwaters region, Appalachia plays a crucial role in providing a clean drinking water supply to over 19 million public water supply users and over three million groundwater users in ARC counties (Kenny et al., 2009). Also, the region's power plants withdraw over 29,000 mgd of water, generating over 550,000 gigawatt hours of electricity. Understanding these and other uses provides a foundation for managing water resources in a sustainable manner.

2.1 Components and framework

Publicly available data were procured to examine water quantity across the Appalachian region; only regionally consistent databases were queried. Our analysis of water quantity investigates the following four indicators. As illustrated in Table 8, each of these indicators is based on one to three metrics.

1. **Water withdrawal and consumption**: The United States Geological Survey (USGS) reports water withdrawals at the county level every five years. This indicator measures surface and groundwater withdrawals for a variety of uses. Using withdrawals and use type, actual consumption of water is calculated.
2. **Water sustainability.** Based on a 2010 study (Roy et al., 2010), this indicator projects the future use of water in the region and pinpoints areas of concern based on future supply and demand.
3. **Floods:** This indicator measures the number of floods per county, providing a regional overview of where flooding occurs and at what rate.
4. **Surface water quantity**: This indicator provides a simple measure of surface water flow and stream order, which helps distinguish counties with large rivers versus those with headwater streams.

Table 8: Water quantity assessment components

Indicator	Metric	Denominator	Unit of measurement	Data source and date
Water withdrawal and consumption	• Surface water withdrawal • Groundwater withdrawal • Total consumption	n/a	mgd	Kenny et al., 2009 Shaffer, 2009
Water sustainability	• Projected water withdrawal change • Projected water sustainability risk with climate change	n/a	• Percent change • Narrative index	Roy et al., 2010
Floods	• Number of floods	n/a	Count, 1994-2010	National Oceanic and Atmospheric Administration, 2010
Surface water quantity	• Mean annual maximum flow • Percent of headwater streams	County acres	• Cubic feet per second • Percent	USGS National Hydrography Dataset, version 1, 2005

Figure 2: Appalachian region hydrology

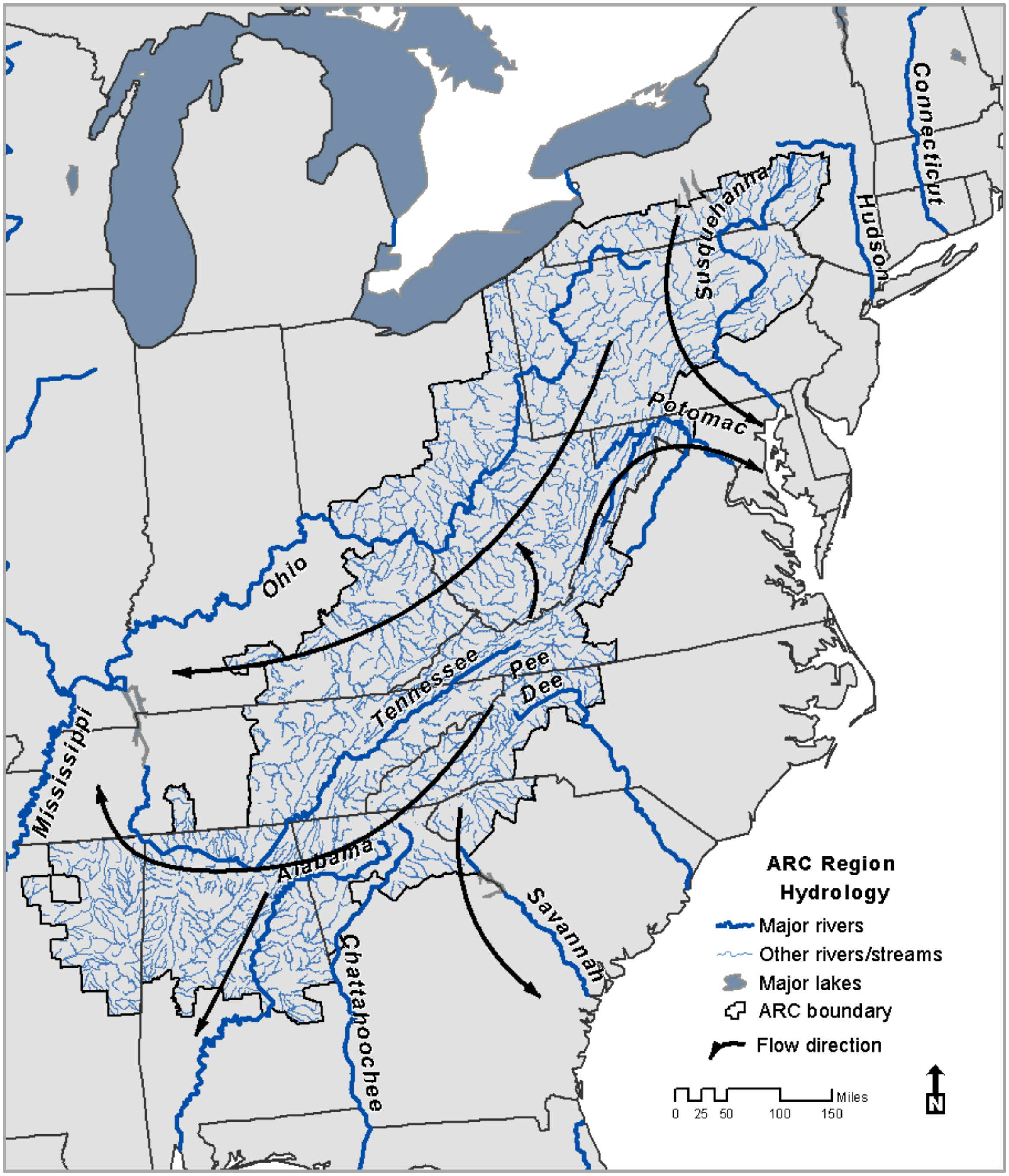
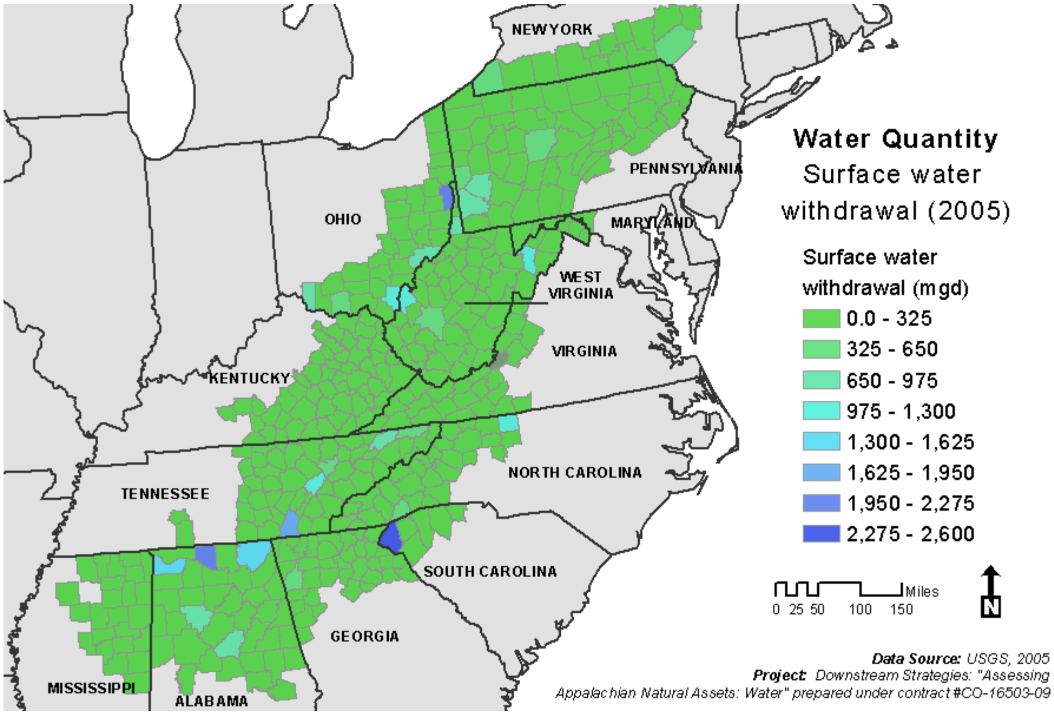
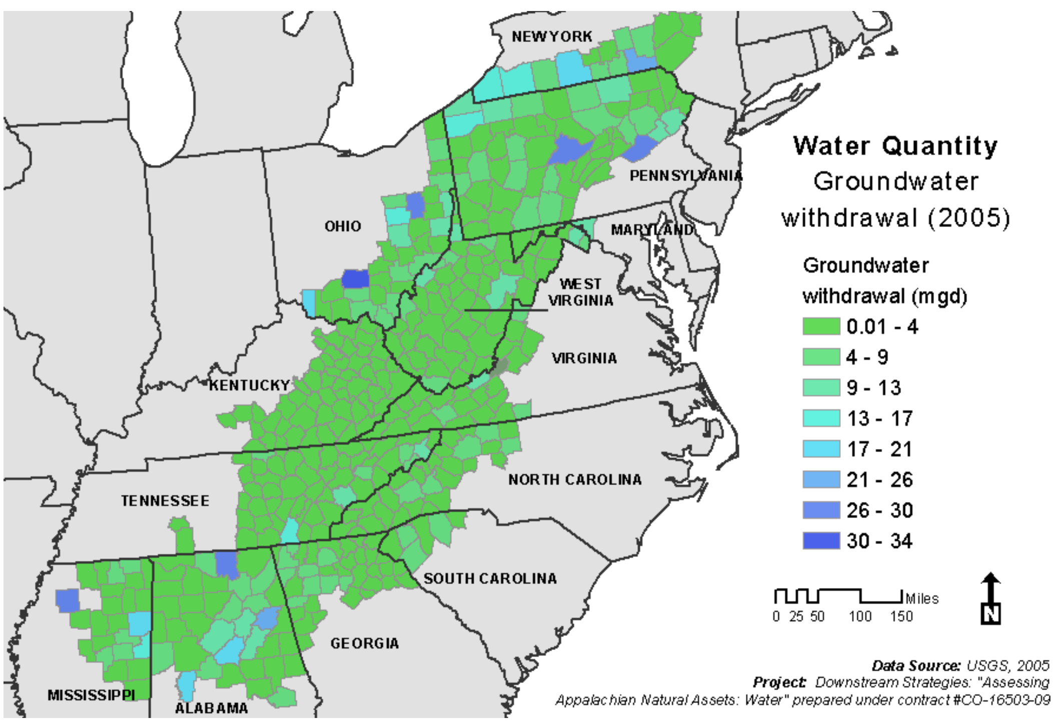


Figure 3: (A) Total surface water withdrawal by county; (B) Total groundwater withdrawal by county

A



B



2.1.1 *Water withdrawal and consumption*

USGS has been collecting water withdrawal data and producing summary reports since the 1950s. The 2005 data[2] were used to examine total surface and groundwater withdrawals and to calculate consumption across the Appalachian region. USGS collected data from a wide range of entities, including state, federal, and local agencies (Kenny et al., 2009).

We used these data to report two separate water withdrawal and consumption metrics: surface water withdrawals and groundwater withdrawals. Data are reported to the USGS as water withdrawals, or water that was withdrawn from a water source—river, lake, pond, or the ground—for a specific purpose or industry. These withdrawal statistics do not account for the water that is consumed, or water not returned to the source. For example, thermoelectric plants withdrawal vast amounts of water to generate electricity, but return 98 percent of these withdrawals back to the water source. To gain a more realistic understanding of water consumption, we estimate water consumption in addition to withdrawal. These metrics can provide stakeholders with an overview of water use in their county or region and can help inform decisions on the wise use and management of water resources.

Unfortunately, these metrics do not take into account the levels of increased water consumption due to recent natural gas well development in the Marcellus and Utica Shale regions. The most recent USGS data were published before the widespread development of shale gas resources in the Appalachian region. A follow up to this study could examine the 2010 data—slated to be published in 2014 by USGS —and quantify water consumption trends that incorporate gas well development in Pennsylvania, New York, Ohio, and West Virginia.

Panel A in Figure 3 illustrates total surface water withdrawals across the following uses: irrigation, thermoelectric, industrial, public water supply, aquaculture, mining, and raising livestock.[3] Surface water withdrawals account for 37,000 mgd, or 96 percent of the total water withdrawn in the region. The largest sector by far is thermoelectric generation, withdrawing over 29,000 mgd, or 60 percent of the total water withdrawn in the region. Thermoelectric is followed by public water supply (3,185 mgd) and industrial (2,910 mgd) withdrawals. The combined counties of Alabama have the highest state surface water withdrawal, 7,400 mgd, followed by Ohio with 6,502 mgd and Tennessee with 5,264 mgd.

Panel B in Figure 3 illustrates county groundwater withdrawals across the region. Groundwater withdrawals only represent 4 percent of the total water withdrawals in the region, with a large portion dedicated to drinking water for public or private water supply: 655 mgd. Alabama (133 mgd) and Ohio (115 mgd) are the largest consumers of groundwater for public water supply. Pennsylvania (72 mgd) and North Carolina (44 mgd) are the top private ground water supply consumers, and Alabama has the highest state groundwater withdrawal of 204 mgd, followed by Georgia (104 mgd) and Kentucky (17 mgd).

As discussed above, to understand the effect of human use on the hydrologic cycle, one must account for return flow, or the amount of water returned after withdrawal. This study used coefficients to determine total water consumption (see Table 9). These coefficients are based on a study (Shaffer, 2009) that quantified the percentage of flow not returned to the water source by category for the Great Lakes Basin and surrounding areas, including several Appalachian states. For this analysis, Ohio was selected to represent the ARC region. These coefficients were used to compute water consumption for all the states in the ARC region by applying them to surface water withdrawals; we assume that groundwater withdrawals are not returned.

[2] At the time of report development, the 2005 report was the most recent available. Since then, USGS has released 2010 data.

[3] This map—along with all maps in this report—is categorized and displayed using equal interval classification, which allows for the interpretation of an equal distribution of data across the region. Each color represents the same interval. For example, the interval used in Figure 3 (A) is 325 mgd. An alternative method would shade counties such that the same number of counties are within each category. The equal interval method, however, provides an objective view of the data and allows readers to identify distributions and outliers.

Figure 4 maps total water consumption by county across the region and highlights the top eight counties. Figure 5 breaks down water consumption by sector for these top water-consuming counties. In these counties, the thermoelectric sector consumes the most water—even after considering that the sector returns 98 percent of its water withdrawal—and the industrial sector consumes the second-most water.

Figure 6 illustrates water consumption by sector for the entire region. Thermoelectric plants account for 45 percent of all consumption across the region, and water supply accounts for an additional 30 percent.

Cities and areas with the highest consumptive water use are those containing populated and industrialized areas such as Pittsburgh, Pennsylvania; Weirton, West Virginia; Huntsville, Alabama; and the Ohio River Valley. County patterns emerge that show industries located in the Kanawha Valley of West Virginia and Ohio River Valley, among other areas, consume large amounts of water for various industrial processes.

Table 9: Waters consumption coefficients

Category	Water consumption coefficient
Water supply	7 percent
Industrial	10 percent
Thermoelectric	2 percent
Irrigation	78 percent
Livestock	76 percent
Commercial	17 percent
Mining	10 percent
Aquaculture	0 percent

Source: Shaffer (2009). Note: Irrigation coefficient is the average of crop and golf course coefficients.

Figure 4: Total water consumption

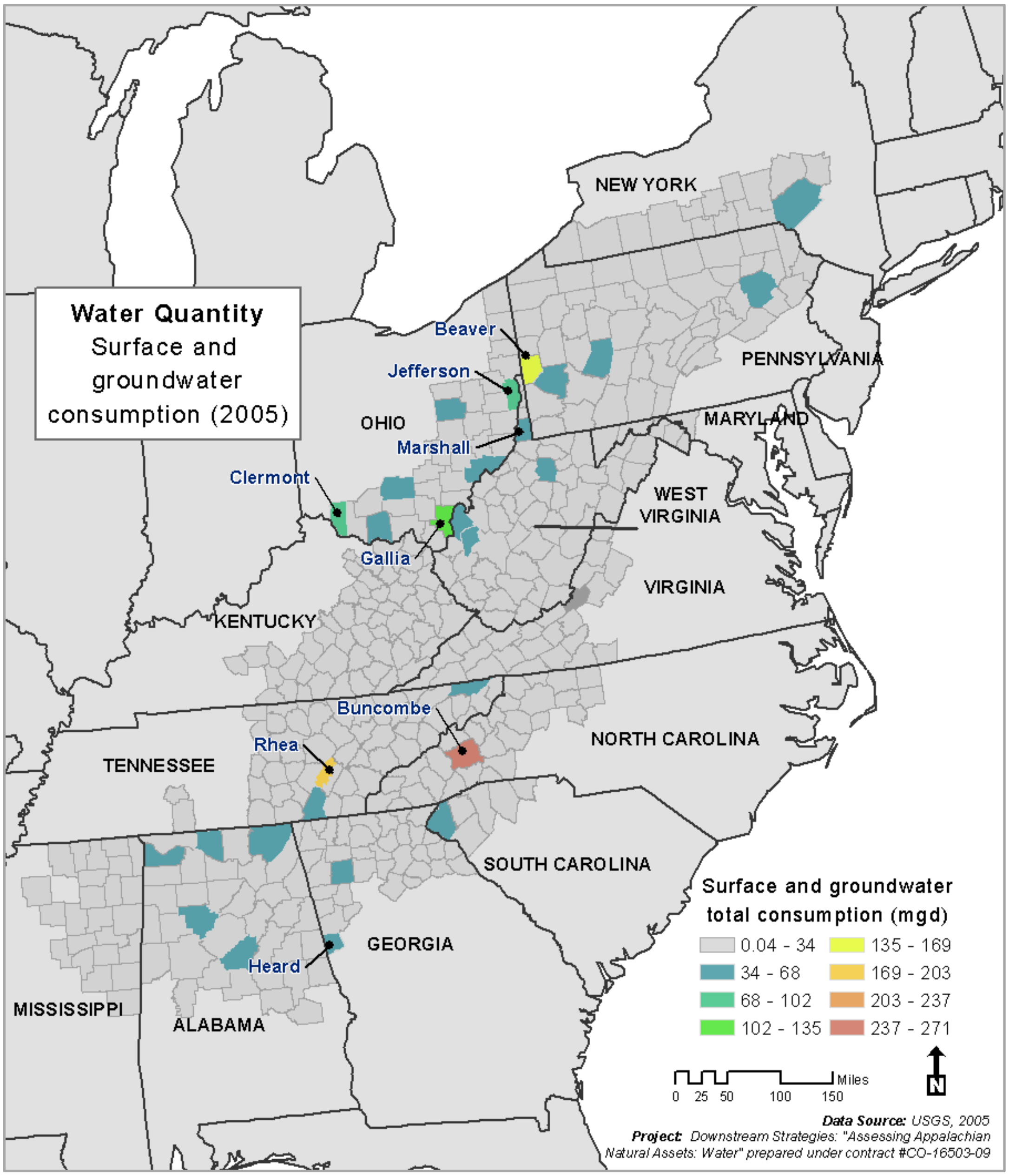
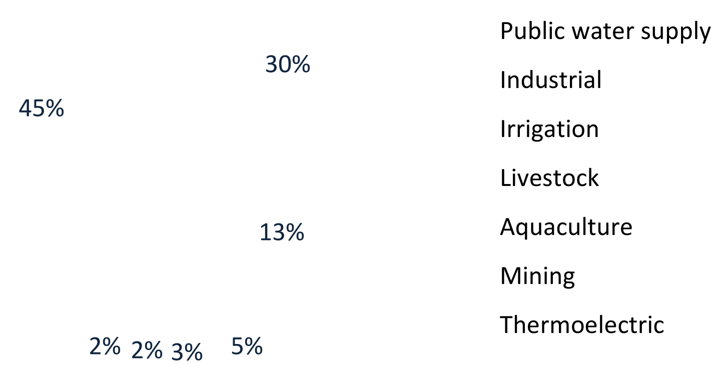


Figure 5: Top county water consumers

Figure 6: Water consumption categories for the ARC region



2.1.2 ***Water sustainability***

For resource managers and planners, understanding future water supply conditions can be beneficial for water resource planning. As discussed earlier, water withdrawals and consumption are critical components of daily life, from industrial and food production to electricity generation. Understanding the limitations of that resource could help guide decisions based on water availability. This section highlights results for two water sustainability metrics obtained directly from published work (Roy et al., 2010). This study developed a methodology to predict supply and demand of water in 2050 under current growth conditions, as well as estimated conditions due to climate change. The results are not intended to predict where water deficits will specifically occur, but rather where they are more likely to occur.

Panel A in Figure 8 maps projected changes in water withdrawals through 2050. The projected water withdrawal data were only calculated by the researchers for thermoelectric and drinking water supply. Panel B in Figure 8 maps the water sustainability index, which is based on predicted climate change patterns, or areas that are at risk of withdrawing more water than is available in the future. These two projections show areas most vulnerable to water quantity conflicts and demands.

Figure 7 provides additional information about the eight counties with the largest projected increases in water withdrawal. Both of the sectors considered in this research—thermoelectric and drinking water supply—show increases. It appears that increased consumption could be influenced by population growth, which results in additional demands for drinking water and electricity. The combined increase in energy production for the eight highlighted counties totals 22,830 gigawatt hours (GWh)—a nearly 45 percent increase. The projected drinking water consumption increases by over 350 percent in the four counties surrounding Atlanta, rising from 76 mgd to 274 mgd. These metrics are just one way to examine water withdrawal trends in the ARC region.

