Duck River Watershed Plan

FINAL WATERSHED ASSESSMENT

U.S. Army Corps of Engineers, Nashville District
May 2018

Executive Summary

This Watershed Plan is a Final Watershed Assessment (FWA) of the Duck River watershed, located in south-central Tennessee. This assessment was prepared under the authority of Section 729 of the Water Resource Development Act of 1986, as amended, which authorizes the U.S. Army Corps of Engineers to undertake watershed planning. This Watershed Plan identifies existing conditions within the watershed, details the major water resources problems and opportunities in the watershed, and provides specific recommendations for implementation. This study was undertaken with collaboration and input from four non-federal sponsors: The Duck River Development Agency (DRWA), The Nature Conservancy (TNC), Tennessee Department of Environment and Conservation (TDEC), and the Buffalo/Duck Resource Conservation and Development Council.

The Duck River is considered one of the most biologically diverse rivers in North America and is an outstanding national resource. It has an almost unsurpassed variety of freshwater animal life and is one of three most diverse streams for fish and mussel diversity in the world. The Duck River basin provides habitat for 35 species listed as federally endangered, threatened, candidate or species of concern. The developed landscape ranges from small cities and towns to sparsely populated rural areas with the upper part of the watershed experiencing rapid urbanization and population growth. More than 250,000 middle Tennessee residents rely on the Duck River as their sole source of water.

The watershed's ecosystem is under stress from rapid urban development, land use changes, incompatible agricultural practices, wastewater management and water supply practices, and resource extraction activities. Many communities in the watershed are experiencing periodic flooding which is only expected to worsen as development continues. The major resource issues identified in this FWA are water quality and water supply. Water quality problems stem from riparian buffer alteration, bank erosion, sedimentation, nutrient loading, low dissolved oxygen, and land management and agricultural practices. Water supply problems are controversial because a high quality and quantity water flow is essential for both supporting rare aquatic species and meeting the basin's growing municipal water demands.

DISCLAIMER:
The information presented in this report is to provide a strategic framework of potential options to address problems within the watershed. Options identified will follow normal authorization and budgetary processes of the appropriate agencies. Costs presented were rough-order-magnitude estimates used for screening purposes only.

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1.0 Introduction

1.1 STUDY AUTHORITY

The authority for this assessment is Section 729 of the Water Resource Development Act (WRDA) of 1986 (33 U.S.C. 2267a), as amended by Section 202 of the WRDA of 2000 and Section 2010 of the WRDA of 2007. In general terms, Section 729, as amended, allows the U.S. Army Corps of Engineers (USACE) to assess the water resources needs of entire river basins and watersheds of the United States, in consultation with appropriate federal, state, interstate and local agencies and stakeholders. The full text of the original Section 729 authorization and all amendments is included below.

WATER RESOURCES DEVELOPMENT ACT OF 1986: PUBLIC LAW 99-662

SEC. 729. STUDY OF WATER RESOURCES NEEDS OF RIVER BASINS AND REGIONS.

(a) The Secretary, in coordination with the Secretary of the Interior and in consultation with appropriate Federal, State, and local agencies, is authorized to study the water resources needs of river basins and regions of the United States. The Secretaries shall report the results of such study to Congress not later than October 1, 1988.
(b) In carrying out the studies authorized under subsection (a) of this section, the Secretaries shall consult with State, interstate, and local governmental entities.
(c) There is authorized to be appropriated $5,000,000 for fiscal years beginning after September 30, 1986, to carry out this section.

WATER RESOURCES DEVELOPMENT ACT OF 2000: PUBLIC LAW 106–541

SEC. 202. WATERSHED AND RIVER BASIN ASSESSMENTS.

Section 729 of the Water Resources Development Act of 1986 is amended to read as follows:

''SEC. 729. WATERSHED AND RIVER BASIN ASSESSMENTS.
''(a) IN GENERAL.—The Secretary may assess the water resources needs of river basins and watersheds of the United States, including needs relating to—
    ''(1) ecosystem protection and restoration;
    ''(2) flood damage reduction;
    ''(3) navigation and ports;
    ''(4) watershed protection;
    ''(5) water supply; and
    ''(6) drought preparedness.
''(b) COOPERATION.—An assessment under subsection (a) shall be carried out in cooperation and coordination with—
    ''(1) the Secretary of the Interior;
    ''(2) the Secretary of Agriculture;
    ''(3) the Secretary of Commerce;

''(4) the Administrator of the Environmental Protection Agency; and
''(5) the heads of other appropriate agencies.

''(c) CONSULTATION.—In carrying out an assessment under subsection (a), the Secretary shall consult with Federal, tribal, State, interstate, and local governmental entities.

''(d) PRIORITY RIVER BASINS AND WATERSHEDS.—In selecting river basins and watersheds for assessment under this section, the Secretary shall give priority to—

''(1) the Delaware River basin;
''(2) the Kentucky River basin;
''(3) the Potomac River basin;
''(4) the Susquehanna River basin; and
''(5) the Willamette River basin.

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''(e)ACCEPTANCE OF CONTRIBUTIONS.—In carrying out an assessment under subsection (a), the Secretary may accept contributions, in cash or in kind, from Federal, tribal, State, interstate, and local governmental entities to the extent that the Secretary determines that the contributions will facilitate completion of the assessment.

''(f) COST-SHARING REQUIREMENTS.—

''(1) NON-FEDERAL SHARE.—The non-Federal share of the costs of an assessment carried out under this section shall be 50 percent.

''(2) CREDIT.—

''(A) IN GENERAL.—Subject to subparagraph (B), the Secretary may credit toward the non-Federal share of an assessment under this section the cost of services, materials, supplies, or other in-kind contributions provided by the non-Federal interests for the assessment.

''(B) MAXIMUM AMOUNT OF CREDIT.—The credit under subparagraph (A) may not exceed an amount equal to 25 percent of the costs of the assessment.

''(g) AUTHORIZATION OF APPROPRIATIONS.—There is authorized to be appropriated to carry out this section $15,000,000.''.

WATER RESOURCES DEVELOPMENT ACT OF 2007: PUBLIC LAW: 110-114

SEC. 2010. WATERSHED AND RIVER BASIN ASSESSMENTS.

Section 729 of the Water Resources Development Act of 1986 is amended–

(1) in subsection (d)–

(A) by striking `and' at the end of paragraph (4);
(B) by striking the period at the end of paragraph (5) and inserting a semicolon; and
(C) by adding at the end the following:

(6) Tuscarawas River Basin, Ohio;
(7) Sauk River Basin, Snohomish and Skagit Counties, Washington;
(8) Niagara River Basin, New York;
(9) Genesee River Basin, New York; and
(10) White River Basin, Arkansas and Missouri;

(2) by striking paragraph (1) of subsection (f) and inserting the following:

(1) NON-FEDERAL SHARE- The non-Federal share of the costs of an assessment carried out under this section on or after December 11, 2000, shall be 25 percent.'; and

(3) by striking subsection (g).

1.2 BACKGROUND

The Duck River is considered one of the most biologically diverse rivers in North America and is an outstanding national resource. It has an almost unsurpassed variety of freshwater animal life and is one of three most diverse streams for fish and mussel diversity in the world. The Duck River basin provides habitat for 35 species listed as federally endangered, threatened, candidate or species of concern. The developed landscape ranges from small cities and towns to sparsely populated rural areas with the upper part of the watershed experiencing rapid urbanization and population growth. More than 250,000 middle Tennessee residents rely on the Duck River as their sole source of water.

The watershed's ecosystem is under stress from rapid urban development, land use changes, incompatible agricultural practices, wastewater management and water supply practices, and resource extraction activities. Many communities in the watershed are experiencing periodic flooding which is only expected to worsen as development continues.

1.3 SPONSORS

This study was undertaken with collaboration and input from four non-federal sponsors: The Duck River Development Agency (DRWA), The Nature Conservancy (TNC), Tennessee Department of Environment and Conservation (TDEC), and the Buffalo/Duck Resource Conservation and Development Council (B/D RC&D).

2.0 Study Purpose and Scope

2.1 GOALS AND OBJECTIVES

The goal of this Watershed Plan is to identify and document water resource related problems, needs and opportunities in the Duck River Watershed, and provide specific implementable recommendations. The Watershed Plan's objective is to define the study area, describe existing baseline conditions, and identify the opportunities for addressing the watershed needs. The Watershed Plan will also describe the coordination efforts, to date, with other agencies and identify potential federal, state, or local agencies and non-profit groups able to implement the Plan's recommendations.

2.2 STAKEHOLDER INVOLVEMENT

The Duck River Development Agency's established Water Resources Council (WRC) was utilized as a forum to initiate dialog and contact with stakeholder agencies and organizations and to gather information about the watershed. The WRC is intended to foster cooperation among council members and the coordination of the member's activities in the watershed pertaining to ground and surface water resources. Current membership includes utility providers, TDEC, TN

Dept. of Economic and Community Development, Tennessee Scenic Rivers Association (TSRA), The Tennessee Valley Authority (TVA), Tennessee Wildlife Resource Agency (TWRA), the Natural Resources Conservation Service (NRCS), United States Geological Survey (USGS), TNC, DRWA, U.S. Environmental Protection Agency, U.S. Fish & Wildlife Service (USFWS), World Wildlife Fund, and USACE, Nashville District. The WRC has proven to be an excellent source of information and data for the Initial Watershed Assessment (IWA) and allowed initiation of contacts with a majority of the stakeholders in the study area. USACE presented the findings of the IWA to the WRC members and received additional feedback and comments. There was also direct communication and collaboration with TDEC/WPC office, TVA, and TNC's Duck River field office in data (mapping, reports) gathering and incorporation into the assessment. Stakeholders were especially interested in bringing available data from multiple sources into one database and creating an ecological model to assist in collaborative watershed management and science-based impartial decision making.

During the course of the Assessment, USACE also attended numerous events in the watershed, including a Duck River clean-up day, and set up a booth to solicit public involvement in the watershed assessment.

A collaboration with South East Aquatic Resource Partnership led to a stakeholder workshop in the fall of 2017 to present the ecological model and its results to a wide audience consisting of federal, state, local government representatives, non-governmental organizations, private firms, local universities, and citizens. The workshop resulted in two additional meetings based on collaborative initiative to apply for NRCS Regional Conservation Partnership Program (RCPP) funds and target watershed improvement actions to the most disturbed and stressed streams in the Duck River Watershed.

Agency stakeholder activities with the Department of Interior (U.S. Fish and Wildlife Service), Department of Commerce (Nashville Weather Forecast Office), Department of Agriculture (Natural Resources Conservation Service), and Environmental Protection Agency were initiated and included a formal request for the agencies to serve as cooperating and coordinating agencies on the watershed assessment. All of the agencies responded via letters or e-mails affirming their willingness to assist in the study by providing data, technical expertise, participating in the meetings and workshops, and document reviews.

Two stakeholder meetings were held in March of 2018 to discuss recommendations for the Watershed Plan and receive input on priority issues that need to be addressed.

2.3 VISION STATEMENT

Duck River is one of the most species-rich and biologically diverse rivers in North America. It is also a sole source of water for 250,000 people in Middle Tennessee. As a nationally and regionally significant water resource, the Duck River Watershed would benefit from integrated water resource management efforts. Over the years, many studies have been completed and an agglomeration of data have been collected by various agencies and entities working in the watershed.

Working with the local stakeholders, combining existing data into a knowledge-base, and developing a science-based ecological model would allow for selecting management strategies in a targeted and coordinated manner. Leveraging of available resources across all levels of government agencies, non-profit organizations, and other stakeholders is imperative to achieve a holistic water resources management of the Duck River Watershed in order to preserve its ecological diversity, and long-term viability as a water source.

3.0 Study Area

3.1 LOCATION OF WATERSHED

The study area includes the entire Duck River watershed in south central Tennessee (see Figure 1). The Duck River is approximately 270 miles long. It is one of Tennessee’s most-scenic waterways and is the longest river located entirely within the state’s borders. Boasting more fish and mussel species than all of Europe, the Duck River is noted for its biological diversity and richness. The Duck River is the sole water source for more than 250,000 people in Middle Tennessee, including the cities of Columbia, Centerville, Shelbyville, Manchester, and Tullahoma.

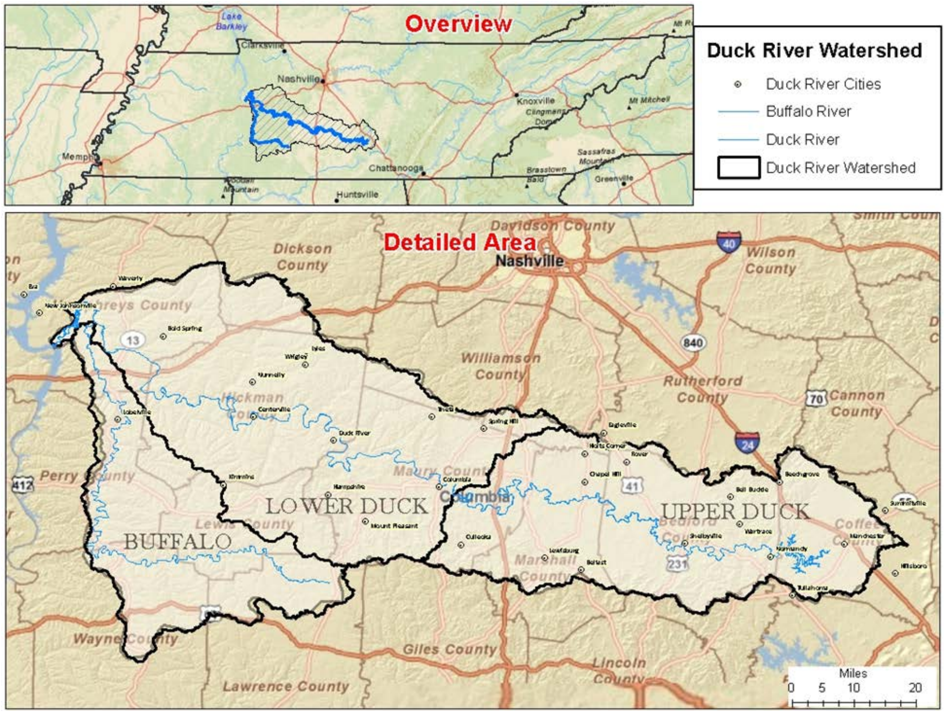


Figure 1 – Duck River Watershed

The Duck River watershed is located within the Tennessee River Watershed (TRW). The Nature Conservancy considers the Tennessee River basin, as a whole, to be the single most biologically diverse river system for aquatic organisms in the United States. The diversity of mollusks and fish in the Tennessee River is a reflection of the unique aquatic habitats that exist throughout the TRW. The Tennessee River supports about 240 fish species and hosts the most diverse mollusk fauna in North America. Approximately 102 species of native freshwater mussels have been recorded. Along with its unmatched diversity, the TRW also has one of the most imperiled faunas. It harbors the highest number of imperiled species of any large watershed in North America with 57 fish species and 47 mussel species considered to be "at risk." The USFWS currently lists 51 aquatic species (fish and mollusks) as either threatened or endangered with most of these occurring in three of the total 32 eight-digit TRW Hydrologic Unit Code (HUC) watersheds; specifically the Clinch River and Upper and Lower Duck River watersheds. This situation makes the Clinch and Duck River watersheds the most diverse and unique ecosystems in the entire TRW.

3.2 CONGRESSIONAL DISTRICTS

The Duck River watershed is located entirely within the State of Tennessee. Figure 2 shows the congressional district boundaries within the watershed. The watershed is represented by the following congressional representatives and senators:

- TN-4th Congressional District (Representative Scott DesJarlais - R)
- TN-5th Congressional District (Representative Jim Cooper – D)
- TN-6th Congressional District (Representative Diane Black - R)
- TN-7th Congressional District (Representative Marsha Blackburn - R)
- Senator Bob Corker – R – TN
- Senator Lamar Alexander – R – TN

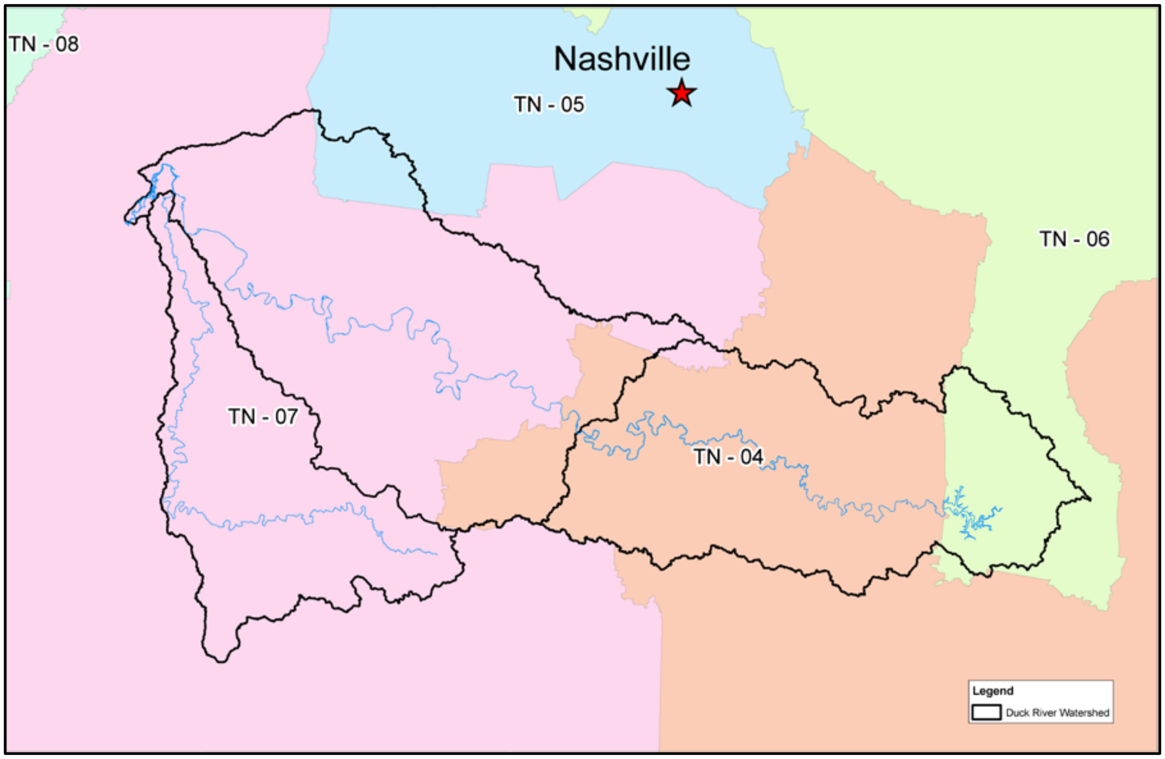


Figure 2 - Map of Congressional District Boundaries

4.0 Existing Conditions

This section will discuss the baseline conditions of the watershed including point sources, non-point sources, 303(d) listed stream segments, current pollution abatement management, aquatic biota, threatened and endangered species, species of special concern, and invasive species assessment.

4.1 HYDROLOGIC FEATURES

Over 30 tributaries contribute flow to the main river but most of the river's flow arises from groundwater seeping out of the limestone rich karst topography in the central portion of the basin. The Buffalo River, the longest un-impounded river in Middle Tennessee, flows into the Duck River a few miles above its mouth. Just below this confluence, the Duck River flows into the Tennessee River (River Mile 110.8) at Kentucky Lake in Humphreys County.

The U.S. Geological Survey has divided the Duck River watershed into three eight-digit hydrologic units with each assigned a unique Hydrologic Unit Code (HUC). They are the Lower Duck River (HUC 06040003), Upper Duck River (HUC 06040002), and Buffalo River (HUC 06040004). Lower Duck River watershed drains about 1,548 square miles, Upper Duck River – 1,182 square miles, and Buffalo River – 763 square miles.

4.2 ECOREGIONS

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. The Duck River watershed is located within the Interior Plateau (71) ecoregion consisting of four sub-ecoregions (See Figure 3):

71f – Western Highland Rim is characterized by dissected, rolling terrain of open hills, with elevations of 400 - 1,000 feet. Streams are characterized by coarse chert gravel and sand substrates with areas of bedrock, moderate gradients, and relatively clear water. The region is heavily forested with oak-hickory natural vegetation. The Lower Duck and Buffalo River watersheds are located in this sub-ecoregion.

71g – Eastern Highland Rim has more level terrain than the Western Highland Rim, with landforms characterized as tablelands of moderate relief and irregular plains. Limestone, chert, shale, and dolomite predominate, and karst terrain sinkholes and depressions are noticeable. Numerous springs and spring-associated fish fauna also typify the region. Barrens and former prairie areas are now mostly oak thickets or pasture and cropland. The headwaters of the Upper Duck River are in this sub-ecoregion.

71h – Outer Nashville Basin has rolling and hilly topography. The region's limestone rocks and soils are high in phosphorus. Deciduous forest with pasture and cropland are the dominant land covers. Streams are low to moderate gradient, with productive, nutrient-rich waters, resulting in algae, rooted vegetation, and occasionally high densities of fish. A portion of Lower Duck River, downstream of Columbia, is located in this sub-ecoregion as well as a small part of the Upper Duck River.

71i – Inner Nashville Basin has less hilly topography and is lower in elevation than the Outer Nashville Basin, outcrops of limestone are common, and the generally shallow soils are redder and lower in phosphorus. Streams are lower gradient then surrounding regions, often flowing over large expanses of limestone bedrock. The most characteristic hardwoods within the inner basin are a maple-oak-hickory-ash association. The limestone cedar glades of Tennessee, a unique mixed grassland/forest cedar glades vegetation type with many endemic species, are located primarily on the limestone of the Inner Nashville Basin. The more xeric, open characteristics and shallow soils of the cedar glades also result in a distinct distribution of amphibian and reptile species. Urban, suburban, and industrial land use in the region is increasing. The majority of the Upper Duck River is located in this sub-ecoregion.

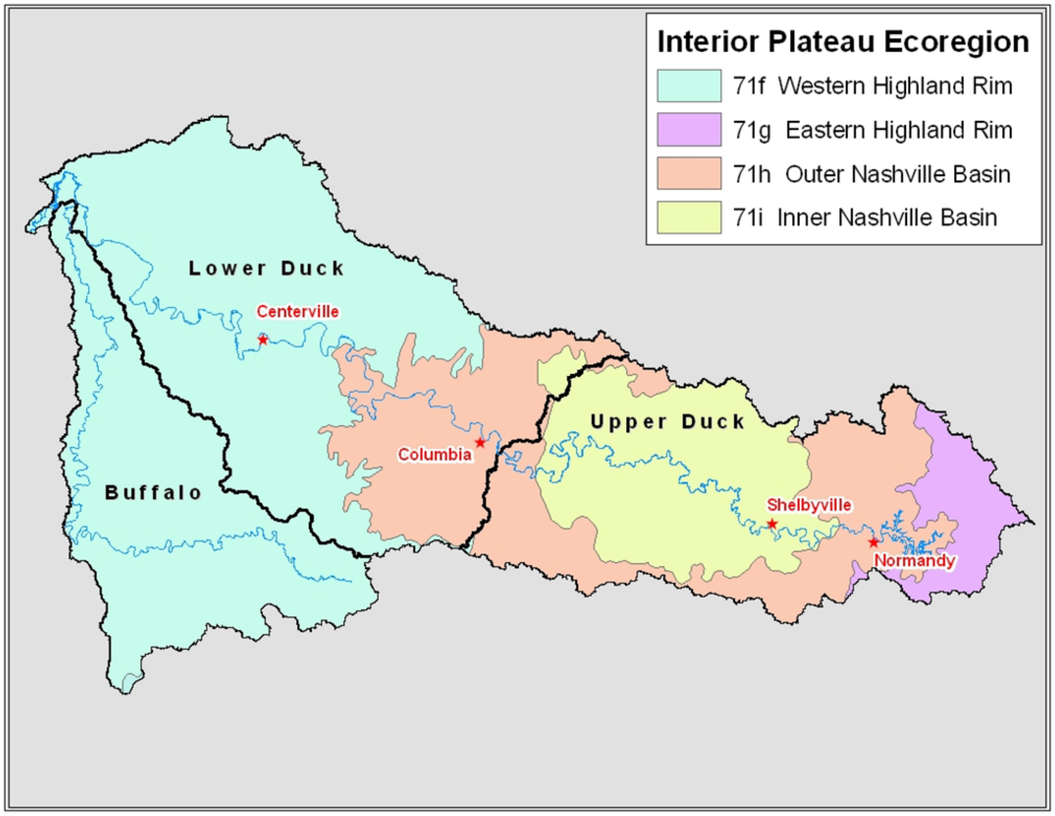


Figure 3 - Interior Plateau (71) Ecoregion

4.3 CLIMATE

The Duck River watershed is characterized by its temperate climate, with warm summers and mild winters. The climatic differences within sub-ecoregions are shown in Table 1 below.

Table 1 - Watershed Climate

Sub-Ecoregion	Precipitation Mean annual (inches)	Frost Free Mean annual (days)	Mean Temperature January min/max July min/max Degrees Fahrenheit (˚F)
71f Western Highland Rim (Lower Duck, Buffalo River)	50-56	185-205	24/46 65/89
71g Eastern Highland Rim (Upper Duck headwaters)	52-56	190-210	25/46 65/88
71h Outer Nashville Basin (Lower Duck, Upper Duck)	48-54	190-210	25/47 66/89
71i Inner Nashville Basin (Upper Duck)	48-53	190-210	25/46 66/90

Projected climate change in the Southeast is expected to alter regional temperature and precipitation patterns. The climate of the Southeast is generally warm and wet, with mild winters and high humidity. Over the past century (1901-2008), the average annual temperature did not noticeably change; however, since 1970 (1970-2008), the annual average temperature during the winter months has risen approximately 2°F. Since the mid-1970s, moderate to severe spring droughts have increased by 12%; and summer droughts have increased by 14% (that now extend into the fall months when precipitation used to increase). Climate models forecast that increased warming will continue through the end of this century for all seasons with the greatest temperature increases in the summer months across the Southeast. Average temperatures are projected to rise between 4.5-9 °F by the 2080s. Very hot days (>90 °F) are expected to increase from approximately 60 currently to 120 days by the end of this century. Because higher temperatures lead to more evaporation, drier soils, and water loss from streams, the frequency, duration, and intensity of droughts will likely continue to increase.

Under this forecast of increasing temperatures, warmer water holds less dissolved oxygen; it is expected that dissolved oxygen in streams, lakes, and rivers will decline, potentially leading to fish kills and loss of other aquatic species. Other effects may include new distribution patterns for native plants and animals, changes in location (migrating northward), and timing of migrations. Under this new distribution pattern, it is possible that the local loss of many state and federally listed species will occur.

4.3.1 Regional Climate Change Assessment

One of the clearest precipitation trends in the United States is the increasing frequency and intensity of heavy downpours. Since 1901, the average fall precipitation in the Southeast has increased by 30% with an increased frequency in heavy downpours. For northern states in the Southeast region, such as Tennessee, precipitation is projected to increase in winter and spring, and to become more intense throughout the year. Heavy downpours increase storm water runoff, resulting in increased soil erosion, increased sediment runoff into streams, and increased stream turbidity that reduce stream and aquatic habitat quality. Large amounts of suspended sediments can settle on fish spawning beds and freshwater mussels disrupting water quality, feeding, migration, and reproduction.

The Lower Tennessee River watershed, in which the Duck River watershed is located, is a region where the risk due to climate change is relatively low compared to other areas (such as coastal regions or arid regions). According to the USACE screening and analysis tools (see Appendix C for Climate Change Assessment), there may be an increase in the intensity and magnitude of flooding events in the Lower Tennessee River basin in the future. There is not enough data to determine whether or not this will increase the risk to future projects in the Duck River basin. The tools show a trend of increasing mean flow in the lower and middle part of the Duck River basin and of decreasing mean flow in the upper part of the Duck River basin. The latter may be attributed to the construction of Normandy Dam which is operated in part for flood control. However, the magnitude and impact of climate change in the Duck River basin cannot be quantitatively established using the tools currently available.

4.4 POPULATION AND LAND USE

The Duck River watershed covers approximately 3,500 square miles and includes portions of Bedford, Coffee, Dickson, Hickman, Humphreys, Lawrence, Lewis, Marshall, Maury, Perry, Williamson, and Wayne Counties in Tennessee. The river originates near the town of Manchester in Coffee County. It meanders its way across twelve counties before emptying into Kentucky Lake on the Tennessee River. The four largest cities in the watershed are located on the banks of the Duck River: Manchester (population 10,387, US Census 2016 estimate) in the headwaters, Shelbyville (population 20,916, US Census 2016 estimate) and Columbia (population 36,130, US Census 2016 estimate) in the middle portion of the basin, and finally Centerville (population 3,538, US Census 2016 estimate) in the lower end of the basin. There are two smaller cities, Linden (population 881, US Census 2016 estimate) and Lobelville (population 887, US Census 2016 estimate), located on the banks of the Buffalo River. There are also two state parks, Old Stone Fort and Henry Horton, within the basin.

The population of the basin is roughly 250,000, with most living in the upper basin. The developed landscape ranges from small cities and towns to sparsely populated rural areas. The upper part of the basin is rapidly urbanizing and experiencing a high rate of growth. Land use in the Duck River basin is estimated at 66.1% forest, 20.5% pasture/hay/grasses, 9.9% cropland, 1.2% commercial/residential, 0.9% woody/emergent wetlands, 0.8% mines/rock/cleared areas, and 0.6% water. The Buffalo River watershed is rather sparsely populated. Forests and agriculture of mainly pasture, hay, and crop land, dominate the landscape. Land use map is shown in Figure 4.

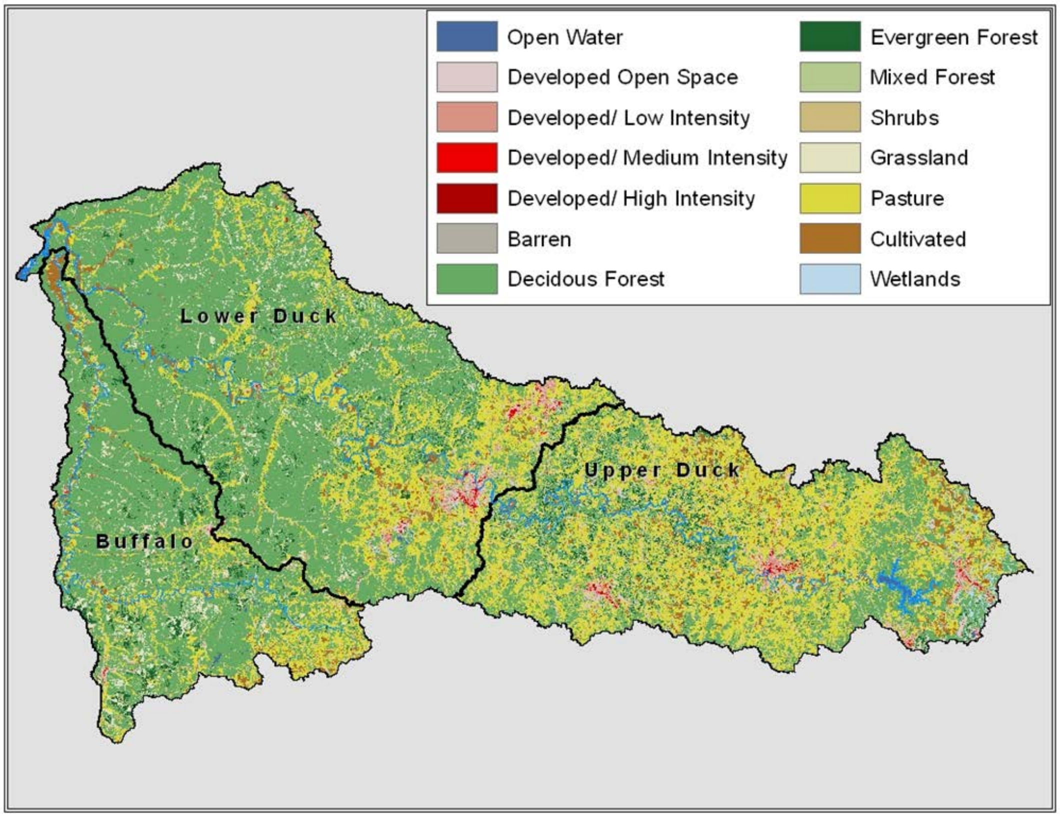


Figure 4 - Land Use Pattern

4.5 AQUATIC LIFE

The Duck River supports a diverse community of aquatic life. According to TNC, the Duck River is generally considered to be the richest river in varieties of freshwater animals on the North American Continent. Several federally listed mussel species have been relocated to the Duck River. A diverse species assemblage includes 151 species of fish, 56 freshwater mussel species, and 22 species of aquatic snails. Macroinvertebrate surveys identified at least 225 species of aquatic insects, crustaceans, and worms. Freshwater mussels and aquatic insects are important indicators of the health of the aquatic environment, because unlike fish, these animals cannot move quickly or long distances. These benthic groups are unable to escape changing and undesirable environmental conditions. The Duck River aquatic ecosystem was featured in the February 2010 National Geographic Magazine as one of four of the most biologically rich places in the world. State and federally listed aquatic species found in the Duck River watershed are listed in Table 2. The Buffalo River, a major tributary to the Lower Duck, is an outstanding native fisheries resource, containing over 100 fish species.

4.6 TERRESTRIAL LIFE

The Duck River watershed contains several endangered plant and animal species that are listed by the USFWS and the State of Tennessee (Table 2). The primary riparian species of trees in the floodplain are boxelder (*Acer* negundo), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), willow oak (*Quercus phellos*), and water oak (*Quercus nigra*). Riparian habitat supports white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), squirrel (*Sciurus spp.*), Eastern cottontail rabbit (*Sylvilagus floridanus*), bobwhite quail (*Colinus birginianus*), gray fox (*Urocyon cinereoargenteus*), opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*), muskrat (*Ondatra zibethicus*), beaver (*Castor canadensis*), mink (*Neovison vison*), weasel (*Mustela frenata*), otter (*Lontra canadensis*), several species of mice, bats, and many species of amphibians and reptiles. Riparian bottomland can support two to five times as many game animals as nearby upland forest. Three federally listed bat species occur in the study area: Gray (*Myotis grisescens*), Northern long-eared bat (*Myotis septentrionalis*) and Indiana (*Myotis sodalis*) bats forage primarily along river corridors and lake shorelines. The Indiana and Northern long-eared bats are known to roost under the bark of some trees such as the shagbark hickory (*Carya ovata*). Numerous waterfowl, such as the great blue heron (*Ardea Herodias*), green heron (*Butorides virescens*), snowy egret (*Egretta thula*), eagles, and kingfishers use these bottomlands.

4.7 FEDERALLY LISTED SPECIES

The Duck River watershed is one of the last refuges for many federally listed species. Species are listed as federally endangered, threatened, in need of management, or species of concern (Table 2). Three endangered mussel species on the list are presumed extinct. In the future, additional listed species may be relocated into this watershed in hopes of increasing their numbers and protecting them from jeopardy in their home watershed.

Table 2 - Federal and State Listed Species in the Duck River Watershed

Species - Common Name	Species - Scientific Name	Federal Status	State Status
Plants			
Eggert’s sunflower	*Helianthus eggertii*	DM	S
Leafy prairie-clover	*Dalea foliosia*	E	E
Price’s potato-bean	*Apios priceana*	T	E
Short’s Bladderpod	*Lesquerella globosa*	E	E
Tennessee coneflower	*Echinacea tennesseensis*	DM	T
Tennessee Yellow-eyed Grass	*Xyris tennesseensis*	E	E
Mammals			
Gray bat	*Myotis grisescens*	E	E

Species - Common Name	**Species - Scientific Name**	**Federal Status**	**State Status**
Indiana bat	*Myotis sodalis*	E	E
Northern long-eared bat	*Myotis septentrionalis*	T	E
Fish			
Barrens darter	*Etheostoma forbesi*	UR	E
Barrens topminnow	*Fundulus julisia*	UR	E
Egg-Mimic darter	*Etheostoma pseudovulatum*	UR	E
Pygmy madtom	*Noturus stanauli*	E	E
Slackwater darter	*Etheostoma boschungi*	T	T
Spotfin chub	*Erimonax monachus*	T	T
Striated darter	*Etheostoma striatulum*	UR	T
Mussels			
Birdwing pearlymussel	*Lemiox rimosus*	E	E
Clubshell	*Pleurobema clava*	E	E
Cracking Pearlymussel	*Hemistena lata*	E	E
Cumberland Monkeyface	*Quadrula intermedia*	E	E
Cumberlandian combshell	*Epioblasma brevidens*	E	E
Duck River dartersnapper	*Epioblasma ahlstedti*	UR	E
Fluted kidneyshell	*Ptychobranchus subtentum*	E	R
Orangefoot pimpleback	*Plethobasus cooperianus*	E	E
Oyster mussel	*Epioblasma capsaeformis*	E	E
Pale lilliput	*Toxolasma cylindrellus*	E	E
Pink Mucket	*Lampsilis abrupta*	E	E
Rayed bean	*Villosa fabalis*	E	R
Ring pink	*Obovaria retusa*	E	E
Rough pigtoe	*Pleurobema plenum*	E	E
Shiny pigtoe	*Fusconaia cor*	E	E
Slabside pearlymussel	*Pleuronaia dolabelloides*	E	R
Spectaclecase	*Cumberlandia monodonta*	E	R
Tan riffleshell	*Epioblasma florentina walkeri*	E	E
Tubercled blossom pearlymussel	*Epioblasma torulosa torulosa*	E	E

Status Codes: E – Endangered; T – Threatened; DM – In Need of Management; UR – Under Review; R – Rare-Not Listed; S – Special Concern

4.8 WETLANDS

Several wetland types and similar habitats have been identified in the watershed. Tennessee Valley Authority used infrared photography and the USFWS National Wetlands Inventory maps to identify potential wetlands on TVA lands. Sites were evaluated for potential wetland soil, vegetation, and hydrologic characteristics. Over 50 acres of potential wetland development sites were identified in the Yanahli Wildlife Management Area (WMA) located near Columbia in Maury County. Twenty acres of potential sites occur in scattered locations along the Duck River.

Other sites were located outside the 100-year floodway and were associated with surface streams.

TDEC Division of Natural Resources maintains a database of wetland records in Tennessee. According to TDEC/WPC watershed reports, there are 211 records of wetland sites in the Upper Duck River watershed, 22 sites in the Lower Duck River watershed, and 5 sites in Buffalo River watershed. These records could be used in identifying the sites for wetland restoration.

In summary, there are 238 wetland site records in the entire Duck River basin that have the potential to be restored and added to the National Wetlands Inventory. While these records are a good starting point, it is likely there are many additional sites with restoration potential. Also, mapped information indicates that these TDEC records do not include the additional wetland sites listed by TVA.

4.9 EROSION

Streambank and upland erosion are problems throughout the Duck River watershed. The soils in the Duck River Basin tend to have fairly shallow depths and are erosive. Reference streams used by TDEC/WPC indicate that natural stream systems lose an average of nearly 500 pounds of soil per acre per year. However, impaired streams on the 303(d) list are losing 5% to 55% more soil per year than the natural streams. Because of the Total Maximum Daily Load (TMDL) studies conducted by TDEC/WPC, streams with severe sediment loading have been identified and can be targeted so that sediment reduction activities can be concentrated to produce the greatest benefit per cost.

Excessive sediment load caused by erosion from urban development runoff, fields, gullies, pastures, and denuded stream banks is a serious environmental concern. In addition to the obvious lowered aesthetics, the erosion causes the loss of wetlands and riparian buffers. Denuded wetlands, open areas, and riparian habitat harm the terrestrial ecosystem, including federally listed species, by reducing the highly productive terrestrial wildlife habitat. Increased sediment loads on the river and stream substrates essentially eliminates aquatic habitat by clogging interstitial openings between the rocks and gravel on the stream and river bottom. The interstitial spaces are required by mussels and aquatic insects, the primary fish food source, for places to hide, attach, feed, and reproduce. Reduced numbers of aquatic insects reduces the number of fish a stream can support. Sediment decreases depth of pools and destroys the gravel nesting habitats of fish, smothering fish eggs, clogging fish gills, and accelerating growth of submerged aquatic plants, which further decreases fish spawning habitat. Mussel beds are similarly affected, with layers of silt covering the mussel gills and newly hatched mussels (glochidia). Mussels require host fish to carry and drop glochidia to new stream locations. Reduced fish numbers reduces reproductive and distribution success for the mussels. Excessive sediments, therefore, reduce biological productivity by burying fish spawning, benthic, and mussel habitats, which adds stress to the entire aquatic ecosystem including federally listed species. Under natural conditions, well vegetated riparian zones, wetlands, and swales filter out eroded sediment before it reaches the stream.

Severe stream erosion often leads to streambank failures. The sudden deposition of soil and fallen debris buries aquatic life, impedes stream flow, and adds sediment and turbidity to downstream reaches of the streams. Bank failures result in loss of land and damage to archeological, agricultural, and urban sites.

4.10 RIPARIAN BUFFERS

The riparian fringe plays an important role in preventing or reducing silt loads from reaching the river and in stabilizing the banks to prevent erosion. Riparian vegetation also provides shade for the streams and helps maintaining cooler water temperatures. Cooler water retains higher concentration of dissolved oxygen needed to sustain aquatic life.

The Duck River watershed’s floodplain bottomland hardwoods and forests have been largely cleared and minimized to increase agricultural fields and provide river views for urban development. Nearly one third of the stream and river banks in the watershed have 200-foot wide buffers, but due to human activities they have lost half of their natural vegetation cover. Another 10% of the riparian buffers are less than 100 feet wide and have lost more than 70% of their natural vegetation. Due to these agricultural and urban development practices, many banks have been denuded, leaving exposed, easily eroded soil.

4.11 WATER QUALITY

Quality of the aquatic habitat throughout the Duck River watershed varies and depends on a variety of factors. Those factors causing the most stress to a given stream’s aquatic health can be determined by looking at state’s 303(d) list. To comply with the Clean Water Act, TDEC compiles a 303(d) list of the waters of Tennessee that fail to support some or all of their classified uses. Once a stream is placed on the 303(d) list, it is considered a priority for water improvement efforts. Figure 5 shows all the streams placed on 303(d) list within Duck River watershed.

4.11.1 Sediment Loading

At least 43 streams within the Duck River watershed, comprising 300 stream miles, have been identified on Tennessee’s 303(d) list for loss of biological integrity and excessive sediment. Sediment loading not only impairs these listed stream segments but also healthy streams as turbid waters can flow several miles into unlisted healthy streams. Turbidity impairs sight feeding fish and reduces light penetration, which interferes with the photosynthesis of algae covered rocks that provide food for aquatic insects.

4.11.2 Bacteria Counts and Nutrient Loading

Water Quality and recreation have been impaired by high nutrient loading and high bacteria counts from livestock wastes, failing septic tanks, failing wastewater collection systems, and wastewater plant discharges. A total of 27 streams comprising 216 stream miles have been identified on the 303(d) list as impacted by *E. coli* based on bacterial samples exceeding state water quality standards. The organic waste is also high in nitrogen. The waste, together with the nitrogen compounds found in agricultural fertilizer, result in abnormally high nitrogen levels in stream water.

