Valuing Natural Assets in the Roanoke River Basin

Benefits to Local Communities and Economies

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Abbreviations & Key Terms

Ecosystem Services (ES) are, simply and in the terms chosen by the U.S. Forest Service, "the benefits people obtain from ecosystems" (USDA Forest Service, 2012). We prefer a definition with a little more power to guide analyses of ecosystem services:

"Ecosystem services are the effects on human well-being of the flow of benefits from ecosystems to people over given extents of space and time" (Johnson, Bagstad, Snapp, & Villa, 2010).

The italics are to emphasize that ecosystem services are about human welfare, not nature for its own sake. They are about flows of benefits (as opposed states of nature). Ecosystem services also flow from one place to another at one time or another (they are not static). This definition is an important component of the lens through which we have viewed and evaluated the existing literature.

Ecosystem Service Value (ESV) is the translation of a flow of benefits into dollar terms. So, we can say that a flow of a million gallons of water per day in a watershed is an ecosystem service. And if each gallon is worth a penny, we could say that the ecosystem service value of that daily flow would be $10,000.

Benefit Transfer Method (BTM) is a means of establishing the value of ecosystem service flows in one setting by transferring values derived through primary research in another setting. For example, if a study of the ecosystem service value of riparian areas in one state determines that each acre of bottomland forest generates $1,000 per acre per year in recreational value (because it is good birdwatching habitat, say), we might transfer that value to an otherwise similar acre of riparian area in another location. This is an example of the sub-genre of BTM known as "unit value transfer", in which a single number or set of numbers is transferred over from the earlier study.

Hedonic Pricing Method estimates peoples' nonmarket values of recreational opportunities, natural beauty, and other environmental features through analysis of property values in the housing market (Alberini, n.d.).

Willingness-to-Pay (WTP) is the maximum amount a consumer (landowner, resident, etc.) is willing to pay, give up, or exchange, to receive a good or avoided an undesired outcome, such as pollution.

All pictures used in the report are credited to Brian Williams, unless otherwise noted.

Executive Summary

This report introduces and examines the economic value of ecosystem services, including their spatial distribution and value, across the entire Roanoke River Basin (including the Dan River and Lower Roanoke subbasins). We explore economic outcomes from potential resource management actions that can affect the value of key ecosystem services in the region, focusing on four environmental issue areas that were identified as important to regional communities and stakeholders: recreation, urban and agricultural runoff, coal ash, and uranium mining.

Baseline Ecosystem Service Value of the Roanoke River Basin

Initial ecosystem service assessments of the Roanoke River Basin, the Dan River subbasin, and the Lower Roanoke River subbasin provide baseline values of ecosystem services such as air quality, water supply, protection from extreme events, and soil formation based on the land cover distribution in the region. Annual ecosystem service value in the Roanoke River Basin is estimated to total $14.7 billion, including over $6.6 billion in annual recreational value, $2.3 billion in food/nutritional value, and $1.4 billion in water flows.

In the Dan River subbasin, a largely forested region within the Roanoke River Basin, we estimate approximately $4.6 billion in ecosystem service value. The Upper Dan River provides slightly more of that value, a significant portion of which, almost $3 billion, is associated with recreational values tied to forested land cover and open water. The Lower Roanoke River subbasin in North Carolina is estimated to have $4.4 billion in ecosystem service value, with a significant portion coming from food value ($1.5 billion) and water flows ($1.1 billion).

Community Input: Environmental Concerns and Valued Natural Assets

After performing a baseline ecosystem service assessment of the Roanoke River Basin, we sought input from stakeholders in the region, including watershed organizations, landowners, town planners, and state officials. We held community workshops to gauge regional perspective on ecosystem services and the environmental issues potentially affecting their value.

Stakeholder input from workshops and surveys in the Roanoke River Basin revealed top environmental concerns and highly-valued natural assets for the communities in the region. Uranium mining was the most frequently listed environmental issue, followed by agricultural runoff, invasive species and coal ash spills, water pollution, and waterways lacking riparian buffers.

The key ecosystem services provided in the region, cited most frequently in the workshops and follow-up survey, include fishing and other water-based recreational activities, access to high quality drinking water, habitat for species (biodiversity), aesthetic values, and erosion control (see Appendix B). This input was used to develop priorities for modeling potential changes in ecosystem service values associated with resource management actions or policies.

Recreation Benefits from Water Quality Improvements

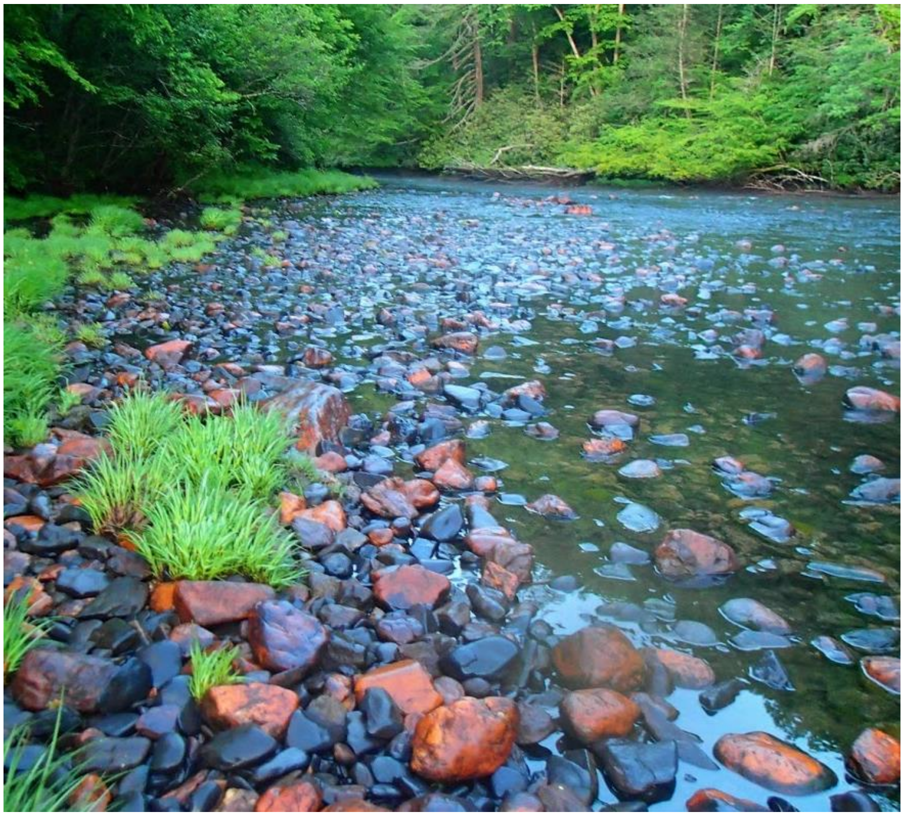
Improvements in water quality can result from many different management actions, including creating or increasing riparian buffers, implementation of urban and agricultural Best Management Practices (BMPs), and municipal stormwater management upgrades. Improved water clarity can contribute to increases in the number of days people participate in boating, swimming, fishing, and other water-based recreation activities. In turn, this can result in greater spending on trip related purchases such as food, travel, kayak rentals, etc., which benefits local communities.

Research indicates that outdoor recreationists are willing to pay for improved water quality. For example, Chesapeake Bay boaters surveyed were willing to pay a median of $26 per year for water quality improvements (2018 dollars; Lipton, 2003), and in New England, recreational users of waterways reported annual willingness to pay values ranging from $14 for boating and fishing to $119 for swimming (2018$; Parsons, Helms, & Bondelid, 2003).

We estimate the recreational value of water quality improvements in the Roanoke River Basin based on the number of annual water-related outdoor recreation days in the Roanoke River Basin and apply the average recreational user's willingness to pay for improved water quality. Results from a survey of recreation users in North Carolina suggest a mean willingness to pay for improved water quality of 24 cents per day trip across all watersheds (2018$; Phaneuf, 2002). Multiplied by water-related outdoor recreation days, this results in a total benefit estimate of $3.2 million for improved water quality in the RRB.

Regional Benefits from Forested Riparian Buffers

Forested riparian buffers are one of the most cost-effective management tools for maintaining and improving water quality while providing recreational opportunities, erosion control, and other ecosystem services to nearby and downstream communities. Currently, natural riparian buffer cover, which includes shrub, forest, and wetlands within the stream management zone of a waterway, totals



122,363 acres in the Roanoke River Basin (U.S. Geological Survey, 2018). We examine two scenarios of riparian buffer management in the Basin, applying a 150' forested buffer to half of the waterways in the river basin versus all of the waterways in the basin. These scenarios would translate to a 115,064 acre increase in forested buffer and 230,130 acre increase in forested buffer, respectively.

Existing literature provides estimates for the ecosystem service value of nutrient retention, aesthetics, recreation, carbon storage, flood mitigation, and air quality for an acre of forested riparian buffer (Rempel & Buckley, 2018). We estimate that the existing natural riparian buffer in the Roanoke River Basin provides at least $1.1 billion in annual benefits from nutrient retention, carbon storage, air quality, and recreational value alone (Rempel & Buckley, 2018). Developing a 150' forested buffer along half the waterways (about 7,700 miles) in the Roanoke River Basin would provide at least $1 billion in additional annual ecosystem service benefit to the region, and a one-time property value gain of $283 million to adjacent properties. Should a 150' buffer be developed along all waterways in the Roanoke River Basin, we could see a $2.1 billion million annual ecosystem benefit to the region and a one-time property value gain of $566 million to nearby properties.

The estimated annual cost of developing a forested buffer, which includes forgone economic opportunities on the land, averages to $3,500 an acre, and translates to $403 million and $805 million in each scenario, respectively (Berger, 2016). The potential net annual benefit of forested riparian buffer scenarios in the Roanoke River Basin are then $663 million and $1.3 billion, respectively, not including property value gains.

Excavation of Dan River Basin Coal Ash

The risk of coal ash spills, existence of unlined coal ash impoundments, and disposal of coal ash in landfills in the region are all concerns to communities in the Roanoke River Basin. Following the Dan River coal ash spill in February 2014, which sent 39,000 tons of coal ash 70 miles downstream the Dan

River and increased media attention on the health and environmental risks of unlined coal ash basins, state legislators have turned toward more stringent regulation of coal ash disposal in the region. Unlined coal ash basins are the source of toxins such as arsenic, boron, lead, cadmium, and selenium leaching into groundwater and surface water, contaminating drinking water and poisoning fish and wildlife.

The key ecosystem services currently inhibited or damaged by poor coal ash management include drinking water quality, recreation, habitat for species and aesthetic value. We examine the ecosystem service benefits that could be returned from the closure of four unlined storage sites in the Dan River Basin: The Mayo Plant, Roxboro Plant, Belew's Creek Steam Station, and Dan River Steam Station. Some historical and ongoing damage estimates attributed to toxins leaching from these sites include $3 million in water treatment upgrades for downstream communities and $1.5 billion in ecological damage and recreational opportunity loss from permitted discharges at the Mayo, Roxboro, and Belew's Creek sites (Lemly & Skopura, 2012). A 6-month assessment after the Dan River spill estimated approximately $300 million in ecological and recreational damage (Lemly, 2015).

We assess the potential societal benefits of improved water quality from closing these four sites through human health damages avoided and gains in consumer surplus -- the benefit gained by the nearby public represented by the amount they would have been willing to pay to avoid the risk of exposure to water contaminants. We find the human health damages avoided from reduced rates of cancer from arsenic in water ranges between $1.0 to 1.8 million. Benefits to downstream water users in the Roanoke River Basin from reduced risk of exposure range from $7 million to nearly $30 million should the unlined sites be closed this year. Depending on the current toxicity concentrations in downstream aquatic communities, such as Belew's Lake, Dan River, and Hyco Reservoir, annual recreational damages avoided could reach $2 million and annual ecological damages avoided could be as high as $8.3 million.

Uranium Mining Ban and Key Ecosystem Service Values at Risk

The threat of a reversal on the ban on uranium mining in Virginia was the highest-rated concern to stakeholders in the Roanoke River Basin. The fate of the ban, in the hands of the Supreme Court, will likely be challenged if overturned in 2019. No uranium mines currently exist on the east coast of the United States, and the prospect of a uranium mine in Pittsylvania County, Virginia poses a great regulatory challenge and potentially catastrophic environmental risks due to the wet climate, increased flooding and extreme events such as hurricanes in the region.

Ecosystem services at risk from uranium extraction and disposal include groundwater and surface water quality, aesthetic value, air quality, and recreation. A number of studies, including one performed by the National Academy of Sciences, have examined the exposure pathways and risk to the environment, noting the level of uncertainty surrounding these risks and the challenges that state regulators would face in developing a legal framework for safe extraction and management in the region.

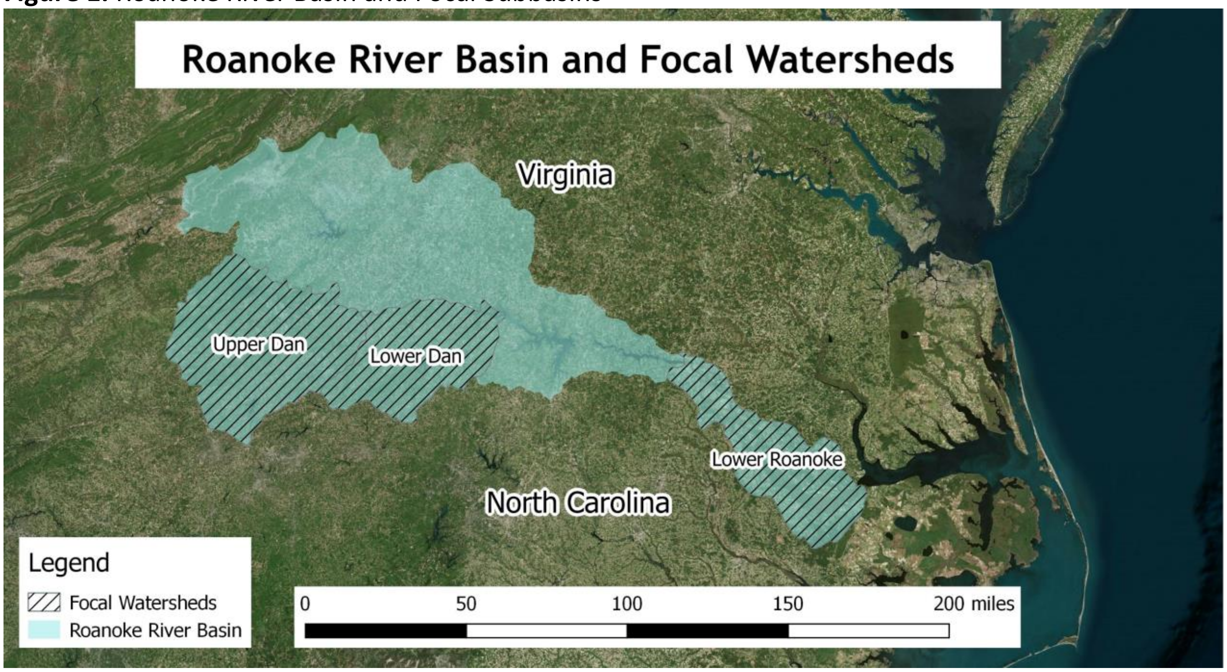
Existing studies note potential regional stigma effects that a uranium mine operation could have on both the agricultural and tourism industries, estimating that a 10% decline in these industries in the case of contamination would result in a 5-year loss of $357 million to these economic sectors (Chmura Economics, 2011). In the case of a major contamination event resulting in a 20% loss to the agricultural and tourism sectors, the region could experience a 5-year loss of $530 million in economic value (Chmura Economics, 2011).

We also examine potential losses in ecosystem service value that would result in human health damages, lost consumer surplus, lost property values, and avoidance costs for nearby populations and communities downstream of the mining facilities in the Roanoke River Basin. We estimate human health damages from radon exposure at $27 million for uranium workers and $41.5 million to the nearby population over the course of the mine's operation. Nearby private well water users will likely have increased radon monitoring costs, and in the case of radon contamination in groundwater, treatment costs of up to $1 million. Lost consumer surplus, based on downstream water users' willingness to pay to reduce their exposure risk to toxins, could reach $160 million over the mine's 35-year planned operation period.

Project Purpose

The land and water in the Roanoke River basin (RRB) provide a suite of ecosystem service benefits for society. Ecosystem services (ES) are the values of goods and services provided by healthy and functional ecosystems that people would otherwise need to provide for themselves (Phillips, Silverman, & Gore, 2008). Examples of ecosystem services in the Basin include, but are not limited to, water supply, local climate regulation, scenic views, experiences in nature, and fertile soil to grow food. Recent studies in the Roanoke River Basin (RRB) have addressed ecosystem services at a conceptual level and conservation measures have sought to protect these services, including water supply, water purification, and water-based recreation, among others (Rashleigh, Lagutov, & Salathe, 2012; Roanoke River Basin Association, n.d.).

Figure 1. Roanoke River Basin and Focal Subbasins



This project examines a broad suite of ecosystem services, including their spatial distribution and value, across the entire RRB (including the Dan River and Lower Roanoke subbasins). In the baseline assessment, basin-wide information on ecosystem service values (ESV) provides a foundation for which citizens, planners, and resource managers at state and federal agencies can form a better understanding of how protecting and restoring ecosystem services will lead to economic benefits.

To our knowledge, this is the first study that analyzes, quantifies, and maps priority services in two focal sub-basins of the Roanoke River Basin, the Lower Roanoke, and (together) the Upper and Lower Dan. Using participatory research techniques, we can establish which ecosystem services are of greatest importance to stakeholders in the region (National Research Council, 2008). Furthermore, using the tools and techniques outlined in the National Ecosystem Service Partnership (NESP) Guidebook, we provide a framework for ecosystem service analysis that allows us to link changes in land/resource management to outcomes including market and non-market benefits (National Ecosystem Services Partnership, 2016).

Finally, and in the interest of supporting broader efforts to quantify and understand ecosystem services, this project develops an open source computer program that connects spatial and tabular information on land cover/land use to their ecosystem benefits called "EcoValuator". The code was created in Python for use in QGIS, an open-source geographic information system package. Accordingly, the code itself is open-source and available as a free download and/or distributed as a QGIS "plugin". This package allows less technical users to easily input geographical boundaries of interest in order to develop custom ecosystem services assessments.

At a high level, this work is a small part of the transformation of society, and especially the economy, in ways that bring the health of ecosystems and the associated welfare of people to bear on everyday economic decisions.

This project:

- Advances understanding of the relationships among human and natural systems in the RRB and especially in the Dan and Lower Roanoke watersheds;
- Equips key stakeholders with information to support land conservation, river restoration, and sustainable economic development actions, such as smart growth planning, green infrastructure projects, the purchase of easements for areas important for the provision of key ecosystem services; and
- Applies and tests tools and techniques described in the NESP guidebook, thereby providing further lessons learned and examples to follow for federal agencies and others incorporating ecosystem services thinking into land and resource management decisions.

Background: Roanoke River Basin

The Roanoke River Basin stretches from the headwaters of the Blue Ridge Mountains in Virginia to the Albemarle Sound on the coast of North Carolina. The basin spans 9,850 square miles and contains over 14,400 stream miles, including the Roanoke River, which flows over 400 miles (US Geological Survey, 2018). The North Carolina-Virginia state line cuts through the Roanoke River Basin, with about two-thirds of the land in Virginia and one-third of the land in North Carolina. Across the basin, the region is largely rural, with only 5% of land developed as towns, cities, or residential neighborhoods (U.S. Geological Survey, 2011). The majority of the region is forested, with the significant remaining portion used for agricultural production, both as pasture and cropland. In the Lower Roanoke subbasin, forests and agricultural production transition into wetlands and expansive floodplain around the Roanoke River before reaching the coast.

Table 1. Roanoke River Basin Profile

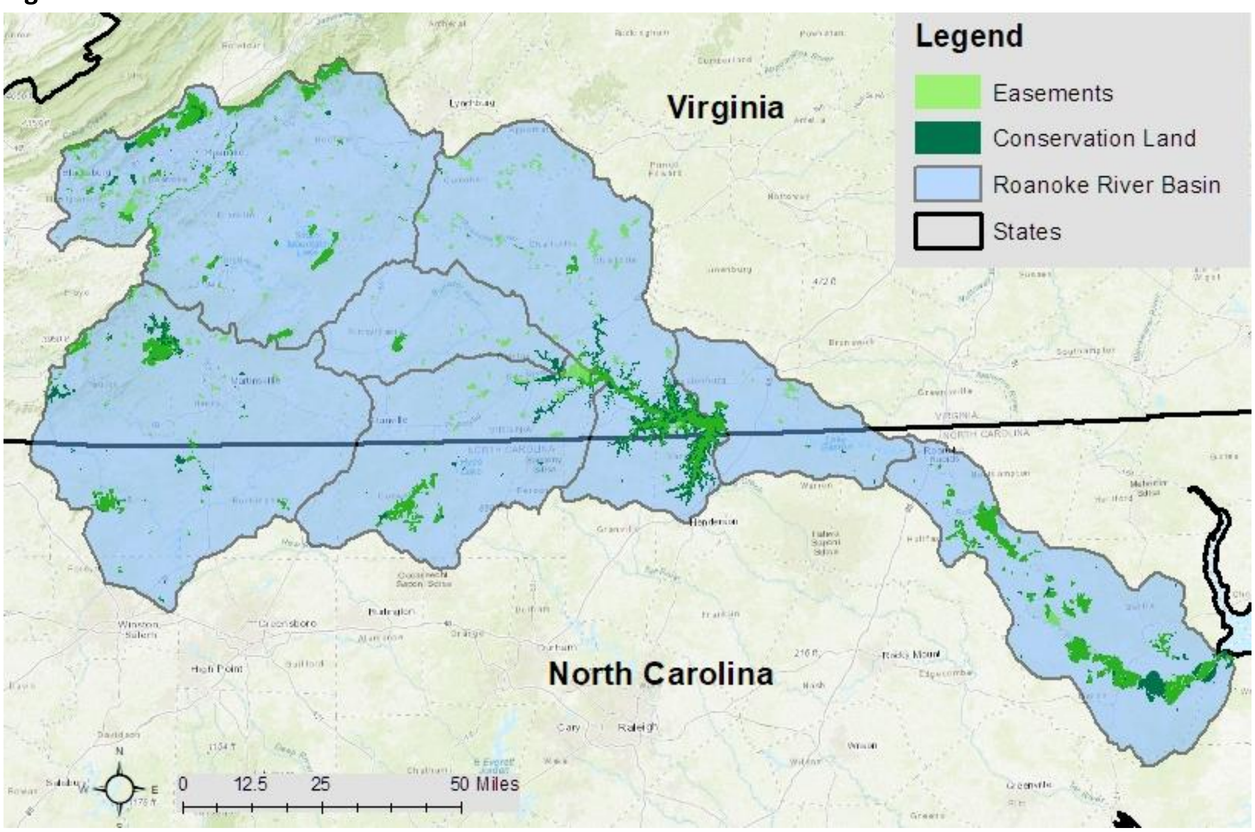
Indicator	Level
Area (square miles)	9,850 mi^2
Stream Miles	14,400 mi
Population	1,163,016
Per Capita Earnings (2017$)	$27,806
Median Housing Value (2017$)	$137,600

History & Natural Assets

The Roanoke River, known as the "river of death" to Native Americans and early settlers, claimed lives in frequent spring floods which over time allowed for rich and fertile agricultural land to form in the RRB (NC DEQ & NC OEEP, 2013).[1] In the past century, the decline of the agricultural and manufacturing industries in the macroeconomy, along with the construction of three major dams along the Roanoke River, transformed ecological conditions and the basis of livelihoods for communities in the Basin (NC DEQ & NC OEEP, 2013; Stober, Ford, & Wallace, 2012).

The basin provides habitat for rare and threatened species, water supply for communities and industries, rich land for agriculture and farming, and scenic waterways, viewsheds, and natural attractions for recreation. Recreation and resource opportunities range from wildlife viewing in the Roanoke River National Wildlife Refuge to kayaking and fishing along the Dan River.

Figure 2. Land Conservation in the Roanoke River Basin



Nearly 200,000 acres are under conservation easements in the Virginia portion of the Roanoke River Basin, and another 122,000 acres are conserved in easements in the North Carolina portion (Figure 2)

[1] North Carolina Department of Environmental Quality & North Carolina Office of Environmental Education and Public Affairs

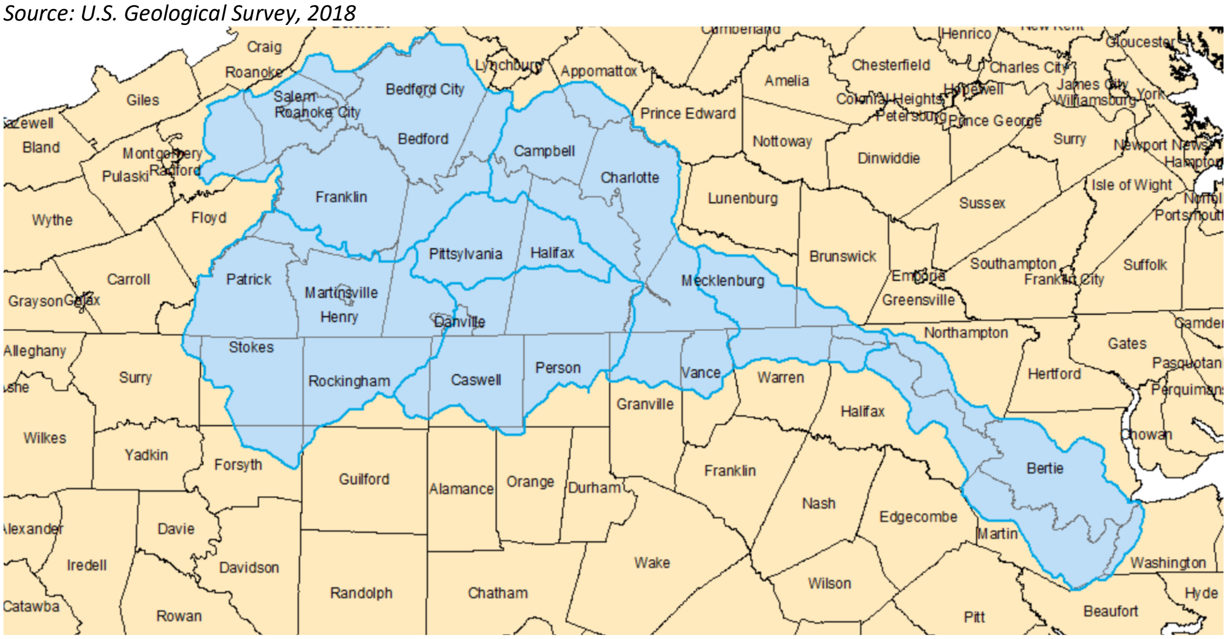
(U.S. Geological Survey, 2016). Another 176,000 acres of the RRB in Virginia are protected as parks, recreation areas, preserves, and wildlife management areas, including popular destinations such as the Blue Ridge Parkway, Smith Mountain Lake, and the John H. Kerr Reservoir (Virginia Department of Conservation and Recreation, 2018). In North Carolina, at least 182,000 acres are protected as heritage areas, parks, game lands, and refuges, including Hanging Rock State Park in Stokes County, North Carolina and the Roanoke River Wildlife Refuge in the Lower Roanoke River (North Carolina Natural Heritage Program, 2019).

Extractive resource opportunities exist throughout the region, including logging and agriculture. The wetlands along the Lower Roanoke serve as natural buffers to low-lying properties and communities vulnerable to flooding and extreme weather events (North Carolina Department of Environmental Quality, n.d.).