Figure 7: Top counties with change in water withdrawal: 2005-2050

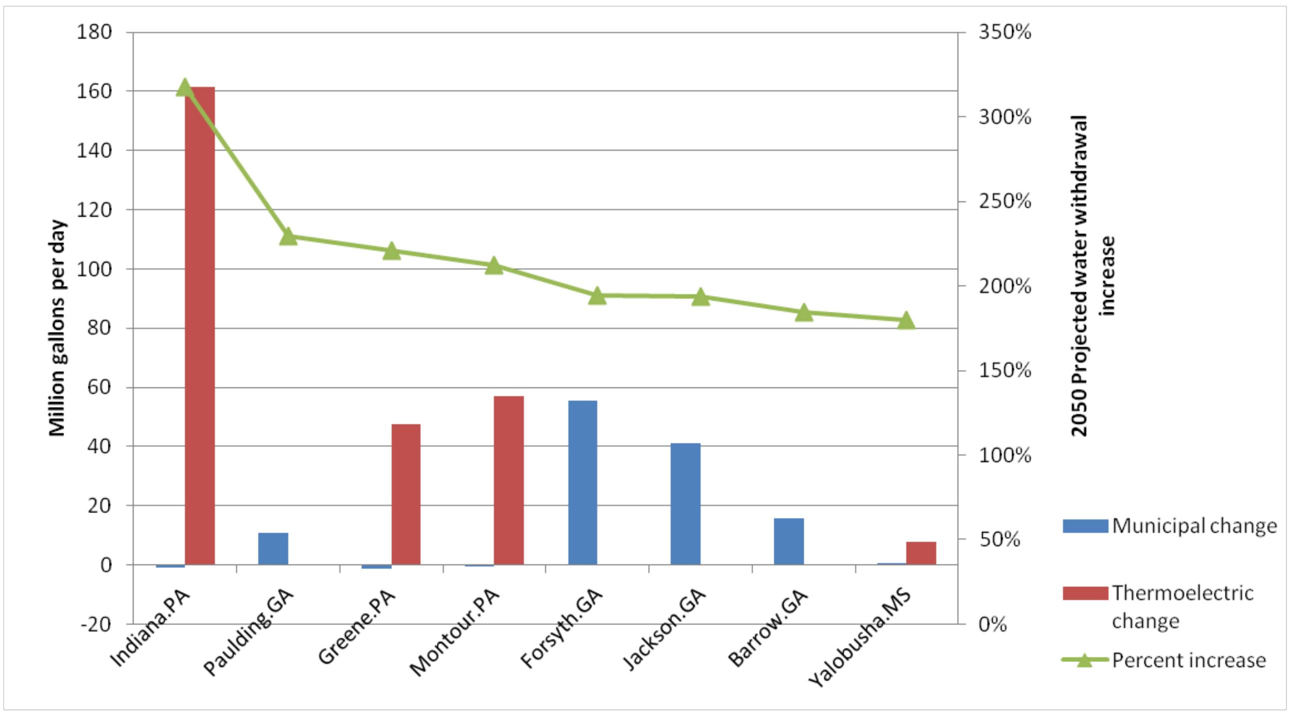
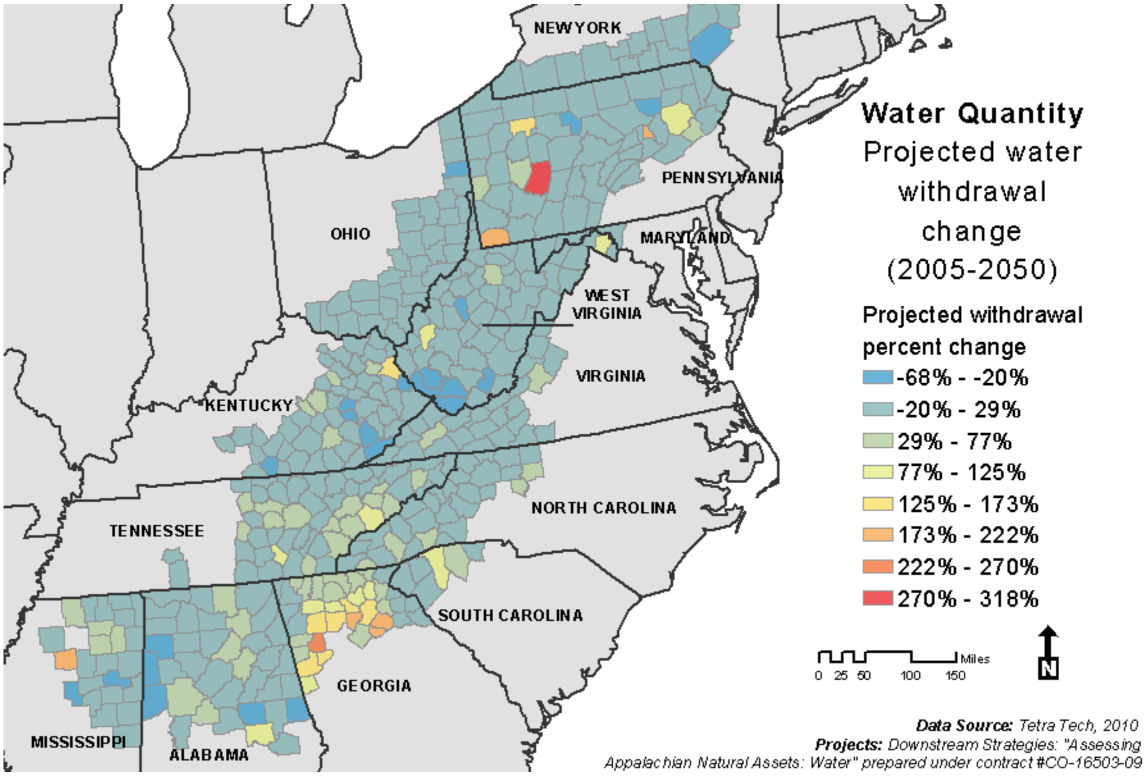
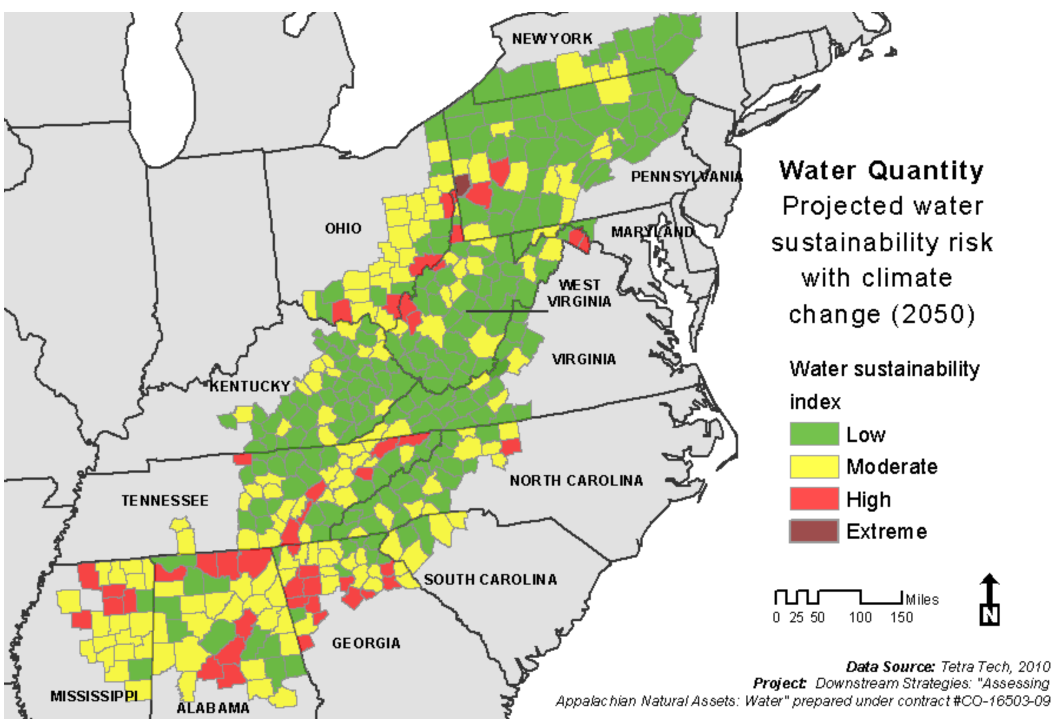


Figure 8: (A) Projected water withdrawal change (2005-2050); (B) Projected water sustainability risk with climate change (2050)

A

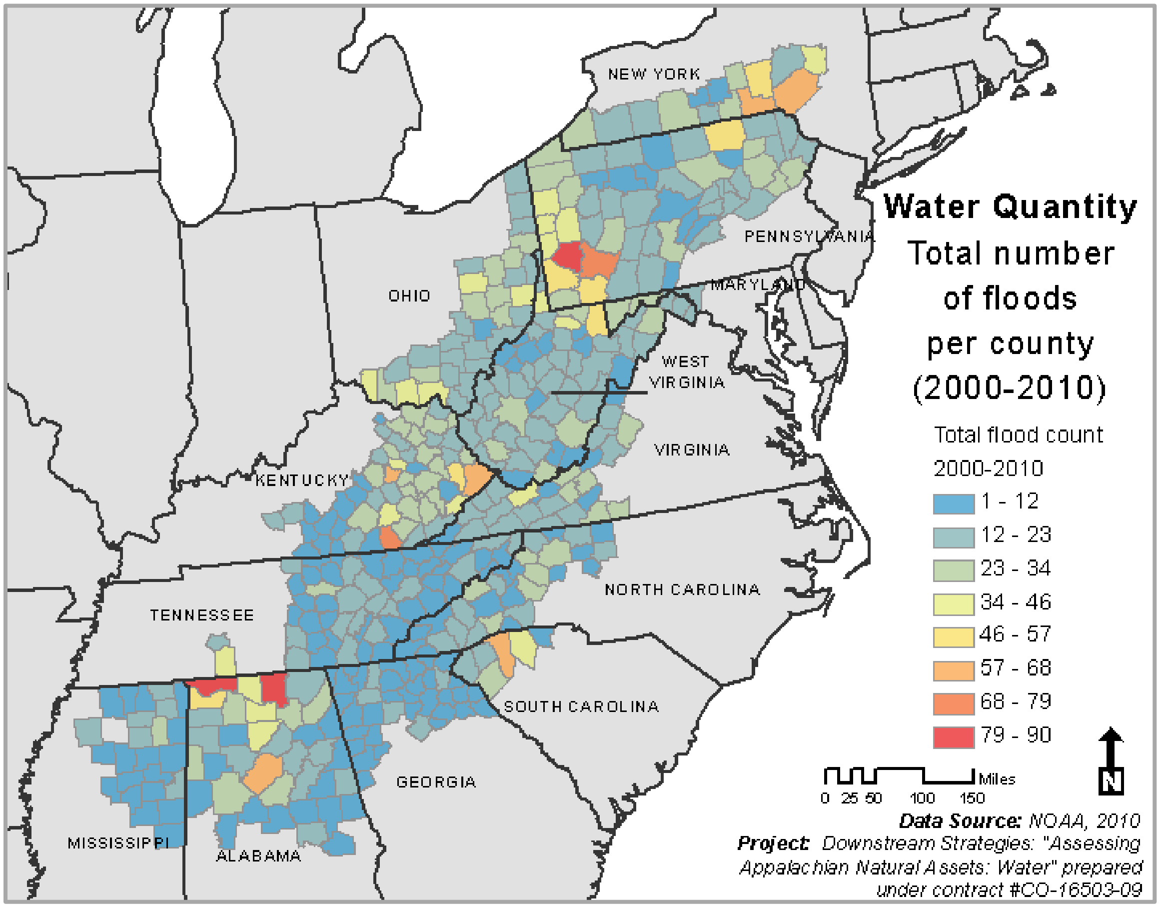


B



Panel B in Figure 8 maps counties with water supplies potentially at risk by 2050, particularly when considering the impacts from climate change. The water sustainability index is comprised of five criteria: available renewable precipitation, sustainable groundwater use, susceptibility to drought, growth in water demand, and an increased need for storage. These five factors were used to score each county across the US and ultimately create an index of risk. Georgia counties surrounding Atlanta stand out considerably, as do heavy industrial areas neighboring densely populated areas in Pennsylvania. Most rural areas with light industry and minimal projected population growth are largely safe from projected water availability risks, while areas with growing populations or large agricultural demands are at risk.

Figure 9: Total number of floods per county



2.1.3 *Floods*

Flood data were provided by the National Climatic Data Center (NCDC) at the National Oceanic and Atmospheric Administration (NOAA). NCDC compiled storm data from 124 regional offices of the National Weather Service (NWS). We queried this database for events between September 2000 and August 2010 in the "flood" and "flash flood" categories. Figure 9 maps floods per county in this ten-year period.

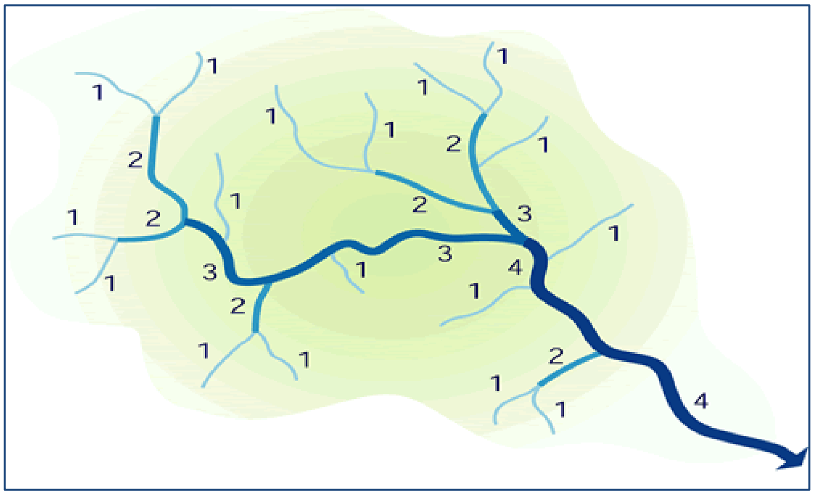
NWS compiles data based on forecast zones. For the most part, these zones correspond with county boundaries; however, a few counties with large topographic and geographic variability are split into two forecast zones. For consistency, storms occurring in these split-county forecast zones were reviewed to ensure that a single flood event was documented and was only counted as one flood in that county.

Regions with greater than average flood counts are found in northern Alabama, South Carolina, eastern Kentucky, western Pennsylvania, and the eastern ARC counties in New York.

2.1.4 *Surface water*

Large rivers are important because they provide a significant amount of water for potential withdrawals and consumption. Headwater streams are also important, though, because they help maintain the ecological integrity of downstream waters. In this section, we analyze two county-level surface water metrics: one focusing on large rivers and the second focusing on headwater streams.

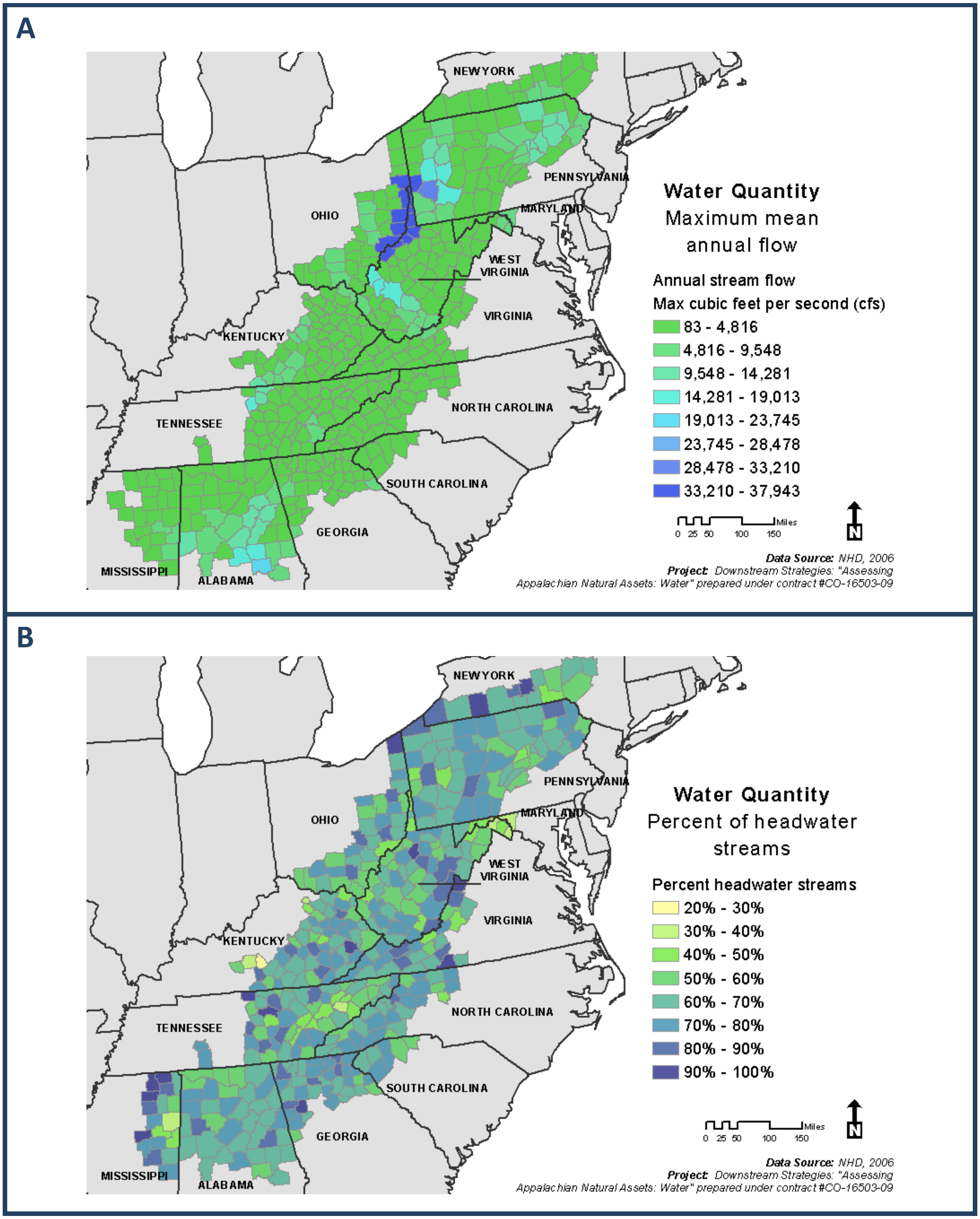
Figure 10: Stream order example



Panel A in Figure 11 illustrates the maximum mean annual stream flow for each county. This metric was calculated by identifying the maximum mean annual flow from catchments within a county. The Ohio River, which flows along the border between Ohio and West Virginia, stands out in this map, as do other major rivers including the Susquehanna River in Pennsylvania, the Kanawha River in West Virginia, and the Alabama River in Alabama.

Panel B in Figure 11 summarizes the percent of streams in each county classified as headwaters streams. Headwater streams can be identified by stream order, or the order in which the stream drains. Figure 10 illustrates this hierarchy, where stream order 1 is the smallest tributary and 4 is shown as a larger river. In the ARC region, the largest rivers are ninth-order streams. For this study, stream orders 1 through 3 are considered headwaters streams. The darker blue counties in Panel B show areas with the largest percentage of headwater streams and could be considered headwater regions. The Appalachian region contains a significant amount headwaters streams, with 65 percent of its streams classified as headwater streams, whereas 29 percent are medium sized streams, and only 6 percent are classified as larger streams. Several counties in the region have only headwaters streams: Alcorn, Tippah, and Webster counties in Mississippi; Ashtabula County in Ohio; and Highland County in Virginia.

Figure 11: (A) Maximum mean annual flow; (B) Percent of headwater streams



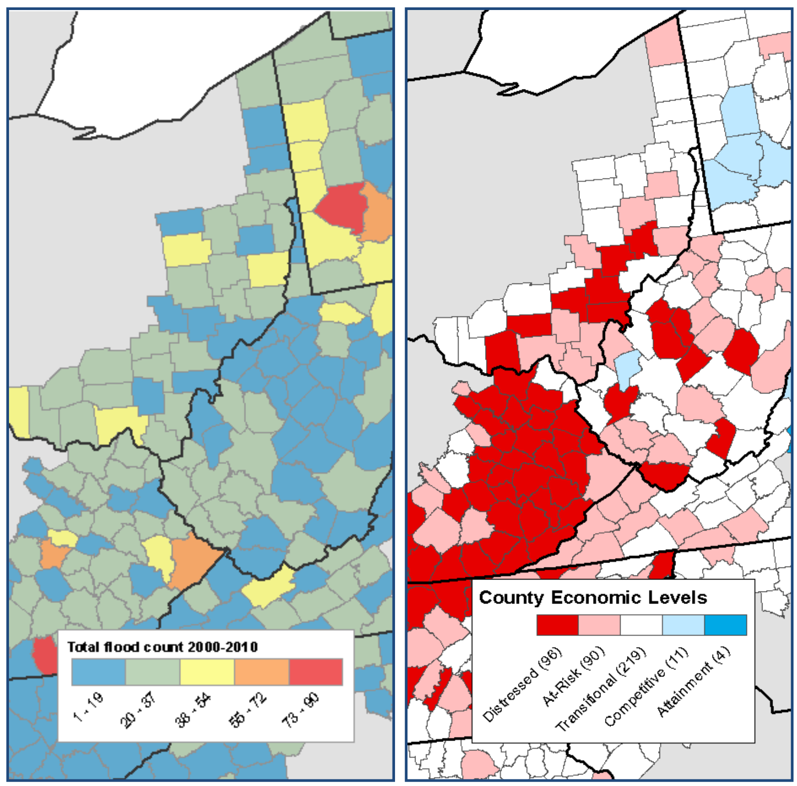
2.2 Discussion

Counties with the highest consumptive water use are those containing populated and industrialized areas such as Pittsburgh, Pennsylvania; Weirton, West Virginia; Huntsville, Alabama; and the Ohio River Valley. After excluding thermoelectric uses, other categories emerge as major water consumers. The four counties with the highest water consumption for 2005 were Allegheny, Pennsylvania (industry, public supply); Delaware, New York (public supply); Sullivan, Tennessee (industry); and Transylvania, North Carolina (aquaculture). The majority of water withdrawals in the ARC region are taken from surface water; in 2005, the total water withdrawn from the surface was nearly twenty-four times the amount taken from the ground.

2.2.1 *Water quantity case study*

Flash flooding is one of the most hazardous natural events and has environmental, social, and economic implications. The Buffalo Creek disaster is one of the best-documented cases of the long-term impacts of flooding. In February 1972, 132 million gallons of debris-filled, muddy water burst through an earthen mine dam, killing 125 people in the small community of Buffalo Creek, West Virginia. Approximately 4,000 of the 5,000 residents lost their homes; 93 percent of residents suffered from emotional disturbance; nearly all had close experiences with death; and, following the disaster, a once–tightly knit community ended up with little concern for one another (Gruntfest, 1995). A study by Erickson (1998) concluded that the community of Buffalo Creek suffered two disasters: the gradual deterioration of mountain culture and the flood disaster itself. As such, policymakers, regulators, and managers need to recognize the long-term impacts of floods on communities.

Figure 12: Comparing flooding and economic status

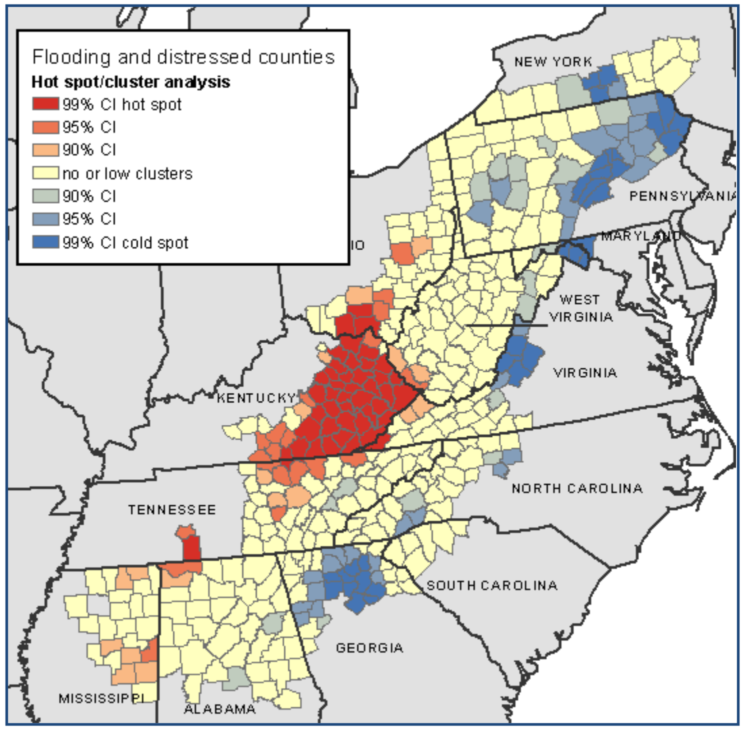


Flooding can have tremendous impacts on society. Loss of human life, injury, and endangerment, as well as impacts on the environment are often associated with larger floods. Every year, people are killed and displaced by flooding. Additional impacts of flooding include polluted water, food shortage, loss of homes, damage to personal property, exposure to elements, disruption of education and community cohesion, and loss of security, jobs, and enforcement programs. However, there is no consensus about the long-term social impacts of flooding. Studies generally indicate that socioeconomic trends in place prior to a flood are reinforced following a flood (Gruntfest, 1995). When a flood impacts a community already experiencing economic troubles, the flood can exacerbate or accelerate the rate of downturn. In recurrent flood-prone areas of Appalachia, communities can get caught in a continuing feedback cycle of disaster, relief, and repair, followed by another disaster (Gautam and van der Heok, 2003).

The economic impacts of flooding can be detected at local, regional, and national scales. Since 1978, more than 8 billion dollars were paid in total loss payments in Appalachian counties (NFIP, 2011). Responding to and recovering from flood events can be a burden to local, county, state, and federal governments and can detract from business and residential development.

To illustrate flood impact vulnerability across the region, the ARC DST was used to rank counties based on two parameters: ARC economic status and the number of floods. A heaver weight was placed on areas with frequent floods, while a slightly lesser emphasis was placed on a county's economic status. Once each county was ranked, a spatial cluster analysis—part of the ARC Toolbar—was performed to show "hot-spots" or clusters of counties that experience the same mix of flooding frequency and distressed economic status. Figure 13 illustrates those results and highlights areas of southeastern Kentucky.