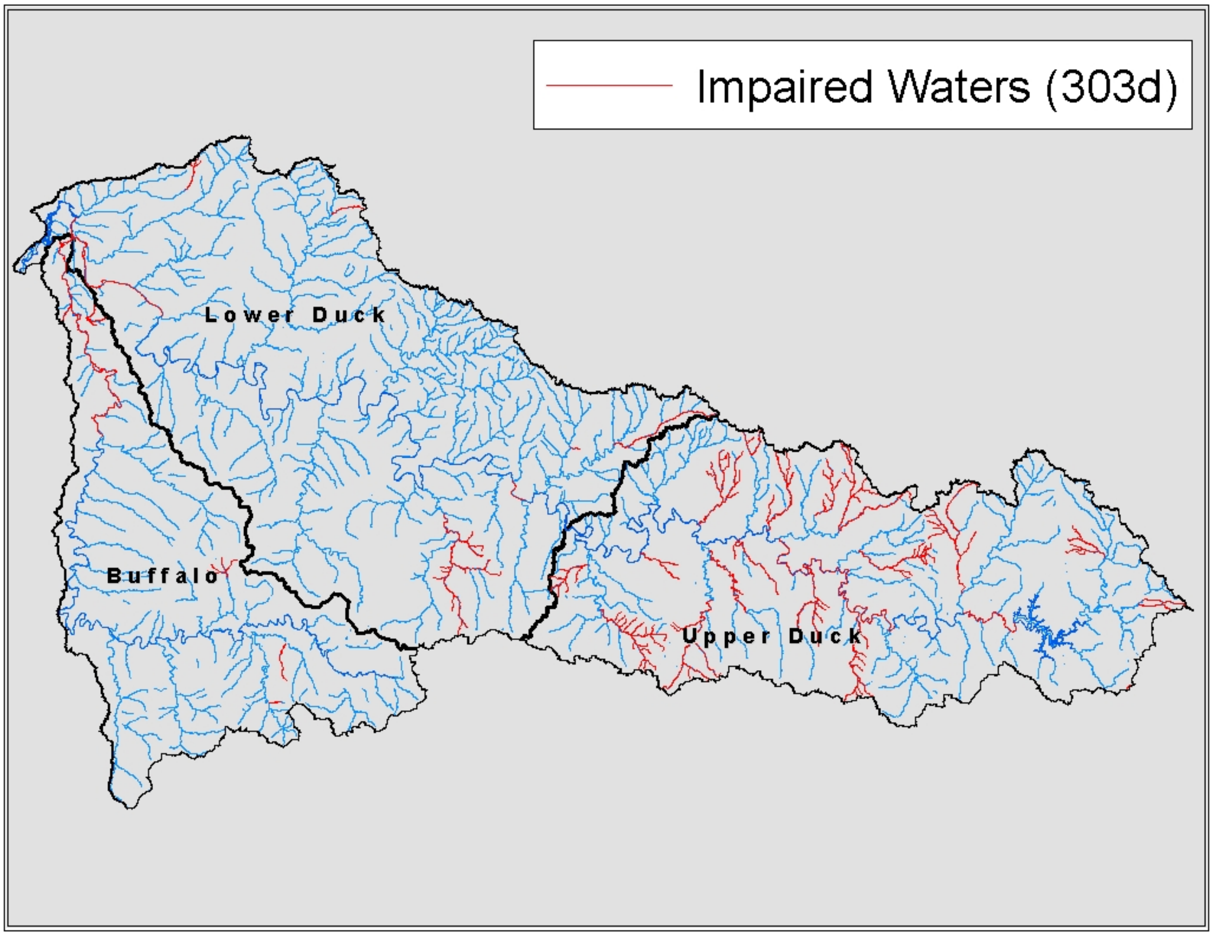


Figure 5 - Streams on 303(d) list

4.11.3 Dissolved Oxygen

Dissolved oxygen (DO) is a very important indicator of a water body's ability to support aquatic life. Fish "breathe" by absorbing dissolved oxygen through their gills. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algal photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter. A variety of factors affect DO concentration and most of them are interrelated:

- Volume and velocity: Fast-moving water is aerated by bubbles as it churns over rocks and other stream features. In slow, stagnant waters, oxygen only enters the top layer of water, and deeper water is often low in DO concentration caused by decomposition of organic matter. Historically, low dissolved oxygen has been a main issue at Normandy Dam and Reservoir. In 1994, TVA installed aeration equipment in the reservoir to add oxygen to the deep water near the dam and to improve conditions in the Duck River downstream from the dam. A new, larger compressor and four new diffuser lines were added to the aeration system in 1997. Despite these efforts, Normandy Reservoir rated poor in 2010 for dissolved oxygen, consistent with poor ecological health ratings since 2000.

- Climate/Temperature/Season: The colder the water, the more oxygen can be dissolved in the water, thus, DO concentrations are usually higher in the winter and lower in the summer. During the warm, dry season, when water levels decrease, flow rate slows down, and water temperatures rise, the DO concentration tends to decrease. Thus, regulation of Normandy Dam releases is especially important to aquatic environment during dry and warm season in the Duck River.
- Dissolved and suspended solids: Oxygen is more easily dissolved into water with low levels of dissolved or suspended solids. Sediment washed off of eroding banks and carried by runoff from farmlands in the Duck River watershed is contributing to the decrease in DO concentration.
- Amount of nutrients and organic wastes: High amounts of nutrients can produce large quantities of algae. Leaves, grass clippings, dead plants or animals, animal droppings, and sewage are common organic wastes that also enter the streams. Bacteria decomposes dead algae and organic matter by using up oxygen. The streams in the Duck River watershed that are identified as having excessive amounts of nutrients and high bacteria counts are also having decreased DO concentrations, especially during low flow conditions.
- Riparian vegetation: Removing trees and vegetation reduces shade on the streams, allowing the sun to warm the water. Also, bare soil is prone to erosion which, in turn, increases the amount of dissolved and suspended solids in the water.

4.11.4 Phosphates

The Lower Duck River watershed faces additional problems. The soils in the vicinity of the city of Columbia are naturally high in phosphates. In this area, the river gradient becomes very flat, and a large number of abandoned phosphate strip mines in the vicinity of Columbia contribute additional amounts of phosphates to the streams. The soil carried into the river carries both high nitrogen and phosphate loads that can lead to rapid growth of algae and bacteria within the river. Greatest growth occurs during the spring and early summer when there is ample stream flow resulting in algae and bacteria covered stream substrate. However, in the late summer, the flow in the river and streams decrease. During these low flow conditions that usually last for 3 months the Duck River carries as little as 160 cubic feet per second (cfs) of flow. At such a low flow, the river is transformed into a series of pools 1/4 to 1/2 mile long and 3 to 5 feet deep. The algae and other organic matter are confined to these pools and begin to die and decompose. Decomposition progressively drops dissolved oxygen to critically low levels, killing fish and benthic organisms. This cycle kills off many desirable organisms, lessens populations of others and generally degrades the aquatic ecosystem.

4.11.5 Mining Activities

Water quality management plans for the Duck River basin, prepared by TDEC in 2005, list 11 active permitted mining sites. The majority were limestone quarries and one sandstone quarry.

4.12 WATER SUPPLY AND LOW WATER FLOWS

Water supply is a key issue important to water resources planning in the Duck River Watershed. More than 250,000 people rely on the Duck River as their sole water source. Over the years, water supply studies have been performed by numerous parties including TVA, USACE, TDEC, DRA, TNC, and the local water utilities. Minimum flows in the river are a key consideration for planning water supply flows in the Duck River. Past minimum flow requirements at various points have been controlled by releases from TVA's Normandy Dam. Flows were set to provide for both water supply, waste assimilation, and aquatic habitat needs. The TNC has worked with Hyrologic, Inc., using the company's OASIS software to develop a computer model of a water resources system for the Duck River. The model assisted TNC and partner agencies to work collaboratively and make decisions regarding water supply alternatives. The goal was to optimize water use for both water supply and seasonal flow requirements for the rich aquatic resources (Palmer, 2008).

During its regional water supply study led by DRA, it was discovered that during extreme or prolonged drought conditions there is the potential for a deficit of up to 32 million gallons per day (MGD) for users of the Duck River in the year 2060. Currently, drought conditions such as those experienced in 2007 could result in a 4 MGD deficit, straining the river's ability to maintain water supply for all uses.

4.13 FLOODING AND FLOODPLAINS

Nearly 90% of the Duck River is unregulated below Normandy Dam (DRM 248.6). The cities of Columbia and Shelbyville are known to routinely experience flooding problems. Most of the counties and municipalities within the watershed participate in the National Flood Insurance Program. As such, they are required to enact floodplain management ordinances that should limit most new development within the designated floodways of the jurisdiction and reduce damages to new construction in the flood fringe through elevation or through wet or dry flood proofing. The efficacy of the ordinances is dependent upon local jurisdiction enforcement of the ordinance requirements and limited variances.

During the May 2010 flood event, record stages occurred at many locations in central Tennessee, including points along the Duck River. Rainfall on May 1st and 2nd, 2010 resulted in record flood stages in the lower Duck River basin. Radar rainfall in the lower Duck River Basin ranged from 4 inches to 15 inches; gage rainfall ranged from 10 inches to 14 inches over the two-day period. The stream gage at Columbia recorded flooding 4.4 feet below the previous flood of record, which occurred in 1973. The stream gage at Hurricane Mills, however, recorded flooding 5.6 feet above the previous flood of record in 1975. Gages in the lower Duck River basin are located at the E. 6th Street Bridge in downtown Columbia, and 1.4 miles downstream of the Highway 13 Bridge, southeast of Hurricane Mills, Tennessee.

There were 192 structures damaged in the Duck River watershed during the May 2010 flood, resulting in a total damage of $29,004,000. Table 3 classifies damage by category. **Error! Reference source not found.** indicates the locations and severity of damages estimated using the USACE Hydrologic Engineering Center's (HEC) Flood Impact Analysis (HEC-FIA) modeling software (USACE, 2012).

Table 3 - Duck River Damage by Category ($1,000)

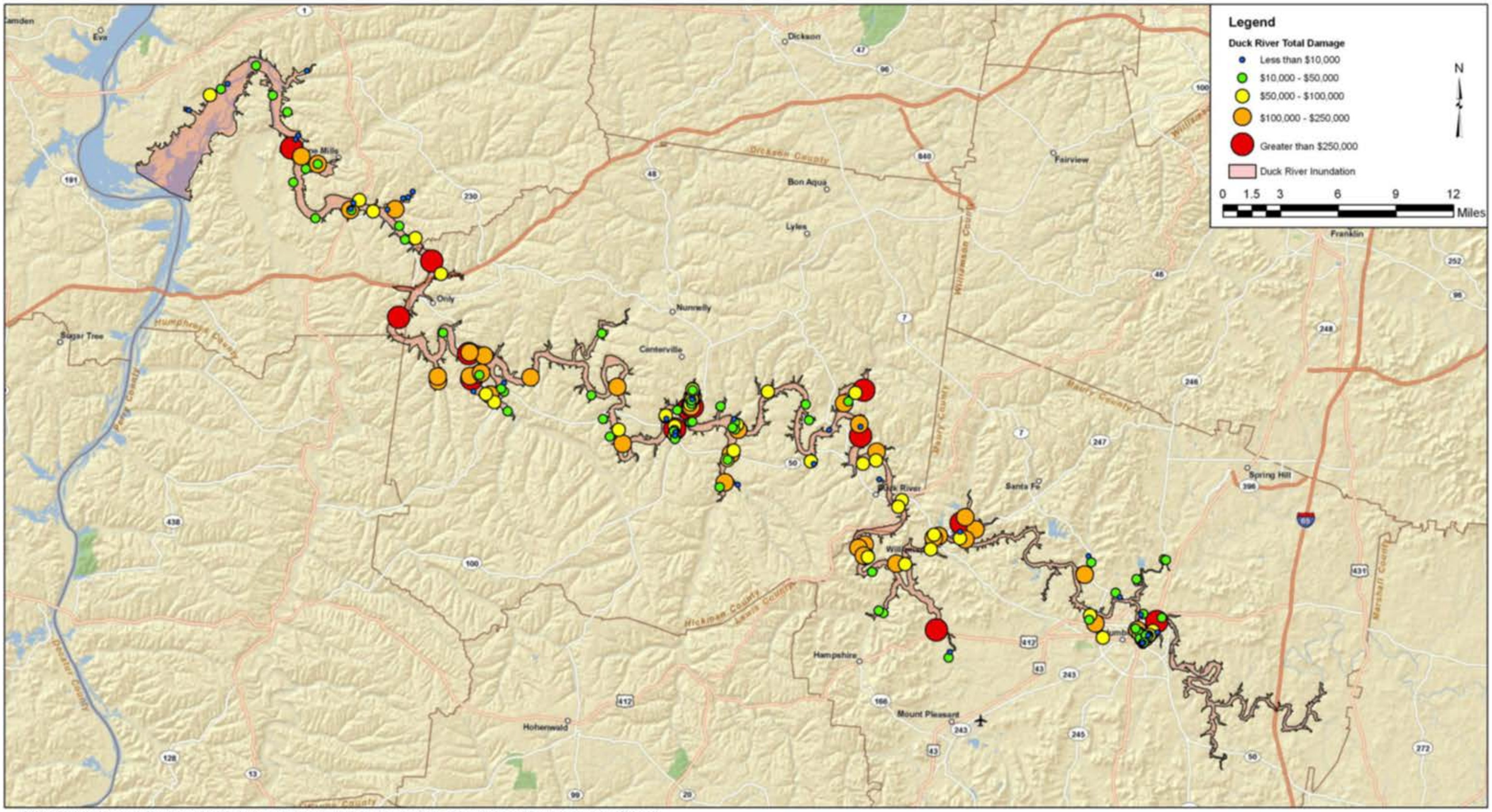
Category	Structure	Contents	Car	Total
Commercial	$8,499.90	$15,622.16	$1,277.77	$25,399.83
Industrial	$2.00	$4.65	$3.02	$9.67
Public	$3.17	$14.00	$106.77	$123.94
Residential	$2,016.67	$1,090.59	$363.26	$3,470.52
Total in Watershed	**$10,521.75**	**$16,731.39**	**$1,750.82**	**$29,003.96**

During May 2010, flood radar rainfall in the Buffalo River watershed ranged from 6 inches to 11 inches; gage rainfall ranged from 6 inches to 9 inches over the two-day period. Stream gages at Flatwoods and Lobelville recorded flooding 0.5 feet and 0.8 feet above the previous flood of record, respectively, which occurred in 1991. Gages in the Buffalo River basin are located 0.5 miles downstream of the Highway 13 bridge crossing, near Old Highway 93 to the north of Flatwoods and at a further downstream bridge crossing of Highway 13, to the north of Lobelville, Tennessee.

As reported by the HEC-FIA model, 136 structures were damaged in the Buffalo River watershed during the May 2010 flood, resulting in a total damage of $5,640,000. Table 4 classifies the HEC-FIA output by damage category. Figure 7, indicates the locations and severity of damages estimated using the HEC-FIA modeling software.

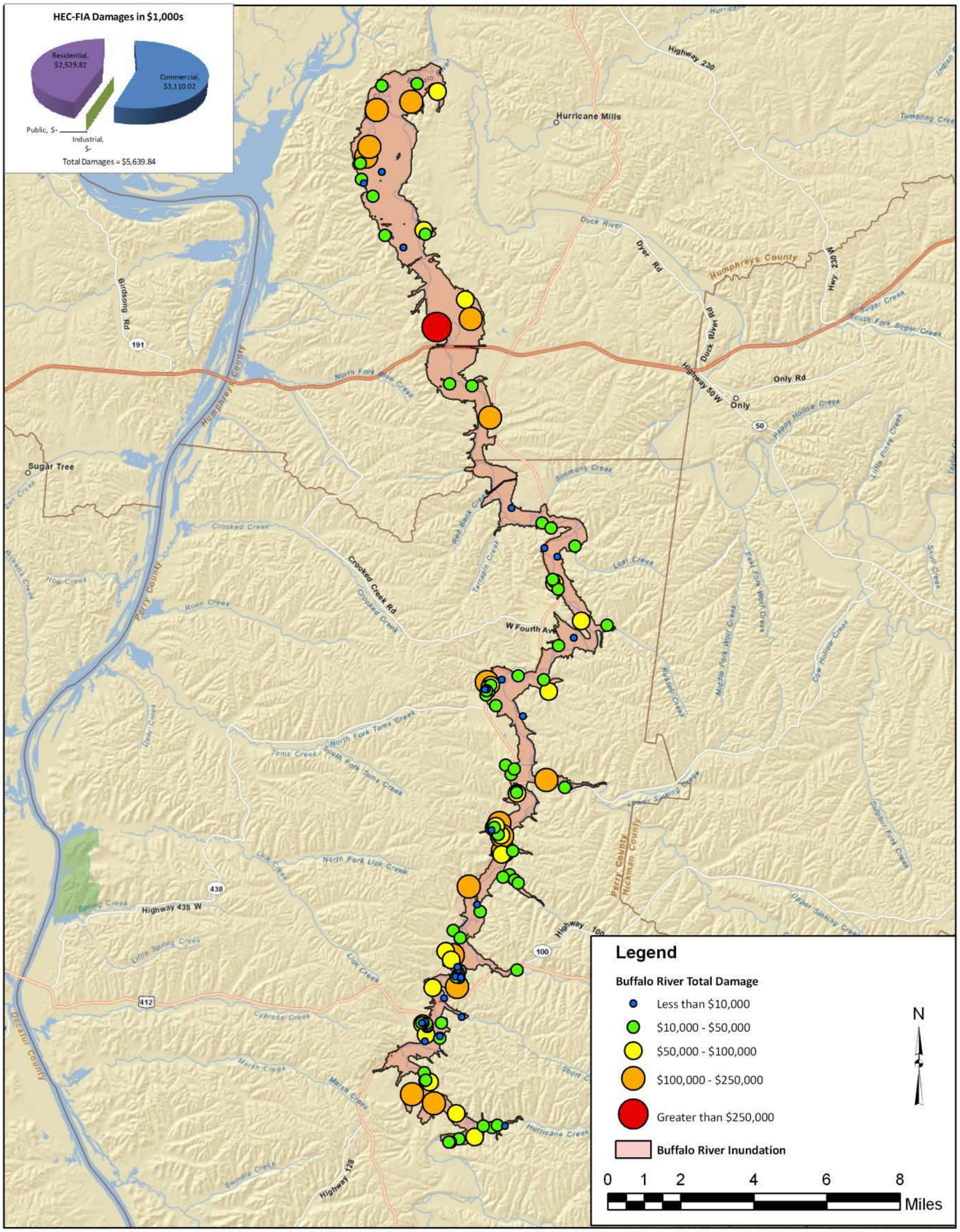
Table 4 - Buffalo River Damage by Category ($1,000)

Category	Structure	Contents	Car	Total
Commercial	$1,143.98	$1,787.48	$178.56	$3,110.02
Industrial	$-	$-	$-	$-
Public	$-	$-	$-	$-
Residential	$1,406.29	$755.82	$367.72	$2,529.82
Total in Watershed	**$2,550.26**	**$2,543.30**	**$546.28**	**$5,639.84**



Note: Inundation area developed and shown only for study streams. Additional flooding may have been experienced outside the study areas.

Figure 6 - Duck River May 2010 Damage Locations and Magnitude



Note: Inundation area developed and shown only for study streams. Additional flooding may have been experienced outside the study areas.

Figure 7 - Buffalo River May 2010 Damage Locations and Magnitude

Residential Damages by county as reported to FEMA after May 2010 flood are shown in Table 5.

Table 5 - Residential Flood Damages, May 2010 (FEMA, 2010)

	Reported May 2010 Flood Damages
County	**Residential Damage**
Williamson	**$9,985,956**
Hickman	**$3,447,448**
Lawrence	**$153,673**
Humphreys	**$2,211,202**
Dickson	**$1,358,061**
Lewis	**$392,233**
Marshall	**$82,855**
Maury	**$1,313,631**
Perry	**$2,623,635**
Wayne	**$555,602**

In addition to the residential damages resulting from the May 2010 flood, two of the Duck River watershed's counties experienced three deaths. Hickman County had 1 death, while Perry County had 2 losses of life.

The TDEC Division of Water Supply maintains a dam inventory for the entire Duck River watershed. These dams either retain a minimum of 30 acre-feet of water or have structures that are 20 feet tall or higher. Over half of these dams (53) are located in the Lower Duck watershed. There are 18 dams in the Upper Duck watershed and 10 dams in the Buffalo watershed resulting in a total of 81 dams in the entire Duck River watershed.

Between 2009 and 2010, the TDEC Division of Water Supply inspected 367 dams in Tennessee. Some of the dams were repaired after being damaged during the floods. Until subsequent inspections are completed there is a potential that some dams in the Duck River watershed may have been damaged by the May 2010 flood.

4.14 RECREATION

Recreational boating is a large sector of local economies, especially in the Lower Duck and Buffalo watersheds. A handful of commercial outfitters provide canoeing, kayaking, and tubing opportunities in these watersheds. An estimated 150,000 - 160,000 people per year recreate on these rivers and their smaller tributaries in the Humphreys, Lewis, Perry, and Wayne Counties. The total annual economic benefit of recreational boating in these counties averages $6 million.

The Duck River watershed contains approximately 70,000 acres of park land, wildlife management, and state natural areas (see Table 6). These properties are managed for hunting, fishing, camping, hiking and canoeing. They are also managed for wildlife and fisheries conservation and preservation of federally listed species. Additional recreation opportunities may be developed in the watershed; however, recreation will be limited on streams listed as impaired for nutrients and high bacteria counts.

Table 6 - Parks, Wildlife Management Areas (WMA), State Natural Areas (SNA) and State Scenic Rivers (SSR) in the Duck River Watershed

County	Public Land	Acres
Maury	Maury County Park	200
Maury	Chickasaw Trace Park	300
Marshall	Henry Horton State Park	1140
Maury	Duck River - SSR 30 mi 50’ 100‘ 50’	~73
Hickman	MTSU WMA	800
Hickman	John Noel/Bon Aqua SNA	35
Hickman	Beaver Dam Creek WMA	7,619
Coffee	Maple Springs WMA	122
Coffee	Bark Camp Barrens WMA	2,800
Coffee	Hickory Flats WMA	800
Coffee	May Prairie SNA	250
Coffee	Old Stone Fort State Archeological Park	876
Coffee	AEDC WMA (partial) ~ 5,000 a of 32K	~ 5,000
Coffee	Short Springs SNA	420
Coffee	Normandy WMA	750
Bedford	Coy Gaither/Bedford Lake	47
Maury	Yanahli WMA (contains Duck R Complex SNA)	12,800
Maury	Williamsport WMA & 6 lakes	1,722
Maury	Stillhouse Hollow Falls SNA	90
Humphreys	Tennessee NWR (Duck Mouth)	~5,000
Lewis	Hick Hill WMA	3,608
Lewis	Langford Branch SNA	23
Lewis	Devil’s Backbone SNA	950
Lewis	Natchez Trace Parkway 40 mi	~ 5,000
	Buffalo River Watershed Below:	
Lewis	Auntney Hollow SNA	26
Lewis	Dry Branch SNA	2,169
Lewis	Lewis State Forest	1,287
Lawrence	Buffalo River - SSR ~ 15 mi x 5280’L x 100’W/ sq a	182
Lawrence	Laurel Hill and Lake WMA	14,000
Lawrence	VFW Lake – managed by TWRA	22
Lawrence	Natchez Trace Parkway -- 7 mi	~850
Wayne	Natchez Trace Parkway – 12 mi	~1500
Total Public Acres =		**70,461**

4.15 CULTURAL RESOURCES

Duck River watershed has been utilized by human beings for at least the past 11,000 years. All cultural periods (Paleoindian, Archaic, Woodland, Mississippian, and Historic) have been documented; represented by almost 2,000 known archaeological sites. The National Register of Historic Places includes numerous locations, structures, and districts within the Duck River watershed ranging from prehistoric archaeological districts to historic domestic, industrial, commercial, military, government, religious, and agricultural significance.

The abundance of prehistoric archaeological sites within the Duck River watershed attests to the easily habitable and hospitable terrain and climate of the watershed. Old Stone Fort Archaeological Area is a Woodland era ceremonial site used for at least four centuries. Link Farm State Archaeological Site features a prehistoric Mississippian era mound. Shelby Bend Archaeological District consists of a complex of prehistoric archaeological sites representing a predominately Late Archaic occupation and mortuary area.

Historic sites range from early settler’s cabins and plantations to mill and industrial transportation sites. History of the Duck River watershed was shaped by its unique physiography, geography, geology and determined pioneers and settlers. Numerous natural springs in the eastern headwaters along the Highland Rim acted as nuclei for farmsteads and various industries including distilleries, mills, tanneries, and health spring tourism. The ridge formed by the Highland Rim was a key geographic feature of the Civil War Tullahoma Campaign. Liberty Gap Battlefield was one of several gaps in the Highland Rim which were attacked by the Union Army. The capture of these gaps resulted in the retreat of Confederate troops from the Duck River Valley and the abandonment of Middle Tennessee to the Union Army.

Industrial and economic activities helped shape the cultural history of the Duck River watershed. Historic forges and furnaces utilized deposits of iron ore found on crests and side slopes of ridges in the northern half of Hickman County. The most important mineral in the region, phosphate, was the basis of an important regional industry in the late nineteenth and twentieth centuries. Limestone has been quarried and used as agricultural lime, flux in iron making, highway aggregate, dimension stone for walls and structures, and fill at building sites. Settlers used fieldstone and some quarried limestone for construction, mainly for fences and chimneys.

The Duck River watershed also has noteworthy routes that traverse its landscapes. Natchez Trace Parkway National Park commemorates an ancient trail that connected southern portions of the Mississippi River to salt licks in modern-day Tennessee. Between 1785 and 1820, boatmen floated goods down-river and walked back on the 444-mile Trace. With the coming of railways in the 1850s, the river was used for little commerce other than floating timber to sawmills. Benge’s Route of the 1838-1839 Cherokee Trail of Tears crossed through several counties in central Tennessee, and followed the Duck River for many miles.

Cultural history of the Duck River watershed is rich and varied; it is a product of the natural environment. As part of which, it must be protected along with the abundant wildlife and ecosystems that made the Duck River watershed so attractive to humans throughout prehistory and history.

4.16 SUB-WATERSHED DATA AND CHARACTERISTICS

4.16.1 Upper Duck Rivet Watershed

The Upper Duck watershed (UDW) roughly begins at Columbia (DRM 137) and ends in the headwaters of the Duck River in Coffee County (DRM 274). The aquatic habitat, characterized by the quality of the water in this reach, has high bacteriological counts after heavy rains. The high bacteriological counts are mostly due to the large number of livestock produced in the area and the use of the tributary streams as livestock watering sources. At least 17 streams affecting 185 stream miles are specifically listed on the 303(d) list for *Escherichia coli* (*E. coli*) in the UDW. The NRCS is actively working with farmers on the implementation of Best Management Practices (BMPs) and have achieved noteworthy improvements over the last few years. Many of the streams impaired due to *E. coli* are located in the headwaters that empty into Normandy Lake. Nutrient loading has contributed to low dissolved oxygen in Normandy Lake. As a result, TVA has been aerating releases from Normandy Dam. Upstream of the City of Columbia (DRM 137), nearly 100 stream miles of the Duck River support a diverse community of aquatic life, including several endangered species. This river segment contains the Yanahli WMA which covers nearly 30 river miles between DRM 137 and DRM 166. The Yanahli WMA protects the river floodplain and river corridor from development. However, the UDW contains nearly 28 streams (about 200 river miles) that are affected by the loss of biological integrity due to siltation, loss of riparian vegetation, and low dissolved oxygen. Additionally, the UDW supports one of the most species-rich aquatic communities in North America, as well as highly degraded stream segments. There is an abundance of information produced by the decommissioned Columbia Dam project. The dam was nearly complete when it was halted due to impacts the impoundment would have on federally endangered mussels (Birdwing pearlymussel and Cumberland monkeyface) located upstream and in what is now the Yanahli WMA. This river corridor in Yanahli WMA offers the best protection for ecosystem restoration projects because of land development restrictions.

4.16.2 Lower Duck River Watershed

The Lower Duck watershed (LDW) extends from DRM 137 downstream to the mouth of the Duck River (DRM 0). Downstream from the city of Columbia (DRM 137) to the town of Williamsport (DRM 104), the aquatic diversity declines dramatically. Problems in this area include heavy silt loads, low dissolved oxygen levels during periods of low flow, high bacteriological counts after heavy rains, and denuded riparian zones. Eight streams and 24 stream miles are impacted due to *E. coli*. There are also numerous abandoned phosphate mines in the upstream portion of the LDW. Excessive levels of phosphates (erosion from the mines) and nitrogen (from animal wastes) in the stream cause an overabundance of algal growth. When the algae die and decay, dissolved oxygen drops to low levels that are harmful to the aquatic life. The LDW predominately flows through sparsely populated areas and agricultural crop land.

Streambank erosion, which increases the stream's sediment load, has been identified by the stakeholders as a major problem in the watershed. The LDW contains nearly 15 streams (about 100 river miles) that are affected by the loss of biological integrity due to siltation, loss of riparian vegetation, and low dissolved oxygen.

4.16.3 Buffalo River Watershed

The Buffalo River is the largest Duck River tributary entering the Lower Duck watershed near DRM 15.5. The Buffalo River originates in Lawrence County and flows 110 miles to the lower Duck River. The watershed's primary land use is agriculture. Unincorporated areas rely on septic systems to dispose of household sewage with no existing system to track or record failures. It is the longest unimpounded river in Tennessee and is used as a municipal water supply for Lobelville, Linden, Waynesboro, and Summertown. Its main stem remains free-flowing with no dams or other large structures present. The undisturbed flow allowed the river to maintain an extremely diverse fish fauna. However, compared to historical records, mussel population has experienced a dramatic decline for several decades and the cause has not been identified. Four streams (11.71 stream miles) are listed on the State 303(d) list for loss of aquatic habitat and low dissolved oxygen levels during periods of low flow. Two streams (6.9 stream miles) are on the State 303(d) list for high bacteriological (*E.coli*) counts. The watershed hosts 4 federally listed endangered fish and mussel species. At least 8 federally listed fish species are of special concern.

5.0 Problems and Opportunities

The Corps of Engineers defines problems as existing negative conditions, while opportunities relate to actions that can be undertaken to solve a problem and achieve desirable future conditions. A "problem" in the context of the aquatic environment is defined as an ecological issue developed as a result of human interference that has negative effects on the sustainability of environmental quality necessary for the diversity, growth, and reproduction of aquatic organisms. In the context of restoration actions, an "opportunity" is a means of establishing a solution for the stated problem(s). Stating clearly and concisely the problems and opportunities in regards to the Duck River Watershed is paramount in the establishment of a common vision among stakeholders and provides a focal point in the planning process.

Development of problem and opportunity statements is preceded by a thorough analysis of water resource conditions in the Duck River Watershed. In addition, accurate formulation of problem and opportunity statements is paramount in recommending watershed plans aimed to improve water resources, land use, hydrogeomorphic conditions, water quality, and socio-economic and cultural benefits.

The identification of problems and opportunities were identified using the following steps:

- Collect background data, analysis and interpretation of low-altitude, high definition video;

- Identify existing stream conditions and causes of impairment;
- Establish reference stream reaches and comparison with impaired reaches;
- Identify the "cause and effect" relationship between the disturbance/alteration and the impairment; and
- Determine the effects of existing management practices on stream corridor structure, processes, and functions.

The following are the most significant problems and opportunities in the context of the entire watershed that have been identified through research and stakeholder outreach. Many of these problems are interlinked and conflicting in nature.

5.1 WATER QUALITY

Water Quality in the Duck River Watershed varies throughout the basin. The major and most common problems are:

- Excessive sediment loading caused by streambank erosion, loss of riparian buffers, and runoff from agricultural lands.
- High bacteria counts after heavy rain events caused by runoff from livestock pastures, concentrated animal feeding operations, and failing septic tanks.
- Nutrient loading caused by runoff from farm lands (fertilizer, organic waste from livestock, etc.)
- Low dissolved oxygen, especially during low flow conditions caused by bacteria decomposing organic waste, increased sediment load and warmer water temperature.
- Excessive amounts of phosphates entering the streams.

States are required to prepare a listing of water quality impaired streams called the 303(d) list. The 303(d) listed streams are a compilation of streams and lakes in Tennessee that are "water quality limited" or are expected to exceed acceptable levels of water quality standards in the next two years and need additional pollution controls. Water quality limited streams are those that have one or more properties that violate water quality standards. They are considered impaired by pollution and not fully meeting designated uses. Once a stream has been placed on the 303(d) List, it is considered a priority for water quality improvement efforts.

Several miles of streams within the Duck River have been listed for water quality impairment. The causes of impairment include: Nutrient enrichment, chemical (e.g., chloride), bacteriological, siltation, habitat alternations, stream-side vegetation cover alterations, suppressed dissolved oxygen, thermal and flow modifications, heavy metal contaminant (e.g., mercury), salinity and total dissolved solids, and synthetic organics contamination (e.g., polycyclic aromatic hydrocarbons).

There is a direct correlation between the chemical and biological causes of water quality impairment and the physical condition of the stream channel and adjacent riparian zone and land use. Direct impacts to the physical, chemical, and biological integrity of streams within the basin include: Unrestricted cattle access to the stream, discharges from municipal stormwater, upstream impoundments, municipal point sources, channelization, dredging, riparian zone alternations, and concentrated animal feeding operations. Exogenous sources of pollution loading to the stream at the reach-scale include: Pasture grazing, crop production, dairies, atmospheric deposition, high density urbanization, land development, landfills, highway construction, and confined animal feeding operations, and leaking underground waste-storage tanks.

5.2 WATER SUPPLY

Water supply is one of the keys issues in the watershed; however, it is also one of the most conflicting problems. Water is needed for both human consumption and to support aquatic and terrestrial life. The highest water demands are in the Upper Duck River watershed which is experiencing rapid growth and urbanization. The majority of surface water withdrawals are for public water supply and are projected to increase tremendously by 2030 during normal conditions. During the drought conditions, water supply is already a pressing problem and it will worsen in the future as demand for water continues to grow. Water supply is closely connected to water quality problems as adequate amounts of flowing water is also needed to sustain the Duck River’s rich aquatic ecosystem which hosts many endangered fish and freshwater mussel species. A certain volume of water is also required to assimilate treated wastewater that is being returned to the Duck River. The known minimum flow required in the Duck River is unknown. TDEC has historically used 100 cfs as the minimum flow for permitting purposes. Determining the true minimum flow to support aquatic and terrestrial life is one opportunity for this watershed assessment.

During the drought and low flow conditions, the river’s assimilative capacity is greatly reduced and water quality suffers. The Duck River Agency (DRA) is currently working on implementing a regional water supply plan encompassing several counties in the Upper Duck watershed. The potential prolonged droughts and population growth challenges faced by the region indicate that flexible, reliable, and collaborative water supply plans are needed to meet both current and future demands and to ensure river’s ability to maintain water supply for all uses.

5.3 ECOSYSTEM DEGRADATION

The Duck River’s rich and diverse aquatic and terrestrial life depends on availability of high quality water and suitable habitat. Ample supply of water is needed to ensure minimum flow requirements for sustaining aquatic life. Freshwater mussels are especially sensitive to declining water quality and are good indicators of stream health. The watershed’s aquatic and terrestrial life is experiencing stress from increased development, hydraulic regime changes, and declining suitable habitats. There is a need for a systematic basin-wide ecosystem restoration and management to ensure that current richness and biodiversity is preserved and improved.

5.4 LAND USE CHANGE

Land use of the watershed is primarily agriculture and natural deciduous forest. This land use is changing rapidly, particularly in the Upper Duck River watershed. While agricultural activities, such as pesticide spraying, fertilizing, irrigation, plowing, grazing etc., contribute non-point source pollutants, the encroaching development is adding additional pollutants to the Duck River and its tributaries. As development in the watershed continues, the pollutants from urban runoff will put additional stress on the watershed's ecosystem, especially its aquatic habitat. Demand for water supply will also increase along with population growth and urbanization.

5.5 FLOOD RISK MANAGEMENT

The Duck River is unregulated below Normandy Dam Reservoir, thus flooding is a problem for communities on the main stem of the Duck River, especially during larger rain events. The Buffalo River and smaller tributaries are flooding during smaller, more frequent events. The communities contacted during the post May 2010 flood investigation indicated that the problem is exacerbated by the accumulation of wood debris and eroded sediment on the stream bottoms.

5.6 GENERAL WATERSHED-SCALE

In general, problems in the Duck River have adversely affected stream conditions at several scales and trophic levels:

1. Channel Stability: The natural channel in cross-section has been altered by channel enlargement in both width and depth. Accelerated sediment deposition has resulted in formation of mid-channel bars exasperating near bank shear stress resulting in bank erosion and failure.
2. Hydrologic Alteration: Stream channels have been altered by bank armoring, straightening/channelization, road and railroad crossings with inadequate bridge or culvert sizes, and dam construction.
3. Riparian Zone: Forested riparian zones have been cleared or modified by agricultural or urban land practices, invasion of exotic plant species, and stream access.
4. Bank Stability: Channel banks are highly eroded due to land-clearing practices and channel enlargement due to hydrologic alteration and reduction in adequate riparian zone width and composition.
5. Water Quality: Elevated water temperature, reduced light penetration, nutrient enrichment predominantly from non-point pollution, high sediment yield, embeddedness, and turbidity has reduced the water quality and the ecological integrity of the stream.
6. Aquatic Habitat: In combination, the above stressors have reduced the available habitat diversity (runs, pools, glides, riffles, leaf packs, woody debris, etc.) and "living space" for fish and benthic macroinvertebrates.

5.9 OPPORTUNITIES

The problems identified in the watershed present opportunities for improvement through coordinated efforts among stakeholders. Many stakeholder agencies and organizations are actively involved in the Duck River watershed and are often working directly with the communities and land owners. The following is a preliminary list of opportunities for addressing water resources problems in the watershed:

- Inventory existing water resources management efforts in the watershed and evaluate their effectiveness. Identify new management opportunities and critical areas where additional management efforts are needed.
- Identify and prioritize areas of most concern. TDEC's 303(d) list of impaired streams and water quality plans could be used as a starting point.
- Create a database with all available Federal, state, and local programs and resources applicable to water resource management.
- Utilize stakeholders' expertise and knowledge of the area to identifying specific sites for applying the BMPs on the agricultural lands.
- Utilize many publicly owned or managed protected areas in the watershed for ecosystem restoration activities without the need to engage in costly real estate acquisitions.
- Select and implement structural and nonstructural watershed management practices.
- Identify possible sites for wetland restoration.
- Use regulatory approaches to manage point and non-point pollutant sources.
- Adopt watershed-wide Low Impact Development (LID) practices to land development.
- Incorporate green infrastructure to help alleviate problems associated with urban runoff.
- Build upon or adapt existing water supply, water conservation, drought management, water quality, wildlife management, and other plans developed by stakeholder agencies and organizations.
- Collaborate with TVA on issues pertaining to releases from Normandy Dam and Reservoir.
- Develop public education and outreach program.

Based on alterations to water resources in the Duck at both watershed and stream reach scales, several opportunities to enhance or restore processes and functions of aquatic resources and associated services and benefits have been identified, including:

- Restore and maintain adequate environmental flows conducive to the life history of endemic fish and macroinvertebrates including threatened and endangered species.
- Reduce flood damages by increasing flood storage.
- Restore hydro-period to historic wetland areas to a specific flood frequency and duration.
- Increase endemic plants (survival and growth) in various strata in abundance and diversity in adjacent riparian zones and wetland areas.
- Stabilize stream banks by restoring riparian zones and restricting livestock access.
- Increase habitat connectivity and fish passage by dam removal.

- Improve water quality by promoting use of agriculture buffer strips and adequately sized riparian zones.
- Enhance economic values, recreation opportunities and social well-being by spatial extent.
- Make recommendations in regards to BMPs.

Some of the common opportunities include: Riparian zone restoration, restoration of channel stability, creation of aquatic habitat, nutrient abatement, improvements in oxygen dynamics, reduction in embeddedness, reduction in sediment transport, creation of greenways and self-guided trails, restoration of stream segments and wetlands, and cattle and livestock exclusion.

6.0 Objectives and Constraints

6.1 OBJECTIVES

The planning objectives were developed based on input received from sponsors and stakeholders. The objectives directly relate to problems identified during the assessment and are as follows:

- Improve water quality in the Duck River Watershed.
- Ensure long-term water supply availability for human consumption and riverine ecosystem.
- Protect and restore ecosystem in the Duck River watershed to support aquatic and terrestrial habitat diversity.
- Reduce flood risk in urban areas and maintain flood pulse and connectivity to wetlands and active floodplains.
- Manage and Influence land use to minimize stressors to the Duck River resources.
- Increase and preserve recreation opportunities in the Duck River Watershed.
- Promote wise use of natural resources by educating and informing the public of Duck River Watershed’s unique resources.

6.2 CONSTRAINTS

In any study, constraints generally exist which impede or jeopardize the achievement of the stated planning objectives. The recommended measures in the Watershed Plan will follow the universal constraints of complying with Federal, state, and local laws, as well as USACE policy.

7.0 Future Conditions

The future condition of the Duck River Watershed without implementation of any recommended watershed strategies would likely continue on the path it is currently on, as described in Section 4.0 Existing Conditions. Continued rapid growth and development, especially in the Upper Duck, will result in reduced water supply to support human needs, as well as aquatic and terrestrial life. The water quality and aquatic habitat would be further degraded resulting in potential loss of species.

8.0 Watershed Modeling

8.1 RED HEN FLYOVER

Helicopter reconnaissance of the Duck and Buffalo watersheds in Tennessee was conducted in February 2014 to collect baseline information on watershed and stream channel condition for use in the watershed assessment. The flight covered the Duck River from its confluence with the Tennessee River (Kentucky Reservoir) to its headwaters above Interstate 24. The Buffalo River was flown from its confluence with the Duck River to the vicinity of U.S. Hwy 43. The major tributaries of both rivers of 3rd order and higher were also flown. There were 32 hours of flight time, with an expected duration of 4 or 5 days to complete coverage of approximately 800 total stream miles. High-definition (HD) geo-referenced digital videos (MPEG-4) were recorded during the flight using the Red Hen Systems, LLC, technology.

8.2 MULTI-SCALE WATERSHED APPROACH

An ecological model was developed by the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) referred to as the Multi-Scale Watershed Approach (MSWA). A knowledge base was developed by compiling and analyzing biological and geomorphological data across HUC12 watersheds from existing databases of fishes, mussels, aquatic habitats, and benthic macroinvertebrates. Additional stream data collected from the Red Hen flyover video, as well as a final subset of eleven of 18 stream geospatial test variables, collected on 213 stream segments, were subjected to statistical analysis. An ecological model, stream condition index (SCI), was formulated based on the degree of statistical correlation (dependency) between the variables. Each of the 64 out of 87 HUC12 watersheds were classified by averaging the model scores of the stream segments within the watershed. For detailed model information see Appendix A. User guide is located in Appendix B. The model was reviewed and approved for use in the Duck River Watershed by the USACE National Ecosystem Restoration Planning Center of Expertise. The approval allows USACE to use the model for future watershed studies and projects in the Duck River watershed.

8.3 STREAM CLASSIFICATION INDEX (SCI)

Statistical analysis was used to develop an algorithm used to calculate SCI using values for channel stability (CS), fish cover (FC), pools (P), riparian zone (RZ), bank stability (BS), canopy density(CAN), hydrologic alteration (HA), water color (WC), nutrient enrichment (NE), embeddedness (EMB), and cattle access (CA).

$$\mathrm{SCI} = \frac{\left(\sqrt[3]{\mathrm{CS} \times \mathrm{FC} \times \mathrm{P}} + \sqrt[3]{\mathrm{RZ} \times \mathrm{BS} \times \mathrm{CAN}}\right) / 2}{\left(\mathrm{HA} + \sqrt[3]{\mathrm{WC} \times \mathrm{NE} \times \mathrm{EMB}} + \mathrm{CA}\right) / 3}$$

Each variable was rated with a value from 0.1 to 1.0 during review of the Red Hen flyover data. These variables are the model inputs and can be varied to determine the effects and outcomes of implementing specific measures and strategies in the watershed. See Table 7 for variable descriptions. Two hundred and thirteen video segments across 64 of 87 HUC12 watersheds were evaluated using the eleven variables listed above. SCI scores were calculated from average variable scores of video segments within each of the 64 watersheds.

The SCI model was tested to ensure that it was capable of addressing a full range of model inputs by using a partial sensitivity analysis, the most commonly used approach. A partial sensitivity analysis uses alternative values for individual key model inputs. The process involves various ways of changing input variables of the model to see the effect on the SCI. Several scenarios were tested by subjecting: (1) one variable to the range of possible input values, while keeping the other ten variables constant; (2) two variable to the range of possible input values, while keeping the other nine variables constant; (3) multiple variables with positive correlations to the range of possible input values, while keeping the other variables constant; (4) multiple variables with negative correlations to the range of possible input values, while keeping the other variables constant; and (5) multiple variables with positive and negative correlations to the range of possible input values, while keeping the other variables constant. Based on each of the aforementioned treatments, a complete range (0 to 1.0) of SCI scores was observed.