Economic Profile

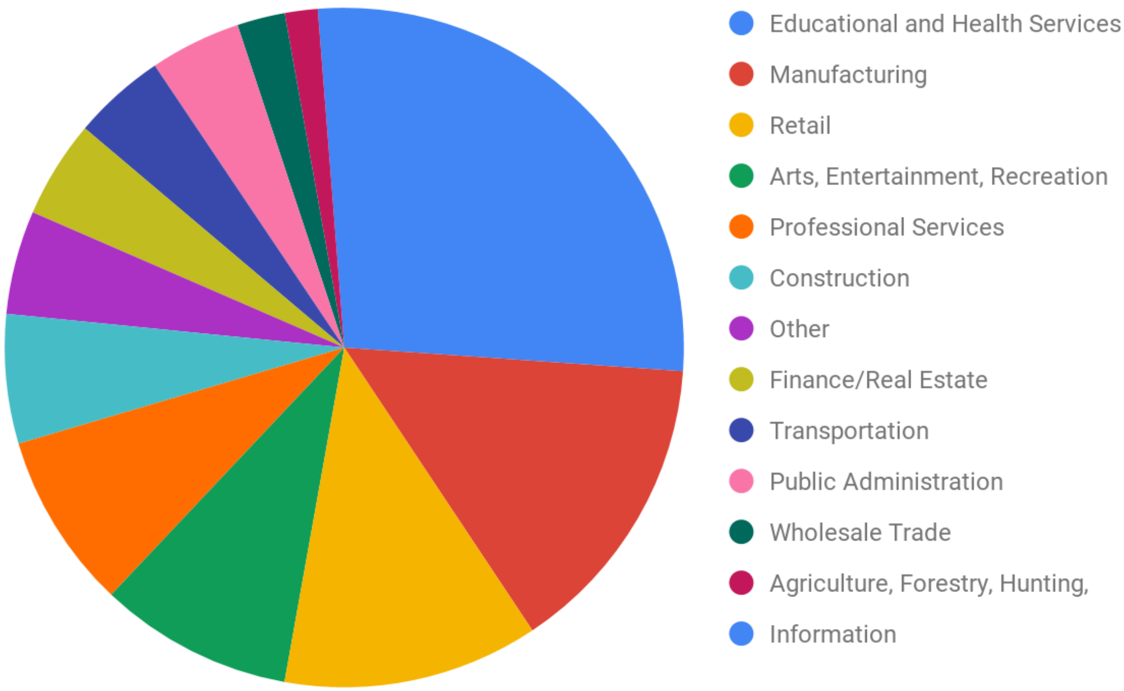
The Virginia and North Carolina counties that overlap the RRB are largely rural, and historically experienced economic growth in manufacturing and agriculture (Figure 3). Population has increased nearly 30% in the study region counties since 1970, with an average annual net migration to the regional counties of 2,686 from 2000 to 2017 (Headwaters Economics, 2019).

Figure 3. Virginia and North Carolina counties that overlap the Roanoke River Basin
Source: U.S. Geological Survey, 2018



The economic landscape of the region has shifted over the past half-century as manufacturing and agriculture (such as tobacco) have experienced declines in employment and earnings. Educational and health services now make up over a quarter of employment in the region (Figure 4).

Figure 4. Employment in the Roanoke River Basin by Industry, 2019
Source: U.S. Census Bureau, 2019



While overall employment steadily increased from 1970 to 2000, the region lost nearly 10,000 jobs between 2000 and 2016 (Headwaters Economics, 2019). However, personal income in the RRB grew from $51 billion in 2000 to over $60 billion in 2016, with per capita income increasing from $33,884 in 2000 to $37,770 in 2016 (2017 dollars) (Headwaters Economics, 2019).

Compared to the U.S. average, the region has a lower per capita income, higher unemployment rate, and has experienced slower population growth (Headwaters Economics, 2019). Counties in the RRB have a higher proportion of persons employed in the government and non-service employment than the U.S. average, with federal, state and local governments employing around 72,000 people in the region (Headwaters Economics, 2019).

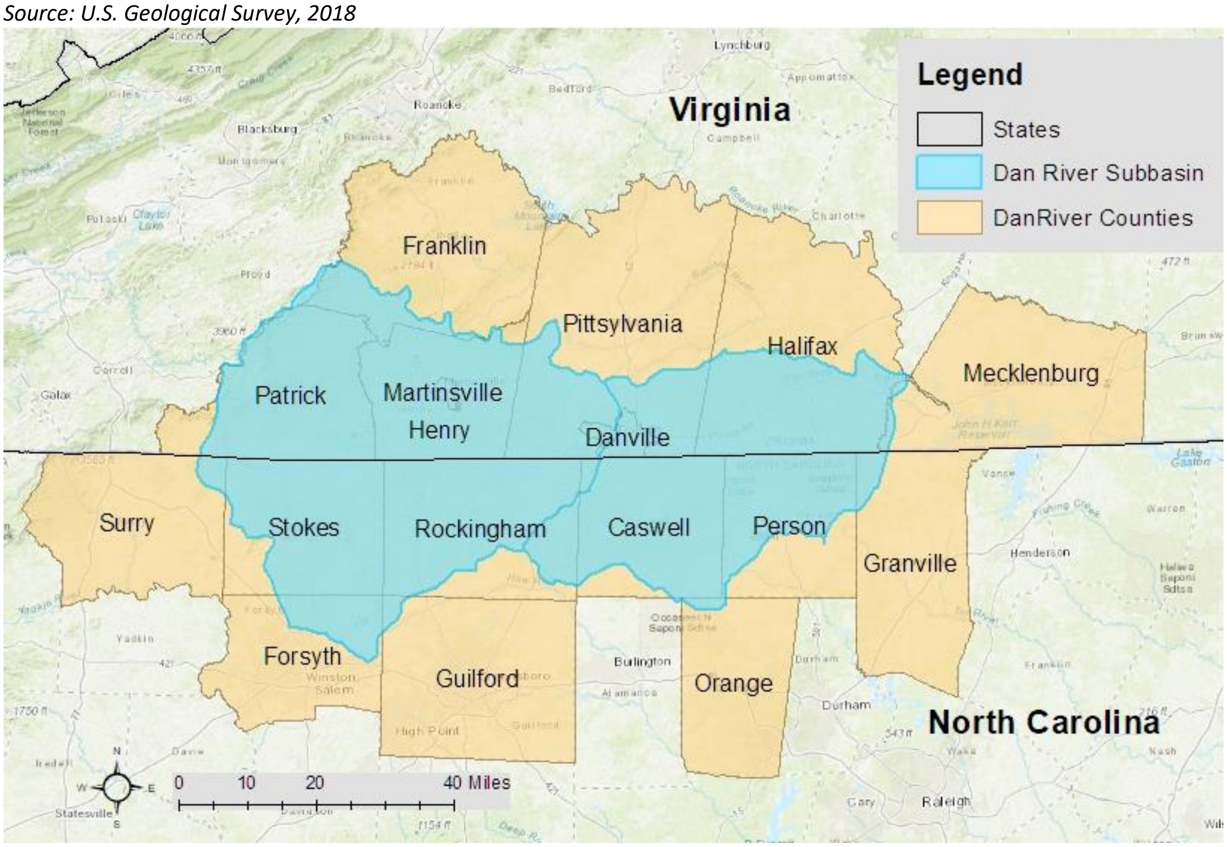
The natural resource sector, which consists of mining, agriculture, forestry, fishing, and hunting, employs 4,770 people in the region with average annual wages of $37,434, near the regional average (Headwaters Economics, 2019). Mining jobs supply the highest average annual wage, at over $68,500, while agricultural, forestry, fishing, and hunting jobs provide lower than average wages of about $33,000 per year (Headwaters Economics, 2019).

Travel and tourism make up nearly 15% of employment in the region and includes sectors such as accommodations and food; arts, entertainment, and recreation; and passenger transport and retail trade (Headwaters Economics, 2019). From 1998 to 2016, travel and tourism employment increased by 7,387 jobs, with the largest increases in arts, entertainment and recreation (38% increase) and accommodation and food services (30% increase). During the same period, employment in all other industries shrank by 45,000 jobs. The travel & tourism economy in the Roanoke River Basin can continue to serve as a leading sector in regional economic growth with concerted efforts by states, regional agencies, and counties to manage and promote the natural recreation opportunities.

Dan River Subbasin

The Upper and Lower Dan River subbasins (referred to as the Dan River subbasin) spans over 3,300 square miles of land and contains around 4,800 stream miles (U.S. Geological Survey, 2018). The Dan River subbasin offers recreational opportunities in the Philpott Reservoir, Hanging Rock State Park, the upper reaches of the John H. Kerr Reservoir, and water activities such as tubing, fishing, and kayaking on the Dan River. The counties of Patrick, Henry, Pittsylvania, and Halifax encompass the majority of the Virginia portion of the subbasin, while Stokes County, Rockingham County, Caswell County, and Person County encompass the majority of the subbasin in North Carolina (Figure 5).

Figure 5. Dan River Sub-basin Watershed Boundaries and Counties
Source: U.S. Geological Survey, 2018



The Dan River subbasin faces unique challenges in water quality monitoring and planning, as the North Carolina-Virginia state line divides the basin into two separate EPA planning regions (Stober et al., 2012). National attention turned to the Dan River subbasin in 2014 when a stormwater pipe burst at a coal ash impoundment in Rockingham County, North Carolina, releasing 39,000 tons of coal ash 70 miles downstream along the Dan River (Wireback, 2014). Major challenges and environmental stressors in the

Dan River watershed include four major coal ash impoundments, increasing urban development, and a lack of adequate riparian buffers along waterways.

Table 2. Dan River Subbasin Profile

Indicator	Level
Area (square miles)	3,336 mi^2
Stream Miles	~4,725 mi
Population	445,872
Per Capita Earnings (2017)	$31,286
Major Industries	Educational and Health Care Services, Manufacturing, Retail

History & Natural Assets

Significant portions of the Dan River watershed are under conservation easements, including over 24,000 acres in Halifax County, Virginia alone (Headwaters Economics, 2019). The Dan River subbasin has provided rich resources for extractive economies, such as agriculture and forestry, over the past few centuries. During industrialization railroads came to the region, creating economic hubs around Danville and Martinsville, two of the more densely populated areas in the watersheds (Stober et al., 2012). Tobacco and timber are two historically significant economic commodities to the Dan River Basin, but neither bring the same economic vitality they once did to the counties in the region; decreased demand for tobacco and outsourced manufacturing has contributed to lower income levels and higher poverty rates over the past fifty years (Stober et al., 2012).

Despite a low level of urban development in the region, approximately 20% of the waterways in the Dan River Basin are impaired, suggesting that nonpoint pollution sources such as agriculture and forestry could be major sources of stream degradation (Stober et al., 2012). Half of the impaired stream miles in the Dan River subbasin have E. coli levels exceeding federal health guidelines, which indicates livestock, human, and wildlife fecal material could all be contributing to stream impairment (Stober et al., 2012).

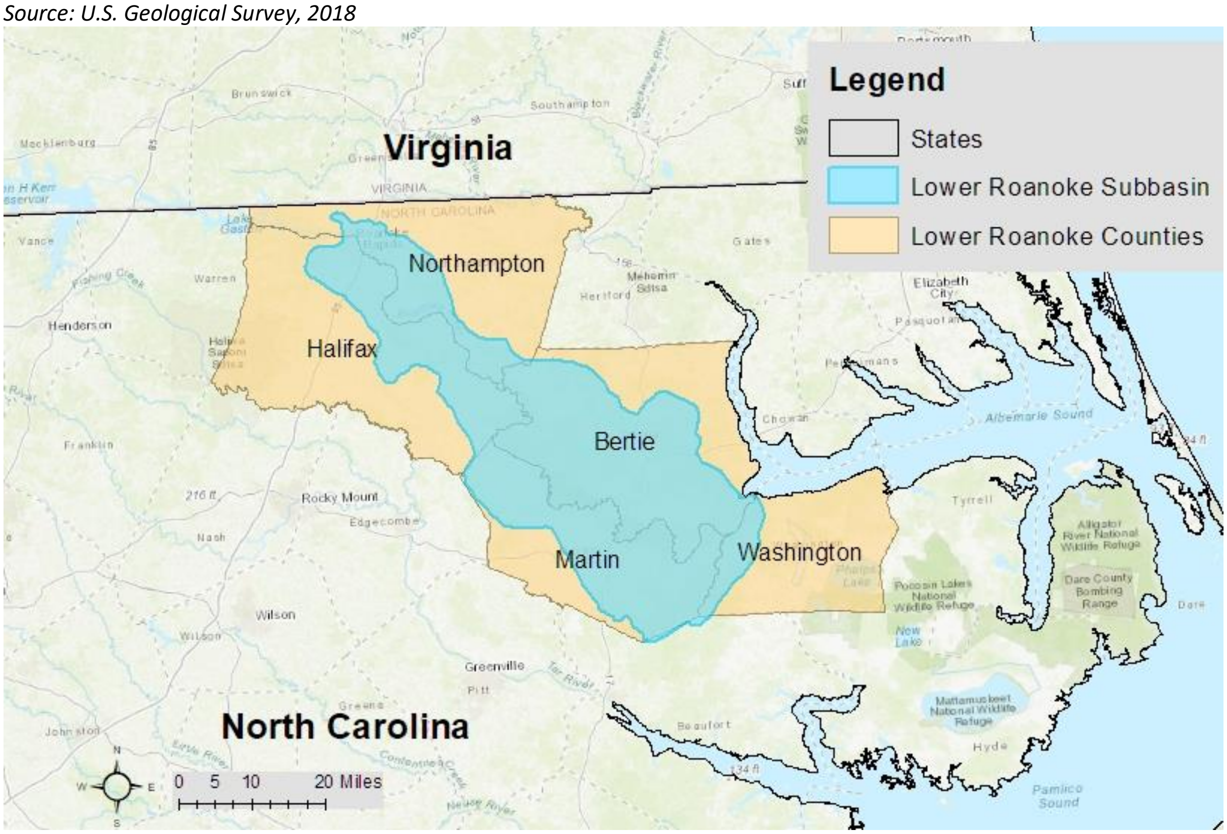
Economic Profile

Since 1970, the population has increased by 7% in the county region that overlaps the Dan River subbasin, while personal income has more than doubled (in real terms) from $10.8 billion in 1970 to over $21.9 billion in 2017 (Headwaters Economics, 2019). From 2000 to 2017, regional earnings in the manufacturing and mining industry declined significantly, while farm earnings slightly increased (Headwaters Economics, 2019). However, even with declines in regional earnings, manufacturing still remains one of the largest economic sectors in the region, with over $2 billion in industry earnings in the Dan River Basin counties in 2017 (Headwaters Economics, 2019). Caswell County, North Carolina has the highest proportion of farm employment in the Dan River Basin, with over 10% of employed in farming, compared to an average of 3% in the county region (Headwaters Economics, 2019). Travel and tourism related employment comprised over 14,000 jobs in the Dan River subbasin in 2016, increasing from 10% to 14% of total employment from 1998 to 2016 (Headwaters Economics, 2019). Stokes County has the highest proportion of travel and tourism employment in the region (19%), while Patrick County has the lowest (9%).

Lower Roanoke River Subbasin

The Lower Roanoke River subbasin covers 1,282 square miles in the northwestern corner of North Carolina and carries the Roanoke River into the Albemarle Sound (Figure 6). The region is home to natural attractions like the Roanoke River National Wildlife Refuge, which includes the largest remaining bottomland hardwood forest in the Mid-Atlantic, Tillery game land, and the Roanoke River Wetlands game lands (NC DEQ & NC OEEP, 2013). These conserved areas provide ample recreational opportunities for wildlife viewing, fishing, hunting, hiking, and boating.

Figure 6. Lower Roanoke Sub-basin Watershed Boundaries and Counties
Source: U.S. Geological Survey, 2018



The land cover in the region is dominated by agriculture and wetlands; 33% of land is classified as either woody or emergent (coastal) wetlands, and another 30% of the land is agricultural (either pasture or cropland) (U.S. Geological Survey, 2011). Only 21% of the subbasin is forested, as opposed to nearly two-thirds of the Roanoke River Basin as a whole (U.S. Geological Survey, 2011).

Table 3. Lower Roanoke River Subbasin Profile

Indicator	Level
Area (square miles)	1,282 mi^2
Stream Miles	~1,675 mi
Population	95,345
Per Capita Earnings (2017)	$27,742
Major Industries	Educational and Health Care Services, Manufacturing, Retail

History & Natural Assets

The richest natural resources in the Lower Roanoke River are fertile land for growing tobacco, soybeans, cotton, and peanuts, and water habitat for anadromous fish like striped bass and herring (NC DEQ & NC OEEP, 2013). Recreational fishing is such a popular attraction in the region that Weldon, North Carolina has been labeled the "Rockfish Capital of the World"; anglers travel from across the world to catch striped bass (known locally as "rockfish") on the Roanoke River in Weldon (Meacham, n.d.).

In the most eastern portion of the Lower Roanoke River subbasin, the Roanoke River Wildlife Refuge contains over 21,300 acres of conserved forest, wetlands, and waterways designed to protect aquatic and migratory bird habitat, other endangered wildlife, and recreation and educational opportunities to the public (U.S. Fish and Wildlife Service, 2014). The refuge, managed by the U.S. Fish and Wildlife Service, is part of a 100,000-acre protected area in the subbasin. The Nature Conservancy, U.S Fish and Wildlife Service, N.C. Wildlife Resources Commission, and private landowners who entered into conservation easements are all managers of this expanse of protected lands, which provides a habitat corridor stretching 137 miles from Roanoke Rapids to Albemarle Sound (NC DEQ & NC OEEP, 2013).

Economic Profile

The North Carolina counties that overlap the Lower Roanoke subbasin have all experienced population declines in the last forty years; the average population in the county region has declined 8.5% since 1970, with Northampton County having the greatest population loss at nearly -15% from 1970 to 2017 (Headwaters Economics, 2019). While personal income has increased over 100% in the last forty years in the Lower Roanoke region, the growth is less than half the U.S. average in the same time period. From 2000 to 2017, average earnings per job in the region declined by 10% (Headwaters Economics, 2019). Employment levels have also declined in nearly every economic sector in the Lower Roanoke county region, with nearly 5,000 jobs lost between 2000 and 2017 (Headwaters Economics, 2019).

Agriculture is a major economic sector in the region, making up 4.2% of private employment, over 4 times the U.S. average, while the timber industry employs 6% of the private sector. In 2016, travel and tourism businesses accounted for nearly 15% of private employment. Employment in the accommodation and food sector increased 13% from 1998 to 2016. Arts, entertainment, and recreation was one of the only other economic sectors that had positive job growth in the same period, with an increase of 4% (Headwaters Economics, 2019). Halifax County, North Carolina has the highest level of employment (20%) related to travel and tourism, while Bertie County, North Carolina has the lowest level (6%).

Baseline Ecosystem Service Assessment

The purpose of a baseline ecosystem service assessment is to set the stage for determining how management scenarios and conservation strategies can result in changes in the supply of ecosystem services. When we incorporate ecosystem service values into funding prioritization, policy-making, and resource management planning, we get a more complete picture of the costs and benefits of any one restoration effort and can make better-informed decisions (National Ecosystem Services Partnership, 2016).

What are Ecosystem Services?

Ecosystem services are the benefits that people receive from nature over space and time (Johnson et al., 2010). Examples of ecosystem services are clean air, clean water, scenic views, experiences in nature, and fertile soil to grow food. We often receive these benefits for free; our ecosystems are filtering our air and water, absorbing harmful toxins, and providing a natural buffer to extreme weather events, all at no cost to us.

Recreation: a cultural ecosystem service; experiences in nature that we value (Balmford et al., 2013)

Protection from Extreme Events: a regulating ecosystem service; value of natural buffers that ecosystems and living organisms provide against extreme weather events or natural disasters, preventing possible damage (Balmford et al., 2013)

Stressors to the ecosystem, such as development and pollution, can reduce or disrupt the supply of these services. This disruption results in an economic cost to society that can be monetarily valued. In some cases, society will need to replace these services through man-made means, which have a material cost, and in some cases, our health suffers as well.

For example, when clean water - an ecosystem service - is polluted, we must pay more in water treatment costs, and can suffer from sickness and lost recreational experiences. All these losses can be quantified in dollar terms and help us understand the benefit of clean water and protected lands in economic terms.

Ecosystem Services in the Roanoke River Basin

The project study region encompasses seven subbasins, including the Upper and Lower Dan River and the Lower Roanoke River. Using the most recent National Land Cover Database (2011) data, we can determine the land cover distribution and the ecosystem service values provided by each land use for the Roanoke River Basin (Tables 4 & 5).

Table 4. Land Cover Distribution in the Roanoke River Basin

Land Use	Total Square Miles
Deciduous Forest	3,900
Pasture/Hay	1,676
Evergreen Forest	1,050
Grassland/Herbaceous	529
Woody Wetlands	506
Shrub/Scrub	502
Developed, Open Space	487
Cultivated Crops	339
Mixed Forest	315
Developed (Low, Medium, High Intensity)	250
Open Water	204
Emergent Herbaceous Wetlands	28
Barren Land	12

Ecosystem services in the Roanoke River Basin provide over $14.8 billion in benefits to the region. Recreation provides $6.6 billion in benefits and water and water flows combined provide roughly $2.4 billion in benefits (Table 5).

Table 5. Baseline Estimate of Ecosystem Service Values in the Roanoke River Basin

Ecosystem Service	Annual Value Provided (2017$)
Aesthetic	$971,013,005
Air Quality	$809,892,856
BioControl	$9,077,789
Climate	$707,856,062
Cognitive	$8,833,985
Energy	$5,052,642
Erosion	$75,421,802
Extreme events	$419,197,144
Food	$2,302,386,386
Genepool	$25,869,511
Nursery	$48,620
Pollination	$8,245,721
Raw materials	$70,003,292
Recreation	$6,638,577,349
Soil fertility	$4,146,843
Soil Formation	$186,348,212
Waste	$55,731,512
Water	$1,029,647,498
Water flows	$1,430,162,058
Grand Total	**$14,757,512,287**

Dan River Subbasin

In the Dan River subbasin (comprised of the Upper and Lower Dan River subbasins), ecosystem services provide over $4.5 billion in natural benefits, with recreation providing nearly $3.0 billion of value in the region (Table 6).

Table 6. Baseline Estimate of Ecosystem Service Values in the Dan River Subbasin

Ecosystem Service	Annual Value Provided in the Upper Dan River Subbasin (2017$)	Annual Value Provided in the Lower Dan River Subbasin (2017$)	Annual Value Provided in the Dan River Subbasin (2017$)
Aesthetic	$133,905,202	$114,800,857	$248,706,060
Air Quality	$221,441,811	$104,381,504	$325,823,315
BioControl	$1,480,638	$1,404,638	$2,885,276
Climate	$178,993,134	$89,542,284	$268,535,419
Cognitive	$1,645,552	$1,331,598	$2,977,150
Energy	$450,093	$514,958	$965,051
Erosion	$2,640,721	$4,409,739	$7,050,460
Extreme events	$66,465,390	$50,600,874	$117,066,264
Food	$126,021,513	$121,887,230	$247,908,743
Genepool	$5,829,250	$3,403,161	$9,232,411
Nursery	$726	$960	$1,686
Pollination	$1,513,356	$1,431,628	$2,944,984
Raw materials	$9,635,088	$8,157,114	$17,792,202
Recreation	$1,582,148,949	$1,401,874,314	$2,984,023,263
Soil fertility	$570,694	$519,985	$1,090,679
Soil formation	$2,684,501	$8,156,729	$10,841,229
Waste	$1,268,455	$2,212,375	$3,480,830
Water	$113,822,298	$128,126,269	$241,948,567
Water flows	$29,630,644	$68,162,256	$97,792,900
Grand Total	**$2,480,148,015**	**$2,110,918,472**	**$4,591,066,487**

Lower Roanoke River Subbasin

In the Lower Roanoke subbasin, ecosystem services provide over $4.4 billion in natural benefits. Food and nutrition (largely from agriculture) contributes to $1.5 billion in benefits and water flows contribute $1.1 billion in benefits (Table 7).

Table 7. Baseline Estimate of Ecosystem Service Values in the Lower Roanoke subbasin

Ecosystem Service	Annual Value Provided in the Lower Roanoke Subbasin (2017$)
Aesthetic	$109,211,276
Air Quality	$32,573,322
BioControl	$3,265,305
Climate	$46,002,340
Cognitive	$556,933
Energy	$400,323
Erosion	$55,653,406
Extreme events	$114,395,874
Food	$1,511,441,052
Genepool	$3,356,531
Nursery	$39,806
Pollination	$2,484,340
Raw materials	$19,134,942
Recreation	$797,384,854
Soil fertility	$1,576,711
Soil formation	$148,582,852
Waste	$43,536,285
Water	$374,255,938
Water flows	$1,102,741,336
Grand Total	**$4,366,593,426**

Stakeholder Input

The foundation for deeper analysis in the Roanoke River Basin required participatory research from communities in the region. Working with the Roanoke River Basin Association, the Dan River Basin Association, and allied groups, the team identified a set of issues, stakeholders, and locations around which to organize two in-person workshops of 4 to 6 hours each. One workshop was held in Danville, Virginia, and focused on issues on the Dan River subbasin; the other workshop was held in Weldon, North Carolina and focused on issues in the Lower Roanoke subbasin in North Carolina. Specifically, the outcomes of the workshops included:

a. An introduction and exploration of the ecosystem services concept/framework;
b. Discussion of how various stressors (climate change, resource extraction proposals, habitat loss, etc.) relate to changes in ecosystem processes and ecosystem benefit (collectively the delivery of ecosystem services);
c. Identification of key, or priority potential ecosystem services relationships (value chains) for further analysis;
d. Assessment of how conservation, management, and policy actions may affect those relationships; and
e. Development of a post-workshop survey for further stakeholder engagement and guidance

In the workshops, participants identified key stressors and activities in their respective sub-basins and, through structured exercises, sketched "means-ends" diagrams that guided further analysis (Figure 7). The post-workshop survey allowed stakeholders who could not attend to voice priorities and concerns to ensure that we had as much input as possible regarding environmental issues and related economic factors in the Roanoke River Basin. The survey results (Appendix B), largely echoing discussions in the workshops, reveal widespread concern about the potential of uranium mining in the region as well as ongoing issues from coal ash storage and disposal. Ecosystem services that stakeholders identified as important to the communities and region as a whole include recreation (including recreational fishing), drinking water quality and water for industrial use, as well as habitat for species (Appendix B).

Guided by the in-workshop exercises and survey results, we next developed ecosystem service concept models (Appendix C) for four major issues areas in the Roanoke River Basin in order to estimate ecosystem service flows in the two sub-basins and assess how key issues, including competing land uses, could affect those flows. Table 8 provides an overview of the four major issue areas examined in further depth, including major ecosystem service values that could be affected by the respective resource management actions.

