



# Southeast Coast Network Surface Water Discharge Monitoring

## *Analysis of Existing Data and Data Acquisition Applications*

Natural Resource Report NPS/SECN/NRR—2010/264



**ON THE COVER**

Wise Lake at Congaree National Park  
NPS Photo

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## Abstract

The surface-water hydrology of the United States has been widely altered by natural and anthropogenic forces. Within the U.S. National Park Service's (NPS) Southeast Coast Network (SECN), some of these alterations include the construction of dams, increases in urban development, stream channelization, erosion, and salt-water intrusion into freshwater marshes. This report summarizes a NPS-funded project that examined surface water trends and monitoring within eleven SECN parks. For many parks within the SECN, there is little information on surface water availability. For others, especially those located near a dam, long-term data sets are readily available through the U.S. Geological Survey (USGS). Data sources relevant to SECN parks were inventoried and analyzed to determine trends in streamflow and identify how anthropogenic influences, such as dams, have influenced surface water hydrology within or near each park. Many gages contain large gaps in data or have been discontinued. In some instances, no long-term data are available, which increases the uncertainty in trend analysis. For smaller parks within the network, automated gaging may not be necessary. However, for those parks in coastal areas and along major rivers prone to flooding, long-term monitoring is necessary to assess how the park may be affected by land-use changes and long-term influences of local and global climate change. To ensure park employees and researchers have adequate access to data and analysis tools, two computer programs are presented within this report that allow surface water data to be easily obtained and processed.



# Glossary of Terms

**Anthropogenic:** Caused by human actions.

**Aquifer:** Layer of water-bearing permeable rock, sand, or gravel capable of providing significant amounts of water.

**Catchment:** The region draining into a river, river system, or other body of water.

**Cubic feet per second (cfs):** A volume of water (measured in cubic feet) flowing in a unit of time (measured in seconds).

**Datum:** A fixed reference point with known elevation.

**Evapotranspiration:** Term used to describe the sum of evaporation and plant transpiration from the earth's land surface to the atmosphere. Evaporation accounts for the movement of water from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. Evapotranspiration is an important part of the water cycle.

**Environmental Flow Component (EFC):** A method that divides the hydrograph into high flow (>75th percentile) and low flow (<50th percentile). High flows are further divided into Large Floods (10 year recurrence), Small Floods (2 year recurrence) and High-flow Pulses (rise faster than 25% and fall faster than 10%). Low flows also include Extreme Low Flows (<10<sup>th</sup> percentile).

**Fall line:** A line connecting the waterfalls of nearly parallel rivers that marks a drop in land level.

**Flow duration curve:** A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

**Gumbel I distribution:** A theoretical statistical distribution within the family of continuous probability distributions used to model the distribution of maximum or minimum events and in hydrology is useful for predicting the chance that an extreme event will occur. Equivalent to the Weibull distribution of a logarithmically transformed variable.

**Hydrologic Alteration Factor (HA):** A measure of the hydrologic change from past conditions; the historical or pre-settlement is set to be the expected value and the recent value is set to be the observed value. The HA indicates, with one number, both the degree (percentage) and direction of change of each flow metric relative to the historical / presettlement values. Negative values indicate a decrease relative to historical / pre-settlement values; positive values indicate an increase.

**Hydrograph:** A graph showing the water level or flow rate for a given point on a stream or in a well with respect to time.

**Hydrologic Unit Code (HUC):** A number corresponding to watershed boundaries established by the USGS in order to standardize watershed classification at local and national levels.

**Hyporheic:** The area located beneath and lateral to a streambed where shallow groundwater and surface water mix.

**Hysteresis:** A relationship between two variables that changes depending upon previous conditions (e.g., the relationship between stage and discharge for a rising tide may be different than for a falling tide).

**Indicators of Hydrologic Alteration (IHA):** A quantitative tool developed by the Nature Conservancy used to evaluate the impacts of changes to a hydrologic system (<http://www.nature.org/initiatives/freshwater/conservationtools/>).

**Log Pearson Type III distribution:** A theoretical statistical distribution within the family of continuous probability distributions that describes the probability of occurrence of a given event and has been widely used to calculate flood re-occurrences. Equivalent to the gamma distribution of a logarithmically transformed variable. The default distribution used by the U.S. Geological Survey for flood studies.

**Measuring Point:** A point accessible on or near a well that is used for measuring the depth to water. The water surface elevation is calculated as the difference between the measuring point elevation and the depth to water.

**Range of Variability Analysis (RVA):** A method that divides the range of pre-impact data values. Delineation into three equal categories, for example, would result in parameters less than or equal to the 33rd percentile, parameters between the 33rd and 67th percentile, and parameters greater than or equal to the 67th percentile. The method calculates the expected frequency at which the post-impact values should occur in each category. A comparison of these data provides a pre- and post-impact measure of the hydrologic alteration between flow regimes.

**Regional skew coefficient:** A measure of the asymmetry of the frequency distribution of a real-valued random variable, averaged over a region. When used for extreme hydrologic events, the distribution is normally taken to be the annual extreme.

**Return frequency:** A measure of how often (on average) an event (precipitation, flood, etc.) will occur that is greater than some chosen value (e.g., 1, 2, 5, 10, 100 year).

**Saltwater intrusion:** The invasion of fresh surface water or groundwater by saltwater.

**Seven-day flow:** The average daily discharge over a week.

**Single-day flow:** The average daily discharge over a day.

**Specific conductance:** A measure of the ability of water to conduct an electrical current adjusted to a reference temperature. It is an indirect measure of the presence of inorganic dissolved solids, such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron.

**Staff gage:** A tool for measuring water level in a body of water. A staff gage is graduated in appropriate units and is placed so that a portion of the gage is in the water body at all times. Observers read the water stage off the staff gage.

**Rating curve:** Relationship between depth and the amount of flow in a channel, or storage in a reservoir.



# Background

## Project Overview

The Southeast Coast Network (SECN) contains twenty parks (Table 1), seventeen of which contain significant and diverse natural resources. In total, SECN parks encompass more than 178,000 acres of federally managed land across North Carolina, South Carolina, Georgia, Alabama, and Florida.