Figure 13: Flooding and distressed counties case study



Page intentionally left blank

3. WATER QUALITY

The relationship between water quality and human health is well-documented (Shiber, 2005; Gaffield et al., 2003). However, links between the quality and quantity of water resources and the influence on the overall regional economic health and sustainability can be more confounding (Deller et al., 2008). States are required under section 305(b) of the Clean Water Act to report on the quality of water resources and determine if the waters are supporting their designated uses—including, for example, water supply, recreation, and aquatic life. States are also required under section 303(d) of the Act to list impaired waters, which do not meet their designated uses. Also, states are required to create strategies and develop plans that address these impairments, known as Total Maximum Daily Loads.

Figure 15: Impaired streams in the ARC region

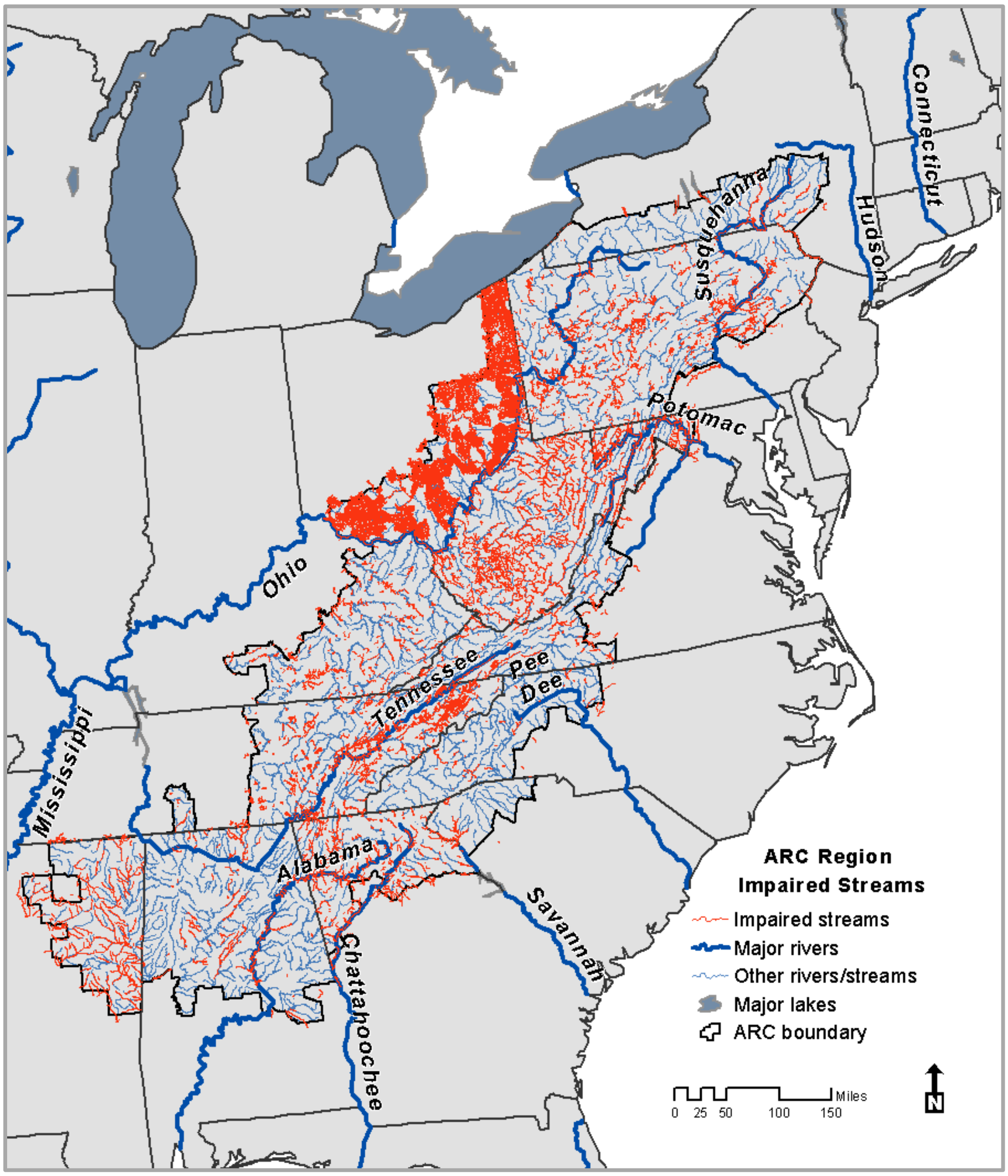


Figure 15 shows 303(d)-listed impaired streams across the region (USEPA, 2008). While states are mandated to submit lists of impaired streams to the United States Environmental Protection Agency (USEPA), many specifics are left up to the states. For example, surface water quality standards vary state-by-state. In addition, watershed assessment programs—through which data are collected to document impairments—are quite variable. Further inconsistencies are introduced when different states specify impairments differently. For example, Ohio lists impaired streams using watershed boundaries, while South Carolina maps stream segments based on impaired point locations. Other states such as West Virginia list stream segments with specific starting and ending points. These inconsistencies make it problematic to use state-generated lists of impaired waters as a basis for assessing water quality across the Appalachian region.

To provide a consistent characterization of water quality across the region, we developed a set of statistical models that predict water quality for every stream segment in the ARC region. These models use boosted regression trees (BRTs) to predict instream conditions based on myriad natural and anthropogenic landscape variables (Section 3.1 further details this approach). The resulting models have regionally consistent input and output variables and have been peer reviewed by the United States Fish and Wildlife Service (USFWS) and other partner clients (Martin et al., 2012). This methodology has been used to successfully model a multitude of individual response variables for several regions across the country (Table 10).

Table 10: United States Fish and Wildlife Service habitat models

Response variable	Response type	Client/Region	Source
Brook trout	Presence/absence	Driftless Area Restoration Effort (DARE)	www.midwestfishhabitats.org/resources
Brown trout	Presence/absence	DARE	www.midwestfishhabitats.org/resources
Cottus (sculpin)	Presence/absence	DARE	www.midwestfishhabitats.org/resources
Longnose dace	Presence/absence	DARE	www.midwestfishhabitats.org/resources
Smallmouth bass	Presence/absence	DARE	www.midwestfishhabitats.org/resources
Small streams signature Index	Index score	Ohio River Basin Fish Habitat Partnership (ORBFHP) & Southeast Aquatic Resource Partnership (SARP)	www.midwestfishhabitats.org/resources
Modified index of center of diversity	Index score	ORBFHP & SARP	www.midwestfishhabitats.org/resources
Intolerant mussels	Presence/absence	ORBFHP & SARP	www.midwestfishhabitats.org/resources
Smallmouth bass	Presence/absence	ORBFHP & SARP	www.midwestfishhabitats.org/resources
Great river guild	Presence/absence	ORBFHP & SARP	www.midwestfishhabitats.org/resources
Intolerant redhorse	Presence/absence	ORBFHP & SARP	www.midwestfishhabitats.org/resources
Intolerant fish	Percentage	ORBFHP & SARP	www.midwestfishhabitats.org/resources
Coldwater guild	Presence/absence	Midwest Glacial Lakes Partnership (MGLP)	www.midwestfishhabitats.org/resources
Walleye	Abundance	Midwest Glacial Lakes Partnership (MGLP)	www.midwestfishhabitats.org/resources
Bluegill	Presence/absence	Midwest Glacial Lakes Partnership (MGLP)	www.midwestfishhabitats.org/resources
Northern pike	Presence/absence	Midwest Glacial Lakes Partnership (MGLP)	www.midwestfishhabitats.org/resources
Trophic state index: total summer phosphorus	mg/L	Midwest Glacial Lakes Partnership (MGLP)	www.midwestfishhabitats.org/resources
Brook trout	Presence/absence	Great Lakes Basin Fish Habitat Partnership (GLBFHP)	www.midwestfishhabitats.org/resources
Coldwater guild	Presence/absence	GLBFHP	www.midwestfishhabitats.org/resources
Walleye	Presence/absence	GLBFHP	www.midwestfishhabitats.org/resources
Large river guild	Presence/absence	GLBFHP	www.midwestfishhabitats.org/resources
Lithophilic spawners	Presence/absence	GLBFHP	www.midwestfishhabitats.org/resources
Blacknose shiner	Presence/absence	Fishers and Farmers Fish Habitat Partnership (FFFHP)	www.midwestfishhabitats.org/resources
Brook silverside	Presence/absence	FFFHP	www.midwestfishhabitats.org/resources
Golden Shiner	Presence/absence	FFFHP	www.midwestfishhabitats.org/resources
Smallmouth bass	Presence/absence	FFFHP	www.midwestfishhabitats.org/resources
Fish richness	Total richness	FFFHP	www.midwestfishhabitats.org/resources
Northern headwaters guild	Presence/absence	Great Plains Fish Habitat Partnership (GPFHP)	www.midwestfishhabitats.org/resources

Southern headwaters guild	Presence/absence	GPFHP	www.midwestfishhabitats.org/resources
Darter guild	Presence/absence	GPFHP	www.midwestfishhabitats.org/resources
Madtom guild	Presence/absence	GPFHP	www.midwestfishhabitats.org/resources
Turbid river guild	Presence/absence	GPFHP	www.midwestfishhabitats.org/resources
Coldwater guild	Presence/absence	USFWS Midwest Regional Assessment	www.midwestfishhabitats.org/resources
Coolwater guild	Presence/absence	USFWS Midwest Regional Assessment	www.midwestfishhabitats.org/resources
Warmwater guild	Presence/absence	USFWS Midwest Regional Assessment	www.midwestfishhabitats.org/resources

Independent models were created to assess the following common water quality parameters:

- **pH,** the acidity or alkalinity of water;
- **fecal coliform,** an indicator of pollution from fecal matter from warm-blooded animals;
- **dissolved oxygen,** which is required to support aquatic life in streams and rivers; and
- **specific conductivity,** the ability of water to conduct electricity—a commonly used indicator of the quantity of dissolved ions in waters. High levels of specific conductivity could indicate pollution from a variety of sources including mining, urban runoff, or agriculture.

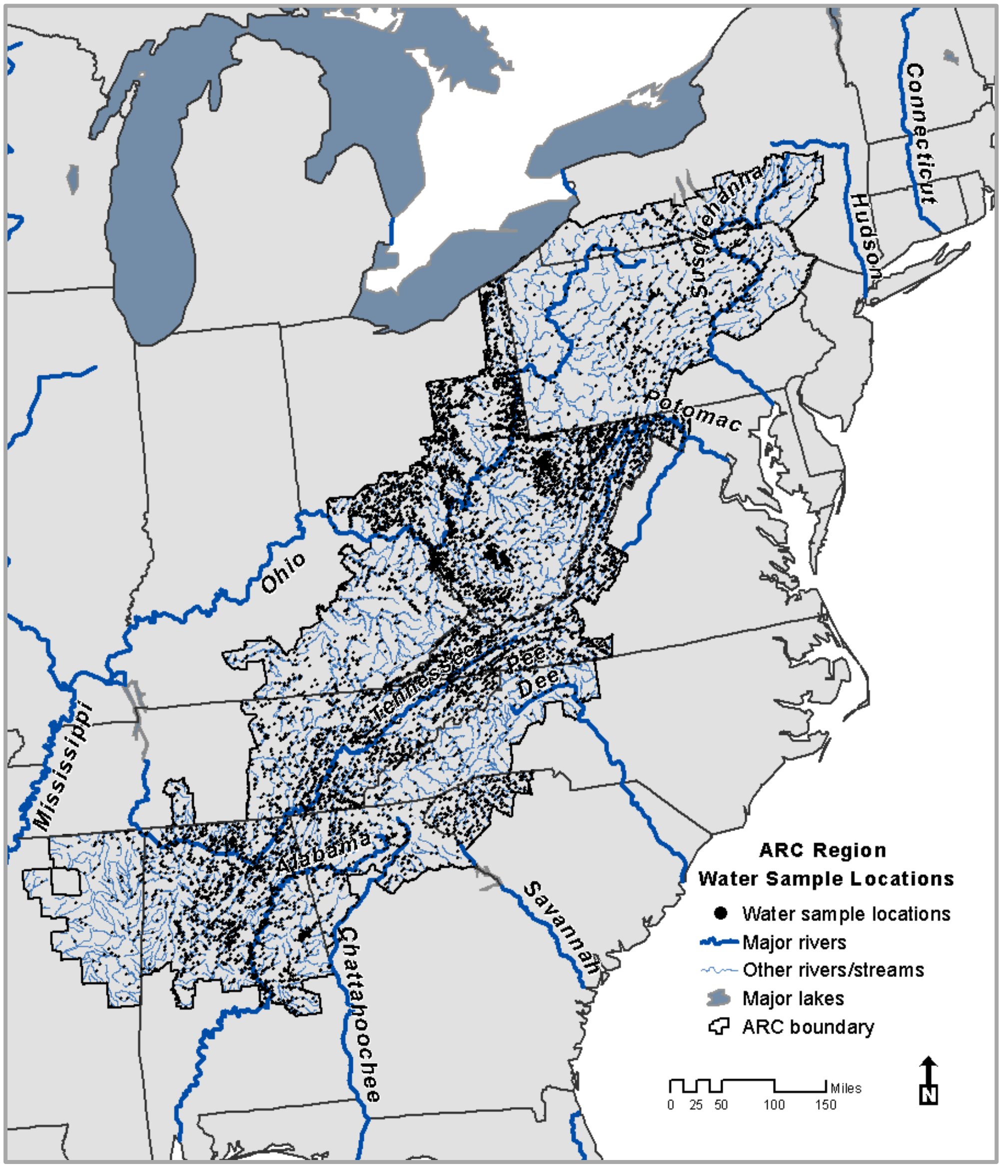
These parameters are commonly measured across the region and enable an understanding of basic water quality conditions. Water sampling data were compiled from federal water quality databases and other state and local data providers (see Table 11); our compiled database includes over 11,000 sample locations (Figure 16) with approximately 700,000 total samples.

Table 11: Water quality data sources

Data source	Parameter	State(s)	Data date range
USEPA STORET (STOrage and RETrieval) Data Warehouse	pH, fecal coliform, dissolved oxygen, and specific conductivity	Alabama, Georgia, Kentucky, Maryland, Mississippi, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, and Virginia	2000-2010
Alliance for Aquatic Resource Monitoring	Dissolved oxygen, pH, and turbidity	Pennsylvania	2001-2008
Alabama Water Watch	Dissolved oxygen and pH	Alabama	2001-2012
Virginia Department of Environmental Quality	Fecal coliform and pH	Virginia	2002-2012

Using these sampling data combined with the segment-level landscape characteristics, the model predicts current conditions across the region. Additionally, results are aggregated to the county level to provide information consistent with the remainder of this report.

Figure 16: ARC region water sample locations



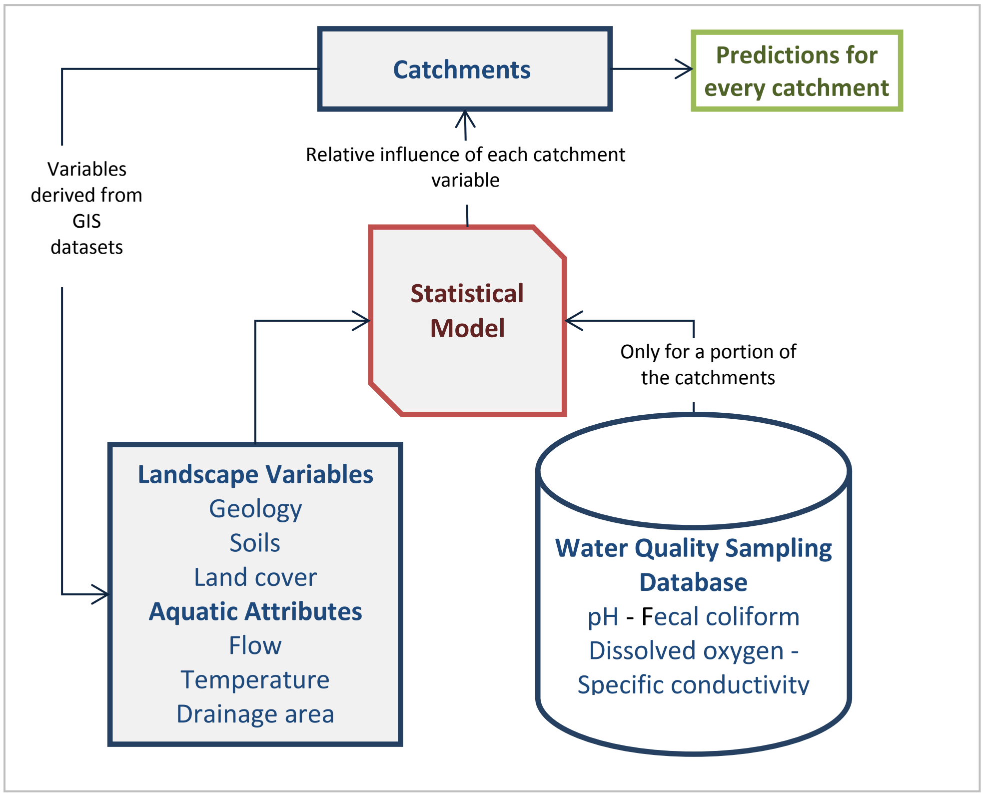
3.1 Components and framework

The modeling framework begins with two types of inputs: response variables and predictor variables. Response variables are the instream measures of condition: pH, fecal coliform, dissolved oxygen, and specific conductivity. A separate model and assessment was created for each response variable.

Predictor variables are typically measures of land-use or land-cover derived from GIS, such as percent impervious surface area or road crossing density. Predictor variables are compiled at the local catchment scale using the 1:100k USGS National Hydrography Dataset (NHD) stream catchments. A catchment is defined as the land area that ***directly*** contributes runoff to a particular stream. To set-up the model, each catchment has predictor variables allocated to its area, for example the percent forest cover per catchment. Additionally, the predictors—such as percent forest—are summarized for the upstream contributing watershed, creating cumulative statistics for each catchment (e.g. upstream percent forest cover, upstream density of road crossings, or upstream average imperviousness). Water sampling points were assigned to a specific catchment to link the appropriate predictor variables with the measured response variable.

As shown in Figure 17, we employ a BRT statistical modeling approach to relate the instream response variable to the landscape-based predictor variables. This process results in a series of quantitative outcomes, including predictions of expected current conditions for all catchments in the region, measures the accuracy of those predictions, a quantification of each predictor variable's relative influence on the predictions (i.e., variable importance), and a series of plots illustrating the modeled functional relationship between each predictor and the response (e.g., plot of impervious area versus water quality response).

Figure 17: Modeling process



Predictive accuracy is quantified using an internal cross-validation (CV) method (Elith et al., 2008). The method consists of randomly splitting the input dataset into ten equally-sized subsets, developing a BRT model on a single subset and testing its performance on the remaining nine, and then repeating that process for the remaining nine subsets. Thus, the CV correlation coefficient actually averages ten separate correlation measurements. A standard error for the ten estimates is also given. CV measures are designed to estimate how well the model will perform using independent data, and are reported below in Table 12.

3.2 Thresholds

To evaluate the projected conditions from each of our four models, thresholds were created for each parameter. The most applicable thresholds would be the water quality criteria adopted by each state; however, states often adopt different criteria, and for some parameters, one state may have a criterion while another may not. Rather than comparing the model results with a different set of thresholds for each state, we selected a single threshold for each model.

3.2.1 *pH*

pH indicates the acidity or alkalinity of surface waters. USEPA provides a national recommended water quality criterion for this parameter: pH must be between 6.5 and 9 standard units (USEPA, 2012). We therefore adopted this range as the threshold for our model. This is the only parameter with an acceptable range rather than a maximum or minimum value; therefore, pH values may fail to meet this threshold if they are too low or too high.

3.2.2 *Fecal coliform*

Fecal coliform is one measure of bacteriological contamination of surface waters. It is used as an indicator of contamination by feces from warm-blooded animals such as humans, livestock, or wild animals. While many states use fecal coliform for surface water quality criteria, others use *E. coli.* Our model requires a consistent dataset across all Appalachian states, and we therefore use fecal coliform.

Rather than providing a single number in its national recommended water quality criteria table for fecal coliform, it provides a reference to the "Gold Book," a USEPA report that lays the groundwork for a wide variety of recommended criteria (USEPA, 1986). This document proposes using a maximum geometric mean[4] of 200 colony-forming units (cfu)/100 milliliter (mL) for fecal coliform, along with geometric means for *E. coli* and *enterococci* based on limiting the number of illnesses for swimmers at both fresh water and marine beaches. It then proposes single-sample maximums for *E. coli* and *enterococci,* but does not explicitly propose a single-sample maximum for fecal coliform.

West Virginia, which still uses fecal coliform in its instream water quality criteria, applies the USEPA-recommended threshold of 200 cfu/100 mL for a geometric mean of sufficient samples, along with a single-sample maximum of 400 cfu/100 mL.[5] We apply this single-sample maximum of 400 cfu/100 mL for our fecal coliform model.

3.2.3 *Dissolved oxygen*

Unlike other criteria, which are set as maximums, the dissolved oxygen criterion is set as a minimum because aquatic organisms need a certain amount of dissolved oxygen to survive. As with fecal coliform, rather than providing a single number in its national recommended water quality criteria table for dissolved oxygen, it provides a reference to the "Gold Book" (USEPA, 1986). This document, in turn, provides a variety of dissolved oxygen criteria that differ for coldwater versus warmwater species, for early life stages versus other life stages, and for different averaging periods. Instantaneous minimum values range from 3 to 8 milligrams per liter (mg/L), and mean values range from 5.5 to 9.5 mg/L.

For comparison, West Virginia's water quality criteria range from 4 mg/L in certain locations on the large Ohio and Kanawha Rivers, to 5 mg/L in warmwater streams, to more stringent levels in coldwater streams (6

[4] This geometric mean is to be calculated using five or more samples within a 30-day period.
[5] 47 Code of State Rules Series 2, Appendix E, Section 8.13. While West Virginia's criterion of 400 cfu/100 mL cannot be exceeded in "more than ten percent of all samples taken during the month," this is essentially a single-sample maximum because more than one sample are rarely collected in a single month.

mg/L at any time and 7 mg/L in spawning areas.[6] Because our model applies to a wide range of stream types and sizes across a broad geographic area, we selected a threshold of 5 mg/L.

3.2.4 *Specific conductivity*

Specific conductivity measures the ability of water to conduct electricity and is a commonly used measure of dissolved ions in surface waters. These ions include a variety of positively charged cations (sodium, calcium, magnesium, potassium) and anions (chloride, bicarbonate, carbonate, sulfate), among others. Conductivity typically increases in surface waters due to earth disturbances such as coal mines, road construction, and urbanization.

USEPA does not provide a national recommended water quality criterion for conductivity. It does provide a recommended criterion for dissolved solids and salinity: 250 mg/L for chlorides and sulfates in domestic water supplies. While related to conductivity, the concentration of dissolved chlorides and sulfates uses different units and is not directly applicable to choosing a threshold for conductivity.

USEPA recently studied central Appalachian streams and calculated a field-based aquatic life benchmark of 300 microsiemens per centimeter (µS/cm) for conductivity (USEPA, 2011). This benchmark is expected to avoid the local extirpation of 95 percent of native species. The model was generated using state agency data collected in West Virginia and was validated using data collected in Kentucky. According to this report:

> The benchmark is applicable to mixtures of ions dominated by salts of Ca^{2+}, Mg^{2+}, SO_4^{2-} and HCO_3^{-} at a circum-neutral to alkaline pH. The impetus for the benchmark is the observation that high conductivities in streams below surface coal mining operations, especially mountaintop mining and valley fills, are associated with impairment of aquatic life. However, application of the benchmark is not limited to that source. (USEPA, 2011, p. viii)

Given that this recent study underwent rigorous review by a panel from USEPA’s Science Advisory Board, we applied this threshold of 300 µS/cm to our conductivity model.

3.3 Modeling results

In this section, predictions of current conditions are visualized in a spatially explicit manner using GIS. These results are then summarized and mapped by county, based on the percentage of catchments within each county not meeting the thresholds established for each parameter. The BRT output includes a list of the predictor variables used in each model, ordered and scored by their relative importance in structuring the predictive response, which can aid in determining stressors and targeting management options. Table 12 summarizes the modeling results, including model strength (CV correlation) and the most influential predictor variables and their relative weights.

[6] 47 Code of State Rules Series 2, Appendix E, Section 8.12.