Figure 7. Sample Means-Ends Diagram

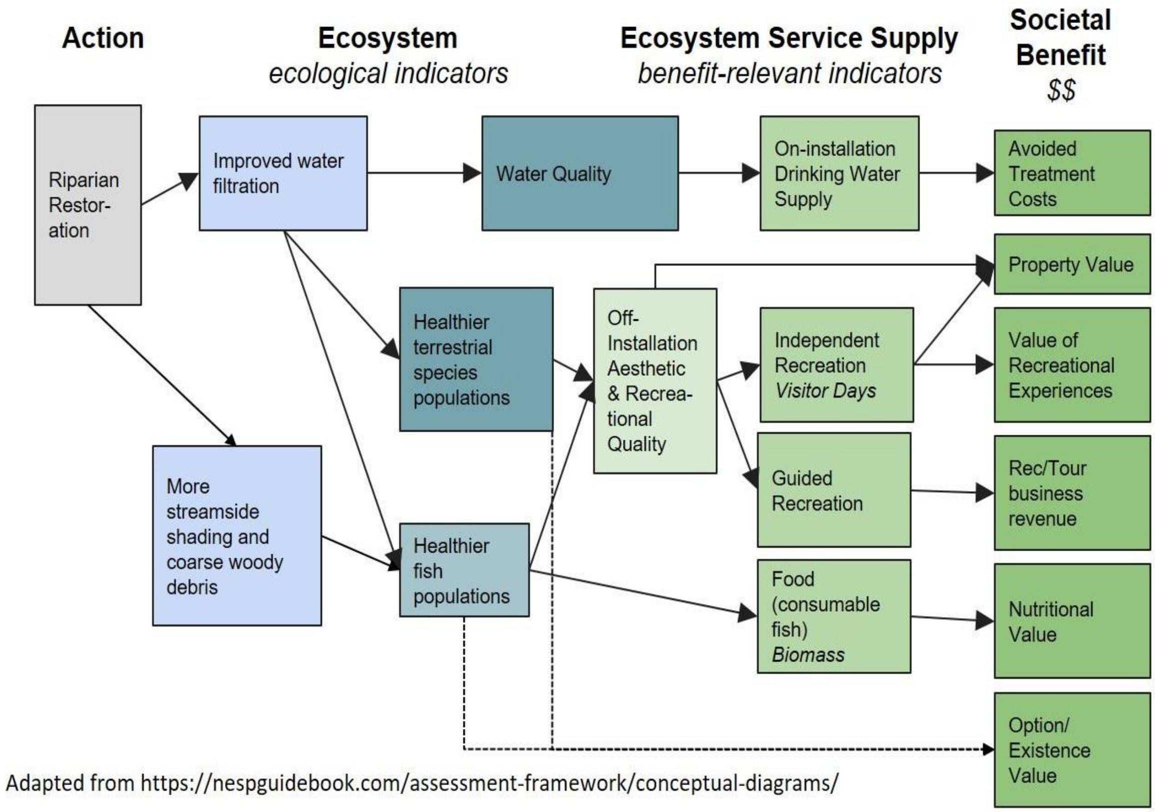


Table 8. Roanoke River Basin Means-End Diagrams Overview

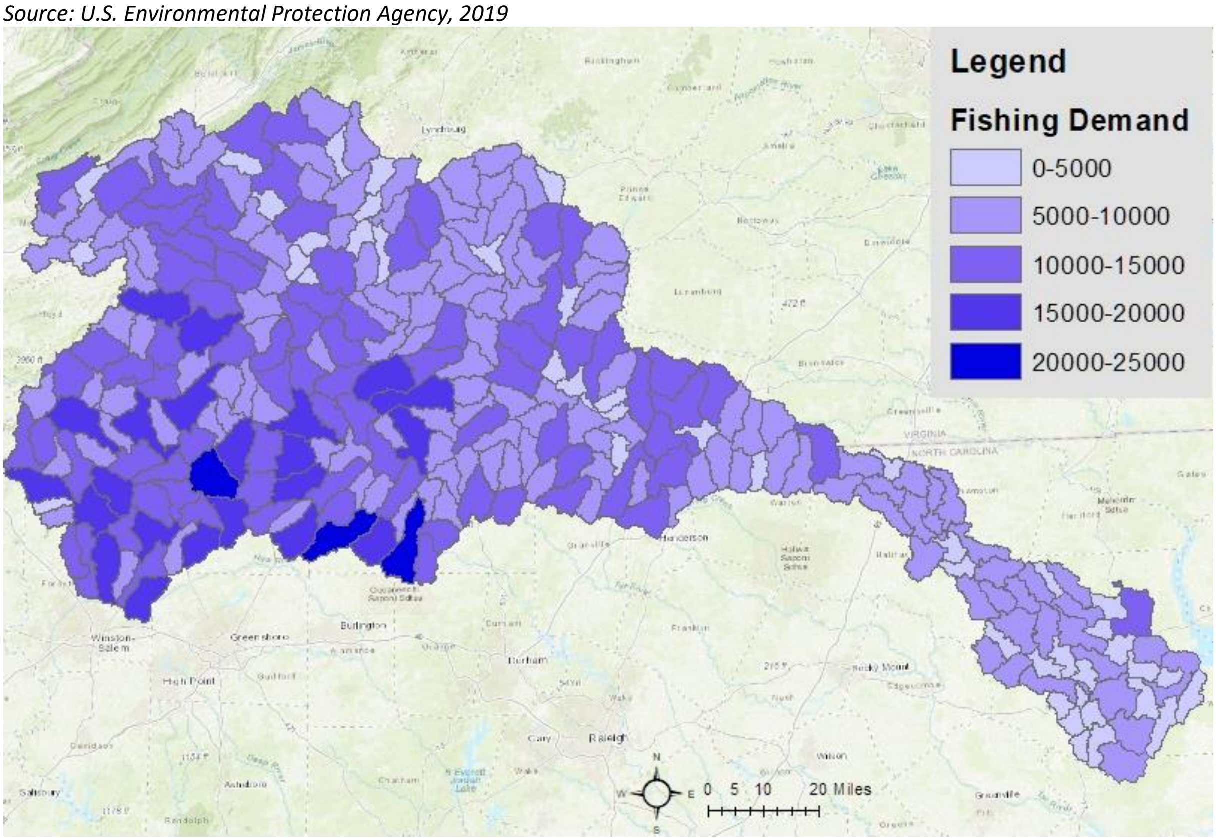
Environmental Issues	Actions and Interventions	Ecosystem Services for Analysis
Uranium Mining (ban lifted)	Uranium mining begins on Cole Hill	Water Quality, Air Quality, Aesthetics, Recreation
Agricultural Runoff	Encourage expanded natural riparian buffers	Water Quality, Waste Assimilation, Aesthetics, Recreation, Protection from Extreme Events, Air Quality
Pollution from Industry		
Coal ash spills/coal ash disposal	Excavation and disposal of four Duke Energy coal ash ponds in Dan River Basin	Water Quality, Recreation, Habitat for species
Water Quality & Recreation	General Water Quality Improvements	Water Quality, Recreation

Recreation and Sustainable Ecotourism

The Roanoke River Basin provides a myriad of opportunities for outdoor recreationists. A 2013-2014 survey of ecotourism in Virginia's Upper Reach of the Basin identified the most popular activities such as kayaking, canoeing, hiking, bird watching, wildlife observation, camping, and fishing (Ellerbrock et al., 2015). The economic impact analysis based on survey results estimated that paddlers in the Upper Reach spend approximately $9.7 million a year, generating an additional $10.2 million in economic output and $12.3 million in income per year based on average expenditures of $239 per day per paddler (2018$; Ellerbrock et al., 2015).

Recreational anglers devote a total of 2.6 million days a year fishing in the Roanoke River Basin (Figure 8), with expenditures of about $167 million annually based on an average of $64 per day for travel, food, fishing equipment, bait, etc. (2018$; U.S. Fish and Wildlife Service, 2011).

Figure 8. Freshwater Recreational Fishing Demand Days in the Roanoke River Basin, 2010-2011
Source: U.S. Environmental Protection Agency, 2019



Recreation Benefits from Water Quality Improvements

Improvements in water quality can result from many different management actions, including creating or increasing riparian buffers, implementation of Best Management Practices (BMPs), and municipal stormwater management upgrades (see Appendix C). Improved water clarity can contribute to increases in the number of days people participate in boating, swimming, fishing, and other water-based recreation activities. In turn, this can result in greater spending on trip related purchases such as food, travel, kayak rentals, etc., which in turn benefits local communities.

Research indicates that outdoor recreationists are willing to pay for improvements in water quality. In the Chesapeake Bay, for example, registered boaters were asked to rate water quality as poor, fair, good, very good, or excellent in relation to the extent it affected their boating activities. Survey results suggest the boaters were willing to pay an average of $92 per year for a one-step improvement in water quality (e.g., from fair to good), with a median willingness to pay of $26 per year (Lipton, 2003).[2]

Parsons, Helms, and Bondelid (2003) estimated the economic benefits of water-quality improvements to recreational users of lakes, rivers, and coastlines in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut. Their survey found that annually, average per person willingness to pay for water quality improvements (from medium to high[3]) ranged from $14.00 for boating and fishing

[2] Values were reported by Lipton in 2001 dollars of $63 and $17.50 and adjusted to 2018 dollars.

[3] Water quality is defined in terms of biological oxygen demand, total suspended solids, dissolved oxygen, and fecal coliform levels. Sites with medium water quality have some game fishing and usually few visible signs of pollution. Sites with high water quality are suitable for extensive human contact, have the highest natural aesthetic, and support high quality sport fisheries" (Parsons, Helms, & Bondelid, 2003).

uses, $53.29 for viewing[4], and $119.40 for swimming use.[5] These average values include participants and nonparticipants of the different recreational activities.

In North Carolina, a study of the benefits of ambient water quality improvements in river basins and watersheds used travel costs as the implicit price of a recreation visit. Results suggest a mean willingness to pay for improved water quality of 17 cents per day trip across all watersheds in the state, with a range from $0 to $1.44 per day trip (assumed 2001 dollars; Phaneuf, 2002). This corresponds to a mean of 24 cents per trip, or up to $2.04 per trip in 2018 dollars. Phaneuf (2002) notes these estimates should be interpreted as underestimates of the use value associated with recreational trips because the calculation does not allow for an increase in the number of trips taken due to the quality improvement.

Estimate for the Roanoke River Basin

We use the number of water-related outdoor recreation days in the Roanoke River Basin and apply the average willingness to pay for improved water quality in North Carolina (Phaneuf, 2002) to estimate the recreational value of water quality improvements in the RRB. The number of water-related outdoor recreation days in Virginia was calculated by dividing the total population in the Roanoke River Basin by the total population in Virginia to obtain the percentage of the state's population residing in the Basin and then multiplying this percentage by the number of days Virginians participated in water-based recreation activities in 2017 (U.S. Census Bureau, 2019; Ellis et al., 2017).

The number of water-related outdoor recreation days was not located for North Carolina. We instead estimate the number of water-based recreation days by multiplying the population of North Carolina counties in the Roanoke River Basin by the percent of the state's population that participate in water-based recreation activities (U.S. Census Bureau, 2019; NC Department of Environment and Natural Resources, 2015). Multiplying the estimate of the number of participants by 4[6] gives us an estimate of the total number of days participants engaged in water-related outdoor recreation each year.

This results in an estimated 13.5 million annual water-related days in the Roanoke River Basin (Table 9). Multiplied by the average willingness to pay of 24 cents per day trip for improved water quality results in a total benefit of $3.2 million in the RRB (see Appendix D).

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[4] The survey defined viewing as trips where the primary purpose was to visit a beach or waterside for picnics, nature study, or other purposes.

[5] All values are adjusted and reported in 2018 dollars. The study reports values in 1994 dollars as $8.25 for boating, $8.26 for fishing, $31.45 for viewing, and $70.47 for swimming.

[6] This figure is based on North Carolina State Parks survey data that found the greatest portion (28% of respondents) average 3 to 5 state park visits per person per year (N.C. Department of Natural and Cultural Resources, 2018). We use the midpoint of 4 visits per person per year as a proxy for the number of days each participant engaged in water-related outdoor recreation annually and multiply by the number of participants to estimated total water-related recreation days.

Table 9. Water-Related Outdoor Recreation Days in the Roanoke River Basin

Activity	Days per Year (thousands)
Swimming	2,734
Viewing the water	2,651
Freshwater fishing	2,594
Power boating	1,291
Canoe/kayaking	1,197
Visiting beach/lake	997
Bird/wildlife watching	634
Water ski/jet skiing	558
Tubing	474
Sailing	145
Paddleboarding	108
Paddle-in camping	23
Windsurf/kitesurf/kiteboarding	17
Sailboarding	13
Other water-dependent	114
Total	**13,469**

Cost-Savings from Implementing Riparian Buffers

Water pollution, erosion, and runoff from agriculture and urban activity are all high-priority environmental concerns for stakeholders in the Roanoke River Basin. Unlike coal ash and uranium mining, for which the resource management action is either heavily or exclusively dependent on state regulation, addressing runoff concerns and erosion control around waterways in the Roanoke River Basin can be effectively controlled and managed by local governments and regional organizations.

In general, BMPs[7] are described as practices implemented to protect water quality and promote soil conservation in riparian zones (NC Forest Service, 2017). BMPs can be both physical structures and actions and processes, either targeting the area of runoff or promoting mitigation of runoff downstream

[7] "Best" Management Practices are sometimes called "Acceptable" or "Recommended" Management Practices, and readers may see BMP, AMP, RMP or other acronyms used, depending on the state, the agency, and the context.

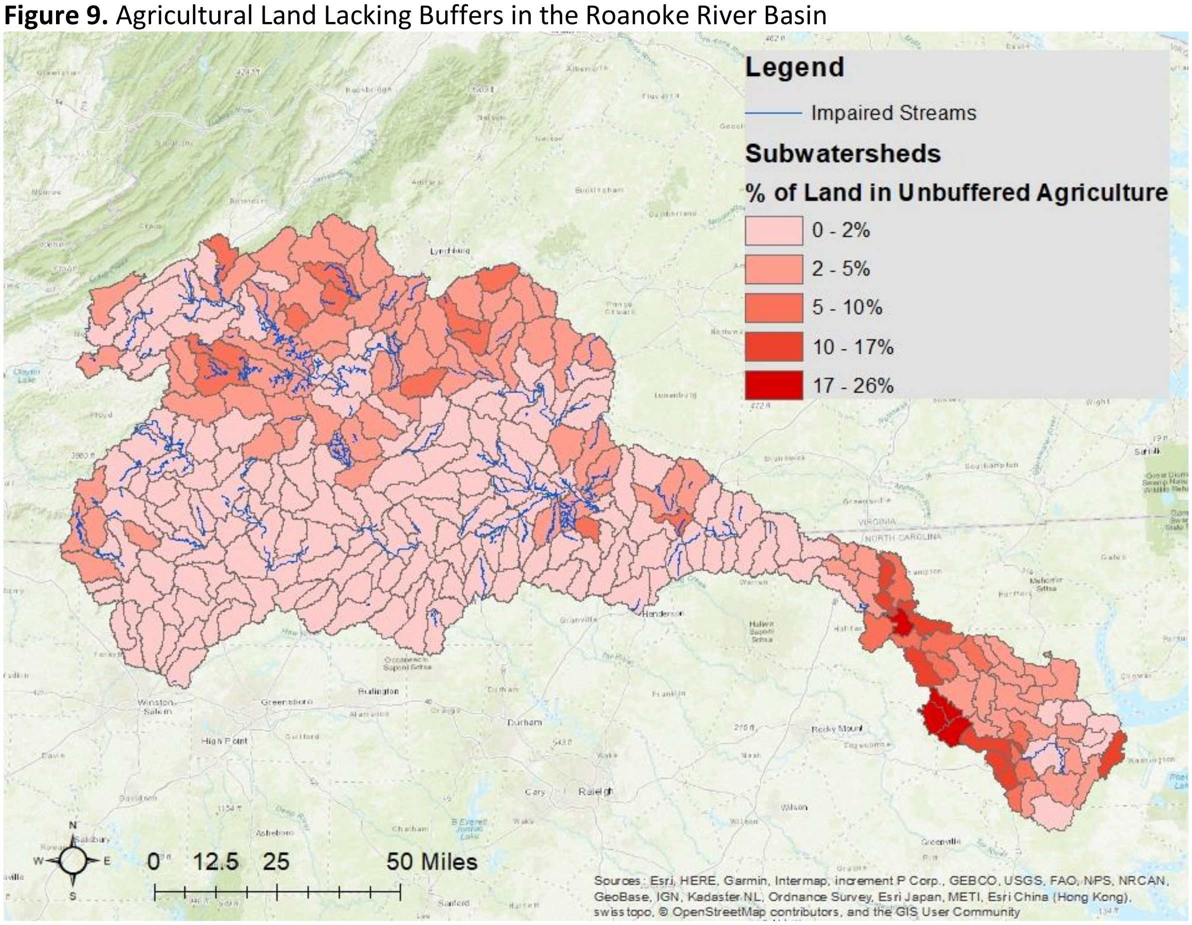
(NC Forest Service, 2017). Examples of structural BMPs include fencing and vegetation plantings while preventive strategies and processes include stormwater management and reduced fertilizer application.

At a Glance: Riparian Buffers in the Roanoke River Basin

A riparian buffer is land adjacent to a waterway that is maintained in order to protect ecosystem health, including water quality, habitat for fish and wildlife, soil stability, and other benefits to onsite and downstream communities (Klapproth & Johnson, 2009). The effectiveness of riparian buffers in promoting downstream ecosystem quality and health is in part dependent on the width of the buffer and the buffer's vegetation type; riparian forest buffers are far more valuable for the ecosystem services of water filtration and regulation, for example, compared to grass buffers (Klapproth & Johnson, 2009).

In the Roanoke River Basin, the percent of total unbuffered agricultural land in the region is approximately 24% (U.S. Environmental Protection Agency, 2019). The Lower Roanoke River Basin contains a larger portion of its total land used for farming and has the greatest portion of total land designated as unbuffered agriculture. Many sub-watersheds around Martin, Northampton, and Halifax County, North Carolina contain unbuffered agricultural land as high as 26% of the total land cover (Figure 9) (U.S. Environmental Protection Agency, 2019).

Figure 9. Agricultural Land Lacking Buffers in the Roanoke River Basin



The release of nitrogen and phosphorous in soil particles from agricultural fields corresponds with the amount of unbuffered agricultural land (see Figures 10 and 11). The significant nutrient runoff in these subwatersheds can lead to higher water treatment costs, impaired biota and reduced aquatic life, and poor recreational experiences. The figures below do not show nutrient runoff impacts from poor urban stormwater management, which can also lead to similar downstream damages.

Figure 10. Movement of Nitrogen (in metric tons) attached to soil eroding from agricultural fields in each subwatershed

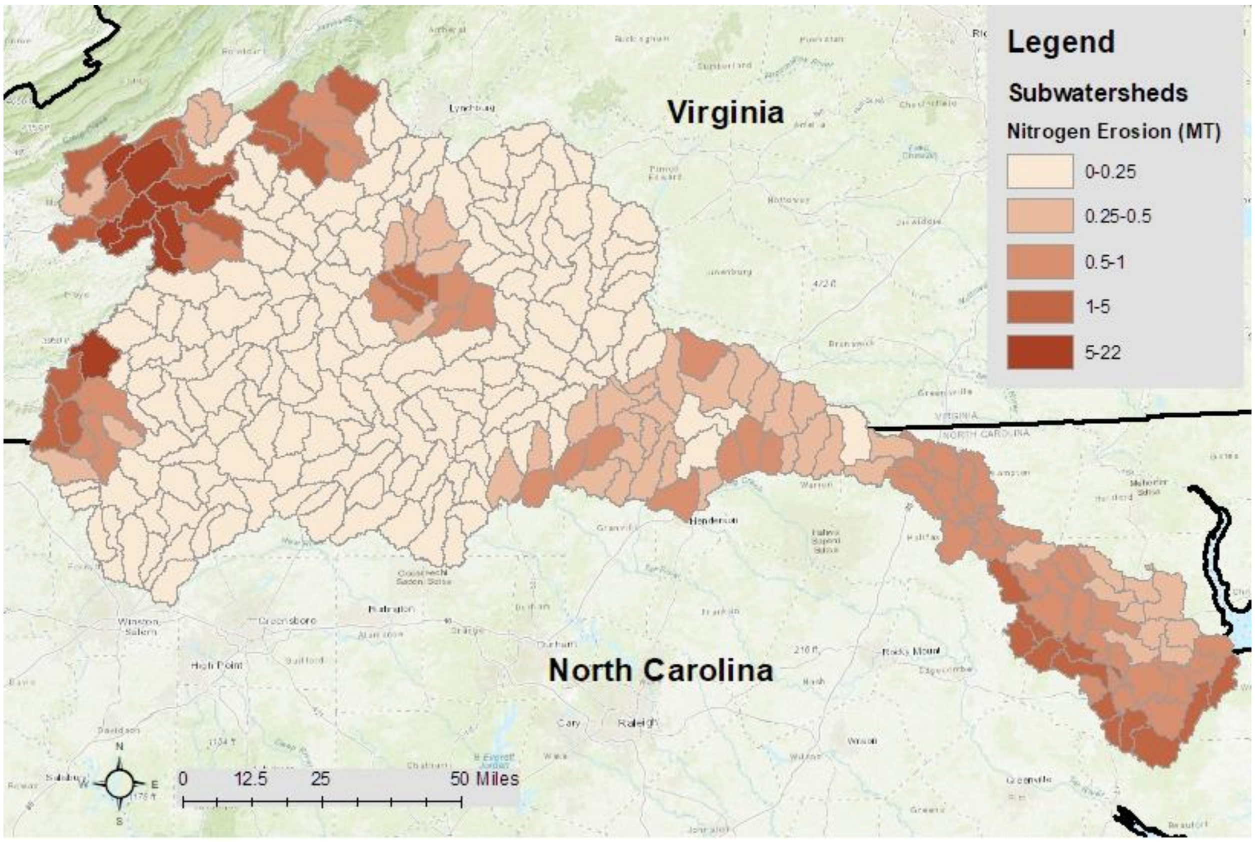
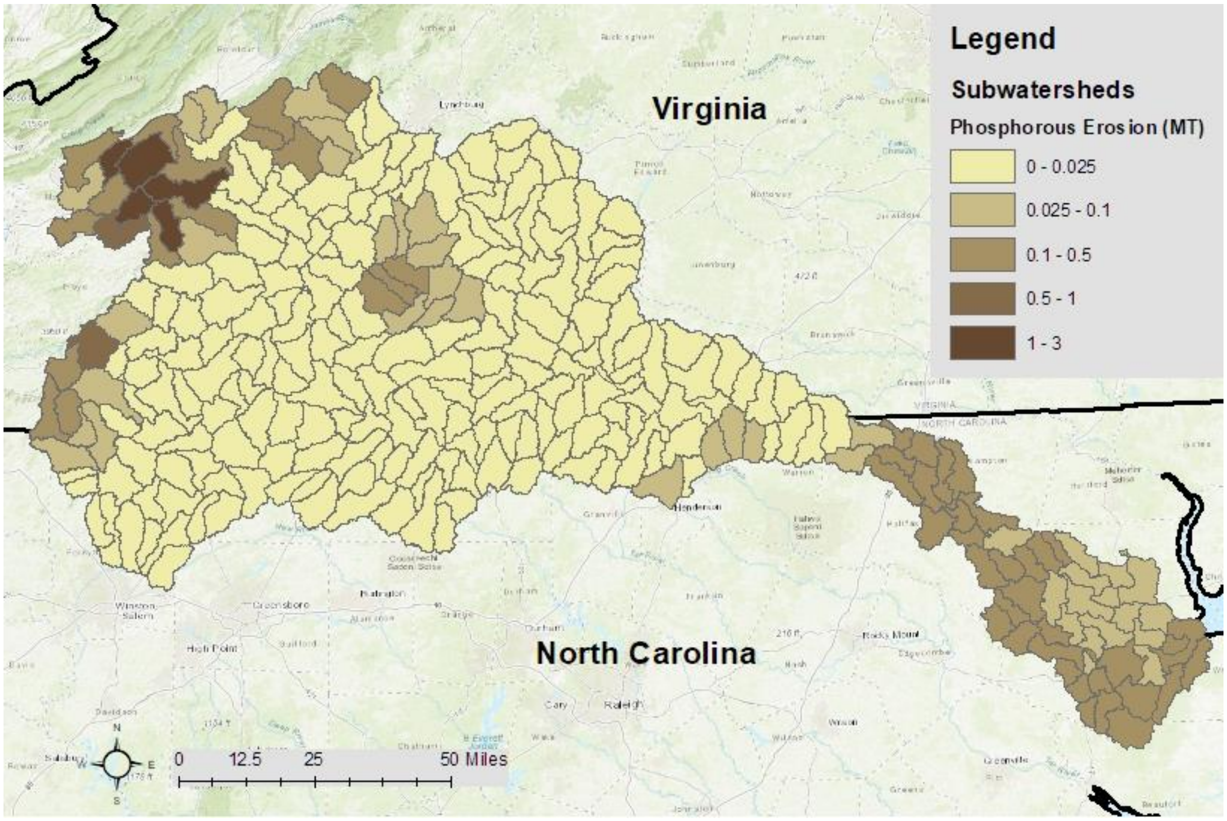


Figure 11. Movement of Phosphorus (in metric tons) attached to soil eroding from agricultural fields in each subwatershed



Cost and Benefits: BMPs in the Roanoke River Basin

The costs of implementing and maintaining agricultural, stormwater, and other BMPs varies widely. The 2016 Roanoke River TMDL Implementation Plan focuses on the cost-effectiveness of BMP options in the Roanoke River Basin and provides estimates per acre for a variety of BMPs (Berger, 2016). Table 10 highlights a handful of BMPs geared toward stormwater management and agricultural activity, both of which can contribute to downstream benefits, or lack thereof.

Table 10. BMP Costs in the Roanoke River Basin

Source: Berger, 2016

BMP Type	BMP	Cost (2017$ per acre)	Sediment Removal Efficiency (%)	Bacteria Removal Efficiency (%)
Agricultural	Vegetative Cover on Critical Areas	$3,500 - $5,000	75	75
	Woodland Buffer Filter Area	$700	70	57
	Wet Detention Pond for Pastureland	$150	50	70
	Continuous No-Till	$100	70	70
	Small Grain Cover Crop	$30	20	20
	Permanent Vegetative Cover on Cropland	$175	75	75
Residential	Septic System Pump-Out	$300 (per system)	N/A	5
	Sewer Connection	$9,500 (per system)	N/A	100
	Repaired Septic System	$3,600	N/A	100
Urban	Rain Barrel	$150 (per system)	6	N/A
	Permeable Pavement	$240,000	80	N/A
	Bioretention	$10,000	70	90
	Rain Garden	$5,000	70	70
	Constructed Wetland	$2,900	50	80
	Riparian Buffer Forest	$3,500	70	57
	Riparian Buffer: Grass/Shrub	$360	50	50
	Street Sweeping	$520 (per curb mile)	variable[8]	variable

[8] Sediment removal is estimated to be 0.171 tons/curb mile/year and phosphorous removal is estimated to be 163.4 lbs/curb mile/year (VA DCNR, 2010).

A LOOK AT THE BENEFITS OF URBAN STORMWATER BMPs: STREET SWEEPING IN DANVILLE, VIRGINIA

Street sweeping is a cost-effective urban stormwater management practice that helps reduce the amount of debris, sedimentation, and excess nutrient runoff entering stormwater systems. In 2018, the City of Danville swept 21,113 curb miles and removed 462 tons of debris (Goss & Simmons, 2019).

Typical costs of urban BMPs like street sweeping include equipment (purchase as well as operation and maintenance), labor, and fuel. Street sweeping costs can vary widely from city to city, with variable costs affected by the density of the curb miles and the frequency of street sweeps.

In-city benefits of street sweeping include, most notably, improved stormwater management infrastructure and improved aesthetics along city streets. These would be a direct result of routine debris removal and removal after an extreme weather event. Reduced nutrient runoff, sediment, and toxin loading are also benefits of street sweeping, and can lead to other downstream benefits such as lower water treatment costs, lower human health costs, and increased recreation spending.

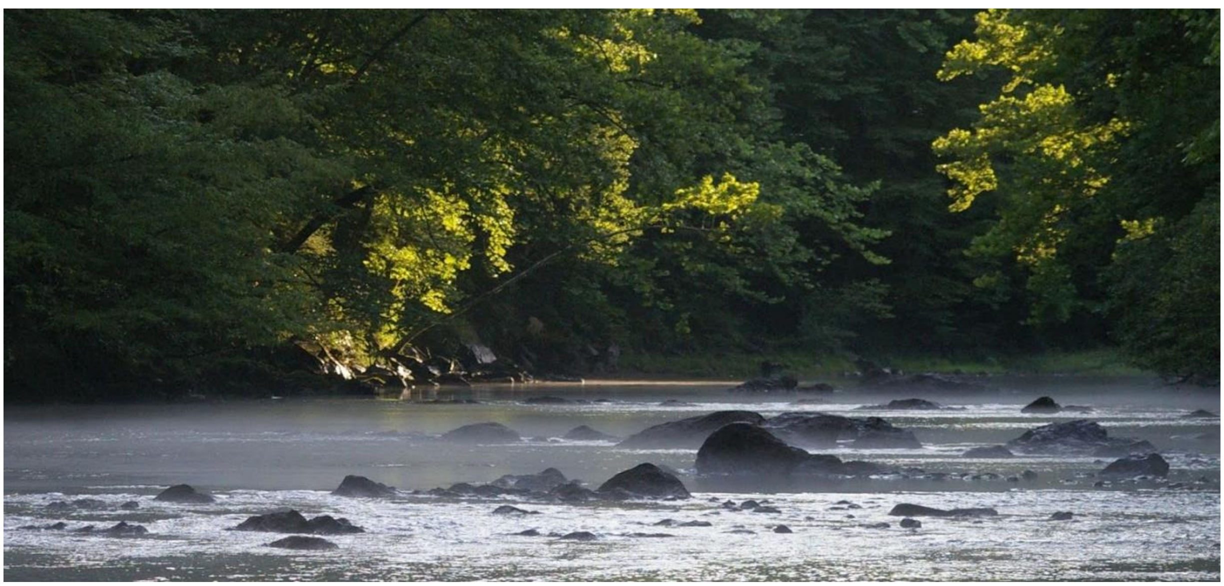
Figure 12. Street Sweeping in Roanoke City, VA
Source: Roanokeva.gov

Virginia and North Carolina Programs for Riparian Buffer Management

Federal, state, and non-profit programs and funding in both North Carolina and Virginia are in place to support landowners that implement a riparian buffer or restore riparian land. The Virginia General Assembly passed the Riparian Buffer Tax Credit in 2000 that provides Virginia forest landowners a 25% tax credit for the value of timber retained as a riparian buffer[9] (Virginia Department of Forestry, 2017).

After phosphorus and nitrogen pollution led to extensive fish kills in the Neuse River Basin in North Carolina in the 1990s, the North Carolina General Assembly passed mandates on limiting development in riparian zones for several river basins including the Neuse River Basin and Tar-Pamlico River Basin (North Carolina Conservation Network, 2016). North Carolina currently does not have buffer protection in place in the Roanoke River Basin, similar to the Virginia tax credit.

Ecosystem Service Benefits from Forested Riparian Buffers in the Roanoke River Basin



Maintaining natural riparian buffers are one of the most cost-effective BMP tools we can employ to improve water quality and stream habitat. Forested and natural riparian buffers along waterways can support nutrient retention and waste assimilation, species habitat, prevent erosion and sedimentation, and bolster downstream water quality.