Table 7 - Stream Condition Index Variable Scoring and Descriptions

Channel Stability-Longitudinal (CS)	Natural channel; no structures, dikes. No evidence of down cutting or excessive lateral cutting	Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levies are set back to provide access to an adequate flood plain.	Altered channel; <50% of the reach with riprap and/ or channelization. Excess aggradation; braided channel. Dikes or levees restrict flood plain width.	Channel is actively down-cutting widening. >50% of the reach with riprap or channelization. Dikes or levees prevent access to flood plain.	(intentionally blank)
CS Score →	**1.0**	**0.7**	**0.3**	**0.1**	**---**
Hydrologic Alteration (HA)	Flooding every 1.5 to 2 years. No dams, no water withdrawals, no dikes or other structures limiting the stream's access to the flood plain. Channel is not incised.	Flooding occurs only once every 3 to 5 years; limited channel incision. Or Withdrawals, although present, do not affect available habitat for biota.	Flooding occurs only once every 6 to 10 years; channel deeply incised. Or Withdrawals significantly affect available low flow habitat for biota.	No flooding; channel deeply incised or structures prevent access to flood plain or dam operations prevent flood flows.	(intentionally blank)
HA Score →	**1.0**	**0.7**	**0.3**	**0.1**	**---**
Riparian Zone (RZ)	Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. Or If less than one width, covers entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. Or Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. Or Lack of regeneration.
RZ Score →	**1.0**	**0.8**	**0.5**	**0.3**	**0.1**
Bank Stability (BS)	Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); out- side bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).	(intentionally blank)
BS Score →	**1.0**	**0.7**	**0.3**	**0.1**	**---**
Water Color (WC)	Very clear, or clear but tea-colored; objects visible at depth 3 to 6	Occasionally cloudy, especially after storm event, but clears	Considerable cloudiness most of the time; objects	Very turbid or muddy appearance most of the time; objects	(intentionally blank)

	ft (less if slightly colored); no oil sheen on surface; no noticeable film on submerged objects or rocks.	rapidly; objects visible at depth 1.5 to 3 ft; may have slightly green color; no oil sheen on water surface.	visible to depth 0.5 to 1.5 ft; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. Or Moderate odor of ammonia or rotten eggs.	visible to depth < 0.5 ft; slow moving water may be bright green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface. Or Strong odor of chemicals, oil, sewage, etc.	
WC Score →	**1.0**	**0.7**	**0.3**	**0.1**	**---**
Nutrient Enrichment (NE)	Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.	(intentionally blank)
NE Score →	**1.0**	**0.7**	**0.3**	**0.1**	**---**
Fish Cover (FC)	>7 cover types available	6 to 7 cover types available	4 to 5 cover types available	2 to 3 cover types available	None to 1 cover type available
FC Score →	**1.0**	**0.8**	**0.5**	**0.3**	**0.1**
Pools (P)	Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 5’ deep.	Pools present, but not abundant; from 10 to 30% of the pool bottom is obscure due to depth, or the pools are at least 3’ deep.	Pools present, but shallow; from 5 to 10% of the pool bottom is obscure due to depth, or the pools are less than 3’ deep.	Pools absent, or the entire bottom is discernible.	(intentionally blank)
P Score →	**1.0**	**0.7**	**0.3**	**0.1**	**---**
Canopy (CAN)	25 to 90% of water surface shaded; mixture of conditions.	> 90% shaded; full canopy; same shading condition throughout reach.	< 25% water surface shaded in reach.	(intentionally blank)	(intentionally blank)
CAN Score →	**1.0**	**0.7**	**0.1**	**---**	**---**
Cattle Access (CA)	Evidence of livestock access to riparian zone.	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream. Or Untreated human waste discharge pipes present.	(intentionally blank)	(intentionally blank)
CA Score →	**0.5**	**0.3**	**0.1**	**---**	**---**

Embeddedness (EMB)	Gravel or cobble particles are < 20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40% embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
EMB Score →	**1.0**	**0.8**	**0.5**	**0.3**	**0.1**

8.4 FISH INDEX OF BIOTIC INTEGRITY (IBI)

In addition to the analysis of geospatial data, fish Index of Biotic Integrity (IBI) scores were evaluated based on twelve metrics which addressed species richness and composition, trophic structure, fish abundance, and fish condition. Scores for the twelve metrics were summed to produce the IBI value for the site.

By comparing the SCI to fish IBI scores, it was found that aquatic biota impairment was predominantly due to loss of streamside canopy, reduction of in-stream cover, and impacts to channel stability, all of which were considered to be the limiting factors to sustaining a healthy aquatic ecosystem in the Duck River watershed.

Based on the fish IBI results, only 17 of the 90 IBI stations were rated good/excellent or excellent, (see Figure 8). Twenty-four percent of the 90 stations received a fair or lower rating for fish IBI.

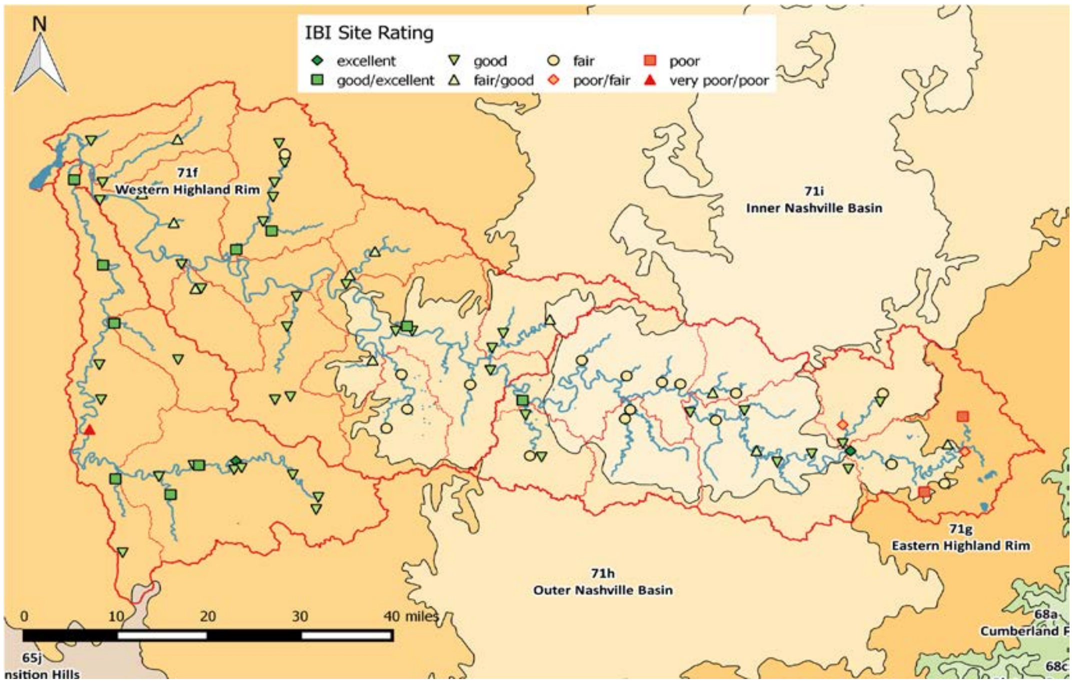


Figure 8 - Fish IBI site ratings

8.7 MODEL RESULTS – SCI APPLICATION

This section summarizes the model results including fish data, stream geomorphology, riparian zone, aquatic habitat, mussel data, aquatic macroinvertebrate, effects of dams, and stream condition index. This section also explains how the model can be applied in making decisions to manage water resources.

The findings of this model can be used to: 1) prioritize watersheds for restoration, enhancement and conservation; 2) plan and conduct intensive ecosystem studies, justify significant project prioritization; and 3) assess ecosystem outcomes applicable to future with and without restoration actions including alternative, feasibility, and cost/benefit analyses.

Two hundred and thirteen video segments across 64 of 87 HUC12 sub-watersheds were evaluated using the eleven variables listed above. SCI scores were calculated from average variable scores of video segments within each of the 64 sub-watersheds where low altitude, high definition video was provided. SCI scores were estimated in the remaining 23 sub-watersheds by statistical analysis (quantile regression). Twenty of the 87 sub-watersheds were considered to exhibit “major or severe disturbance to biotic and abiotic attributes” (Figure 9). Thirty-nine of the 87 sub-watersheds were considered to exhibit “minor disturbance to biotic and abiotic attributes”, and 28 of the 87 sub-watersheds exhibited “minimally disturbed to relatively undisturbed.”

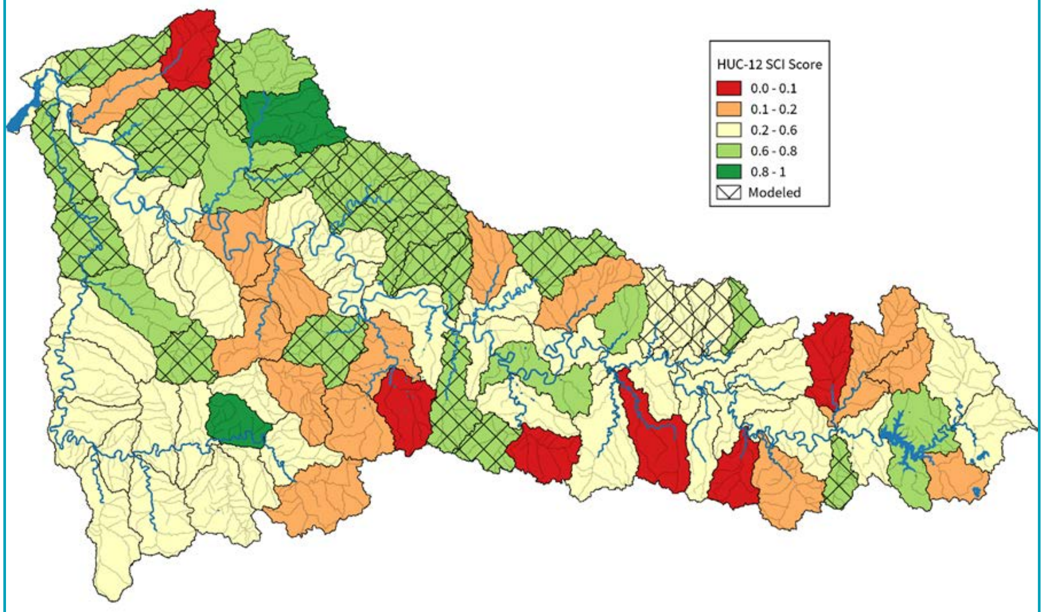


Figure 9 - Duck River watershed depicting Stream Condition Index (SCI) rescaled to Best Attainable Condition (BAC) across 87 HUC12 watersheds

8.8 MODEL USES

8.8.1 Prediction of Future With- and Without Project

Traditionally, project planners have quantified the future ecological state of a restoration action by comparing the quantity and quality of habitat for the future with- (FWP) and without- project (FWOP) conditions over a 50-year planning horizon (Figure 8). In the scenarios below, the SCI score in response to FWP is assumed to increase over a period of time and then, at some point, plateau. In contrast, the SCI score in response to FWOP is shown to decrease over time. However, for some aquatic processes and functions, FWOP could actually not change or increase (be enhanced) over time (e.g., natural channel lateral migration). In the restoration scenarios below, we assumed FWOP did not change over the 50-year horizon. It is at the discretion of the user to determine if, when, and in which direction functional attributes (SCI input variables) would change under FWOP conditions based on best professional judgment and field observations.

Quality is ascribed herein using the SCI, which is normalized to a zero to one scale with one representing best attainable conditions - BAC ("best" possible conditions). When the SCI is multiplied by an area (e.g., wetland) or length (e.g., stream), the output is referred to as a Stream Condition Unit (SCU). The term "ecological lift" or ecosystem outcomes is used to describe the difference between the trajectory lines in Figure 10, and reflects the net increase in SCI of the project over the project planning period (50 years). A similar graphic can be created that represents the ecologic lift in SCUs. This net increase in SCUs ("benefits") can be divided by the number of years to establish an annualized benefit which can be used in cost/benefit analysis, alternative analysis, and adaptive monitoring and management.

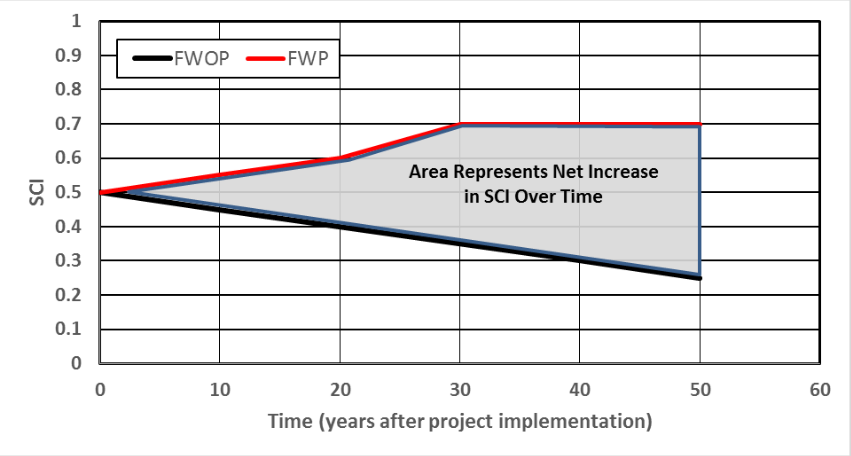


Figure 10 - Net benefits in terms of the Stream Condition Index calculated by the difference in the future with- (FWP) and future without-project (FWOP) conditions over a 50-year planning horizon.

SCI scores were calculated for 64 HUC12 watersheds based on assessment of low altitude video. The remaining 23 HUC12 watersheds were estimated by the linear equation formulated from quantile regression analysis for a total of 87 HUC12 watersheds (Table 8). Following rescaling to BAC, the SCIs were classified into five major categories. The descriptive statistics in Table 8 characterize the data variability.

Table 8 - Stream Condition Index (SCI) descriptive statistics, class frequencies, and GIS map colors for video assessments and extrapolation to watersheds without video assessments.

Descriptive Statistics		**Frequency**			**SCI Category**	**Condition**	**GIS Image Color**
		Bins	**Class**	**Subclass**			
n	87	0.1	6	6	SCI ≤ 0.1	Servere Disturbance	Red
min	0.00	0.15	7				
max	1.00	0.2	7	14	0.2 ≥ SCI > 0.1	Major Disturbance	Orange
avg	0.44	0.4	27				
stdev	0.26	0.6	12	39	0.6 ≥ SCI > 0.2	Minor Disturbance	Yellow
skewness	0.24	0.8	26	26	0.8 ≥ SCI > 0.6	Minimally Disturbed	Light Green
kurtosis	-1.26	1.0	2	2	1.0 ≥ SCI > 0.8	Relatively Undisturbed	Dark Green

Four scenarios are presented here in regards to assessing the ecological outcomes at the HUC12 scale in response to stream and/or riparian zone restoration and prioritization. Two HUC12 watersheds within the Garrison Fork watershed were assessed using the Red Hen video and are included as examples below (Noah Fork, 060400020202; and Garrison Fork main stem, 060400020203). The land use of the two watersheds was predominantly open fields (65.3 and 51.9 percent of the watersheds, for Noah Fork, and Garrison Fork, respectively) which contribute, in part, to the poor watershed condition. Crumpton Creek (060400020103), located in the headwaters of the Duck River, and Cane Creek (060400040202), located in the middle Buffalo River watershed, are also included as examples below. In addition, the effects beyond the project footprint (i.e., downstream) are calculated for Noah Fork scenario.

Noah Fork and Garrison Fork Restoration Scenarios. Garrison Fork watershed (HUC10, 0604000202) is adversely affected by agriculture, cattle grazing and access to the stream channel, loss of riparian zone (quantity and quality), sediment deposition (embeddedness), fish habitat loss, bank erosion, and confinement by roads. In this scenario, the restoration action would restore and stabilize 250 feet of stream banks (both left and right banks) along the upper reach of Noah Fork, by stabilizing the stream banks, replanting the riparian zone with native plants, fencing the riparian zone to preclude access by cattle to the stream channel, and creating aquatic habitat including a series of runs, pools, glides, riffles, and coarse woody structure. Four Red Hen stream segments were assessed in Noah Fork (Flight numbers 11519003 to 006). For this exercise, SCI scores associated with the four segments were averaged,FWOP was set to an average SCI score of 0.10, and SCI was assumed to not change over time. There is a direct relationship between channel stability, riparian zone, fish cover, and canopy density. In contrast, an indirect relationship was observed between channel stability and water clarity, nutrient enrichment and embeddedness. Consequently, restoration of the channel, riparian zones, and aquatic habitat improves or enhances bank stability, fish cover, pools (“bedform diversity”), and canopy density (stream shading and nutrient buffering functions) (Table 9). The difference between FWP and FWOP yields an ecological lift of 0.57 (in SCI). The product of SCI and restoration length (250 feet X 2) yields 285 SCU. The SCI increased in Noah Fork in response to project implementation (FWOP versus FWP, Figures 9 and 10, respectively). Benefits beyond the project footprint can be realized in the watershed downstream of the project. For instance, since the restoration action in this scenario reduces bank erosion, it is assumed that embeddedness, water color, and nutrient enrichment are reduced and fish cover and pools are improved in the HUC12 downstream (Garrison Fork, 060400020203). Consequently, the SCI model was run again using the estimated variable scores resulting in an ecological lift of 0.16 for downstream in Garrison Fork (Table 9). The stream length of the improvement is at the discretion of the project manager. Also, since the model is most appropriate at the HUC12 scale, we assume the entire HUC improves. In reality, the smaller tributaries to Garrison Fork do not improve, necessarily, due to the upstream restoration action in Noah Fork (**Error! Reference source not found.** and **Error! Reference source not found.** represent FWOP and FWP, respectively).

Table 9 - Future with (FWP) and Without Project (FWOP) under different scenarios for Noah Fork, Garrison Fork, Crumpton Creek and Cane Creek

Scenario	**SCI Input Score (by variable)**											**SCI**
Noah Fork	**CS**	**FC**	**P**	**RZ**	**BS**	**CAN**	**HA**	**WC**	**NE**	**CA**	**EMB**	**(BAC)**
1 (FWOP)	0.2	0.4	0.4	0.2	0.3	0.1	0.0	0.7	0.4	0.9	0.4	0.10
1 (FWP)	0.9	0.8	1.0	1.0	0.9	0.9	0.4	0.8	0.9	1.0	0.8	0.67
Ecological Lift												0.57
Benefits Beyond the Project Footprint (Downstream in Garrison Fork)												
1 (FWP)	0.2	0.4	0.8	0.8	0.3	0.4	0.4	0.8	0.7	1.0	0.6	0.25
Ecological Lift												0.16
Crumpton	**CS**	**FC**	**P**	**RZ**	**BS**	**CAN**	**HA**	**WC**	**NE**	**CA**	**EMB**	**SCI (BAC)**
2 (FWOP)	0.7	0.5	0.7	0.5	0.7	0.7	0.3	1.0	0.3	0.5	0.5	0.09
2 (FWP)	1.0	0.3	0.1	1.0	1.0	0.7	0.3	1.0	0.9	1.0	0.9	0.50
Ecological Lift												0.41
Cane Crk	1.0	1.0	1.0	1.0	1.0	0.7	0.7	0.7	0.3	0.8	0.7	0.82

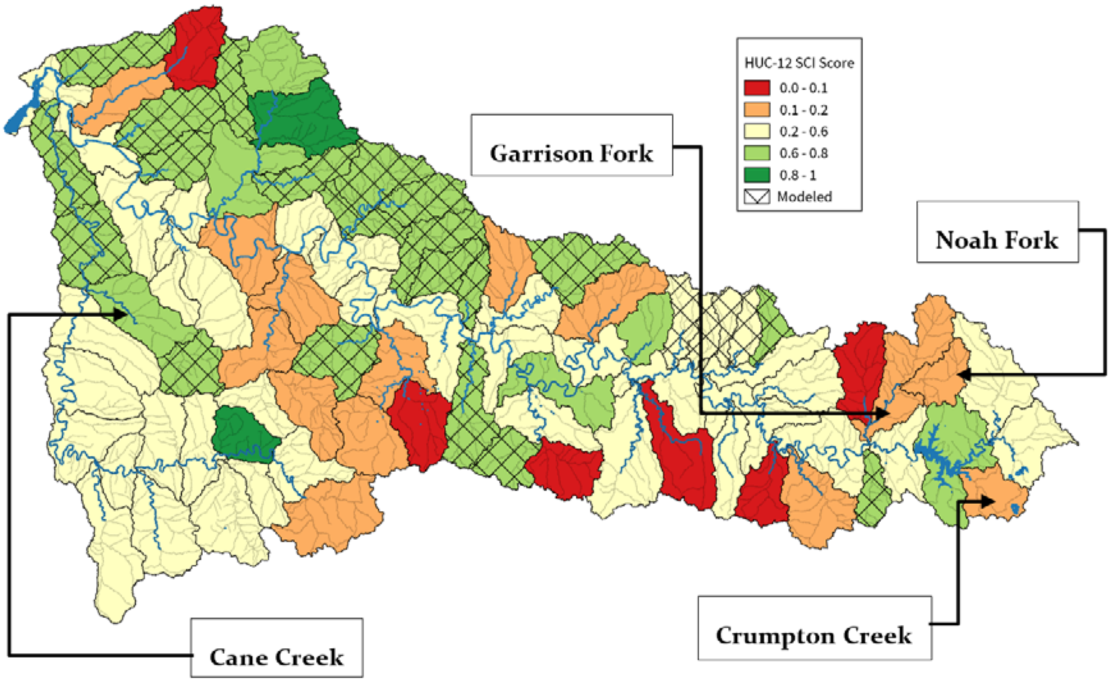


Figure 11 - Future Without Project (FWOP), Duck/Buffalo watersheds depicting Stream Condition Index (SCI) scores

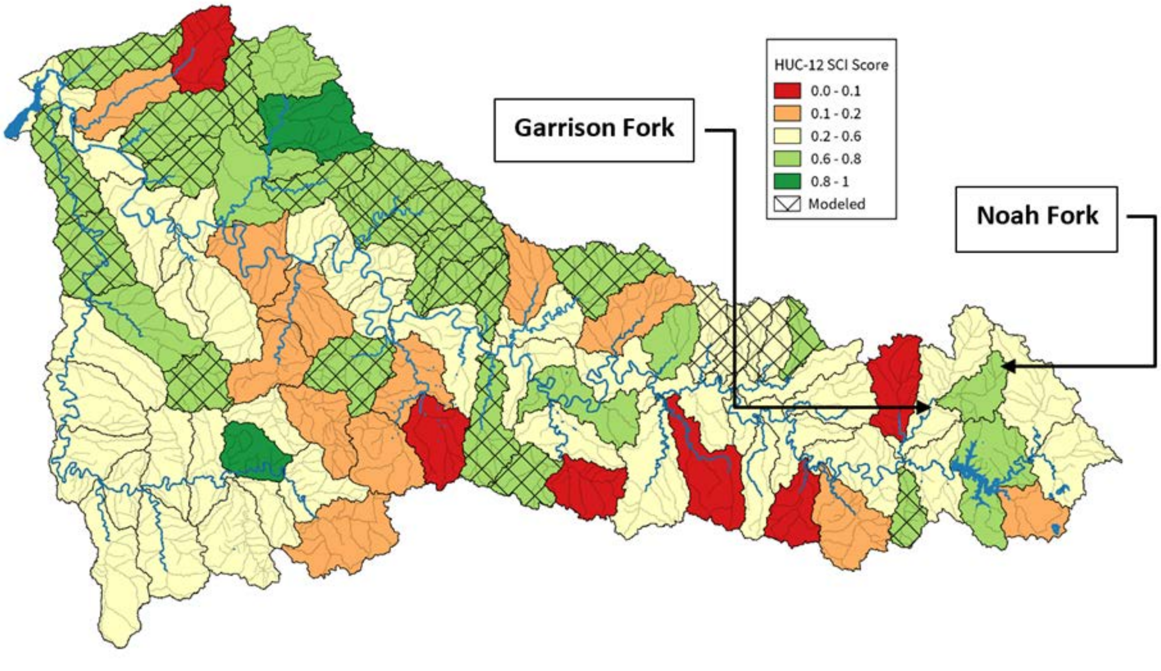


Figure 12 - Future With Project (FWP), Duck/Buffalo watersheds depicting improvements in Noah Fork and benefits beyond the footprint of the project downstream in Garrison Fork (compare with Figure 11, FWOP)

Crumpton Creek Restoration Scenario. Crumpton (HUC12, 060400020103) is located in the upper Duck River watershed near Manchester (**Error! Reference source not found.**). The SCI calculated for the Crumpton Creek was 0.09 (Table 9). In this restoration scenario, the quality and quantity (width) of the riparian zone was improved, and the cattle were precluded from the stream channel and riparian zone by fencing. Consequently, the restoration action was a passive approach to riparian zone restoration that did not include construction of in-stream structures or bank stability techniques. As a result, water color, nutrient enrichment, canopy density and shading, and embeddedness improves. Consequently, an ecological lift of 0.41 is realized. In this scenario, no provision is made for benefits beyond the project footprint downstream. If 500 linear feet of stream corridor is restored, the ecological lift equals 205 SCUs.

Depending upon degree of restoration actions on-site and existing conditions downstream of the project site, benefits can be realized downstream of the project at the discretion of the project manager. Benefits downstream of the project can be justified by running the SCI model on downstream stream conditions using FWOP and FWP scenarios as presented above.

Cane Creek Restoration Scenario. Cane Creek (HUC12, 060400040202) is located in the Buffalo River watershed and was not assessed during the Red Hen video flyover (**Error! Reference source not found.**). USACE staff conducted a surface (“boots-on-the-ground”) assessment on Cane Creek, August 25, 2016. The SCI calculated for Cane Creek was 0.82 (Table 9). In this restoration scenario, the quality and quantity of the stream segment is relatively high. Consequently, the restoration action would not result in a significant ecological lift and outcome. It would be more beneficial to select a different stream segment for restoration.

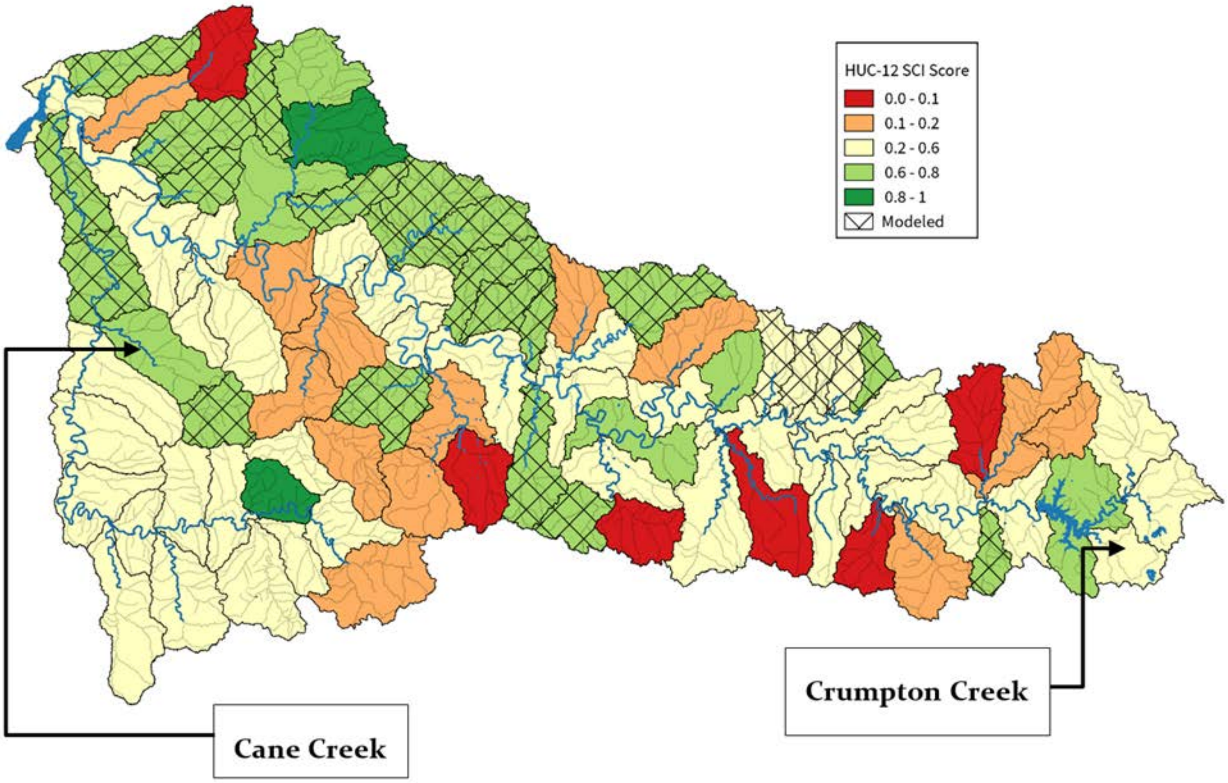


Figure 13 - Future With Project (FWP), Duck/Buffalo watersheds depicting improvement in Crumpton Creek (SCI score change from orange to yellow based on restoration action scenario); No change in SCI score in Cane Creek because of current high quality (Compare with Figure 11, FWOP)

8.8.2 Ability to Rank and Prioritize Projects

The overall goal of the Civil Works program in regards to significant ecosystem restoration or watershed-scale investigations, such as the Duck River Watershed Assessment, is to invest in restoration projects or features that make a positive contribution to the Nation's environmental resources in a cost-effective manner (EC 11-2-204, pg. C-2-3). The SCI model formulated for the Duck River Watershed Assessment improves the consistency, objectivity, and scientific basis to justify significant project prioritization at both regional and national scales. The correspondence between budget ranking elements and SCI variables are presented in Table 10. Based on the SCI scores calculated for FWOP and FWP, estimations of each ranking element were calculated and normalized to the maximum ranking points of each ranking element. The overall ecological lift was estimated to be 70.8 (FWP – FWOP) or 54% of maximum ranking points. The ecological lift calculated from the difference between FWP and FWOP from the seven budget ranking elements and can now be applied to the restoration area or length which is 500 feet. Consequently, SCU equals 0.81 SCU (in stream miles).

Table 10 - Ecological lift by budget ranking elements using the Noah Fork restoration scenario

Budget Ranking Element	Maximum Ranking Points	Related SCI Variables	SCI for FWOP	SCI for FWP
Habitat Scarcity & Status	25	Channel Stability, Hydrologic Alteration, Riparian Zone, Bank Stability, Fish Cover, Pools, Embeddedness	2.4	17.3
Connectivity (longitudinal and lateral)	25	Hydrologic Alteration, Riparian Zone Condition, Water Color, Nutrient Enrichment	2.4	18.4
Special Status Species	10	Hydrologic Alteration, Riparian Zone, Fish Cover, Pools, Canopy Density, Embeddedness	1.0	4.9
Hydrologic Character	20	Channel Stability, Hydrologic Alteration, Riparian Zone, Bank Stability, Fish Cover, Pools, Cattle Access, Embeddedness	1.9	13.0
Geomorphic Condition	20	Channel Stability, Hydrologic Alteration, Riparian Zone, Bank Stability, Fish Cover, Pools, Embeddedness	1.9	12.1
Ecosystem Sustainability	20	Channel Stability, Hydrologic Alteration, Riparian Zone, Bank Stability, Fish Cover, Pools	1.9	10.6
Plan Recognition	10	Number of Sponsors	0	6.0
Totals	130		11.5	82.3
		Ecological Lift		70.8

8.9 MODEL ADVANTAGES AND LIMITATIONS

This section will describe model advantages and limitations in detail. In summary they are:

Advantages:

1. At watershed and stream segment scales, it provides a rapid and reproducible method of covering more area expeditiously;
2. Acquiring private property access is not required;
3. Planform geometry (meander wave length, radius-of-curvature, and amplitude) is easily elucidated and measured using photogrammetry especially on large rivers;
4. Watershed-scale models (SCI) can be tested, refined and finalized by re-visiting the video several times without a field excursion;
5. Land use/cover and relative riparian zone condition is more obtainable;
6. Identification of sources of pollutants and sources of accelerated sediment is easily elucidated;

7. Identification of attainable reference conditions, by establishing the reference domain of all stream segments, is more easily achievable;
8. At the valley flat scale, video assessment facilitates the potential of re-coupling adjacent wetlands to the frequent flood event;
9. The upstream and downstream effects of dams (fish barriers) can be visualized better;
10. With future flyovers, trend analysis can be conducted at watershed and stream segment scales including monitoring natural and anthropogenic changes, catastrophic events, and effects of climate change on stream hydrology and geomorphology; and
11. Video assessment provides a platform such that the general public can visualize stream corridor conditions.

Disadvantages:

1. Ecological assessments that require sampling of fish, benthic macroinvertebrates, mussels, etc. cannot be conducted. However, stream attributes that affect aquatic habitat can be assessed using low altitude video at the watershed-scale. Considering the scale of this effort and utility of readily available physical and biological data, aquatic biota databases were adequately addressed; and
2. Currently, the process of evaluating variables using video is extremely laborious and meticulous. Future computer software may reduce this level of effort.

Overall, the results of SCI-IBI scores observed in this watershed assessment can be utilized to:

1. Prioritize stream segments and subwatersheds for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts.
2. Assess proposed project alternative analysis and cost/benefit analysis.
3. Develop performance standards and success criteria applicable to restoration actions.
4. Address impacts or improvements beyond the footprint of the project.
5. Establish monitoring plans including adaptive management.
6. Forecast future ecosystem outcomes.
7. Estimate the long-term effects of climate change on ecosystem processes and functions.
8. Assess stream conditions elsewhere and compare against reference conditions established during this watershed assessment.
9. Justify proposed projects at the national significant priority scale.

The statistical treatise used in model development for the Duck Watershed can be utilized elsewhere in other physiographic areas and USACE Districts. The protocol used herein for establishing stream corridor conditions is applicable to the Tennessee River basin within Tennessee. However, the protocol can be transported to other river basins with additional beta testing and model refinement.

9.0 Watershed Plan Recommendations

The problems identified during the assessment were related to water quality, water supply, ecosystem degradation, land use, and flood risk management. The vision and strategy for carrying out the assessment was to pull all the existing data and studies into one knowledge base and determine the baseline condition of the watershed. This was achieved via the MSWA model (see Section 8.0). Knowing the baseline condition of the watershed at the HUC12 scale allows for tailored strategies for areas needing restoration or intervention the most. It also provides a unified frame of reference for water resource management in the Duck River watershed to maintain and improve the conditions in this nationally recognized resource. The following paragraphs discuss potential solutions related to the problems identified during the assessment and Sections 9.6 and 9.7 provide the recommended strategies for prioritization within the watershed.

9.1 WATER QUALITY, AQUATIC HABITAT & ECOSYSTEM

As previously discussed, the Duck River watershed is a nationally significant resource due to its richness in aquatic fauna and ability to support numerous endangered and threatened species. Aquatic habitat for fish and aquatic life has been adversely affected in many areas by reduction in physical habitat diversity (runs, pools, glides, and riffles), nutrient enrichment, embeddedness, reduction in canopy density, allochthonous material, and food chain support. The following actions can be undertaken to address problems related to water quality and aquatic habitat and ecosystem degradation.

1. Targeting sub-watersheds or stream segments for restoration, enhancement or preservation can be prioritized using two different scenarios: 1) higher ecological lift (ecosystem outcomes) potential over the entire Duck River watershed; or 2) higher ecological lift in headwaters only. For instance, if the project objective calls for restoration actions on main stem Duck River, several segments on the Duck can be assessed based on the relative SCI scores, associated ecological lift potential, and cost/benefit analysis. Cost/benefits analysis should include incorporation of the project area or length with the SCI score to calculate Stream Condition Units (SCU). SCU scores can be used in the alternative analysis to compare the cost and benefits of several candidate restoration actions to select the project that maximizes return and ecosystem outcomes (See Section 8.8.1 Future With and Without Project).

2. Form partner coalitions to leverage resources and programs to target specific problems related to water quality and ecosystem restorations. Many agencies and organizations are already working in the Duck River Watershed. By partnering together, a wider swath of issues could be addressed with pooled resources and programs. Watershed scale resource management would be the most effective if done in unison and cooperation among all involved parties. Southeast Aquatic Resources Partnership has already initiated such efforts in 2017 by bringing a multitude of stakeholders together and facilitating the dialogue. The result was several agencies working together to apply for the NRCS Regional Conservation Partnership Program (RCPP) which encourages partners to join in efforts with agricultural producers to

increase the restoration and sustainable use of soil, water, wildlife, and related natural resources on regional or watershed scales. The Duck River Agency has been leading the Water Resources Council for many years and utilized the established partnerships for water supply and drought management planning efforts. Using one lead organization to bring others together has worked in the past. Such partnerships and groups could be replicated allowing for focus on a variety of issues and specific sub-watersheds.

3. Employ sedimentation abatement measures. Streambank erosion is the largest contributor of sediment. By stabilizing stream banks and reducing accelerated sediment yield and embeddedness the aquatic habitat diversity could be restored or enhanced. Excessive amounts of sediment deposition from eroding stream banks tend to cover suitable aquatic habitat, and smother mussels. Addressing bank erosion, would improve water quality (decreased turbidity) and increase aquatic habitat for sensitive species.

Another sedimentation abatement measure is to reduce accelerated mass wasting of hillsides by restoring upland forests and grasslands and reducing impervious surfaces. Runoff carries sediment, and anything it encounters along the way. Tree canopy and dense native grasslands slow down runoff and capture rainwater onsite allowing for water infiltration and capture of nutrients and other pollutants. This also reduces erosion by slowing down overland water flow.

4. Abate nutrient loading by restoring riparian zones. Healthy riparian zone is imperative to a healthy stream. It stabilizes eroding stream banks and also acts as a filtering zone to prevent excessive nutrients and bacteria from agricultural runoff and pollutants from urban runoff to enter the stream. Vegetative buffer limits livestock from accessing the stream. Riparian zone restoration would improve water quality by reducing nutrient loads, increase dissolved oxygen and reduce algal blooms. These improvements would benefit aquatic species, water supply, and safe recreational use of the streams in the watershed.

5. Restore, enhance and protect existing wetlands and create new wetlands to reduce surface water runoff, sequester and transform nutrients and improve wetland-dependent wildlife habitat. These actions would contribute to improvement in water quality and aquatic habitat. Wetlands are able to store storm water and help alleviate some of the flooding. They are also important for recharging ground water aquifers.

6. Ecosystem restoration could be undertaken in order to look at the issues holistically as many of the water quality and aquatic habitat problems are interrelated. This effort could also target sub-watersheds with low SCI score. Specific reaches with sensitive species experiencing a decline in habitat quality could be selected for an ecosystem restoration project as well. Ecosystem restoration also provides opportunities for multiple partnerships and leveraging of resources.

7. Employ a wide array of conservation practices on agricultural lands. Efforts can be targeted to the most impaired sub-watersheds and streams. Working with land owners and the agricultural community by educating and assisting them with the best land and water resource management

practices would improve water quality, aquatic habitat, and overall health of the watershed ecosystem.

9.2 WATER SUPPLY

As previously discussed, water supply is especially important in the Duck River as it is a sole source of water to an estimated 250,000 people in the middle Tennessee region. Ample water supply is also needed to sustain nationally important aquatic species. As the region continues to grow, the demand for ample supply of good quality water will only increase. The following actions can be undertaken to address problems related to water supply:

1. Balance water supply demands among population, industry, and aquatic resources through comprehensive water supply planning in the entire watershed. The Duck River Agency (DRA), created by the Tennessee General Assembly in 1965, is a comprehensive regional development agency with a mission "to develop, protect, and sustain a clean and dependable Water Resource for all citizens of the Duck River region." In 2011, the DRA has developed a "*Comprehensive Regional Water Supply Plan for Bedford, Coffee, Marshall, Maury, and southern Williamson Counties.*" The plan encompasses the Upper Duck Watershed, which is more urbanized and developed. What happens in the Upper Duck has a direct impact to the Lower Duck watershed, therefore, a comprehensive water supply plan for the entire watershed would be beneficial. Effective water supply management and planning would require partnerships, cooperation, and shared responsibility among federal, state, and local agencies, as well as private and public parties.

2. Identify zones of groundwater discharge and prevent groundwater contamination. The underlying limestone and karst topography of the Duck River watershed requires careful consideration and management of groundwater. In karst topography, groundwater flows though weathered underground channels and rock fractures. As such, groundwater is much more prone to contamination as it does not undergo the filtration process though soil and sand layers. Groundwater is part of the overall water supply as it feeds various surface streams and water bodies. Knowing where groundwater intersects with surface water would aid water supply planning and water quality management efforts.

3. Maintain a watershed-wide drought preparedness plan. In 2013, the DRA prepared a "*Duck River Regional Drought Management Plan*", which encompassed the Upper Duck River reach. A comprehensive watershed-wide drought management plan, prepared in partnership with multiple levels of governmental agencies and local partnerships, would benefit the region and its ability to manage water during droughts, ensuring water is available both to human consumption and to sustain threatened and sensitive aquatic species.

4. Study of environmental flows for smaller watershed segments to facilitate the permitting of water withdrawals. Each segment of the Duck and Buffalo rivers used for water supply hosts different species, thus, required environmental flows could differ across stream reaches. Studying segments with known critical habitats and species would allow the estimation of

environmental flows needed and aid in decision-making pertaining to water withdrawals and discharges.

9.3 FLOODING

As previously discussed, flooding was one of the issues identified by the stakeholders. Normandy Dam in the headwaters of the Duck River is the only structure regulating water flow on the Duck River. The rest of the Duck River is unregulated and free flowing. Buffalo River, the longest non-impounded river in middle Tennessee, is also unregulated and free flowing. Flood risk is present in the communities settled along the Duck and Buffalo Rivers. The following actions could be taken to address issues related to flood risk.

1. Install and maintain “real-time” stream/rain gage stations as needed in the watershed for advance planning and estimating flood risk. Currently, there are nine stream gages in the Upper Duck, six in the Lower Duck, and only two in the Buffalo River Watershed. Stream gages provide substantial information for the development of Hydrologic and Hydraulic (H&H) modeling and aid in determining flood risk management strategies. Ensuring there are adequate numbers of gages available in key locations would aid future flood risk management strategies. Gages also provide stream flow and rain data to calibrate watershed models, verify forecasts, or trigger alarms as part of a Flood Warning System or Flood Warning and Emergency Evacuation Plan. Steam gage location typically depends on its purpose.

2. Develop Hydrologic and Hydraulic (H&H) models for the watershed or targeted communities. H&H models could be used to update FEMA’s Flood Insurance Rate Maps as part of the National Flood Insurance Program (NFIP). This would ensure that property owners have adequate flood insurance coverage. The H&H modeling would also aid in effective floodplain management as the model takes into account the changes in the floodway and floodplain. As development continues, the delineated floodway and floodplain would aid in ensuring that new construction does not occur in the 100-year floodplain and especially not in the floodway portion of the floodplain. It would also help to identify critical infrastructure currently located in the high flood hazard areas, determine appropriate measures that could be taken to reduce the risk of impacts from flooding, and improve community resilience and recovery time.

3. Improve the use of Light Detection and Ranging (LiDAR) mapping with application to flood extent and inundation zones. LiDAR technology and capabilities have improved tremendously. If a community does not have the resources to procure H&H modeling, LiDAR can serve as a substitute in floodplain and inundation mapping.

4. Reduce flood damages in the watershed by restoring floodplain/wetland connectivity to enhance surface water storage and reduce downstream flood frequency and magnitude. The Duck River watershed is still largely rural and many floodplain areas remain undeveloped or impacted. If actions are taken early to protect floodplains and wetlands, the region will fare much better in the future managing flood risk.

5. Establish consistency in floodplain management across the watershed. Inconsistent floodplain management can cause undesirable effects across the watershed. If one county or municipality is more lax on allowing development in floodplains, it can exacerbate flooding problems in other areas as flood waters would need to compensate for reduced floodplain capacity. A watershed-wide adoption of sound floodplain management principles would help manage flood risk without unduly subjecting some areas to more flooding. This effort would require engaging all floodplain managers in the watershed to work on creating and adopting a unified approach for the watershed.

6. Encourage the application of green infrastructure, pervious surfaces, and rain gardens to re-introduce surface water runoff to groundwater (recharge). There is common understanding among stakeholders that urban growth directly correlates to increased frequency and intensity of flooding. Urban development and expansion comes with an increase in impervious surface. Impervious surface is anything water cannot penetrate, such as rooftops, driveways, parking lots, streets, and buildings. When it rains, water runs across these surfaces and accumulates fast as it cannot infiltrate into the ground. As it travels across the surface, it picks up numerous pollutants (from roads, contact with vehicles, roof shingles, pet waste, and trash) that negatively impact water quality in the streams receiving the water. Green infrastructure refers to application of on site management measures and/or techniques that strive to manage water where it hits the ground allowing for infiltration, absorption, or evaporation. Examples include porous pavement, green roofs, rain gardens, grassy swales, and bio-retention basins. Green infrastructure can be implemented on large or small scales: From a sub-watershed or community scale, to individual site-specific scale. Even if green infrastructure features are slowly installed as opportunities and funding become available, benefits are realized and accumulate. Municipalities could encourage or require installation of green infrastructure on new construction sites.

7. Use engineering techniques to detain water and sediment and release water slowly to streams. In some cases, a detention basin could be beneficial to the community in reducing flood risk. Detention basins temporarily store stormwater runoff, thereby reducing the peak rate of runoff to a stream or storm sewer. They help to prevent localized flooding and, if designed to do so, provide some water quality benefits and reduce streambank erosion downstream.