Table 12: Water quality model results summary

Parameter	Model statistics	Most influential variables with weights	Unit of measurement
pH	• 3,806 locations with at least 3 distinct sample dates reporting pH measurements • Data ranged from 2000-2012 • CV correlation = 0.664 ± 0.009 • Model results extrapolated to 270,756 catchments	• Network percent carbonate geology (25.95) • Network percent barren land (7.28) • Network percent shale geology (7.00) • Network percent grassland (6.28) • Network impervious surface cover (5.35)	Predicted 10th percentile pH measurement (standard units)
Fecal coliform	• 4,206 sample locations reporting fecal coliform measurements • Data ranged from 2000-2012 • CV correlation = 0.588 ± 0.012 • Model results extrapolated to 270,756 catchments	• Network impervious surface cover (10.63) • Catchment minimum elevation (8.11) • Network baseflow index (7.72) • Network percent grassland (7.49) • Network road crossing density (7.43)	Predicted 90th percentile fecal coliform measurement (cfu/100 mL)
Dissolved oxygen	• 6,051 sample locations reporting DO measurements between June and September • Data ranged from 2000-2012 • CV correlation = 0.504 ± 0.012 • Model results extrapolated to 270,756 catchments	• Catchment mean annual temp (26.48) • Network baseflow index (10.71) • Network cattle density (7.23) • Catchment minimum elevation (6.28) • Network percent agriculture (5.37)	Predicted summer dissolved oxygen measurement (mg/L)
Specific conductivity	• 3,942 locations with at least 3 distinct sample dates reporting specific conductivity measurements • Data ranged from 2000-2012 • CV correlation = 0.857 ± 0.004 • Model results extrapolated to 270,756 catchments	• Network baseflow index (16.05) • Network impervious surface cover (14.84) • Catchment mean annual precip (12.30) • Network percent shale geology (10.34) • Network percent carbonate geology (9.44)	Predicted 90th percentile conductivity measurement (µS/cm)

Note: As described in Section 3.2.3, the dissolved oxygen prediction is not based on a specific percentile.

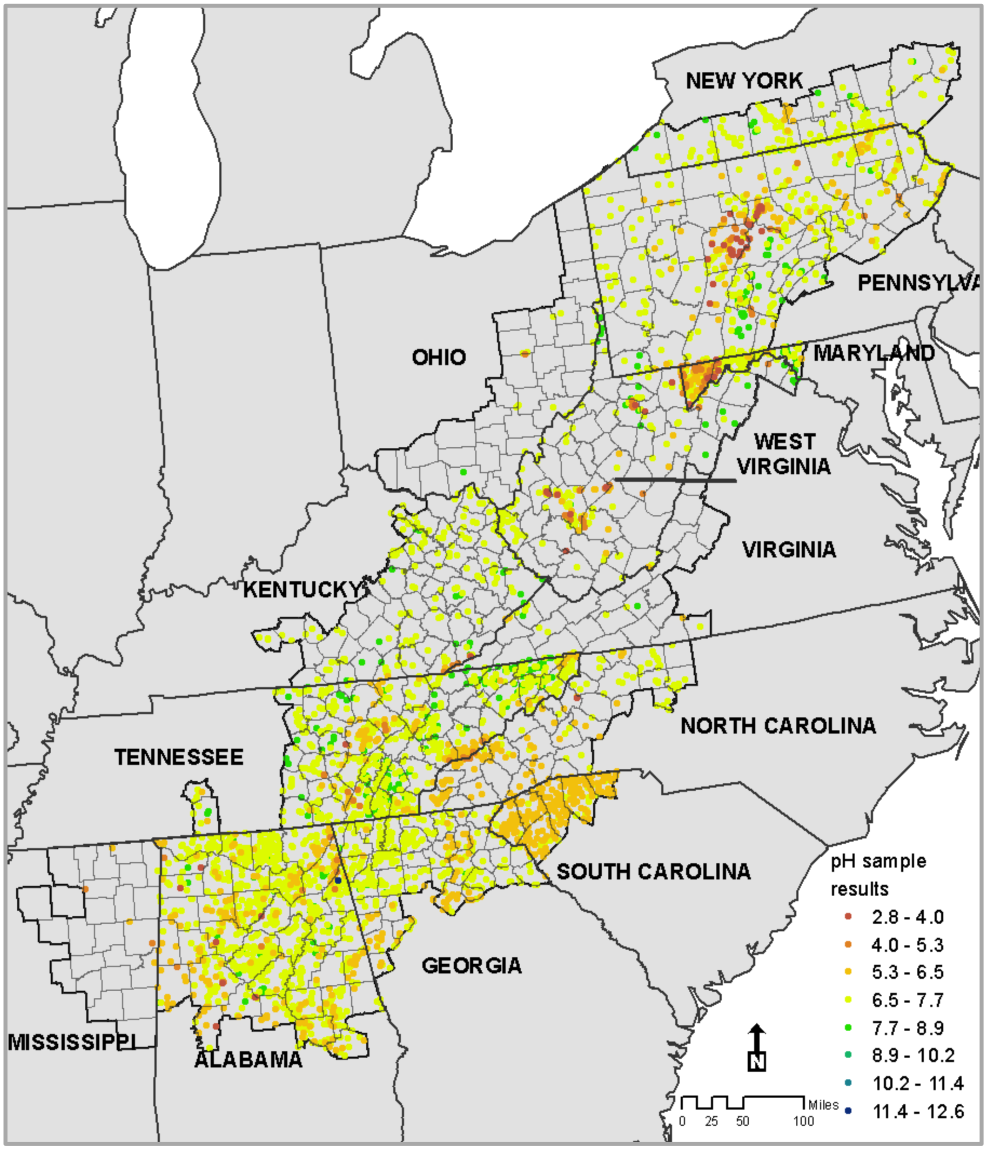
3.3.1 *pH*

For the pH model, 67 predictors were evaluated. From that list, 37 variables were removed due to statistical redundancy (r > 0.6) or logical redundancy, resulting in a final list of 30 predictor variables for the BRT model and assessment. A preliminary model was run to determine which additional predictor variables could be removed from the analysis because of minimal contribution to the final model. During this preliminary modeling, an additional 12 variables were indicated as very low relative influence (less than 1.0) and were removed from the final model. The final model therefore utilized 18 predictor variables. See Appendix B for a full data dictionary.

For the response variable, we compiled instream pH monitoring data for 3,806 distinct catchments, with collection dates for the data ranging from 2000 to 2012.

Response data for catchments were only used if two or more pH samples were taken from that catchment between 2000 and 2012. A review of these pH samples shows that low pH is more common than high pH across the region; therefore, we used the 10th percentile value to characterize each catchment in the model. While not the most acidic value measured in each catchment, the 10th percentile provides an indication of a relatively acidic result. Figure 18 maps the sampling sites used to construct the model.

Figure 18: pH sample results (10th percentile) used in the model



The BRT output includes a list of the predictor variables used in the model, ordered and scored by their relative importance. The relative importance values are based on the number of times a variable is selected for splitting, weighted by the squared improvement to the model as a result of each split, and averaged over all trees (Friedman and Meulman, 2003). The relative influence score is scaled so that the sum of the scores for all variables adds to 100, where higher numbers indicate greater influence, as show in Table 13.

Figure 19: (A) Predicted 10th percentile pH values; (B) Predicted percent of county catchments below the pH threshold

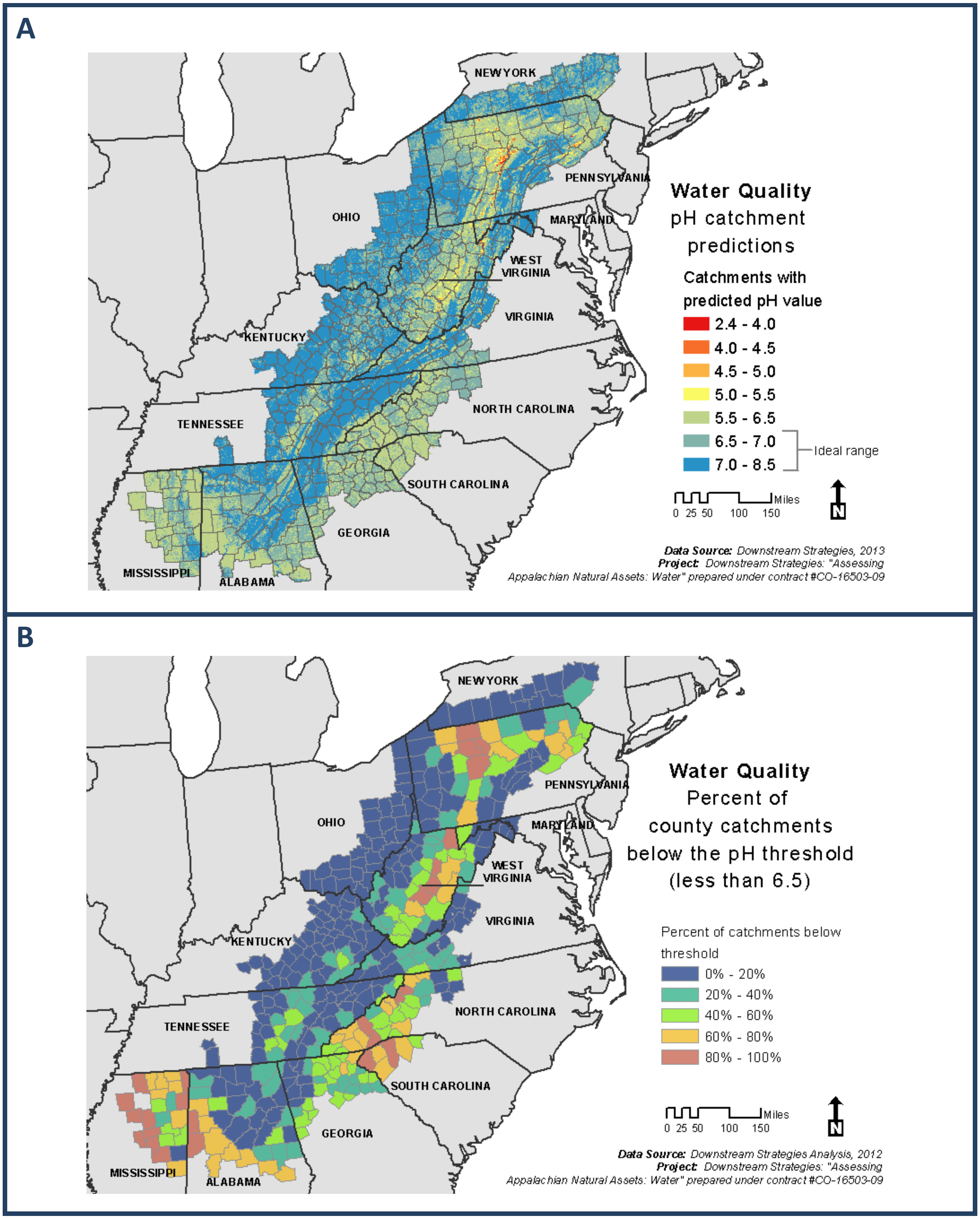


Table 13: Predictor variable influence for pH model

Variable of influence	Measurement	Relative influence	Data source
Network carbonate bedrock geology	Percent of network drainage area that has carbonate bedrock geology	26.0	USGS
Network barren land cover	Percent of network drainage area that is barren land area	7.3	NLCD 2006
Network shale bedrock geology	Percent of network drainage area that has shale bedrock geology	7.0	USGS
Network grassland cover	Percent of network drainage area that is grassland/herbaceous area	6.3	NLCD 2006
Network impervious surface cover	Percent of network drainage area that is impervious	5.4	NLCD 2006
Network baseflow index	Percent of network streamflow that can be attributed to ground-water discharge into stream	5.2	USGS
Catchment mean annual precipitation	Mean annual precipitation per catchment, millimeters	5.1	NHD PLUS
Network sandstone bedrock geology	Percent of network drainage area that has sandstone bedrock geology	4.9	USGS
Catchment minimum elevation	Minimum elevation of local catchment	4.8	NHD PLUS
Catchment forest cover	Percent of the local catchment area that is forest land area	4.7	NLCD 2006
Network surface water use	Total network surface water use by county, millions gallons per day/km2	4.3	NFHP
Network drainage area	Square kilometers of network drainage area	4.0	NHD PLUS
Network shrub/scrub land cover	Percent of network drainage area that is shrub/scrub area	3.5	NLCD 2006
Catchment barren land cover	Percent of the local catchment area that is barren land area	2.8	NLCD 2006
Network agriculture land cover	Percent of network drainage area that is agricultural area	2.8	NLCD 2006
Network ground water use	Total network groundwater use by county, millions gallons per day/km2	2.2	NFHP
Network wetland cover	Percent of network drainage area that is wetland area	1.9	NLCD 2006
Catchment road crossing density	Count of road crossing per square kilometer, #/km2 in catchment	1.8	NFHP

Note: Network variables include the landscape data for the catchment and all upstream catchments.

We then extrapolated the BRT model to all catchments, which allowed us to predict pH results in unsampled catchments. Panel A of Figure 19 shows the predicted 10th percentile pH value for each 1:100k catchment in the ARC region. Panel B of Figure 19 shows the percentage of catchments in each county that have predicted values less than the threshold of 6.5 standard units.

Generally, these maps show areas of high predicted pH levels where geology type is dominated by limestone. Areas with high forest cover show lower predicted pH levels, consistent with acid rain deposition and the low buffering capacities observed in forest soils. Low predicted pH levels found in Mississippi and Alabama are consistent with natural background levels observed in these areas. Areas with low predicted pH levels are also found in pockets in Pennsylvania and West Virginia; these areas are typically associated with active and historic mining of high-sulfur coal, which can be expected to contribute acidity and lower pH.

3.3.2 *Fecal coliform*

For the fecal coliform model, 67 predictors were evaluated. From that list, 31 variables were removed due to statistical redundancy ($r > 0.6$) or logical redundancy, resulting in a final list of 36 predictor variables for the BRT model and assessment. A preliminary model was run to determine which additional predictor variables could be removed from the analysis because of minimal contribution to the final model. During this preliminary modeling, an additional 17 variables were indicated as very low relative influence (less than 1.0) and were removed from the final model. The final model utilized 19 predictor variables. See Appendix B for a full data dictionary.

For the response variable, we compiled instream fecal coliform monitoring data for 4,206 distinct catchments, with collection dates ranging from 2000 to 2012.

All fecal coliform samples taken within a catchment were analyzed, and the 90th percentile value for each catchment was calculated. This value was used to characterize the catchment for the model. Rather than using an arithmetic or geometric mean, the 90th percentile provides an indication of a relatively high result found in each county. Figure 20 maps all of the sampling sites that were used to construct the model.

The BRT output includes a list of the predictor variables used in the model, ordered and scored by their relative importance. The relative influence score is scaled so that the sum of the scores for all variables adds to 100, where higher numbers indicate greater influence, as show in Table 14.

We then extrapolated the BRT model to all catchments to predict fecal coliform results in unsampled catchments. Panel A in Figure 21shows the predicted 90th percentile fecal coliform value for each catchment. Panel B in Figure 21 shows the percentage of catchments in each county where the predicted fecal coliform value exceeds the threshold of 400 cfu/100 mL.

Large areas of low predicted fecal coliform concentrations correspond with high forest cover, such as the Allegheny National Forest in Pennsylvania and the Monongahela and George Washington National Forests in West Virginia and Virginia. Moving south, the assessed areas in North Carolina, South Carolina, and Georgia all show high predicted coliform concentrations in areas that are generally urbanized. This is likely due to significant loading from nonpoint and point sources associated with recent, rapid urban and suburban development in these areas. In eastern Kentucky, high predicted coliform concentrations could be consistent with high incidence of untreated sewage discharges and failing decentralized septic systems.

Figure 20: Fecal coliform sample results (90th percentile) used in the model

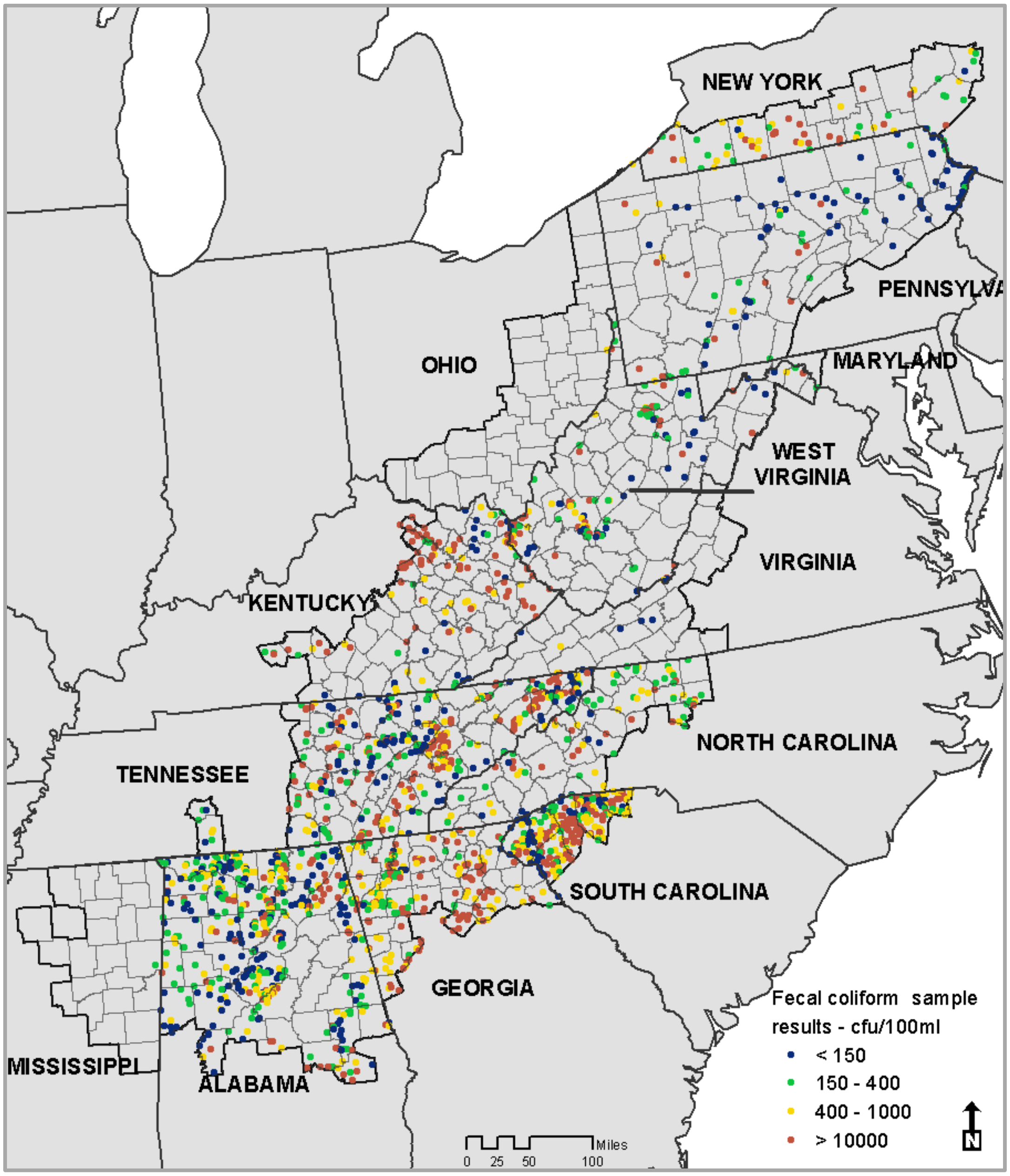


Figure 21: (A) Predicted 90th percentile fecal coliform values; (B) Predicted percent of county catchments above the fecal coliform threshold

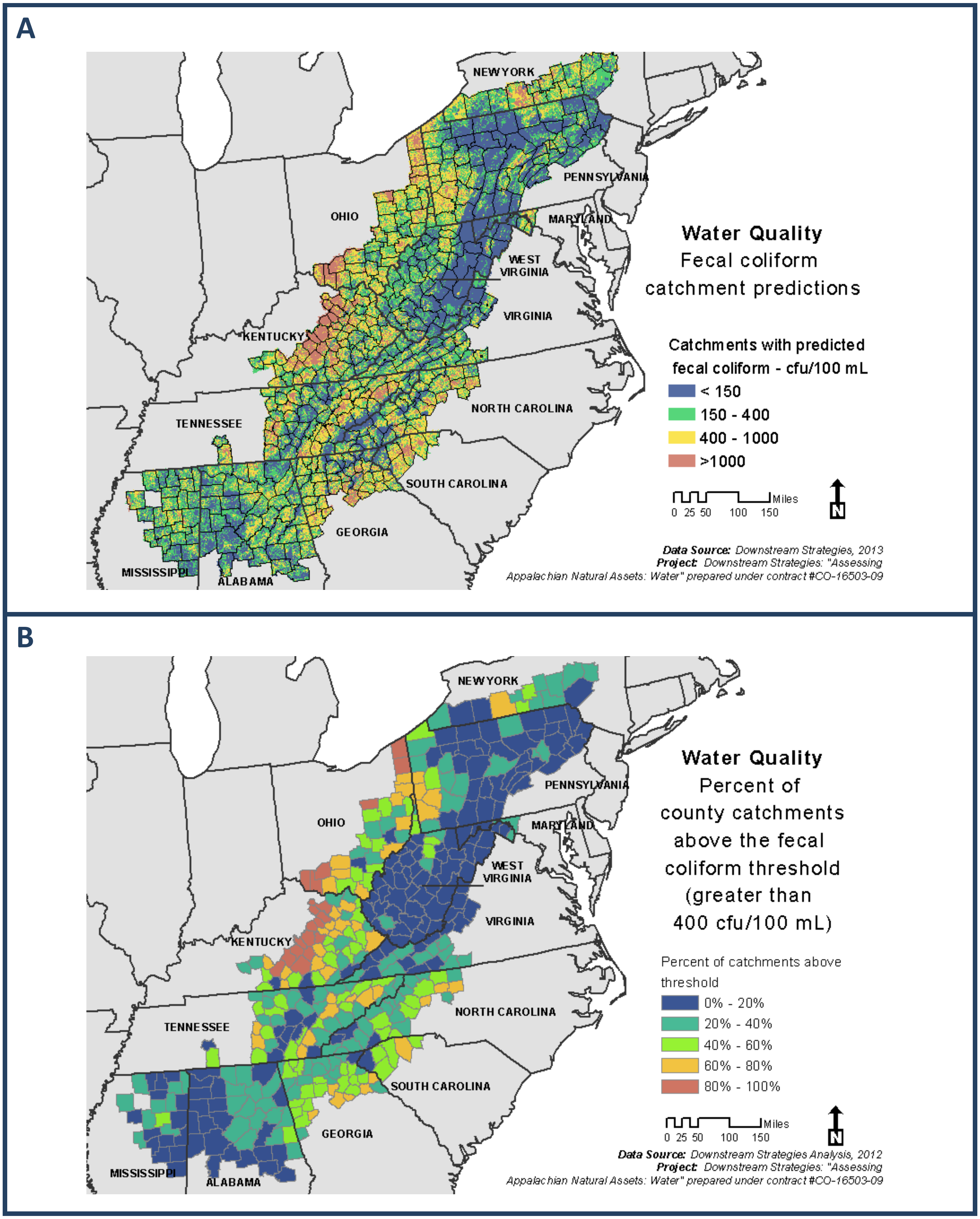


Table 14: Predictor variable influence for fecal coliform model

Variable of influence	Measurement	Relative influence	Data source
Network impervious surface cover	Percent of network drainage area that is impervious	10.6	NLCD 2006
Catchment minimum elevation	Minimum elevation of local catchment	8.1	NHD Plus
Network baseflow index	Percent of network streamflow that can be attributed to ground-water discharge into stream	7.7	USGS
Network grassland cover	Percent of network drainage area that is grassland/herbaceous area	7.5	NLCD 2006
Network road crossing density	Count of road crossing per square kilometer, #/km2 in network	7.4	NFHP
Network agriculture land cover	Percent of network drainage area that is agricultural area	7.2	NLCD 2006
Catchment road crossing density	Count of road crossing per square kilometer, #/km2 in catchment	6.9	NFHP
Catchment population density	Count of population per square kilometer, #/km2 in catchment	5.8	NFHP
Network ground water use	Total network groundwater use by county, millions gallons per day/km2	5.6	NFHP
Network drainage area	Square kilometers of network drainage area	5.3	NHD Plus
Catchment mean annual precipitation	Mean annual precipitation per catchment, millimeters	5.2	NHD Plus
Network surface water use	Total network surface water use by county, millions gallons per day/km2	4.7	NFHP
Catchment surface water	Percent of catchment that has surface water area	4.0	USGS
Network sandstone bedrock geology	Percent of network drainage area that has sandstone bedrock geology	3.5	USGS
Catchment road density	Count of road length per square kilometer, km/km2 in catchment	3.1	NFHP
Network barren land cover	Percent of network drainage area that is barren land area	2.2	NLCD 2006
Network carbonate bedrock geology	Percent of network drainage area that has carbonate bedrock geology	2.0	USGS
Network shale bedrock geology	Percent of network drainage area that has shale bedrock geology	1.6	USGS
Catchment barren land cover	Percent of catchment drainage area that is barren land area	1.5	NLCD 2006

Note: Network variables include the landscape data for the catchment and all upstream catchments.