A hundred feet has generally been accepted as the minimum buffer width required to meet common desired objectives, such as sedimentation reduction and nutrient retention, while 350 feet is often

[9] The 25% tax credit is up to a certain value amount ($17,500 in 2017$), and qualification for the tax credit is contingent on completion of a Stewardship plan and maintaining the buffer greater than 35 feet from the waterway but no more than 300 feet (Virginia Department of Forestry, 2017).

required for species' habitat benefits (Buckley & Rempel, 2018). We use 150 feet as the proposed buffer width in developing scenarios for estimated ecosystem service value benefits associated with maintaining and increasing natural riparian buffers within the region. We adopted this proposed buffer distance from previous work for the wetland forest initiative (Phillips, Stoner, Schmidt, and Davis, 2017). There, a "conservation scenario" for wetland forests included expanding BMPs for wetland forests to 150', a distance that had been widely discussed (and less widely implemented) as necessary for protecting aquatic and riparian habitat.

Existing Buffer Value in Riparian Zones in the Roanoke River Basin

Within the stream management zone, 150 feet within waterways in the Roanoke River Basin's watersheds, there are 122,363 acres of natural land cover from forest and woody wetlands. These 122,363 acres support valuable ecosystem services, including recreation, aesthetics, nutrient retention/waste assimilation, and air quality. The natural buffered acres in existing riparian zones across the basin provide over $1.1 billion in ecosystem service value (Table 11).

Ecosystem Service Benefits
Aesthetics
Nutrient Retention
Carbon Storage
Recreation
Air Quality

Table 11. Annual Ecosystem Service Values provided by Existing Riparian Zones in the Roanoke River Basin

Ecosystem Service	Existing Value in Roanoke River Basin Riparian Zone
Nutrient Retention	$302,963,449
Carbon Storage	$809,985,157
Air Quality	$8,259,536
Recreation	$7,708,900
Total	$1,128,917,042
*Aesthetic Value	$243,314,455
*one-time property premium enhancement	

Ecosystem Service Benefits from 150-foot Riparian Buffers

We examine changes in ecosystem service benefits that would occur by expanding riparian buffers in the region for two scenarios: increasing forested riparian buffers to 150' on half of the streams (7,200 miles) in the region and on all of the streams in the region. Expanding to 150' buffers on half of the streams in the region translates to an increase in forest cover of 115,065 acres in riparian zones while expanding to a 150' buffer across all waterways is equivalent to an additional 230,130 acres of forest cover.

In order to determine the net benefit of these two scenarios, we compare the ecosystem service value gained by increases in forest cover to the cost associated with expanding forested riparian buffer acres. Berger (2016) estimates that the cost of a forested riparian buffer acre in the Roanoke River Basin is $3,500, which includes the forgone average opportunity cost of the land[10] and the cost of planting and/or maintenance (Berger, 2016). We apply this estimate to the number of additional forested buffer acres in the two scenarios to determine the net benefit of increasing riparian forest buffers in the region. The additional 115,065 acres in riparian zones from scenario one and the additional 230,130 acres added in scenario two would cost $403 million and $805 million, respectively (Table 12). On the other hand, increasing the acreage of riparian buffers in the region would translate to ***total*** ecosystem service benefits of $2.1 billion million under scenario one, and $3.1 billion under scenario two (Table 12). Expanding riparian buffers will produce significant positive net benefits in the region, with over $663 million in net benefits from scenario one and $1.3 billion from scenario two. Table 12 contains the annual ecosystem service value, cost, and net benefit from expansion of forested riparian buffers along the Roanoke River Basin. We examine the ecosystem service values in further detail below.

Table 12. Net Ecosystem Service Benefit from Forested Riparian Buffers in the Roanoke River Basin

Ecosystem Service	Scenario 1: Half of RBB Streams with Additional 150' Buffer	Scenario 2: All RRB Streams with Additional 150' Buffer
Nutrient Retention	$284,892,330	$569,784,660
Carbon Storage	$761,671,283	$1,523,342,566
Air Quality	$7,766,872	$15,533,745
Flood Protection	$3,888,854	$3,888,854
Recreation	$7,249,081	$14,498,162
Total Benefit	**$1,065,468,421**	**$2,127,047,987**
Cost of Buffers	**$402,726,715**	**$805,453,430**
Net Benefit	**$662,741,705**	**$1,321,594,557**

Viewshed Aesthetics & Property Values

Natural riparian buffers can provide increased aesthetic viewshed value to nearby residents and recreators alike. A review of existing studies on the value of property premiums in the riparian zone shows a range of less than 1% to upwards of 26% in added amenity value due to the presence and effectiveness of a natural buffer (Rempel & Buckley, 2018; Young, 2016). Applying an average, 13.5% in enhanced value for properties with natural buffers, the existing natural buffer land cover in the Roanoke

[10] The opportunity cost of the riparian buffers includes the value from the use of the land if it was not preserved as a forested buffer (i.e. timber harvest, development).

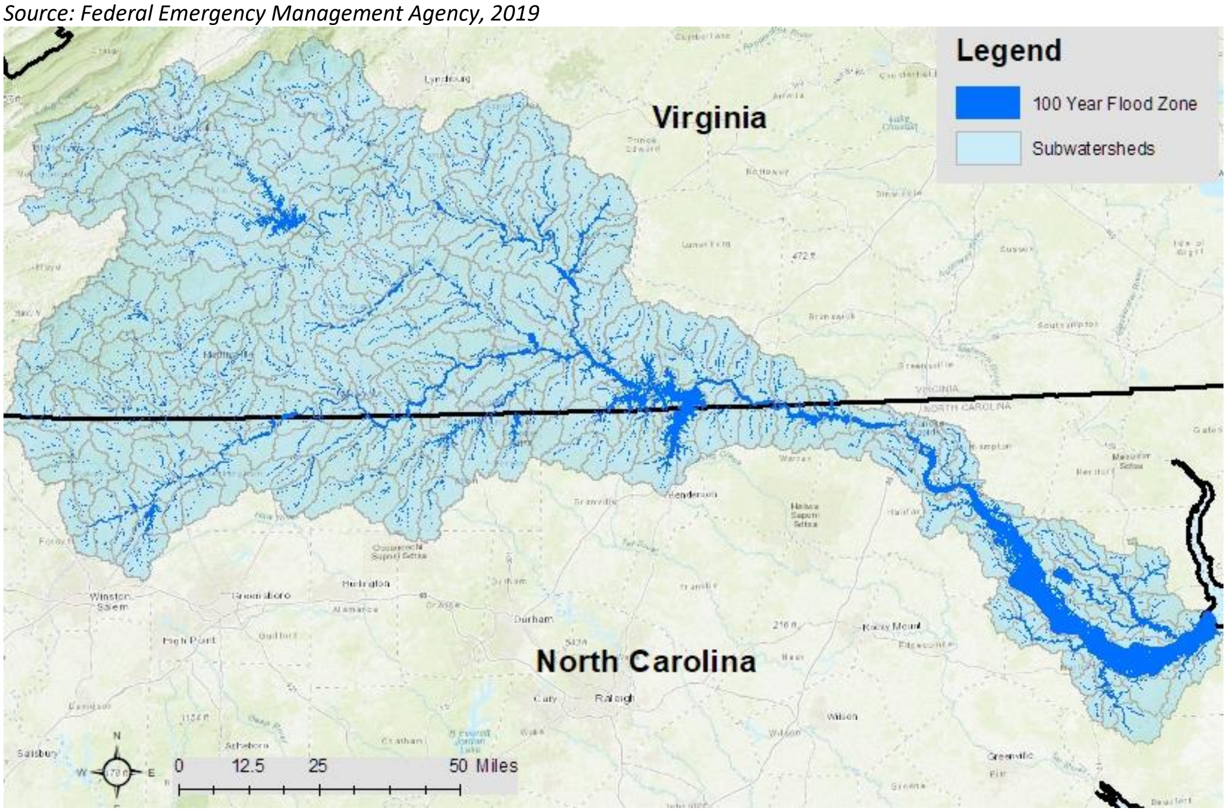
River Basin is estimated to provide $278 million in added property value to 13,317 households a year (see Appendix D).

Expanding to a 150' forested buffer along half the waterways in the region and every waterway in the region could yield approximately $283 million and $566 million in enhanced property value, respectively, for the estimated additional 13,500 to 27,100 households that would be affected by a 150' buffer zone. This increase in property value could provide additional property tax revenues on the order of millions of dollars to Virginia and North Carolina counties within the Roanoke River Basin.

Flood Protection

Forested riparian buffers also provide protection and mitigation from flooding and extreme weather events to nearby and downstream properties. FEMA's maps of the 100-year flood zone along waterways display the extent of flooding that could occur in a once-in-one-hundred-years flood event (Figure 13). We use these maps to estimate the dollar value of flood protection from an acre of forested buffer based on property damage avoided, for both private landowners and for municipalities (Burby, 1988). A study of 10 programs nationwide designed to redirect development away from flood-prone areas found that land values adjacent to protected floodplains that contain the 100-year flood zone increase by $21,605 an acre (2017$) (Burby, 1988).

Figure 13. 100-Year Flood Zone in the Roanoke River Basin
Source: Federal Emergency Management Agency, 2019



We estimate that approximately 180 acres of the 100-year flood zones along these segments could increase significantly in value if converted to a forested buffer, providing at least $3.9 million in annual flood protection and avoided property damage benefits[11]. If 50% of the streams targeted for a 150' riparian buffers were to include the stream segments that would contain the extent of the 100-year flood zone, $3.9 million in annual flood protection could be achieved in both scenarios.

The creation of 180 acres of forested riparian buffers would provide additional flood protection and mitigation to downstream properties and communities, therefore $3.9 million represents a conservative value for a 150' forested buffer across the entire region. In practice, the buffered stream segments that contain the flood zone and exist upstream of higher-density communities may be the most cost-effective areas to target.

Nutrient Retention

We examine the benefits of increased phosphorus and nitrogen absorption, measured as pounds averted from downstream waterways. In general, the cost of preventing nitrogen and phosphorous from entering waterways as runoff is roughly four to five times cheaper than the cost of treating or removing the same amount of nutrients from downstream wastewater or stormwater (Rempel & Buckley, 2018). The North Carolina Ecosystem Enhancement Program (NCEEP) provides a market for riparian buffer values by completing mitigation projects and selling credits to private companies, landowners, or other agencies that are required to purchase mitigation as part of a development project (Rempel & Buckley, 2018). We apply the NCEEP dollar values of $14.99/lb for nitrogen and $274.78/lb of phosphorous, which yields an estimated value of $2,475/acre of forested riparian buffers/year (2017$) in nutrient retention.

With a 150' forested buffer applied to half of the waterways in the Roanoke River Basin, the annual nutrient retention benefit provided to the region is estimated at $285 million, while the benefit achieved from a 150' buffer throughout the entire region is $570 million.

Air Quality

Forested riparian zones contribute to higher regional air quality through pollutant removal, which provides a societal benefit in the form of reduced health damages and healthcare costs (Rempel & Buckley, 2018). The value of air quality for an acre of forest buffer will naturally be higher in urban areas with higher population densities, ranging from $42 to $132 an acre/year, compared to $3 to $7 an acre/year in rural areas (Rempel & Buckley, 2018). Using these estimates, the annual benefit from improved air quality from a 150' buffer applied to half the streams and all of the streams in the Roanoke River Basin is $7.8 million and $15.5 million, respectively.

[11] This 180 acre figure is a conservative estimate for flood protection benefits from forested riparian buffers, including only stream segment slivers of flood zones that fall entirely within the 150' foot buffer.

Recreation

The recreational value of the region is expected to increase as a result of improved habitat for aquatic species and waterfowl and viewsheds for wildlife watching and water-based recreation such as kayaking and fishing. This can be measured by increases in the number of trips taken, the amount of money spent at nearby businesses, and recreators' willingness to pay for their experience, or their consumer surplus. An acre of natural riparian cover can provide an average of $63 in recreational benefits per year (Rempel & Buckley, 2018). Using this estimate, a 150' buffer applied to half of the Roanoke River Basin's streams could yield an additional $7.2 million in recreational value per year, while a 150' buffer applied to all waterways could yield $14.5 million in recreational value annually.

Uranium Mining in the Roanoke River Basin

Communities, Economies, and Rivers at Risk

In rural Southern Virginia, Pittsylvania County is at the center of a decades-old fight over uranium. In 2018, the issue of whether to lift the uranium mining ban in Virginia went all the way to the Supreme Court (Liptak, 2018).

> *"Many participants saw the presence of the mine and mill as putting the region at a disadvantage in attracting new business, potentially limiting the overall growth of the region."*

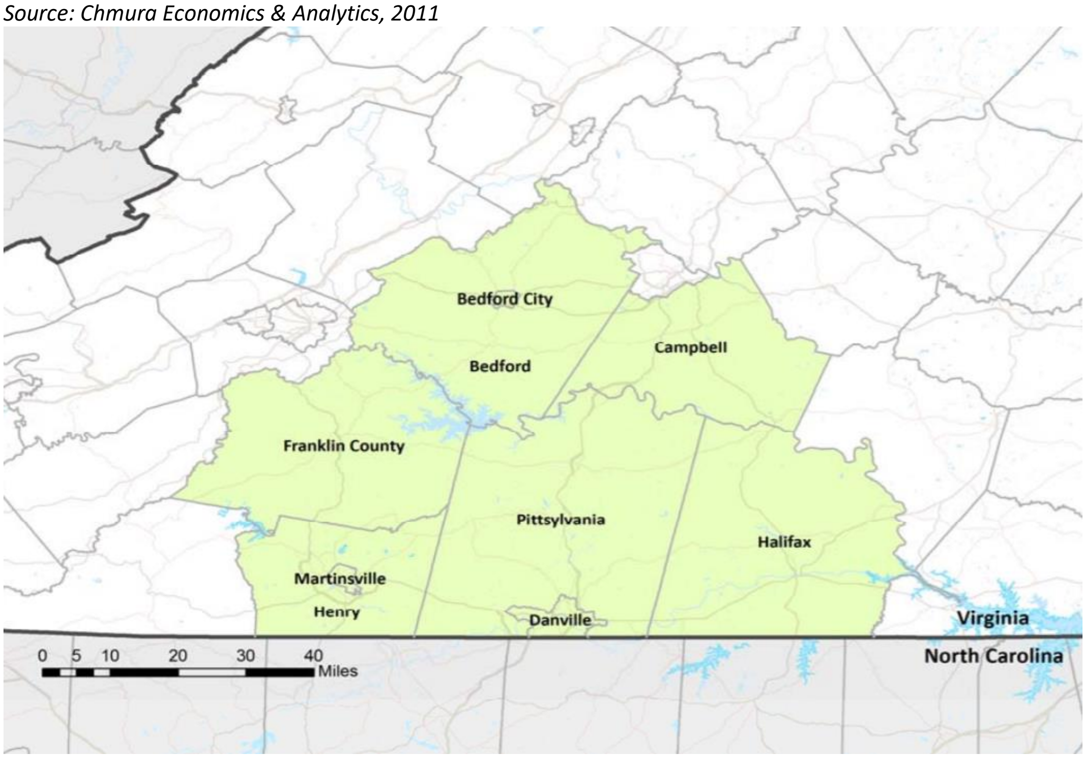
The large but poor-quality uranium deposit at Coles Hill would require extensive mining and surface disturbance during extraction, along with considerable land for the disposal of mining waste. Currently there is no precedent or regulation for uranium mining on the east coast of the U.S., which experiences wetter climates, more frequent flooding, and hurricane events compared to the arid west, where the majority of uranium mining currently occurs (Moran, 2011). In 2011, the threat of the uranium mining ban being lifted earned the Roanoke River a spot on American River's annual list of the 10 most endangered rivers, which emphasized the risk of water contamination to over one million people who rely on the Roanoke River for drinking water, recreation, and agriculture (Southern Environmental Law Center, 2011).

Existing Literature: Environmental Risks, Socioeconomic Impacts, and Public Perception

Virginia Uranium, Inc. (VUI), announced plans in 2007 to renew its efforts to open a uranium mine and milling facilities at Coles Hill in Pittsylvania County, Virginia. Since then, reports commissioned by both those fighting and supporting the ban detail potential environmental risks and socioeconomic benefits of uranium mining. The Danville Regional Foundation commissioned a study, conducted by RTI International, that used stakeholder workshops to provide insight into regional perspectives on potential environmental, economic, and social impacts that could result from uranium mining. As noted in the quote above, many people in the community were concerned about the ability of the region to attract new businesses and maintain regional economic vitality, particularly noting potential impacts to agriculture and tourism (RTI International, 2012).

The socioeconomic impact study on potential uranium mining impacts to the Chatham Labor Shed (Figure 14) commissioned by VUI estimates that at a market price for uranium at $60/lb, the net economic impact of the 35-year operation life of the mine could be $5 billion, adding at least 1,000 jobs to the regional economy[12] (Chmura Economics & Analytics, 2011). Socioeconomic impact estimates for alternative scenarios, including lower uranium prices and potential environmental contamination exceeding federal standards, were provided in the report.

Figure 14. Chatham Labor Shed
Source: Chmura Economics & Analytics, 2011



[12] The Chatham Labor Shed includes Bedford, Franklin, Henry, Pittsylvania, Campbell, and Halifax counties, as well as Bedford City, Martinsville, and Danville (Chmura Economics & Analytics, 2011).

Potential Ecosystem Service Losses from Lifting the Ban

The lack of existing or proposed regulation on uranium mining in Virginia coupled with the lack of experience handling radioactive material in a wet and variable climate makes the risk of ecosystem service losses and damage high, even if the likelihood of any one scenario occurring is difficult to predict.

Air Quality & Human Health Damages

Major Ecosystem Services at Risk
Air Quality
Water Quality
Recreation
Raw Materials

Exposure to radon, both to mine workers and nearby populations, can lead to cancer and other respiratory issues, as documented in other regions with uranium mines (Jones, 2014; Committee on Uranium Mining in Virginia, Committee on Earth Resources, & National Research Council, 2012). Data from over forty years of uranium mine operation in Grant, New Mexico, indicate that the excess-exposure death rate from lung cancer for uranium mine workers exposed to radon is 2.6% under low-exposure conditions (Jones, 2014). The total health cost, including both direct costs from medical expenditures and indirect costs from years of life lost, is estimated to average at $4.6 million per excess death (2017$) (Jones, 2014).

We apply these values and assume similar rates of radon exposure for the 224 mine workers VUI estimates would be employed during the 35-year operation of the Coles Hill site (Beahm & Kyle, 2013). This results in estimated human health costs for approximately six uranium mine workers totaling $26.8 million for lifetime medical costs of lung cancer treatment and cost to society of premature death (Appendix D).

While the risk of radon exposure is much lower to the surrounding populations and the general public, models of radon exposure from hypothetical uranium mining development in Culpeper County, Virginia estimate a latent cancer fatality rate of 1.6 in 100,000 within an 80 kilometer (about 50 miles) radius of the site (SC & A, 2011). An estimated 563,000 people live within 50 miles of the Coles Hill site, suggesting health damages from additional lung cancer deaths could total an additional $41.5 million (U.S. Census Bureau, 2010; Jones, 2014) (Appendix D).

Water Quality: Avoidance Costs & Public Perception

In addition to exposure to environmental contaminants through the air, leading to lower air quality and lung cancer deaths in the region, water quality is also at risk. Failures or improper management in tailings disposal can result in radioactive waste leaking into groundwater and surface water, and the risk of flooding in the region could produce a catastrophic event with radioactive materials entering the groundwater, surface water, and soil at dangerous levels (Committee on Uranium Mining in Virginia, Committee on Earth Resources, & National Research Council, 2012). Over the course of 30 years, the chance of a major flooding event at the Coles Hill Site is 26%, and there are no regulations or policies in place to ensure containment of radioactive materials and mitigate or prevent contamination (Moran, 2011).

Downstream of the Coles Hill site, over 420,000 people in Roanoke River Basin communities rely on public water from surface water intakes (Kolotushkina, 2012). The closest intakes to the Coles Hill Site supply water to 2,400 people, including the town of Clarksville. While some downstream residents may not be concerned with an increased risk of degraded water quality or a catastrophic failure resulting in exposure to radioactive material, other people in downstream communities place a high value on the safety of their drinking water and have a willingness to pay (WTP) to avoid the risk of exposure to radioactive and other harmful contaminants. Assuming that 50% of the downstream water users have a positive WTP to avoid risk of exposure, the loss in consumer surplus - the amount people are willing to pay to avoid an outcome in this case - is estimated at $80.2 million over the course of the life of the mine (Holloday, 2012). This does not take into account future consumer surplus lost from the anxiety of exposure after the mine has been closed.

Aesthetics & Nearby Property Values

The existence of a uranium mining operation in Pittsylvania County, regardless of possible contamination, can lead to a loss in aesthetic value in surrounding properties. Average property value losses around mining facilities range from 2% to 8% (RTI International, 2012; Chmura Economics & Analytics, 2011). There are approximately 208 properties within a 2-mile radius of the proposed uranium mining facility, with a land market value of approximately $41 million (Whitt, 2018). Within a 5-mile radius, there are 2,164 properties with a land market value of $266 million (Whitt, 2018).

The extent of property value loss could be affected by the stringency of regulations imposed if the ban is lifted, cases of environmental contamination once mining begins, and the regional stigma that forms around the industry. In the case of a contamination event, property values may be permanently lowered or temporarily depressed and then recover. Should the uranium mine have a moderate but consistent effect on nearby property values, losses could range from $3.3 million to $21.3 million.[13]

Losses in property values could correspond to a prolonged property tax revenue loss for Pittsylvania County. While property values are often used to measure changes to the aesthetic value provided by a nearby ecosystem, changes to property values could also reflect concerns about human health related to both air quality and water quality (Young, 2016; Rempel & Buckley, 2018; McCluskey & Raussner, 2001). This is to say, the values estimated likely overlap and should not be considered additive.

Considerations in Policy and Resource Management

The Supreme Court's decision addressing the state of Virginia's right to uphold a ban on uranium mining is expected to be announced before the Court recesses in June 2019. If the Court rules in favor of

[13] The range represents property value impacts in a 2-mile radius versus a 5-mile radius.

Virginia Uranium Mining, Inc., uranium mining is not guaranteed in Pittsylvania County; it would likely be years before mining could begin due to the regulatory process required. An economic case for uranium mining that neglects environmental considerations or ecosystem service values may not even be strong enough alone to justify mining in Virginia.

Coal Ash: Unlined Storage and Risk of Spills

On February 2, 2014, a single stormwater pipe burst at a Duke Energy containment pond in Eden, North Carolina and released 39,000 tons of coal ash and 27 million gallons of wastewater into the Dan River (Figure 9). Ash containing toxins and metals deposits were found up to 70 miles away from the retired Dan River Steam Station, and while Duke Energy has committed approximately $3 million to the recovery effort, only about 10% of the coal ash spilled has been recovered (Fernandez, 2019).

The Dan River spill marks the largest coal ash spill since the TVA Kingston spill. The TVA Kingston spill, the greatest fly ash release in U.S. history, occurred in December 2008 and released over 1.1 billion gallons of coal fly ash slurry covering over 300 acres of surrounding land (Chatlani, 2018). After the Kingston spill, the EPA released a list of 44 coal ash disposal sites across the country rated as "high-hazard", meaning a high likelihood of loss of life that would occur in the event of a dam failure (U.S. Environmental Protection Agency, 2009). North Carolina has the most "high-hazard" coal ash disposal sites compared to any other state, with 12 of the 44 listed sites. Two of those 12 disposal sites, the Belews Creek Steam Station and the Dan River Steam Station, are in the Roanoke River Basin. Only five years after the EPA list was released the Dan River Steam Station failed, becoming the site of the third largest coal ash spill in history.

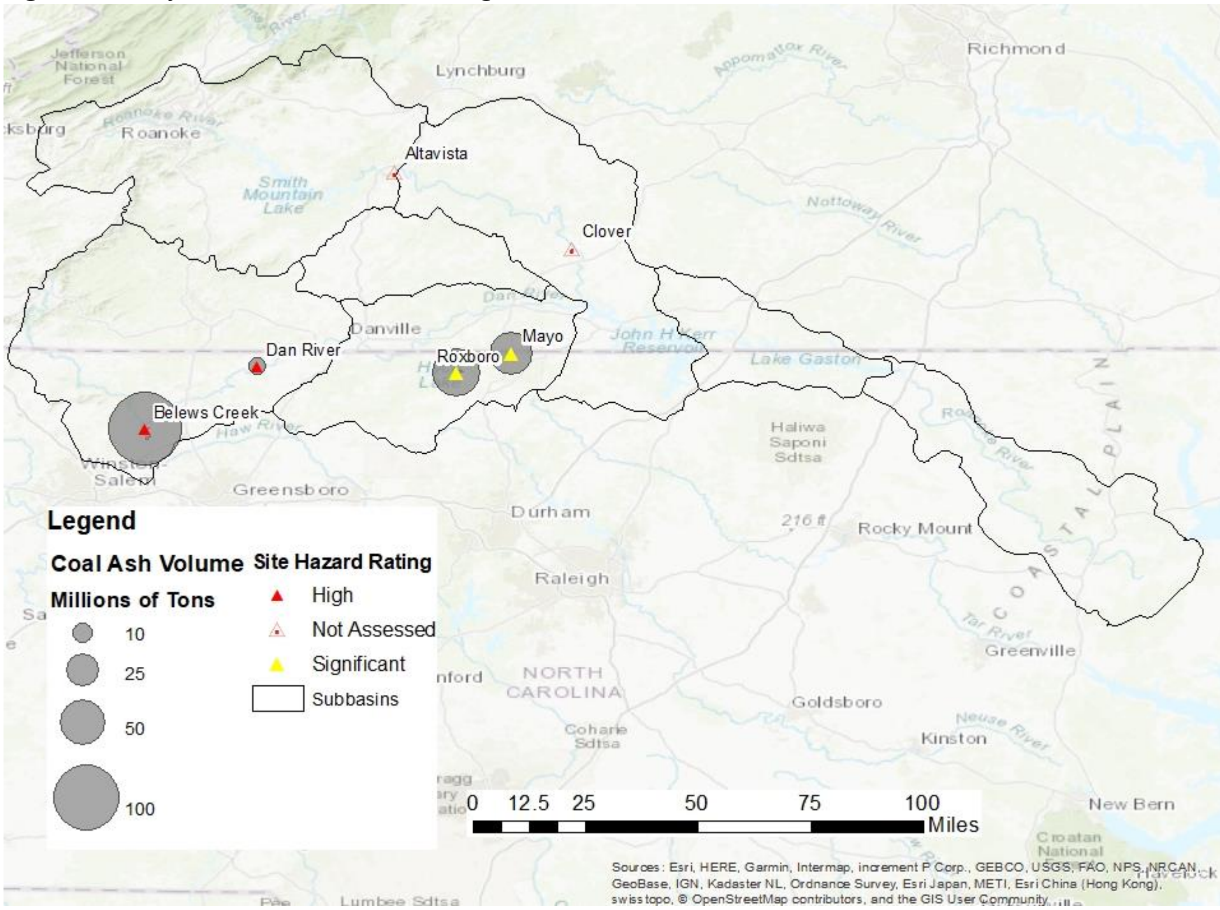
The 2014 spill brought renewed attention to coal ash storage regulations in North Carolina, particularly the threat posed by unlined coal ash impoundments that are susceptible to leaching and contaminating nearby waterways, as well as extreme weather events or failures in infrastructure that result in coal ash spills. In response to the spill, the North Carolina state legislature passed the Coal Ash Management Act of 2014 which required Duke Energy to clean up and close its 30 coal ash impoundments in the state by 2029. The Dan River site was included as one of the first to be closed and is set to close by the end of 2019 (Fernandez, 2019).

Figure 15. Collapsed Coal Ash Impoundment at Dan River Steam Station in Eden, NC (2014)
Source: Wikimedia Commons

High-Risk Coal Ash Impoundments in the Roanoke River Basin

Most of the disposal sites in the Roanoke River Basin contain unlined coal ash ponds and landfills, with at least eight unlined impoundments and 10 sites unassessed for lining (Sackett, 2015). Nearly 233 million tons of coal ash is reportedly stored in the Roanoke River Basin, with at least 228 million tons stored in unlined coal ash impoundments, mostly at the Belews Creek Station site, Dan River site, Roxboro site, and Mayo site (Figure 16) (Sackett, 2015). All four of these sites are within the Dan River subbasin.

Figure 16. Major Unlined Coal Ash Storage Sites in the Roanoke River Basin



The major facilities in the Dan River subbasin are all owned and operated by Duke Energy and about 136 million tons of the existing coal ash is stored in unlined disposal sites rated as high-hazard by the EPA (Table 13).