8. Install Flood Warning Systems (FWSs) and develop Flood Warning and Evacuation Plans (FWEEPs) in the flood-prone communities. Most FWSs are based on a system of stream and rain gages which report data to the National Weather Service (NWS) allowing public warnings of potential flood danger to the public. The FWS allows for increased warning time and for predictions on flood crest times and flooding severity. Once the flood warning or watch is issued, individuals can then take action to protect themselves and their property. The data collected by the FWS can also be used for many other purposes: Management of reservoirs, water allocation, irrigation, water management and water quality forecasting. Communities could partner with other “commercial businesses, public utilities, and State, Federal, and local agencies to share the costs and benefits of data” (NOAA, 2012). Generally, FWSs are costly in

terms of implementation and operation and maintenance (O&M). They require a high level of commitment to maintenance and support beyond the initial installation. The NWS states that, "those with the most success have proactive, energetic staff members; strong, long term operational funding; and a good rapport with the local NWS forecast office" (NOAA, 2012). The *NOAA's National Weather Service Flood Warning Systems Manual* is the best source of information on the FWS installation and O&M.

The FWEEP is typically prepared after the FWS system is implemented and dictates actions to be taken during high water events to reduce threat to life and maintain safety of residents within a community. A typical FWEEP consists of the following parts:

1) Preparedness – activities required prior to a flood event to ensure participants have a sufficient level of readiness;
2) Flood Threat Recognition – procedures to guide city officials in defining the appropriate level of flood threat and selection of the appropriate emergency response options;
3) Warning Dissemination – procedures to notify everyone involved in responding to a flood event of the level of the threat, and the need for implementation of emergency response activities;
4) Emergency Response Actions – delineation of emergency preparedness actions for implementation, specification of general guidelines for selection of emergency response action(s), and determination of the organizational structure and procedures for implementation of each emergency response action; and
5) Post Flood Recovery Recognition – identification of activities to assure an orderly and timely re-establishment of pre-flood condition, to the greatest extent possible.

9.4 LAND USE

Land use management can be used to manage land development practices. Land use change was identified as one of the contributing stressors to the Duck River watershed impacting water quality, aquatic habitat, ecosystem, and contributing to the increase in flooding. The following actions could be taken to address issues related to land use changes and practices.

1. Improvements to local land use policies and zoning ordinances. Communities and local governments in the watershed can establish more effective land use and zoning ordinances that would address storm water runoff and infiltration, floodplain development, and preservation of green corridors along streams.

2. Conduct land use planning and trend analysis regionally. Local municipalities could work with regional planning organizations to plan for development and land use changes. Regional planning would facilitate better natural resource conservation.

3. Engage in coordinated regional economic development master planning with Nashville and surrounding metropolitan areas. As Nashville continues to grow, the southward migration towards the Duck River watershed will continue driving growth in the Upper Duck watershed.

Engaging in coordinated economic development planning would allow the region to be better prepared and to control how and where development occurs. This would ensure the Duck River ecosystem is protected from development related stressors.

4. Agricultural land use regulations, policies and practices can be used to prevent excess nutrient runoff and in-stream cattle watering. Working with landowners and educating them on available programs and assistance could lead to water quality improvements and less stress to the aquatic habitat.

5. Engage in land conservation and protection actions. These could involve the following:

- Transfer of Development Rights (TDR) is a voluntary, incentive - based program that allows landowners to sell development rights from their land to a developer or other interested party who then can use these rights to increase the density of development at another designated location.
- Purchase of Development Rights (PDR) is a voluntary farmland protection technique that compensates landowners for limiting future development on their land. PDR has been used by local and state governments on the east coast since the mid-1970s. Under a PDR program, an entity, such as a town or a private organization, purchases development rights to a piece of property. By doing so, the organization or government agency is essentially buying the landowner's right to develop that land. The land itself remains in private ownership and the landowner still retains all other rights and responsibilities associated with being a property owner.
- Conservation easement is a voluntary legal agreement between a landowner and a land trust or government agency that permanently limits uses of the land in order to protect its conservation values. Landowners retain many of their rights, including the right to own and use the land, sell it, and pass it on to their heirs. Many non-profit organizations engage in conservation easement programs, such as Land Trust Alliance, The Nature Conservancy, and others.

6. Adopt watershed-wide Low Impact Development (LID) practices. The term low impact development (LID) refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration, or use of stormwater in order to protect water quality and associated aquatic habitat.

9.5 GENERAL RECOMMENDATIONS

The following recommended actions are related to general communication, public outreach, and education. Educating public about the watershed they live in and its importance can go a long way in enlisting public's support for recommended actions.

1. Continued public and stakeholder education and involvement in watershed problems and their origins would encourage a change in behavior and practices. Even though there are already

locally organized clean-up events across multiple counties and other educational programs for local school students, the watershed needs more.

2. Communication of the Final Watershed Assessment to landowners, local public officials and elected members to foster continued dialogue. Fostering partnerships and cooperation across all levels of government and various non-profit and civic organizations is key to successful implementation of recommendations outlined in this watershed plan.

9.2 RECOMMENDATION SCREENING CRITERIA

The 26 initial recommendations have been screened initially by using constraints, judgment, and input from stakeholders, to focus on those that will contribute towards meeting the planning objectives. The measure screening criteria includes: Relevance to the shared vision statement, relevance to identified watershed problems, likelihood of implementation and complexity, and overall impact to the watershed.

9.6 PRIORITIZATION OF RECOMMENDED STRATEGIES

The potential actions and solutions to the water resource issues in the Duck River Watershed were identified and described in the sections above. Any and all of the recommended 25 solutions would be beneficial for the watershed. In order for the decision makers to pursue the recommendations and as opportunities and resources become available, the recommendations were prioritized based on the biggest impact on the watershed by the Nashville District project delivery team (including stakeholder input).

The recommendations, presented in the tables below, are scored 1 through 5, with 1 being the highest and 5 the lowest priority. Potential leads/champions for the actions were also identified to allow stakeholders to identify strategies for implementation and prioritization in their annual budget requests.

Water Quality, Aquatic Habitat & Ecosystem

Table 11 - Prioritization of Water Quality, Aquatic Habitat & Ecosystem Recommendations

Score	Recommendation	Potential Lead for this Action
1	Target efforts in HUC12 sub-watersheds with severe and major disturbance (SCI score 0.2 or less)	USACE, TNC, EPA, NRCS, TDEC, USFWS, TVA, SARP
1	Form partner coalitions to leverage recourses and programs to target specific problems related to water quality & ecosystem	SARP, USACE, TNC, NRCS, TDEC, USFWS, TVA, EPA

Score	Recommendation	Potential Lead for this Action
2	Employ a wide array of conservation practices on agricultural lands	NRCS, TNC
2	Employ sedimentation abatement measures	NRCS, TNC
4	Restore existing & create new wetlands	NRSC
1	Ecosystem restoration efforts (study & projects)	USACE, TNC, NRCS
3	Abate nutrient loading (riparian zone, limit cattle access)	NRCS

Water Supply

Table 12 - Prioritization of Water Supply Recommendations

Score	Recommendation	Potential Lead for this Action
1	Balance water supply demands among population, industry, and aquatic resources though water supply planning in entire watershed	Ongoing effort led by DRA for Upper Duck. TDEC, TVA, USACE, Municipalities, Utilities - could lead for Lower & Buffalo Watersheds.
2	Maintain watershed-wide drought preparedness plan	DRA, TVA, TDEC
1	Study of environmental flows for smaller watershed segments to facilitate permitting water withdrawals	TDEC, USGS, TNC, USACE
5	Identify zones of groundwater discharge and prevent groundwater contamination	TDEC, DRA, TNC

Flooding

Table 13 - Prioritization of Flooding Recommendations

Score	Recommendation	Potential Lead for this Action
1	Hydrologic and Hydraulic Modeling for the watershed or targeted communities	USACE, FEMA, Municipalities, USGS
3	Installation and maintenance of “real-time” stream and rain gage stations for advance planning and estimating flood risk	NOAA, Municipalities, USGS, NWS
3	Flood Warning Systems and Flood Warning and Emergency Evacuation Plans in the communities	Municipalities, NWS, USACE, USGS
1	Restore floodplain/wetland connectivity	TNC, USACE, Municipalities
2	Encourage application of green infrastructure for stormwater mitigation	Municipalities (Codes), Duck River Watershed Association, U.S. Forest Service, EPA, USACE.
4	Establish consistency in floodplain management	Municipalities, FEMA
5	Improve the use of LiDAR mapping with application to flood extent and inundation zones.	Municipalities, FEMA, USACE

Land Use

Table 14 - Prioritization of Land Use Recommendations

Score	Recommendation	Potential Lead for this Action
2	Improvements to local land use zoning	Municipalities
3	Conduct land use planning and trend analysis in conjunction with regional planning organizations to facilitate better natural resource conservation	Municipalities, USACE
2	Adopt watershed-wide Low Impact Development (LID) practices	Municipalities, combined effort
1	Engage in land conservation and protection actions (easements, TDR, PDR)	NRCS, TNC
4	Coordinated regional economic development master plans (Nashville and surrounding metropolitan areas)	Municipalities, Counties, USACE

9.7 PRIORITY RECOMMENDATIONS

After consultation with stakeholders and project sponsors, the following recommendations are considered a top priority (Table 15). This decision was made based on ongoing efforts that needed support, or actions having a high likelihood for implementation. Broader recommendations addressing connected problems were also favored. Some recommendations were thought to support multiple objectives and address interrelated problems. For example, ecosystem restoration encompasses a variety of measures and target both water quality and supply, as well as aquatic and terrestrial resources, and could include actions to address streambank erosion, runoff, riparian zones, etc.

Top Recommendations

Table 15 - Top Recommendations

Recommendation	Issues Addressed	Benefits to the Watershed
Target efforts in HUC-12 sub-watersheds with SCI score 0.2 or less	Water quality, aquatic habitat, resource conservation, ecosystem	Ongoing. Directs immediate efforts to the most critical areas. Allows for coordination of actions. Proposed impacts can be modeled to estimate effectiveness
Form partner coalitions to leverage resources & programs	Aquatic habitat, water quality, resource conservation, ecosystem, water supply	Ongoing effort lead by SARP and NRCS (RCCP program) with other partners
Ecosystem restoration efforts (study & projects)	Aquatic habitat, water quality, ecosystem	Can employ multiple measures and solutions in a larger area, than localized small scale efforts and could become a joint effort by many partners
Study of environmental flows for smaller watershed segments to facilitate permitting water withdrawals	Water Supply, water quality, aquatic habitat, ecosystem	Will facilitate permitting and regulatory actions for water withdrawals within specific reaches to account for sensitive species and resources
Hydrologic and Hydraulic Modeling for the watershed or targeted communities	Flooding	Will allow for accurate delineation of the floodway and floodplain, development of FIRMS and aid in development of future water resource projects
Restore floodplain/wetland connectivity	Flooding, water quality, aquatic habitat, ecosystem	Will allow for more water storage during flooding, increases opportunities for water infiltration, retains sediment and nutrients

Recommendation	Issues Addressed	Benefits to the Watershed
Engage in land conservation and protection actions (easements, TDR, PDR)	Land use, water quality, aquatic habitat, ecosystem, flooding	Efforts are underway and programs available. Educating land owners about the options available and benefits of conservation would boost the practice

10.0 Potential Funding Sources

Finding sources of funding and available programs is a key challenge to implementation success of the plan recommendations. The sections below present a listing of potential funding sources and available programs for each problem area, as well as the agency which manages the program.

10.1 POTENTIAL FUNDING SOURCES FOR WATER QUALITY, AQUATIC HABITAT AND ECOSYSTEM PROBLEMS

The U.S. Army Corps of Engineers (USACE):

Continuing Authorities Program, Section 206 authorizes USACE to conduct Aquatic Ecosystem Restoration projects with non-federal entities. The feasibility study cost is shared equally (50/50) and the implementation phase cost is shared 65 percent federal and 35 percent non-federal.

USDA Natural Resources Conservation Service (NRCS):

Wetlands Reserve Program (WRP) – A voluntary conservation program that offers landowners the means and opportunity to protect, restore, and enhance wetlands on their property through perpetual easements, 30-year easements, or Land Treatment Contracts. NRCS manages the program and provides technical and financial support to participating landowners.

Agricultural Management Assistance (AMA) – helps agricultural producers use conservation to manage risk and solve natural resource issues through natural resources conservation. NRCS administers the AMA conservation provisions while the Agricultural Marketing Service and the Risk Management Agency implement other provisions under AMA.

Conservation Stewardship Program (CSP) - helps agricultural producers maintain and improve their existing conservation systems and adopt additional conservation activities to address priority resources concerns. Participants earn CSP payments for conservation performance—the higher the performance, the higher the payment.

Environmental Quality Incentives Program (EQIP) - provides financial and technical assistance to agricultural producers in order to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, reduced soil erosion and sedimentation or improved or created wildlife habitat.

The Regional Conservation Partnership Program (RCPP) - encourages partners to join in efforts with producers to increase the restoration and sustainable use of soil, water, wildlife, and related natural resources on regional or watershed scales. Through the program, NRCS and its partners help producers install and maintain conservation activities in selected project areas. Partners leverage RCPP funding in project areas and report on the benefits achieved. Eligible Partners: Agricultural or silvicultural producer associations, farmer cooperatives or other groups of producers, state or local governments, American Indian tribes, municipal water treatment entities, water and irrigation districts, conservation-driven nongovernmental organizations, and institutions of higher education. Eligible Participants**:** Under RCPP, eligible producers and landowners of agricultural land and non-industrial private forestland may enter into conservation program contracts or easement agreements under the framework of a partnership agreement.

EPA Grant Community Program:

Urban Waters Small Grants (UWSG) – is a program to fund research, investigations, experiments, training, surveys, studies, and demonstrations that will advance the restoration of urban waters by improving water quality through activities that also support community revitalization, economic development, and other local priorities, with an emphasis on underserved communities. This program supports communities in their efforts to access, improve, and benefit from their urban waters and the surrounding land.

10.2 POTENTIAL FUNDING SOURCES FOR FLOODING AND FLOOD RISK MANAGEMENT

10.2.1 Hydrologic and Hydraulic Modeling, Flood Warning, Floodplain Management

There are several ways Hydrologic and Hydraulic Modeling in the Duck River Watershed could be accomplished.

Federal Emergency Management Agency (FEMA):

The Hydrologic and Hydraulic Modeling, or an update to existing models, could be developed by FEMA. This type of update would typically be undertaken when FEMA is updating the FIRMs for the area. Coordination with the state NFIP coordinator through the Tennessee Silver Jackets Program regarding this modeling update could favorably influence FEMA priorities for a FIS update in this watershed.

FEMA's Hazard Mitigation Grant Program – The HMGP provides grants to states and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the HMGP is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. The HMGP is authorized under Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act. Eligible applicants include states, local governments, Indian tribes, and private, non-profit organizations. Individual homeowners and businesses may not apply directly to the program; however an eligible applicant may apply on their behalf.

USACE:

Floodplain Management Services (FPMS) Program – The authority for FPMS comes from Section 206 of the 1960 Flood Control Act (PL 86-645), as amended. The program's objective is to foster public understanding of the options for dealing with flood hazards and to promote productive use and management of the nation's floodplains. The program develops or interprets site-specific data on obstructions to flood flows, flood formation and timing; and the extent, duration and frequency of flooding. The program can also provide assistance and guidance in the form of "Special Studies" on all aspects of floodplain management planning. Some examples include: Floodplain Delineation/Flood Hazard Evaluation Studies, Flood Warning/Preparedness Studies, Comprehensive Floodplain Management Studies, and Stormwater Management Studies. For more information on the FPMS program (Fact Sheet will be included in the final report).

Planning Assistance to States (PAS) – The PAS program authority stems from Section 22 of the Water Resources Development Act of 1974, as amended. It allows USACE to assist states, local governments, and other non-federal entities in the preparation of comprehensive plans for the development and conservation of water and related land resources. Typically, studies are only undertaken at the planning level of detail utilizing existing information. However, in some cases (such as the preparation of a Hydrologic and Hydraulic Modeling Update) new data collection is necessary. Some examples of typical PAS studies include: Water Supply and Demand Studies, Water Quality Studies, Floodplain Management Studies, and Environmental Conservation/Restoration Studies.

Continuing Authorities Program, Section 205 – Section 205 of the Flood Control Act of 1948, as amended, provides authority to the USACE to plan and construct small flood damage reduction projects not specifically authorized by Congress. A project is accepted for construction only after detailed investigation clearly shows its engineering feasibility, environmental acceptability, and economic justification. Each project must be complete within itself, not a part of a larger project. The maximum federal expenditure per project is $10,000,000, which includes both planning and construction costs. Costs of lands, easements, and operation and maintenance must be non-federal. There are two types of projects: structural and nonstructural. Structural projects may include levees, flood walls, diversion channels, pumping plants, and bridge modifications. Nonstructural alternatives, which have little or no effect on water surface elevations, might include measures such as flood-proofing, relocation of structures, and FWSs. After a state or local agency requests federal assistance, USACE will conduct a feasibility study pending potential federal interest and available funding. The feasibility study begins at federal expense. Study costs in excess of $100,000 are shared 50/ 50 with the non-federal sponsor according to a Feasibility Cost Sharing Agreement (FCSA). The recommendations of this study that fit the Section 205 authority are listed below (Fact Sheet will be included in the final report).

10.2.2 Green Infrastructure

U.S. Forest Service:

The National Urban and Community Forestry Challenge Cost-Share Program seeks to establish sustainable urban and community forests by encouraging communities to manage and protect their natural resources. The program supports an ecosystem approach to managing urban forests for their benefits to air quality, stormwater runoff, wildlife and fish habitat, and other related ecosystem concerns.

USACE:

Planning Assistance to States (PAS) – See section 10.2.1 for description and details. The PAS program could be used for green infrastructure planning. USACE could work with local decision makers to identify the locations where green infrastructure features could make the biggest impact and help to design a plan for implementation.

10.3 POTENTIAL FUNDING SOURCES FOR WATER SUPPLY

USACE:

Environmental Infrastructure, Section 219 program. – The Section 219 of the 1992 Water Resources Development Act (WRDA), as amended, authorizes USACE to assist non-Federal interests in carrying out water-related environmental infrastructure and resource protection and development projects. The projects include water supply and waste water infrastructure planning, design, and construction.

Planning Assistance to States (PAS) – See section 10.2.1 for description and details. The PAS program could be utilized for water supply planning.

10.4 POTENTIAL FUNDING SOURCES FOR LAND USE

EPA Grant Community Program:

Office of Sustainable Communities - Technical assistance is awarded by EPA's Office of Sustainable Communities intermittently throughout the year to support community efforts to improve the environmental and health outcomes resulting from land use decision making and design.

NRCS – Easement Programs:

Agricultural Conservation Easement Program (ACEP) - provides financial and technical assistance to help conserve agricultural lands and wetlands and their related benefits. Under the Agricultural Land Easements component, NRCS helps American Indian tribes, state and local governments, and non-governmental organizations protect working agricultural lands and limit non-agricultural uses of the land. Under the Wetlands Reserve Easements component, NRCS helps to restore, protect and enhance enrolled wetlands.

Healthy Forests Reserve Program (HFRP) - assists landowners, on a voluntary basis, in restoring, enhancing and protecting forestland resources on private lands through easements, 30-year contracts and 10-year cost-share agreements. The objectives of HRFP are to: 1) Promote the recovery of endangered and threatened species under the Endangered Species Act (ESA); 2) Improve plant and animal biodiversity; and 3) Enhance carbon sequestration.

10.5 POTENTIAL FUNDING SOURCES FOR GENERAL RECOMMENDATIONS

EPA Grant Community Program:

Environmental Justice Small Grants Program - provides financial assistance to eligible organizations to build collaborative partnerships, to identify the local environmental and/or public health issues, and to envision solutions and empower the community through education, training, and outreach.

11.0 Conclusions

The Duck River Watershed is a nationally significant water resource supporting a remarkable biodiversity of aquatic species. Continued development and growing water supply demands are presenting a challenge to manage water resources among competing uses. The Duck River Watershed Plan uses a scientific approach to document the baseline condition of the watershed by utilizing existing data and performing statistical analysis to develop a Multi-Scale Watershed Approach for ecological modeling. The model and the watershed plan recommendations can be used for managing water resources in the Duck River Watershed by providing a tool and framework for federal, state, and local governmental agencies, non-profit organizations and other public entities to prioritize funding to improve the resources within the watershed. Section 10 provided a summary of Federal funding resources that local stakeholders could use to collaborate and implement the recommended strategies using the appropriate federal expertise in combination with local experience.

12.0 References

NOAA. (2012). *NOAA's National Weater Service Flood Warning Systems Manual.* Washington, DC: NOAA.

Palmer, S. R. (2008). Averting Water Supply Crisis While Protecting Endangered Species: Partnerships Pay Off for Tennessee's Duck River. *American Water Works Association*, 40-43.

USACE. (2012). *Cumberland and Duck River Basins: May 2010 Post Flood Technical Report.* Nashville: USACE.

Appendix A – MSWA Documentation

Model Documentation

Multi-Scale Watershed Approach
Duck River Watershed Assessment, Tennessee

(Bruce A. Pruitt, K. Jack Killgore, W. Todd Slack, and L.E. Miranda)

Abstract. Pursuant to Section 729 of the Water Resources Development Act of 1986 (as amended), a Watershed Assessment Plan was developed for the Duck River watershed located in the Interior Plateau, Tennessee. The overarching goals of the Duck River Watershed Plan were to evaluate the stream corridors in regards to establishing current (baseline) conditions and identifying water resource problems, needs and opportunities. The study area, which is within the Tennessee River Drainage Basin, included the Duck and Buffalo River watersheds, HUC 8 – 06040002 & 003 and 06040004, respectively. The drainage area of the Duck watershed encompasses 3,493 square miles (approximately 2,730 and 763 sq. mi. in the Duck and Buffalo drainages, respectively). A knowledge base was developed by compiling and analyzing biological and geomorphological data across HUC 12 watersheds from existing databases of fishes, mussels, aquatic habitats, and benthic macroinvertebrates. Additional stream data collected from low altitude, high resolution video, as well as a final subset of eleven of 18 stream geospatial test variables, collected on 213 stream segments, were subjected to statistical analysis. An ecological model, stream condition index (SCI), was formulated based on the degree of statistical correlation (dependency) between the variables. Each of the 64 HUC12 watershed were classified by averaging the model scores of the stream segments within the watershed. Forty-six of the 64 watersheds were experiencing major to severe ecological disturbance compared to 15 watersheds experiencing minimal to minor ecological disturbance. Only three watersheds were considered relatively undisturbed (attainable reference conditions). However, based on interpretation of low altitude video, 15 stream segments were considered reference quality. In addition to the analysis of geospatial data, fish IBI scores were evaluated based on twelve metrics which addressed species richness and composition, trophic structure, fish abundance, and fish condition. Scores for the twelve metrics were summed to produce the IBI value for the site. By comparing the SCI to fish Index of Biotic Integrity (IBI) scores, aquatic biota impairment was predominantly due to loss of streamside canopy, reduction of in-stream cover, and impacts to channel stability, all of which were considered to be the limiting factors to sustaining a healthy aquatic ecosystem in the Duck River watershed. The findings of this study can be used to: 1) prioritize watersheds for restoration, enhancement and conservation, 2) plan and conduct intensive ecosystem studies, justify significant project prioritization, and 3) assess ecosystem outcomes applicable to future with and without restoration actions including alternative, feasibility, and cost/benefit analyses.

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INTRODUCTION

Setting. Located south of Nashville, Tennessee, the study area was the Duck River watershed (hereinafter referred to as, "Duck Watershed") which is part of the Interior Plateau (71) Ecoregion. The Duck Watershed extends through four Level IV Ecoregions: Western Highland Rim (71f), Eastern Highland Rim (71g), Outer Nashville Basin (71h), and Inner Nashville Basin (71i) (Figure 1). The study area, which is within the Tennessee River Drainage Basin, includes the Duck and Buffalo River watersheds (Hydrologic Unit Codes, HUC 8 – 06040002 & 003 and 06040004, respectively). The confluence of the Buffalo and Duck Rivers is approximately 12.7 miles upstream of the Tennessee River. The drainage area of the Duck Watershed encompasses 3,493 square miles (approximately 2,730 and 763 square miles in the Duck and Buffalo drainages, respectively).

The Duck River is home to one of the most diverse freshwater faunas in North America (Schilling and Williams 2002; Ahlstedt et al. 2004). The basin includes more species of fish than all European rivers combined, and higher species richness per kilometer than any other river in North America. Overall, the Duck River supports a remarkable fish biodiversity, including approximately 150 species (Etnier and Starnes 1993). The Nature Conservancy states that the Duck River is North America's richest river in variety of freshwater animal species, and in addition to fish, includes 60 freshwater mussel species and 22 species of aquatic snails. (http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/tennessee/placeswe protect/duck-river.xml).

Background. This study was undertaken by the USACE Nashville District and the USACE Engineer Research and Development Center (ERDC) as an integral part of the Duck River Watershed Assessment under the Section 729 of the Water Resources Development Act (WRDA) of 1986. The purpose of the assessment was to develop a Watershed Plan that identified existing conditions within the watershed, detailed the major water resources problems and opportunities in the watershed, and recommended tools and a strategic course of action for achieving desired conditions in the watershed. Paramount to assessing the Duck Watershed across various degrees of ecological impairment (at different spatial scales), a model was formulated to determine existing conditions, identify problems in the watershed, and recommend future spin-off projects for USACE or other agencies. The effort represents a new method for assessing ecosystems, using multiple attributes across multiple scales, referred to as the "Multi-Scale Watershed Approach (MSWA). The concept behind the MSWA was to establish a means of utilizing existing data to create a comprehensive knowledge base collected by multiple agencies and stakeholders. The outcome of MSWA can become the principle component of the decision-making process, so that water resource managers can make scientifically defensible decisions, not only at project specific scales, but also beyond the footprint of the project to the entire watershed. From a watershed perspective, cause and effect relationships between land use, water quality and quantity, in-channel and riparian conditions, and biotic responses culminate at a single point from the watershed and represent the ecological condition of the watershed. In addition, assessment at the watershed scale offers advance planning including design, construction, operation, maintenance, repair, replacement, and restoration of aquatic ecosystems.

Multi-Disciplinary Team. A Duck Watershed workshop was held in February 2015, which was attended by the Project Delivery Team (PDT) and stakeholders. Problems and opportunities and study goals and objectives were discussed at the workshop. The PDT membership was composed of the Project Manager, Ramune Matuliauskaite-Morales, Craig Carrington, and Joy Broach (USACE, Nashville District, Planning), Tim Wilder (USACE, Nashville District, Regulatory, former Principle Investigator), Bruce Pruitt, current Principle Investigator, Jack Killgore, and Todd Slack (USACE, ERDC). Steve Miranda, USGS Cooperative Unit at Mississippi State University, assisted in data analysis and reporting. Stakeholders included representatives from the Tennessee Department of Environment and Conservation, the Duck River Agency, the Nature Conservancy, and the Tennessee Valley Authority. Bob Wallus, former employee of TVA and one of the developers of the IBI, was present as a technical expert. Subsequent webinars were held on June 12, 2015, February 8 and 22, 2016, and September 22, 2016. Since August 2015, regularly-scheduled, semi-monthly conference calls have been organized and attended by the PDT. Consequently, the process of data acquisition, reduction, analysis, and interpretation has been well vetted by the PDT, leading to the formulation and testing of the stream condition model, which is the subject of this Model Documentation.

Project Goals. The overarching goals of the Duck River Watershed Plan were to establish current (baseline) conditions in representative stream corridors and identify water resource problems, needs and opportunities. The results of the Plan will be utilized to: prioritize watersheds for restoration, enhancement and conservation, plan and conduct ecosystem studies, and assess ecosystem outcomes applicable to future with and without restoration actions, including alternative, feasibility, and cost/benefit analyses.

Project Objectives. Study objectives identified during the Duck Watershed workshop which were supportive of the above project goals included:

1. Consolidate pertinent literature references and databases into a knowledge base applicable to assessment of current and future land use and impacts from potential actions within the Watershed;
2. Identify watersheds at the HUC 12 scale and stream segments that need additional intensive studies;
3. Identify the cause and source of pollution including accelerated erosion, sediment transport and deposition, and habitat loss or impairment;
4. Establish attainable reference conditions at both watershed and stream segment scales;
5. Prioritize watersheds and stream segments for restoration, enhancement, and conservation;
6. Identify stream reaches conducive to development of an information/educational component; and
7. Provide recommendations on long-term monitoring and condition trajectories.

In order to successfully accomplish the above objectives 2 through 5 above, a model called the stream condition index (SCI) was formulated. The SCI was the basis for classifying and ranking the HUC12 watersheds, identifying the causes of stream impairment, establishing the relationship between problems and opportunities, and prioritizing the watersheds for future intensive studies and restoration potential.

METHODS

Several steps were undertaken to formulate and document a mathematical model (algorithm) that could be used to achieve the project objectives, as discussed below (Figure 2).

Literature Review & Knowledge Base. A subset of references from the Duck Watershed Plan applicable to model approval is included below. A knowledge base is a body of knowledge that formally organizes entities of interest and their relation to each other in a logical framework that allows inferences about a particular problem. The knowledge base links datasets in a structural format that facilitates the cause and effect relationship. Several databases were compiled, reviewed, and reduced into a knowledge base pertinent to the overall Duck Watershed Plan, as well as for this model approval process, as follows:

1. TVA Fish IBI data (83 stations, sampled repeatedly, n = 214);
2. National Hydrography Dataset;
3. Low altitude video (600 GB, 213 video segments across 64 of 92 HUC 12 watersheds);
4. Numerous geospatial data sources;
5. USACE National Dam Inventory; and
6. NRCS Web Soil Survey and SSURGO.

Stratify by Ecoregions and Watersheds. The Duck Watershed extends through four Level IV Ecoregions: Western Highland Rim (71f), Eastern Highland Rim (71g), Outer Nashville Basin (71h), and Inner Nashville Basin (71i) (Figure 1). In an effort to control for this level of natural variability the Duck Watershed was stratified by these four ecoregions (Figure 3) and further subdivided into 92 Hydrologic Unit Maps (HUC 12) watersheds (Figure 4) (Griffith et al., 1998 and Seaber et al., 1994).

Stream Condition Index. The objective of the stream condition index was to develop an ecological model formulated from low altitude video cinematography that could be used to assess the overall condition of the stream corridor including the riparian zone. Consequently, a Stream Condition Index (SCI) was developed from interpretation of the Red Hen™ video (Red Hen™ helicopter video shot at approximately 400 feet altitude). The low altitude flyover was conducted during February 2014, provided an opportunity to assess physical geospatial data related to natural, as well as probable stressors (Figure 5). The length of the stream segments varied with the duration of the video clip. However, the scores of each of the video clips were averaged per HUC12 to ameliorate for this variation. Prior to selection and documentation of model variables, the utility of this low altitude video was evaluated and found to be adequate to be included in the proposed model.

Eighteen physical features were identified and tested that represented stream and riparian zone conditions, as follows:

1. Stream and valley classification;
2. Channel and vegetative riparian zone width;
3. Evidence of accelerated bank failure;
4. Evidence of head cutting;
5. Evidence of accelerated sediment deposition and embeddedness;
6. Evidence of active versus abandoned floodplain;
7. Presence and distribution of large woody debris;
8. Land use and cover of the adjacent valley flat (e.g., pasture grazing, crop production);
9. Location and extent of rills and gullies;
10. Dredging operations;
11. Channelization and de-snagging;

12. Unrestricted cattle access to stream channel;
13. NPDES outfalls and discharges from MS4 areas;
14. Impoundments and low flow dams;
15. Discharges from dairies and confined/concentrated animal feeding operations;
16. Commercial and residential properties near the stream channel;
17. Adjacent landfills; and
18. Silviculture and logging road construction/maintenance.

The above features were tested based on competency in regards to identification from aerial video, ability to discriminate between stream segments and watersheds, and capacity to determine departure from attainable reference conditions (discussed below).

Attainable Reference Conditions. In order to develop a gradient of impacts from which departure from reference conditions can be assessed in the Duck Watershed, it was essential to establish attainable reference conditions based on aquatic diversity and habitat (*sensu* Stoddard et al., 2006). Types of reference conditions can be on-site or off-site analogs, historical, constructs, or derived by creating a regional index. Reference sites provide a scale, against which, to compare the condition of other sites. In addition to establishing achievable performance standards, it is paramount to monitor analog reference sites in conjunction with restoration sites is to understand variation with respect to normal seasonal fluctuations, drought, climatic changes and catastrophic events (*force majeure*) which may not accurately reflect the cause of success or failure in response to restoration actions.

In order to determine departure from reference conditions, reference watersheds and associated stream segments were identified within each HUC 12 watershed, if present. If the natural variation associated with the attributes across reference watersheds were insignificant, the reference watersheds were aggregated for comparison against other watersheds that were considered impaired. Watersheds with similar types and degree of impairment were aggregated, as well.

IBI Database. The TVA has been collecting fish data in the Tennessee River system since 1986 and developed an IBI to monitor trends of the fish community following assessment of biotic integrity using fish communities (Karr 1981). TVA established fixed and random monitoring stations to evaluate the watershed and levels of human alterations such as point-source discharge and non-point source runoff. Sites sampled repeatedly were considered “end of the pipe” monitoring stations to evaluate long-term trends. The Duck and Buffalo Rivers were sampled most frequently. The IBI database was provided by TVA (Evan Crews and Terry O’Quinn) along with descriptions of the protocols used in data collection.

Sampling Methods. Sampling occurred in the spring and summer of each year. Juvenile and adult fish were targeted (i.e., young-of-year were not sampled). All captured fish were sorted by species, counted, examined for anomalies, and released; voucher specimens were retained as well. Sampling crews characterized each site as either riffle, run, or pool. In smaller, wadable streams, two techniques were used: seine hauling and backpack shocking into the seine. Seine hauling was used to sample shallow pool and run habitats that were relatively free of boulders, snags, or other obstacles that could have fouled the seine. Backpack shocking into the seine was used in riffle and run habitats. This was accomplished by positioning the seine perpendicular to the stream flow and shocking a predefined area downstream to the seine. Stunned fish drift downstream and into the seine. The area sampled by either technique is calculated as the width of the seine times the length of the transect hauled or shocked. A backpack shocker and dip net were used to collect fish from around logs, boulders, undercut banks, and brush piles in shallow water. The area sampled was calculated by multiplying the length (ft) of the shocking run times the effective width sampled (e.g., two feet). A boat-mounted, 230 volt DC generator was used to sample deep pool areas. A ten-minute shocking run was made in a downstream direction which allowed stunned fish to rise to the surface in front of the boat. Sampling efforts alternated between mid-channel and shoreline habitat.

Five minutes of boat shocking was considered equivalent to the effort spent sampling 300 square feet area (Each10 minute boat shocking run is considered equivalent to two units of effort). With the exception of shoreline, habitats were sampled until three consecutive units of sampling effort produce no additional species for that habitat. Shoreline habitat, which overlaps the other three habitats, was sampled until a shocking effort stunned no new species in the site. A unit of sampling effort covered 300 square feet (e.g. 15 ft by 20 ft) in streams averaging more than 15 feet in width. In narrower streams, each sample effort covered an area 10 feet times the average width (e.g., 10 ft by 8 ft for an 8 ft wide stream).

IBI Metrics. TVA developed the index of biotic integrity (IBI) as an environmental assessment tool following the procedure of (Karr 1981). Twelve metrics addressed species richness and composition, trophic structure, fish abundance, and fish condition (Table 1). Each metric reflected the condition of one aspect of the fish community and was scored against expectations under reference conditions. Potential scores were 1-poor, 3-intermediate, or 5-the best to be expected. Scores for the 12 metrics were summed to produce an IBI for the site. The IBI was then classified using the scoring system developed by Karr et al. (1986), by which we rated the sites from “Very poor” to “Excellent” (Table 2).

Designations for tolerance, trophic guilds, and spawning guild for scoring metrics 5 through 9, and 11 were based on ecological information presented by Balon (1975), Pflieger (1975), Smith (1979), Lee et. al. (1980), Etnier and Starnes (1994), and on professional judgment of TVA biologist. Alternate metrics for metrics 2, 3, 4, and 11 (Table 1) were prescribed for use in perennial headwater streams located at elevations under 1,800 feet. Headwater streams were defined as: Ridge and Valley Ecoregion and Interior Plains Ecoregion streams having less than five square miles of drainage area, Blue Ridge Ecoregion streams having less than 10 square miles of drainage area, and Southwestern Appalachian Ecoregion streams having less than 100 square miles of drainage area. Naturally low fish diversity found in these streams reduced the accuracy of the four original metrics. Alternative metrics 2, 3, and 11 measured ecological parameters comparable to those measured by the original metrics. Alternate metric 4 (percent compositions by the two most dominate species) was taken from Kerans et al. (1994) and was considered a more sensitive version of metric 7 (percent of fish identified as pollution tolerant species). This metric was chosen to be an alternative metric because disturbed fish communities in headwater streams are sometimes dominated by opportunistic species (*Cottus* sp., *Rhinichthys* sp., *Campostoma* sp., etc.) rather than being dominated by species defined as tolerant.

IBI and SCI Relationships. A subset of IBI sites corresponded to locations where both Red Hen video and Stream Condition Index metrics were quantified (n=51). We compared species abundance to SCI and IBI metrics among sites using non-metric multidimensional scaling of Bray-Curtis similarity matrices of fourth-root transformed data (Primer, Version 6, Plymouth, UK). Rotational vector fitting was used to relate SCI metrics to the fish assemblage and IBI metrics.

Vectors represent the direction and magnitude of correlation between the environmental variables and fish assemblage structure (Pease et al 2011). All multivariate analyses were performed using PRIMER ver. 6.1.8 (PRIMER-E Ltd™, Plymouth, UK) with the PERMANOVA+ add-in (vers. 1.0.1; Anderson and Gorley 2007).

Along with vector fitting, Pearson correlation coefficients were calculated between the IBI and SCI metrics to select those with highest correlation. We quantified relationships and obtained a predictive algorithm between the SCI and IBI metrics using Quantile regression, which is, a non-parametric method for modeling response variables when assumptions of ordinary least squares regression are not met,. Quantile regression is recommended for wedged-shaped distributions, a condition likely to occur in ecological relations (Cade et al., 1999). Quantile regression was used with the Wald statistic to test the null hypothesis that the slope is zero (SAS Institute Inc., 2005). Quantile regression models were extended to the 90th conditional quantiles to represent the upper edge of the wedge-shaped distribution and an algorithm from the regression parameters was developed. The 90th quantile supports the hypothesis that habitat is capable of limiting populations and that numerous other factors often further limit populations below what the habitat could support (Terrell et al. 1996).

RESULTS AND DISCUSSION

SCI Metrics. Based on the results of initial testing of the above stream and valley attributes, eleven variables were selected that represented stream and valley conditions (see Table 6 for variable definitions):

1. Channel stability (CS);
2. Hydrologic alteration (HA);
3. Riparian zone (RZ);
4. Bank stability (BS);
5. Water color (WC);
6. Nutrient enrichment (NE);
7. Fish cover (FC);
8. Pools (P);
9. Canopy closure (CAN);
10. Cattle access (CA); and
11. Embeddedness (EMB).

Because of the similarity between the above variables and the NRCS Stream Visual Assessment Protocol (SVAP) (USDA, 1998), we adapted the SVAP to suit assessment of low altitude video (See Table 6 for variable descriptions). The following modifications to the SVAP were made:

1. Direct observation of insect/invertebrate habitat was not used. However, remote observations of embeddedness functioned as an indirect or surrogate to aquatic habitat condition.
2. Given the remote assessment, salinity could not be measured.
3. “Macroinvertebrates observed” was omitted because it could not be collected remotely by the aerial video.

Model Formulation. A total of 213 video segments across 64 of 92 HUC 12 watersheds were evaluated using the eleven chosen variables (see spreadsheet included, Low_Altitude_

Video_Assessment.xlsx). The model was formulated using a modification of the stream visual assessment protocol which included 12 of the 15 variables in SVAP (USDA 1998). The SCI model was formulated by inspection of ordinations (similarity) and correlations, as follows. Significant correlations were determined based on our regression analysis (F-test, $p < 0.01$) (Table 3). The values of each of the variables were subjected to Spearman's r correlation and tabulated in a product matrix (Table 4). Direct and indirect correlations were summarized (Table 5). The effect of embeddedness which was observed to correspond to nine of the other ten model variables is noteworthy. No significant correlations were observed between dams and other variables, thus it was not used in the model. Consequently, the following variables represent eleven of the 15 variables recommended by USDA (1998). The aforementioned statistical analysis was used to formulate the stream condition index (SCI), where:

$$\mathrm{SCI} = \frac{\left(\sqrt[3]{\mathrm{CS} \times \mathrm{FC} \times \mathrm{P}} + \sqrt[3]{\mathrm{RZ} \times \mathrm{BS} \times \mathrm{CAN}}\right) / 2}{\left(\mathrm{HA} + \sqrt[3]{\mathrm{WC} \times \mathrm{NE} \times \mathrm{EMB}} + \mathrm{CA}\right) / 3}$$

Where:
CS = Channel Stability
FC = Fish Cover
P = Pools
RZ = Riparian Zone
BS = Bank Stability
CAN = Canopy Density
HA = Hydrologic Alteration
WC = Water Color
NE = Nutrient Enrichment
EMB = Embeddedness
CA = Cattle Access

Each variable was rated with a value from 0 to 1.0 (Table 6). More detailed narrative descriptions of the variables, including recommended visual observations, are provided in the MSWA User Guide.

As herein-used, ecological models are empirical equations that express a relationship or correlation based solely on observation rather than theory. An empirical equation is simply a mathematical statement of one or more correlations in the form of an equation. In this case, the correlations were observed to be positive (direct) or negative (indirect) (Table 4). The significance and strength of the correlation was determined by inspecting the p-values of the statistical t-test (Table 3). In turn, the variables were observed to be dependent or independent with respect to one another. For example, channel stability (CS) is highly correlated with fish cover (FC) and pools (P). Consequently, the three variables are considered dependent variables, and the geometric mean of the three variables is derived. The direct or indirect correlations between model variables are summarized in Table 5. The observed interaction between variables occurs when the simultaneous influence of two measures on a model score is not additive. "Interaction" is analogous to dependence where a variable has a statistically significant influence on other variables. In addition, variables used in the numerator of the equation had a positive effect on the overall SCI score. In contrast, variables used in the denominator had a negative effect on the SCI score. For example, when hydrologic alteration (HA) is high, the SCI score is reduced.

Attainable Reference Conditions. Reference conditions were identified based on model scores and video photogrammetry. Reference conditions were identified in only fifteen of 213 video segments (Table 7). However, by constructing a reference state composed of the reference conditions we had identified, a reference standard consists of a stream with minimal bank failure, natural planform, low embeddedness, high canopy shading and a relatively broad forested riparian zone.

Application of Stream Condition Index. Video segments (n=213) across 64 of 92 HUC 12 watersheds were evaluated using the eleven variables listed above. SCI scores were calculated from average variable scores of video segments within each of the 64 watersheds and mapped in Figure 7. Forty-six of the 64 watersheds were considered to exhibit major or severe disturbance to biotic and abiotic attributes. Eleven of the 64 watersheds were considered to exhibit minor disturbance to biotic and abiotic attributes, and seven of the 64 watersheds exhibited minimally disturbed to relatively undisturbed condition.

SCI – IBI Comparison. Ordination of fish species abundances among sites showed a discernible pattern among IBI ratings, with lower reaches clearly separated from excellent reaches (Figure 8). Vector fitting indicated that sites with higher IBI ratings were associated with greater canopy and channel stability, while sites with lower IBI ratings occurred at sites with higher water color (less transparency), nutrient enrichment, embeddedness, and hydrologic alteration. Correlations between SCI and IBI metrics were also examined (Table 8). Six of the SCI metrics were significantly correlated with one or more IBI metrics. Number of darter species was negatively correlated with canopy and pools, which generally occurred in the lower reaches where darters were less common. Intolerant species were negatively correlated with pools and water color and with characteristics of lentic habitats closer to the mouth of river systems. Number of sucker species (per sample station) had the largest number of significant correlations suggesting they are good bioindicators. This taxonomic group was strongly, negatively correlated with canopy, channel stability, and pools. Since both darters and suckers are rheophlic species, lentic habitats (such as pools) are likely avoided by them, particularly if other impairments, such as hydraulic alterations have occurred. Suckers were positively associated with degree of embeddedness, possibly because they tend to be associated with food types that may occur in depositional habitats. Data suggest that loss of canopy and fish cover influence several IBI metrics at once. Pools were also highly negatively correlated with many IBI metrics, indicating the importance of riffle-glide systems in supporting a diverse array of riverine species.