3.3.3 *Dissolved oxygen*

For the dissolved oxygen model, 67 predictors were evaluated. From that list, 37 variables were removed due to statistical redundancy (r > 0.6) or logical redundancy, resulting in a final list of 30 predictor variables for the BRT model and assessment. A preliminary model was run to determine which additional predictor variables could be removed from the analysis because of minimal contribution to the final model. During this preliminary modeling, an additional 12 variables were indicated as very low relative influence (less than 1.0) and were removed from the final model. The final model utilized 18 predictor variables. See Appendix B for a full data dictionary.

For the response variable, we complied instream summer dissolved oxygen data for 6,051 distinct catchments, with collection dates ranging from 2000 to 2012.

For catchments that had multiple summer (June-September) dissolved oxygen samples, we captured the most recent value. Figure 22 maps all of the sampling sites that were used to construct the model.

The BRT output includes a list of the predictor variables used in the model, ordered and scored by their relative importance. The relative influence score is scaled so that the sum of the scores for all variables adds to 100, where higher numbers indicate greater influence, as shown in Table 15.

We then extrapolated the BRT model to all catchments to predict dissolved oxygen results in unsampled catchments. Panel A in Figure 23 shows the predicted summer dissolved oxygen value for each catchment. Panel B in Figure 23 shows the percentage of catchments in each county where the predicted summer dissolved oxygen value was less than the threshold of 5 mg/L.

Most of the assessed area shows high predicted dissolved oxygen, particularly in higher elevation and forested areas such as western Virginia and eastern West Virginia. Areas with low predicted dissolved oxygen are found in Mississippi and Alabama, which was expected considering they are areas with low slope and warm climates. Mississippi in particular has low dissolved oxygen due to organic enrichment.

Figure 22: Summer dissolved oxygen sample results used in the model

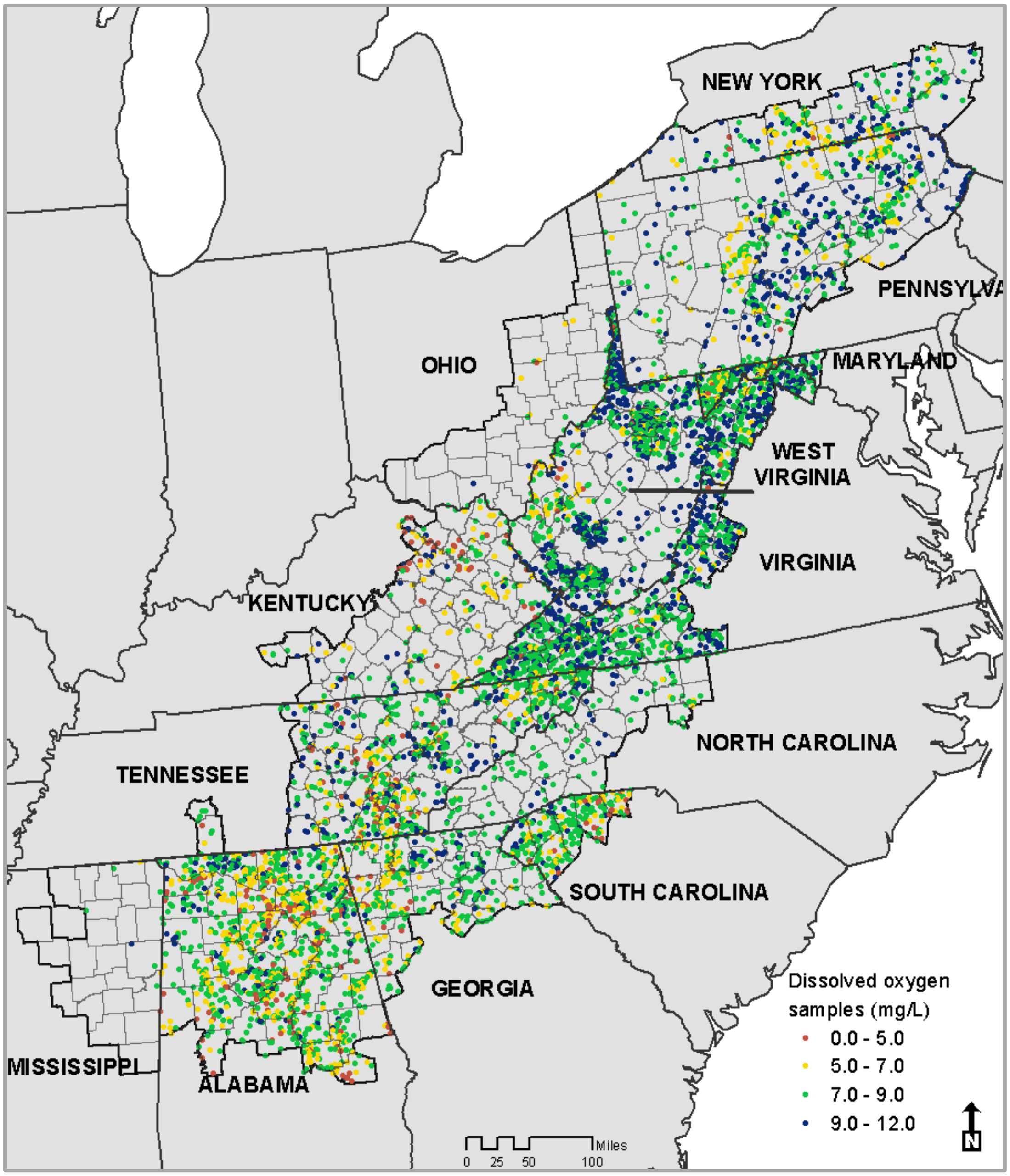


Figure 23: (A) Predicted summer dissolved oxygen values; (B) Predicted percent of county catchments below the dissolved oxygen threshold

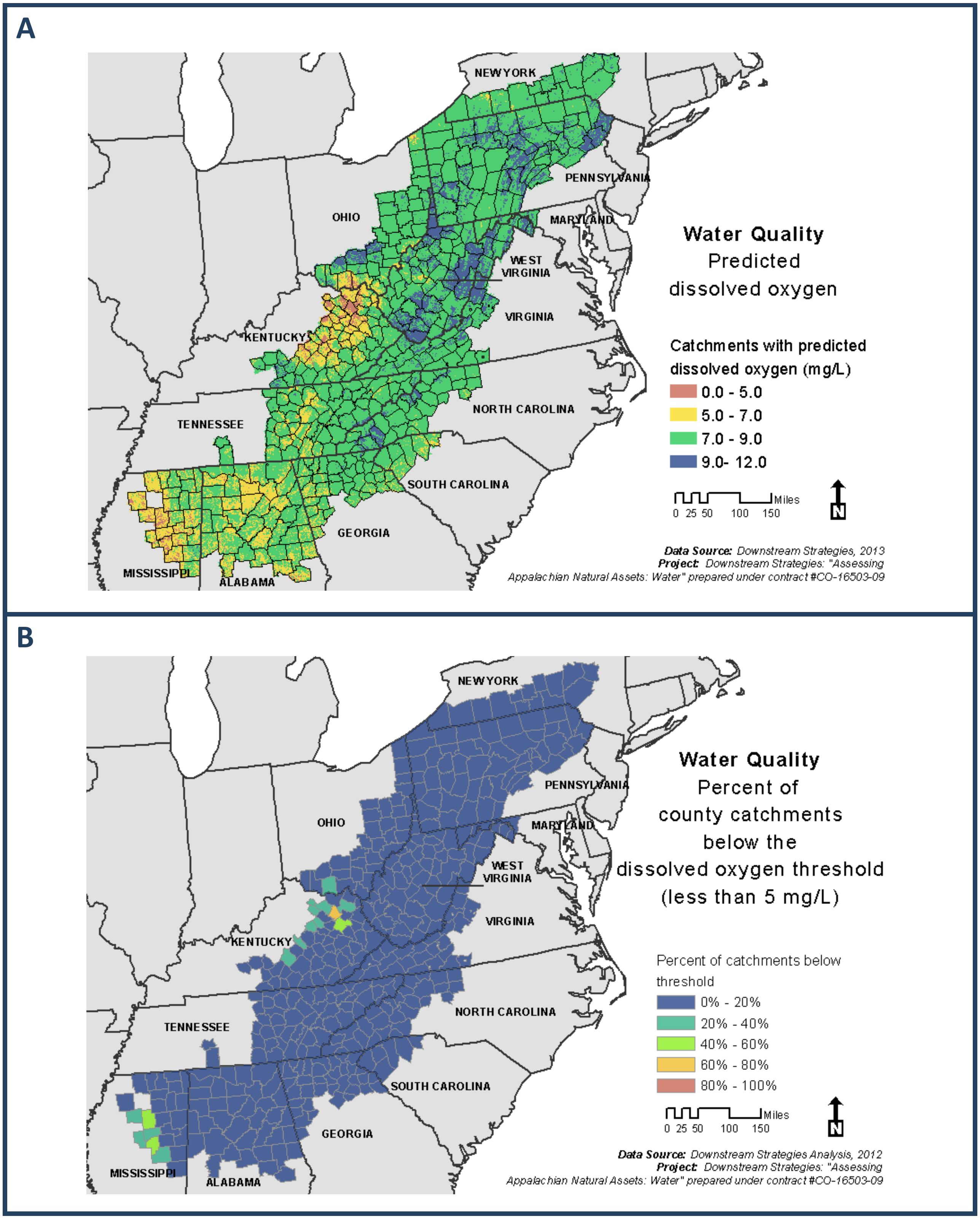


Table 15: Predictor variable influence for dissolved oxygen model

Variable of influence	Measurement	Relative influence	Data source
Catchment mean annual air temperature	Mean annual air temperature in catchment, degrees centigrade*10	26.5	NHD Plus
Network baseflow index	Percent of network streamflow that can be attributed to ground-water discharge into stream	10.7	USGS
Network cattle density	Network average number of cattle per acre	7.2	NFHP
Catchment minimum elevation	Minimum elevation of local catchment	6.3	NHD Plus
Network agriculture land cover	Percent of network drainage area that is agricultural area	5.4	NLCD 2006
Network ground water use	Total network groundwater use by county, millions gallons per day/km2	5.3	NFHP
Catchment flowline slope	Total slope of catchment flowline, cm/cm	4.8	NHD Plus
Network surface water use	Total network surface water use by county, millions gallons per day/km2	4.7	NFHP
Network grassland cover	Percent of network drainage area that is grassland/herbaceous area	3.8	NLCD 2006
Network road crossing density	Count of road crossing per square kilometer, #/km2 in network	3.6	NFHP
Network impervious surface cover	Percent of network drainage area that is impervious	3.3	NLCD 2006
Network sandstone bedrock geology	Percent of network drainage area that has sandstone bedrock geology	3.2	USGS
Network shale bedrock geology	Percent of network drainage area that has shale bedrock geology	3.0	USGS
Network carbonate bedrock geology	Percent of network drainage area that has carbonate bedrock geology	2.9	USGS
Network wetland cover	Percent of network drainage area that is wetland area	2.6	NLCD 2006
Catchment road crossing density	Count of road crossing per square kilometer, #/km2 in catchment	2.4	NFHP
Network barren land cover	Percent of network drainage area that is barren land area	2.2	NLCD 2006
Catchment shrub/scrub land cover	Percent of catchment drainage area that is shrub/scrub land area	2.1	NLCD 2006

Note: Network variables include the landscape data for the catchment and all upstream catchments.

3.3.4 *Specific conductivity*

For the specific conductivity model, 67 predictors were evaluated. From that list, 34 variables were removed due to statistical redundancy (r > 0.6) or logical redundancy, resulting in a final list of 33 predictor variables for the BRT model and assessment. A preliminary model was run to determine which additional predictor variables could be removed from the analysis because of minimal contribution to the final model. During this preliminary modeling, an additional 18 variables were indicated as very low relative influence (less than 1.0) and were removed from the final model. The final model utilized 15 predictor variables. See Appendix B for a full data dictionary.

For the response variable, we compiled instream specific conductivity monitoring data for 3,942 distinct catchments, with collection dates ranging from 2000 to 2012.

Response data for catchments were only used if three or more conductivity samples were taken from that catchment between 2000 and 2012. We used the 90th percentile value to characterize each catchment in the model. While not the highest conductivity measured in each catchment, the 90th percentile provides an indication of a relatively high conductivity result found in each catchment. Figure 18 maps the sampling sites used to construct the model.

The BRT output includes a list of the predictor variables used in the model, ordered and scored by their relative importance. The relative influence score is scaled so that the sum of the scores for all variables adds to 100, where higher numbers indicate greater influence, as show in Table 16.

We then extrapolated the BRT model to all catchments to predict specific conductivity results in unsampled areas. Panel A in Figure 25 shows the predicted 90th percentile specific conductivity value for each catchment. Panel B Figure 25 shows the percentage of catchments in each county where the predicted specific conductivity value exceeds the threshold of 300 µS/cm.

Large areas of low predicted conductivity can be observed in areas of high forest cover such as the Allegheny National Forest in Pennsylvania and the Monongahela and George Washington National Forests in West Virginia and Virginia. Areas with high predicted conductivity are found in eastern Kentucky, southeastern Ohio, southwestern Pennsylvania, southwestern Virginia and southern and northern West Virginia; these areas are all associated with active and historic coal mining, which can be expected to contribute to high conductivity. The area surrounding Birmingham, Alabama also shows high predicted conductivity due to runoff from impervious areas associated with urban and suburban development.

Figure 24: Specific conductivity sample results (90th percentile) used in the model

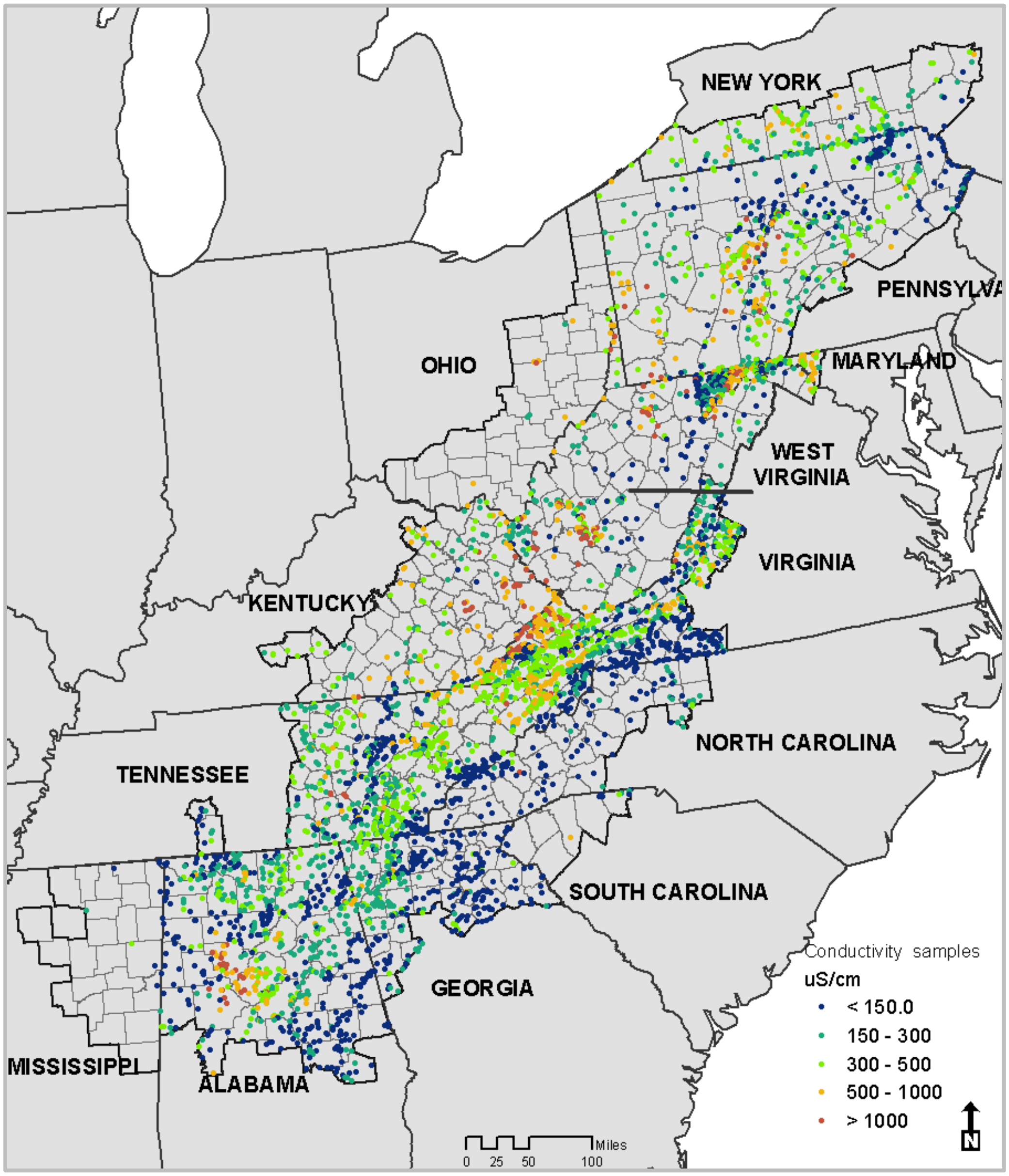


Figure 25: (A) Predicted 90th percentile specific conductivity values; (B) Predicted percent of county catchments above the specific conductivity threshold

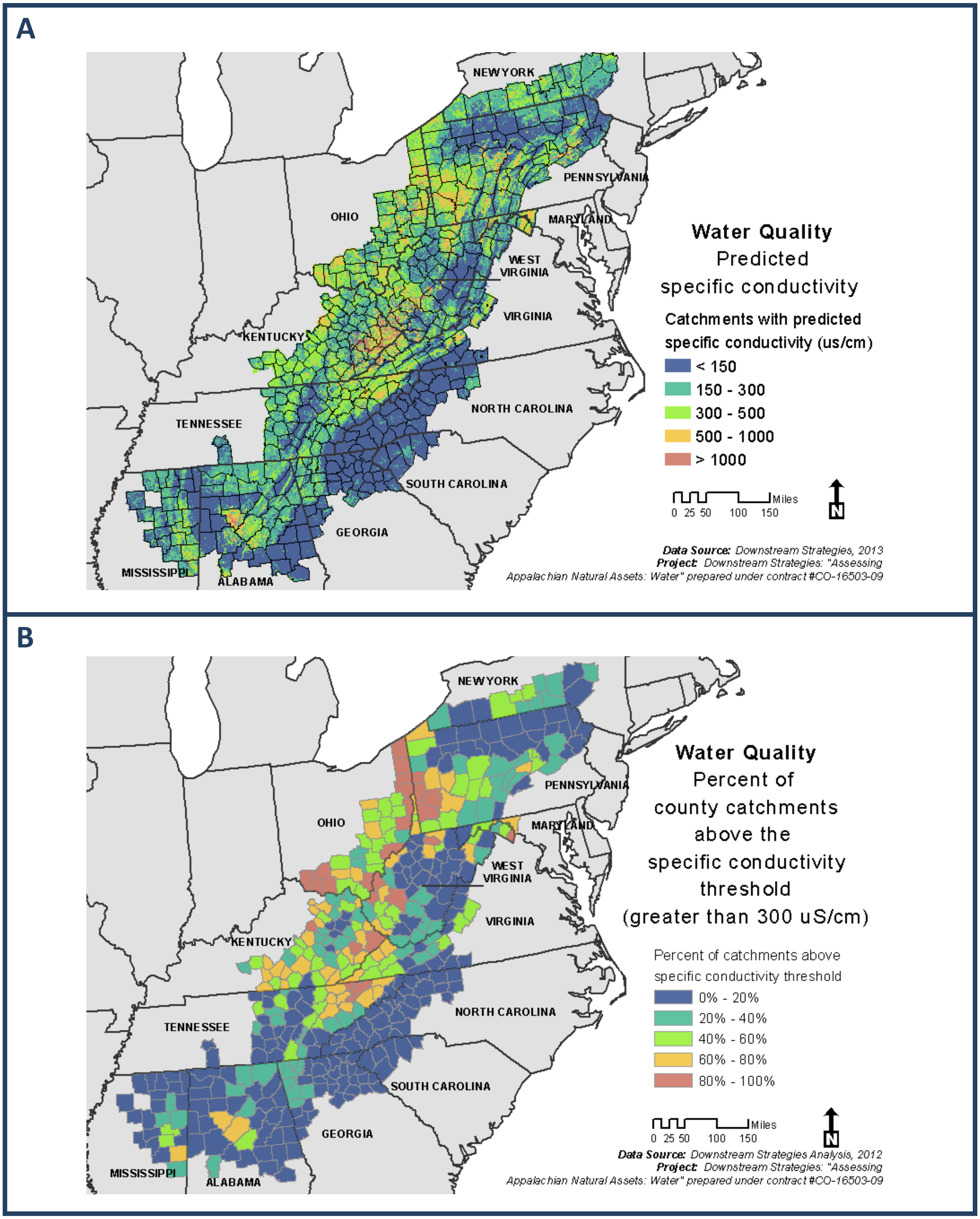


Table 16: Predictor variable influence for specific conductivity model

Variable of influence	Measurement	Relative influence	Data source
Network baseflow index	Percent of network streamflow that can be attributed to ground-water discharge into stream	16.0	USGS
Network impervious surface cover	Percent of network drainage area that is impervious	14.8	NLCD 2006
Catchment mean annual precipitation	Mean annual precipitation per catchment, millimeters	12.3	NHD Plus
Network shale bedrock geology	Percent of network drainage area that has shale bedrock geology	10.3	USGS
Network carbonate bedrock geology	Percent of network drainage area that has carbonate bedrock geology	9.4	USGS
Network barren land cover	Percent of network drainage area that is barren land area	9.0	NLCD 2006
Catchment minimum elevation	Minimum elevation of local catchment	5.4	NHD Plus
Network road crossing density	Count of road crossing per square kilometer, #/km2 in network	4.6	NFHP
Network surface water use	Total network surface water use by county, millions gallons per day/km2	4.5	NFHP
Network agriculture land cover	Percent of network drainage area that is agricultural area	3.9	NLCD 2006
Catchment forest cover	Percent of the local catchment area that is forest land area	2.4	NLCD 2006
Network grassland cover	Percent of network drainage area that is grassland/herbaceous area	2.0	NLCD 2006
Network drainage area	Square kilometers of network drainage area	2.0	NHD Plus
Network ground water use	Total network groundwater use by county, millions gallons per day/km2	1.7	NFHP
Network mafic bedrock geology	Percent of network drainage area that has mafic bedrock geology	1.6	USGS

Note: Network variables include the landscape data for the catchment and all upstream catchments.

3.4 Discussion

Throughout the region, mountainous, forested counties and those far from large cities and large rivers tend to have the best water quality. The simple explanation is that the higher mountainous areas are not conducive to agriculture or transportation infrastructure, which often limits industry and development. These counties also contain vast stretches of protected lands. These include the Allegheny National Forest in Pennsylvania, the Monongahela National Forest in West Virginia, the George Washington National Forest in Virginia, the Pisgah and Nantahala National Forests and Great Smoky Mountains National Park in North Carolina and Tennessee, the Chattahoochee National Forest in Georgia, and the Daniel Boone National Forest in Kentucky.