Table 13. Coal Ash Storage Sites in the Roanoke River Basin[1]

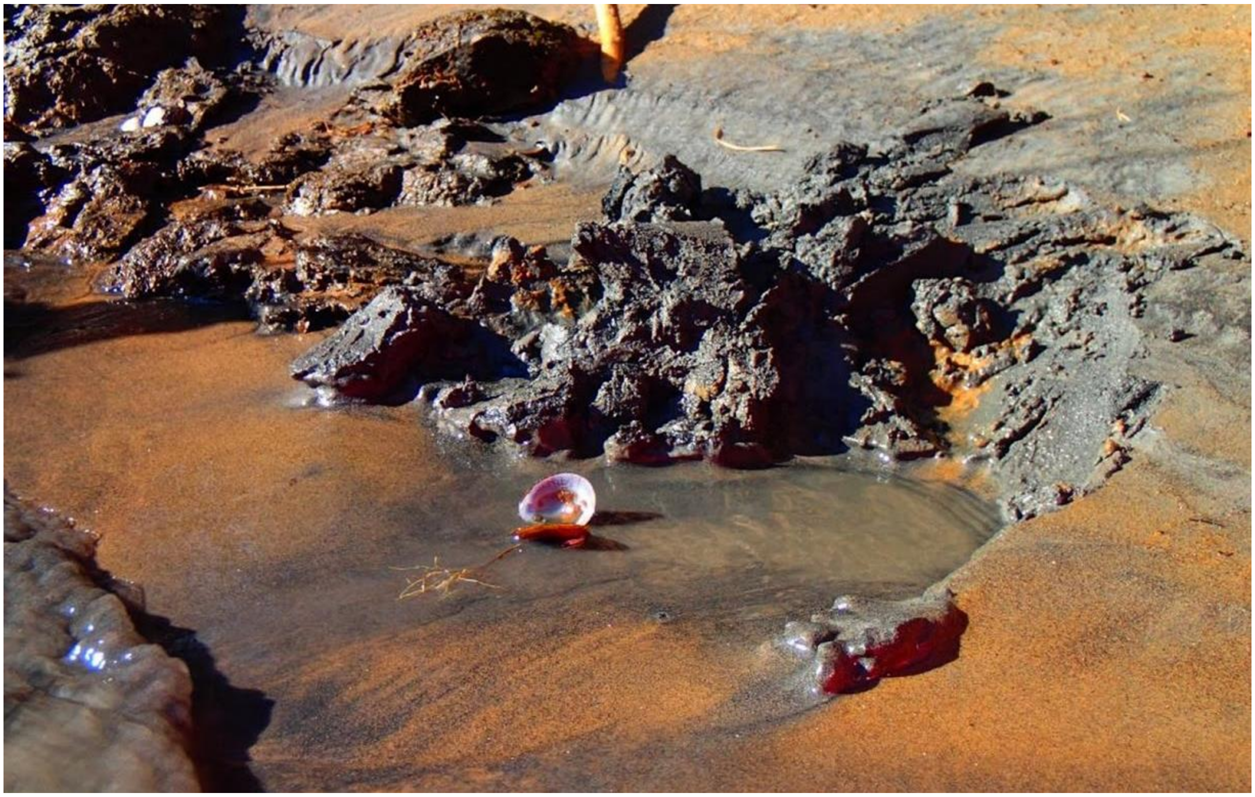
Site	# of Storage Facilities	Hazard Rating	Coal Ash Volume (gallons)	Nearest Water Body	Disposal Types	Water Contamination[2]
Belews Creek Steam Station	6	High	4,123 million	Belews Lake	Unlined ash ponds and unlined landfills	Vanadium, exceedances over 630x the health-based standard
Dan River Power Station	4	High	216 million	Dan River	Unlined ash ponds, potentially unlined dry storage	
Roxboro Power Station	7	Significant	1,718 million	Hyco River, Hyco Lake, Sergeants Creek	Unlined ash ponds and landfills, lined flush and settling pond	Exceedances of vanadium, chromium, manganese, lead, sodium
Mayo Power Station	3	Significant	1,336 million	Mayo Creek, Mayo Lake, Crutchfield Branch	Unlined ash and settling ponds	Exceedances of vanadium, lead, and sodium
Clover Power Station	8	Not Rated	Unknown	Roanoke River, Black Walnut Creek	Lined landfills, Lined sludge ponds	

[1] Adapted from Southeast Coal Ash
[2] Sackett, 2015

Ecological and Human Health Impacts

The ecological damages from coal ash spills are well-documented; the release of coal ash with high levels of toxins such as mercury, arsenic, and selenium pose a risk to both humans and aquatic biota through surface and groundwater contamination (Ruhl et al., 2009; Dan River Natural Resource Trustee Council, 2015; Lemly, 2015; Lemly & Skorupa, 2012). The physical release of such great volumes of ash impact water supply regulation and alter stream flows as sediment is deposited downstream, suffocating benthic organisms and other macroinvertebrate, impacting fish, other higher-order aquatic biota, and birds (Ruhl et al., 2009; Dan River Natural Resource Trustee Council, 2015; Lemly, 2015).

Coal Ash on a Stream Embankment



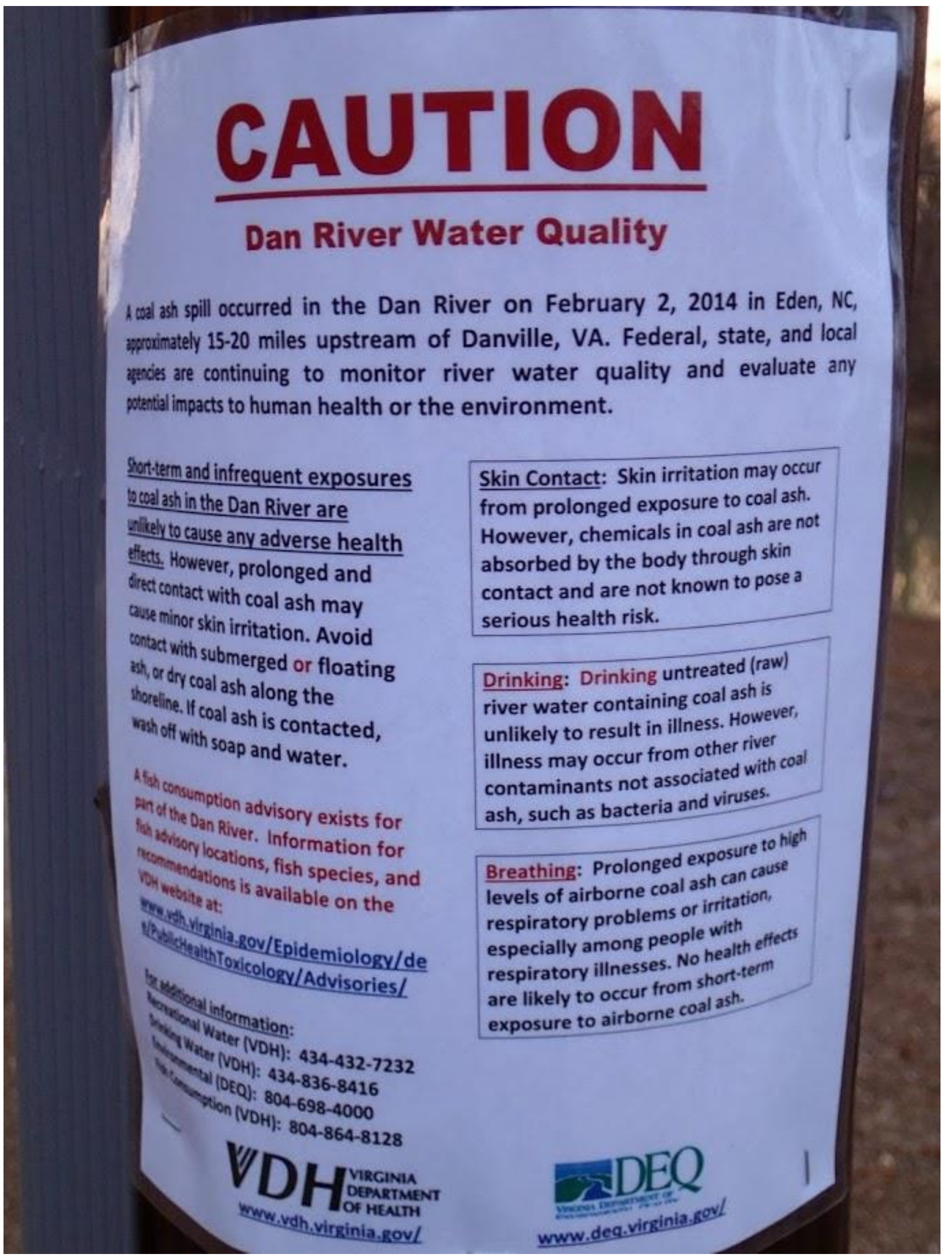
While a number of biological assessments following both the Kingston spill and Dan River spill showed minimal risk of toxins accumulating in fish species downstream, a portion of the damages from spills are not evident until years later (Rigg et al., 2015; NC Division of Water Resources, 2016). Ten years after the Kingston spill, over 30 of the clean-up workers are deceased and 250 sickened (Gaffney, 2018). In November 2018, a federal jury in Knoxville ruled that Jacobs Engineering, the company paid to clean up the spill, endangered the health of its workers (Gaffney, 2018).

The existence of unlined coal ash ponds and landfills have damaged and continue to harm the health of nearby ecosystems and communities. Water quality testing of both nearby groundwater and surface water shows unlined storage facilities are leaking coal combustion residuals (CCRs) effluent, and a study of groundwater wells in North Carolina found that of 58 impacted monitoring stations, 48 stations - or 30% of the total wells - exceeded EPA water standards (Harkness et al., 2016).

Estimated Economic Damages from Unlined Coal Ash Impoundments in the Roanoke River Basin

Following the Dan River spill in 2014, a study of the damages within the first six months found ecosystem service losses totaled over $295 million (Lemly, 2015). This estimate included ecological damages of over $113 million, recreational losses of over $31 million, human health and consumptive (food) losses of over $75 million, and an intrinsic value loss of $75 million. Specifically, ecological damages included both the damage from wildlife poisoning and acute toxicity as well as the degradation of physical habitat for fish and benthic organisms (Lemly, 2015). Recreational losses were estimated from angler days lost in the six months after the February spill, which included popular times of year for recreating on the Dan River. Human health damages included anxiety from public health risk and fish not consumed because of consumption and recreation advisories in the six months following the spill (Lemly, 2015).

Recreation Advisory after Dan River Coal Ash Spill



The ecosystem services impacted by coal ash waste include drinking and recreational water quality, habitat for species, and human health. Habitat for species and water quality are two ecosystem services that ranked highly from participatory research in the Roanoke River Basin. In the concept modeling exercise for coal ash (see Appendix C) we follow the biophysical effects and resulting impacts on ecosystem services from the posited intervention of lining and safely storing the coal ash currently in unlined impoundments in the Roanoke River Basin. Key ecosystem services modeled include changes in water quality, habitat for species, and human health, which result in estimates for consumer surplus from improved water quality, human health damage savings, water treatment cost savings, and expected value benefits from avoiding a spill.

Historical and Ongoing Costs from Unlined Coal Ash Sites

At the four unlined sites in the Dan River subbasin, existing and documented damages include increased water treatment costs for municipalities and costs associated with ecological and recreational damage downstream from sites discharging waste. While these costs may not necessarily reflect potential future damages in the region from unlined coal ash impoundments, they provide evidence of historical losses to ecosystem services in the form of lower water quality, degraded habitat for fish, and forgone recreation opportunities.

In the past five years the towns of Eden and Madison, North Carolina, and Henry County, Virginia have made upgrades to their water treatment systems, collectively costing approximately $3.7 million (Gutierrez, 2017). The main factor forcing water treatment system upgrades in Eden and Madison was the presence of trihalomethanes, a cancer-causing chemical formed from the reaction of bromide (a toxin in coal combustion waste) and chlorine (a disinfectant used in drinking water treatment) (Gutierrez, 2017). The bromide levels were connected directly to unlined coal ash storage in Belew's Creek Steam Station, a few miles upstream from Madison and Eden, and Duke Energy reimbursed the municipalities for their treatment system upgrades (Gutierrez, 2017).

For decades, discharges permitted by the National Pollutant Discharge Elimination System (NPDES) released contaminated coal ash effluent into surface water, allowing toxins like selenium, arsenic, and mercury to settle in downstream sediment and bioaccumulate in fish (Lemly & Skorupa, 2012). Case studies on three of the four unlined sites in the Dan River Subbasin (Belew's Creek, Mayo, and Roxboro) revealed evidence of ongoing ecological damage to fish populations from 1976 to 2007, largely from selenium bioaccumulation in aquatic organisms, resulting in poisoning and reproductive issues (Lemly & Skorupa, 2012). Direct loss of fish populations and acres of degraded aquatic habitat were metrics used to estimate ecological damages resulting from the coal ash discharges, while lost fishing trips and lost numbers of harvestable sport fish during consumption advisories were used to estimate recreational damages (Lemly & Skorupa, 2012).

Using data on discharges and associated damages from the Mayo, Roxboro, and Belew's Creeks stations, we would expect on average $8.2 million in annual ecological damage and $0.5 million in annual recreational losses regionally during years that selenium concentrations are above 4 ppm (Lemly &

Skorupa, 2012). Regular water quality monitoring for selenium toxicity downstream of these sites would help inform if these ecological and recreational damages are ongoing.

Groundwater Quality and Human Health Damages

The Environmental Protection Agency studied exposure pathways of toxins leaching from coal ash to surface and groundwater and found that the risk of cancer for nearby groundwater users can be as high as 1 in 50 (Gottlieb, Gilbert, & Evans, 2010). This cancer rate applies to residents within 1 mile of unlined coal ash impoundments that have co-disposed rather than conventional CCW (coal combustion waste) (RTI International, 2007). The EPA also estimated the cost to human health from exposure to arsenic resulting in cancer using willingness to pay (WTP) values for avoiding cancer (Abt Associates, 2000).

Spatial data on unlined coal ash storage in the Dan River Basin and nearby populations allows us to estimate the number of groundwater well users within a mile of the four sites. Using Census block data that contains information on population and household counts, we estimate that 2,916 people live within a mile of the four unlined coal ash sites, with an estimated 10.9%, or least 317 people, that use groundwater wells for drinking water (U.S. Census Bureau, 2010; U.S. Environmental Protection Agency, 2014).

Based on these estimates, the removal of unlined coal ash impoundments in the Dan River Basin could result in at least $7.16 million (2017$) in avoided human health damages associated with drinking water from groundwater wells within a mile radius of unlined impoundments (Abt Associates, 2000). This estimate does not take into account cancer-related human health damages associated with groundwater consumption outside the mile radius of the unlined impoundments, cancer-related human health damages that may result from the two unassessed sites in the Virginia portion of the Roanoke River Basin, or other non-cancer-related human health damages associated with ingestion of toxins from ground or surface water contaminated by the coal ash sites.

Consumer Surplus from Improved Water Quality

Aside from the direct human health damages incurred from unlined coal ash impoundments in the region, there are economic benefits associated with downstream water users' and communities' reduced anxiety and risk of exposure to toxins in their water supply. Over 78,000 residents in the Roanoke River Basin rely on public drinking water supplied from intakes downstream of the four unlined coal ash sites (Sackett, 2015). Towns and municipalities nearby include Madison, Eden, Danville, South Boston, and Clarksville (Sackett, 2015).

We assume the population downstream from the coal ash impoundments would experience a benefit from the removal of the industrial waste; this benefit can be measured by their estimated willingness to pay (WTP) for reducing their risk of exposure to leached contaminants such as boron, arsenic, cadmium, and mercury (Holladay, 2009). The average WTP to avoid exposure to leached contaminants is $22.80 per person per year (2017$) (Holladay, 2009). The average facility lifespan is 75 years, and on average the four sites have 34 years left before they would be retired[14] (Holladay, 2009; Sackett, 2015). Under these conditions, downstream residents could experience a net present value of $7.1 million to $29.8 million in benefits if all four sites were closed this year[15,16] (2017$).

Belews Lake near Greensboro, NC

Property Value Gains from Closure

Property values close to coal ash impoundments and landfills can be diminished by a variety of factors. For example, groundwater contamination or the risk of exposure to toxic coal ash can lower an individual's willingness to pay to live in the surrounding area. Coal ash storage sites may decrease aesthetic values for properties nearby and can also curtail recreational opportunities.

A number of studies have employed hedonic pricing methods[17] and WTP valuation to estimate losses to property values in the vicinity of landfills, hazardous waste sites, or similar disposal areas. In Baltimore, houses within a mile of hazardous waste sites and landfills were found to have, all else equal, 3.3%

[14] This would be the average number of years left if policy or other legal interventions were not involved.

[15] Net present value (NPV) is calculated by multiplying future annual benefits from the coal ash sites closing and using a 5% discount rate.

[16] The range in consumer surplus includes a lower estimate of just the closest populations (Towns of Madison and Eden) being affected, versus drinking water users farther downstream.

[17] The hedonic pricing method estimates peoples' nonmarket values of recreational opportunities, natural beauty, and other environmental features through analysis of property values in the housing market (Alberini, n.d.).

lower values (Thayer et al., 1992). A hedonic pricing study on properties near a coal ash disposal site in Knoxville, Tennessee found that living an additional mile away from the site increased annual consumer surplus by $778 to $1,168 per household (Rae et al., 1991).

Because of the proximity of the Dan River coal ash spill to communities in the Roanoke River Basin, there are likely additional property value gains from reduced risk of or anxiety about spills because people are more aware of its impacts and damage. Even more likely, the media attention devoted to coal ash since the spill in 2014 has increased awareness of the environmental issues associated with coal ash storage, which could be reflected more ubiquitously across the regional housing market than it would be otherwise.

There are 8,965 households[18] with a median household value of $132,865 (2017$), within the one-mile potential zone of impact for property value discounts from coal ash waste sites. Based on existing literature on property value losses near landfills and hazardous waste sites, the excavation of coal ash and closure of the four unlined sites could raise nearby property values by $40.6 million in the Dan River Basin alone, with a potential of nearly $274,000 in additional property tax revenue for Person, Stokes, and Rockingham County, North Carolina combined.

Property values could also increase in Virginia counties surrounding the Clover Plant and Altavista Plant should coal ash be excavated, although they are not included in our resource management scenario[19]. Property values around the Dan River Steam Station in Rockingham County, North Carolina, may benefit the most from the excavation of coal ash (set to be completed by the end of 2019) due to the site's high hazard level and 2014 coal ash spill[20].

An important consideration associated with property value gains is that some households may experience short-term negative impacts. Some families, especially those residing in low-income or minority communities, may not be able to afford the increase in property taxes that would accompany increases in property value. This illustrates an environmental justice issue that is not easily remedied; while low-socioeconomic households are disproportionately burdened by environmental degradation, their ability to pay to live farther away from, or otherwise avoid environmental contamination, may be lower than their more affluent counterparts due to their income and circumstances. Nevertheless, potential benefits to nearby property values are a factor worth including in the discussion of responsible coal ash disposal policy and future plans within the Roanoke River Basin.

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[18] This estimate is derived using the same census block data on households and population within a mile radius of the four unlined coal ash storage sites in the Roanoke River Basin.

[19] Because the status of lining at Altavista and Clover is less certain, they are not included in the resource management scenario, but nearby property values could likely be positively impacted by more stringent coal ash disposal regulations.

[20] The $40.6 million in property value gain is based on a conservative estimate from the literature; depending on the level of contamination at each site, we would expect to see varying levels of property value increases in each county.

Responsible Coal Ash Disposal: Costs and Regulations

The questions, proposals, and concerns surrounding safe coal ash disposal are mounting for states, utilities, and nearby residents alike. The EPA reports that in 2012, about 40% of coal combustion residual was reused, while 60% was disposed in surface impoundments and landfills (U.S. Environmental Protection Agency, 2018). Of the 60% disposed in surface impoundments and landfills, about 80% is disposed at the production site; the facilities at Belew's Creek, Dan River Steam Station, Roxboro, and Mayo are included in this 80%.

EPA's 2015 coal ash ruling includes new requirements for coal ash impoundments and landfills, including (U.S. Environmental Protection Agency, 2018):

- Groundwater monitoring around all surface impoundments and landfills,
- Liners required for all **new** surface impoundments and landfills, and
- The closure of all unlined facilities polluting groundwater.

In 2018, the Environmental Protection Agency eased regulations, allowing utilities and states flexibility in complying with these safety measures. Even under the 2015 rule, many did not believe the regulations were strong enough. The Coal Ash Management Act in North Carolina requires Duke Energy to close all its coal ash basins in 2029, which includes the four unlined storage facilities in the Roanoke River Basin. Duke Energy's current plans and timeline for disposal at the four sites are shown in Table 14. For all of its coal ash sites, Duke Energy is submitting proposals for disposal, which include:

- Closure in place - capping the coal ash at the existing site,
- Closure by removal - excavation and transport to a landfill, and
- Hybrid closure - consolidating ash into a reduced footprint within the existing storage facility and then capping.

Table 14. Coal Ash Disposal Plans for Coal Ash Sites in the Dan River Basin

Source: Duke Energy, 2016; 2019

	Belew's Creek	Roxboro	Mayo	Dan River
Disposal Method	Hybrid closure	Closure in place or hybrid closure	Closure in place or hybrid closure	Closure by removal
Completion Year	2029	2026-2029	2025-2028	2019
Estimated Cost	$135 million	$104 million - $256 million	$75 million - $109 million	$260 million

Cap in place and excavation both have environmental consequences, although most environmental advocates and organizations agree that excavation and transport to a dry landfill is the only permanent solution addressing leached toxins. Utilities are vying for closure in place methods at coal ash sites because of the lower cost, arguing that capping coal ash impoundments safely reduces the risk of contamination and leaching while sparing nearby communities from construction disturbance and associated air quality issues that would come with excavation. Excavation, while significantly more expensive, requires more time and resources but eliminates the risk of future leaching, which closure in place cannot guarantee (Sowers, 2017).

In March 2019, Virginia passed legislation that requires coal ash stored in the Chesapeake Bay watershed be recycled or excavated and transported to lined landfills (Leonor, 2019). This legislation, stricter than both North Carolina's act on coal ash management and the EPA's regulations on coal ash management, does not allow for closure in place, citing risks to groundwater quality (Early, 2019).

The location of new, lined landfills raises other environmental concerns: low-income, minority communities disproportionately house toxic coal ash, and the new regulations on coal ash disposal and management does not address issues of environmental justice (Bienkowski, 2016). Property values near new coal ash landfills could be permanently depressed, reflecting a loss in aesthetic value, even if there is no risk for environmental contamination.

While communities in the Dan River Basin are facing the ongoing environmental threat of unlined coal ash storage, communities in the Lower Roanoke River Basin are now facing the possibility of new coal ash landfills needed to store excavated coal ash from Duke Energy's unlined impoundments (Sorg, 2017). An environmental remediation company requested permits for two new lined landfills near Seaboard in Northampton County, North Carolina (Sorg, 2017). Northampton County, one of the counties overlapping the Lower Roanoke River subbasin, is 57% African American, and 22% of its residents live at or below the poverty line (Sorg, 2018). Local pushback from residents in Northampton County was strong enough that the planning board in Northampton County voted against the rezone ordinance that would have been required for the landfill permits (Sorg, 2018). Still, the question remains of where most of the excavated coal ash in Virginia and North Carolina will end up.

Outreach & Ecosystem Service Framework Applications

On March 6, 2019, we held an event "Valuing Natural Assets in the Roanoke River Basin" in Danville, Virginia to present the results of our ecosystem service assessments on the four issue areas and provide an opportunity to gather regional stakeholders together to discuss how county, regional, and state-level planners can begin incorporating an ESV framework into their roles. We invited over 300 people from a variety of organizations and backgrounds, including landowners; county-level developers, planners, and administrators; regional watershed and environmental organizations; regional soil and water conservation district staff; members of state and federal agencies; and state legislators. Among the 37 participants attending the workshop were representatives from:

- Roanoke River Basin Association
- Dan River Basin Association
- Halifax County, Virginia
- City of Danville, Virginia
- Stokes County, North Carolina

- Caswell County, North Carolina
- City of Greensboro, North Carolina
- North Carolina Wildlife Resources Commission
- Land Trust Alliance
- Virginia United Land Trusts
- Preservation Virginia
- Virginia Department of Conservation and Recreation
- Headwaters, LLC
- US Army Corps of Engineers
- Sierra Club
- US Fish and Wildlife Service
- US Geological Survey

Learning from ES Framework Applications in Maryland

A portion of the event was dedicated to presentations from representatives of groups who are currently incorporating ecosystem service values into the work they do. While the ecosystem services framework is increasingly used by agencies and organizations at the federal level, there is less evidence of the framework applied regionally and locally. We hosted three guest speakers from Maryland: Elliott Campbell of Maryland Department of Conservation and Natural Resources (DCNR), Ted Weber of The Conservation Fund, and Bryan Lightner of Cecil County, Maryland.

Maryland DCNR has invested in mapping ecosystem service values across the state, including the value of carbon sequestration, nitrogen removal, air pollution mitigation, groundwater recharge, and wildlife (Campbell, Marks, & Conn, 2017). The state uses this mapping tool to evaluate the economic benefits of and help prioritize conservation and restoration projects throughout Maryland.

The Conservation Fund is a national organization devoted to conservation outcomes at the intersection of environment and economics (The Conservation Fund, 2019). In Maryland, The Conservation Fund led a project funded through the National Fish and Wildlife Foundation as part of the Greater Baltimore Wilderness Coalition to explore the use of green infrastructure[21] (GI) in the region to promote resiliency to and protection from extreme events (The Conservation Fund, 2019). Following the Greater Baltimore Resiliency Assessment, The Conservation Fund performed county-level assessments for Harford and Cecil County, Maryland to help the counties develop green infrastructure plans (Weber, 2019). In Harford County, this included identifying core and critical habitat areas, modeling habitat corridor connectivity, and working with community stakeholders to identify GI priorities and goals.

[21] Green infrastructure is strategically planned and managed networks of natural lands and working landscapes and spaces that conserve ecosystem services and values while providing benefits to nearby human communities and populations (Weber, 2019).

Bryan Lightner, a resource planner in Cecil County, Maryland, introduced the Green Infrastructure (GI plan) plan that the county has been developing, explained why the county has decided to develop and invest in this approach to resource planning, and its benefits. Cecil County held community workshops to prioritize goals from the GI plan, such as shoreline protection, infrastructure protection, and natural resource protection, and benefits like clean air and water (Lightner, 2019). Natural resource protection strategies in Cecil County include ensuring sufficient habitat protection in high development areas in the county as well as managing county lands for habitat protection and deer control (Lightner, 2019). Green stormwater management strategies include developing watershed master plans and monitoring and communicating cost-saving benefits of nature-based projects (Lightner, 2019).

A Q&A session with the guest speaker panel led to discussion about possible collaboration and information-sharing between Virginia and Maryland at the state level, as well as the potential for Southside Virginia counties collaborating on the development of regional-level GI planning. Virginia does not currently have mapping tools available that evaluate ecosystem service values, which could be a valuable resource in prioritizing state conservation and restoration projects moving forward.

Attendees were curious about the barriers to implementing GI plans regionally and locally, and how to market the concept of a Green Infrastructure plan, particularly in rural, more politically conservative counties. Lightner noted that a GI plan can help the county earn points in programs such as the Community Rating System (CRS) under FEMA's National Flood Insurance Program, which allows residents to purchase flood insurance for their homes and businesses. Points toward the Community Rating System, from the development of flood protection and mitigation measures under the county's GI plan, can help lower residents' flood insurance premiums, resulting in cost-savings in these communities. This is a measured economic benefit from the implementation of GI plans that can draw widespread appeal in counties that may otherwise encounter significant pushback toward environmentally-framed policies.

While the GI plan in Cecil County, Maryland has not been implemented long enough to evaluate challenges and feedback, discussions during the event were aimed toward keeping an open line of communication between county-level planners and managers in Maryland, Virginia, and North Carolina, to share experiences, lessons learned, and other tips for Roanoke River Basin counties considering the development of GI plans.

Applying the Ecosystem Services Framework in the Roanoke River Basin

One of the most important outcomes for both the workshops and the final event in Danville was introducing the ecosystem services framework to key stakeholders in the basin and integrating the concepts into potential resource management examples. We walked through group exercises using sample resource management scenarios and determined the resulting potential impacts to ecosystem services, as well as potential barriers to incorporating the ecosystem service values into the resource management process.