Bivariate plots of SCI (normalized to 0 to 1) and IBI ratings showed a wedge-shaped distribution (Figure 9), suggesting that anthropogenic changes in habitat quality act as a limiting factor in fish populations. Wedge-shape bivariate relationships violate the assumptions of ordinary least squares regressions and are better described by quantiles of the dependent variable (Dunham et al 2002). An advantage of using quantile regression to model heterogeneous variation in response distributions is that there is no specification required as to how variance changes are linked to the mean, nor is there any restriction to the exponential family of distributions (Cade and Noon 2003). We developed an algorithm to predict SCI as a function of IBI score (Figure 9). This relationship indicated that the IBI score can predict SCI or vice-versa, which provided a tool for us to predict both stream conditions and status of the fish assemblages.

SCI Verification. In order to test the competency of assessment and our interpretation of the low altitude, high definition video, a preliminary set of 18 possible variables were tested on video clips that represented a sample set of the total video clips (213). The test set was reduced to twelve variables that were then intensively assessed as described above in the Methods section entitled, "Stream Condition Index". Next, the SCI was verified using ground-truthing. The method was assessed during the week of August 22, 2016 at 20 fish IBI stations that had also been videoed. A significant difference was observed between the paired sets of SCI scores, or low-altitude video vs. on-ground (surface) assessments ($\chi^2 = 0.0049$, $\alpha = 0.05$). The difference was due to the bridge affect associated with the surface assessments. In addition, since the video segments were averaged within each HUC12, the final scores represented a more complete depiction at the watershed scale which was the overall objective of the effort.

Sensitivity Analysis. The SCI model was tested to ensure that it was capable of addressing a full range of model inputs (variables) by using a partial sensitivity analysis, the most commonly used approach. A partial sensitivity analysis uses alternative values for individual key model inputs (variables). The process involves various ways of changing input variables of the model to see the effect on the output value (SCI score). Several scenarios were tested by subjecting: (1) one variable to the range of possible input values, while keeping the other ten variables constant; (2) two variables to the range of possible input values, while keeping the other nine variables constant; (3) multiple variables with positive correlations (Table 4) to the range of possible input values, while keeping the other variables constant; (4) multiple variables with negative correlations to the range of possible input values, while keeping the other nine variables constant; and (5) multiple variables with positive and negative correlations to the range of possible input values, while keeping the other variables constant. Based on each of the aforementioned treatments, a complete range of SCI scores (0 to 1.0) was observed.

CONCLUSIONS

A total of 213 video segments across 64 of 92 HUC 12 watersheds were evaluated. The use of low altitude, high definition video provided several advantages and disadvantages, listed below:

Advantages

1. Provides a rapid and reproducible method of covering more area expeditiously at watershed and stream segment scales;
2. Access to private property is not required;
3. Planform geometry (meander wave length, radius-of-curvature, and amplitude) was easily measured using photogrammetry, especially useful on the larger rivers;
4. Watershed-scale models (SCI) could be tested, refined and finalized by re-visiting the video several times without another field excursion;
5. Land use/cover and relative riparian zone condition was more-easily obtainable;
6. Pollutant sources, including accelerated sediment sources, are easily identified;
7. Identification of attainable reference conditions, by establishing the reference domain of all stream segments, was more easily achievable;
8. At the valley flat scale, video assessment helped visualize the potential for re-coupling adjacent wetlands to the frequent flood event;
9. Facilitates visualization of upstream and downstream effects of dams (fish barriers);

10. With future flyovers, trend analysis could be conducted at watershed and stream segment scales including monitoring natural and anthropogenic changes, catastrophic events, and effects of climate change on stream hydrology and geomorphology; and
11. Video assessment provided a platform for the general public to visualize stream corridor conditions.

Model Assumptions and Limitations

1. Ecological assessments that require sampling of fish, benthic macroinvertebrates, mussels, etc., cannot be conducted via video photogrammetry. However, stream attributes that affect aquatic habitat can be assessed using low-altitude video at the watershed-scale. Considering the scale of this effort and utility of readily available physical and biological data, aquatic biota databases were adequately addressed;
2. Low altitude video assessment was for qualification only.
3. Averaging scores within HUC12 watershed assumes a central tendency of the stream segments which does not account for a continuum of impacts and recovery.
4. Video interpretation is bias based on the experience and background of the interpreter.
5. Currently, the process of evaluating variables using video is extremely laborious and meticulous. Future computer software may reduce the level of effort required for this assessment.

Ecological models, such as the Stream Condition Index (SCI), help define problems, lead to a better understanding of the correspondence between biotic and abiotic attributes of an aquatic ecosystem, provide analytical tools to enhance data interpretation, enable comparisons between and across ecosystem types and physiography, and facilitate communication about ecological processes and functions across scientific disciplines and to the public. In addition, a process-based approach was applied to this effort that identified critical processes and pathways in regards to the cause and effect relationship between geospatial data and aquatic biota.

The SCI provided an excellent method of rating watersheds based on their valley land use and cover, riparian zone condition, stream geomorphology, stream bedform and habitat diversity, and water quality conditions. The SCI was formulated using statistical methods, consequently, reducing bias and subjectivity (Tables 3 and 4). Based on the SCI scores calculated across 64 HUC 12 watersheds, the following can be concluded:

1. Sediment in the form of embeddedness was the predominant cause of aquatic habitat loss. Embeddedness affected nine of the other ten variables (Table 5). Embeddedness was indirectly correlated to degree of channel and bank stability, riparian zone condition, and canopy closure, and directly related to hydrologic alteration, water color and nutrient enrichment.
2. Agricultural practices and cattle access contributed to bank failure and erosion leading to high sediment loadings as evidenced by the condition of the riparian zone and bank stability indices.
3. As evidenced by reduction in fish cover and pools, fish and aquatic benthic habitat were adversely affected by degree of embeddedness, hydrologic alteration, and nutrient enrichment.

Based on the direct relationship between SCI and IBI scores, the biotic condition of the stream can be estimated from the SCI score. This is more important because establishing biotic response variables is difficult and expensive. Consequently, by conducting a visual assessment of stream condition using the SCI, conclusions can be made regarding fish diversity and distribution within a stream segment or a watershed. Overall, the results of SCI-IBI scores observed in this watershed assessment can be utilized to:

1. Prioritize stream segments and watersheds for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts.
2. Assess proposed project alternative analyses and cost/benefit analyses.
3. Develop performance standards and success criteria applicable to restoration actions.
4. Address impacts or improvements beyond the footprint of the project.
5. Establish monitoring plans, including adaptive management.
6. Forecast future ecosystem outcomes.
7. Estimate the long-term effects of climate change on ecosystem processes and functions.
8. Assess stream conditions elsewhere and compare them against reference conditions established during this watershed assessment.
9. Justify proposed projects at the scale of nationally significant priorities

. The protocol used herein for establishing stream corridor conditions is applicable to the Tennessee River basin within Tennessee. However, the protocol can be transported to other river basins with additional beta testing and model refinement. Therefore, the statistical treatise used in our model development for the Duck Watershed can be utilized elsewhere in other physiographic regions and USACE Districts.

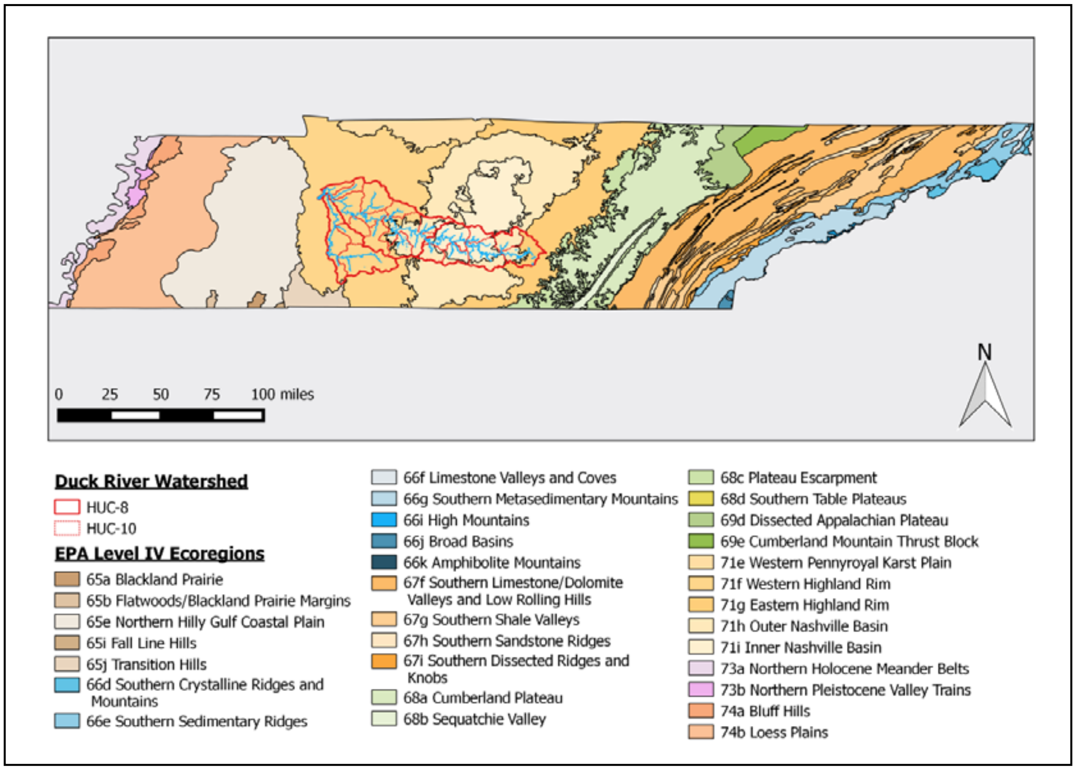

Figure 1. Tennessee Level IV Ecoregions depicting Duck River Watershed (demarcated in red).

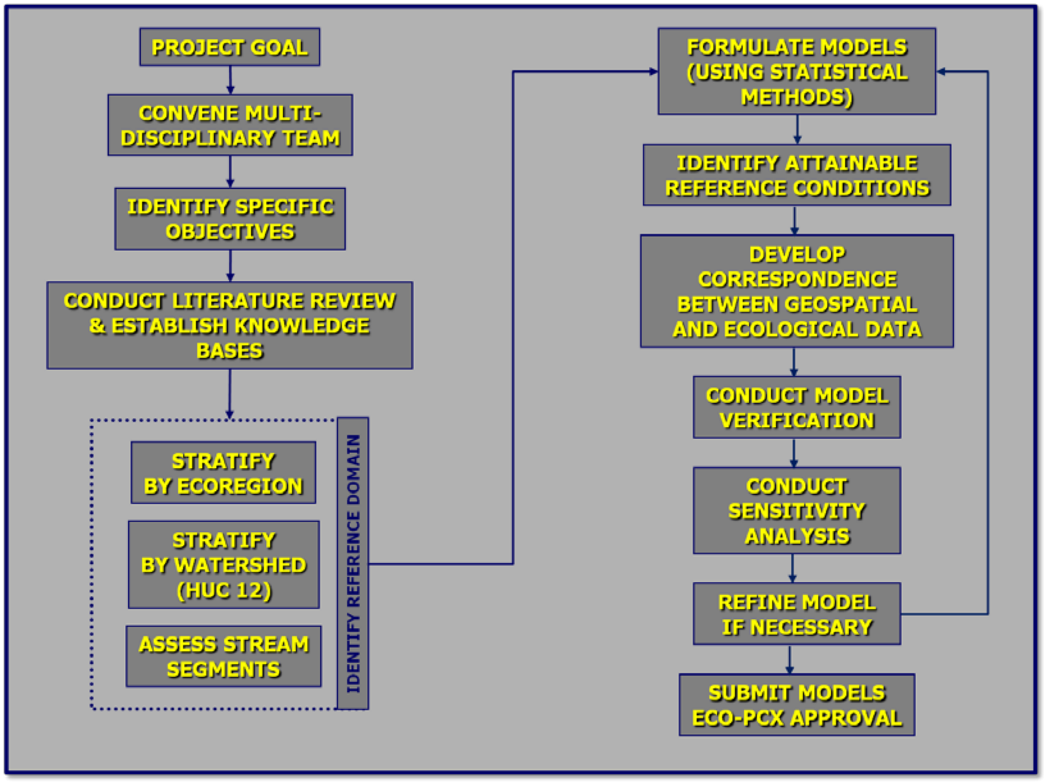

Figure 2. Model development process.

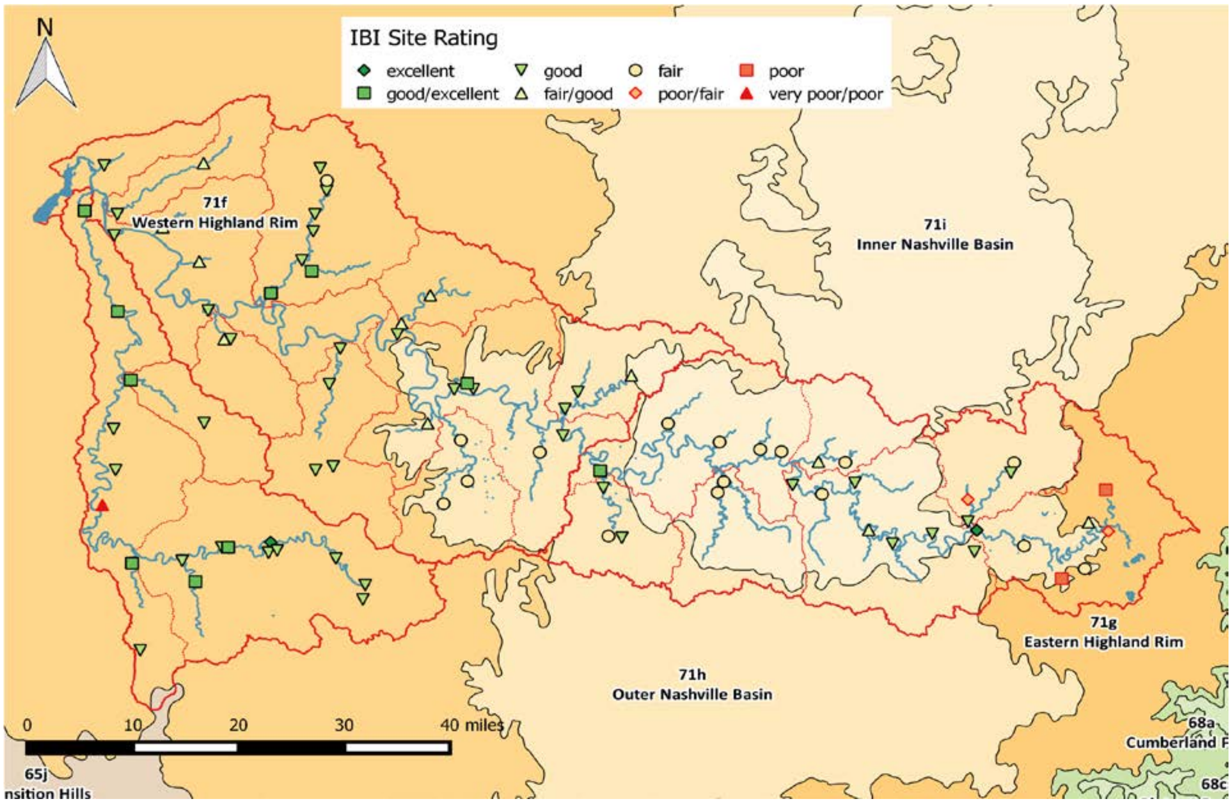

Figure 3. Level IV Ecoregions and HUC 10 watersheds depicting fish IBI stations by ratings.

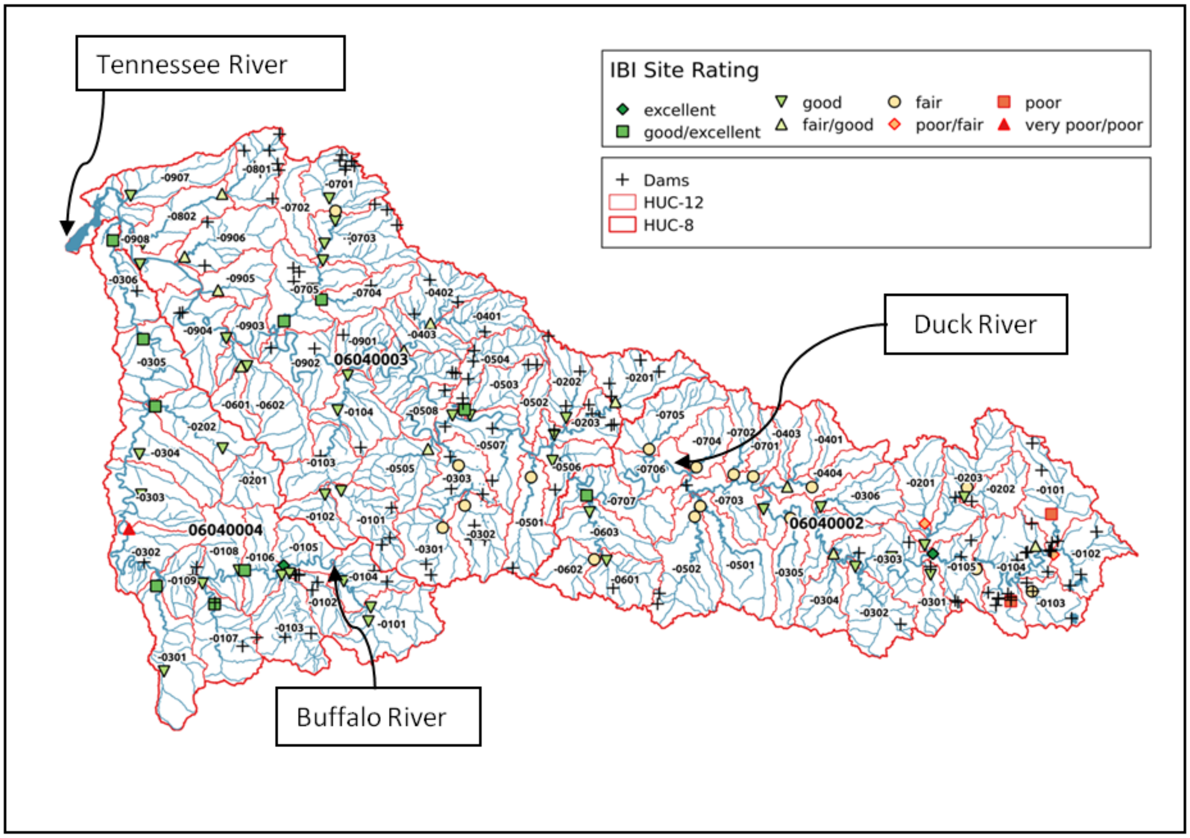

Figure 4. HUC 8 and HUC 12 watersheds, Duck River watershed, Tennessee.

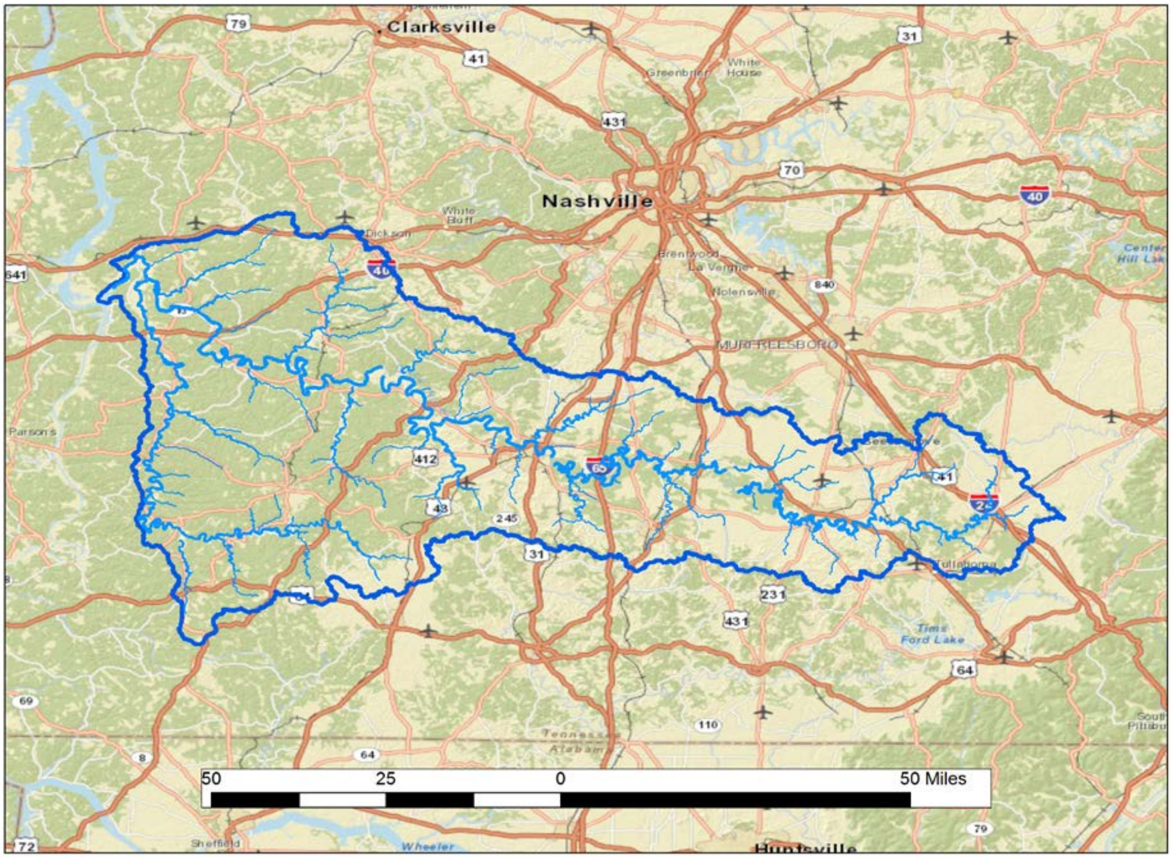

Figure 5. Red Hen low altitude flowover path, Duck River watershed, Tennessee.

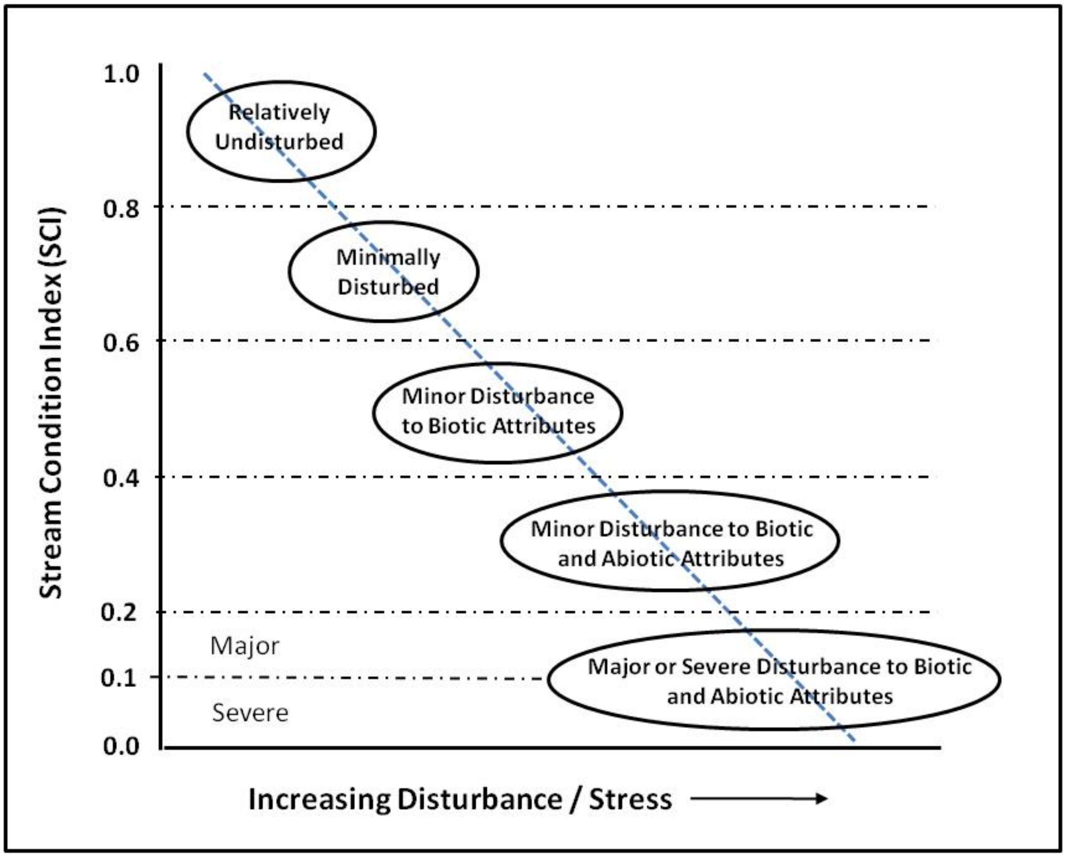

Figure 6. Stream condition index (SCI) scaled against environmental disturbance gradient (adapted from Pruitt et. al. 2012).

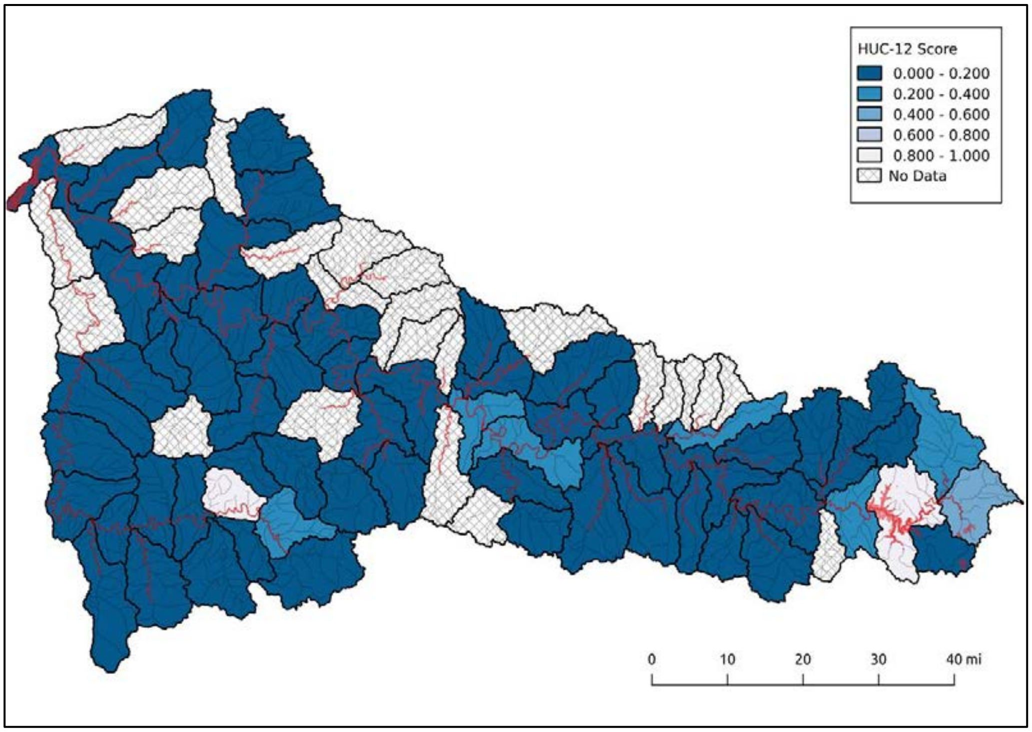

Figure 7. Stream condition index (SCI) scores per HUC 12 watersheds, Duck River Basin, Tennessee.

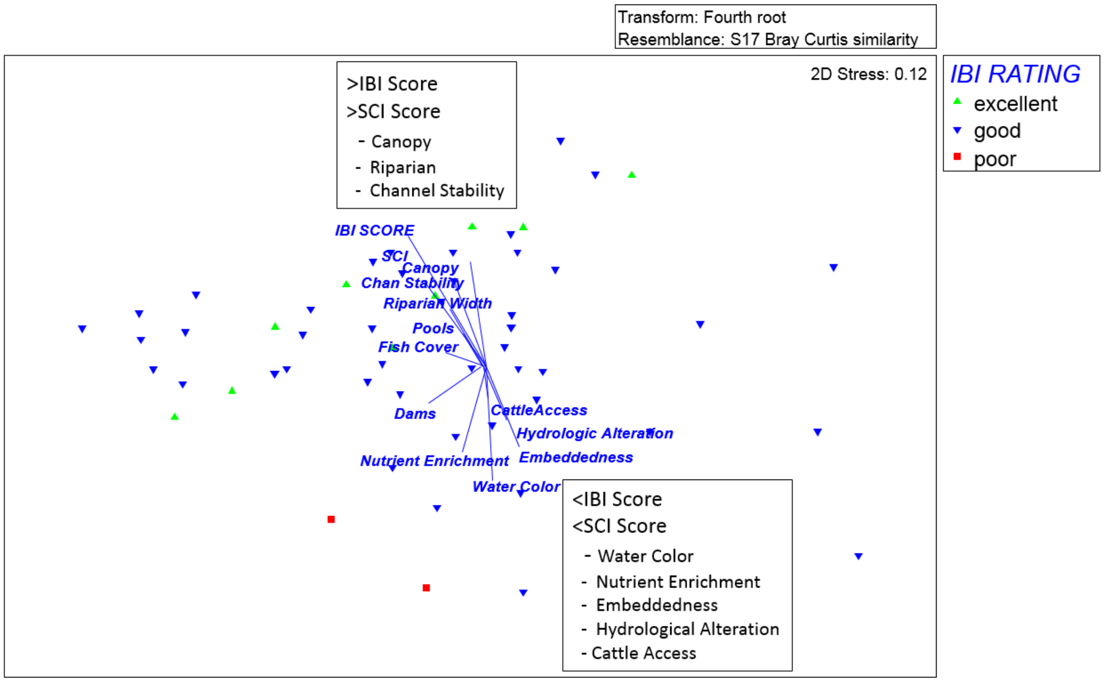

Figure 8. Nonmetric multidimensional scaling ordinations of fish species among sites. Index of Biotic Integrity (IBI) ratings depicted by symbols. Vectors indentify the direction and strength of correlations; boxes summarize quadrat characteristics.

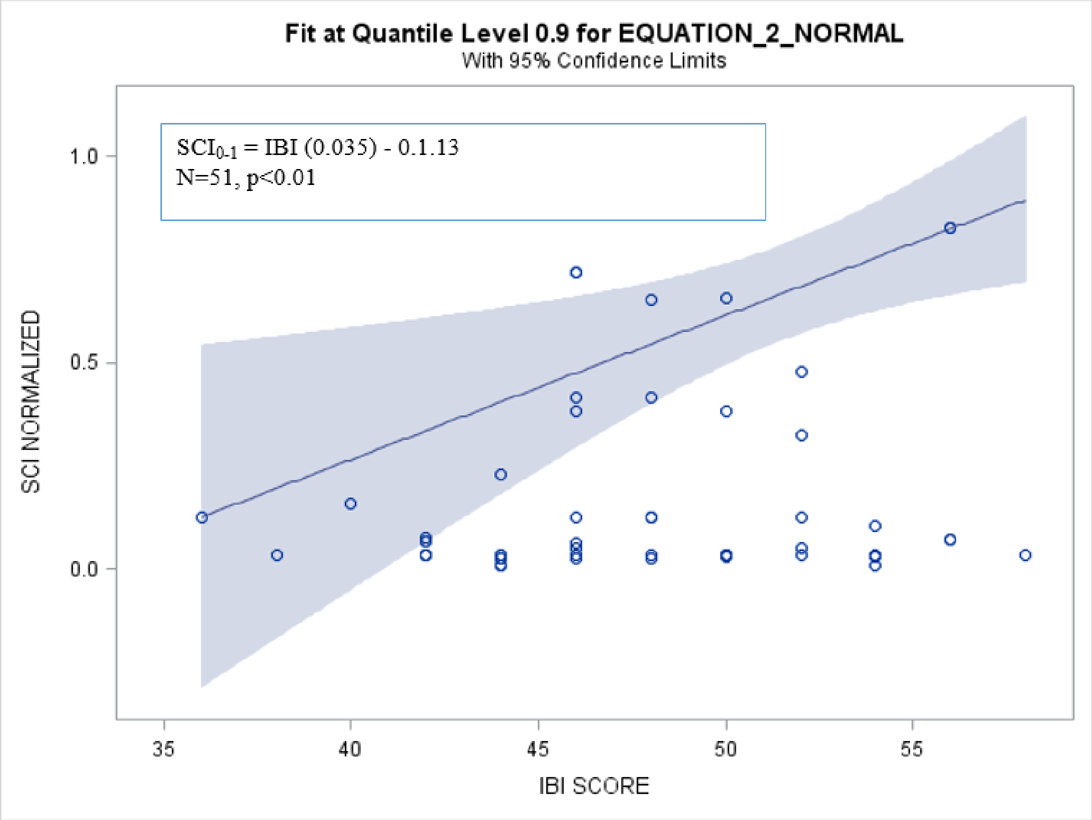

Figure 9. Estimate of 90th regression quantile equation for stream condition index (SCI), normalized to 0-1 as a function of the fish Index of Biotic Integrity (IBI).

Table 1. List of metrics used in calculating the TVA Index of Biotic Integrity. Each metric is assigned a value as follows: 1-poor, 3-intermediate, and 5-the best to be expected. The IBI for a given site is the sum of those values.

1. Number of native species
2. Number of native darter species, of for headwater streams[1], Number of riffle species
3. Number of native sunfish species (less *Micropterus* sp.), or for headwater streams, Number of pool species
4. Number of native sucker species, or for headwater streams, Percent composition by two most dominate species
5. Number of headwater intolerant species
6. Percentage of fish as tolerant species
7. Percentage of fish as omnivores and stoneroller species
8. Percentage of fish as specialized insectivores
9. Percentage of fish as piscivores
10. Catch rate (average number/300 FT^2 or 5 minutes of boat shocking)
11. Percentage of fish as hybrids, or for headwater streams, Percentage of fish as simple lithophilic spawners
12. Percentage of fish with disease, tumors, fin damage, and other anomalies

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[1] Some metrics differ for headwater streams, which perennial streams with drainage areas less than 5 to one square mile (Central Appalachian Ridge and Valley, and the Interior Plateau Ecoregions), less than 10 to one square miles (Blue Ridge Mountains Ecoregion) or less than 100 to 10 square miles (Southwestern Appalachian Ecoregion).

Table 2. Biotic integrity classes in assessing fish communities along with general descriptions of their attributes (Karr et al. 1986).

Class	Attributes	IBI Range
Excellent	Comparable to the best situations with minimal human influence ; all regional species expected for the habitat and stream size, including th most intolerant forms, are present with full array of age and sex class balanced trophic structure.	58-60
Good	Species richness somewhat below expectation, especially due to loss most intolerant forms; some species with less than optimal abundances or size distribution; trophic structure shows some signs of stress.	48-52
Fair	Signs of additional deterioration include fewer intolerant forms, more skewed trophic structure (e.g., increasing frequency of omnivores); o age classes of top predators may be rare.	40-44
Poor	Dominated by omnivores, pollution-tolerant forms, and habitat gener few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.	28-34
Very Poor	Few fish present, mostly introduced or tolerant forms; hybrids comm disease, parasites, fin damage, and other anomalies regular.	12-22
No fish	Repetitive sampling fails to find any fish.	

Table 3. Stream condition index linear regression analysis showing F-test, p-values, which correspond to correlations presented in Table 4.

CS	HA	RZ	BS	WC	NE	DAMS	FC	P	CAN	CA	EMB	Symbol	Variable
1.0000	0.0000	0.0000	0.0000	0.0001	0.0007	0.0232	0.0000	0.0000	0.0000	0.8298	0.0000	**CS**	**Channel Stability**
	1.0000	0.0000	0.0000	0.1944	0.0515	0.0568	0.0000	0.0000	0.0000	0.0000	0.0001	**HA**	**Hydrologic Alteration**
		1.0000	0.0000	0.0059	0.0031	0.0287	0.0001	0.0000	0.0000	0.3082	0.0000	**RZ**	**Riparian Zone**
			1.0000	0.0000	0.0000	0.3906	0.3076	0.0000	0.0004	0.8158	0.0000	**BS**	**Bank Stability**
				1.0000	0.0000	0.1462	0.0021	0.0009	0.0514	0.2418	0.0000	**WC**	**Water Color**
					1.0000	0.5326	0.0000	0.0000	0.0216	0.1826	0.0000	**NE**	**Nutrient Enrichment**
						1.0000	0.5094	0.0987	0.1879	0.4730	0.5063	**DAMS**	**Structural Dams**
							1.0000	0.0000	0.0160	0.0316	0.0001	**FC**	**Fish Cover**
								1.0000	0.0003	0.4516	0.0000	**P**	**Pools**
									1.0000	0.6804	0.0000	**CAN**	**Canopy Closure**
										1.0000	0.9123	**CA**	**Cattle Access**
											1.0000	**EMB**	**Embeddedness**

Table 4. Correlation product matrix on stream condition index variables, significant correlations for positive and negative relationships highlighted with green and magenta, respectively.

CS	HA	RZ	BS	WC	NE	DAMS	FC	P	CAN	CA	EMB	Symbol	Variable
1.00	-0.74	0.84	0.76	-0.46	-0.42	0.28	0.64	0.75	0.59	-0.03	-0.66	**CS**	**Channel Stability**
	1.00	-0.78	-0.50	0.17	0.25	-0.24	-0.55	-0.59	-0.55	0.30	0.48	**HA**	**Hydrologic Alteration**
		1.00	0.73	-0.34	-0.37	0.27	0.47	0.65	0.60	-0.13	-0.54	**RZ**	**Riparian Zone**
			1.00	-0.61	-0.56	0.11	0.50	0.63	0.43	-0.03	-0.61	**BS**	**Bank Stability**
				1.00	0.56	0.19	-0.38	-0.41	-0.25	-0.15	0.64	**WC**	**Water Color**
					1.00	0.08	-0.49	-0.51	-0.29	0.17	0.54	**NE**	**Nutrient Enrichment**
						1.00	0.08	0.21	0.17	0.09	-0.09	**DAMS**	**Structural Dams**
							1.00	0.83	0.30	-0.27	-0.48	**FC**	**Fish Cover**
								1.00	0.44	-0.10	-0.51	**P**	**Pools**
									1.00	-0.05	-0.56	**CAN**	**Canopy Closure**
										1.00	-0.01	**CA**	**Cattle Access**
											1.00	**EMB**	**Embeddedness**

Table 5. Direct and indirect correlations between stream condition index model variables (embeddedness - EMB, highlighted).

Channel Stability ~ RZ, BS, FC, Can, 1/HA, 1/WC, 1/NE, 1/EMB
Hydrologic Alteration ~ EMB, 1/RZ, 1/BS, 1/FC, 1/P, 1/CAN
Riparian Zone ~ BS, FC, P, CAN, CS, 1/HA, 1/EMB
Bank Stability ~ CS, RZ, FC, P, CAN, 1/EMB
Water Color ~ NE, EMB, 1/P, 1/CS, 1/BS
Nutrient Enrichment ~ EMB, WC, 1/FC, 1/P, 1/CS, 1/BS
Structural Dams ~ none
Fish Cover ~ P, RZ, BS, 1/EMB, 1/HA, 1/NE
Pools ~ CAN, CS, RZ, BS, 1/NE, 1/EMB
Canopy Closure ~ CS, RZ, BS, P, 1/HA, 1/EMB
Cattle Access ~ none
Embeddedness ~ HA, WC, NE, 1/CS, 1/RZ, 1/BS, 1/FC, 1/P, 1/CAN

Where:
CS = Channel Stability
FC = Fish Cover
P = Pools
RZ = Riparian Zone
BS = Bank Stability
CAN = Canopy Density
HA = Hydrologic Alteration
WC = Water Color
NE = Nutrient Enrichment
CA = Cattle Access
EMB = Embeddedness

Table 6. Stream condition index variable scoring and descriptions.

Channel Stability-Longitudinal (CS)	Natural channel; no structures, dikes. No evidence of down cutting or excessive lateral cutting	Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levies are set back to provide access to an adequate flood plain.	Altered channel; <50% of the reach with riprap and/ or channelization. Excess aggradation; braided channel. Dikes or levees restrict flood plain width.	Channel is actively downcutting or widening. >50% of the reach with riprap or channelization. Dikes or levees prevent access to the flood plain.	
CS Score →	1.0	0.7	0.3	0.1	
Hydrologic Alteration (HA)	Flooding every 1.5 to 2 years. No dams, no water withdrawals, no dikes or other structures limiting the stream's access to the flood plain. Channel is not incised.	Flooding occurs only once every 3 to 5 years; limited channel incision. or Withdrawals, although present, do not affect available habitat for biota.	Flooding occurs only once every 6 to 10 years; channel deeply incised. or Withdrawals significantly affect available low flow habitat for biota.	No flooding; channel deeply incised or structures prevent access to flood plain or dam operations prevent flood flows.	
HA Score →	1.0	0.7	0.3	0.1	
Riparian Zone (RZ)	Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. Or If less than one width, covers entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. Or Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. Or Lack of regeneration.
RZ Score →	1.0	0.8	0.5	0.3	0.1

Table 6. Stream condition index variable scoring and descriptions (continued).

Bank Stability (BS)	Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); out- side bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
BC Score →	1.0	0.7	0.3	0.1
Water Color (WC)	Very clear, or clear but tea-colored; objects visible at depth 3 to 6 ft (less if slightly colored); no oil sheen on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; objects visible at depth 1.5 to 3 ft; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; objects visible to depth 0.5 to 1.5 ft; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. Or Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; objects visible to depth < 0.5 ft; slow moving water may be bright-green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface. Or Strong odor of chemicals, oil, sewage, other pollutants.
WC Score →	1.0	0.7	0.3	0.1
Nutrient Enrichment (NE)	Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
NE Score →	1.0	0.7	0.3	0.1

Table 6. Stream condition index variable scoring and descriptions (continued).

Fish Cover (FC)	>7 cover types available	6 to 7 cover types available	4 to 5 cover types available	2 to 3 cover types available	None to 1 cover type available
FC Score →	1.0	0.8	0.5	0.3	0.1
Pools (P)	Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 5-ft deep.	Pools present, but not abundant; from 10 to 30% of the pool bottom is obscure due to depth, or the pools are at least 3 feet deep.	Pools present, but shallow; from 5 to 10% of the pool bottom is obscure due to depth, or the pools are less than 3-ft deep.	Pools absent, or the entire bottom is discernible.	
P Score →	1.0	0.7	0.3	0.1	
Canopy (CAN)	25 to 90% of water surface shaded; mixture of conditions.	> 90% shaded; full canopy; same shading condition throughout the reach.	(intentionally blank)	< 25% water surface shaded in reach.	
CAN Score →	1.0	0.7		0.1	
Cattle Access (CA)	Evidence of livestock access to riparian zone.	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream. OR Untreated human waste discharge pipes present.		
CAN Score →	0.5	0.3	0.1		
Embeddedness (EMB)	Gravel or cobble particles are < 20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40% embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
EMB Score →	1.0	0.8	0.5	0.3	0.1

Table 7. Reference stream segments, Duck River watershed, Tennessee.

HUC12	Stream Segment	Reference Condition	Latitude	Longitude
60400020101	Duck: Upper reach	Broad forested corridor and excellent planform	35.594867	-86.099413
60400020101	Duck: Upper reach	Broad forested corridor and excellent planform	35.587572	-86.084452
60400020101	Duck: Upper reach	Broad forested corridor and excellent planform	35.603688	-86.105227
60400020101	Duck: Upper reach	Broad forested corridor and excellent planform	35.526413	-86.099838
60400020102	Shankin Branch lower reach - trib to Wolf Creek	Dense forested riparian and valley corridor	35.49215	-85.985055
60400020102	Wolf Creek complete reach - trib to Little Duck River	Dense forested riparian and valley corridor	35.491037	-86.034538
60400020102	Little Duck River mid reach	Forested corridor in tact for majority of clip	35.473197	-86.069343
60400020102	Little Duck River lower reach	Large forested corridor	35.487037	-86.09624
60400020302	Lower-Middle Flat Creek	Broad riparian, high canopy density	35.441035	-86.461158
60400030703	West Piney River - US of I40 - across good IBI station	Diversity habitat due to active floodplain and water expansion	N/A	N/A
60400020503	Big Rock Creek - Upper Mid reach	Broad forested corridor and excellent planform	35.474737	-86.773558
60400020503	Big Rock Creek - Lower Mid reach	Pond on right valley w/o outlet (good example of off-line cattle drinking)	35.504408	-86.76688
60400020601	Globe Creek - Lower reach across good IBI station	Broad riparian, high canopy density	N/A	N/A
60400040105	Buffalo: Mid reach Pine Bluff Rd. to Edwards Rd.	Broad riparian, high canopy density	35.465068	-87.478023
60400040301	Green River upper mid reach	Example of confinement by natural geology	35.313457	-87.760877

Table 8. Spearman correlation coefficients of Stream Condition Index (SCI) and IBI metrics (n=55). IBI metrics with low sample sizes were deleted. Yellow-highlighted values indicate strong correlations ($p < 0.01$).