These parks span a wide diversity of cultural missions also, including four National Seashores, two National Historic Sites, two National Memorials, seven National Monuments, two National Military Parks, as well as a National Recreation Area, National Battlefield, and an Ecological and Historic Preserve. The parks range in size from slightly more than twenty to nearly 60,000 acres, and when considered with non-federal lands jointly managed with SECN parks, the Network encompasses more than 242,000 acres<sup>1</sup>.

SECN stream systems have been altered by human activities, including impoundments, channelization, lowering of water tables, increased runoff, pollution, sedimentation, recreation, and introduced species (including mussels, fishes, and aquatic plants). Many examples of effects on stream biota can be cited (Hackney and Adams 1992) and nearly all major stream systems have been channelized or dammed (Adams and Hackney 1992). In the Southeast, 144 major reservoirs have been built (Soballe et al. 1992) and one-third of all Florida Rivers have impoundments. Major hydropower facilities are located upstream of three of the six river parks in the network (CONG, HOBE, CHAT).

**Table 1.** Southeast Coast Network (SECN) National Park units covered in this report.

| Alpha Code <sup>2</sup> | Park Unit                                    |
|-------------------------|----------------------------------------------|
| CHAT                    | Chattahoochee River National Recreation Area |
| CONG                    | Congaree National Park                       |
| FOFR                    | Fort Frederica National Monument             |
| FOMA                    | Fort Matanzas National Monument              |
| FOPU                    | Fort Pulaski National Monument               |
| FOSU                    | Fort Sumter National Monument                |
| HOBE                    | Horseshoe Bend National Military Park        |
| KEMO                    | Kennesaw Mountain National Battlefield Park  |
| MOCR                    | Moore's Creek National Battlefield           |
| OCMU                    | Ocmulgee National Monument                   |
| TIMU                    | Timucuan Ecological and Historic Preserve    |

Surface water dynamics is ranked ninth among all of the potential vital signs evaluated by the SECN even though streamflow characteristics offer some of the most appropriate and useful indicators for assessing river ecosystem integrity and changes over time. The hydrologic output of a watershed is a function of land characteristics and human use, weather and climate conditions, urbanization and soil characteristics. Hydrologic variation plays a key part in

<sup>1</sup> Additional information can be found at <http://science.nature.nps.gov/im/units/secn/index.cfm>

<sup>2</sup> The NPS assigns each park unit a unique Alpha Code, which is used throughout this report.

structuring the biotic diversity within river ecosystems by controlling critical habitat conditions within the river channel, the floodplain, and hyporheic zones. Stream hydrology data provide key support data for vital signs indicators including water chemistry, stream Threatened and Endangered (T&E) species and fish assemblages, T&E amphibians and reptiles, wetlands, and riparian habitat.

## Population Changes

Urbanization of natural areas is a growing concern. All of the parks, except for Horseshoe Bend, are located in counties that experienced population increases from 2000 to 2008 based on population data provided by the U.S. Census Bureau. The projected populations all showed population increases (Table 2).

**Table 2.** Recent and projected populations for counties containing SECN parks<sup>3</sup>.

| Park | County         | 2000<br>Population | 2008<br>Population | Percent<br>Change | Projected Population |
|------|----------------|--------------------|--------------------|-------------------|----------------------|
| CHAT | Cobb, GA       | 607,747            | 698,158            | 14.9%             | 811,129 (2015)       |
| CHAT | Forsyth, GA    | 98,407             | 168,060            | 70.8%             | 232,948 (2015)       |
| CHAT | Fulton, GA     | 815,844            | 1,014,932          | 24.4%             | 832,751 (2015)       |
| CHAT | Gwinnett, GA   | 588,450            | 789,499            | 34.2%             | 1,030,700 (2015)     |
| CONG | Richland, SC   | 320,779            | 364,001            | 13.5%             | 425,960 (2030)       |
| FOFR | Glynn, GA      | 67,568             | 75,884             | 12.3%             | 100,483 (2030)       |
| FOMA | St. Johns, FL  | 123,148            | 181,540            | 47.4%             | 287,456 (2030)       |
| FOPU | Chatham, GA    | 232,347            | 251,120            | 8.1%              | 307,472 (2030)       |
| FOSU | Charleston, SC | 309,974            | 348,046            | 12.3%             | 386,660 (2030)       |
| HOBE | Tallapoosa, AL | 41,802             | 40,773             | -2.5%             | 44,567 (2025)        |
| KEMO | Cobb, GA       | 607,747            | 698,158            | 14.9%             | 811,129 (2015)       |
| MOCR | Pender, NC     | 41,082             | 51,314             | 24.9%             | 78,479 (2030)        |
| OCMU | Bibb, GA       | 153,887            | 155,216            | 0.9%              | 155,240 (2015)       |
| TIMU | Duval, FL      | 778,866            | 850,962            | 9.3%              | 1,147,189 (2030)     |
| TIMU | Nassau, FL     | 57,663             | 69,835             | 21.1%             | 107,452 (2030)       |

## Climate Change

The Intergovernmental Panel on Climate Change (IPCC) has provided projections and estimations on how climate change may impact water resources (Kundzewicz et al. 2007); however, understanding how these changes have influence at different regional scales is difficult and requires long-term monitoring (Brekke et al. 2009). It has been suggested that in rain-dominated catchments, such as the Southeastern United States, flow seasonality will increase. This will result in higher flows during the peak flow season and lower flows during low-flow seasons and/or longer dry periods (Kundzewicz et al. 2007). The timing of these events is also likely to change, but regional variation is also expected (Stewart et al. 2005; Hodgkins et al., 2003; Knowles et al. 2006; Hodgkins et al. 2007). The large amount of uncertainty has led to a federal recommendation to increase the amount of tracking of water resources so that changes can be monitored more closely and water availability can be anticipated (Brekke et al. 2009).