Six groups in the event worked through their own selected resource management process; four groups chose implementation of riparian buffers, one group chose management of state game lands, and one group chose an ordinance on increasing home elevation in the floodplain zone. We asked for factors that are typically important to the chosen management decision, some of which are highlighted:

Riparian Buffers

- Landowner willingness/public acceptance (2)
- Political feasibility
- Equity: incidence of cost and benefits
- Economic impact from tourism
- Width: fixed vs. varying
- Operation and maintenance costs (i.e. invasive species management)
- Nutrient loading
- Water quality issues
- Land use restrictions/utility conflicts (2)
- Cost of income lost from revenue associated with timber harvest
- Flood damage reduction

State Game Land Management

- Water quality
- Property values
- User conflict
- Funding - O&M costs
- Aesthetics

Elevation in the Floodplain

- Flood levels
- Property values
- Aesthetics

Next, we examined the key ecosystem services that were likely to be affected by the management decision, and the direction and strength of impact:

Riparian Buffers

- Water purification/water quality (+)
- Habitat & biodiversity (+)
- Aesthetics (+/-)
- Erosion control (+)
- Flood control/protection from extreme events (+)

State Game Lands

- Recreation (+)
- Drinking water (-)
- Aesthetics (+)
- Erosion control (+)

Floodplain Elevation

- Aesthetics (+/-)
- Groundwater recharge (+)
- Soil formation (+)
- Water quality (+)

Finally, we asked what barriers exist that prevent the values associated with the ecosystem services listed above to be incorporated into the resource management decisions. Some of the major barriers mentioned across the management actions include:

- Public perception & resistance to change
- Difficulty quantifying values
- Lack of expertise/tools
- Unequal spatial distribution of benefits
- Competing interests
- Lack of state regulation

Stakeholder Perspective and Feedback on the Event

We asked event participants to complete a survey at the end of the event, which included questions on the usefulness of the event format and content, background on ecosystem services, and feasibility of incorporating the information and background from the project into their work.

A summary of feedback received follows:

- 83% of respondents had heard of ecosystem services before the event, and their level of knowledge/experience working with the concept averaged 6 on a scale of 1 to 10, with 1 representing no knowledge about or experience with the concept and 10 indicating the highest level of knowledge and experience.
- Most respondents found it useful to hear how other groups and governments have applied an ecosystem service framework to their work (on a scale of 1-5 with 1 being not useful and 5 being very useful, the average response was 4).
- There were mixed responses on the feasibility of applying an ecosystem service framework to the respondents' work (on a scale of 1-5 with 1 being infeasible and 5 being feasible, the average response was 4).
- 67% of respondents believe their colleagues would support incorporating ES values into their collaborative work, while 33% are unsure. No respondents answered that their colleagues would be unsupportive.
- When asked whether they would attend a similar event for the Roanoke River Basin annually, 42% of respondents said "yes", and 58% of respondents said "maybe". No respondents surveyed answered "no".

Recommendations

This report provides an important first step towards incorporating information about ecosystem service values in the Roanoke River Basin into decisions made about the basin's resources at the local, regional, and state level. The input, feedback, and experience shared among stakeholders in the region guides our recommendations for further study and further engagement among key stakeholder groups.

We asked participants in the final Symposium specifically what resources may be most useful for incorporating ES into their work, and what topics should be addressed at future workshops. The resources that participants suggested could be useful to applying the ES framework include more economic data on ecosystem services, spatial data on specific localities, and free spatial tools (i.e., other than GIS).

Because there was widespread positive response to the possibility of holding an annual event on ecosystem services and natural resources in the Roanoke River Basin, we see great potential in watershed organizations and other key stakeholder groups holding smaller, more targeted workshops. For example, both riparian buffers and recreation/ecotourism as umbrella concepts for future topics generated widespread interest among participants and Steering Committee members, and workshops could be tailored to specific localities.

Other future topics mentioned include barriers to implementation of the ecosystem service framework, water quality impacts to major water bodies (i.e., reservoirs) downstream of land use changes, restoring lost or impaired ecosystem services, enhancements and incentives for maintaining ES, GI planning, and a focus on ecosystem service tools (such as the Ecovaluator). Each of these topics could be addressed in separate workshops. Convening future workshops would require funding and other support from organizations willing to sponsor them.

Specific recommendations for furthering the use of the ES framework in the Roanoke River Basin include:

1. Continued communication between RRB resource managers and leaders in counties, state agencies, and other organizations that are currently applying ecosystem service values and frameworks into resource management, conservation and restoration planning, and other resource planning processes.
2. Developing standard procedures and guidelines for county, state, and local agencies to incorporate ES valuation into GI, mitigation, and other plans.
3. Integration of cost-benefit analyses that incorporate ecosystem service benefits into resource management planning and actions, particularly for BMPs. The model of forested riparian buffers provides a large-scale example of information that can be applied at a subwatershed or county level.

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Appendix A: Ecosystem Service Valuation Methods

Ecosystem Service Estimation Methods

Economists have developed widely used methods to estimate the monetary value of ecosystem services and/or natural capital. The most commonly known example is from a study by Costanza et al. (1997) that valued the natural capital of the entire world. That paper and many others employ the Benefit Transfer Method (BTM) to establish a value for the ecosystem services produced or harbored by a particular place. According to the Organization for Economic Cooperation and Development, BTM is "the bedrock of practical policy analysis," particularly when collecting new primary data is not feasible (OECD, 2006).

BTM takes a rate of ecosystem benefit delivery calculated for one or more "source areas" and applies that rate to conditions in the "study area." Typically, the rates are drawn from previous studies that estimate the value of various ecosystem services from similar land cover/biome types. Benefits (in dollars per unit area) from the source areas are transferred and applied to the study area land with the same land cover. For example, data from the source area may include the value of forestland for recreation. In that case, the per-acre value of recreation from the source area can be applied to the number of acres of forestland in the study area. Multiplying that value by the number of acres of forestland in the study area to produce the estimate of the recreational value of the study area's forests. Furthermore, it is important to use source studies that are from regions with similar underlying economic, social, and other conditions to the study area. This ensures that the estimated values are accurate given the study area's specific demographics.

Estimation of ecosystem service value requires two general steps:

1. Identify total hectares within each land cover classification within the Roanoke River Basin and within the subwatersheds: Upper Dan, Lower Dan, and Lower Roanoke.
    a. This was performed in GIS, by clipping the NLCD layer to a shapefile of the Roanoke River Basin, delineated by watershed boundaries. There are seven subwatersheds in the Roanoke River Basin: Upper Roanoke River, Middle Roanoke River, Upper Dan River, Lower Dan River, Banister, Roanoke Rapids, and Lower Roanoke River.
2. Multiply total hectares in each land cover classification by the ecosystem service value per hectare per year for each individual ecosystem service, where applicable, to arrive at a final value of ecosystem service value in ($/yr) for each land cover in each subwatershed.
    a. Some land types, such as shrub/scrub and deciduous forests, only have one ecosystem service with quantified value(s) that were appropriate for benefit-transfer valuation. Others, particularly wetlands, have a handful of measured ecosystem service values, ranging from air quality to recreation.

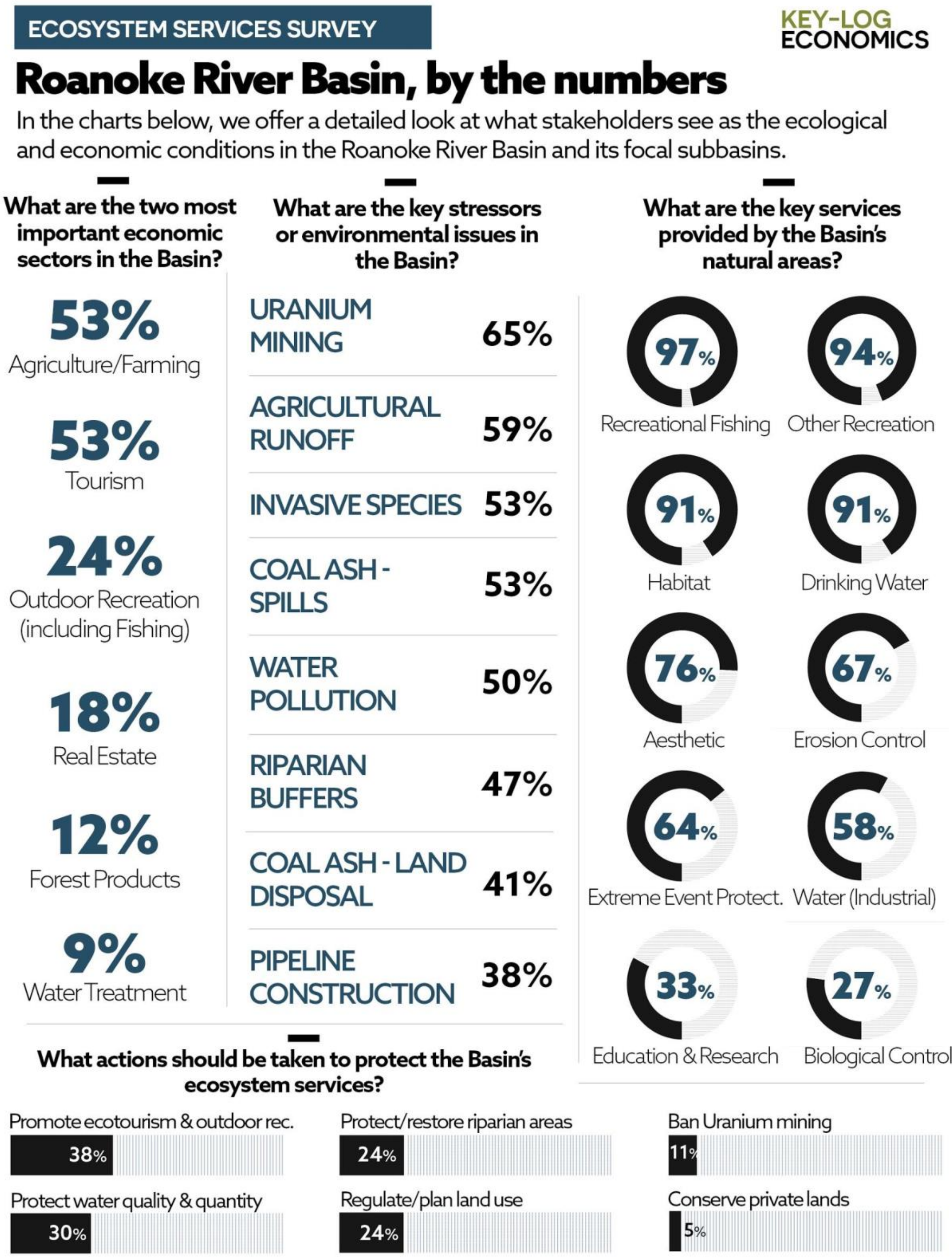
b. The variety in ecosystem services measures and number of studies for each land cover is a result of both the existence of any primary studies in each type of land and service, and by the suitability of those values in application to the Roanoke River Basin. For example, there are a handful of ecosystem service valuation studies for grasslands, but nearly all of the studies estimated values in African grasslands and were not applied to grasslands in the Roanoke River Basin. Similarly, ecosystem service values for river basins in large cities, such as the Charles River Basin in Massachusetts, were excluded in this assessment.

The result is a three-dimensional dataset with dollar-value estimates of ecosystem services in each hectare of the study region based on land cover type. This provides a preliminary baseline assessment of the region's ecosystem service value that will allow us to create land-use change scenarios and measure the impact of potential actions or policies.

Appendix B: Survey Results

Following the two workshops in Danville, Virginia and Weldon, North Carolina in April 2018, a Google Form survey was sent out to workshop participants and invitees unable to attend with follow-up questions on key environmental stressors, ecosystem services, and potential actions to address them in the region. Respondents specified whether they were answering for the Roanoke River Basin as a whole, or one of the two focal subbasins (Dan River Subbasin and Lower Roanoke River Subbasin) in the study. In total, 39 respondents provided input.

The graphic below shows results for all 39 respondents, regardless of whether they answered for a focal subbasin. The focus on the Dan River Subbasin and Lower Roanoke River Subbasin informed the decision to model key ecosystem services and economic impacts resulting from the following interventions (Appendix D): 1) uranium mining ban lifted, 2) coal ash impoundment closure, 3) voluntary urban and agricultural BMPs implemented, and 4) "nature-based" recreation gains value from water quality improvements.

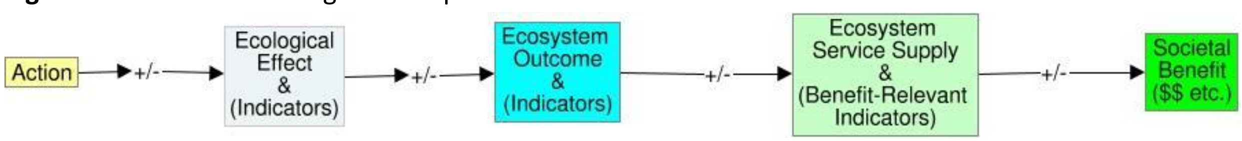

ECOSYSTEM SERVICES SURVEY
KEY-LOG ECONOMICS
Roanoke River Basin, by the numbers
In the charts below, we offer a detailed look at what stakeholders see as the ecological and economic conditions in the Roanoke River Basin and its focal subbasins.
What are the two most important economic sectors in the Basin?
53% Agriculture/Farming
53% Tourism
24% Outdoor Recreation (including Fishing)
18% Real Estate
12% Forest Products
9% Water Treatment
What are the key stressors or environmental issues in the Basin?
URANIUM MINING 65%
AGRICULTURAL RUNOFF 59%
INVASIVE SPECIES 53%
COAL ASH - SPILLS 53%
WATER POLLUTION 50%
RIPARIAN BUFFERS 47%
COAL ASH - LAND DISPOSAL 41%
PIPELINE CONSTRUCTION 38%
What are the key services provided by the Basin's natural areas?
97% Recreational Fishing
94% Other Recreation
91% Habitat
91% Drinking Water
76% Aesthetic
67% Erosion Control
64% Extreme Event Protect.
58% Water (Industrial)
33% Education & Research
27% Biological Control
What actions should be taken to protect the Basin's ecosystem services?
Promote ecotourism & outdoor rec. 38%
Protect/restore riparian areas 24%
Ban Uranium mining 11%
Protect water quality & quantity 30%
Regulate/plan land use 24%
Conserve private lands 5%

Appendix C: Means-End Diagrams

As funders, developers, and other decision-makers involved in the management of natural resources become more interested in the value of benefits we receive from nature, a model for assessing how decisions or policies impact these benefits becomes increasingly important. The use of ecosystem service conceptual models, like means-end diagramming, help simplify complex relationships between humans and their environment, while providing a common and credible framework for intervention.

In the Roanoke River Basin, the means-end framework allows us to connect biophysical processes to economic outcomes, which creates a more complete picture of environmental interventions that will result in the greatest change in benefits to communities and the general public over space and time by quantifying the value that we receive from those affected ecosystem services. Figure 17 lays out the means-end diagram framework.

Figure 17. Means-Ends Diagram Template



The following conceptual models were reviewed by the Steering Committee and informed the literature review and exploration of ecosystem service pathways in the models. While not all pathways are modeled -- due to either limitations in literature connecting actions, biophysical impacts, and economic damages, or due to data gaps -- the means-end diagrams provide a blueprint for the pathways modeled and estimated changes to ecosystem service values in this analysis.

Figure 18. Water Quality Improvements and Recreation Benefits Conceptual Model

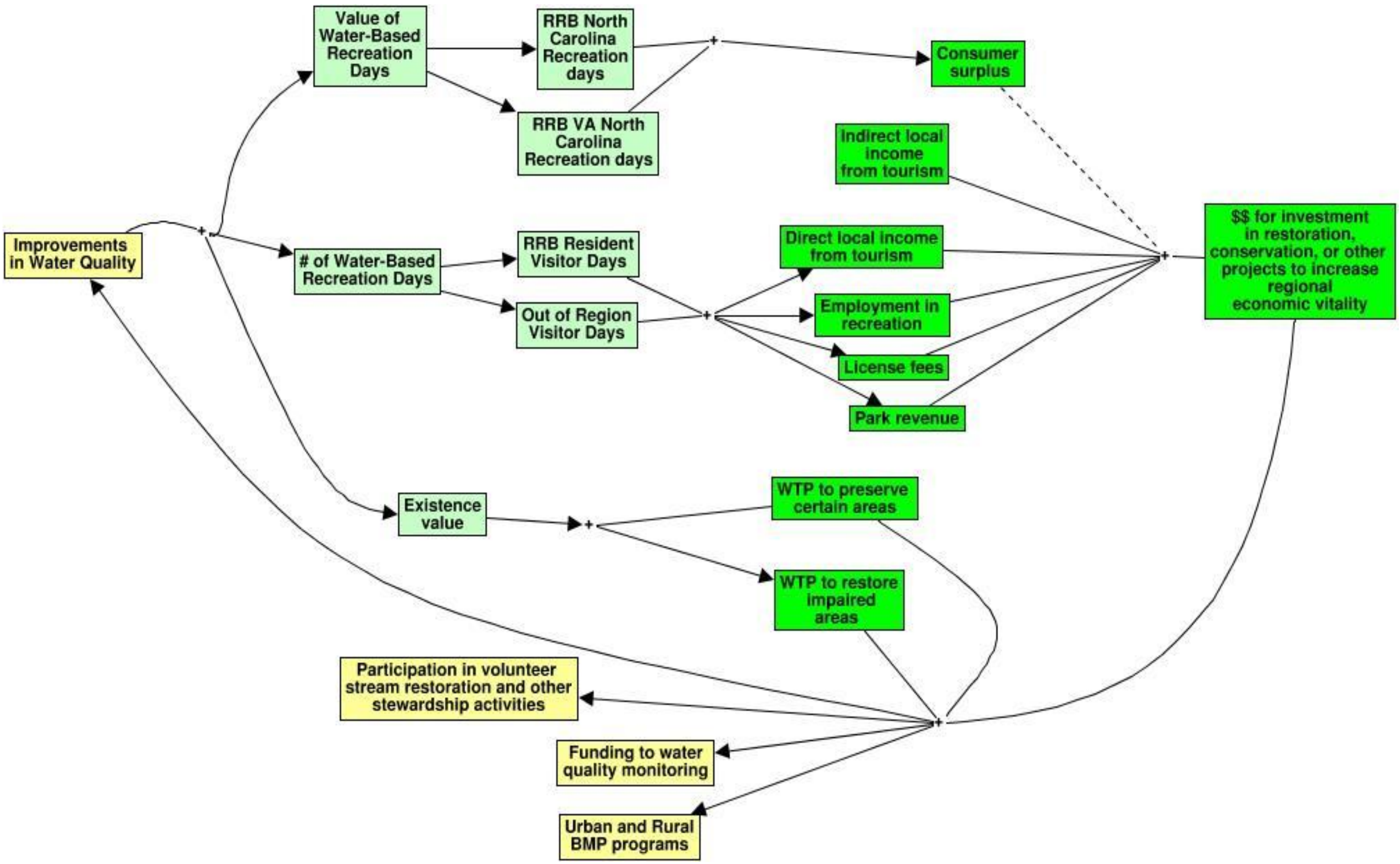


Figure 19. Voluntary BMPs Pathways Conceptual Model

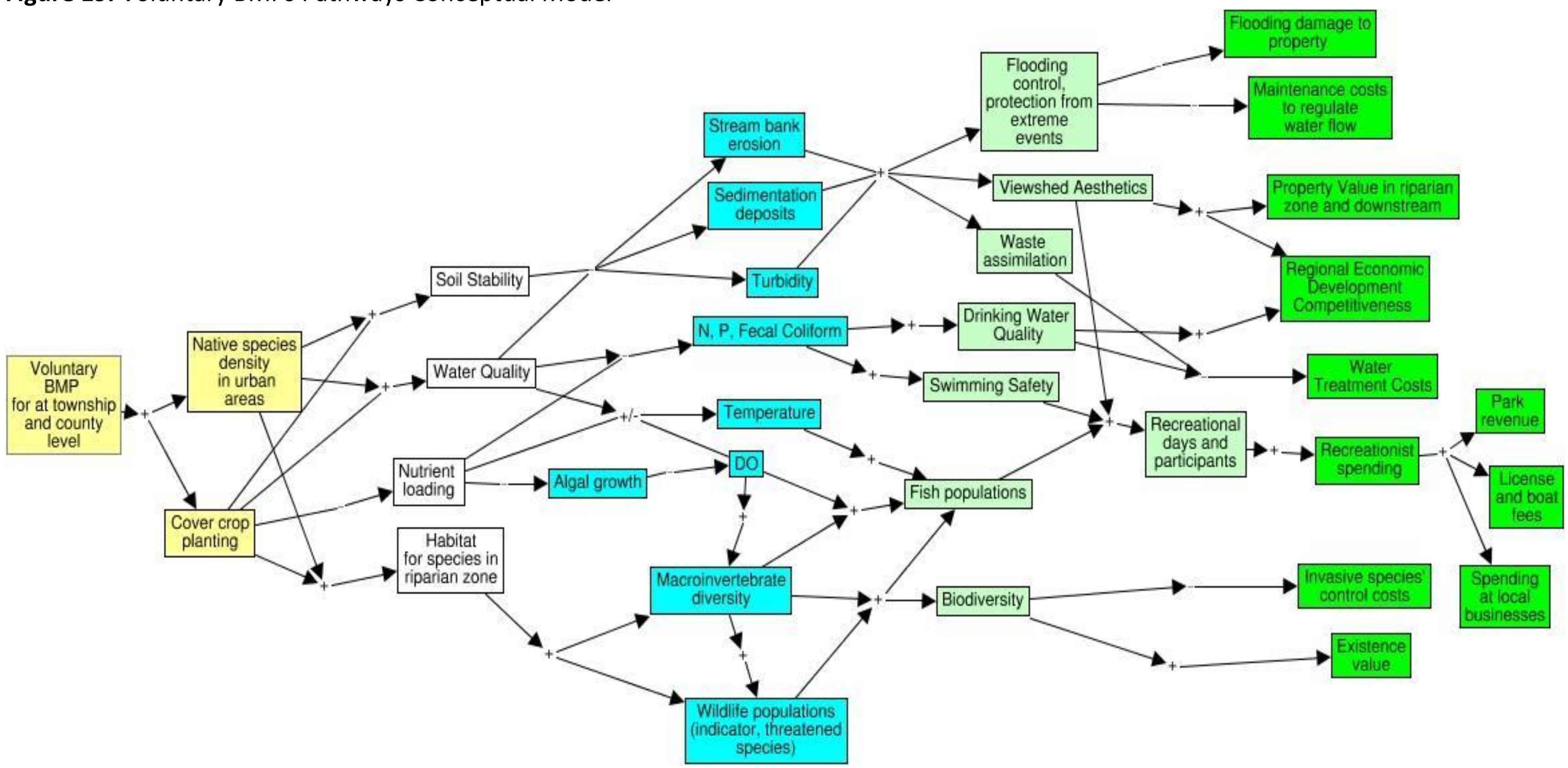


Figure 20. Uranium Mining Ecosystem Service Pathways Conceptual Model

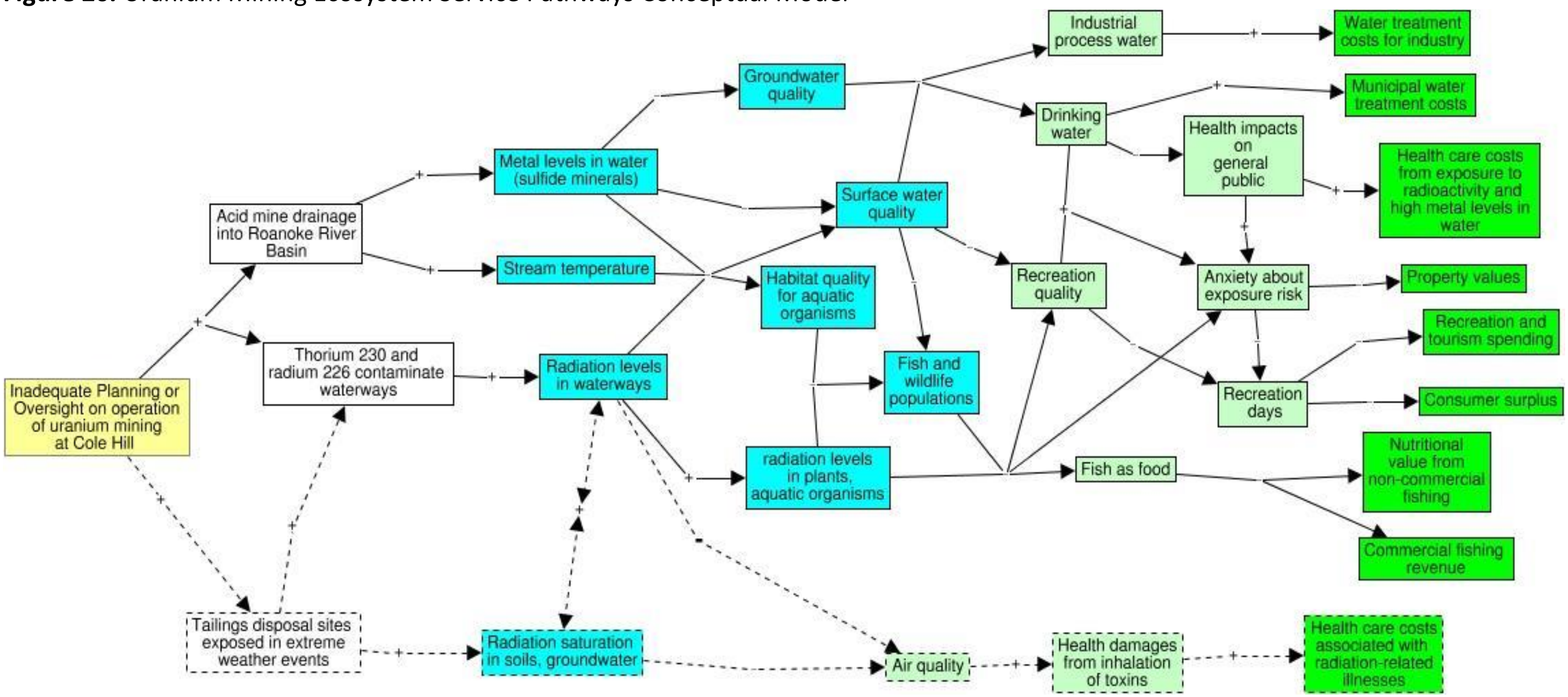
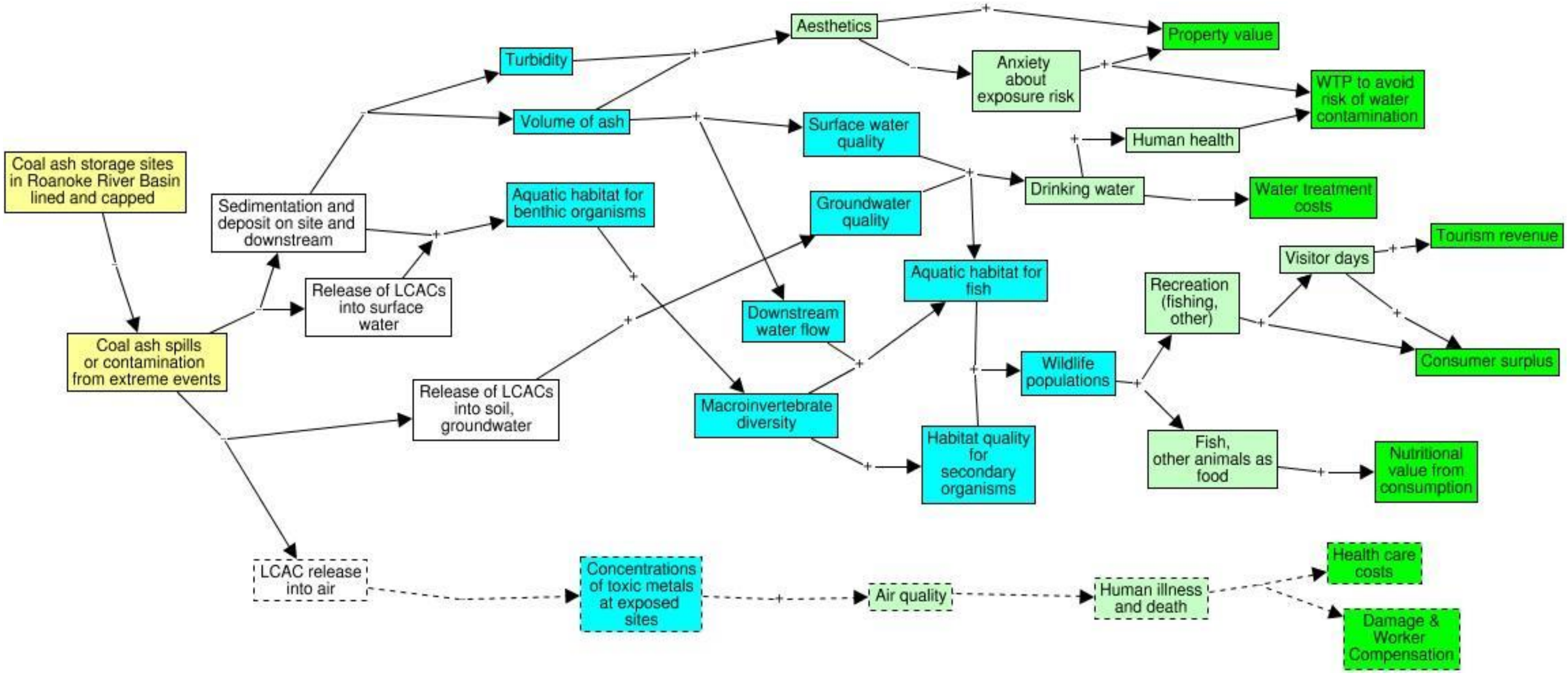


Figure 21. Coal Ash Ecosystem Service Pathways Conceptual Model



Appendix D: Modeling Methods

Water Quality Improvements & Recreation Benefits

We estimate the value of water quality improvements to recreational users of the Roanoke River Basin by applying the average willingness to pay for improved water quality to the number of water-related outdoor recreation days in the Basin. Data for participation in water recreation activities is available for Virginia and North Carolina; freshwater fishing data is available for the entire RRB encompassing both states.