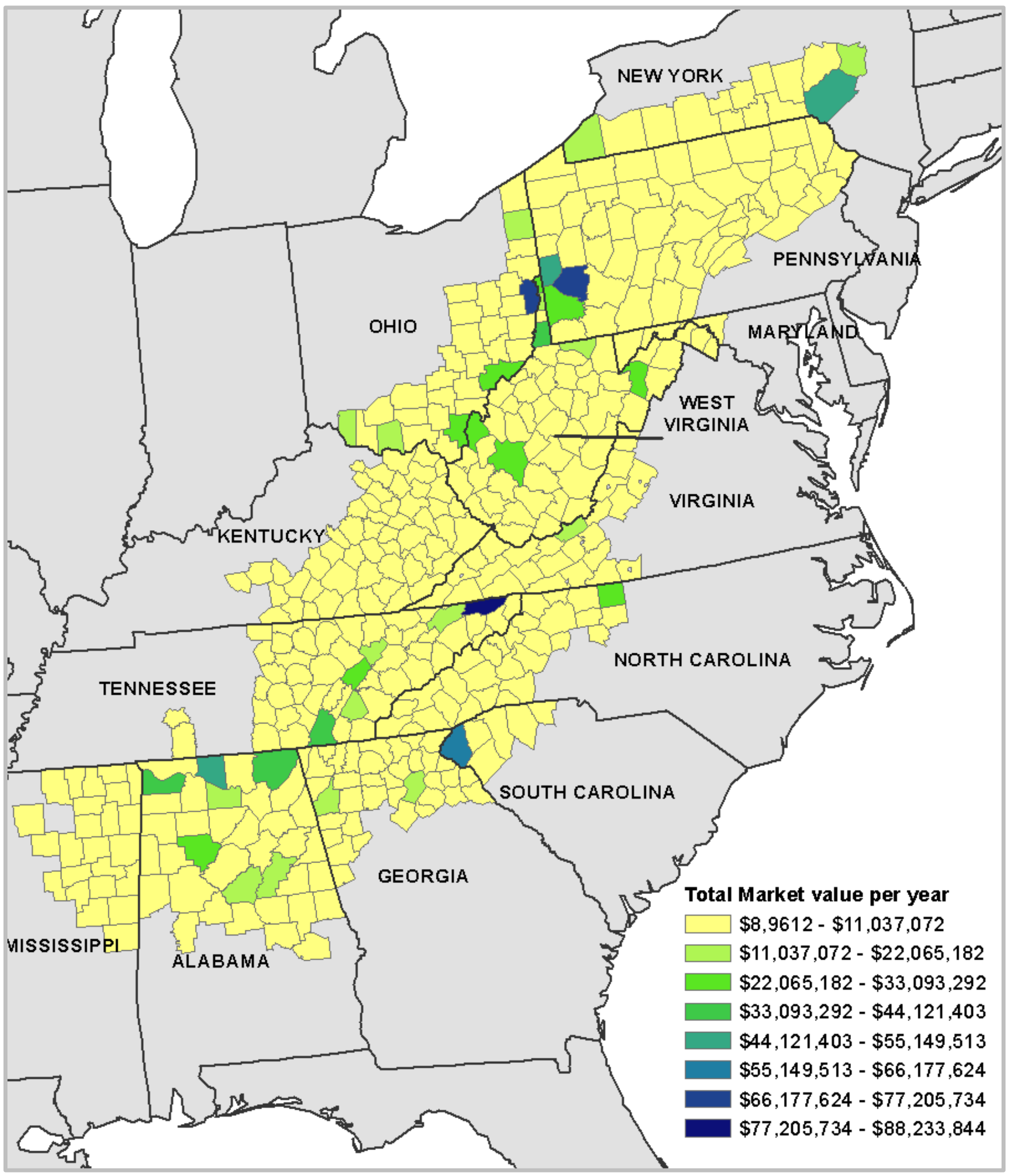
Not all federally protected lands have high water quality. The Wayne National Forest in Ohio and the Bankhead National Forest in Alabama are among the exceptions. Counties that exhibit poorer water quality are generally those in mining, agricultural, or urbanized areas. As mentioned previously, agriculture is prevalent in the lower-elevation, less-mountainous, peripheral counties of the ARC region, especially in the southern region along the Tennessee River and its tributaries. In the north, agriculture is present in southwestern Pennsylvania, but the industrial boom that occurred along the major waterways of the Monongahela, Allegheny, and Ohio Rivers heavily influences water quality. This region is also subject to current and historical coal mining influences. Mining also influences water quality in the Cumberland Mountain region of southern West Virginia, eastern Kentucky, and southwestern Virginia. Despite being heavily forested, the impacts from this actively mined area are evident in our analysis.

The areas surrounding Pittsburgh, Pennsylvania and Knoxville, Tennessee, as well as the Upper Ohio River Valley are areas of high concern, also likely due to urbanization and industrialization. The coalfields of eastern Kentucky and southern West Virginia show areas of poor water quality, again likely from legacy and ongoing coal mining operations. The other areas of highest concern for water quality fall mainly within highly agricultural regions, including the Tennessee River valley, Shenandoah Valley, and the western edge of the ARC boundary in Ohio and Kentucky where the Appalachian Plateau transitions to farmland.

4. WATER VALUE

A variety of existing methods have been used by economists to place monetary value on natural resources like water. These methods include information derived from markets (such as observed market prices) and information estimated from survey data or observed behaviors. In this section, the monetary values for surface water resources are based on both market information from water withdrawal uses and non-market information derived from contingent valuation studies. In both cases, the values reflect a willingness-to-pay (WTP) for the water resource. Figure 28 provides an example of the total water market values across the ARC region, and further explanation is provided in the following section. Industrial and drinking water uses were found to have the most effect on a county's water value.

Figure 28: Total market value per county



4.1 Components and framework

Both market and non-market methods of valuation were used to quantify a county's water value. The market valuation uses imputed values for water use and county-level surface water withdrawals by sector to determine total valuations for water use per county. These imputed values were derived for four sectors of water users: agricultural, domestic, industrial processing, and thermoelectric. Non-market values were derived using a benefits transfer process from contingent valuation studies, which were used to value surface water quality. This approach includes techniques such as contingent valuation, property value hedonics, and the travel cost method.

Indicators or measurements for both market and non-market are listed in Table 17. These five indictors include:

1. **Market value-agricultural/irrigation value**: This value is estimated for water uses relating to agricultural and irrigation use across the ARC region.
2. **Market value-domestic value:** A value related to drinking water that includes both distributed and private water consumption through wells or springs.
3. **Market value-industrial processing:** This value reflects a dollar amount related to water withdrawn for manufacturing and/or the production of commodities.
4. **Market value-thermoelectric generation value:** This value is calculated based on the water usage for generating electricity from steam-driven generators.
5. **Non-market value-willingness to pay per household for surface water quality:** A calculated value per household for clean surface water.
6. **Non-market value-surface water quality value:** The value of surface water quality per county based on the number of households per county and the benefits transfer process.

Table 17: Water value assessment components

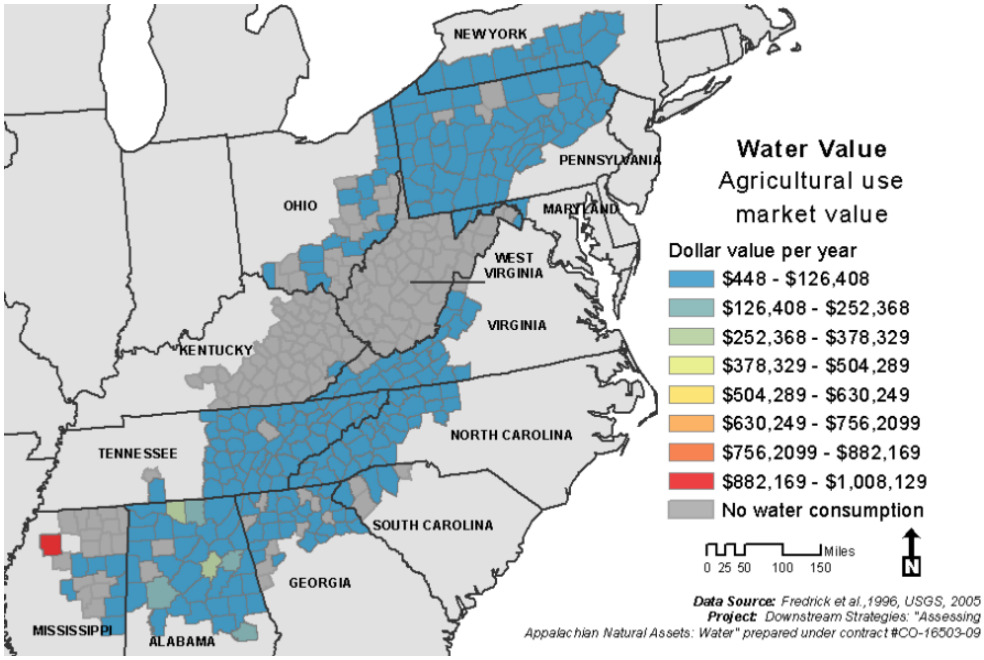
Indicator	Value category	Metric	Denominator	Unit of measurement	Data source and date
Agricultural/irrigation value	Market	• Water consumption * value multiplier	N/A	Annual dollar value	Kenny et al., 2009
Domestic value	Market	• Water consumption * value multiplier	N/A	Annual dollar value	Kenny et al., 2009
Industrial processing value	Market	• Water consumption * value multiplier	N/A	Annual dollar value	Kenny et al., 2009
Thermoelectric generation value	Market	• Water consumption * value multiplier	N/A	Annual dollar value	Kenny et al., 2009
Surface water quality willingness to pay per household	Non-market	• Dollar value per household	N/A	Annual dollar value	Report analysis
Surface water quality value	Non-market	• Total value per county	N/A	Annual dollar value	Report analysis

4.2 Water market value

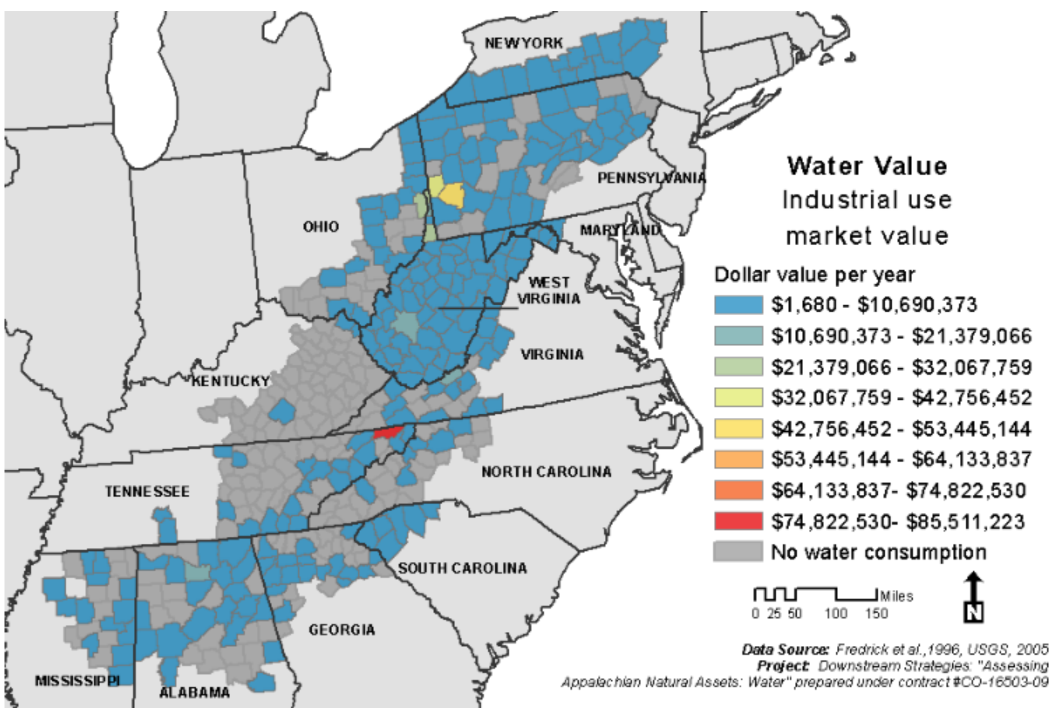
To understand market valuation, imputed values for water use and county-level data based on surface water withdrawals by sector were used to determine total valuations for water use per county. These imputed values (shown in Table 18) were derived for four sectors of water users: agricultural, domestic, industrial processing, and thermoelectric.

Figure 29: (A) Agricultural and irrigation value and (B) industrial value

A



B



Data from Frederick et al. (1996) was used to impute reasonably accurate, relative values for water use by sector. In their summary of water valuation studies, national averages of water values were calculated by sector. Issues arise when trying to use these national averages, given the national variance in water supply. To adjust national averages to reflect eastern water values, the average water value for the 17 studies (Frederick et al. 1996) applicable to water values in the eastern US was computed as a percentage of the national average water value. This percentage was 38.5 percent (29 dollars per acre foot in the eastern US/75 dollars per acre foot for a national average). National average water values reported were, therefore, multiplied by 0.385 to adjust national averages to eastern water values. A gross domestic product deflator of 1.37 was used to adjust to the 1994 values from 2009 monetary values. Table 18 reports the water values used per sector that were used to compute the market value for this report.

Table 18: Water values by use sector

Use sector	2009 Water value (dollars per acre-foot)
Agricultural irrigation	40
Domestic self-supply and public supply	100
Industrial processing	150
Thermoelectric	20

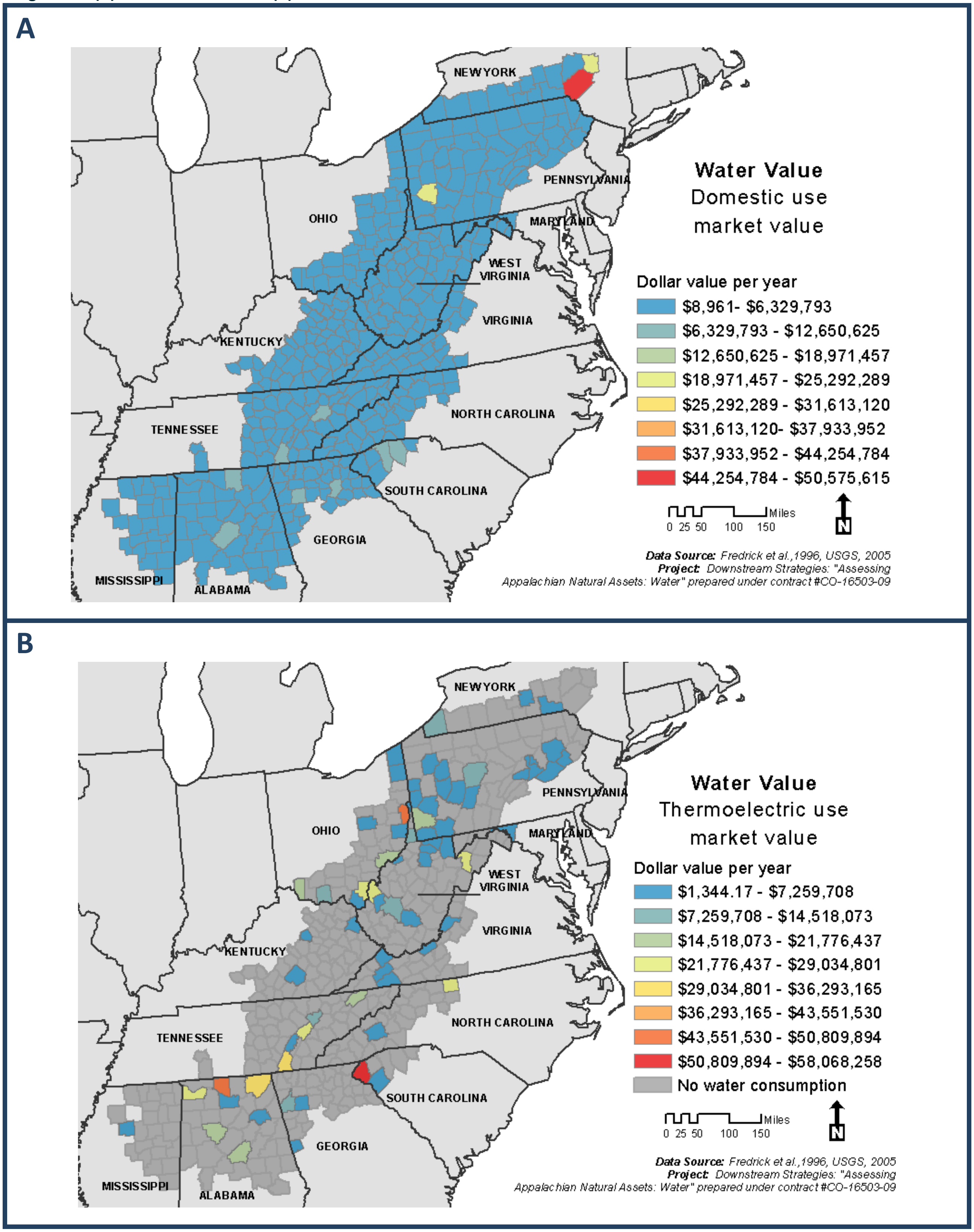
Note: Values are rounded.

There are many important factors to consider when calculating water value based on consumption. First, and perhaps most important, a wide variety of valuation methods have been used in the individual studies summarized by Frederick et al. (1996). Thus, the values generated from this analysis do not necessarily provide readily comparable estimates. Second, users must take care when comparing the values over time (or using them in the present period) because water values obtained from a particular study are a function of the demand and supply (e.g., technology) available at the time of the individual study. In other words, water use can vary considerably over time. Other important limitations specific to the value estimates include:

- quantity is the only dimension considered in the value estimates so that quality, which is important for both domestic and industrial water use values, is not directly reflected in the estimated water use values;
- timing of water use affects its value, and the values from this report do not necessarily reflect the value of uses within different seasons of the year;
- water use values vary widely among locations so that even within the same basin, allowances need to be made for the costs of transporting water from the water source to the site of use;
- the values for domestic use may be understated relative to other uses due to the estimation methods used;
- the study does not adequately reflect the fact that few water uses are completely consumptive; and
- the methods used to convert use values to 1994 dollars are imperfect.

Because of these caveats, the water use values per sector were considered reflective of relative values between sectors rather than absolute measures of water value.

Figure 30: (A) Domestic value and (B) thermoelectric value



4.2.1 *Agriculture and irrigation water value*

Panel A in Figure 29 shows the value of water used for agriculture and irrigation in Appalachian counties. Generally, there is a greater agricultural value in the southwestern portion of the region, with most counties lumped into the lower value categories of under approximately 127,000 dollars. West Virginia, with the exception of Jefferson County, withdraws zero gallons of water for agricultural or irrigation use. Pandola County, Mississippi is shown as an outlier with a value over a million dollars, consuming more than 23 mgd, mostly from groundwater. The next closest county, Limestone in Alabama, only consumes 6.9 mgd, where, according to a recent USEPA study, 65 percent of the groundwater withdrawal is primarily for rice production.

4.2.2 *Industrial water value*

Panel B of Figure 29 shows the industrial use value across the ARC region. The map highlights the industrial centers of Pittsburgh, Pennsylvania and the northern panhandle and Kanawha Valley of West Virginia, which are home to industries dependent on large quantities of water for use in various capacities. The outlier of the region is Sullivan County, Tennessee, with a value estimated at over 85 million dollars per year. Sullivan County consumes over 500 mgd, which is nearly 72 percent of Tennessee's total industrial withdrawal. This consumption is due in part to a large manufacturing base, employing over a half-million people with an annual payroll exceeding twelve million dollars with annual sales exceeding 140 billion dollars per year (US Economic Census, 2012). Manufacturing and industrial use of water resources play a significant role in the northeastern Tennessee economy.

4.2.3 *Domestic water value*

Domestic water use includes drinking water, sanitation, and lawn watering (Kenny et al., 2009). This water use includes both supplied water, such as water provided by a utility, and self-supplied withdrawals, such as private wells and springs that are mostly located in rural areas. Panel A in Figure 30 shows the market value for domestic consumption of water resources in the region. Generally, most counties in Appalachia that are more rural in nature have less-developed water resources. The value patterns follow population density, with one interesting exception. Delaware County, New York has the highest public water supply withdrawal of over 448 mgd (31 mgd when considering return), but has a very low population of 47,000, when compared to the regional average county population of 60,103. According to the Delaware County Soil and Water Conservation District, over nine million people are supplied with drinking water that comes from the Delaware County water system. The two Delaware county reservoirs—the Pepacton and Cannonsville—are part of the water system that serves New York City through a series of tunnels and aqueducts. These water supply resources have a market value of over 50 million dollars according to this study; however, when compared with consumers paying $3.39 per 748 gallons (NYC Water Board, 2013), the annual value of water delivered to consumers in New York City reaches over 1 billion dollars.

4.2.4 *Thermoelectric value*

The value of water to produce electricity was computed for each county in the region, though only a few counties actually have a thermoelectric plant. Panel B in Figure 30 shows the value of the water for electric production across the region, which appears to be evenly distributed. Thermoelectric water use is the largest consumer of water across the region, accounting for 45 percent of all withdrawals. These values are based on total consumption and do not include the return analysis presented in the water quantity section. Oconee County, South Carolina has the highest consumption value across the region. Located on Lake Keowee, the Oconee Nuclear Station began operation in the mid 1970s. This 2.6-gigawatt plant has produced over 500 million MWh since completion (Duke, 2013) A large portion of the water withdrawn by this plant is returned, but the computation of value considers water withdrawn and not consumed. States with the highest values include Alabama, where a majority of state plants are hydroelectric (Alabama Power, 2012), Ohio, where most of the plants are along the Ohio River, and Tennessee.

4.3 Water non-market value

In order to understand non-monetary or non-market values for water on a county-by-county basis, a meta-analysis was conducted. It is important to understand and quantify this value in order to account for the non-transactional economy and to place value on people's perceptions of what clean water is worth to them. This analysis combined the results of numerous studies to arrive at a value conclusion—in this case: what the current surface water quality is worth to county populations in the ARC region. Economists utilize two approaches to estimate monetary values that reflect what individuals are either: (1) willing to pay to acquire the resource if it is not owned by an individual or (2) willing to give up in exchange for this resource if it is owned by an individual.

Our approach calculates a monetary value based on the quality of surface water, which is estimated from econometric models using a meta-analysis of contingent valuation studies. We then apply a benefit-transfer method using these models. Johnston et al. (2005) provided a template for how to conduct this meta-analysis in terms of what explanatory variables to include in the models and what functional forms to use for the econometric models to explain WTP for a surface water quality change. Three different functional forms (semi-log, translog, and weighted semi-log based on the number of WTP observations obtained from the study) were estimated in order to assess the robustness in statistical results. The estimated coefficients from the three models and projected values for the explanatory variables were used to estimate county mean WTP per household for existing surface water quality. These mean WTP values represent our estimate of what would have been found if a contingent valuation study had been conducted with county-level accuracy throughout the entire Appalachian region to value surface water quality.