Habitat Variables	Catch Rate	No. Darter species	No. Intolerant species	No. Sucker Species	No. Sunfish Species	% Individuals as Lithophils	% Individuals as Omnivores	% Individuals as Piscivores	% Individuals as Tolerant
RIVER_MILE	-0.05299	0.17349	0.13896	0.34937	0.37678	-0.0753	0.31609	0.50807	0.47479
Drainage Area (sq. mile)	-0.2928	0.29903	0.24299	0.47	0.38055	0.22929	0.14258	0.63774	0.38877
Canopy	0.04712	-0.22301	-0.19507	-0.31829	-0.21705	-0.06729	-0.09766	-0.23341	-0.14593
Cattle Access	-0.00366	-0.05676	-0.04293	-0.11745	-0.06611	-0.09526	0.03813	-0.16665	-0.01926
Channel Stability	-0.13664	-0.19477	-0.17575	-0.23386	-0.18256	-0.02595	-0.10067	-0.17097	-0.08668
Embeddedness	0.03399	0.13204	0.12788	0.20346	0.10978	0.13547	0.15629	0.07274	0.10851
Fish Cover	-0.32631	-0.05176	-0.05709	0.03324	-0.04634	0.15202	-0.21763	0.07407	-0.10981
Dams	-0.06244	0.04543	-0.00681	-0.03609	0.04543	-0.05167	0.01687	0.11882	0.1161
Hydrological Alteration	0.15623	0.08323	0.08141	0.09162	0.12551	-0.11193	0.14674	0.03081	0.05317
Nutrient Enrichment	0.06469	0.14161	0.1362	0.18558	0.1487	-0.02714	0.11739	0.07597	0.12616
Pools	-0.23849	-0.26076	-0.22104	-0.2154	-0.24564	0.0377	-0.24216	-0.2131	-0.19713
Average Riparian Width	-0.07441	-0.10317	-0.06673	-0.16803	-0.10676	-0.0269	-0.01923	-0.06283	-0.01465
Water Color	-0.08421	0.22076	0.21332	0.30374	0.23291	0.08786	0.13095	0.26675	0.26017

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Appendix B – MSWA: Calculator User Guide

Multi-Scale Watershed Assessment

User Guide

US Army Corps of Engineers

Nashville District
Engineer Research and Development Center

Acknowledgments

The development of the Multi-Scale Watershed Assessment (MSWA) was a multidisciplinary and multiagency effort which included numerous coordinated meetings and field work by the Project Delivery Team (PDT). The PDT was composed of the Project Manager, Ramune Matuliauskaite-Morales, Craig Carrington, and Joy Broach (USACE, Nashville District, Planning), Tim Wilder (USACE, Nashville District, Regulatory, former Principle Investigator), Bruce Pruitt, current Principle Investigator, Jack Killgore, and Todd Slack (USACE, ERDC). Stakeholders included representatives from the Tennessee Department of Environment and Conservation, the Duck River Agency, the Nature Conservancy, and the Tennessee Valley Authority.

A “kickoff” Duck Watershed workshop was held in February 2015 and was attended by PDT. Bob Wallus, former employee of TVA and one of the developers of the fish Index of Biotic Integrity, was present as a technical expert. Problems and opportunities and study goals and objectives were discussed at the workshop. Subsequent webinars were held on June 12, 2015, February 8 and 22, 2016, September 22, 2016. Since August 2015, regularly scheduled semi-monthly conference calls have been organized and attended by the PDT. Consequently, the process of data acquisition, reduction, analysis, and interpretation was well vetted by the PDT leading to the formulation and testing of the stream condition model which is the cornerstone of the MSWA.

Steve Miranda (USGS Cooperative Unit at Mississippi State University) assisted in data analysis and reporting. External peer review was provided by William Ainslie and Morris Flexner (USEPA) and Rick Rheinhardt (East Carolina University).

Caveats

This User Guide was developed as part of the Duck River Watershed Assessment under the Section 729 of the Water Resources Development Act (WRDA) of 1986, with amendments. The Watershed Assessment was undertaken by the USACE Nashville District and the Engineer Research and Development Center (ERDC).

Appropriate Citation

Pruitt, B.A., K.J. Killgore, and W.T. Slack. 2017. Multi-Scale Watershed Assessment User Guide, Engineer Research and Development Center. *In support of* Duck River Watershed Plan, Final Watershed Assessment, U.S. Army Corps of Engineers, Nashville District.

INTRODUCTION

Background

This User Guide was developed by the USACE Engineer Research and Development Center (ERDC) as an integral part of the Duck River Watershed Assessment under the Section 729 of the Water Resources Development Act (WRDA) of 1986 as directed by the USACE Nashville District. The purpose of the Watershed Plan was to identify existing conditions within the Duck Watershed, describe the major water resources problems and opportunities in the watershed, and recommend tools (User Guide) and a strategic course of action for achieving the desired conditions in the watershed. Paramount to assessment of the Duck Watershed across various degrees of ecological impairment at different scales, a model was formulated which was utilized to determine the existing conditions, identify the problems in the watershed, recommend future spin-off projects for USACE or other agencies, and apply to the User Guide.

The Duck Watershed Assessment represents a new method of assessing ecosystems using multi-attributes across multi-scales, called the "Multi-Scale Watershed Approach (MSWA). The concept behind the MSWA was to establish a means of utilizing readily available data to create an overall knowledge base collected by multiple agencies and stakeholders. The outcome of MSWA can become the principle component of the decision-making process such that water resource managers have the ability to make scientifically defensible decisions not only at project specific scales, but also beyond the footprint of the project to the entire watershed. From the watershed perspective, the cause and effect relationships between land use, water quality and quantity, in-channel and riparian conditions, and biotic responses culminate at a single outlet from the watershed and are representative of the ecological condition of the watershed. In addition, assessment at the watershed scale offers advance planning including design, construction, and operation, maintenance, repair, replacement and restoration of aquatic ecosystems. By developing the User Guide, additional stream segments or watersheds can be evaluated in the future using the variables and Stream Condition Index (SCI) presented herein and the SCI spreadsheet calculator. The results of the future assessments can be compared against the Duck Watershed Assessment and Plan (MSWA).

Geographic Region and Scale

The statistical treatise used in model development for the Duck Watershed can be utilized elsewhere in other physiographies and USACE Districts. The protocol used herein for establishing stream corridor conditions is applicable to the Tennessee River basin within Tennessee. However, the protocol can be transported to other river basins with additional beta testing and model refinement, if necessary.

This User Guide was developed for the application of the MSWA protocol. It was designed to be applied consistently and rapidly, yet maintain precision and reproducibility across assessment areas and between practitioners possessing a fundamental understanding of hydrological and ecological processes. The assessment protocol is based primarily on physical and biological attributes of stream corridors including aquatic habitat, riparian zone, and watershed/valley conditions. It is intended to be applied at multiple scales using low altitude photogrammetry, on-ground observations/ measurements or in combination.

The MSWA User Guide provides a means of systematic assessment of relevant aspects of stream and riparian zone conditions with respect to geophysical and biological attributes, assuring that all important factors are consistent and reproducible among users. Because of its utility, ease-of-use and application across several scales, MSWA using low altitude, high resolution video provides the following advantages:

1. At watershed and stream segment scales, it provides a rapid and reproducible method of covering more area expeditiously;
2. Acquiring private property access is not required;
3. Planform geometry (meander wave length, radius-of-curvature, and amplitude) is easily elucidated and measured using photogrammetry especially on large rivers;
4. Watershed-scale models (SCI) can be tested, refined and finalized by re-visiting the video several times without the need for additional field work;
5. Land use/cover and relative riparian zone condition is more obtainable;
6. Identification of sources of pollutants and sources of accelerated sediment is easily elucidated;
7. Identification of attainable reference conditions, by establishing the reference domain of all stream segments, is more easily achieved;
8. At the valley flat scale, video assessment facilitates the potential of re-coupling adjacent wetlands to the frequent flood event;
9. The upstream and downstream effects of dams (fish barriers) can be visualized better;
10. With future flyovers, trend analysis can be conducted at watershed and stream segment scales including monitoring natural and anthropogenic changes, catastrophic events, and effects of climate change on stream hydrology and geomorphology; and
11. Video assessment provides a platform such that the general public can visualize stream corridor conditions.

User Guide Purpose

The MSWA User Guide was developed as a companion to the Excel ™ spreadsheet used to calculate the SCI. The WSWA of evaluating stream and riparian zone conditions is meant to be a rapid, uncomplicated method. In general, it represents a relatively coarse level in a hierarchy of ecological assessment protocols. However, based on model validation during on-ground field surveys, the SCI calculator and associated input variables can be applied at a range of scales from the stream segment scale to a coarser watershed scale.

The overall purpose of this User Guide is to provide the rationale and scoring descriptions of the eleven input variables required in the SCI. Even though the SCI was formulated based on assessment of low altitude, high resolution video, the protocol was validated via on-ground field surveys. Thus, it can be used for on-ground stream and valley assessments in the future as well as using low altitude aircraft (e.g., helicopters, unmanned aircraft systems). Consequently, MSWA can be used for remote surveys, reconnaissance including identification of attainable reference conditions, routine on-ground, field assessments at the stream segment scale, or identification of more intensive investigations. Generally, remote or reconnaissance assessments are conducted first, followed by identification of areas needing more intensive investigations. In addition, MSWA can be used for determining departure from attainable reference conditions and monitoring of restoration activities including developing success and performance criteria.

Generally, the objective of the remote or reconnaissance assessment is to evaluate stream condition of a reach in less than one hour depending upon site access and logistics. The practitioner would use readily available data to rate model variables. This initial approach is limited to remote surveys using aerial imagery (preferably low altitude photogrammetry), web-based tools and data sources, and information already published in existing reports (e.g., ambient monitoring). Windshield surveys where road access or bridge crossings are located along stream corridors may also be conducted to rapidly make observations in a phased approach to stratifying or grouping stream segments based on relative condition. At this level, practitioners would need to rely on indicators or surrogates of stream condition or impairment and land use stressors unless previous assessment data are available. However, as additional sites are rated via reconnaissance, a relative condition or ranking of the stream corridor can be developed, and sites can be prioritized for more intensive studies or stratified into a sample population for extrapolation to the parent population.

Intensive assessment requires effort beyond the scope of the WSWA and associated variables and site scoring. Intensive assessments are not limited to the amount of data or observations that is collected in a few hours. However, the results of the WSWA, which provides a holistic depiction of stream condition, can be used to develop an assessment or monitoring strategy for data collection in an intensive study.

MODEL INPUT VARIABLES

Ecological models, such as the SCI, help define the problem, lead to a better understanding of the correspondence between biotic and abiotic attributes of an aquatic ecosystem, provide analytical tools to enhance data interpretation, enable comparisons between and across ecosystem types and physiography, and facilitate communication in regards to ecological processes and functions across scientific disciplines and to the public. In addition, a process-based approach was applied to this effort that identified critical processes and pathways in regards to the cause and effect relationship between geospatial data and aquatic biota.

The SCI provides an excellent method of rating watersheds based on their valley land use and cover, riparian zone condition, stream geomorphology, stream bedforms and habitat diversity, and water quality conditions. The SCI was formulated using statistical methods, consequently, reducing bias and subjectivity. This User Guide was developed to provide detailed variable descriptions for the practitioner to score and rank stream conditions at a range of scales from the stream segment scale to the watershed scale. An Excel™ spreadsheet was created to facilitate the scoring of eleven variables (WSWA_SCI_Calculator.xlsx). It is composed of 17 worksheets as follows (numbers below coincide with worksheet sequence in spreadsheet calculator):

Desktop Assessment

1. Readily Available Data
2. Objectives/Location
3. Site Properties
4. Identify "Known" Stressors

Eleven Model Variables

5. Channel stability (V_{CS})
6. Hydrologic alteration (V_{HA})
7. Riparian zone (V_{RZ})
8. Bank stability (V_{BS})
9. Water color (V_{WC})
10. Nutrient enrichment (V_{NE})
11. Fish cover (V_{FC})
12. Pools (V_{P})
13. Canopy closure (V_{CAN})
14. Cattle access (V_{CA})
15. Embeddedness (V_{EMB})

MODEL INPUT VARIABLES

Channel Stability (CS)
Hydrologic Alteration (HA)
Riparian Zone (RZ)
Bank Stability (BS)
Water Color (WC)
Nutrient Enrichment (NE)
Fish Cover (FC)
Pools (P)
Canopy Closure (CAN)
Cattle Access (CA)
Embeddedness (EMB)

Final Calculations

16. SCI Score Card
17. SCI Summary Table

Readily Available Data

The importance of compiling existing studies and dataset into a knowledge base cannot be over emphasized. Existing studies and databases provide a means of improving and validating indirect measures and observations. Sources of pertinent data can be obtained from local, state and federal agencies, non-governmental organizations, state and federal parks, and a plethora of on-line web sites (see first worksheet in spreadsheet calculator).

Project Objectives

The worksheet named “objectives” describes the goal and purpose of the project, the project location the assessment area (AA) boundaries, and any species of special concern, conservation and recreational areas, or designated protected lands.

Assessment Area (AA) Properties

The AA worksheet provides remote characterization and stream morphology. The users should complete this worksheet based GIS analysis and available data. However, in many cases, the existing stream morphology may not be known until a field survey is conducted. In addition, protocols such as Bank Erosion Hazard (Rosgen 19xx) and width-depth ratios require more effort than required to collect visual data needed for the SCI score. Even though more intensive direct measures are not required, they can be used to validate the visual or indirect variables used in the SCI. Consequently, it is at the discretion of the practitioner to determine the level of effort required to meet the project objectives.

Identification of Stressors

In the context of the WSMA and the User Guide, stress refers to any cause of stream physical or hydrologic alteration or aquatic life impairment from in-stream or land use sources of pollution or disturbance. Several causes of stress or disturbance at different scales can be attributed to the following stressors:

Watershed, Valley and Riparian Zone Scales

- Vegetative Clearing
- Soil exposure or compaction
- Land grading
- Hard surfacing and imperious surfaces
- Contaminant runoff

- Irrigation and drainage
- Overgrazing
- Cattle access
- Concentrated feed lots and operations
- Roads and railroads
- Utility crossings
- Trails
- Reduction in floodplain
- Exotic or non-native species

Stream Reach or Segment Scales

- Channelization or dredging
- Woody debris removal (de-snagging operations)
- Head cutting (channel degradation)
- Accelerated sedimentation/siltation (channel aggradation)
- Dams
- Artificial levees
- Water withdrawal
- Streambed disturbance
- Stream bank armoring
- Dredging for mineral extraction
- Bridges/culverts (especially undersized)
- Piped discharge

When scoring model variables, the above stressors and potential sources of stream impairment should be considered.

Scoring System

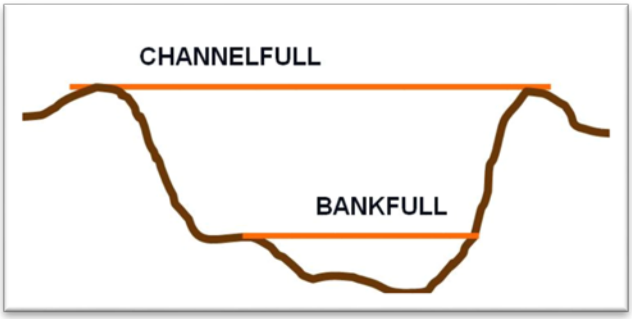
Each assessment element is rated with a value of 0.1 to 1.0. Using the appropriate variable worksheet in the WSWA Excel™ spreadsheet, record the score that best fits the observations you make based on the narrative descriptions provided for each variable. Unless otherwise directed, assign the lowest score that applies. For example, if a reach exhibits attributes of several narrative descriptions, assign a score based on the lowest scoring description that contains indicators present within the reach. You may record values intermediate to those listed. Some background information is provided for each assessment element, as well as a description of what to look for. If the evaluation is conducted on-ground, the assessment site should be a bound at a minimum of two meander wave-lengths. If the evaluation is conducted using low altitude photogrammetry, the assessment site can be bound at the discretion of the practitioner at any stream length depending on the project objectives and stream condition consistency.

V_{CS}: Channel Stability

Natural channel in cross-section relative to reference conditions; No evidence of channel widening; Little or no formation of mid-channel bars.	Evidence of past channel alteration, but with significant recovery of channel and banks. Moderate evidence of channel widening and mid-channel bar formation.	Altered channel; Excess aggradation; Some braided or anastomosed channel. Severe channel widening and mid-channel bar formation.	Highly altered channel; Excess aggradation; Predominate braiding or anastomosed channel. Extreme channel widening causing active bank failure.
1.0	0.7	0.3	0.1

Maintaining a natural channel within a normal range of channel widths is important for several reasons including sediment transport, depth variation, bedform and aquatic habitat maintenance, aquatic fauna access to multiple habitats. The width of a stream channel is measured at bankfull (W_{bkf}) dimension across the channel. Bankfull discharge maintains the channel's cross-sectional geometry within normal ranges with respect to the watershed size (ref). In incised stream channels, W_{bkf} may be contained within the channel levees (i.e., low entrenchment ratio).

Indirect Indicators of Channel Instability: Evidence of channel instability includes increase in channel width, as measured from levee to levee (channelfull width) or bankfull width (see illustration), mid-channel bar formation, and bank failure. An increase in channel width can be determined by comparison with a reference reach of similar watershed size, a dramatic width change relative to upstream or downstream, regional hydraulic curves, or departure from reported ranges of channel width based on stream class. Ideally, determination of channel width should be measured at a riffle. If local regional curves are not available, bankfull channel dimensions versus drainage area can be used (Dunne and Leopold 1978).



Natural channel; no structures, dikes. No evidence of down- cutting or excessive lateral cutting. No artificial channel confinement. Flood frequency onto active floodplain every 1.5 to 2 years RI.	Evidence of past channel alteration, but with significant recovery of channel and banks. Channel slightly incised. Minimum artificial channel confinement. Flood frequency onto active floodplain every 3 to 5 years RI.	Moderately altered channel; <50% of the reach with riprap and/ or channelization. Channel deeply incised. Flood frequency onto active floodplain every 6 to 10 years RI.	Channel is actively downcutting or widening. >50% of the reach with riprap or channelization. Channel severely incised. Flood frequency onto active floodplain > 10 years RI.
1.0	0.7	0.3	0.1

Stream meandering generally increases as the gradient of the surrounding valley decreases. Often, development in the area results in changes to this meandering pattern and the flow of a stream. These changes in turn may affect the way a stream naturally does its work, such as the transport of sediment and the development and maintenance of habitat for fish, aquatic insects, and aquatic plants. Some modifications to stream channels have more impact on stream health than others. For example, channelization and dams affect a stream more than the presence of pilings or other supports for road crossings.

Indicators of downcutting in the stream channel include nickpoints associated with headcuts in the stream bottom and exposure of cultural features, such as pipelines that were initially buried under the stream. Exposed footings in bridges and culvert out- lets that are higher than the water surface during low flows are other examples. A lack of sediment depositional features, such as regularly-spaced point bars, is normally an indicator of incision. A low vertical scarp at the toe of the streambank may indicate downcutting, especially if the scarp occurs on the inside of a meander. Another visual indicator of current or past downcutting is high streambanks with woody vegetation growing well below the top of the bank (as a channel incises the bankfull flow line moves down- ward within the former bankfull channel). Excessive bank erosion is indicated by raw banks in areas of the stream where they are not normally found, such as straight sections between meanders or on the inside of curves.

Active downcutting and excessive lateral cutting are serious impairments to stream function. Both conditions are indicative of an unstable stream channel. Usually, this instability must be addressed before committing time and money toward improving other stream problems. For example, restoring the woody vegetation within the riparian zone becomes increasingly difficult when a channel is downcutting because banks continue to be undermined and the water table drops below the root zone of the plants during their growing season. In this situation or when a channel is fairly stable, but already incised from previous down- cutting or mechanical dredging, it is usually necessary to plant upland species, rather than hydrophytic, or to apply irrigation for several growing seasons, or both. Extensive bank-armoring of channels to stop lateral cutting usually leads to more problems (especially downstream). Often stability can be obtained by using a series of structures (barbs, groins, jetties, deflectors, weirs, vortex weirs) that reduce water velocity, deflect currents, or act as gradient controls. These structures are used in conjunction with large woody debris and woody vegetation plantings. Hydrologic alterations are described next.

Bankfull flows, as well as flooding, are important to maintaining channel shape and function (e.g., sediment transport) and maintaining the physical habitat for animals and plants. High flows scour fine sediment to keep gravel areas clean for fish and other aquatic organisms. These flows also redistribute larger sediment, such as gravel, cobbles, and boulders, as well as large woody debris, to form pool and riffle habitat important to stream biota. The river channel and flood plain exist in dynamic equilibrium, having evolved in the present climatic regime and geomorphic setting. The relationship of water and sediment is the basis for the dynamic equilibrium that maintains the form and function of the river channel. The energy of the river (water velocity and depth) should be in balance with the bedload (volume and particle size of the sediment). Any change in the flow regime alters this balance.

If a river is not incised and has access to its flood plain, decreases in the frequency of bankfull and out-of-bank flows decrease the river's ability to transport sediment. This can result in excess sediment deposition, channel widening and shallowing, and, ultimately, in *braiding* of the channel. Rosgen (1996) defines braiding as a stream with three or more smaller channels. These smaller channels are extremely unstable, rarely have woody vegetation along their banks, and provide poor habitat for stream biota. A *split channel,* however, has two or more smaller channels (called side channels) that are usually very stable, have woody vegetation along their banks, and provide excellent habitat. Conversely, an increase in flood flows or the confinement of the river away from its flood plain (from either incision or levees) increases the energy available to transport sediment and can result in bank and channel erosion.

The low flow or baseflow during the dry periods of summer or fall usually comes from groundwater entering the stream through the stream banks and bottom. A decrease in the low-flow rate will result in a smaller portion of the channel suitable for aquatic organisms. The withdrawal of water from streams for irrigation or industry and the placement of dams often change the normal low-flow pattern. Baseflow can also be affected by management and land use within the watershed — less infiltration of precipitation reduces baseflow and increases the frequency and severity of high flow events. For example, urbanization increases runoff and can increase the frequency of flooding to every year or more often and also reduce low flows. Overgrazing and clearcutting can have similar, although typically less severe, effects. The last description in the last box refers to the increased flood frequency that occurs with the above watershed changes.

Indirect Indicators of Hydrologic Alteration: Signs of channelization or straightening of the stream may include an unnaturally straight section of the stream, high banks, dikes or berms, lack of flow diversity (e.g., few point bars and deep pools), and uniform-sized bed materials (e.g., all cobbles where there should be mixes of gravel and cobble). In newly channelized reaches, vegetation may be missing or appear very different (different species, not as well developed) from the bank vegetation of areas that were not channelized. Older channelized reaches may also have little or no vegetation or have grasses instead of woody vegetation. Drop structures (such as check dams), irrigation diversions, culverts, bridge abutments, and riprap also indicate changes to the stream channel.

Ask the landowner about the frequency of flooding and about summer low-flow conditions. A flood plain should be inundated during flows that equal or exceed the 1.5- to 2.0-year flow event (2 out of 3 years or every other year). Be cautious because water in an adjacent field does not necessarily indicate natural flooding. The water may have flowed overland from a low spot in the bank outside the assessment reach.

Evidence of flooding includes high water marks (such as water lines), sediment deposits, or stream debris. Look for these on the banks, on the bank side trees or rocks, or on other structures (such as road pilings or culverts). Excess sediment deposits and wide, shallow channels could indicate a loss of sediment transport capacity. The loss of transport capacity can result in a stream with three or more channels (braiding).

Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. ***or*** If less than one width, covers entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. ***or*** Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. ***or*** Lack of regeneration.
1.0	0.8	0.5	0.3	0.1

This element is the width of the natural vegetation zone from the edge of the active channel out onto the flood plain. For this element, the word natural means plant communities with (1) all appropriate structural components and (2) species native to the site or introduced species that function similar to native species at reference sites.

A healthy riparian vegetation zone is one of the most important elements for a healthy stream ecosystem. The quality of the riparian zone increases with the width and the complexity of the woody vegetation within it. This zone:

- Reduces the amount of pollutants that reach the stream in surface runoff.
- Helps control erosion.
- Provides a microclimate that is cooler during the summer providing cooler water for aquatic organisms.
- Provides large woody debris from fallen trees and limbs that form instream cover, create pools, stabilize the streambed, and provide habitat for stream biota.
- Provides fish habitat in the form of undercut banks with the "ceiling" held together by roots of woody vegetation.
- Provides organic material for stream biota that, among other functions, is the base of the food chain in lower order streams.
- Provides habitat for terrestrial insects that drop in the stream and become food for fish, and habitat and travel corridors for terrestrial animals.
- Dissipates energy during flood events.
- Often provides the only refuge areas for fish during out-of-bank flows (behind trees, stumps, and logs).

The type, timing, intensity, and extent of activity in riparian zones are critical in determining the impact on these areas. Narrow riparian zones and/or riparian zones that have roads, agricultural activities, residential or commercial structures, or significant areas of bare soils have reduced functional value for the stream. The filtering function of riparian zones can be compromised by concentrated flows. No evidence of concentrated flows through the zone should occur or, if concentrated flows are evident, they should be from land areas appropriately buffered with vegetated strips.

Evidence of Riparian Zone Condition: Compare the width of the riparian zone to the active channel width. In steep, V-shaped valleys there may not be enough room for a flood plain riparian zone to extend as far as one or two active channel widths. In this case, observe how much of the flood plain is covered by riparian zone. The vegetation must be natural and consist of all of the structural components (aquatic plants, sedges or rushes, grasses, forbs, shrubs, understory trees, and overstory trees) appropriate for the area. A common problem is lack of shrubs and understory trees. Another common problem is lack of regeneration. The presence of only mature vegetation and few seedlings indicates lack of regeneration. Do not consider incomplete plant com- munities as natural. Healthy riparian zones on both sides of the stream are important for the health of the entire system. If one side is lacking the protective vegetative cover, the entire reach of the stream will be affected. In doing the assessment, examine both sides of the stream and note on the diagram which side of the stream has problems. There should be no evidence of concentrated flows through the riparian zone that are not adequately buffered before entering the riparian zone.

Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); out- side bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
1.0	0.7	0.3	0.1

This element is the existence of or the potential for detachment of soil from the upper and lower stream banks and its movement into the stream. Some bank erosion is normal in a healthy stream. Excessive bank erosion occurs where riparian zones are degraded or where the stream is unstable because of changes in hydrology, sediment load, or isolation from the flood plain. High and steep banks are more susceptible to erosion or collapse. All outside bends of streams erode, so even a stable stream may have 50 percent of its banks bare and eroding. A healthy riparian corridor with a vegetated flood plain contributes to bank stability. The roots of perennial grasses or woody vegetation typically extend to the baseflow elevation of water in streams that have bank heights of 6 feet or less. The root masses help hold the bank soils together and physically protect the bank from scour during bankfull and flooding events. Vegetation seldom becomes established below the elevation of the bankfull surface because of the frequency of inundation and the un- stable bottom conditions as the stream moves its bedload.

The type of vegetation is important. For example, trees, shrubs, sedges, and rushes have the type of root masses capable of withstanding high streamflow events, while Kentucky bluegrass does not. Soil type at the surface and below the surface also influences bank stability. For example, banks with a thin soil cover over gravel or sand are more prone to collapse than are banks with a deep soil layer.

Evidence of Bank Instability: Signs of erosion include unvegetated stretches, exposed tree roots, or scalloped edges. Evidence of construction, vehicular, or animal paths near banks or grazing areas leading directly to the water's edge suggest conditions that may lead to the collapse of banks. Estimate the size or area of the bank affected relative to the total bank area. This element may be difficult to score during high water.

V_{WC}: Water Color

Very clear, or clear but tea-colored; objects visible at depth 3 to 6 ft (less if slightly colored); no oil sheen on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; objects visible at depth 1.5 to 3 ft; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; objects visible to depth 0.5 to 1.5 ft; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. ***or*** Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; objects visible to depth < 0.5 ft; slow moving water may be bright- green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface. ***or*** Strong odor of chemicals, oil, sewage, other pollutants.
1.0	0.7	0.3	0.1

This element compares turbidity, color, and other visual characteristics with a healthy or reference stream. The depth to which an object can be clearly seen is a measure of turbidity. Turbidity is caused mostly by particles of soil and organic matter suspended in the water column. Water often shows some turbidity after a storm event because of soil and organic particles carried by runoff into the stream or suspended by turbulence. The water in some streams may be naturally tea-colored. This is particularly true in watersheds with extensive bog and wetland areas. Water that has slight nutrient enrichment may support communities of algae, which provide a greenish color to the water. Streams with heavy loads of nutrients have thick coatings of algae attached to the rocks and other submerged objects. In degraded streams, floating algal mats, surface scum, or pollutants, such as dyes and oil, may be visible.

Evidence of Poor Water Clarity: Clarity of the water is an obvious and easy feature to assess. The deeper an object in the water can be seen, the lower the amount of turbidity. Use the depth that objects are visible only if the stream is deep enough to evaluate turbidity using this approach. For example, if the water is clear, but only 1 foot deep, do not rate it as if an object became obscured at a depth of 1 foot. This measure should be taken after a stream has had the opportunity to "settle" following a storm event. A pea-green color indicates nutrient enrichment beyond what the stream can naturally absorb.

V_{NE}: Nutrient Enrichment

Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
1.0	0.7	0.3	0.1

Nutrient enrichment is often reflected by the types and amounts of aquatic vegetation in the water. High levels of nutrients (especially phosphorus and nitrogen) promote an overabundance of algae and floating and rooted macrophytes. The presence of some aquatic vegetation is normal in streams. Algae and macrophytes provide habitat and food for all stream animals. However, an excessive amount of aquatic vegetation is not beneficial to most stream life. Plant respiration and decomposition of dead vegetation consume dissolved oxygen in the water. Lack of dissolved oxygen creates stress for all aquatic organisms and can cause fish kills. A landowner may have seen fish gulping for air at the water surface during warm weather, indicating a lack of dissolved oxygen.

Evidence of High Nutrient Enrichment: Some aquatic vegetation (rooted macrophytes, floating plants, and algae attached to substrates) is normal and indicates a healthy stream. Excess nutrients cause excess growth of algae and macrophytes, which can create greenish color to the water. As nutrient loads increase the green becomes more intense and macrophytes become more lush and deep green. Intense algal blooms, thick mats of algae, or dense stands of macrophytes degrade water quality and habitat. Clear water and a diverse aquatic plant community without dense plant populations are optimal for this characteristic.

V_{FC}: Fish Cover

> 7 cover types available	6 to 7 cover types available	4 to 5 cover types available	2 to 3 cover types available	None to 1 cover types available
1.0	0.8	0.5	0.3	0.1

Cover types: Logs/large woody debris, deep pools, overhanging vegetation, boulders/cobble, riffles, undercut banks, thick root mats, dense macrophyte beds, isolated/backwater pools, other:____.

This assessment element measures availability of physical habitat for fish. The potential for the maintenance of a healthy fish community and its ability to recover from disturbance is dependent on the variety and abundance of suitable habitat and cover available.

Evidence of Good Fish Cover: Observe the number of different habitat and cover types *within a representative sub-section of the assessment* reach that is equivalent in length to *five times* the active channel width. Each cover type must be present in appreciable amounts to score. Cover types are described below.

Logs/large woody debris—Fallen trees or parts of trees that provide structure and attachment for aquatic macroinvertebrates and hiding places for fish.

Deep pools—Areas characterized by a smooth undisturbed surface, generally slow current, and deep enough to provide protective cover for fish (75 to 100% deeper than the prevailing stream depth).

Overhanging vegetation—Trees, shrubs, vines, or perennial herbaceous vegetation that hangs immediately over the stream surface, providing shade and cover.

Boulders/cobble—Boulders are rounded stones more than 10 inches in diameter or large slabs more than 10 inches in length; cobbles are stones between 2.5 and 10 inches in diameter.

Undercut banks—Eroded areas extending horizon- tally beneath the surface of the bank forming underwater pockets used by fish for hiding and protection.

Thick roots mats—Dense mats of roots and rootlets (generally from trees) at or beneath the water surface forming structure for invertebrate attachment and fish cover.

Dense macrophyte beds—Beds of emergent (e.g., water willow), floating leaf (e.g., water lily), or sub- merged (e.g., riverweed) aquatic vegetation thick enough to provide invertebrate attachment and fish cover.

Riffles—Area characterized by broken water surface, rocky or firm substrate, moderate or swift current, and relatively shallow depth (usually less than 18 inches).

Isolated/backwater pools—Areas disconnected from the main channel or connected as a "blind" side channel, characterized by a lack of flow except in periods of high water.

V_P: Pools

Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 5 feet deep.	Pools present, but not abundant; from 10 to 30% of the pool bottom is obscure due to depth, or the pools are at least 3 feet deep.	Pools present, but shallow; from 5 to 10% of the pool bottom is obscure due to depth, or the pools are less than 3 feet deep.	Pools absent, or the entire bottom is discernible.
1.0	0.7	0.3	0.1

Pools are important breeding, resting and feeding sites for fish. In addition, the glides that form immediately downstream of the pools (pool tail), provides additional breeding sites for Salmonidae species (redds). A healthy stream has a mix of shallow and deep pools. A *deep* pool is 1.6 to 2 times deeper than the prevailing depth, while a *shallow* pool is less than 1.5 times deeper than the prevailing depth. Pools are abundant if a deep pool is in each of the meander bends in the reach being assessed. To determine if pools are abundant, look at a longer sample length than one that is 12 active channel widths in length. Generally, only 1 or 2 pools would typically form within a reach as long as 12 active channel widths. In low order, high gradient streams, pools are abundant if there is more than one pool every 4 channel widths.

Evidence of Pools: Pool diversity and abundance are estimated based on walking the stream or probing from the streambank with a stick or length of rebar. You should find deep pools on the outside of meander bends. In shallow, clear streams a visual inspection may provide an accurate estimate. In deep streams or streams with low visibility, this assessment characteristic may be difficult to determine and should not be scored.

V_{CAN}: Canopy

25 to 90% of water surface shaded; mixture of conditions.	> 90% shaded; full canopy; same shading condition throughout the reach.	intentionally blank	< 25% water surface shaded in reach.
1.0	0.7		0.1

Shading of the stream is important because it keeps water cool and limits algal growth. Cool water has a greater oxygen holding capacity than does warm water. When streamside trees are removed, the stream is exposed to the warming effects of the sun causing the water temperature to increase for longer periods during the daylight hours and for more days during the year. This shift in light intensity and temperature causes a decline in the numbers of certain species of fish, insects, and other invertebrates and some aquatic plants. They may be replaced altogether by other species that are more tolerant of increased light intensity, low dissolved oxygen, and warmer water temperature. For example, trout and salmon require cool, oxygen-rich water. Loss of streamside vegetation (and also channel widening) that cause increased water temperature and decreased oxygen levels are major contributing factors to the decrease in abundance of trout and salmon from many streams that historically supported these species. Increased light and the warmer water also promote excessive growth of submerged macrophytes and algae that compromises the biotic community of the stream. The temperature at the reach you are assessing will be affected by the amount of shading 2 to 3 miles upstream.

Estimating Canopy Cover: Try to estimate the portion of the water surface area for the whole reach that is shaded by estimating areas with no shade, poor shade, and shade. Time of the year, time of the day, and weather can affect your observation of shading. Therefore, the relative amount of shade is estimated by assuming that the sun is directly overhead and the vegetation is in full leaf-out. First evaluate the shading conditions for the reach; then determine (by talking with the land- owner) shading conditions 2 to 3 miles upstream. Alternatively, use aerial photographs taken during full leaf out. The following rough guidelines for percent shade may be used:

stream surface not visible	>90
surface slightly visible or visible only in patches………………………………………………..	70 – 90
surface visible, but banks not visible……………………………………………………………..	40 – 70
surface visible and banks visible at times………………………………………………………	20 – 40
surface and banks visible	<20

V_{CA}: Cattle Access

Intentionally blank	Some evidence of livestock access to riparian zone or adjacent floodplain or valley flat.	Moderate evidence of livestock access to riparian zone or adjacent floodplain or valley flat.	Extensive evidence of livestock access to riparian zone or adjacent floodplain or valley flat. or Extensive amount of manure on banks or in stream.
	0.5	0.3	0.1

Manure from livestock may enter the water if livestock have access to the stream or from runoff of grazing land adjacent to the stream. Manure increase biochemical oxygen demand, increase the loading of nutrients, and alter the trophic state of the aquatic biological community.

Evidence of Cattle Access: Do not score this element unless livestock operations are present. Look for evidence of animal droppings in or around streams, on the streambank, or in the adjacent riparian zone. Well-worn livestock paths leading to or near streams also suggest the probability of manure in the stream. Areas with stagnant or slow-moving water may have moderate to dense amounts of vegetation or algal blooms, indicating localized enrichment from manure.

V_{EMB}: Embeddedness

Gravel or cobble particles are < 20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40% embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
1.0	0.8	0.5	0.3	0.1

Riffles are areas, often downstream of a pool, where the water is breaking over rocks or other debris causing surface agitation. In coastal areas riffles can be created by shoals and submerged objects. (This element is sensitive to regional differences and should be related to reference conditions.) Riffles are critical for maintaining high species diversity and abundance of insects for most streams and for serving as spawning and feeding grounds for some fish species. Embeddedness measures the degree to which gravel and cobble substrate are surrounded by fine sediment. It relates directly to the suitability of the stream substrate as habitat for macroinvertebrates, fish spawning, and egg incubation.

Evidence of Embeddedness: This assessment characteristic should be used only in riffle areas and in streams where this is a natural feature. The measure is the depth to which objects are buried by sediment. This assessment is made by picking up particles of gravel or cobble with your fingertips at the fine sediment layer. Pull the particle out of the bed and estimate what percent of the particle was buried. Some streams have been so smothered by fine sediment that the original stream bottom is not visible. Test for complete burial of a streambed by probing with a length of rebar.

STREAM CONDITION INDEX (SCI)

The Stream Condition Index (SCI) model was formulated using a modification of the stream visual assessment protocol which included 15 variables (USDA 1998). The practitioner should become familiar with the stream visual assessment protocol as a reference. Three variables: 1) Insect/invertebrate habitat; 2) salinity; and 3) macroinvertebrates observed, were omitted due to the remote natural of the low altitude video assessment. In addition, no correlation was observed between dams and the remaining twelve variables. Thus, it was omitted from the SCI model. The following model was formulated from eleven of the 15 variables recommended by USDA (1998):

$$\mathrm{SCI} = \frac{\left(\sqrt[3]{\mathrm{CS} \times \mathrm{FC} \times \mathrm{P}} + \sqrt[3]{\mathrm{RZ} \times \mathrm{BS} \times \mathrm{CAN}}\right) / 2}{\left(\mathrm{HA} + \sqrt[3]{\mathrm{WC} \times \mathrm{NE} \times \mathrm{EMB}} + \mathrm{CA} / 3\right)}$$

Where:

CS = Channel Stability

FC = Fish Cover

P = Pools

RZ = Riparian Zone

BS = Bank Stability

CAN = Canopy Density

HA = Hydrologic Alteration

WC = Water Color

NE = Nutrient Enrichment

EMB = Embeddedness
CA = Cattle Access

As used herein, ecological models are algorithms which are empirical equations that express a relationship or correlation based solely on observation rather than theory. An empirical equation is simply a mathematical statement of one or more correlations in the form of an equation. In this case, the correlations were observed to be positive (direct) or negative (indirect). In turn, the variables were observed to be dependent or independent with respect to each other. The observed interaction between variables occurs when the simultaneous influence of two measures on a model score is not additive. “Interaction” is analogous to dependence where a variable has a statistically significant influence on other variables. For example, in the algorithm above, channel stability (CS) is observed to be highly correlated with fish cover (FC) and pools (P). Consequently, the three variables are considered dependent variables, and the geometric mean normalized the three variables. In addition, variables used in the numerator of the equation had a positive effect on the overall SCI score. In contrast, variables used in the denominator had a negative effect on the SCI score. For example, when hydrologic alteration (HA) is high, the SCI score is reduced.

Application of Stream Condition Index in Resource Planning

By conducting a visual assessment of stream condition using the SCI, conclusions can be made in regards to aquatic habitat, diversity and distribution of fish and benthic macroinvertebrates at multiple scales (stream reach, segment or watershed). Overall, the results of SCI scores can be utilized to:

1. Prioritize stream segments and watersheds for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts.
2. Evaluate project alternative analysis and cost/benefit analysis.
3. Develop performance standards and success criteria applicable to restoration actions.
4. Address impacts or improvements beyond the footprint of the project.
5. Establish monitoring plans including adaptive management.
6. Forecast future ecosystem lift or outcomes.
7. Estimate the long-term effects of climate change on ecosystem processes and functions.
8. Assess stream conditions elsewhere and compare against reference conditions established during this watershed assessment.
9. Justify proposed projects at the national significant priority scale.

The statistical treatise used in model development for the Duck Watershed can be utilized elsewhere in other physiographies and USACE Districts. The protocol used herein for establishing stream corridor conditions is applicable to the Tennessee River basin within Tennessee. However, the protocol can be transported to other river basins with additional beta testing and model refinement.

Table 1. Stream Condition Index (SCI) Variable Scoring Table.

Channel Stability-Cross-section (CS)	Natural channel in cross-section relative to reference conditions; No evidence of channel widening; Little or no formation of mid-channel bars.	Evidence of past channel alteration, but with significant recovery of channel and banks. Moderate evidence of channel widening and mid-channel bar formation.	Altered channel; Excess aggradation; Some braided or anastomosed channel. Severe channel widening and mid-channel bar formation.	Highly altered channel; Excess aggradation; Predominate braiding or anastomosed channel. Extreme channel widening causing active bank failure.	
CS Score →	**1.0**	**0.7**	**0.3**	**0.1**	
Hydrologic Alteration (HA)	Natural channel; no structures, dikes. No evidence of down- cutting or excessive lateral cutting. No artificial channel confinement. Flood frequency onto active floodplain every 1.5 to 2 years RI.	Evidence of past channel alteration, but with significant recovery of channel and banks. Channel slightly incised. Minimum artificial channel confinement. Flood frequency onto active floodplain every 3 to 5 years RI.	Moderately altered channel; <50% of the reach with riprap and/ or channelization. Channel deeply incised. Flood frequency onto active floodplain every 6 to 10 years RI.	Channel is actively downcutting or widening. >50% of the reach with riprap or channelization. Channel severely incised. Flood frequency onto active floodplain > 10 years RI.	
HA Score →	**1.0**	**0.7**	**0.3**	**0.1**	
Riparian Zone (RZ)	Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. or If less than one width, covers entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. or Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. or Lack of regeneration.
RZ Score →	**1.0**	**0.8**	**0.5**	**0.3**	**0.1**

Table 1. Stream Condition Index (SCI) Variable Scoring Table (continued).

Bank Stability (BS)	Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); out- side bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
BC Score →	**1.0**	**0.7**	**0.3**	**0.1**
Water Color (WC)	Very clear, or clear but tea-colored; objects visible at depth 3 to 6 ft (less if slightly colored); no oil sheen on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; objects visible at depth 1.5 to 3 ft; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; objects visible to depth 0.5 to 1.5 ft; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. or Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; objects visible to depth < 0.5 ft; slow moving water may be bright- green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface. or Strong odor of chemicals, oil, sewage, other pollutants.
WC Score →	**1.0**	**0.7**	**0.3**	**0.1**
Nutrient Enrichment (NE)	Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
NE Score →	**1.0**	**0.7**	**0.3**	**0.1**

Table 1. Stream Condition Index (SCI) Variable Scoring Table (continued).