Virginia RRB Water Recreation Days

The number of water-related outdoor recreation days in Virginia was calculated by first dividing the number of people in Virginia's Roanoke River Basin counties by the total population of Virginia (in 2017; U.S. Census Bureau, 2019). This results in an estimate of the portion of the state's population residing in the Basin (assuming population is evenly distributed throughout the state):

- Population of Roanoke River Basin in Virginia = 866,527
- Population of Virginia = 8,474,020
- Portion of Virginia's population residing in the Basin = 866,527 / 8,474,020 = 10.3%

We then multiply this percentage by the number of days Virginians participated in water-based recreation activities in 2017 (Ellis et al., 2017) excluding freshwater fishing. (Because Basin-wide data for participation in freshwater fishing is available we use that instead of state estimates.)

- Demand for water recreation (person days) = 69,562,000 days * 10.3% = 7,168,000 days in RRB

  Water-based activities included in the data are jet skiing/personal watercraft, powerboating, sailing, sailboarding, canoe/kayaking, water skiing, tubing, swimming, paddle boarding, kiteboarding, and viewing the water.

North Carolina Roanoke River Basin Water Recreation Days

The number of water-related outdoor recreation days was not located for North Carolina. We instead estimate the number of water-based recreation days by multiplying the population of North Carolina counties in the Roanoke River Basin by the percent of the state's population that participate in water-based recreation activities (in 2017; U.S. Census Bureau, 2019; N.C. Department of Environment and Natural Resources, 2015).

- Population of Roanoke River Basin counties in North Carolina = 328,644
- Portion of the state's population that participate in water-based recreation activities, except fishing, percentage by activity = 3,707,104 participants in RRB

  Activities included in the data are swimming, power boating, canoeing, kayaking, bird/wildlife watching, tubing, water/jet skiing, sailing, windsurfing, and kitesurfing, and visiting a beach or lake.

To estimate the number of days each North Carolinian in the RRB engaged in water-related recreation each year we multiply the number of participants by 4, an estimate of the average annual recreation days per person. This is based on North Carolina State Parks survey data that found the greatest portion, 28%, of respondents average 3 to 5 state park visits per person per year (N.C. Department of Natural and Cultural Resources, 2018). This is consistent with results of a 2013-2014 survey of ecotourism in the Virginia RRB which found that 33% of non-resident respondents reported they traveled to the RRB for recreation 4 or more times per year (Ellerbrock et al., 2014).

Roanoke River Basin Water Recreation Days and WTP

RRB water related recreation days are the sum of the VA and NC days presented above, plus the number of (demand) days for freshwater fishing days in the RRB (U.S. Environmental Protection Agency, 2019):

- Water-based recreation days in RRB = 7,168,000 + 3,707,104 + 2,594,294 = 13,470,398 days

This results in an estimated 13.5 million annual water-related days in the Roanoke River Basin (Table 15). Multiplied by the average recreational user's willingness to pay 24 cents per day trip for improved water quality (Phaneuf, 2002; see *Water Quality Improvements & Recreation Benefits*) results in a total benefit estimate of $3.2 million for the RRB.

Table 15. Water-Related Outdoor Recreation Days in the Roanoke River Basin

Activity	Days per Year (thousands)
Swimming	2,734
Viewing the water	2,651
Freshwater fishing	2,594
Power boating	1,291
Canoe/kayaking	1,197
Visiting beach/lake	997
Bird/wildlife watching	634
Water ski/jet skiing	558
Tubing	474
Sailing	145
Paddleboarding	108
Paddle-in camping	23
Windsurf/kitesurf/kiteboarding	17
Sailboarding	13
Other water-dependent	114
Total	**13,469**

Riparian Buffers and Other Best Management Practices

Figure 19 in Appendix C shows the ecosystem service concept model and means-end pathways used to guide literature review and analysis of potential ecosystem service values and changes associated with best management practices, particularly increasing forested and vegetated riparian buffers. We also utilized feedback from the working group section of the final event, which honed in on the importance of widening natural riparian buffers in both urban and rural areas. The foundation of our calculations relies heavily on the benefit transfer method from a recent study of the economic value of riparian buffers in the Delaware River Basin (Rempel & Buckley, 2018).

Relative to the other issue areas, the ecosystem service values presented in this model can be more easily incorporated into cost-benefit analyses, as some markets, including in North Carolina, already exist for the value of natural riparian buffers. We compare the value of the ecosystem service benefits associated with an acre of forested riparian buffer to the opportunity cost of an acre of land that could be utilized for timber or agriculture. A suite of ecosystem services are examined for added value from a variety of scenarios focused on increasing natural riparian buffer cover in the Roanoke River Basin.

Flood Mitigation and Protection

We calculate a conservative estimate of the value of flood mitigation and protection from forested riparian buffers by applying a $/acre/year value of flood protection to acres that make up the 100-year floodplain *and* are within a 150' buffer of waterways. This spatial extent yields approximately 180 acres and excludes acres of the 150' forested buffer that extend beyond the boundaries of the 100-year flood zone in those stream segments. We apply a value of $21,605/acre/year (in 2017 dollars) in floodplain protection, taken from a national study examining the average increase in value of land adjacent to protected floodplains (Burby, 1988). Because the 180 acres within 100-year flood zones could be targeted in both buffer scenarios (assuming the 50% of streams targeted for forested buffer are inclusive of the 180 acres containing the 100-year flood zones), we apply the same calculation:

- 180 acres (riparian area completely inclusive of 100-year floodplain) x $21,605/acre/year (in 2017 dollars) = $3,888,854/year in flood protection

Nutrient Retention (Waste Assimilation)

We use the North Carolina Ecosystem Enhancement Program (NCEEP) market values for a pound of nitrogen and phosphorous averted from surface waters to estimate cost-savings associated with nutrient retention from forested buffers in the Roanoke River Basin (Rempel & Buckley, 2018). The NCEEP dollar values applied in the NCEEP are $14.99/lb for nitrogen and $274.78/lb for phosphorous (Rempel & Buckley, 2018). We use ECONorthwest's calculations on nutrient retention per acre from their study on riparian buffers in the Delaware River Basin to translate $/lb to $/buffer acre (Rempel & Buckley, 2018). The Chesapeake Bay Commission estimates that an acre of riparian buffer treats total nitrogen loads from four upland acres and phosphorous and sediment loads from two upland acres (Rempel & Buckley, 2018). The $/buffer acre/year value is estimated as the following:

- $14.99/lb of nitrogen (NCEEP market value) x 75.77 lbs/acre/year (NCEEP estimated nitrogen removed by an acre of natural buffer) + $274.78/lb of phosphorous x 4.88 lbs/acre/year (NCEEP estimated phosphorus removed by an acre of natural buffer) = $2,475.93/acre/year in nutrient retention (2017 $)

Using the total additional riparian buffer acreage proposed in the scenarios discussed, we arrive at the following annual benefit from nutrient retention:

- 50% RRB waterways with 150' forested buffer: 115,065 acres of additional forested buffer x $2,475.93 (nutrient retention value/acre/year in 2017$) = $284,892,330 in annual benefit from nutrient retention
- 100% RRB waterways with 150' forested buffer: 230,130 acres of additional forested buffer x $2,475.93 (nutrient retention value/acre/year in 2017$) = $569,784,660 in annual benefit from nutrient retention

Air Quality

Forested riparian zones contribute to higher regional air quality through pollutant removal, which provides a societal benefit in the form of reduced health damages and healthcare costs (Rempel & Buckley, 2018). The value of air quality for an acre of forest buffer will naturally be higher in urban areas with higher population densities, ranging from $42 to $132 an acre/year, compared to $3 to $7 an acre/year in rural areas (Rempel & Buckley, 2018). These dollar values, calculated by the Forest Service, represent healthcare cost-savings from avoided air pollutants causing human health damages (Rempel & Buckley, 2018).

Applying the average value between urban and rural values per acre, we arrive at the following annual benefit to air quality from the two forested buffer scenarios:

- 50% RRB waterways with 150' forested buffer: 115,065 acres of additional forested buffer x $67.5 (air quality value/acre/year in 2017$) = $7,766,872 in annual benefit from improved air quality
- 100% RRB waterways with 150' buffer: 230,130 acres of additional forested buffer x $67.50 (air quality value/acre/year in 2017$) = $15,533,745 in annual benefit from improved air quality

Aesthetics & Property Values

Existing studies on the value of property premiums in the riparian zone shows a range of less than 1% to 26% in added amenity value due to the presence and effectiveness of a natural buffer (Rempel & Buckley, 2018; Young, 2016). Using block data from the U.S. Census, we estimate the number of households within the existing natural riparian buffers in the Roanoke River Basin and within a 150' buffer of the waterways within the Roanoke River Basin. We use the Census' American Community Survey's 2017 block group data to estimate the current median and total housing values of households within the existing natural riparian buffers and the 150' natural buffer scenario. We then apply a 13.5%

average property premium from existing literature to arrive at the following aesthetic benefit, reflected in property values, from existing buffers and our two buffer scenarios:

- Total property premium in existing natural riparian buffer: 13,317 households x $146,166 (median housing value for block groups intersecting existing natural riparian buffers) = $1,946,515,639 in total housing stock x .875 (predicted housing value without natural buffer) = $1,703,201,184
  - $1,946,515,639 (current value with buffer) - $1,703,201,184 (predicted value without buffer) = $243,314,455 in estimated aesthetic value (property premium) from current natural buffer
- Total property premium in 50% scenario (150' forested buffer applied to half of RRB waterways): 13,543 households x $146,473 (median housing value for block groups intersecting 150' riparian buffer) = $1,983,675,031 in total housing stock / .875 (predicted housing value with increased forest buffer) = $2,267,057,178
  - $2,267,057,178 (potential value with buffer) - $1,983,675,031 (existing value without increased buffer) = $283,382,147 in estimated aesthetic value (property premium) from 50% forest buffer scenario
- Total property premium in 100% scenario (150' forested buffer applied to all RRB waterways): 27,086 households x $146,473 (median housing value for block groups intersecting 150' riparian buffer) = $3,967,350,061 in total housing stock / .875 (predicted housing value with increased forest buffer) = $4,534,114,356
  - $4,534,114,356 (potential value with buffer) - $3,967,350,061 (existing value without increased buffer) = $566,764,294 in estimated aesthetic value (property premium) from 100% forest buffer scenario

Recreation

The value of recreation per acre of forested buffer can be measured by increased recreation trips taken when the viewshed is improved, increased enjoyment within each recreation trip, and/or increased spending per trip (Rempel & Buckley, 2018). We apply the recreational value/acre/year applied for the Delaware River Basin in the Roanoke River Basin, an estimated $63/acre/year (Rempel & Buckley, 2018). Total annual recreational benefit from the two forest buffer scenarios are estimated as:

- 50% RRB waterways with 150' forested buffer: 115,065 acres x $63/acre/year = $7,249,081 in additional annual benefit from recreation
- 100% RRB waterways with 150' forested buffer: 230,130 acres x $63/acre/year = $14,498,162 in additional annual benefit from recreation

Uranium Mining in Virginia

Figure 20 in Appendix C shows the ecosystem service concept model and means-end pathways used to guide literature review and analysis of potential ecosystem service values and changes associated with lifting the ban on uranium mining in Virginia. Because the regulatory framework around uranium mining in the region has not been developed, the pathways modeled are all potential scenarios with great levels of uncertainty. The results are meant to illustrate economic consequences that could arise from potential changes to the surrounding ecosystem and demonstrate that some of these costs can be quantified and should be considered when weighing predicted economic benefits to the region from industry development.

Human Health Damages & Air Quality

Indirect and direct medical costs associated with cancer from potential radon exposure were calculated using existing literature on exposure to mine workers in Grant, New Mexico[22], and modeled exposure rates to general populations in Culpeper County, Virginia. These cost estimates assume similar conditions of exposure for mine workers and the general public. We believe this is a reasonable assumption because 1) Virginia has not developed regulations on radon exposure standards for uranium mining, and 2) the federal standards for radon exposure have not been updated since 1971 (Jones, 2014).

Human Health Damages to Uranium Mine Workers

We apply the excess exposure death rate of uranium mine workers from lung cancer under the low radon exposure conditions (post-1971) to arrive at estimated excess mine worker deaths in the Roanoke River Basin based on Virginia Uranium Mining's projected numbers of mine workers (Beahm & Kyle, 2013):

- 224 mine workers (Virginia Uranium Mining estimate) x 0.026 (excess-exposure death rate for low exposure uranium mine workers) = 5.8 excess lung cancer deaths

The cost per excess death is calculated using an estimate of lifetime medical costs associated with diagnosing and treating lung cancer (direct costs) and the cost to society of premature miner mortality (indirect costs) (Jones, 2014). Applying this method to the estimated 5.8 mine workers exposed to radon, we arrive at an estimate of the total cost to human health from lower air quality:

- 5.8 excess deaths x $234,679 (medical costs over the lifetime of a uranium mine worker with lung cancer, 2017 $) = $1.4 million direct costs, lung cancer diagnosis and treatment
- 5.8 excess deaths x 20.6 (average years of life lost) x $212,688 (value of statistical life year lost, 2017 $) = $25.4 million indirect costs, cost to society of premature miner mortality

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[22] Grant, New Mexico is the largest uranium mining district in the United States and was chosen based on extensive literature and data pertaining to health damages of uranium mine workers.

- $1.4 million direct costs + $25.4 million indirect costs = $26.8 million total cost of mine worker deaths over 35-year mine life

This estimate represents a net present value of human health damages (lung cancer treatment and mortality) from exposure to radon over the lifetime of the mine.

Human Health Damages to the Nearby Population

The risk of radon exposure and subsequent cancer rates and mortality to the general public through inhalation is much lower than the risk to uranium mine workers but is still present. The U.S. Environmental Protection Agency contracted work with S. Cohen and Associates to develop risk assessments of radon emissions from operating uranium mill tailings facilities and included two generic site risk assessments based on existing uranium deposits. The eastern generic site assessment was modeled in Culpeper County, Virginia and chosen partly because there is no population living within 1 km of the Culpeper County deposit (S. Cohen & Associates, 2011). The estimated annual radon exposure to the general population within 80 km (approximately 50 miles) of the site is 1,025 to 1,750 Ci, with a best reasonable latent cancer fatality risk of 1.6 per 100,000. For the purpose of estimating potential human health damages to nearby populations within 50 miles, we assume similar weather conditions and population densities between Culpeper County and Pittsylvania County.

Approximately 562,840 people (according to the 2010 U.S. Census Bureau block group data) live within 50 miles of the Coles Hill site in Pittsylvania County. Using the latent cancer fatality rate from radon exposure within 50 miles of the mill tailings facility, we expect:

- 562,840 people x (0.000016) = 9.01 excess deaths from radon decay exposure

In order to arrive at a cost estimate for human health damages to the nearby populations, we apply the same estimates of damages per excess death for uranium mine workers. This assumes a similar average age of a uranium mine worker and average age of a person in the nearby population:

- 9.01 excess deaths x $234,679 (medical costs over the lifetime of a nearby resident with lung cancer, 2017 $) =$2.1 million direct costs, lung cancer diagnosis and treatment
- 9.01 excess deaths x 20.6 (average years of life lost) x $212,688 (value of statistical life year lost) = $39.4 million in direct costs, cost to society of premature miner mortality
- $2.1 million direct costs + $39.4 million indirect costs = $41.5 million total cost to the general public (within 50 miles) from lower air quality over the lifetime of the uranium mine. This does not include indirect and direct medical costs associated with other respiratory issues and non-cancer health issues.

Avoidance Cost & Water Quality

Another potential exposure pathway that could lead to ecosystem service value loss is from groundwater contamination through radon exposure (Committee on Uranium Mining in Virginia, Committee on Earth Resources, & National Research Council, 2012). Existing studies have identified 250 private wells within 2 to 3 miles of the proposed facility (Moran, 2011). While rates of exposure and human illness through groundwater contamination from radon were not found in the literature, we examine the potential costs associated with groundwater users that arise from behavior change under the case of uranium mining. Cost avoidance, or the cost of actions taken to prevent or mitigate against future damages, would include increased groundwater quality monitoring for individuals to ensure they are not consuming water with high radon concentrations.

The cost of testing for radon in water ranges from $25 to $50, and assuming the water is tested annually over the 35-year lifetime of the mine, this amounts to $218,750 to $437,500 in water quality monitoring for private well users within 2 to 3 miles alone (PennState Extension, 2015). Treatment of radon in well water, should high levels of radon be present, would cost an additional $2,000 to $4,000 per system (PennState Extension, 2015). If groundwater contamination occurs within the 2-3-mile radius of the facilities at any time over the course of operation, treatment for well owners could reach $1.0 million (in 2017 dollars). This assumes every private well user within the vicinity of the mine and milling facilities tests for radon exposure in groundwater each year.

Perceived Surface Water Quality & Willingness to Pay to Avoid Potential Contamination

In this pathway, we consider potential consumer surplus lost from lifting the ban on uranium mining associated with perceived water quality, which makes a number of assumptions: 1) there is a positive willingness to pay in the region to avoid water contamination in general, 2) people have a positive willingness to pay to avoid the risk of a catastrophic event, and 3) downstream water users are either aware of the risk of water contamination or are unaware but with education on the issue would have a positive willingness to pay to avoid the risk of human health damages from exposure to toxins.

People in the region have heterogeneous preferences about the decision to mine uranium based on their perception of how they may be impacted. Some residents may not be concerned about water quality while others are willing to pay a high amount to avoid the risk of a potential flooding event, containment cell collapse, or other "catastrophic" event that would lead to widespread contamination of downstream drinking water.

Approximately 420,759 residents of the Roanoke River Basin get their drinking water from surface water intakes downstream of the proposed site at Coles Hill (Kolotushkina, 2012). The 2,400 residents in the Towns of Clarksville and Halifax are closest to the proposed facility. While Virginia Beach residents (approximately 700,000) also get their drinking water from a surface intake in Lake Gaston and it would be fair to assume they also have a positive WTP to avoid contamination in their drinking water, we do not estimate WTP of users outside the study region. Because income levels, education, and perception of risk all factor into an individual's WTP to avoid environmental damage, those living closest to the uranium mine do not necessarily have the highest WTP to avoid any potential damage to water quality from its presence (McCluskey & Rausser, 2001). In fact, residents in Virginia Beach may have a higher WTP than many residents within the Roanoke River Basin if they are more inclined to believe that the risk of contamination is high; some may even believe it is certain.

A synthesis of WTP measures for a number of leached contaminants, including heavy metals, estimate an average WTP to avoid exposure to contaminants of $22.90/person/year (2017 $) (Holloday, 2009). Over the 35-year operational period of the mine, the present value of this WTP, assuming a 5% discount rate, is approximately $381/person (Holloday, 2009). In other words, a person may be willing to pay $381 on average to avoid altogether 35 years of risk of drinking water contamination from the operation of a uranium mine in the region.

If every single downstream water user in the Roanoke River Basin has the average positive WTP to avoid risk of surface water contamination, we could expect $381 x 420,759 = $160,351,255 in lost consumer surplus over the lifetime of the uranium mine operation at Coles Hill (Kolotushkina, 2012; Holloday, 2009). We can view this $160 million as lost consumer surplus because individuals in the region were willing to pay to avoid contamination risk and currently benefit from not having that contamination risk.

Aesthetics & Nearby Property Value Loss

The hedonic pricing method estimates peoples' nonmarket values of recreational opportunities, natural beauty, and other environmental features through analysis of property values in the housing market (Alberini, n.d.). We are able to estimate the value people place on lakefront or riverfront viewsheds based on the premium people pay for property along waterways, all else equal. Likewise, the difference in property values around a landfill or power plant relative to other properties provides an indicator of the external cost of living close to an undesirable or potentially hazardous environmental disruption.

Literature shows that the presence of extractive activities such as mining and drilling lowers nearby property values; an analysis of residential property values in states with coal mining found that the addition of a surface mine to the average county reduces aggregate property values between 0.34% and 1.7% (Williams, 2011). The residual or lingering effects of resource extraction can continue to impact property values as well; in Grand Rapids, Michigan, people are willing to pay $1,544 to live an additional mile away from a Superfund site (Gayer, 2000). In West Virginia's Cheat River Watershed, properties within a quarter-mile of streams impaired by acid mine drainage from abandoned coal mines were valued 12% lower than properties along unimpaired streams in the watershed, all else equal (Thurston et al., 2009).

To our knowledge, no hedonic pricing study on residential or other properties near uranium mine and milling facilities has been completed. The operation of uranium mining and milling facilities presents a unique environmental disruption because property values may not only be impacted by a change in the landscape, lowering aesthetic value for nearby properties, but also by the risk of environmental contamination through air and water. A socioeconomic impact study performed by Chmura Economics & Analytics cites existing literature showing a range of 2% to 8% in property value losses within a 5-mile radius associated with the negative stigma effect of an environmentally damaging industries such as uranium mining, and we follow the range estimates from this study. By their estimates, households within a 2-mile radius of the Coles Hill site would experience a 5% decrease in value on average (the midpoint of 2% to 8%), resulting in a permanent loss of $1.9 million in property value, and an associated $10,600 in annual property tax loss to Pittsylvania County (Chmura Economics & Analytics, 2011).

We obtained parcel data from Pittsylvania County and examined land market value within 2, 5 and 10 miles of the Coles Hill site. Within these distances, there's approximately $41.2 million, $266.4 million, and $2.3 billion worth of property value, respectively (Whitt, 2019). Within 2 miles, $0.8 million - $3.3 million in property value is likely to be permanently lost, with $2.1 million as an average. Within 5 miles, $5.3 million - $21.3 million in property value could be diminished, either temporarily or permanently. If the stigma effect, or event of contamination at the site, permanently depressed housing values within 5 miles, Pittsylvania County could lose between $33,036 and $132,143 in property tax revenue annually[23] (Whitt, 2019; Pittsylvania County, 2019).

Limitations

The limitations in the modeling exercise for non-market value changes from uranium mining at the Coles Hill site are twofold: 1) uncertainty surrounding the risk of environmental contamination and the potential stigma effect in the region, and 2) the likely overlap in values estimated from non-market valuation methods and 3)lack of nonmarket valuation studies on uranium mining available for benefit transfer method.

As noted in all major studies we've reviewed on uranium mining in Pittsylvania County, Virginia, the operation of a uranium mine and milling facility on the east coast of the U.S., in a wet climate increasingly prone to flooding and extreme weather events, is unprecedented. Without a state regulatory framework in place to address the contamination risks unique to Virginia, the ability for any party to estimate the likelihood of a contamination event, exceedance in federal standard, or other failure during operation and reclamation is greatly reduced. Additionally, the stigma effect on the regional economy may hinge significantly on the level of oversight, regulation, and general involvement or response from the state should the uranium ban be lifted in Virginia.

The estimated values associated with potential changes to air quality, water quality, and aesthetic value are intended to illustrate possible damages to society through losses in ecosystem services, not estimate regional economic or market impacts. Besides the limitation of risk uncertainty surrounding disposal management and radioactive contamination, the values we estimate likely overlap and should not be treated as additive potential costs associated with uranium mining. For example, losses in property value would likely reflect both a degraded aesthetic value in the surrounding area and potential human health risks from inhalation or ingestion of radioactive material that people are willing to pay to avoid (by living elsewhere).

[23] This assumes a tax rate of 0.62% on personal property, Pittsylvania County's tax rate in 2018.

Unlined Coal Ash Impoundments

Figure 21 in Appendix C shows the ecosystem service concept model and means-end pathways used to guide literature review and analysis of potential ecosystem service values and changes associated with ecosystem services currently affected by coal ash whose value could be raised from proper resource management. In this case, the resource management action is excavation and safe disposal of coal ash from four unlined storage impoundments in the Roanoke River Basin. Ecosystem services currently affected by unlined coal ash storage include surface and groundwater quality, habitat for aquatic species, and recreation. Modeled values associated with lining coal ash sites include consumer surplus for drinking water users and health cost-savings from lower human health damages. Case study information from historical damages at the Mayo, Roxboro, and Belew's Creek sites were used to estimate average annual recreational and species' habitat damages in the Roanoke River Basin.

Groundwater Contamination & Human Health Damages

The first exposure pathway modeled involves toxins, such as arsenic, leaching into the groundwater supply of private well water users. Human health costs associated with cancer induced by drinking water contaminated with high levels of arsenic, as well as the rate of cancer around unlined coal ash storage facilities, were obtained from analyses by or for the U.S. Environmental Protection Agency (EPA). The EPA studied exposure pathways of toxins leaching from coal ash to surface and groundwater and found that the risk of cancer for nearby groundwater users can be as high as 1 in 50 (Gottlieb, Gilbert, & Evans, 2010). This cancer rate applies to residents within 1 mile of unlined coal ash impoundments that have codisposed CCWs (coal combustion waste) and coal refuse (RTI International, 2007). Coal refuse is "waste coal produced from coal handling, crushing, and sizing operations", usually characterized by a high sulfur content and low pH (RTI International, 2007). Codisposed coal refuse refers to different combinations of waste, including "combined ash and coal gob" (RTI International, 2007). In the EPA's risk assessment of coal ash sites, 70 of the sites assessed mixed coal ash and other coal ash waste; a majority of Duke Energy's coal ash sites mix ash and coal waste (Schaeffer et al., 2009).

In order to estimate human health damages avoided by excavating the four unlined impoundments, we first estimate the number of private well water users within a mile radius of the four sites. We overlay spatial data on the unlined coal ash impoundments in the Roanoke River Basin with block data from the U.S. Census Bureau and create a mile radius buffer around the four sites (Sackett, 2015; U.S. Census Bureau, 2010; 2017). The four unlined impoundments, all within the Dan River Subbasin in North Carolina, highlighted in this model are Belew's Creek Steam Station in Stokes County, Mayo Plant in Person County, Dan River Steam Station in Rockingham County, and Roxboro Plant in Caswell County. We also collect block data surrounding Dominion's coal ash sites in the Roanoke River Basin, Clover Plant and Altavista Plant, in which the liner status of coal ash storage is unclear, but do not report the block data as part of human health damage calculations.

Because census blocks do not align perfectly with the radial mile buffer around the coal ash sites, we recognize there could be households that fall just outside of the mile buffer of the coal ash sites. When intersecting blocks with the mile radius buffer of the four unlined sites in the Dan River Basin, we estimate there are approximately 1,647 households and 2,916 people within a mile of the four unlined coal ash sites.

We use WSIO data (Watershed Index Online) from the U.S. Environmental Protection Agency to gather data on groundwater well users reported on the subwatershed level. The four HUC12 watersheds that contain the four unlined coal ash impoundments are Town Creek-Dan River, Cane Creek-Hyco Lake, Mayo Creek-Mayo Reservoir, and Reed Creek-Dan River. These four subwatersheds have an average groundwater drinking population of approximately 10.9% (U.S. Environmental Protection Agency, 2014). Applying this percent to the population we estimate to be within a mile radius of the four unlined sites, results in at least 317 people relying on groundwater for drinking within a mile radius of the four unlined sites.

An EPA economic analysis on regulations pertaining to arsenic in drinking water estimates the monetized benefit to human health from avoiding non-fatal bladder cancer (among others) using willingness to pay (WTP) values (Abt Associates, 2000). Using these values, we calculate potential savings in human health damages within a mile radius of the four unlined sites:

- 317 people drinking contaminated water x 0.02 (cancer rate within 1-mile radius of unlined coal ash storage) = an estimated 6.35 people to contract cancer from drinking well-water within 1-mile radius of four unlined sites in Dan River Basin
- 6.35 people x $1,128,460 (2017 $ WTP to avoid non-fatal cancer) = $7,160,321 in avoided human health damage

Water Quality & Consumer Surplus

In addition to actualized human health damages avoided if the source of arsenic-contaminated water is removed, nearby populations who rely on at-risk surface and groundwater for drinking will benefit by eliminating that contamination risk. In addition to the population receiving groundwater near coal ash sites leaching toxins, there are 78,317 people in downstream Roanoke River Basin communities whose drinking water supply comes from surface water at risk of contamination (Sackett, 2015).