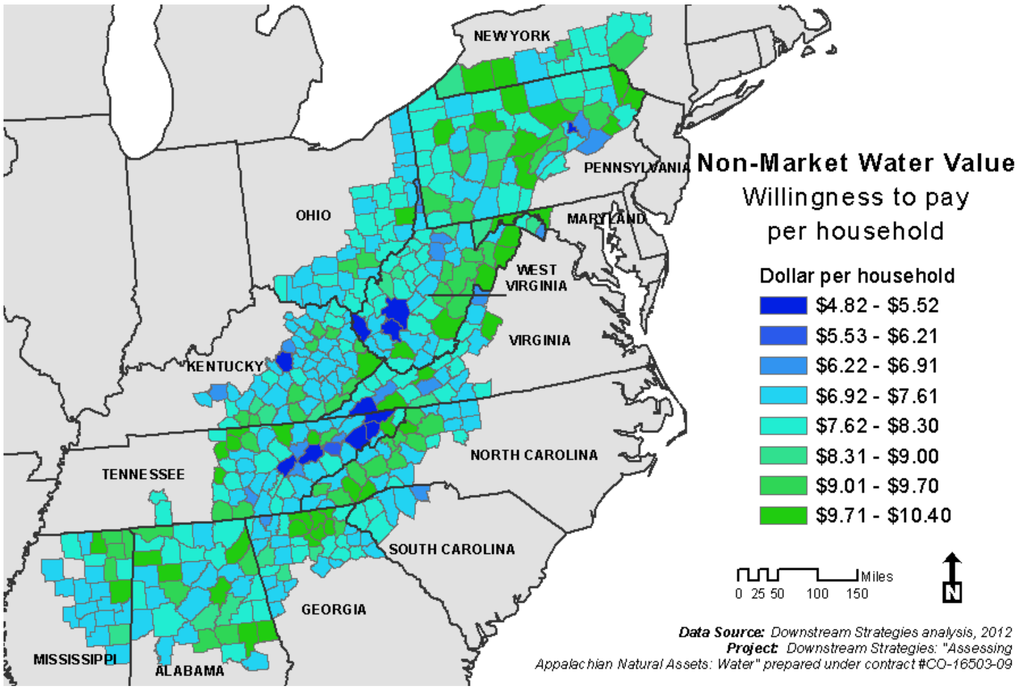
Data for the meta-analysis came from a total of 49 contingent valuation studies. Johnston et al. (2005) provided 81 observations from 34 studies conducted between 1981 and 2001. Additionally, a data set of 27 observations from 15 studies conducted between 2000 and 2009 were collected. The studies included 29 journal articles, 13 research reports or academic papers, four Ph.D. dissertations, one book, and two Master's theses. Only contingent valuation studies conducted in the U.S. were used. Non-published research studies were included if they were conducted within the Appalachian region.

Across the 420 counties of the Appalachian region, the average projected annual mean WTP for surface water quality was about $8.50 per household. Panel A in Figure 31 maps the per household WTP for each county across the Appalachian region. Cannon County, Tennessee had the highest annual mean WTP per household ($10.39). Counties from Tennessee and West Virginia were the most prevalent in the bottom ten with five and three counties, respectively. Scott County, Virginia had the lowest average mean WTP per household ($4.81).

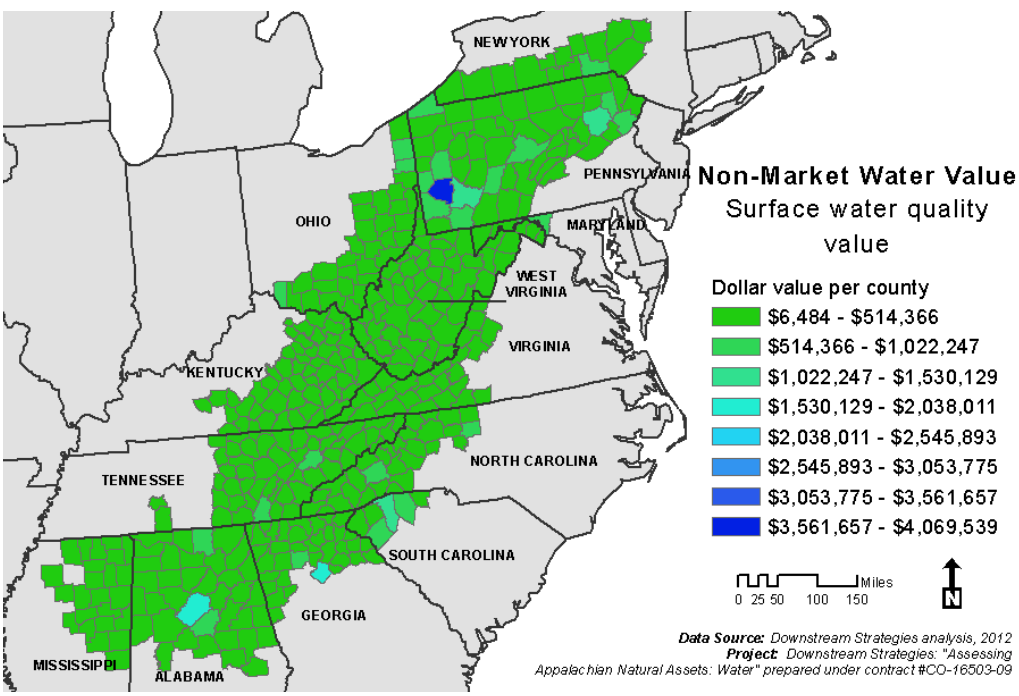
Surface water quality value was calculated by multiplying the per household WTP value by each county's number of households. This reveals that while the value per household is higher in rural areas, the number of households has a significant influence on the final surface water value. Panel B in Figure 31 maps the value of surface water quality for each county across the Appalachian region. Allegheny County, Pennsylvania—one of the most populous counties in the region—had the highest surface water value (4,069,539 dollars). The Pittsburgh metropolitan region topped the surface water values and, along with southern populated areas of Georgia, Alabama, and South Carolina, dominated the top ten counties within Appalachia. Counties with smaller populations, located in West Virginia, Kentucky, Virginia, and Tennessee, were the most prevalent at the bottom of the ranking. Highland County, Virginia had the lowest surface water value: 6,483 dollars.

Figure 31: (A) Willingness-to-pay per household and (B) surface water quality value

A



B



4.4 Discussion

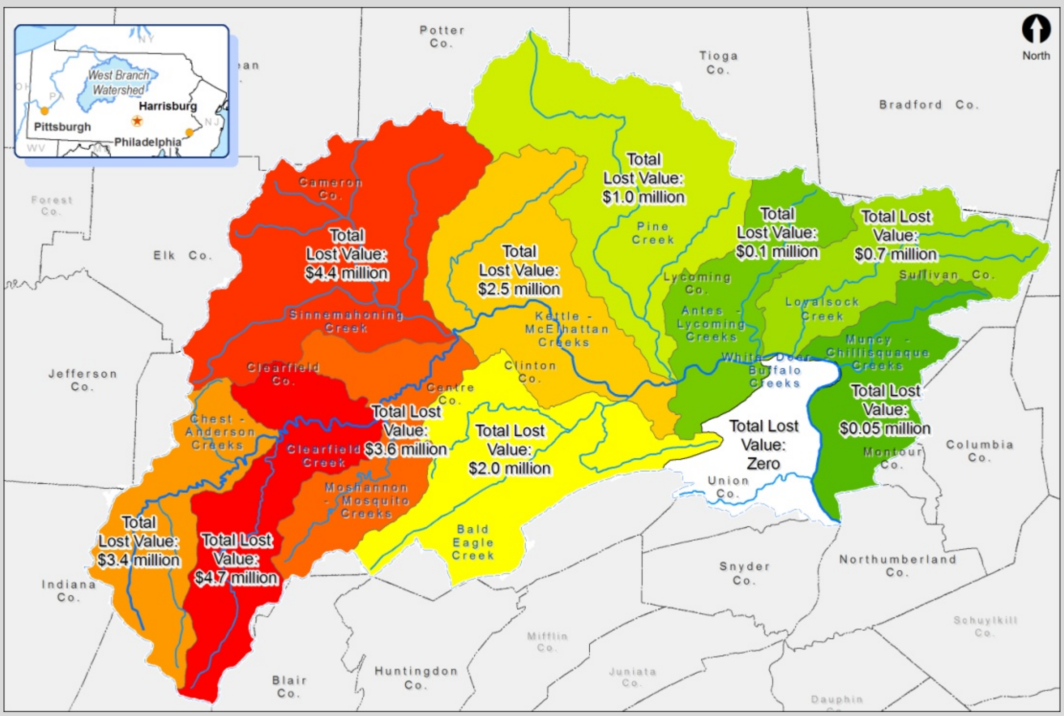
As would be expected, most of the counties in the highest 10 percent for water use valuation were concentrated along major rivers: the Ohio River in Ohio, Pennsylvania, and West Virginia; the Kanawha River in West Virginia; the Tennessee River in Alabama and Tennessee; and the Alabama River in Alabama. Looking at the per capita valuation, West Virginia had the largest number of counties (13) in the highest 10 percent. Tennessee was second at seven counties. Kentucky had the largest concentration of counties in the lowest 10 percent, with 13 counties; and Pennsylvania was second with 11 counties.

These high values in many counties in West Virginia and Tennessee mainly stem from large water withdrawals by power plants and other industrial facilities. Both states have historically been attractive to industries that require large amounts of water, such as electrical power generation.

For non-market surface water quality values, average annual mean WTP values were ranked and divided into six categories (Table 19). Other than Maryland, which has only a few counties, the states of Pennsylvania, North Carolina, and Mississippi had the highest percentages of counties in the top category of WTP scores. Pennsylvania was the only state with 50 percent of its counties in the top two categories. In contrast, the states of Mississippi, Kentucky, and South Carolina had 50 percent or more counties falling into the bottom two categories. One-third of South Carolina counties were in the bottom category.

Table 19: Percentages of counties in sextile categories based on mean county-level WTP rankings for surface water quality

State (# counties)	Highest					Lowest
Alabama (37)	21.6%	16.2%	18.9%	24.3%	8.1%	10.8%
Georgia (37)	18.9%	18.9%	18.9%	13.5%	13.5%	16.2%
Kentucky (54)	5.6%	20.4%	3.7%	18.5%	31.5%	20.4%
Maryland (3)	66.7%	33.3%	0.0%	0.0%	0.0%	0.0%
Mississippi (24)	25.0%	4.2%	8.3%	8.3%	29.2%	25.0%
New York (14)	21.4%	21.4%	35.7%	7.1%	0.0%	14.3%
North Carolina (29)	27.6%	17.2%	6.9%	34.5%	13.8%	0.0%
Ohio (32)	3.1%	6.3%	25.0%	25.0%	34.4%	6.3%
Pennsylvania (52)	28.8%	21.2%	15.4%	13.5%	9.6%	11.5%
South Carolina (6)	0.0%	16.7%	33.3%	0.0%	16.7%	33.3%
Tennessee (52)	15.4%	9.6%	23.1%	11.5%	17.3%	23.1%
Virginia (25)	12.0%	4.0%	32.0%	20.0%	8.0%	24.0%
West Virginia (55)	10.9%	29.1%	12.7%	12.7%	10.9%	23.6%



Total Lost Value: $4.4 million
Total Lost Value: $2.5 million
Total Lost Value: $1.0 million
Total Lost Value: $0.1 million
Total Lost Value: $0.7 million
Total Lost Value: $0.05 million
Total Lost Value: Zero
Total Lost Value: $3.6 million
Total Lost Value: $2.0 million
Total Lost Value: $3.4 million
Total Lost Value: $4.7 million
West Branch Watershed
Harrisburg
Pittsburgh
Philadelphia
North
Potter Co.
Tioga Co.
Bradford Co.
Cameron Co.
Elk Co.
Forest Co.
Jefferson Co.
Clearfield Co.
Centre Co.
Clinton Co.
Lycoming Co.
Sullivan Co.
Columbia Co.
Montour Co.
Union Co.
Snyder Co.
Northumberland Co.
Indiana Co.
Blair Co.
Huntingdon Co.
Mifflin Co.
Juniata Co.
Schuylkill Co.
Dauphin
Sinnemahoning Creek
Clearfield Creek
Chest - Anderson Creeks
Moshannon - Mosquito Creeks
Bald Eagle Creek
Kettle - McElhattan Creeks
Pine Creek
Antes - Lycoming Creeks
Loyalsock Creek
Muncy - Chillisquaque Creeks
White Deer Buffalo Creeks

5. CONCLUSION

Countless challenges exist in assessing the economic value of water resources: “Placing an economic value on this precious resource is an art and science,” said one ARC water assets stakeholder respondent. Quantifying water quality and quantity present other significant challenges. Yet multiple and growing human needs for water necessitate our valuing it as a foundation of Appalachia’s economy. This report documents the region’s water quantity and quality and endeavors to value the region’s water resources, while providing a foundation for future policy- and decision-making.

The dynamics of water resources are very complex, considering temporal variations, flow patterns, and competing uses. Examining a water resource and understanding its quality at a set point in time at a certain location is attainable; however, understanding a water resource’s true condition and value over time is more complicated.

Due to this complexity, this research project utilized existing measures and attempted to broadly assess water resources across the region. The project team proposes several recommendations to further study the region’s water assets.

Data development and consistency

Regional data consistency and sharing of data among local, state, and federal agencies is the key to truly understanding the water assets of the region. For example, USEPA provides states with great flexibility in developing their impaired streams datasets. Many studies now devote large amounts of time and resources to develop methodologies to predict a stream’s quality, rather than using in-stream measurements or impaired stream lists. Standardization of the impaired streams dataset—as well as other datasets that apply across states—would enable more efficient and accurate regional comparisons of natural assets.

Valuation methodology

Water is a very complex resource to value. It is often easiest to value items based on their transactional value. But water has both consumptive and non-consumptive value. More resources should be applied to develop consensus among stakeholders as to the most appropriate method for valuing resources. These types of valuations are far beyond any commodity value that is assigned, either in this study or on the open market. This report ventures to understand that value by looking at both market and non-market values. Our non-market valuation approach took into consideration people’s perceived value of water based on what they would be willing to pay for clean, bountiful, accessible water. More time and resources should be spent developing an approach to understand the true value of natural resources, not only as an exportable commodity, but also as an integral part of life.

Greater support and continuity

Natural resources, such as water, are temporal in that their condition, status, and location change often and sometimes sporadically. This report studies a snapshot in time. It would be beneficial to create a body of resources that would continue to build upon the foundation of this regional assessment and that would build consensus to develop new methods for appraising water resources.

Overall, this report tackles a very difficult subject with many viewpoints, datasets, and competing goals. It would be false to assume that it offers the only answers to the questions surrounding Appalachia’s water assets. However, it contributes to this important conversation, particularly with respect to Appalachia’s water quality, quantity, and value.

REFERENCES

Alabama Power. 2012. Generating plants. http://www.alabamapower.com/about-us/plants/home.asp. Accessed July 20, 2012.

Alexander RB, Boyer EW, Moore RB. 2007. The Role of Headwater Streams in Downstream Water Quality. Journal of American Water Resources Association 43(1): 41–59

Appalachian Land Ownership Task Force. 1981. Land ownership patterns and their impacts on Appalachian communities: A survey of 80 counties. http://www.eric.ed.gov/PDFS/ED325280.pdf Accessed May 20, 2011.

Appalachian Regional Commission (ARC). 2009a. The Appalachian region. www.arc.gov/appalachian_region/TheAppalachianRegion.asp Retrieved Aug 31, 2009.

Appalachian Regional Commission (ARC). 2011. County economic status in Appalachia, FY 2012. www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=55 Accessed June, 2011.

Deller SC, Lledo V, Marcouiller DW. 2008. Modeling regional economic growth with a focus on amenities. Review of Urban and Regional Development Studies, 20 (1), 1-21.

Duckstein L, Opricovic S. 1980. Multiobjective optimization in river basin development. *Water Resources Research* 16(1):14-20.

Duckstein L, Tecle A, Nachnebel HP, Hobbs BF. 1989. Multicriterion analysis of hydropower operation. Journal of Energy Engineering 115(3):132-152.

Duke Energy Oconee Nuclear Station. 2013. http://www.duke-energy.com/power-plants/nuclear/oconee.asp

Economic Development Research Group, Inc., Regional Technology Strategies, Inc., Massachusetts Institute of Technology Dept. of Urban Studies & Planning. 2007. Sources of regional growth in non-metro Appalachia (Volumes 1-4). Technical report prepared for Appalachian Regional Commission.

Elith J, Leathwick JR, Hastle T. 2008. A working guide to boosted regression trees. Journal of Animal Ecology, 77, 802-813.

Erickson KT. 1998. Trauma at Buffalo Creek. Society, Jan/Feb. 35(2): 153-161.

Frederick KD, VandenBerg T, Hanson J. 1996. Economic values of freshwater in the United States: a report to the Electric Power Research Institute. Resources for the Future. Discussion Paper 97-03. Washington DC.

Friedman JH, Meulman JJ. 2003. Multiple additive regression trees with application in epidemiology. Statistics in Medicine 22: 1365-1381.

Freudenburg WH. 1992. Addictive economies: extractive industries and vulnerable localities in a changing world economy. *Rural Sociology, 57* (3), 305-332.

Gaffield SJ, Goo RL, Richards LA, Jackson RJ. 2003. Public health effects of inadequately managed stormwater runoff. American Journal of Public Health, 93 (9), 1527-33.

Gautam KP, van der Heok EE. 2003. Literature study on environmental impacts of floods. Delft Cluster publication: DCI1-233-13.

Gershon M, Duckstein L. 1983. Multiobjective approaches to river basin planning. Journal of Water Resources Planning and Management 109(1):13-28.

Gruntfest. 1995. Long term social and economic impacts of extreme flooding. U.S.-Italy workshop on the hydrometeorology, impacts, and management of extreme floods. Perguia, Italy. November.

Hansen E, Collins A, Svetlik J, McClurg S, Shrecongost A, Stenger R, Schilz M, Boettner F. 2008. An economic benefit analysis for abandoned mine drainage remediation in the West Branch Susquehanna River watershed, Pennsylvania. Downstream Strategies.

Hobbs BF. 1983. Discussion of multiobjective approaches to river basin planning. *Journal of Water Resources Planning and Management* 109(1):13-28.

Hughes J, Whisnant R, Weller L, Eskaf S, Richardson M, Morrissey S, Altz-Stamm B. 2005. Drinking water and wastewater infrastructure in Appalachia: an analysis of capital funding and funding gaps. University of North Carolina Environmental Financing Center. Accessed May 20, 2011. http://www.arc.gov/assets/research_reports/DrinkingWaterandWastewaterInfrastructure.pdf

Johnson KM, Beale CL. 2002. Nonmetro recreation counties: their identification and growth. *Rural America, 17* (4), 12-19.

Johnston RJ, Besedin EY, Iovanna R, Miller C J, Wardwell RF, Ranson MW. 2005. Systematic variation in willingness to pay for aquatic resource improvements and implications for benefit transfer: A meta-analysis. Can. J. Agr. Econ*.* 53: 221-248.

Kenny J, Barber N, Hutson S, Linsey K, Lovelace J, Maupin M. 2009. Estimated Use of Water in the United States in 2005, U.S. Geological Survey Circular 1344, 52p.

Malczewski J. 1999. *GIS and Multicriteria Decision Analysis*. New York, NY: John Wiley and Sons.

Martin R, Petty T, Clingerman J, Boettner F, Letsinger S, Strager J, Hereford A, Hansen E. 2012. Midwest Fish Habitat Partnership fish habitat modeling results: Driftless Area Restoration Effort, Ohio River Basin FHP, Southeast Aquatic Resource Partnership, Fishers and Farmers FHP, Great Lakes FHP, Midwest Glacial Lakes.

National Flood Insurance Program (NFIP). 2011. Loss statistics. http://bsa.nfipstat.com/reports/1040.htm Accessed March 1.

National Oceanic and Atmospheric Administration (NOAA). 2010. 1994-2010 annual storm report and data from the National Climatic Data Center. http://www.ncdc.noaa.gov/stormevents/

New York City Water Board (NYCWB). 2013. Water and wastewater rate schedule: http://www.nyc.gov/html/nycwaterboard/pdf/rates/fy2013_rates.pdf

Nord M, Cromartie JB. 1997. Migration: The increasing importance of rural natural amenities. *Choices 3*, 31-32.

Postel S, Carpenter C. 1997. “Freshwater ecosystem services”, in G. Daily (ed.), *Nature’s Services* (pp. 195-214). Washington D.C.: Island Press.

Robinson L, Campbell P, Butler L. 1996. Trends in commercial fishery landings, 1972-1995. Management Data Series, No. 127. Austin, TX: Texas Parks and Wildlife Department, Coastal Fisheries Division.

Romero C, Rehman T. 1989. *Multiple Criteria Analysis for Agricultural Decisions*. New York, New York: Elsevier Science Publishing Company Inc.

Roy S, Chen L, Girvetz E, Maurer E, Mills W, Grieb T. 2010. Evaluating sustainability of projected water demands under future climate change scenarios. Prepared for Natural Resource Defense Council.

Shaffer, K.H. 2009. Variations in withdrawal, return flow, and consumptive use of water in Ohio and Indiana, with selected data from Wisconsin, 1999–2004: U.S. Geological Survey Scientific Investigations Report 2009–5096, 93 p.

Shiber JG. 2005. Arsenic in domestic well water and health in central Appalachia, USA. Water, Air, and Soil Pollution, 160 (1-4), 327-341.

Shumway JM, Otterstrom SM. 2001. Spatial patterns of migration and income change in the Mountain West: The dominance of service-based, amenity-rich counties. *Professional Geographer, 53*, 492-502.

Southern Appalachian Man and the Biosphere Cooperative. 1996. The Southern Appalachian assessment. Aquatic, Atmospheric, Social/Cultural/Economic, and Terrestrial technical reports.

Tecle A, Yitayew M. 1990. Preference ranking of alternative irrigation technologies via a multicriterion decision making procedure. *American Society of Agricultural Engineers* 33(5):1509-1517.

Tecle A, Fogel MM, Duckstein L. 1988a. Multicriterion analysis of forest watershed management alternatives. *Water Resources Bulletin* 24(6):1169-1177.

Tecle A, Fogel MM, Duckstein L. 1988b. Multicriterion selection of wastewater management alternatives. *Journal of Water Resources Planning and Management* 114(4):383-398.

US Army Corps of Engineers. 1969. Development of water resources in Appalachia. Office of Appalachian Studies.

US Environmental Protection Agency (USEPA). 2011. A Field-Based Aquatic Life Benchmark for Conductivity in Central Appalachian Streams. EPA/600/R-10/023F.

US Environmental Protection Agency (USEPA). 2012. National Recommended Water Quality Criteria. http://water.epa.gov/scitech/swguidance/standards/criteria/current/Retrieved August 16, 2012.

US Environmental Protection Agency (USEPA). 1986. Quality Criteria for Water. http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/upload/2009_01_13_criteria_goldbook.pdf . Retrieved August 16, 2012.

US Census Bureau, 2012. 2012 Economic Census. http://www.census.gov/econ/census/

Ward FA, Michelsen A. 2002. The economic value of water in agriculture: concepts and policy applications. Water Policy 4: 423-446.

Whisman SA, Hollenhorst SJ, Jones CD. 1996. A summary of economic impacts of commercial whitewater rafting in West Virginia: design, management, and implementation of a Limits of Acceptable Change (LAC) process for a three-year study on the Gauley, New, Cheat, Shenandoah, and Tygart Rivers of West Virginia. Final report. National Park Service, Mid-Atlantic Region. Philadelphia, PA.

Young RA. 2005. Determining the economic value of water: concepts and methods. Washington, DC: Resources for the Future.

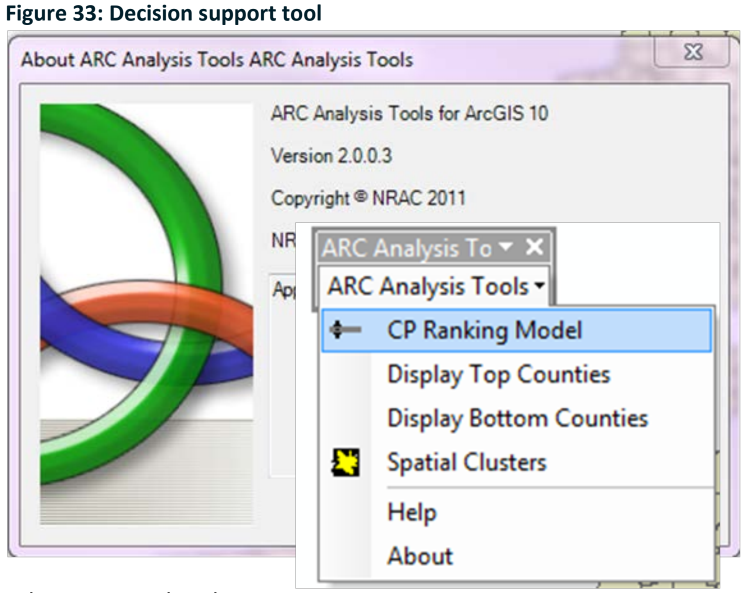
Zeleny M. 1982. *Multiple Criteria Decision Making*. McGraw - Hill Book Company, New York, NY.