Fish Cover (FC)	>7 cover types available	6 to 7 cover types available	4 to 5 cover types available	2 to 3 cover types available	None to 1 cover type available
FC Score →	**1.0**	**0.8**	**0.5**	**0.3**	**0.1**
Pools (P)	Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 5 feet deep.	Pools present, but not abundant; from 10 to 30% of the pool bottom is obscure due to depth, or the pools are at least 3 feet deep.	Pools present, but shallow; from 5 to 10% of the pool bottom is obscure due to depth, or the pools are less than 3 feet deep.	Pools absent, or the entire bottom is discernible.	
P Score →	**1.0**	**0.7**	**0.3**	**0.1**	
Canopy (CAN)	25 to 90% of water surface shaded; mixture of conditions.	> 90% shaded; full canopy; same shading condition throughout the reach.	(intentionally blank)	< 25% water surface shaded in reach.	
CAN Score →	**1.0**	**0.7**		**0.1**	
Cattle Access (CA)	Evidence of livestock access to riparian zone.	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream. or Untreated human waste discharge pipes present.		
CAN Score →	**0.5**	**0.3**	**0.1**		
Embeddedness (EMB)	Gravel or cobble particles are < 20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40% embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
EMB Score →	1.0	0.8	0.5	0.3	0.1

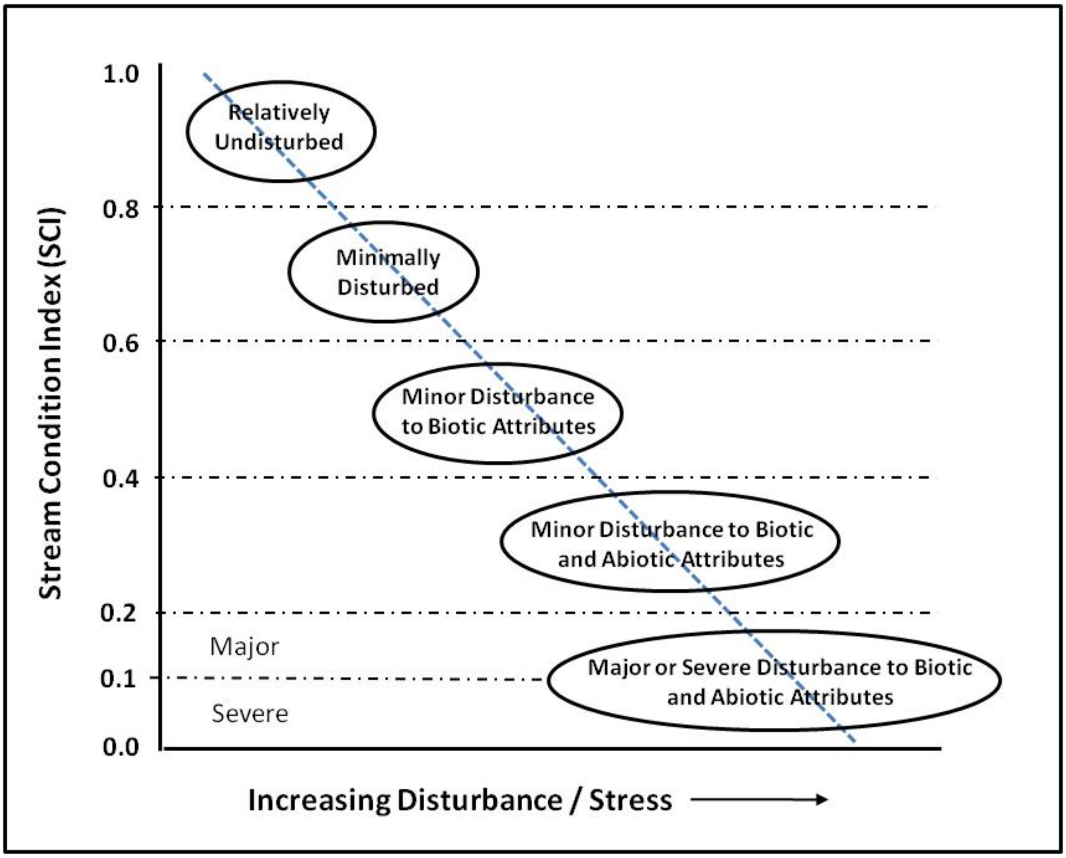


Figure 1. Stream Condition Index (SCI) scaled against environmental disturbance gradient (adapted from Pruitt et al. 2012).

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Appendix C – Climate Change Assessment

Climate Change Assessment – Duck River Watershed Study

Literature Review

The basis of this analysis is the USACE report titled "Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Ohio Region 05", Civil Works Technical Series Report Number CWTS-2015-05.

Climate Hydrology Assessment Tool

The Climate Hydrology Assessment Tool (USACE, 2015) allows users to easily access both existing and projected climate data to develop repeatable analytical results using consistent information: reducing potential error and increasing the development of information so that it can be used earlier in the decision-making process, ideally in the development of risk registers. The tool steps the user through the process of developing information and supplies graphics suitable for use in a report including trend detection in observed annual maximum daily flow, trend detection in observed annual maximum 3-day flow, climate-modeled annual maximum monthly flow range, and trend detection in annual maximum monthly flow models.

The Climate Hydrology Assessment Tool was used to analyze available streamflow data for the Duck River at four points (see Figure 1). The Duck River above Hurricane Mills, Tennessee, gage (USGS Gage #03603000) lies in the lower end of the basin and has a continuous record from 1926 through 1994, a break of 15 years, then another six years of record between 2009 and 2014. The Duck River at Columbia, Tennessee, gage (USGS Gage #03599500) lies in the middle of the Duck River basin and is the gage with the longest continuous period of record in the basin, from 1921 through 2016 (neglecting two historic peaks and an extremely short period of discontinuous record). The Duck River near Shelbyville, Tennessee, gage (USGS Gage #03598000) lies in the upper end of the basin and has a continuous record from 1935 through 2015. The Buffalo River near Flat Woods, Tennessee, gage (USGS Gage #03604000) lies in the lower end of this major tributary to the Duck River and has a continuous record from 1921 through 2014. The results of the Annual Peak Instantaneous Streamflow Analysis tool are shown in Figure 2 throughFigure 5. The Hurricane Mills, Columbia, and Flat Woods gages show a slight upward trend in flow values with p-values of 0.0848002, 0.585892, and 0.207147 respectively. The Shelbyville gage shows a strong downward trend in flow with a p-value of 0.0095379. The p-value obtained for the Hurricane Mills, Columbia, and Flat Woods gages is well above 0.05 indicating the results have no statistical significance while the p-value obtained for the Shelbyville gage is well below 0.05 indicating the results have statistical significance. Normandy Dam was constructed on the Duck River in 1976 with one of its primary purposes being flood control. The dam lies at Duck River mile 248.6 which is upstream of all three gages on the Duck River mainstem and so affects flows on the majority of the Duck River but to a lesser degree as one moves downstream. This likely causes the difference in trend at the upper Shelbyville gage versus the middle and lower Columbia and Hurricane Mills gages. There have never been any significant flow regulation structures on the Buffalo River tributary to the Duck River.

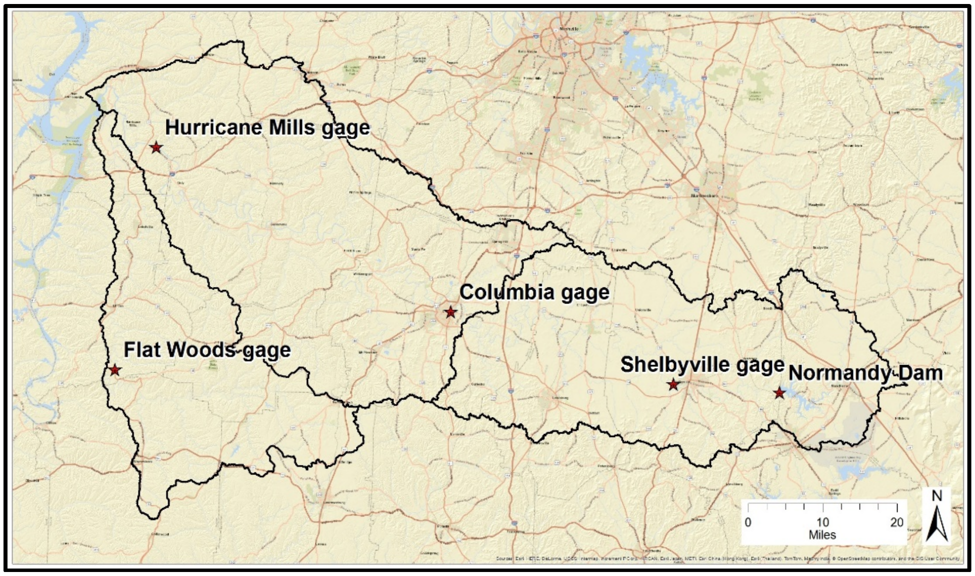


Figure 1: Map showing location of USGS stream gages and Normandy Dam

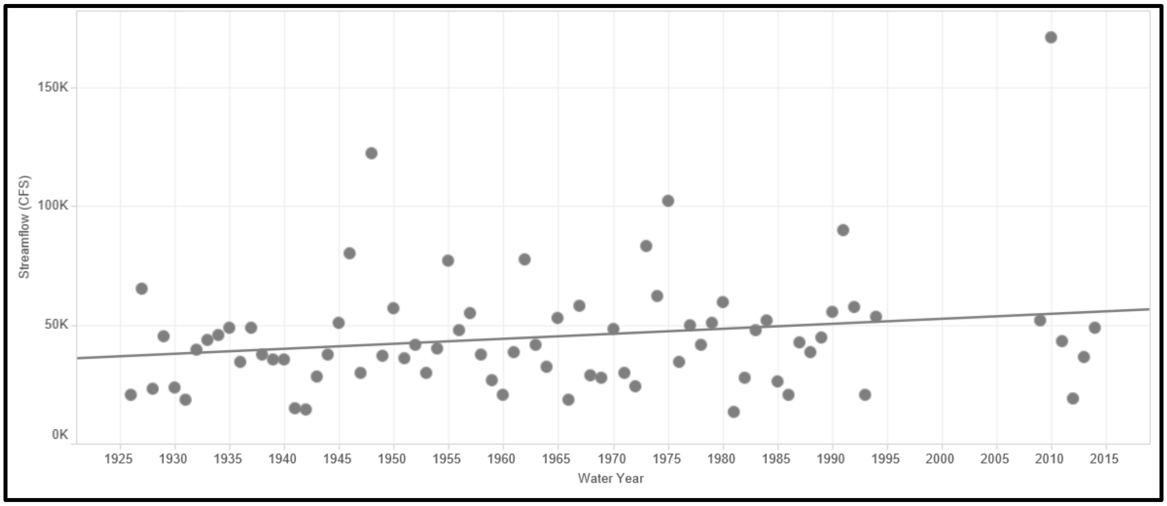


Figure 2: Annual Peak Streamflow Analysis for the Duck River above Hurricane Mills, TN, gage

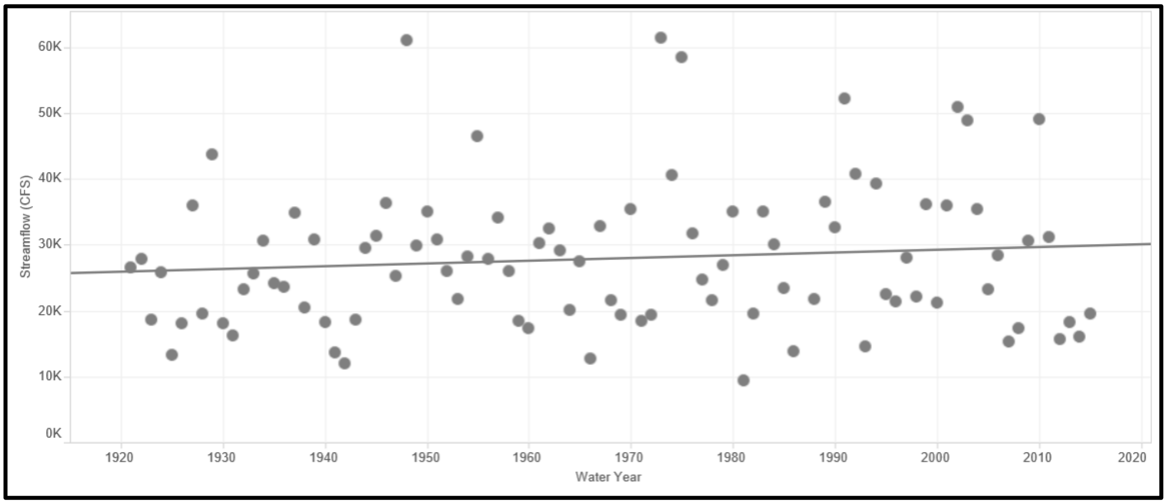


Figure 3: Annual Peak Streamflow Analysis for the Duck River at Columbia, TN, gage

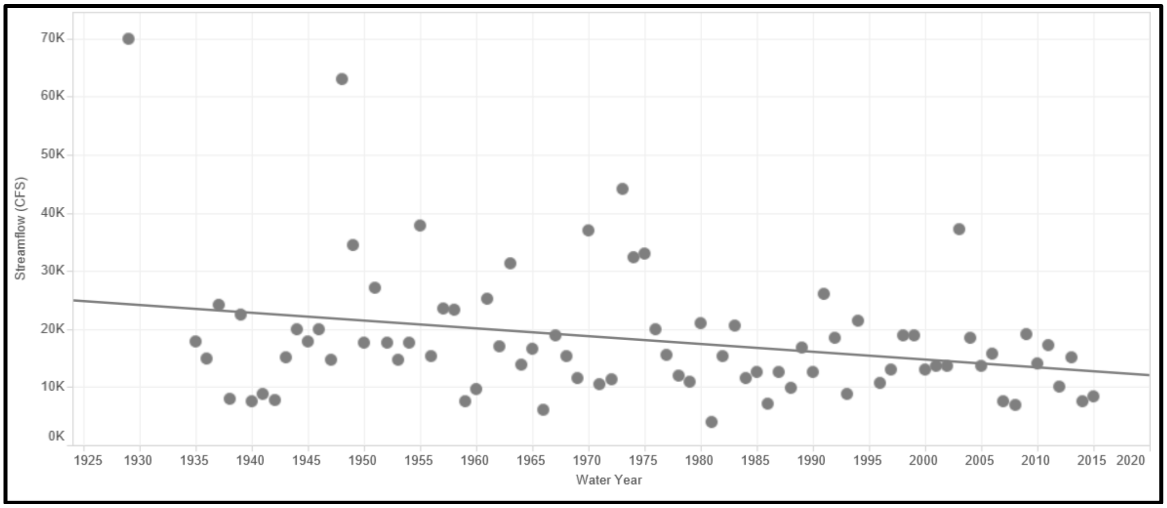


Figure 4: Annual Peak Streamflow Analysis for the Duck River near Shelbyville, TN, gage

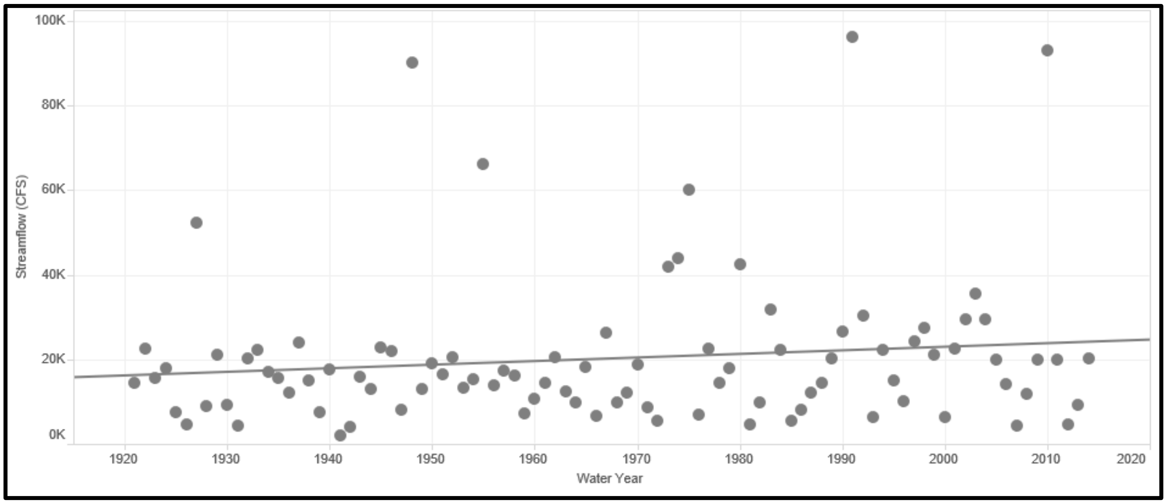


Figure 5: Annual Peak Streamflow Analysis tool results for the Buffalo River near Flat Woods, TN, gage

The Climate Hydrology Assessment Tool also includes a Projected Annual Max Monthly tool which is applied at the HUC-4 level. The HUC-4 within which the Duck River basin is located is HUC-0604, Lower Tennessee region, and is shown in Figure 6. HUC-0604 is comprised of 8,090 square miles so the 3,491 square mile Duck River basin makes up 43% of this HUC.

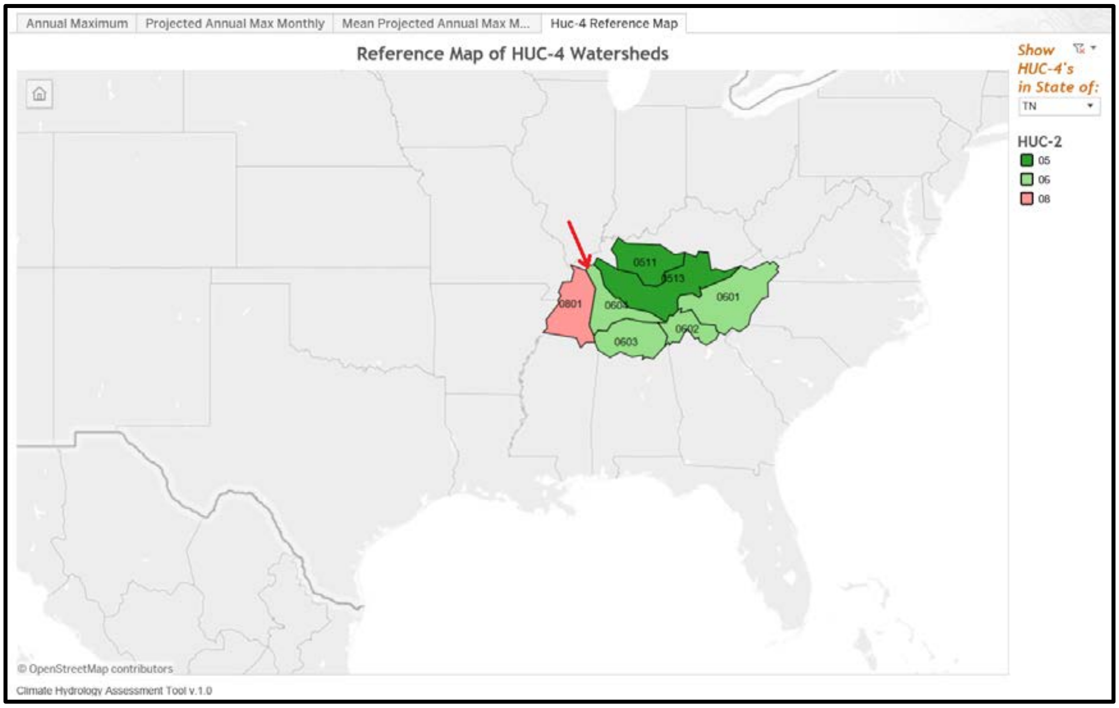


Figure 6: Map showing the location of the Lower Tennessee River HUC-0604

The results of the Projected Annual Max Monthly streamflow analysis tool are shown in Figure 7. The tool projects the monthly flows through 2100 using 93 GCM/RCP model projections. For the Lower Tennessee River region, the models predict more variability in the upper range of projections indicating more intense rainfall. However, the mean line stays fairly flat without any noticeable increase in rainfall.

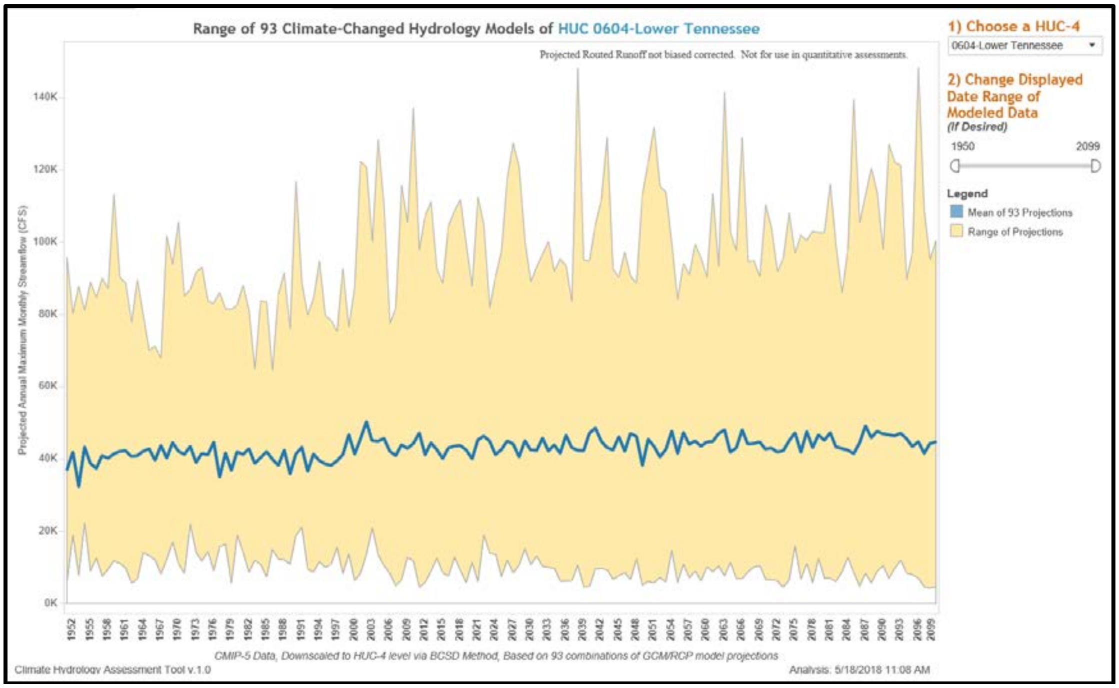
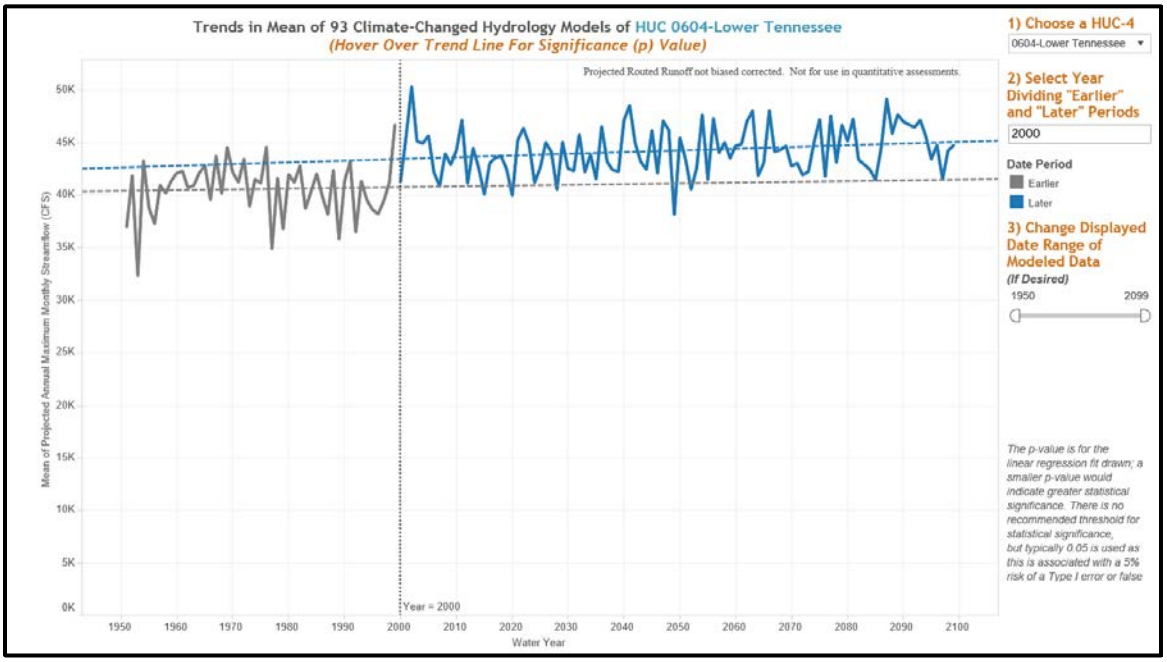


Figure 7: Projected Annual Maximum Monthly Analysis tool results for HUC-0604

The third Climate Hydrology Assessment tool is the Mean Projected Annual Maximum Monthly Streamflow tool. The results of this tool are shown in Figure 8. The tool projects there will be an upward trend in annual monthly streamflow in the Duck River basin. The Duck River basin makes up a large part of the Lower Tennessee River HUC-0604 so it is likely these results would apply to it. Based on the tool's results, we can assume changes in the Annual Maximum Monthly Streamflow will trend upward but the amount of increase cannot be quantified using this analysis.



Projected Routed Runoff not biased corrected. Not for use in quantitative assessments.

0604-Lower Tennessee

2000

The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false

Figure 8: Mean Projected Annual Maximum Monthly Streamflow tool results for HUC-0604

Nonstationarity Detection Tool

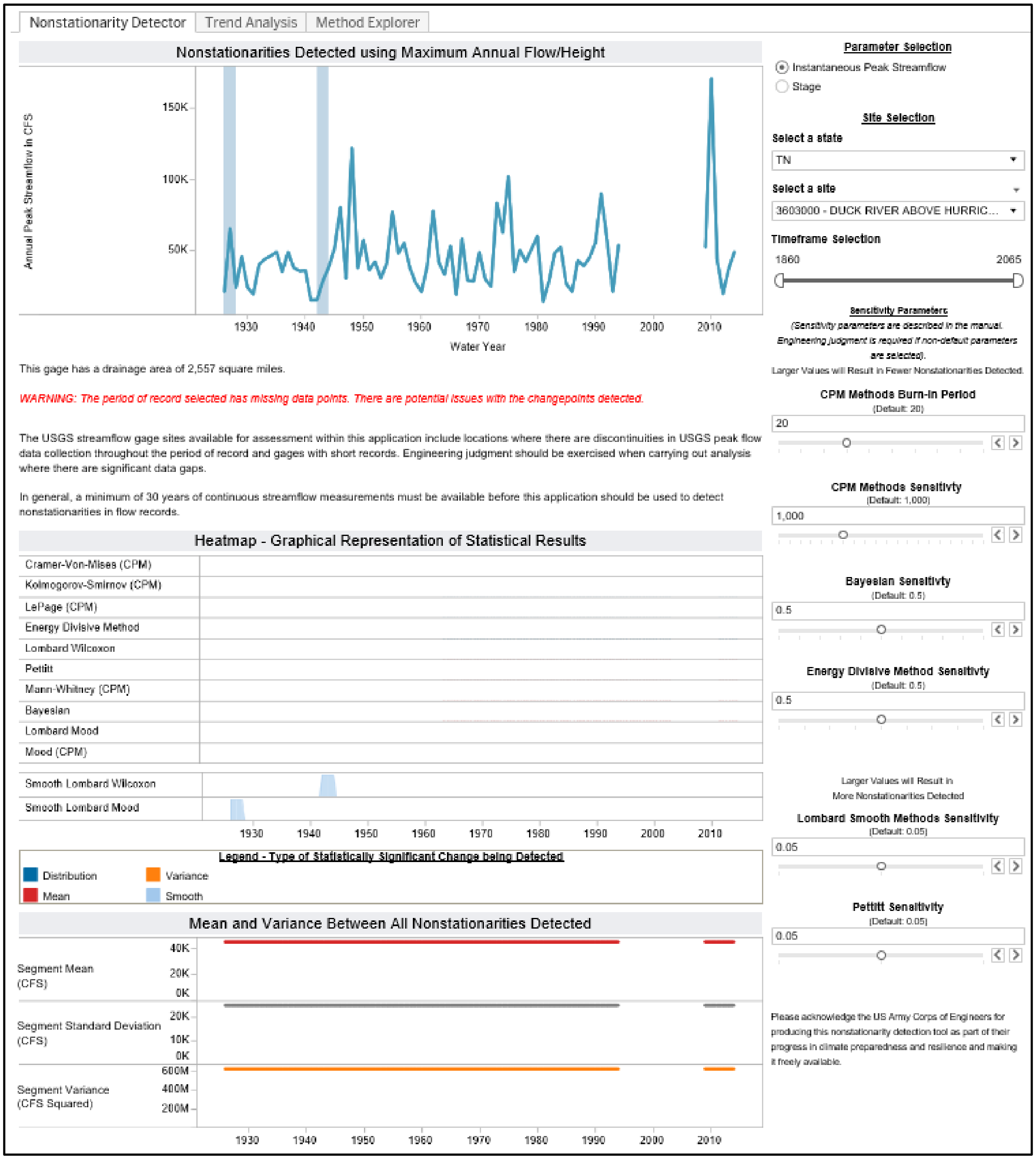
This Nonstationarity Detection Tool was developed in conjunction with USACE Engineering Technical Letter (ETL) 1100-2-3, Guidance for Detection of Nonstationarities in Annual Maximum Discharges, to detect nonstationarities in maximum annual flow time series. Per ETL 1100-2-3, engineers are required to assess the stationarity of all streamflow records analyzed in support of hydrologic analyses carried out for USACE planning and engineering decision-making purposes.

The Nonstationarity Detection Tool enables the user to apply a series of statistical tests to assess the stationarity of annual peak streamflow data series at any United States Geological Survey (USGS) annual instantaneous peak streamflow gage site with more than 30 years of flow record through Water Year 2014. The tool is intended to aid practitioners in identifying continuous periods of statistically homogenous (stationary) annual peak streamflow datasets that can be adopted for further hydrologic analysis.

The web tool detects nonstationarities in the historical record to help the user segment the record into flow datasets whose statistical properties can be considered stationary. The tool also allows users to conduct monotonic trend analysis on the resulting subsets of stationary flow records identified. The web tool facilitates direct access to annual maximum streamflow datasets, does not require the user to have specialized software or a background in advanced statistical analysis, provides consistent, repeatable analytical results that support peer review processes, and allows for consistent updates over time.

This functionality is contained within three different sheets:

Nonstationarity Detector - The Nonstationarity Detector tool uses a dozen different statistical methods to detect the presence of both abrupt and smooth nonstationarities in the period of record. The results of the Nonstationarity Detector are shown in Figure 9 through Figure 12. The tool indicates there are not many nonstationarities at the any of the four gages. It was noted however that the Shelbyville gage clearly reflects a nonstationarity occurring at the time when Normandy Dam was constructed, 1976. There is less indication of nonstationarity at the Columbia gage around 1976 and no indication of nonstationarity at the Hurricane Mills gage during this time. This again reflects the diminishing control the dam has on flows moving from upstream to downstream. There is some indication of nonstationarity at the Flat Woods gage in the late 1980s for which there is no known cause.



This gage has a drainage area of 2,557 square miles.

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Parameter Selection

● Instantaneous Peak Streamflow

○ Stage

Site Selection

Select a state

TN

Select a site

3603000 - DUCK RIVER ABOVE HURRIC...

Timeframe Selection

1860 2065

Sensitivity Parameters

(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).

Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period

(Default: 20)

20

CPM Methods Sensitivty

(Default: 1,000)

1,000

Bayesian Sensitivty

(Default: 0.5)

0.5

Energy Divisive Method Sensitivty

(Default: 0.5)

0.5

Larger Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity

(Default: 0.05)

0.05

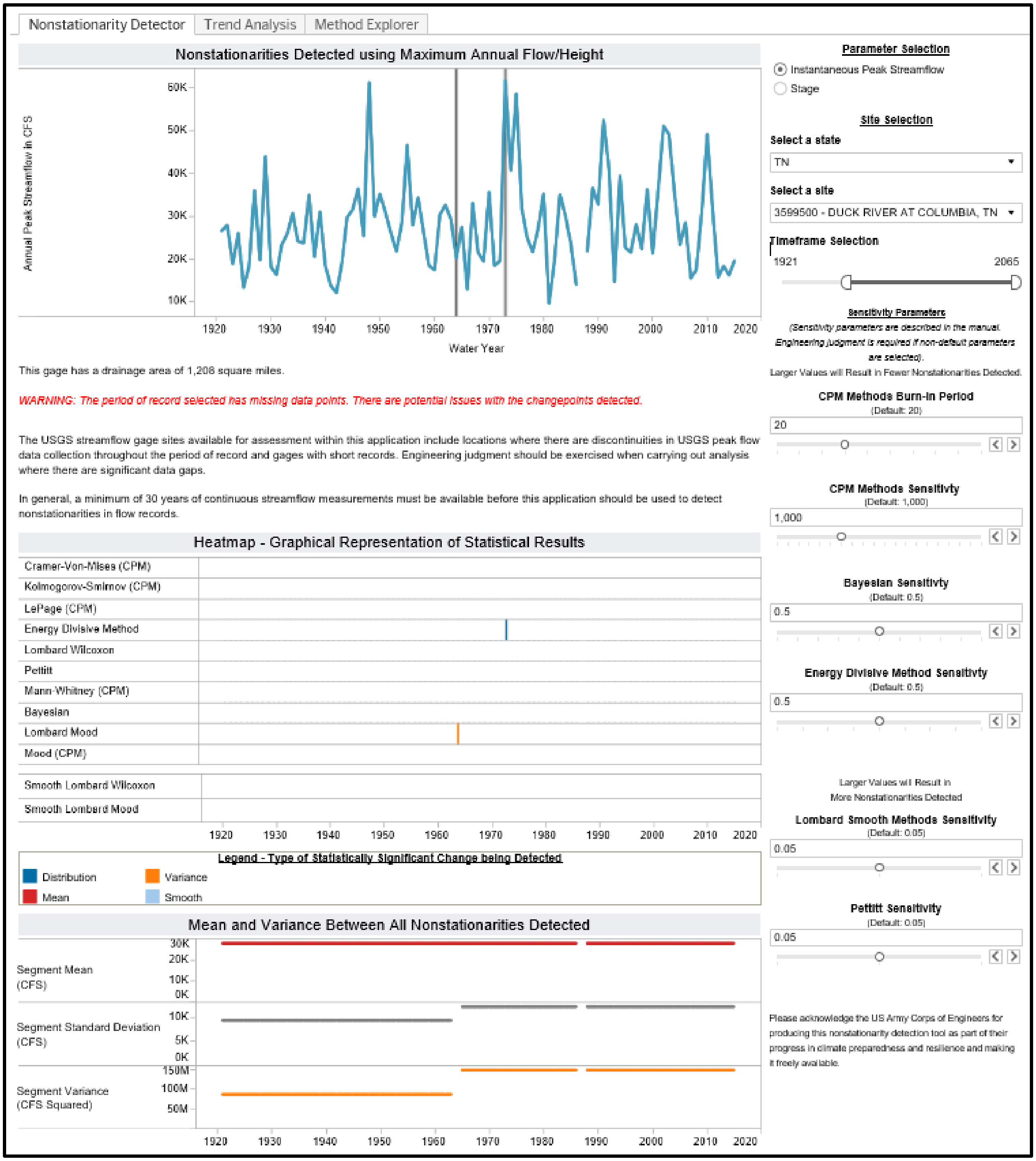
Pettitt Sensitivity

(Default: 0.05)

0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 9: Non-stationarity Detector tool results for the Duck River above Hurricane Mills gage



This gage has a drainage area of 1,208 square miles.

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

● Instantaneous Peak Streamflow
○ Stage

Select a state: TN

Select a site: 3599500 - DUCK RIVER AT COLUMBIA, TN

1921 – 2065

(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).

Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period (Default: 20): 20

CPM Methods Sensitivty (Default: 1,000): 1,000

Bayesian Sensitivty (Default: 0.5): 0.5

Energy Divisive Method Sensitivty (Default: 0.5): 0.5

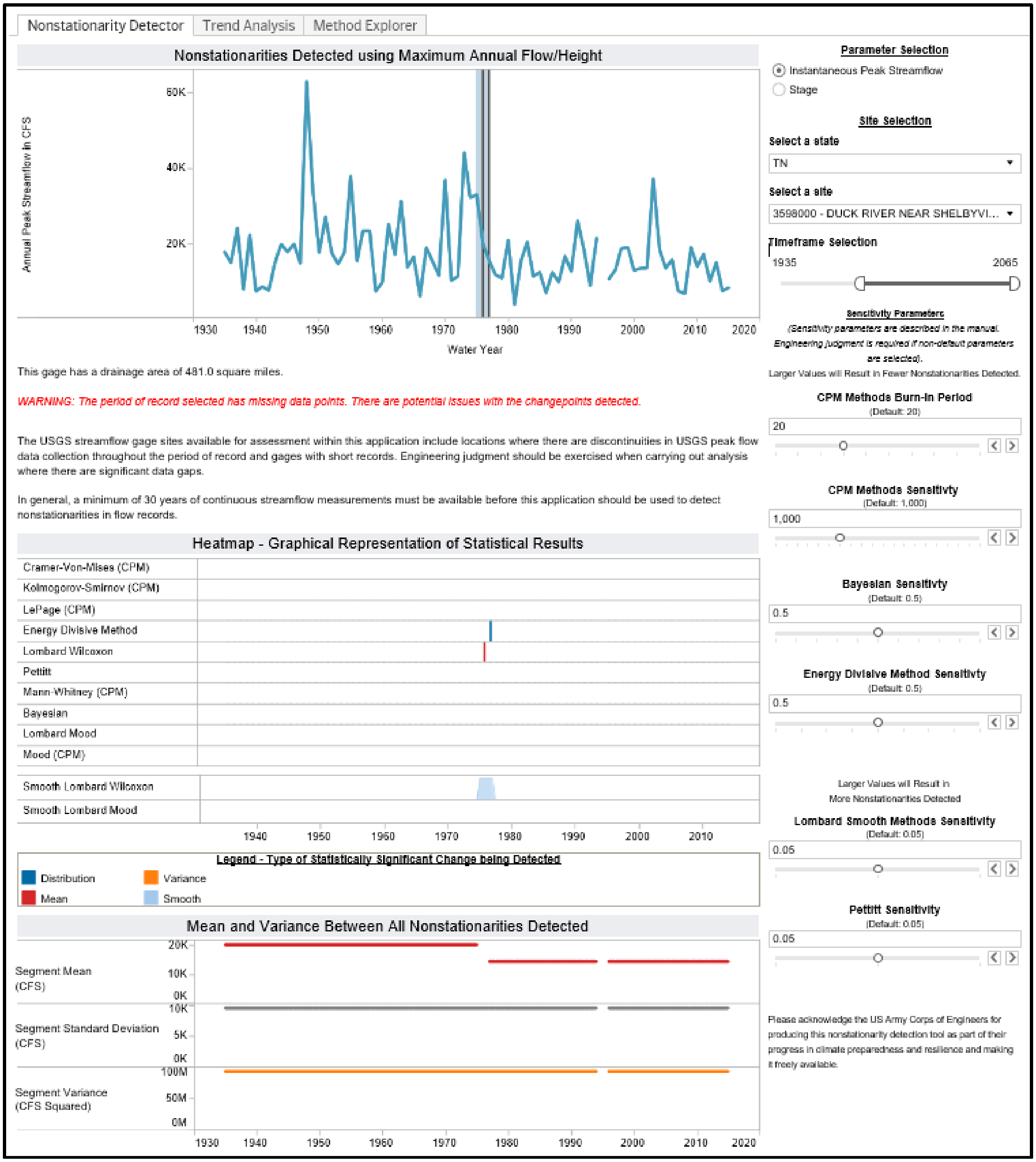
Larger Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity (Default: 0.05): 0.05

Pettitt Sensitivity (Default: 0.05): 0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 10: Non-stationarity Detector tool results for the Duck River at Columbia gage



This gage has a drainage area of 481.0 square miles.

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Parameter Selection

● Instantaneous Peak Streamflow
○ Stage

Site Selection

Select a state: TN

Select a site: 3598000 - DUCK RIVER NEAR SHELBYVI...

Timeframe Selection: 1935 – 2065

Sensitivity Parameters

(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).

Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period (Default: 20): 20

CPM Methods Sensitivty (Default: 1,000): 1,000

Bayesian Sensitivty (Default: 0.5): 0.5

Energy Divisive Method Sensitivty (Default: 0.5): 0.5

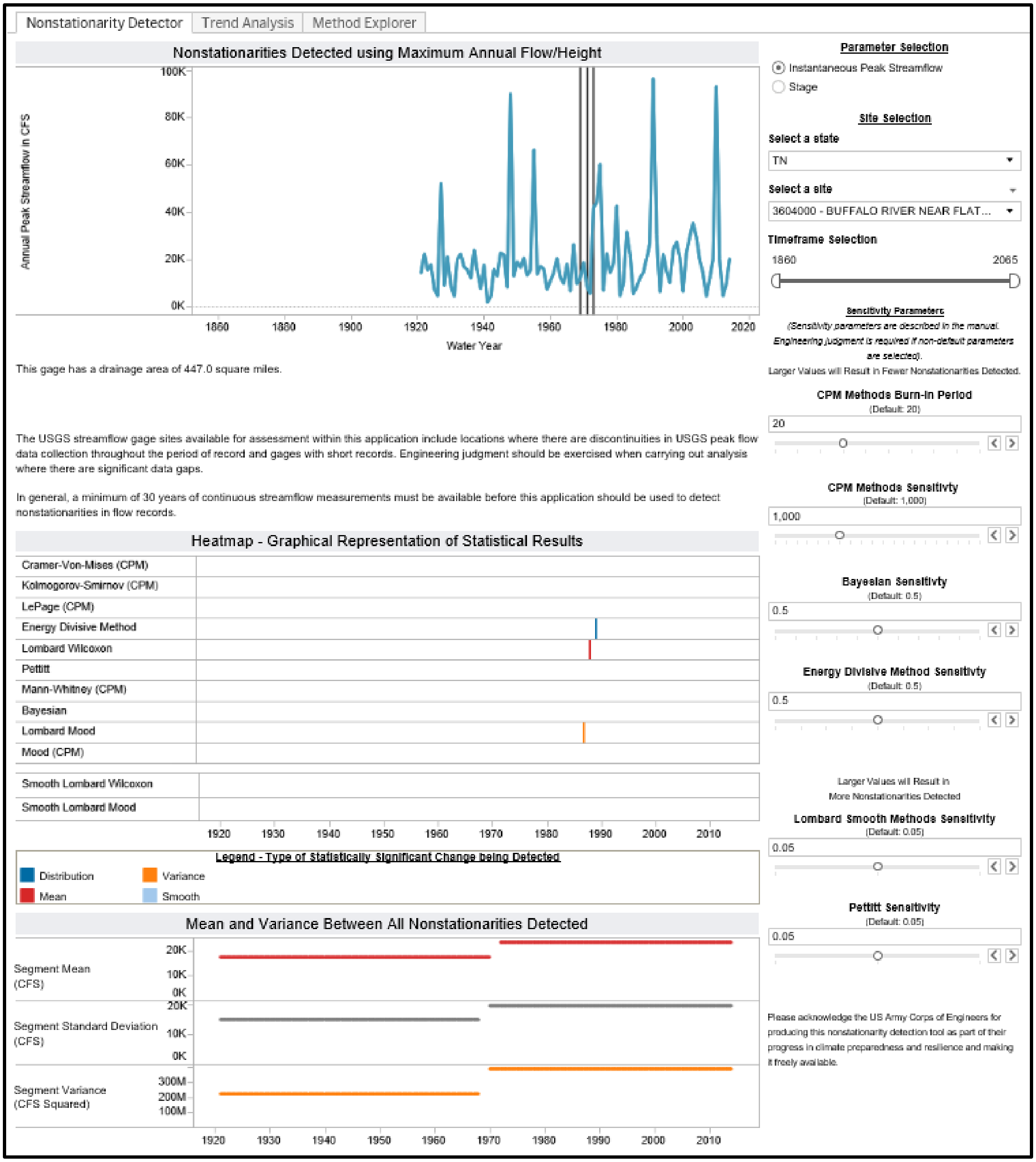
Larger Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity (Default: 0.05): 0.05

Pettitt Sensitivity (Default: 0.05): 0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 11: Non-stationarity Detector tool results for the Duck River near Shelbyville gage



This gage has a drainage area of 447.0 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Parameter Selection

● Instantaneous Peak Streamflow

○ Stage

Site Selection

Select a state: TN

Select a site: 3604000 - BUFFALO RIVER NEAR FLAT...

Timeframe Selection: 1860 – 2065

Sensitivity Parameters

(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).

Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period (Default: 20): 20

CPM Methods Sensitivty (Default: 1,000): 1,000

Bayesian Sensitivty (Default: 0.5): 0.5

Energy Divisive Method Sensitivty (Default: 0.5): 0.5

Larger Values will Result in More Nonstationarities Detected

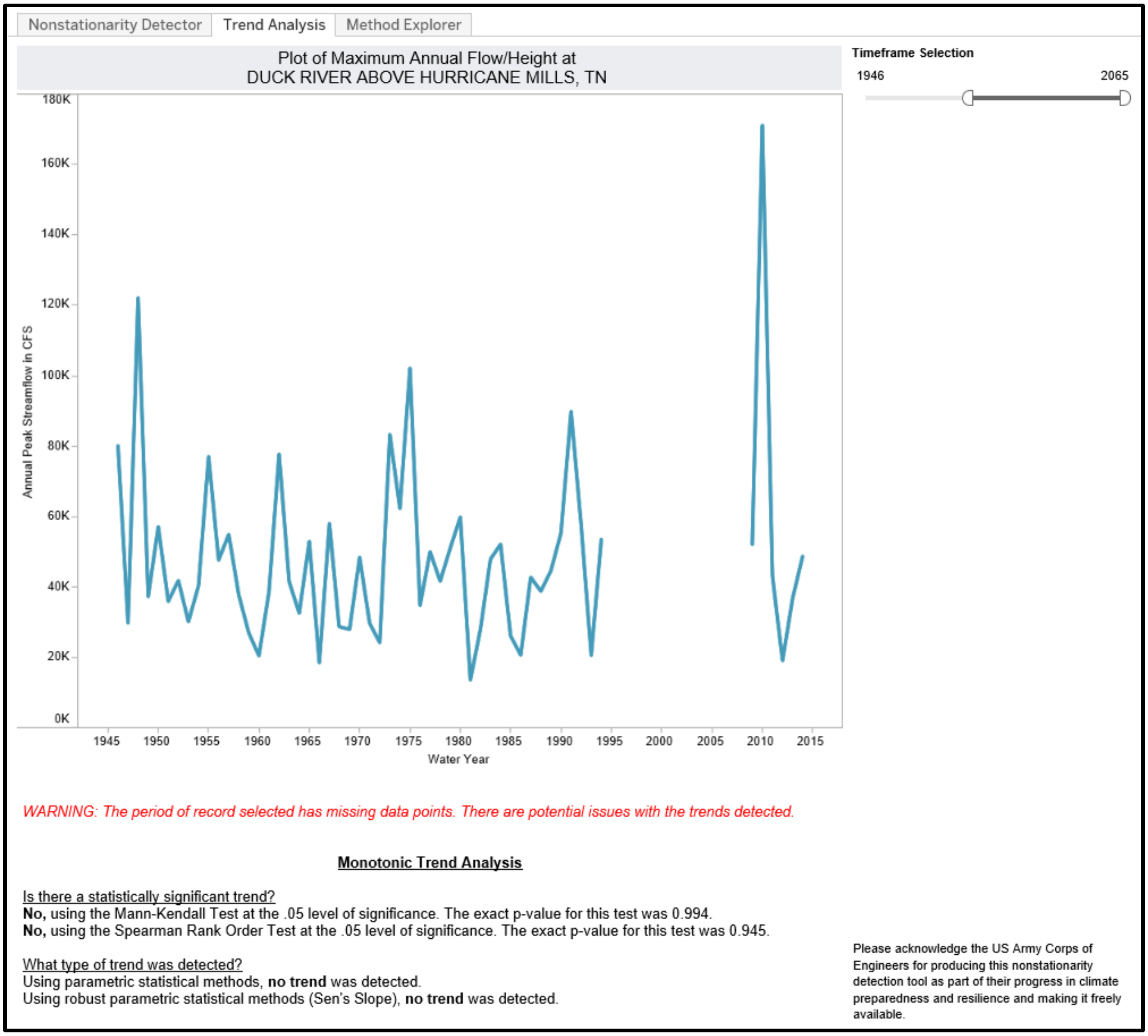
Lombard Smooth Methods Sensitivity (Default: 0.05): 0.05

Pettitt Sensitivity (Default: 0.05): 0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 12: Non-stationarity Detector tool results for the Buffalo River near Flat Woods gage

Trend Analysis - The Trend Analysis tool uses four different statistical methods to perform a monotonic trend analysis. Figure 13 through Figure 16 provide the results of this tool for the Duck River above Hurricane Mills, Duck River at Columbia, and Duck River near Shelbyville gages. Only the Shelbyville gage reflected a monotonic trend and this trend was negative. Again, this likely reflects the effect of regulation by Normandy Dam at this gage and the lesser effect of dam regulation on flow at the two gages which lie further downstream and the absence of dam regulation on the tributary gage.



WARNING: The period of record selected has missing data points. There are potential issues with the trends detected.

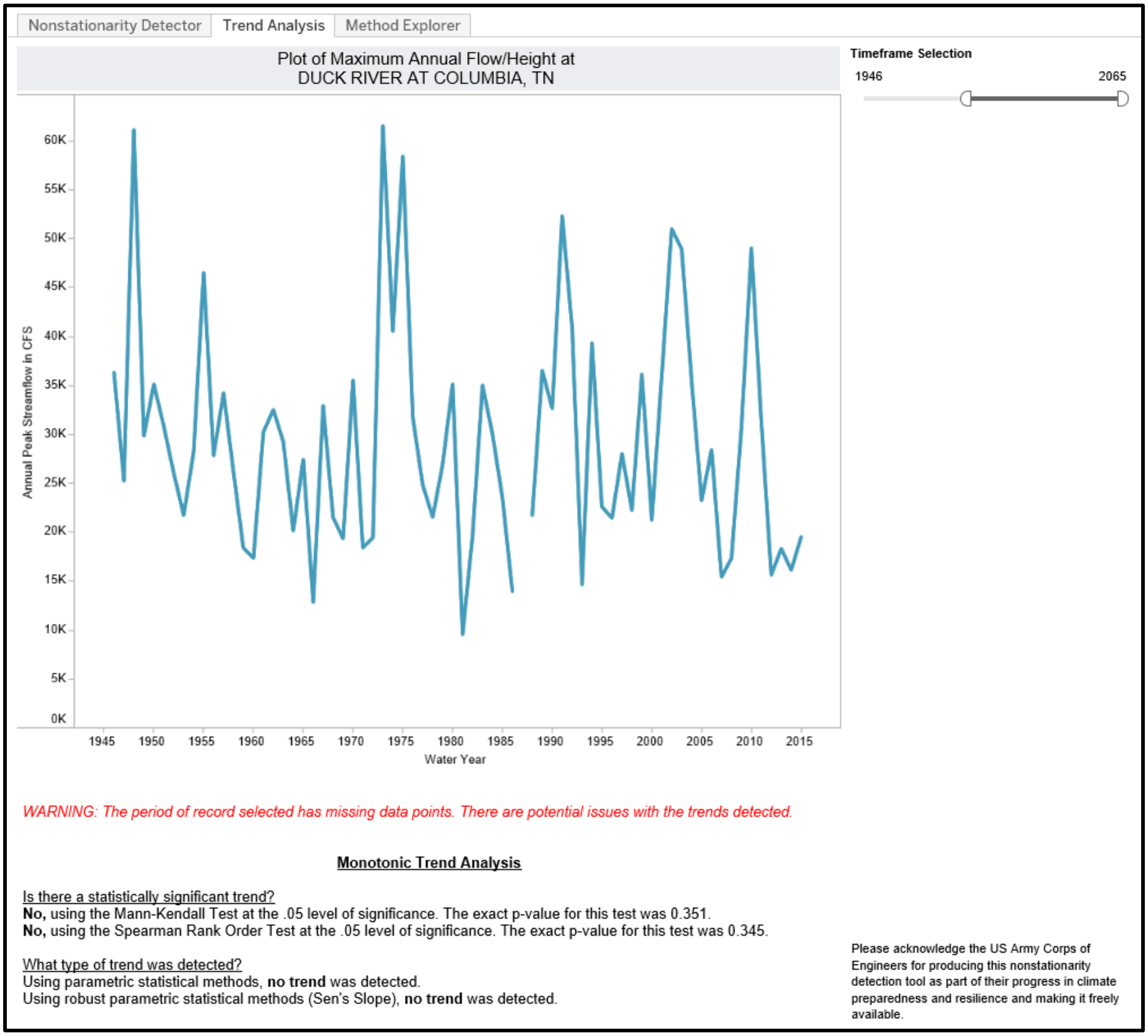
Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.994.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.945.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 13: Trend Analysis tool results for the Duck River above Hurricane Mills gage



WARNING: The period of record selected has missing data points. There are potential issues with the trends detected.

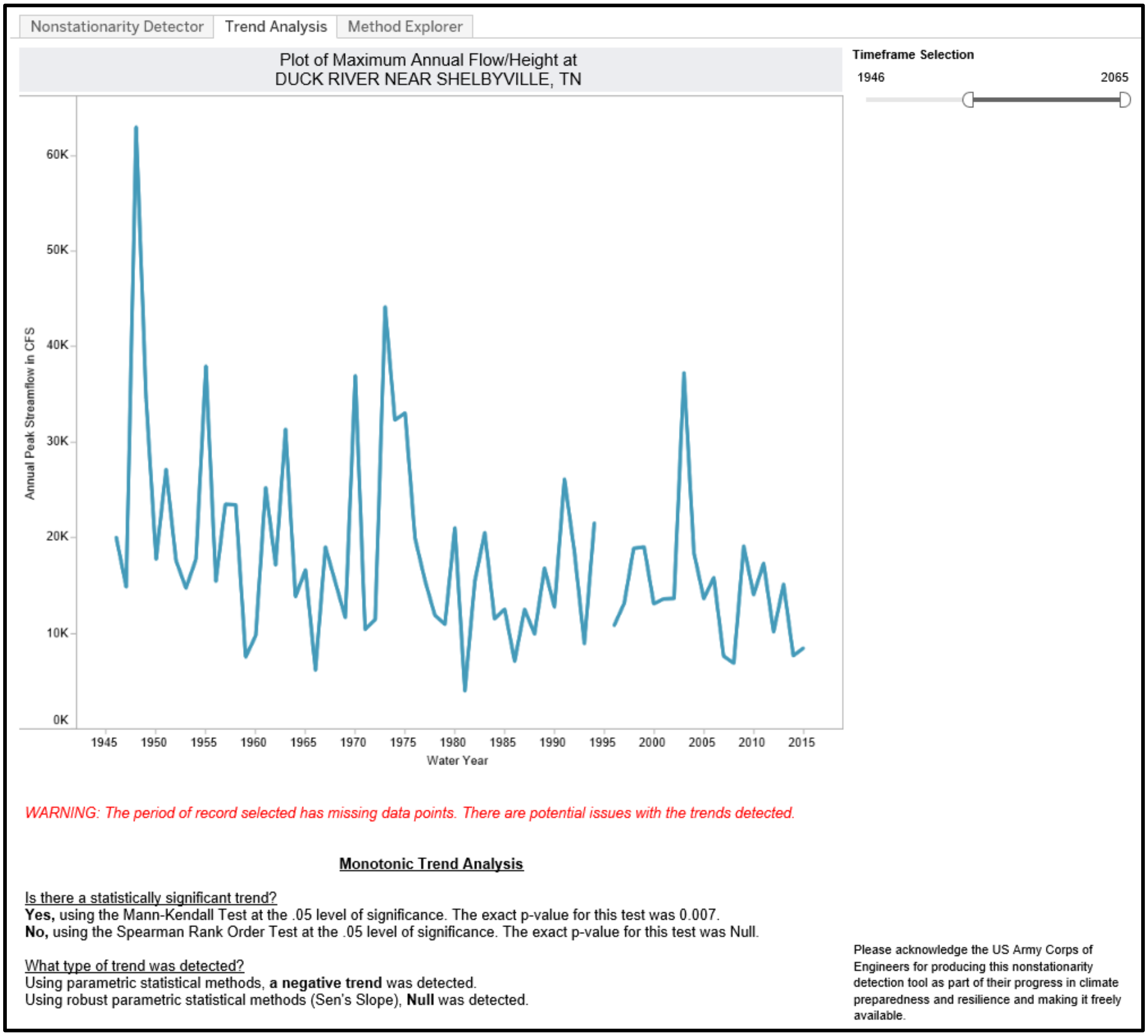
Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.351.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.345.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 14: Trend Analysis tool results for the Duck River at Columbia gage



WARNING: The period of record selected has missing data points. There are potential issues with the trends detected.

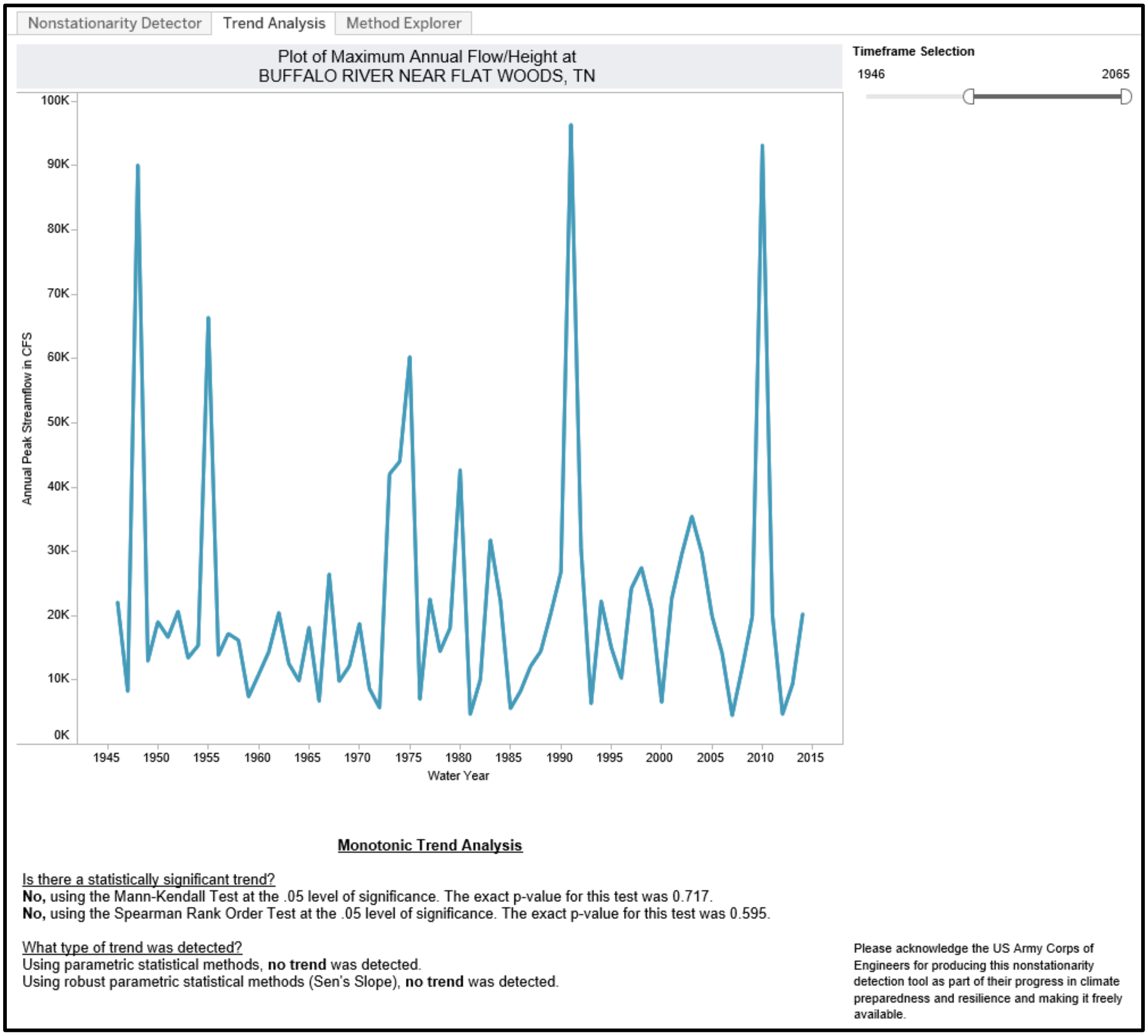
Monotonic Trend Analysis

Is there a statistically significant trend?
Yes, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.007.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was Null.

What type of trend was detected?
Using parametric statistical methods, **a negative trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **Null** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 15: Trend Analysis tool results for the Duck River near Shelbyville gage



Monotonic Trend Analysis

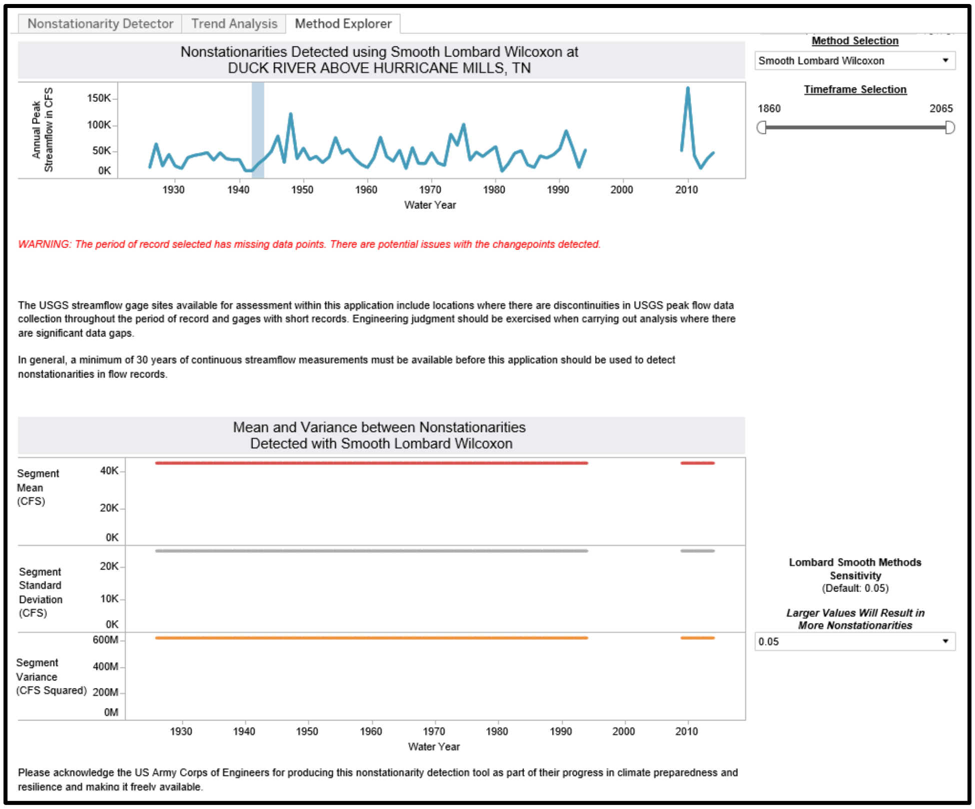
Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.717.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.595.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 16: Trend Analysis tool results for the Buffalo River near Flat Woods gage

Method Explorer - The Method Explorer tool allows the user to delve independently into any of twelve nonstationarity detection methods used in the Nonstationarity Detection tool. For each of the four gages analyzed, those methods which indicated nonstationarity existed were evaluated using the Method Explorer tool with the results shown in Figure 17 through Figure 26. In general, it was seen nonstationary trended from less pronounced in the lower part of the basin to more pronounced in the upper part of the mainstem Duck River basin. Nonstationarity in the Buffalo River basin fell somehwere in between.



Nonstationarities Detected using Smooth Lombard Wilcoxon at DUCK RIVER ABOVE HURRICANE MILLS, TN

Method Selection: Smooth Lombard Wilcoxon

Timeframe Selection: 1860 – 2065

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Mean and Variance between Nonstationarities Detected with Smooth Lombard Wilcoxon

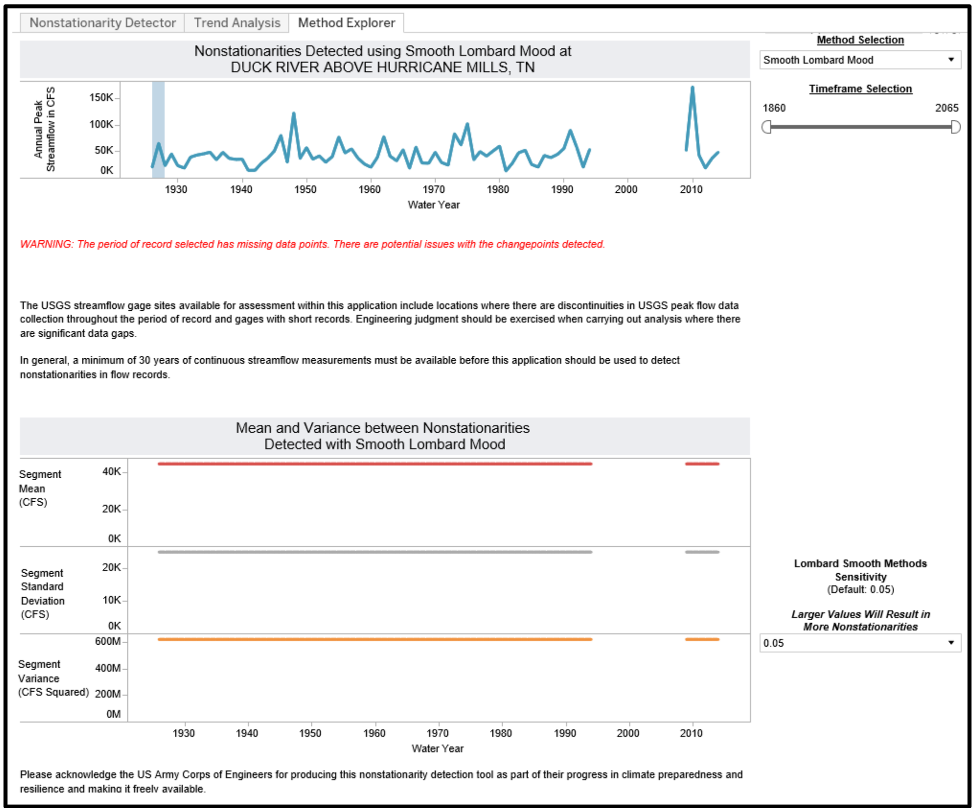
Lombard Smooth Methods Sensitivity
(Default: 0.05)

Larger Values Will Result in More Nonstationarities

0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 17: Method Explorer tool results on Smooth Lombard Wilcoxon method for Duck River at Columbia gage



Nonstationarities Detected using Smooth Lombard Mood at DUCK RIVER ABOVE HURRICANE MILLS, TN

Method Selection: Smooth Lombard Mood

Timeframe Selection: 1860 – 2065

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Mean and Variance between Nonstationarities Detected with Smooth Lombard Mood

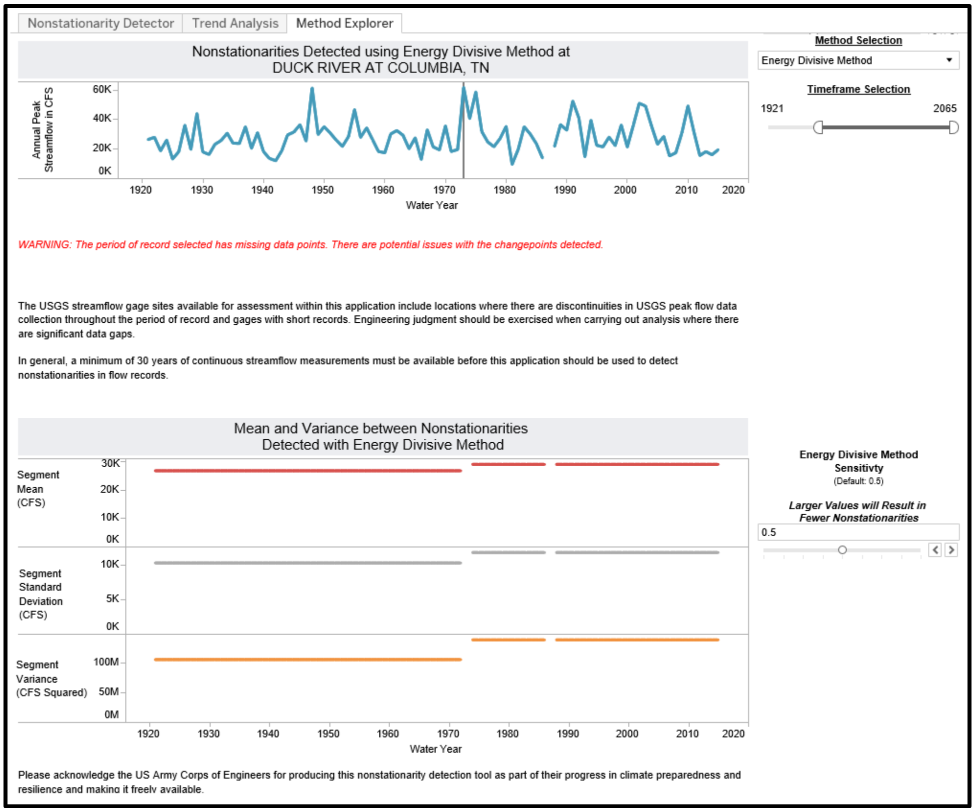
Lombard Smooth Methods Sensitivity
(Default: 0.05)

Larger Values Will Result in More Nonstationarities

0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 18: Method Explorer tool results on Smooth Lombard Mood method for Duck River above Hurricane Mills gage



Nonstationarities Detected using Energy Divisive Method at
DUCK RIVER AT COLUMBIA, TN

Method Selection
Energy Divisive Method

Timeframe Selection
1921 2065

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

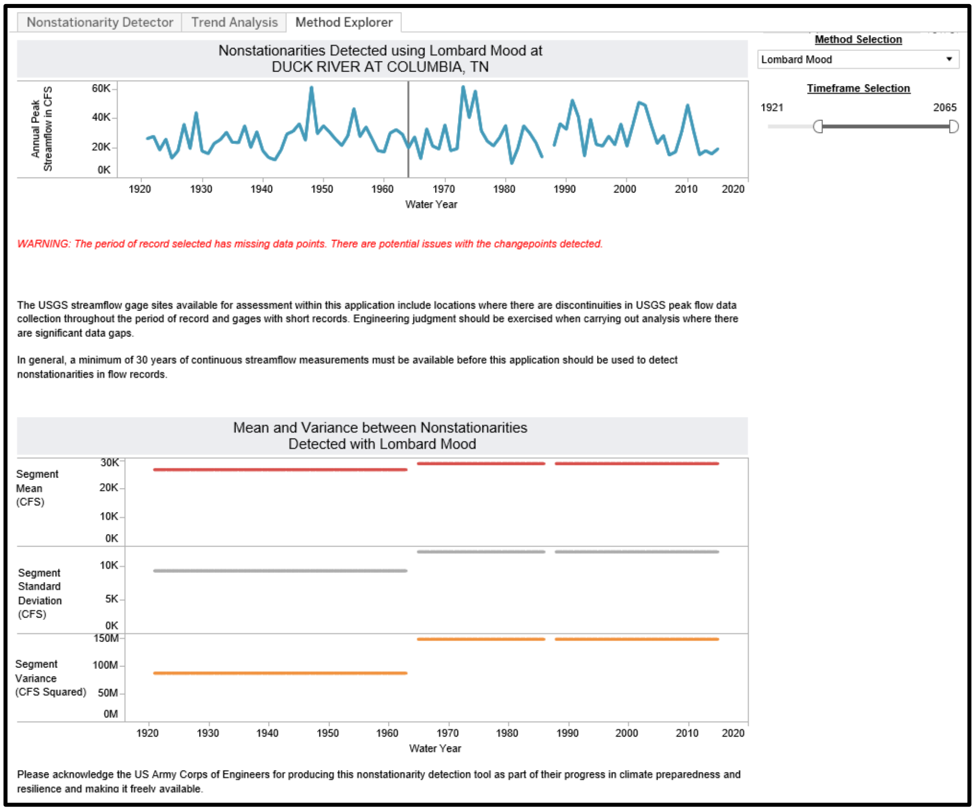
Mean and Variance between Nonstationarities
Detected with Energy Divisive Method

Energy Divisive Method Sensitivty
(Default: 0.5)

Larger Values will Result in Fewer Nonstationarities
0.5

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 19: Method Explorer tool results on Energy Divisive method for Duck River at Columbia gage



Nonstationarities Detected using Lombard Mood at
DUCK RIVER AT COLUMBIA, TN

Method Selection
Lombard Mood

Timeframe Selection
1921 2065

WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

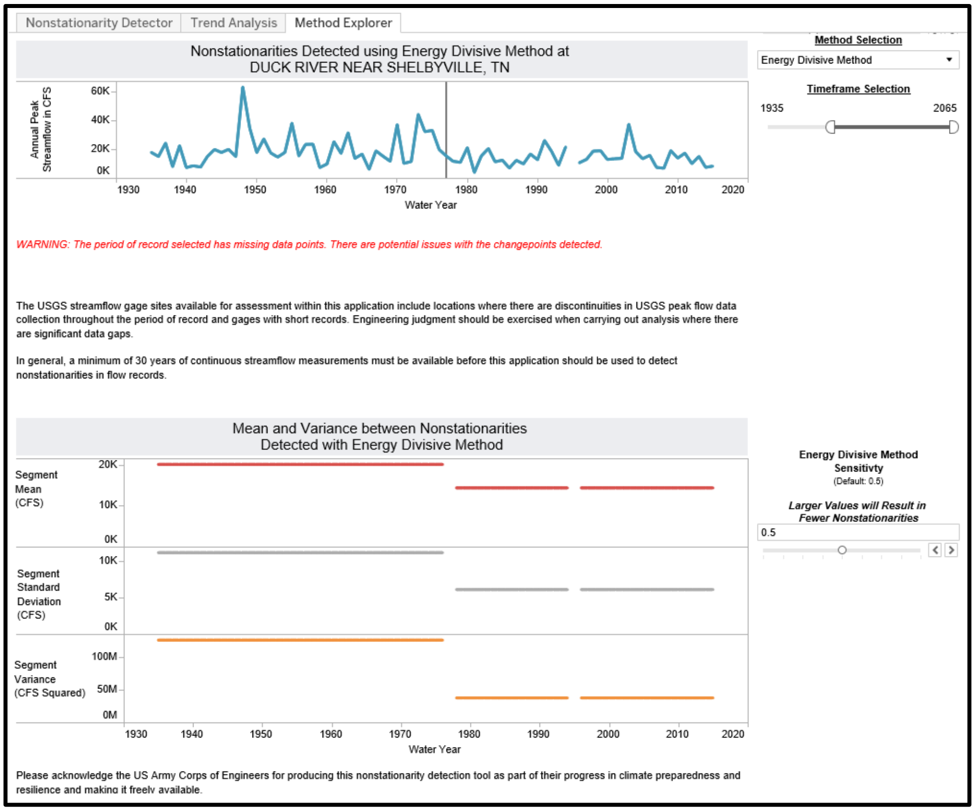
The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Mean and Variance between Nonstationarities
Detected with Lombard Mood

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 20: Method Explorer tool results on Lombard Mood method for Duck River at Columbia gage



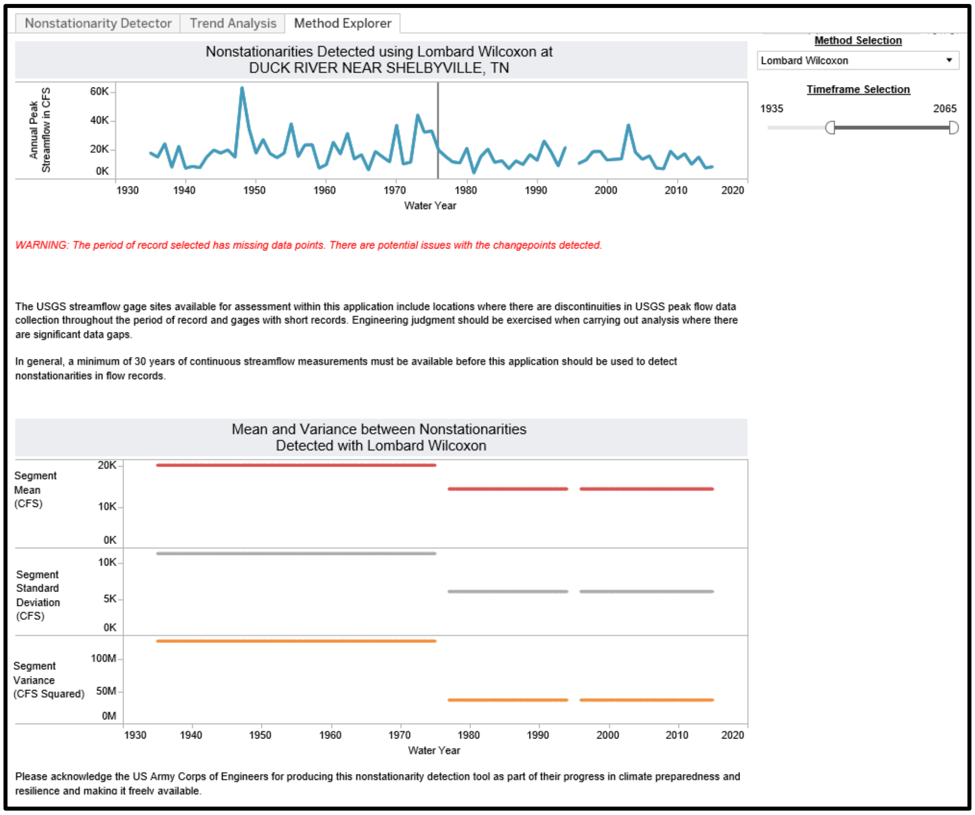
WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 21: Method Explorer tool results on Energy Divisive method for Duck River near Shelbyville gage



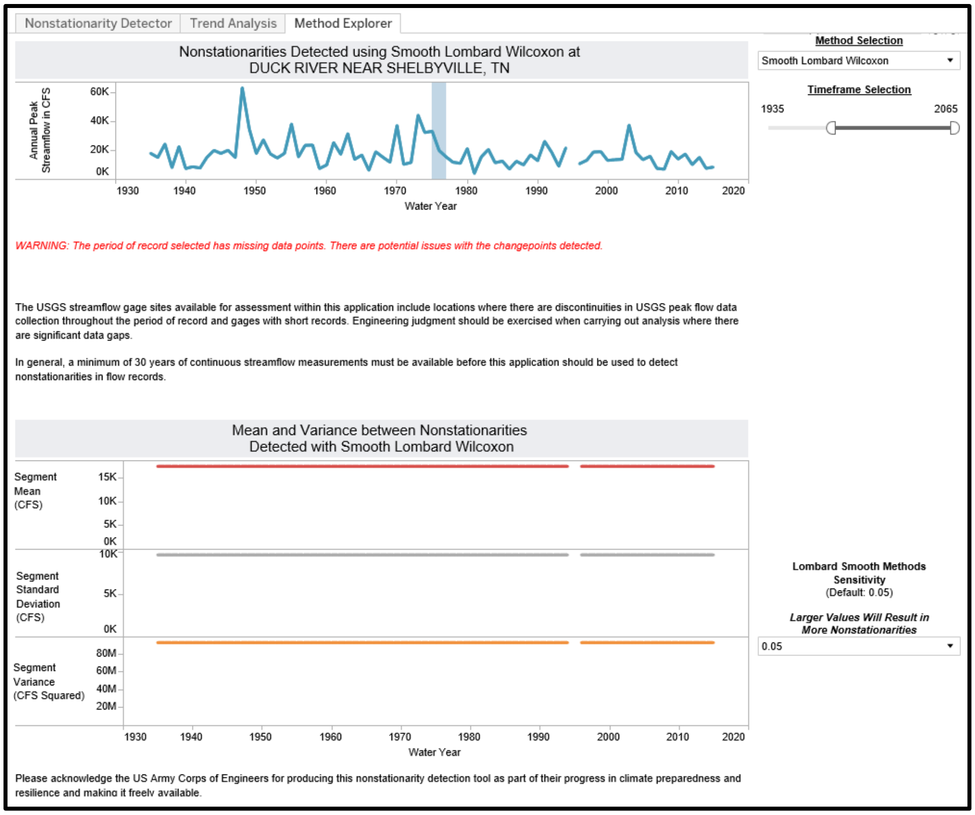
WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 22: Method Explorer tool results on Lombard Wilcoxon method for Duck River near Shelbyville gage



Method Selection
Smooth Lombard Wilcoxon

Timeframe Selection
1935 2065

Lombard Smooth Methods Sensitivity
(Default: 0.05)

Larger Values Will Result in More Nonstationarities
0.05

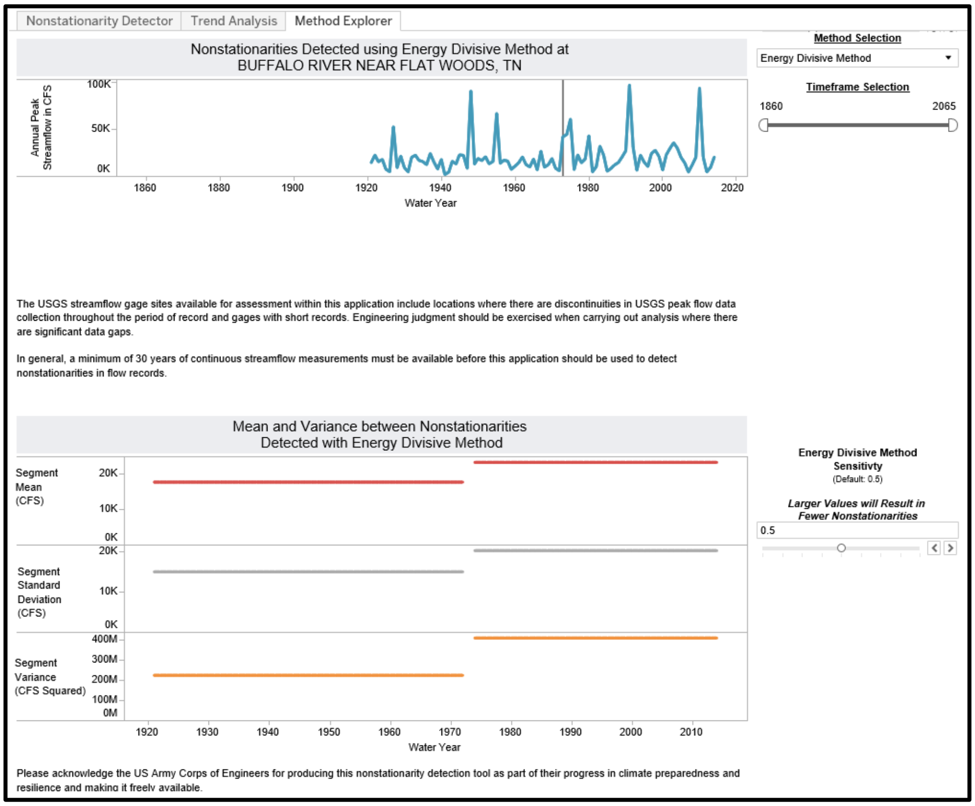
WARNING: The period of record selected has missing data points. There are potential issues with the changepoints detected.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 23: Method Explorer tool results on Smooth Lombard Wilcoxon method for Duck River near Shelbyville gage



Method Selection
Energy Divisive Method

Timeframe Selection
1860 2065

Energy Divisive Method Sensitivty
(Default: 0.5)

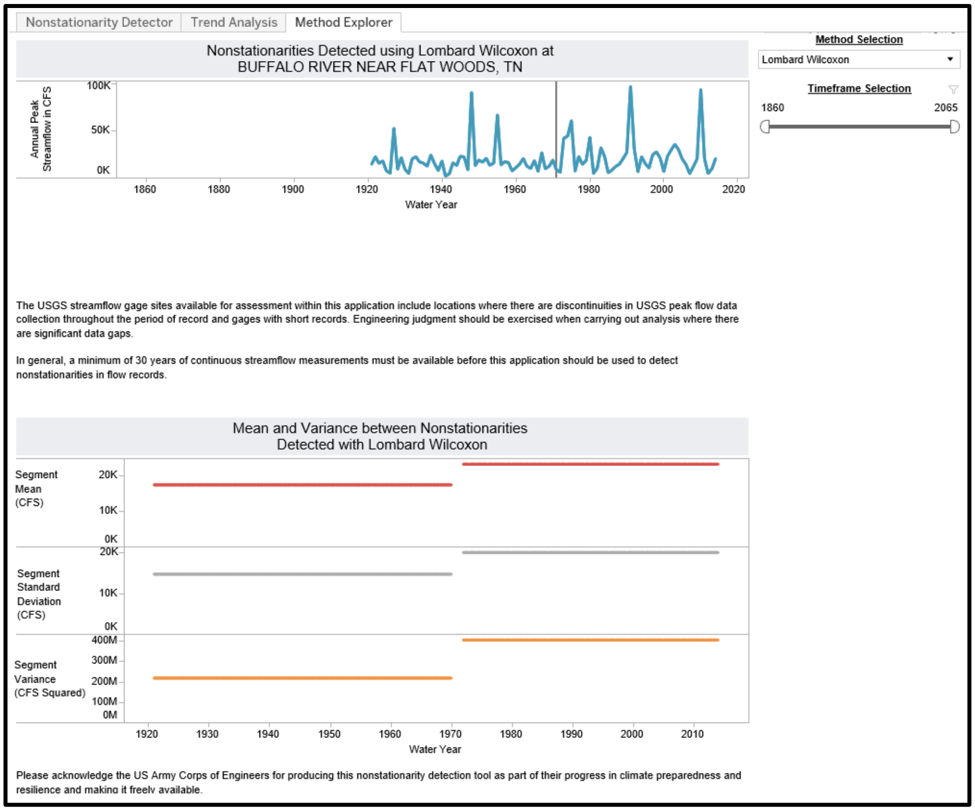
Larger Values will Result in Fewer Nonstationarities
0.5

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 24: Method Explorer tool results on Energy Divisive method for Buffalo River near Flat Woods gage

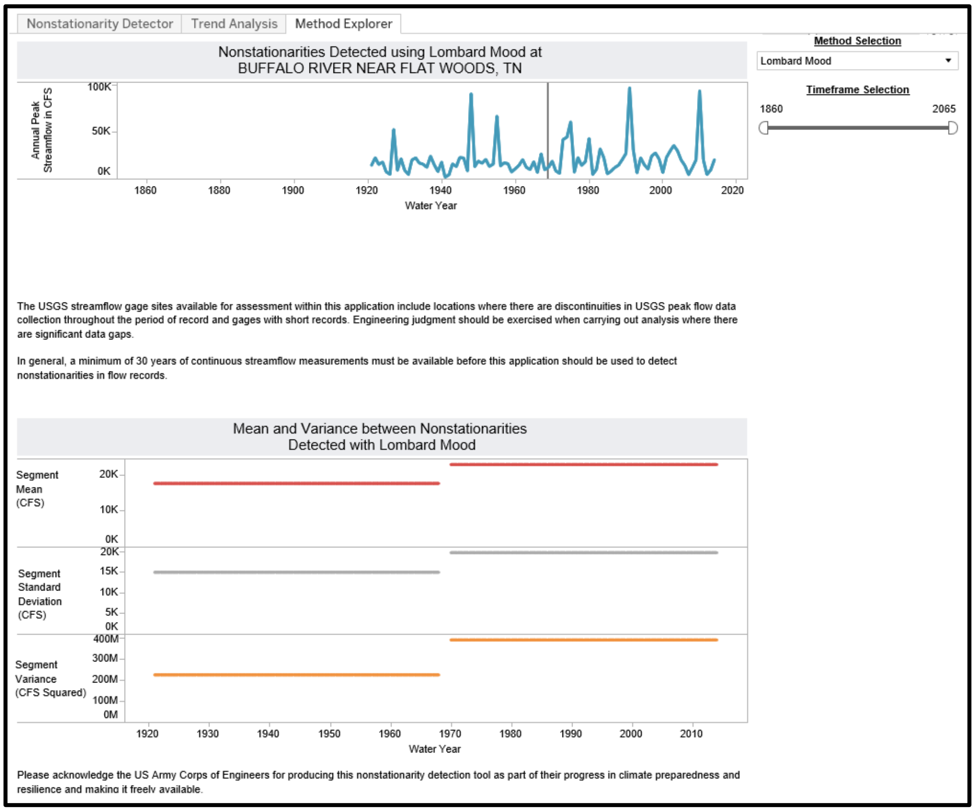


The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 25: Method Explorer tool results on Lombard Wilcoxon method for Buffalo River near Flat Woods gage



The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 26: Method Explorer tool results on Lombard Mood method for Buffalo River near Flat Woods gage

Conclusion

The Lower Tennessee River watershed, in which the Duck River project is located, is a region where the risk due to climate change is relatively low compared to other areas (such as coastal regions or arid regions). According to the USACE screening and analysis tools, there may be an increase in the intensity and magnitude of flooding events in the Lower Tennessee River basin in the future. There is not enough data to determine whether or not this will increase the risk to projects in the Duck River basin. The tools show a trend of increasing mean flow in the lower and middle part of the Duck River basin and of decreasing mean flow in the upper part of the Duck River basin. The latter may be attributed to the construction of Normandy Dam which is operated in part for flood control. However, the magnitude and impact of climate change in the Duck River basin cannot be quantitatively established using the tools currently available.

References

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