<sup>3</sup> Sources: Center for Quality Growth and Regional Development at the Georgia Institute of Technology, GeoPlan Center at the University of Florida, North Carolina State Demographics & Bureau of Economic Analysis, South Carolina Office of Research and Statistics, Office of Planning and Budget for Georgia, The Office of Primary Care and Rural Health, Alabama Department of Public Health, and The Alabama Rural Health Association.

For many of the analyses conducted in this report, as well as nationally recognized standards in estimating trends, it is assumed that future events (high-flows, low-flows, etc.) will occur at the same rate that they have historically. This assumption may not be correct if climate change, as it has been suggested, alters the frequency of these events (Brekke et al. 2009). If climate change is a driving force of the frequency and timing of the seasonality of flow, then current trends may need to be re-evaluated.

The large amount of uncertainty associated with many of the projections of changes in water availability due to climate change (Brekke et al. 2009; Miller and Yates 2006) means that more data is likely needed before the direction and magnitude of the influence can be measured. Given the fact that there is not enough data to determine the trends of surface water flow within the boundaries of some NPS lands, the current recommendation to increase monitoring is a prudent measure that has direct benefits to the parks themselves, as well as to society as a whole. *Climate Change and Water Resource Management: A Federal Perspective*<sup>4</sup> provides an in-depth interagency report prepared by the USGS, USACE, Bureau of Reclamation, and NOAA that explores water management strategies in response to climate change. Much of the information contained within it is beyond the scope of this report; however, the authors emphasize the importance of monitoring and the central role it plays in future planning and decision making.

## **Project Objectives**

This project seeks to develop a protocol, and to collect and analyze existing data to determine the status and trends of water quantity in surface waters upstream, bordering, or within park boundaries; and also determine the frequency, duration and magnitude of peak flow events for eleven parks within the Southeast Coast Network.

Specific objectives of this report include:

1. Summarize and present the results of a literature review on streamflow discharge monitoring efforts relevant to SECN parks, including information about parameters collected/measured, instrumentation used, and existing protocols.
2. Identify and catalog gaging stations and other data sources relevant to SECN parks -
  - a. Including (but not limited to): site ID, description, and relevant parameters.
  - b. History and frequency of measurements and location information (e.g. UTM coordinates).
3. Incorporate data acquired from web-based program archives or other sources such as various State and Federal programs (e.g. USGS) into NPS holdings.
4. Analyze existing data in order to address the following long-term monitoring objectives:
  - a. Determine the status and trends of water quantity in surface waters upstream, bordering, or within park boundaries.

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<sup>4</sup> <http://pubs.usgs.gov/circ/1331/>

- b. Determine the frequency, duration, and magnitude of peak flow events.
  - c. Examine surrounding landscape to quantify landcover types within and surrounding SECN NPS holdings.
- 5. Identify significant data gaps including spatial distribution and temporal coverage and where possible, provide recommendations for filling current gaps within parks that lack adequate monitoring.
- 6. Develop a long-term monitoring protocol for SECN streamflow discharge monitoring that utilizes existing data sources and follows NPS and I&M program guidance for protocol development.
- 7. Provide data analysis software tools for NPS personnel to facilitate the examination of specific questions about surface water hydrology that may arise in the future.
- 8. Provide projections for storm surge and sea level rise that could affect coastal parks.

## Literature Review

This section examines previous publications related to the surface-water hydrology within or near SECN parks, focusing on the water quantity issues at these facilities. The purpose of this literature review is to summarize major studies that address surface water quantity in SECN parks. A list of surface water gages within or near SECN parks is provided as Table 3.

Much of this information is typically found within the context of water quality rather than quantity. With few exceptions, little research has been done to assess the surface-water conditions in many of the NPS SECN parks with respect to water quantity. Although several studies have examined water quality, few have addressed the issue of surface water quantity and trends. In spite of this, studies emphasize the inextricable link between water quality and water quantity (Figure 1).

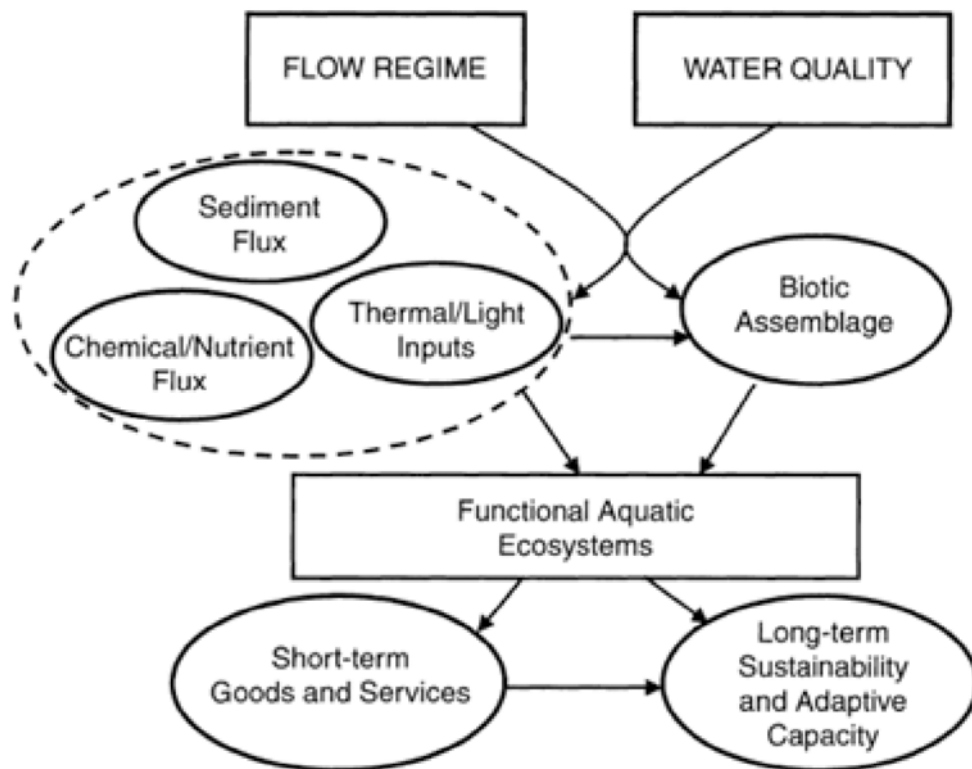


**Figure 1.** Conceptual model of factors influencing freshwater ecosystems (from Baron et al., 2002).

**Table 3.** Surface water gages within or near SECN parks and periods of record for discharge and gage height.[Bolded park names indicate gages located within park boundaries; NA, data not available]