APPENDIX A: DECISION SUPPORT TOOL

Integrated GIS tool

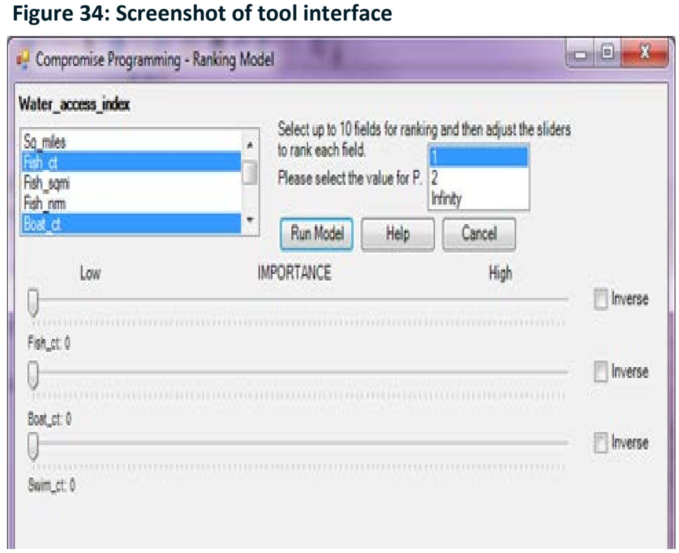
One of the important aspects of any applied research project is the method of communicating results to decision-makers. The output of our study includes an interactive GIS-based DST (Figure 33) that allows resource managers to evaluate inputs and results of this study, thereby understanding the true spatial nature and relationships of these natural assets. This system integrates spatial data, user input, and a ranking algorithm within a multiple criteria analysis (MCA) framework. The goal of this framework is to provide a tool to integrate spatial data with a MCA-solving algorithm called compromise programming (CP), which allows users to quickly and interactively explore and analyze county-level data.

Figure 33: Decision support tool



MCA is an alternative approach to traditional economic evaluation techniques. The basic idea behind MCA is to provide a framework for analyzing choices with multiple criteria and conflicting objectives (Malczewski, 1999). A spatial MCA approach aids in the identification of the most suitable management solution for a given purpose. The approach also allows users to examine the effects of alternative options and presents options in a variety of forms such as monetary units, physical units, and qualitative judgments. This makes it possible to analyze tradeoffs between different objectives and address potential conflicts at an early stage, thereby providing the ability to analyze the sensitivity and robustness of different choices.

Figure 34: Screenshot of tool interface



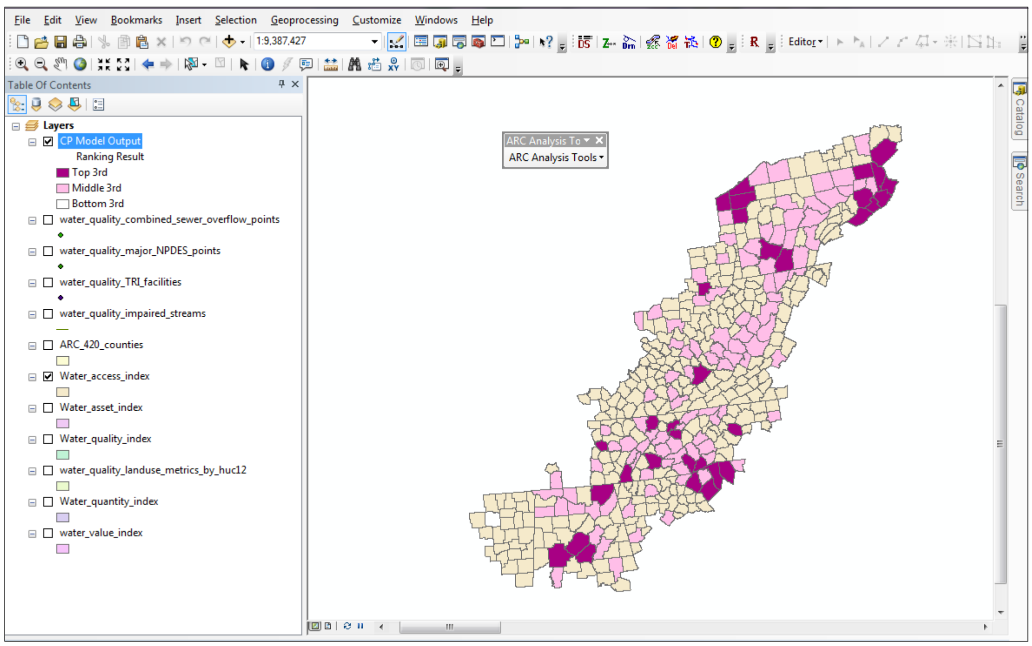
The CP ranking algorithm was chosen because it allows a more theoretically significant ranking of alternatives as compared to a linear weighted model. It also allows the user to integrate sensitivity analysis by altering weights and parameter values to highlight the concern of the decision-maker over the degree of separation or difference from the ideal criteria score. The highest-ranked results are those that are closest to the ideal or furthest from the least preferred alternatives. CP algorithms have been used in many different MCA applications including ranking of irrigation technologies (Tecle and Yitayew, 1990), planning water resource systems (Duckstein and Opricovic, 1980; Gershon and Duckstein, 1983), developing forest watershed management schemes

(Tecle et al., 1988a), selecting wastewater management alternatives (Tecle et al., 1988b), defining hydropower operations (Duckstein et al., 1989), and performing river basin planning (Hobbs, 1983).

The tool allows decision-makers to assign a weight (or importance value) to each individual criterion and then combine all criteria together for a comprehensive overall result. End users can combine and map the various factors for ranking economic development and water resources in the ARC region. The final spatial model uses an extension to ESRI's ArcGIS software. The extension consists of a graphical interface designed to guide the user through the process of interactively specifying weights and viewing results Figure 34. This model also provides the ability to display the top- and bottom-ranked counties and to map spatial clusters.

The CP ranking model requires that the user first highlight or make active a shapefile in the table of contents that contains attributes the user wishes to use for the ranking (Figure 35). It is assumed that the user already calculated or added the needed fields to the table in order to use the ranking model. All of the criteria are normalized by the program, so the user does not have to worry about non-commensurate data. All that is required is the direction of value influence. For example, if a higher value for an attribute is desired, then nothing has to be altered in the CP interface; this is the default. However, if the user feels that a lower value is preferred, the inverse button should be selected.

Figure 35: Selecting a shapefile to be used in the ranking



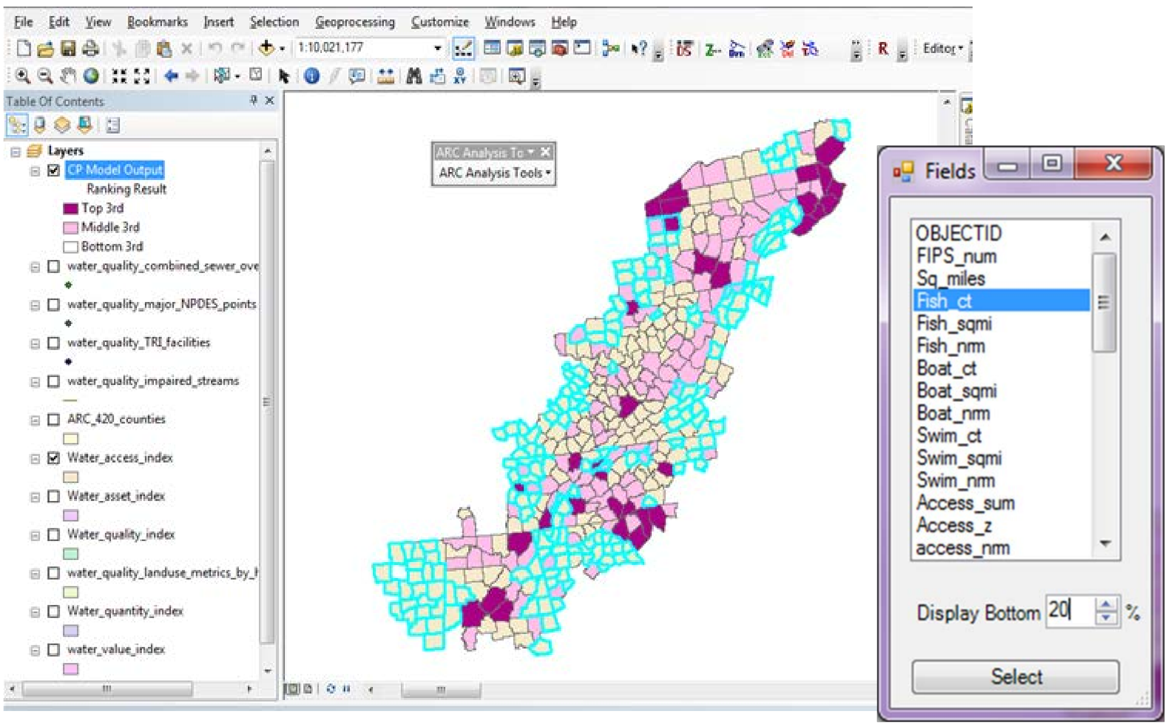
The parameter values of *P* indicate the concern of the decision-maker over the deviation from the ideal values. These values represent the concern of the decision-maker over the maximum deviation (Tecle and Yitayew, 1990; Duckstein and Opricovic, 1980). The larger the value of *P*, the greater the concern. For *P* = 1, all weighted deviations are assumed to compensate each other perfectly. For *P* = 2, each weighted deviation is accounted for in direct proportion to its size. As *P* approaches infinity, the alternative with the largest deviation receives more weight and importance (the largest of the deviations completely dominates) (Zeleny, 1982). To solve the multi-criteria problem using the CP algorithm, the vectors of ideal point values and worst values are determined and then used to compute the calculated values' distances from the ideal points. The preferred alternative has the minimum *Lp* distance value for each *P* and weight set that may be used. Thus, the alternative (county, in our example) with the lowest value for the calculated metric will be the best compromise solution because it is the nearest solution with respect to the ideal point. The parameter *P* acts as a weight attached to the deviations according to their magnitudes. Similar weights for various deviations signify the relative importance of each criterion (Romero and Rehman, 1989).

The result of the model run is the addition of a new field to the shapefile—the calculated CP metric. Lower values are preferred and a legend is produced automatically for the user. This legend can always be altered to show a different display of the ranked counties. The true utility of the tool is in the ability to quickly run different scenarios and test the spatial sensitivity of results.

Finding the top or bottom percentages

Some of the other tools available for the user include the ability to find the top or bottom percentage of ranked features. This was designed to highlight the counties that meet certain threshold requirements in regard to the rankings (Figure 36).

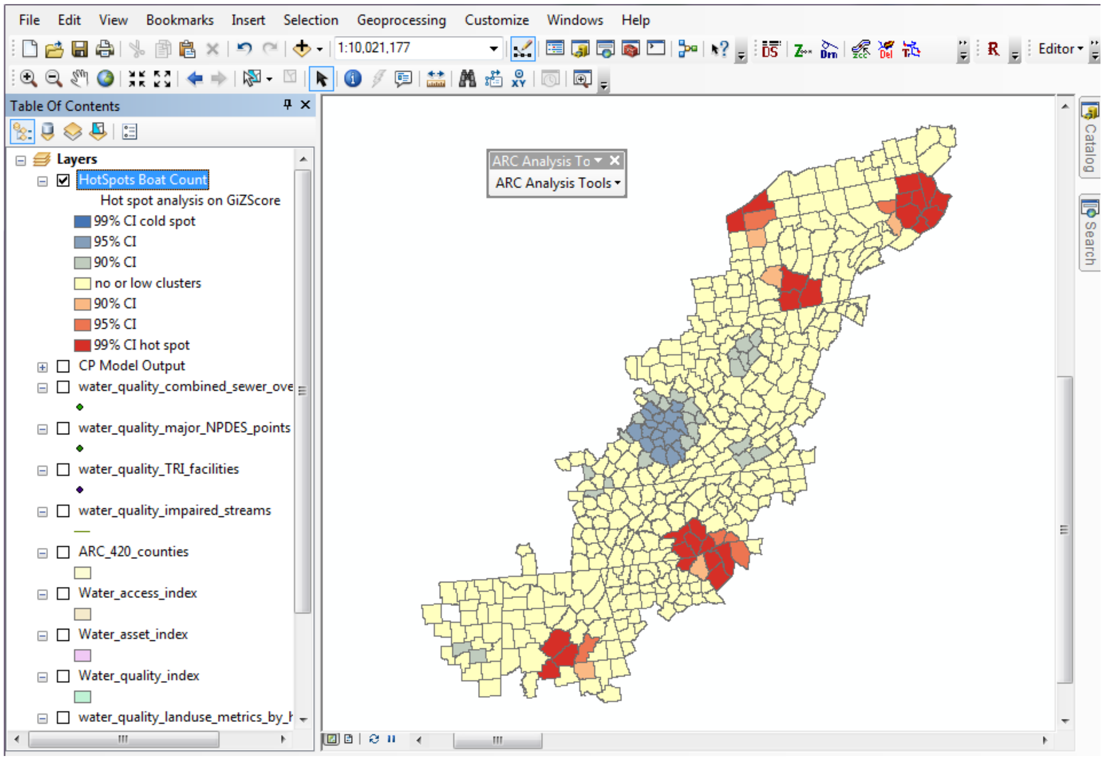
Figure 36: Percentage queries for the highest and lowest percentages



Spatial clusters

The Spatial Clusters Tool is based on a hot-spot analysis. This is a spatial statistical calculation that takes into account the spatial position of features and their attributes. The purpose of using the tool is to find areas with high values surrounded by other high values (hot-spot) or low values surrounded by other areas with low values (cold-spot) that are statistically significant. Figure 37 shows spatial clusters for a sample indicator, which include both hot- and cold-spots.

Figure 37: Hot and cold spots



It is important to carefully select the analysis field. The *Z*-scores and *P*-values are measures of statistical significance, which tell users whether or not to reject the null hypothesis, feature by feature. In effect, they indicate whether the observed spatial clustering of high or low values is more pronounced than one would expect in a random distribution of those same values.

APPENDIX B: WATER QUALITY MODELING DATA DICTIONARY

Field	Description	Source
COMID	catchment comid (unique identifier)	NHDPlus
AREASQKM	area of catchment, sq km	NHDPlus
AREASQKMC	cumulative area of catchment, sq km	NHDPlus
MINELEVRAW	Minimum elevation in meters	catchmentattributesflow.dbf
SLOPE	Slope of flowline (cm/cm)	catchmentattributesflow.dbf
PRECIP	Mean annual precipitation in mm	catchmentattributestempprecip.dbf
TEMP	Mean annual temperature in degrees centigrade * 10	catchmentattributestempprecip.dbf
BFI_MEAN	baseflow index (%) (LOCAL)	USGS
BFI_MEANC	baseflow index (%) (CUMULATIVE)	USGS
RECH_MEAN	recharge, total mean (mm/year) (LOCAL)	USGS
RECH_MEANC	recharge, total mean (mm/year) (CUMULATIVE)	USGS
WATER_GW	LOCAL: USGS National Atlas of the US: Ground Water Use by COUNTY 2000: Millions gallons per day/km2	NFHP local_disturbance_variables.dbf
WATER_SW	LOCAL: USGS National Atlas of the US: Surface Water Use by COUNTY 2000: Millions gallons per day/km2	NFHP local_disturbance_variables.dbf
CATTLE	LOCAL: Agricultural Census 2002, 1:2M scale, INTEGER: average number of cattle/acre farmland	NFHP local_disturbance_variables.dbf
POPDENS	LOCAL: US Population Density 2000, NOAA, scale 1km, #/km2	NFHP local_disturbance_variables.dbf
ROADCR	LOCAL: Census 2000 TIGER Roads, 1:100K scale, road crossings identified by INTERSECT, with points generated, #/km2	NFHP local_disturbance_variables.dbf
ROADLEN	LOCAL: Census 2000 TIGER Roads, 1:100K scale, units not given - m/km2	NFHP local_disturbance_variables.dbf
DAMS	LOCAL: National Inventory of Dams, 2002-2004, #/km2	NFHP local_disturbance_variables.dbf
MINES	LOCAL: USGS Active Mines and Mineral Processing Plants, 2003, #/km2	NFHP local_disturbance_variables.dbf
TRI	LOCAL: USEPA, 2007: #/km2 Toxics Release Inventory Program sites	NFHP local_disturbance_variables.dbf
NPDES	LOCAL: USEPA, 2007: #/km2 National Pollutant Discharge Elimination System sites	NFHP local_disturbance_variables.dbf
CERC	LOCAL: USEPA, 2007: #/km2 Compensation and Liability Information System sites	NFHP local_disturbance_variables.dbf
WATER_GWC	NETWORK: USGS National Atlas of the US: Ground Water Use by COUNTY 2000: Millions gallons per day/km2	NFHP network_disturbance_variables.dbf
WATER_SWC	NETWORK: USGS National Atlas of the US: Surface Water Use by COUNTY 2000: Millions gallons per day/km2	NFHP network_disturbance_variables.dbf
CATTLEC	NETWORK: Agricultural Census 2002, 1:2M scale, INTEGER: average number of cattle/acre farmland	NFHP network_disturbance_variables.dbf
POPDENSC	NETWORK: US Population Density 2000, NOAA, scale 1km, #/km2	NFHP network_disturbance_variables.dbf
ROADCRC	NETWORK: Census 2000 TIGER Roads, 1:100K scale, road crossings identified by INTERSECT, with points generated, #/km2	NFHP network_disturbance_variables.dbf

Field	Description	Source
ROADLENC	NETWORK: Census 2000 TIGER Roads, 1:100K scale, units not given - m/km2	NFHP network_disturbance_variables.dbf
DAMSC	NETWORK: National Inventory of Dams, 2002-2004, #/km2	NFHP network_disturbance_variables.dbf
MINESC	NETWORK: USGS Active Mines and Mineral Processing Plants, 2003, #/km2	NFHP network_disturbance_variables.dbf
TRIC	NETWORK: USEPA, 2007: #/km2 Toxics Release Inventory Program sites	NFHP network_disturbance_variables.dbf
NPDESC	NETWORK: USEPA, 2007: #/km2 National Pollutant Discharge Elimination System sites	NFHP network_disturbance_variables.dbf
CERCC	NETWORK: USEPA, 2007: #/km2 Compensation and Liability Information System sites	NFHP network_disturbance_variables.dbf
AG_P	NLCD 2006, agricultural classes, NLCD 81, 82	NLCD 2006
FOR_P	NLCD 2006, forest classes, NLCD 41, 42, 43	NLCD 2006
WET_P	NLCD 2006, wetland classes, NLCD 90, 95	NLCD 2006
DEV_P	NLCD 2006, developed classes, NLCD 21, 22, 23, 24	NLCD 2006
BAR_P	NLCD 2006, barren land, NLCD 31	NLCD 2006
SHR_P	NLCD 2006, Shrub/scrub, NCLD 52	NLCD 2006
GRS_P	NLCD 2006, Grassland, NLCD 71	NLCD 2006
Reference:		
NLCD 11	NLCD 2006 open water, area (%), catchment	NLCD 2006
NLCD 21	NLCD 2006 developed, open space, area (%), catchment	NLCD 2006
NLCD 22	NLCD 2006 developed, low intensity, area (%), catchment	NLCD 2006
NLCD 23	NLCD 2006 developed, medium intensity, area (%), catchment	NLCD 2006
NLCD 24	NLCD 2006 developed, high intensity, area (%), catchment	NLCD 2006
NLCD 31	NLCD 2006 barren land (rock/sand/clay), area (%), catchment	NLCD 2006
NLCD 41	NLCD 2006 deciduous forest, area (%), catchment	NLCD 2006
NLCD 42	NLCD 2006 evergreen forest, area (%), catchment	NLCD 2006
NLCD 43	NLCD 2006 mixed forest, area (%), catchment	NLCD 2006
NLCD 52	NLCD 2006 shrub/scrub, area (%), catchment	NLCD 2006
NLCD 71	NLCD 2006 grassland/herbaceous, area (%), catchment	NLCD 2006
NLCD 81	NLCD 2006 pasture/hay, area (%), catchment	NLCD 2006
NLCD 82	NLCD 2006 cultivated crops, area (%), catchment	NLCD 2006
NLCD 90	NLCD 2006 woody wetlands, area (%), catchment	NLCD 2006
NLCD 95	NLCD 2006 emergent herbaceous wetlands, area (%), catchment	NLCD 2006
AG_P	NLCD 2006, agricultural classes, NLCD 81, 82 (cumulative)	NLCD 2006
FOR_P	NLCD 2006, forest classes, NLCD 41, 42, 43 (cumulative)	NLCD 2006
WET_P	NLCD 2006, wetland classes, NLCD 90, 95 (cumulative)	NLCD 2006
DEV_P	NLCD 2006, developed classes, NLCD 21, 22, 23, 24 (cumulative)	NLCD 2006
BAR_P	NLCD 2006, barren land, NLCD 31 (cumulative)	NLCD 2006

Field	Description	Source
SHR_P	NLCD 2006, Shrub/scrub, NCLD 52 (cumulative)	NLCD 2006
GRS_P	NLCD 2006, Grassland, NLCD 71 (cumulative)	NLCD 2006
Reference:		
NLCD 11	NLCD 2006 open water, area (%), upstream cumulative	NLCD 2006
NLCD 21	NLCD 2006 developed, open space, area (%), upstream cumulative	NLCD 2006
NLCD 22	NLCD 2006 developed, low intensity, area (%), upstream cumulative	NLCD 2006
NLCD 23	NLCD 2006 developed, medium intensity, area (%), upstream cumulative	NLCD 2006
NLCD 24	NLCD 2006 developed, high intensity, area (%), upstream cumulative	NLCD 2006
NLCD 31	NLCD 2006 barren land (rock/sand/clay), area (%), upstream cumulative	NLCD 2006
NLCD 41	NLCD 2006 deciduous forest, area (%), upstream cumulative	NLCD 2006
NLCD 42	NLCD 2006 evergreen forest, area (%), upstream cumulative	NLCD 2006
NLCD 43	NLCD 2006 mixed forest, area (%), upstream cumulative	NLCD 2006
NLCD 52	NLCD 2006 shrub/scrub, area (%), upstream cumulative	NLCD 2006
NLCD 71	NLCD 2006 grassland/herbaceous, area (%), upstream cumulative	NLCD 2006
NLCD 81	NLCD 2006 pasture/hay, area (%), upstream cumulative	NLCD 2006
NLCD 82	NLCD 2006 cultivated crops, area (%), upstream cumulative	NLCD 2006
NLCD 90	NLCD 2006 woody wetlands, area (%), upstream cumulative	NLCD 2006
NLCD 95	NLCD 2006 emergent herbaceous wetlands, area (%), upstream cumulative	NLCD 2006
IMPSURF_M	NLCD 2006, mean percent impervious, catchment	NLCD 2006
IMPSURF_MC	NLCD 2006, mean percent impervious, cumulative	NLCD 2006
BR1P	Carbonate (LOCAL)	USGS (Reclassified by Letsinger)
BR2P	Felsic (igneous) (LOCAL)	USGS (Reclassified by Letsinger)
BR3P	Mafic (igneous) (LOCAL)	USGS (Reclassified by Letsinger)
BR4P	Metamorphic (LOCAL)	USGS (Reclassified by Letsinger)
BR5P	Sand and gravel (LOCAL)	USGS (Reclassified by Letsinger)
BR6P	Sandstone (LOCAL)	USGS (Reclassified by Letsinger)
BR7P	Shale (LOCAL)	USGS (Reclassified by Letsinger)
BR8P	Unconsolidated (LOCAL)	USGS (Reclassified by Letsinger)
BR999P	No data (LOCAL)	USGS (Reclassified by Letsinger)
BR9P	Water (LOCAL)	USGS (Reclassified by Letsinger)
BR1PC	Carbonate (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR2PC	Felsic (igneous) (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR3PC	Mafic (igneous) (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR4PC	Metamorphic (CUMULATIVE)	USGS (Reclassified by Letsinger)

Field	Description	Source
BR5PC	Sand and gravel (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR6PC	Sandstone (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR7PC	Shale (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR8PC	Unconsolidated (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR999PC	No data (CUMULATIVE)	USGS (Reclassified by Letsinger)
BR9PC	Water (CUMULATIVE)	USGS (Reclassified by Letsinger)