A cost-benefit analysis of coal ash regulation, including the potential benefits of closing coal ash facilities, included a synthesis of WTP estimates to avoid exposure to leached chemicals, including arsenic, lead, and cadmium (Holladay, 2009). The analysis assumed an annual $20 per person WTP for reduced exposure to leached chemicals from coal ash and applied a discount rate of 5% over 45 years (average lifespan remaining in storage facilities) to arrive at a net present value (NPV) of $355 (Holladay, 2009).

We adjust the WTP estimate both for inflation and the average lifespan remaining in storage facilities in the Roanoke River Basin (34.5 years rather than 45 years). Under these adjustments, the NPV is $381, and represents the benefit per person if the unlined coal ash sites in the Roanoke River Basin were all closed today (2018). Applying these values to immediate downstream communities, and all downstream communities in the study region, we could see the following consumer surplus:

- Low estimate: 18,695 people (in communities of Eden and Madison, directly downstream of Belew's Creek) x $381.1 (NPV of benefit in higher drinking water quality) = $7,124,665 in consumer surplus
- High estimate: 78,317 people (RRB communities with drinking water intake downstream of Belew's Creek, Dan River Steam Station, Roxboro, and Mayo) x $381.1 (NPV of benefit in higher drinking water quality) = $29,846,609 in consumer surplus

Recreation & Ecological Damage from Permitted Discharges

Lemly & Skorupa (2012) estimate economic damages associated with contaminated and poisoned fish and wildlife at three of the four unlined coal ash sites in the Roanoke River Basin. For each they identify a period of damage, due in our case to legally permitted discharges, in which selenium levels are above toxic thresholds for wildlife, resulting in losses in the value of ecological habitat and recreation in the region (Lemly & Skorupa, 2012).

The ecological damages are calculated using replacement costs determined by the American Fisheries Society, dollar value penalties assigned through the Migratory Bird Treaty and Endangered Species Act, and WTP estimates of lost habitat (per acre) (Lemly & Skorupa, 2012). Recreational damages are calculated using replacement costs for sport fish and average values for angler/recreational trips (Lemly & Skorupa, 2012). Thresholds for calculating periods and lengths of damages include the selenium toxicity threshold for fish tissue at 4 parts per million and subsequent consumption restriction advisory for fish (Lemly & Skorupa, 2012). The three periods of damage estimates are provided for Belew's Creek, Roxboro, and Mayo:

- Belew's Creek Steam Station
  - Period of Damage: 1976-2006
  - Location of Damage: Belews Lake
  - Average Annual Ecological Damage: $2,661,258
  - Average Annual Recreation Loss: $480,000
- Roxboro Steam Electric Plant
  - Period of Damage: 1978-2005
  - Location of Damage: Hyco Reservoir
  - Average Annual Ecological Damage: $11,983,400
  - Average Annual Recreation Loss: $480,000
- Mayo Steam Plant
  - Period of Damage: 2000-2007
  - Location of Damage: Mayo Reservoir
  - Average Annual Ecological Damage: $10,103,188
  - Average Annual Recreation Loss: unknown

While all periods of damage are over 10 years ago, Lemly & Skorupa emphasize that monitoring data and biological assessments are not consistent enough to determine ongoing damages and that these estimates are cautiously conservative. Based on these historical damages incurred under certain conditions, we calculate average annual losses in the Roanoke River Basin from selenium toxicity at any one unlined site:

- In years that selenium concentrations are >= 4 ppm:
    - Average Annual Ecological Damage: $8,249,282
    - Average Annual Recreational Losses: $480,000

Because data is not available to show whether current selenium concentrations downstream of these four sites are high enough to produce these annual ecological and recreational damage estimates, it is difficult to incorporate these values into benefits gained from excavating the coal ash sites in the Roanoke River Basin in the future.

Property Value Gains from Improved Aesthetics and Reduced Contamination Hazard

The hedonic pricing method estimates an individual's nonmarket valuation of recreational opportunities, natural beauty, and other environmental features through an analysis of property values in the housing market (Alberini, n.d.). Hedonic pricing can put an estimate on how people value nearby aesthetics, but it likely also captures a household's willingness to pay to live farther away from a site of environmental contamination or other environmental disruption. Similar to the section on potential property value losses from nearby uranium mining, we can also estimate the discounted value of property values close to landfills and other hazardous waste sites, all else equal.

There are 8,965[24] households with a median household value of $132,865 (2017$) within a one-mile radius of the four unlined coal ash disposal sites in Rockingham, Stokes, and Person Counties, North Carolina. Rae et al. (1991), estimate that Baltimore housing values within one mile from landfills and hazardous waste sites are 3.3% lower on average than other households, all else equal. We believe this is a conservative estimate relative to other estimates of discounted property values from other literature which cite estimates as high as 56% (Center for Health, Environment, and Justice, 2015). Multiplying the number of households within a mile of the four unlined coal ash sites (8,965) by the median household value ($132,865) gives an estimate of over $1.2 billion (2017$) in residential property value. Assuming this current value is discounted at 3.3% because of its proximity to these contaminated sites, we expect the potential value of the property could be $1,231,780,505, which would be an additional $40,648,757 in property value.

We also estimate the potential impact on property tax revenue streams to the North Carolina counties: Rockingham, Stokes, and Person. Using an average property tax rate of approximately 0.67% in 2018, a

[24] This is likely a conservative estimate since it only includes census blocks that have their centroid within a one-mile radius from a coal ash site.

$40.6 million increase in property value could yield an additional $273,973 in annual property tax revenue for the three North Carolina counties (2017$).

Limitations

Many unknowns remain in the policy decisions that would lead to the full excavation and closure of the four unlined sites in the Dan River Basin. The estimates we provide are not intended to be additive as a total benefit that could be weighed against Duke Energy's proposed costs for excavation and closure of these sites. For example, the property value gains associated with closure and the consumer surplus benefit (measured by WTP) for nearby water users most likely overlaps, as people are willing to pay to live farther away from the risk of contamination. However, the benefits modeled do represent positive economic values that can be expected from the elimination of coal ash contamination in nearby waterways and soil.

Appendix E: Roanoke River Basin Subwatersheds (HUC12) Enviroatlas and WSIO Data

Watershed Name (HUC 12)	Total Stream Length (Miles)	Percent Agricultural Land Buffered	Agricultural Runoff: Nitrogen (Pounds)	Agricultural Runoff: Phosphorous (Pounds)
Lick Fork-Goose Creek (30101010101)	62	64.4	1,892	2,198
Bottom Creek (30101010102)	77	42.5	1,666	1,906
Purgatory Creek-South Fork Roanoke River (30101010103)	47	64.1	1,607	1,427
Elliott Creek (30101010104)	97	31.5	833	570
Brake Branch-South Fork Roanoke River (30101010105)	93	43.9	796	846
Dry Run-North Fork Roanoke River (30101010201)	136	27.0	1,688	1,140
Wilson Creek-North Fork Roanoke River (30101010202)	103	37.5	668	617
Bradshaw Creek-North Fork Roanoke River (30101010203)	92	44.0	1,000	1,914
Sawmill Hallow-Roanoke River (30101010301)	181	38.8	644	1,054
Mason Creek (30101010302)	83	44.3	603	640
Buffalo Creek-Tinker Creek (30101010401)	110	14.9	1,238	654
Carvin Creek (30101010402)	100	29.9	514	244
Glade Creek-Tinker Creek (30101010403)	115	24.1	855	220
Peters Creek-Roanoke River (30101010404)	111	47.3	236	163
Back Creek (30101010405)	160	50.1	1,268	1,154

North Fork Blackwater River (30101010501)	91	47.1	2,525	2,392
South Fork Blackwater River (30101010502)	71	49.8	2,087	2,446
Madcap Creek-Blackwater River (30101010503)	185	48.3	3,126	1,176
Maggodee Creek (30101010504)	142	47.3	1,302	423
Standiford Creek-Smith Mountain Lake (30101010601)	125	73.6	1,337	210
Gills Creek (30101010602)	124	65.5	537	108
Bull Run-Smith Mountain Lake (30101010603)	46	73.8	461	157
Lynville Creek-Smith Mountain Lake (30101010701)	153	69.8	657	97
Beaverdam Creek (30101010702)	104	52.5	1,322	302
Stony Creek-Smith Mountain Lake (30101010703)	75	61.8	756	206
Bettys Creek-Smith Mountain Lake (30101010704)	65	64.7	1,002	78
Craddock Creek-Smith Mountain Lake (30101010705)	31	64.5	1,894	167
Turners Creek-Pigg River (30101010801)	151	51.7	831	558
Powder Mill Creek-Pigg River (30101010802)	133	67.2	2,130	258
Big Chestnut Creek (30101010803)	165	72.0	970	225
Owens Creek-Pigg River (30101010804)	105	75.8	480	226
Crab Creek-Snow Creek (30101010901)	121	71.4	273	323

Turkeycock Creek (30101010902)	103	84.5	745	112
Gourd Creek-Snow Creek (30101010903)	75	81.6	497	200
Tomahawk Creek-Pigg River (30101011001)	115	77.9	494	200
Fryingpan Creek-Pigg River (30101011002)	117	78.9	794	175
North Fork Goose Creek-Goose Creek (30101011101)	216	44.6	3,909	1,296
Bore Auger Creek (30101011102)	60	53.7	2,969	1,049
Wolf Creek-Goose Creek (30101011103)	157	59.3	2,297	1,317
Stony Fork (30101011104)	58	50.7	1,374	412
Mill Creek-Goose Creek (30101011201)	157	67.1	945	120
Carter Mill Creek (30101011202)	47	61.6	1,919	163
Back Creek-Goose Creek (30101011203)	65	69.2	304	75
Clay Branch-Leesville Lake (30101011301)	26	81.3	844	162
Old Womans Creek-Leesville Lake (30101011302)	133	69.5	639	170
Bishop Creek-Roanoke River (30101011303)	55	72.8	535	86
Little Sycamore Creek-Sycamore Creek (30101011304)	62	75.3	741	605
Reed Creek-Roanoke River (30101011305)	54	66.4	881	284
Stony Creek-Big Otter River (30101011401)	169	43.9	3,284	935

North Otter Creek (30101011402)	153	33.1	4,534	1,424
Chestnut Branch-Elk Creek (30101011403)	114	57.4	1,015	153
Roaring Run-Big Otter River (30101011404)	57	63.9	1,647	511
Machine Creek (30101011405)	74	59.0	1,458	1,539
Johns Creek-Little Otter River (30101011406)	113	46.2	2,043	1,738
Orrix Creek-Big Otter River (30101011501)	94	68.2	945	167
Buffalo Creek (30101011502)	60	53.5	824	113
Johnson Creek-Big Otter River (30101011503)	48	56.1	703	64
Flat Creek (30101011504)	87	65.3	684	74
Troublesome Creek-Big Otter River (30101011505)	76	67.2	947	61
Beechtree Creek-Roanoke River (30101020101)	130	77.4	3,608	353
Seneca Creek (30101020102)	138	71.9	6,882	450
Straightstone Creek (30101020103)	100	72.1	683	570
Buffalo Creek-Roanoke River (30101020104)	135	78.4	2,752	368
Whipping Creek-Roanoke River (30101020105)	97	77.2	2,041	254
Reedy Creek-Falling River (30101020201)	94	61.6	628	68
Mulberry Creek-Falling River (30101020202)	87	67.4	748	113
Button Creek-South Fork Falling River (30101020203)	127	76.0	769	198

Mollys Creek (30101020204)	79	66.5	1,489	204
Suck Creek-Falling River (30101020205)	84	68.7	1,081	161
Entry Creek-Little Falling River (30101020206)	120	78.1	1,971	195
Hat Creek-Falling River (30101020207)	83	71.8	613	133
Big Cub Creek (30101020301)	101	77.3	1,012	103
Little Cub Creek (30101020302)	62	76.7	564	129
Rough Creek-Cub Creek (30101020303)	163	81.4	946	185
Louse Creek-Cub Creek (30101020304)	104	82.8	1,686	289
Childrey Creek-Roanoke River (30101020401)	117	84.9	1,064	298
Catawba Creek (30101020402)	81	93.7	678	195
Turnip Creek (30101020403)	110	76.6	1,016	146
Buckskin Creek-Roanoke River (30101020404)	106	84.8	3,161	428
Hunting Creek-Roanoke River (30101020405)	176	86.3	3,646	506
Spring Creek-Roanoke Creek (30101020501)	124	74.8	1,215	208
Ash Camp Creek-Roanoke Creek (30101020502)	83	74.3	1,087	198
Wards Fork Creek (30101020503)	155	79.3	754	167
Twittys Creek (30101020504)	90	74.1	1,915	434
Horsepen Creek (30101020505)	131	77.3	514	293
Lipscomb Branch-Roanoke Creek (30101020506)	56	74.8	1,818	402

Sandy Creek-Roanoke River (30101020601)	155	71.2	741	242
Piney Creek-Difficult Creek (30101020602)	149	84.7	1,952	216
Ashcake Creek-Difficult Creek (30101020603)	54	82.1	2,827	277
Cargills Creek-Roanoke River (30101020604)	48	80.4	557	134
Otter Creek-Bluestone Creek (30101020701)	175	76.8	1,190	430
Little Bluestone Creek (30101020702)	123	74.6	1,884	761
Goodell Creek-Bluestone Creek (30101020703)	50	79.8	2,346	1,022
Sandy Creek-John H Kerr Reservoir (30101020704)	42	82.0	1,604	746
Little Grassy Creek (30101020801)	73	82.7	1,904	559
Mountain Creek-Grassy Creek (30101020802)	95	85.5	2,349	1,179
Beech Creek-Johnson Creek (30101020803)	107	80.0	3,146	598
Spewmarrow Creek-Grassy Creek (30101020804)	78	80.5	1,593	1,204
Beaver Pond Creek North-Grassy Creek (30101020805)	54	60.7	1,266	727
Beaver Pond Creek South-Grassy Creek (30101020806)	37	78.3	1,847	798
Little Island Creek (30101020901)	59	82.4	4,340	529
Island Creek (30101020902)	156	78.9	3,976	737

Panhandle Creek-John H Kerr Reservoir (30101020903)	43	82.7	1,561	796
Butcher Creek (30101020904)	131	80.0	2,031	678
Anderson Creek-Mill Creek (30101021001)	48	92.5	6,406	855
Headwaters Nutbush Creek (30101021002)	135	84.9	9,889	1,338
Nutbush Creek-John H Kerr Reservoir (30101021003)	87	94.6	2,804	683
Eastland Creek-John H Kerr Reservoir (30101021004)	66	86.5	1,767	816
Ivy Creek-Dan River (30101030101)	98	60.9	2,101	1,937
Archies Creek-Dan River (30101030102)	116	62.4	3,316	2,136
Little Dan River (30101030103)	101	62.9	4,066	818
Elk Creek-Dan River (30101030104)	55	79.0	6,010	1,060
Peters Creek-Dan River (30101030105)	121	74.7	4,283	812
Big Creek (30101030106)	132	80.9	2,956	488
Double Creek (30101030107)	45	87.4	621	56
Vade Macum Creek (30101030108)	48	85.1	526	92
Flat Shoals Creek-Dan River (30101030109)	117	87.8	304	123
Headwaters Town Fork Creek (30101030201)	93	78.4	1,380	472
Neatman Creek-Upper Town Fork Creek (30101030202)	109	71.2	1,395	332

Town of Walnut Cove-Middle Town Fork Creek (30101030203)	139	77.5	3,279	290
Lick Creek-Lower Town Fork Creek (30101030204)	69	90.0	3,238	280
Snow Creek (30101030301)	132	77.7	1,819	410
Town Fork Creek-Dan River (30101030302)	73	87.1	2,267	220
Belews Creek-Belews Lake (30101030303)	109	86.1	1,360	189
Belews Lake (30101030304)	73	87.2	3,094	443
Beaver Island Creek (30101030305)	104	87.0	624	107
Reed Creek-Dan River (30101030306)	113	86.0	1,197	172
Poorhouse Creek-Upper South Mayo River (30101030401)	172	62.0	667	205
Russell Creek (30101030402)	70	76.1	3,983	779
Spoon Creek (30101030403)	52	71.3	159	64
Crooked Creek-Lower South Mayo River (30101030404)	122	83.4	489	192
Polebridge Creek-North Mayo River (30101030405)	83	62.4	1,711	245
Horse Pasture Creek (30101030406)	81	73.7	140	49
Koger Creek-North Mayo River (30101030407)	155	69.5	181	46
Pawpaw Creek-Mayo River (30101030408)	107	91.7	1,044	141
Town of Mayodan-Mayo River (30101030409)	74	88.0	1,621	127
Hogan Creek (30101030501)	69	88.9	2,778	376

Jacobs Creek (30101030502)	109	92.2	1,790	215
Massy Creek-Dan River (30101030503)	69	86.5	1,488	128
Rock House Creek-Dan River (30101030504)	117	85.4	2,260	302
Matrimony Creek-Dan River (30101030505)	166	87.1	3,670	217
Rock Castle Creek-Smith River (30101030601)	131	55.6	2,268	1,788
Little Sycamore Creek-Sycamore Creek (30101030602)	52	64.0	3,157	407
Widgeon Creek-Smith River (30101030603)	141	59.7	1,051	465
Otter Creek-Rennet Bag Creek (30101030604)	95	64.2	820	392
Nicholas Creek-Smith River (30101030605)	73	62.4	357	377
Philpott Reservoir-Smith River (30101030606)	107	70.6	1,465	280
Town Creek (30101030701)	121	61.2	245	355
Blackberry Creek-Smith River (30101030702)	104	76.2	460	148
Little Reed Creek-Reed Creek (30101030703)	90	59.7	274	281
Beaver Creek-Smith River (30101030801)	150	60.1	542	106
Marrowbone Creek (30101030802)	94	82.8	173	60
Mulberry Creek-Smith River (30101030803)	56	65.7	587	75
Upper Leatherwood Creek (30101030804)	76	81.7	542	142

Peters Branch-West Fork Leatherwood Creek (30101030805)	89	79.8	470	193
Lower Leatherwood Creek (30101030806)	44	83.6	744	45
Fall Creek-Smith River (30101030807)	136	83.0	537	85
Town Creek-Dan River (30101030901)	97	88.7	708	52
Cascade Creek (30101030902)	110	76.8	287	40
Trotters Creek-Dan River (30101030903)	138	87.4	389	84
Upper Wolf Island Creek (30101030904)	80	78.5	1,687	280
Lower Wolf Island Creek (30101030905)	125	83.0	1,029	98
Danville-Dan River (30101030906)	56	72.7	372	79
Upper Sandy River (30101031001)	72	81.5	309	43
Tanyard Creek-South Prong Sandy River (30101031002)	110	80.8	890	87
Lower Sandy River (30101031003)	138	85.3	821	108
Sandy Creek (West)-Dan River (30101031004)	88	80.0	1,243	113
Fall Creek (30101040101)	98	89.5	746	103
Pumpkin Creek-Dan River (30101040102)	72	81.7	403	70
Lick Fork (30101040103)	50	94.2	3,167	195
Upper Hogans Creek (30101040104)	108	97.3	5,272	319

Lower Hogans Creek (30101040105)	119	92.2	682	81
Upper Moon Creek (30101040106)	93	87.3	1,132	86
Lower Moon Creek (30101040107)	53	92.6	538	83
Rattlesnake Creek (30101040108)	65	84.2	652	84
Cane Creek-Dan River (30101040109)	114	84.4	2,419	295
South Country Line Creek (30101040201)	124	90.2	2,137	194
Upper Country Line Creek (30101040202)	153	94.2	1,584	219
Lower Country Line Creek (30101040203)	114	92.2	530	76
Sandy Creek (30101040301)	53	90.8	5,433	606
Double Creek-Dan River (30101040302)	166	78.1	2,974	377
Winns Creek (30101040303)	71	90.6	1,849	283
Big Toby Creek-Dan River (30101040304)	89	79.2	1,000	142
Birch Creek (30101040305)	191	89.9	586	94
Miry Creek (30101040401)	77	92.1	377	59
Chalmers Creek-Dan River (30101040402)	61	75.5	152	36
Stokes Creek-Lawsons Creek (30101040403)	103	83.3	459	66
Grassy Creek-Dan River (30101040404)	80	85.9	1,290	127
Reedy Fork (30101040501)	49	77.4	1,518	308

Hyco Creek (30101040502)	183	88.9	2,285	608
Upper South Hyco Creek (30101040503)	89	89.2	2,388	882
Middle South Hyco Creek (30101040504)	88	88.6	2,343	451
Lower South Hyco Creek (30101040505)	72	82.9	1,622	295
Hyco Creek-Hyco Lake (30101040506)	55	95.0	542	123
Cane Creek-Hyco Lake (30101040507)	59	80.9	920	178
After Bay Reservoir-Hyco River (30101040601)	66	94.6	1,100	158
Storys Creek (30101040602)	109	87.7	1,538	297
Bowes Branch-Hyco River (30101040603)	79	87.6	1,803	238
Headwaters Mayo Creek (30101040604)	92	84.0	1,781	397
Mayo Creek-Mayo Reservoir (30101040605)	80	67.3	2,399	319
Coleman Creek-Hyco River (30101040606)	84	89.3	1,056	130
Big Bluewing Creek (30101040607)	85	77.8	2,319	266
Larkin Branch-Hyco River (30101040608)	70	78.5	400	125
Headwaters Aarons Creek (30101040701)	84	78.4	3,345	767
Aarons Creek-John H Kerr Reservoir (30101040702)	122	77.0	1,752	284
Peter Creek-Dan River (30101040703)	73	75.7	3,054	290

Buffalo Creek-Dan River (30101040704)	96	79.6	798	406
Strawberry Creek-Banister River (30101050101)	89	85.0	3,794	269
Bearskin Creek (30101050102)	55	74.7	1,863	382
White Oak Creek-Banister River (30101050103)	84	81.0	2,964	284
Cherrystone Creek (30101050104)	110	79.3	728	425
Mill Creek-Whitehorn Creek (30101050201)	106	75.7	1,062	1,253
Georges Creek-Whitehorn Creek (30101050202)	56	82.9	1,425	2,881
Shockoe Creek-Banister River (30101050203)	78	84.3	4,015	1,148
Stinking River (30101050204)	90	79.5	1,285	3,097
Allen Creek-Banister River (30101050205)	110	89.6	1,380	2,824
Elkhorn Creek (30101050206)	55	88.2	6,456	1,741
Bye Creek-Banister River (30101050207)	120	90.6	1,299	515
Upper Sandy Creek (30101050301)	167	84.0	2,898	417
Lower Sandy Creek (30101050302)	105	92.5	3,415	494
Polecat Creek-Banister River (30101050401)	105	90.8	561	116
Terrible Creek (30101050402)	108	89.3	640	245
Winn Creek-Banister River (30101050403)	142	87.2	5,347	389
Layton Creek-Allen Creek (30101060101)	151	83.0	3,169	1,466

Cox Creek-Allen Creek (30101060102)	174	79.3	3,975	1,174
Cotton Creek-Lake Gaston (30101060201)	58	67.7	2,590	1,026
Dockery Creek-Miles Creek (30101060202)	148	79.9	4,022	1,907
Flat Creek-Lake Gaston (30101060203)	102	85.9	3,982	1,904
Newmans Creek-Smith Creek (30101060204)	81	90.3	12,358	5,133
Blue Mud Creek-Smith Creek (30101060205)	98	89.2	9,817	4,308
Hawtree Creek (30101060301)	67	92.5	13,077	5,114
Great Creek-Lake Gaston (30101060302)	99	83.4	3,160	1,300
Sixpound Creek (30101060303)	42	87.6	7,765	2,253
Poplar Creek (30101060304)	94	86.8	2,652	540
Songbird Creek-Lake Gaston (30101060305)	97	84.1	5,206	1,579
Lizard Creek-Lake Gaston (30101060401)	89	86.3	4,159	1,882
Pea Hill Creek-Lake Gaston (30101060402)	119	89.0	3,399	1,006
Deep Creek (30101060403)	96	90.2	11,899	2,991
Roanoke Rapids Lake (30101060404)	76	91.2	12,373	3,618
City of Roanoke Rapids-Roanoke River (30101070101)	40	87.0	21,564	10,882
Town of Weldon-Chockoyotte Creek (30101070102)	38	90.3	22,777	11,563
Arthurs Creek-Roanoke River (30101070103)	44	92.3	25,642	14,697

Quankey Creek (30101070104)	66	94.5	30,470	13,589
Occoneechee Neck-Roanoke River (30101070105)	75	91.7	32,060	19,020
Occoneechee Creek (30101070201)	52	68.7	30,460	18,914
Gumberry Swamp (30101070202)	63	75.6	29,319	16,286
Headwaters Conoconnara Swamp (30101070203)	76	78.6	33,243	22,373
Outlet Conoconnara Swamp (30101070204)	52	51.8	39,944	22,943
Looking Glass Run (30101070205)	47	64.7	33,153	18,177
Bridgers Creek-Roanoke River (30101070206)	85	57.0	38,848	19,102
Sandy Run-Roanoke River (30101070301)	79	71.4	32,224	13,586
Flag Run Gut-Roanoke River (30101070302)	43	84.4	34,842	16,079
Cypress Swamp (30101070303)	65	85.0	33,743	16,672
White Millpond-Kehukee Swamp (30101070304)	82	64.5	41,507	22,397
Blue Hole Swamp-Roanoke River (30101070305)	98	82.0	31,566	19,455
Headwaters Sweetwater Creek (30101070401)	21	83.7	44,977	21,207
Ready Branch (30101070402)	38	71.7	71,235	27,890
Headwaters Hardison Mill Creek (30101070403)	43	92.7	32,435	10,656
Outlet Hardison Mill Creek (30101070404)	43	83.2	37,332	20,138

Outlet Sweetwater Creek (30101070405)	40	79.6	36,812	19,785
Indian Creek (30101070501)	51	80.7	24,516	13,888
Town of Hamilton-Roanoke River (30101070502)	35	65.0	52,857	24,829
Coniott Creek-Roanoke River (30101070503)	46	77.3	44,839	14,269
Etheridge Swamp (30101070504)	80	49.0	48,062	26,775
Upper Conoho Creek (30101070505)	47	53.1	45,681	28,005
Middle Conoho Creek (30101070506)	78	57.7	45,216	29,629
Beaverdam Creek (30101070507)	43	67.6	74,667	24,423
Lower Conoho Creek (30101070508)	105	61.5	60,314	24,127
City of Williamston-Roanoke River (30101070509)	49	67.2	56,953	16,253
Gardener Creek (30101070601)	49	87.4	66,667	14,908
Devils Gut-Roanoke River (30101070602)	40	91.1	30,905	12,769
Broad Creek-Roanoke River (30101070603)	44	79.6	25,455	12,886
Wahtom Swamp (30101070701)	11	89.3	33,844	16,626
Headwaters Cashie River (30101070702)	39	81.3	35,947	16,707
Connaritsa Swamp (30101070703)	31	86.3	27,085	11,605
Whiteoak Swamp (30101070704)	21	85.8	20,774	7,050

Community of Francis Mill-Cashie River (30101070705)	37	88.2	26,216	9,127
Chiska Creek-Cashie River (30101070706)	21	86.6	21,505	8,046
Hoggard Mill Creek (30101070801)	57	88.1	23,545	8,848
Headwaters Roquist Creek (30101070802)	54	85.7	25,923	10,387
Outlet Roquist Creek (30101070803)	36	89.4	24,821	9,544
Town of Windsor-Cashie River (30101070804)	18	94.4	18,785	6,770
Wading Place Creek (30101070805)	25	95.5	17,427	6,815
Swamp Creek-Cashie River (30101070806)	30	86.3	19,112	7,928
Broad Creek-Cashie River (30101070807)	21	88.5	23,755	10,026
Welch Creek (30101070901)	37	89.3	66,425	14,188
Conaby Creek (30101070902)	64	62.5	55,533	14,280
Town of Plymouth-Roanoke River (30101070903)	49	89.4	30,353	11,200

Appendix F: Applying Values to the RRB Worksheet

As a group, select a natural resource management decision you're familiar with (i.e. zoning and land-use, riparian buffer management, water-use ordinances):
List 3-5 factors that are accounted for in the management decision:

1. ____
2. ____
3. ____
4. ____
5. ____

In the table below, list 3-5 ecosystem services, indicate their importance in decision-making NOW, and indicate the direction and strength of changes in the availability of the ES value due to the resource management decision you have chosen.

Ecosystem Service (ES)	Importance[a] (Low, Med, High)	Direction of Impact (+/-)	Strength of Impact (+/++/+++)
1.			
2.			
3.			
4.			
5.			

a. How important is the ecosystem service in making management decisions?

What factors are preventing these ecosystem service values from being used in decision making?

1. ____
2. ____
3. ____