| <b>Park</b> | <b>Gage #</b> | <b>Name</b>                                          | <b>Discharge<br/>Period of Record</b> |           | <b>Gage Height<br/>Period of Record</b> |           |
|-------------|---------------|------------------------------------------------------|---------------------------------------|-----------|-----------------------------------------|-----------|
| CHAT        | 02335450      | Chattahoochee River above Roswell, GA                | 7/7/1976                              | Present   | 10/1/1993                               | Present   |
| CHAT        | 02335815      | Chattahoochee River below Morgan Falls Dam, GA       | 10/2/2000                             | Present   | 10/2/2000                               | Present   |
| CHAT        | 02334430      | Chattahoochee River at Buford Dam near Buford, GA    | 1/27/1942                             | Present   | 10/1/1993                               | Present   |
| CHAT        | 02335000      | Chattahoochee River near Norcross, GA                | 1/1/1903                              | Present   | 10/2/1993                               | Present   |
| CHAT        | 02336000      | Chattahoochee River at Atlanta, GA                   | 8/1/1928                              | Present   | 10/1/1986                               | Present   |
| CHAT        | 023358685     | Sewell Mill Creek at GA 120, near Marietta, GA       | 4/28/2007                             | Present   | 4/28/2007                               | Present   |
| CONG        | 02169670      | Cedar Creek below Myers Creek near Hopkins, SC       | 11/13/1980                            | 9/30/1985 | NA                                      | NA        |
| CONG        | 02169625      | Congaree River at Congaree NP near Gadsden, SC       | NA                                    | NA        | 10/1/1984                               | Present   |
| CONG        | 02169672      | Cedar Creek at Congaree NP near Gadsden, SC          | NA                                    | NA        | 8/27/1985                               | Present   |
| CONG        | 02148315      | Wateree River below Eastover, SC                     | 7/30/1968                             | Present   | NA                                      | NA        |
| CONG        | 02169570      | Gills Creek at Coloumbia, SC                         | 10/1/1966                             | Present   | NA                                      | NA        |
| CONG        | 02169500      | Congaree River at Columbia, SC                       | 10/1/1939                             | Present   | NA                                      | NA        |
| FOFR        | 02226178      | East River at Mayors Pt Terminal Brunswick, GA       | NA                                    | NA        | 11/16/2000                              | 11/2/2003 |
| FOFR        | 022261792     | Brunswick River, Colonels Island, near Brunswick, GA | NA                                    | NA        | 10/1/2000                               | 11/2/2003 |
| FOFR        | 02226180      | Brunswick River at St. Simons Island, GA             | NA                                    | NA        | 11/18/1998                              | 6/17/2009 |
| FOMA        | 02244040      | St. Johns River at Buffalo Bluff near Satsuma, FL    | 10/2/1992                             | Present   | 10/1/1990                               | Present   |
| FOPU        | 02198980      | Savannah River at Fort Pulaski, GA                   | NA                                    | NA        | 10/10/1987                              | 12/4/2005 |
| FOPU        | 021989773     | Savannah River at usace dock Savannah, GA            | NA                                    | NA        | 10/1/2008                               | 3/4/2009  |
| FOPU        | 02198840      | Savannah River near Port Wentworth, GA               | NA                                    | NA        | 6/17/1987                               | 9/30/2005 |
| FOSU        | 021720677     | Cooper River at Filbin Creek at North Charleston, SC | NA                                    | NA        | 4/4/1997                                | Present   |
| FOSU        | 02172100      | Charleston Harbor at Ft Sumter near Mt Pleasant, SC  | NA                                    | NA        | 10/8/1992                               | 9/30/2005 |
| FOSU        | 02172053      | Cooper River at Mobay near N. Charleston, SC         | NA                                    | NA        | 10/1/1986                               | Present   |
| FOSU        | 021720696     | Wando River at Cainhoy, SC                           | 5/1/2004                              | 4/30/2005 | 5/1/2004                                | 4/30/2005 |
| FOSU        | 021720698     | Wando River abover Mt Pleasant, SC                   | NA                                    | NA        | 7/30/1992                               | Present   |
| FOSU        | 021720709     | Cooper River at U.S. Hwy 17 at Charleston, SC        | NA                                    | NA        | 4/11/1997                               | 8/18/2005 |

**Table 4.** (Continued)

| Park | Gage #    | Name                                                   | Discharge<br>Period of Record |            | Gage Height<br>Period of Record |            |
|------|-----------|--------------------------------------------------------|-------------------------------|------------|---------------------------------|------------|
| FOSU | 021720710 | Cooper River at Customs House (Aux) at Charleston, SC  | NA                            | NA         | 10/30/1986                      | 10/22/2002 |
| FOSU | 021720711 | Cooper River at Customs House at Charleston, SC (Tide) | NA                            | NA         | 8/7/1984                        | Present    |
| HOBE | 02414715  | Tallapoosa River near New Site, AL (Horseshoe Bend)    | 11/15/1985                    | Present    | 11/14/1985                      | Present    |
| HOBE | 02414500  | Tallapoosa River at Wadley, AL                         | 10/1/1923                     | Present    | 10/1/1971                       | Present    |
| KEMO | 02336968  | Noses Creek at Powder Springs rd, Powder Springs, GA   | 7/14/1998                     | Present    | 7/15/1998                       | Present    |
| KEMO | 02393377  | Butler Creek at Mack Dobbs rd, near Kennesaw, GA       | NA                            | NA         | 4/13/2007                       | Present    |
| MOCR | 02105769  | Cape Fear river at Lock #1 near Kelly, NC              | 7/1/1969                      | Present    | 1/15/1974                       | 9/30/2008  |
| MOCR | 02108566  | Northeast Cape Fear river near Burgaw, NC              | 11/14/2003                    | 12/12/2005 | 8/12/1999                       | 6/28/2009  |
| MOCR | 02107544  | Black River near Currie, NC                            | 3/1/2004                      | 12/13/2005 | 3/5/2004                        | 12/13/2005 |
| OCMU | 02213050  | Walnut Creek near Gray, GA                             | 10/1/1961                     | 4/26/1994  | NA                              | NA         |
| OCMU | 02213000  | Ocmulgee River at Macon, GA                            | 1/02/1893                     | Present    | 10/1/1992                       | Present    |
| OCMU | 02210500  | Ocmulgee River near Jackson, GA                        | 5/18/1906                     | Present    | 3/12/1987                       | Present    |
| TIMU | 02231289  | Nassau River near Hedges, FL (at HWY 17)               | 6/10/1983                     | 9/30/2004  | 4/19/1983                       | 9/30/2004  |
| TIMU | 02246500  | St. Johns River at Jacksonville, FL                    | 10/1/1971                     | Present    | 10/1/1971                       | Present    |

### CHAT: Chattahoochee National Recreation Area

The Chattahoochee River National Recreation Area (CHAT) is made up of 6,800 acres of mixed pine/hardwood forests and wetlands that buffer 48 miles of the Chattahoochee River. Surface water bodies within the park include the following: Chattahoochee River and associated tributaries, Bull Sluice Lake, Sibley Pond (in the Cochran Shoals unit), and Island Ford Pond. Upstream of the park is Buford Dam that impounds Lake Lanier. Water released from Lake Lanier through Buford Dam into the Chattahoochee River flows from the lower strata of the lake (hypolimnion during the stratification period). The dam also regulates the flow within CHAT. Current regulations require that the flow be 750 cfs at the confluence of the Chattahoochee River and Peachtree Creek; however, beginning last year (2008) Georgia EPD allowed this standard to be lowered by 100 cfs during droughts to preserve storage in Lake Lanier.

The dam moderates peak and low flows to prevent floods and manage droughts. The streamflow data within CHAT is well documented by U.S. Geological Survey (USGS) with six gaging stations within the park (Table 3). In 2000, Kunkle and Vana-Miller reviewed the surface water hydrology, discharge, and water demand for the Chattahoochee. Kunkle and Vana-Miller (2000) also provided estimates of flood frequencies for all gages within the park and they noted the strains placed on CHAT during drought periods. Proposed management actions within their plan

includes evaluating the effects of the tri-state water allocation formula, but no specific recommendations on flow were made.

### **CONG: Congaree National Park**

Congaree National Park is made up of 24,180 acres of currently owned land, and 26,776 acres of authorized area. The park consists of old-growth bottomland forests along the Congaree River, and comprises an extensive floodplain ecosystem. The park averages 100,000 visitors per year and lies in the floodplain of the Congaree River in the Coastal Plain physiographic province of South Carolina. The upstream watershed includes over 5 million acres (Knowles 1996) and major flood events along the Congaree River occur, on average, 10 times per year. Ninety-percent of CONG is annually flooded by major events (Knowles 1996).

The parks surface is composed of freshwater wetlands and forested wetlands. Surface water resources within and near CONG include the Congaree, Wateree, and Santee Rivers; Congaree, Wateree, and other swamps and wetland areas; Cedar, Toms, Gills, Congaree, and many other creeks, oxbows, and other natural lakes and ponds (see Knowles et al. 1996 for complete list). Maintaining a functioning floodplain ecosystem is dependent upon the timing, duration, magnitude and extent of flooding from the Congaree and Wateree Rivers.

Many studies have been conducted on surface water and groundwater characteristics throughout the park. Numerous investigations have been conducted to elucidate how hydrologic forces influence the biotic and abiotic components related to the ecosystem function within CONG. For a detailed literature review see Graf and Stroup (2006). For the purposes of this report, we highlight several relevant surface water investigations and summarize findings from reports published subsequent to the review by Graf and Stroup (2006).

Patterson et al. (1985) studied the effects of hydrology on vegetation distribution throughout Congaree NP and found that the level of the shallow aquifer that exists beneath CONG is related to the stage of the Congaree River. General information on relationships between gage height and what happens at CONG is given in this report, although the information is more qualitative in many respects compared to more current reports. This report also gives details concerning the connection between flood stage on the Congaree River west of Wise Lake to the Congaree River at Columbia and Cedar Creek at Wise Lake. In a similar report (Speiran et al. 1985), further details are given about the decreases in discharge after the construction of Lake Murray and mapped details of the areas of inundation within the park that occur 1%, 10%, and 75% of the time for a given year are illustrated. Similar to Patterson et al. (1985), the relationship between the Congaree River at Columbia, the Congaree River west of Wise Lake, and Cedar Creek is given. Additionally, further information about the average number of times per year for given flooding effects is catalogued as well as the relationship between flood stages and groundwater levels.

Merdun (2003) conducted a flood analysis on CONG to achieve three goals: 1) define flood magnitudes based on upstream gages; 2) determine the lag-time and peak differences in upstream discharge and discharge at CONG; and 3) use regression analysis to find a relationship between upstream rain gages and CONG discharge. Data were used from gaging stations found on the Congaree River, Wise Lake, Rail Road, Saluda River, Broad River, and Wateree River. Merdun's (2003) analysis illustrated that although there was substantial amount of data available

from upstream gaging stations, he was unable to find a relationship between the discharge at CONG and the upstream gages. This makes prediction of flood events somewhat difficult within the Park based on these models. However, several parameters were not included in the models including infiltration, evapotranspiration, interception, soil characteristics, channel length and slope, which may improve the predictive ability of the model. The author also pointed out that substantial differences in the topography and forest structure between CONG and those upstream might account for absence of predictive ability of the models.

Plewa and Graf (2005) examined the hydrologic variation of CONG and connected it to the various stream gages present along the Congaree River. They concluded that the Broad River was the primary determinant of hydrology within CONG and contributes nearly two-thirds of the flow of the Congaree River. By contrast, the Broad River contributes only one third of the flow to the Congaree. This report also details lag-time effects of dam releases from Par Shoals Dam on the Broad River as well as outlining how stage levels on the Congaree influence flows on creeks within the park.

Detailed geospatial inundation modeling was conducted by Graf and Meitzen (2006) to provide a GIS model for various river flows and floodplain inundation depths. Their analysis utilized the Hydrological Engineering Center River Analysis System (HEC-RAS) to process and integrate geospatial data with streamflow models. This resulted in an interactive GIS model that is able to examine different river fluctuations and predict how they impact resources within CONG. Their work suggests that the Saluda Dam operations do influence flood hydrology of the Congaree River, but that the effect is variable. Therefore it would be difficult to assess how the Saluda dam operation would be remedied under re-licensing.

Conrads (et al. 2008) conducted a very detailed analysis of the effects of the Saluda dam on the surface- and ground-water hydrology of the CONG floodplain. The impetus for this investigation was, in part, due to FERC re-licensing of the Saluda Dam that resulted in a temporary modification of streamflow pattern while the backup dam was being constructed. According to the authors, it was a common perception among hydrologists and ecologists that the Saluda Dam had significantly reduced the frequency and magnitude of peak flows of the Congaree River. Their report concluded that peak flow reductions after the construction of Lake Murray were likely the result of climatic variability and decrease (or absence) of large floods since 1930. An analysis of dam effects on daily gage height on the Congaree River showed that gage height was lowered from December to May, but low gage heights from July to November were raised. The authors concluded that dam operation has a greater effect within the riverbanks of the Congaree than on the floodplain. Therefore, frequency of inundation within the park is more likely to be a result of flows from the Broad river.

Although there is an exhaustive amount of literature on the hydrology of CONG, several data gaps exist and park personnel have expressed interest in increasing the amount of monitoring and data collection in several locations. These include increased monitoring along Tom's Creek, establishment of gages within new land acquisitions on the eastern end of the park, and data collection along the U.S. Highway 601 corridor to enable predictions to be made concerning the influence of new construction on park hydrology. Park personnel also expressed additional concern over data that would be necessary to assess any potential impacts that may result from the re-licensing of the Wateree Dam and the construction of a nearby coal ash landfill.

### **FOFR: Fort Frederica National Monument**

Fort Frederica National Monument is located on 241 acres of marsh and upland on St. Simons Island, Georgia. The marshland takes up approximately 150 acres. Aside from the standing water in the marshland, the Frederica River runs adjacent to the park. St. Simons Island is a part of system of barrier islands that parallel the Atlantic and Gulf coasts from Maine to Texas. The primary driver of surface water availability at FOFR is tide fluctuation. The tides affect the water levels and salinity in the marshes, creeks and rivers. Surface water quality data were collected, reported, and summarized in NPS (1998a), however no literature assessing water quantity is available.

However, Bratton (1985) assessed the vegetation history of Fort Frederica that indicate that many extensive ponds and marshes once existed at FOFR, but are much smaller now or no longer present. Changes in the extent of marshland surrounding FOFR undoubtedly impact maximum gage height during heavier storm events such as hurricanes.

### **FOMA: Fort Matanzas National Monument**

Fort Matanzas consists of approximately 300 acres of land and the associated Castillo de San Marcos consists of approximately 18 acres. The parks consist of 15 percent wetland, marshland, and estuarine waterway. The historic Spanish fort on Rattlesnake Island and a Visitor Center attract roughly one million visitors per year.

Surface water resources in the FOMA/CASA watershed include the Atlantic Ocean; portions of the Intracoastal Waterway; the Tolomato, Matanzas, and San Sebastian Rivers; the St. Augustine and Matanzas Inlets; Pellicer Creek and other smaller creeks and numerous tidal swamps, marshes, and estuaries. Many of these water resources are influenced by tidal flow and contain fresh and saline waters in transition. No relevant literature on surface water quantity is available.

### **FOPU: Fort Pulaski National Monument**

Fort Pulaski National Monument is located on Cockspur Island in the Southeastern Coastal Plain physiographic region and contains approximately 5400 acres of surface water marshes and wetlands. Located at the mouth of the Savannah River near Savannah, GA, it receives approximately 500,000 visitors each year.

Surface water bodies, aside from the Savannah River, include two small ponds for mosquito control and the moat that encircles the fort. There are also many man-made dikes and drainage ditches located near the Fort. Other surface water features in the vicinity of the park include the Atlantic Ocean; Intracoastal Waterway; Wassaw Sound; the Savannah, Bull, Wilmington, and many other rivers; Oyster, Tybee, Fields, and numerous other creeks and cuts; a few canals; and many marshes, tidal swamps, and estuaries. Most of these surface-water resources are influenced by tidal flow and contain fresh and saline waters in transition (National Park Service, 1999)

McFarlin and Alber (2005) conducted a report to assess the coastal water resources at FOPU, however, their report focuses primarily on water quality, not quantity and contains little information relevant to the objectives of this report. However, numerous water and coastline assessments have been conducted in and around Fort Pulaski with the primary goal of predicting how the deepening of the Savannah River shipping channel will influence the shoreline (Alexander 2008), water level, and salinity in the region (Conrads et al. 2006). According to

Tiner (1977), approximately 24,000 acres of tidal freshwater wetlands were intact within the lower Savannah River in the late 1960's, however much of that has been greatly reduced by saltwater intrusion.

The Georgia Ports Authority and the United States Army Corps of Engineers was required to conduct an environmental impact assessment (EIA) in order to understand how deepening one of the busiest shipping channels in the world would influence ecological and hydrodynamic processes (Conrads et al. 2006). The result of these studies generated a three-dimensional model designed to simulate changes in water levels and salinity, and a marsh-succession model to assess how plant distribution may be influenced in the tidal marshes as result of the channel deepening. Although these studies did not take place on Fort Pulaski, much the information is relevant and includes analyses of data collected at Fort Pulaski gaging stations in addition to others upstream.

Alexander (2008) determined that although there has been substantial alteration of the shoreline of Cockspur Island, there was not a direct correspondence between the erosion of the shoreline and deepening of the shipping channel. However, he cautioned that the short time period over which the comparisons of shoreline change were made might make it difficult to find statistically significant changes. Significant alteration of the shoreline, due to the deepening of the channel, could have substantial impacts on the salinity and availability of surface water on Cockspur Island although many of these effects are largely unknown (Alexander 2008).

In the summary provided by Conrads et al. (2006), USGS streamflow, water level, and specific-conductance river gages on and around Fort Pulaski were used to try and understand freshwater inflows, tidal water levels, and specific conductance to increase their ability to create a marsh succession model. In the process, nearly 75 years of flow and estuary water level data were analyzed, including data collected at Fort Pulaski. High (95<sup>th</sup> percentile) streamflows generally peak between 30,000 – 50,000 cfs from January to May and then remain relatively stable between 20,000 – 30,000 cfs from June through December. The majority of the flow is dictated by the amount of water released upstream from Thurmond Dam near Augusta, GA. Many of the specific results from this study are beyond the scope of this review, however, the summary provided by Conrads et al. (2006) is a valuable resource that allows for a detailed analyses of surface water flow and depth data within the Savannah River Harbor.

### **FOSU: Fort Sumter National Monument**

Fort Sumter National Monument is a small island located in the mouth of Charlestown Harbor. Surface water resources in the FOSU study area include the Atlantic Ocean; portions of the Intracoastal Waterway; Charleston Harbor and other bays and coves; the Cooper, Ashley, and Wando Rivers; Shem, James Island, Hobcaw, and numerous other creeks and cuts; a few impoundments; and many marshes, tidal flats, and estuaries. Many of these water resources are influenced by tidal flow and contain fresh and saline waters (National Park Service, 2001b).

Adequate attention has been given to reporting the surface water quality in and around FOSU (National Park Service, 2001b). Although there is some analysis of streamflow contained within this report, a comprehensive analysis of surface water quantity is lacking.

**HOBE: Horseshoe Bend National Military Park**

Horseshoe Bend National Military Park is made up of 2,040 acres of mixed hardwood forest. Most of the park is upland, with approximately ten percent of the area representing wetlands. A portion of the forests is recovering farmland. There are many open fields that commemorate historic battlefronts and the park averages 100,000 visitors per year.

Surface water bodies at the park include the Tallapoosa River and Whale Creek. Surface water resources in the HOBE study area include the Tallapoosa River; Emuckfaw, Timbergut, Hillabee, Dobbs, and numerous other creeks; the northern areas of Martin Lake and other reservoirs; and many ponds and springs (National Park Service, 1997b).

Adequate attention has been given to reporting the surface water quality in and around HOBE (National Park Service, 2001b). Although there is some analysis of streamflow contained within this report, a comprehensive analysis of surface water quantity is lacking.

**KEMO: Kennesaw Mountain National Battlefield Park**

Kennesaw Mountain National Battlefield Park is located in the Allatoona Mountain Range and consists of approximately 3000 acres of mixed hardwood pine forest and open fields. Less than ten percent of the park is considered wetlands. Multiple creeks are located within the park including John Ward Creek, Noses Creek and Allatoona Creek, which originate outside the park boundaries in metropolitan Atlanta. Kennesaw Mountain is located in the northern portion of the park, while other portions of the park are bounded and intersected by suburban developments. The park receives approximately 1.5 million visitors per year (includes passing traffic).

No quantitative information about surface water was found for this park.

**MOCR: Moores Creek National Battlefield**

Moores Creek National Battlefield is located 20 miles northwest of Wilmington, North Carolina, and averages approximately 60,000 visitors per year. The park consists of 87.75 acres of forest, creek, wetland, and open fields on the Coastal Plain province of North Carolina. Moores Creek is the only significant stream within the park's boundaries and drains approximately 85 mi<sup>2</sup> at the section of the creek within MOCR. Moores Creek is a third order blackwater stream that drains into the Black River. Although Moores Creek is in the vicinity of the park is a freshwater system, it is influenced by tides from the Cape Fear River (Mallin and McIver 2007).

Freshwater and forested wetlands make up approximately 12-15 acres of MOCR. It is speculated that historically the park used to be a wet pine savannah that was drained and converted to a meadow (Mallin and McIver 2007). Currently, MOCR is working on a 4.5-acre wetland restoration project in the middle of the park called the "savannah", in an area that generally has standing water. Surface water resources near the park include Black River; Moores Creek, Colly Creek, Lyon Creek; Big Branch, Bear Branch, Deer Valley Branch; Long Bay, Flat Bay, Black Bay; and other small creeks, marshes, and swamps (National Park Service, 1997c).

Mallin and McIver (2007) provide a summary of hydrology affecting MOCR and report that Moore's Creek overflows its banks annually and longer floods tend to occur during hurricanes and El Niño years. Maximum elevations of the water surface range from 12 ft above mean sea level for a two-year storm up to 32 ft for a 100-year storm (USACOE 2000). For storms

occurring on a two year frequency, the estimated water velocity at the stream bank is 1.0 ft/sec and increases to 1.5 ft/sec for the 100 year frequency storms (USACOE 2000). Maximum discharges are reported as 1,150 CFS for the two-year frequency storm and increase to 5,940 CFS for the 100-year storms (USACOE 2000). MOCR has also been adversely affected by several hurricanes in the past, including Hurricane Fran in 1996, Bonnie in 1998, and Floyd in 1999 (Mallin and McIver 2007). Based on conversations with NPS personnel, flooding due to Hurricane Floyd was the most extreme within the park since 1946 (Mallin and McIver 2007).

### **OCMU: Ocmulgee National Monument**

Ocmulgee National Monument is located on the Fall Line, near Macon, GA. The 702-acre park is surrounded by urban and suburban development. Roughly 300 acres of the park are classified as emergent wetlands. Surface water resources in the area include the Ocmulgee River; Walnut Creek, Swift Creek, Town Creek, and numerous other creeks; Edwards, Club, Nelsons, and other impounded lakes and ponds; and swamps and wetlands (National Park Service, 2001a). Like many other NPS lands, a comprehensive water quality analysis was conducted for OCMU (National Park Service, 2001a) that included some flow analysis, but a comprehensive flow analyses is lacking.

### **TIMU: Timucuan Ecological and Historic Preserve**

Timucuan Ecological and Historic Preserve was established in 1988 and covers approximately 46,000 acres consisting of Fort Caroline National Memorial, the Theodore Roosevelt Area, Kingsley Plantation, and Cedar Point. The make-up of the park is roughly 70 percent salt marsh and estuary, with mixed forested uplands.

There is limited freshwater at Timucuan. Fort Caroline has Spanish Pond and nearby Lake Timucuan, which are influenced by fresh and saltwater (brackish) inputs. Rivers include St. Johns River and Nassau River. There are many saltwater creeks, estuaries, and the Intracoastal Waterway runs through the park. Surface water resources in the area include the Atlantic Ocean, portions of the Intracoastal Waterway, St. Johns, Fort George, Nassau, South Amelia, Rivers; Dunn, Clapboard, Browns, Cedar Point, and Edwards Creeks; Sample, Clapboard, and other swamps and marshes; interconnected lakes and lagoons; and some small impoundments. Many of these water resources are influenced by tidal flow and contain fresh and saline waters in transition (National Park Service, 2000). Barlow (2003) describes the landward flow of saltwater and its intrusion into coastal freshwater aquifers using several case studies.

Water quality analysis was conducted for TIMU (National Park Service, 2000) that included some flow analysis, but comprehensive flow analyses are lacking.

### **Summary**

There are many factors affecting freshwater ecosystems and surface water flow regime is among the most important (Figure 1). Understanding the characteristics of flow regimes is important to understanding changes in stream biologic communities, channel geomorphic conditions and protecting of the large number of historical structures found on or near stream or river floodplains within the network. Unfortunately, very little comprehensive information and analysis is readily available for many of the parks containing substantial surface water resources. For some parks, information is available for analysis; however, characterization of many of the

flow regimes appears to be lacking or unpublished (e.g. HOBE). Analysis of much of the available data is provided in subsequent sections of this report.

Coastal parks, as well as inland parks (e.g. CONG), within the SECN are susceptible to hydrologic damage due to large storm events such as hurricanes and will likely be affected in the future by changes in sea level and salinity within tidal marshes (Conrads et al. 2006). For both inland and coastal parks, implementing a long-term monitoring program is important for assessing current and historical trends to adequately plan for the future.

# Surface Water Quantity Monitoring and Data Analysis Protocols

Surface water refers to freshwater and near-coastal waters that occur on the Earth's surface. This includes waters collecting on the ground or in a stream, river, lake, sea or ocean, as opposed to groundwater, which is found below the ground surface. For most purposes, two types of data are of interest; stage and discharge. Stage refers to the elevation of the water surface, while discharge refers to the rate of water flow in a channel past a point.

## Stage

Stage is a critical surface-water monitoring variable in surface water systems. This is important in rivers and streams, as well as in estuaries and near ocean systems because water movement is dominated by ocean tides. Stage is also critical in slow-moving aquatic systems such as lakes and wetlands. Stage is also important for determining discharge (streamflow) in streams and rivers.

Stage can be determined using either manual or automated measuring devices. A standard manual device is the staff gage, which is a graduated marker placed vertically in the water so that the water level can be read visually. The marker should be placed at a location suitable for viewing under a wide range of water conditions. In cases where the site is flooded at high water, then a second staff gage can be placed at a nearby location that is suitable for reading during high-water conditions. Another gage may be required during extreme-low conditions if the primary measurement device is not placed in the deepest part of the hydrologic feature.

Automated readings can be collected using a variety of technologies, including pressure transducers, vibrating wire sensors, Doppler level indicators, and capacitance probes. These sensors are commonly connected to a data acquisition system that collects and stores the data.

Stage measurements should be taken frequently enough to capture the maxima and minima of hydrologic variation. For slowly changing systems, the measurements may be taken daily or even weekly, such that the magnitude of the change does not exceed one cm. For tidal systems (or systems with pronounced daily cycles) hourly data would be desired.

Extreme observations should be collected whenever possible, as the highest or lowest observations are critical when trying to determine statistical extremes. Annual maxima and minima should be collected, if possible.

Spatial variation is important and should be recorded in locations where large changes in stage may be present, such as in isolated water bodies. The time lag between peak and low stages should be determined for these systems.

## Discharge

Discharge is more appropriate for moving waters, such as streams and rivers. The accurate measurement of discharge is often resource intensive, requiring significant labor to obtain a single measurement. A stream cross-section is established, and flow velocities are measured across the section. The total flow, or discharge, is calculated using the sum of the product of the velocity and the incremental area. The discharge is related to the stage at the time of the measurements, and the relationship between stage and discharge is characterized using the rating

curve. The rating curve is then used to establish a time series of discharges using the time series of stages. For the purposes of this report, the majority of the available relevant data is discharge, so these data were analyzed to assess trends.

In coastal systems with significant tidal movement, the relationship between stage and discharge is not unique. The rising and falling stages will display hysteretic relationships that must be established over a wide range of conditions. In these cases, an automated velocity sensor can be deployed to better establish the relationship between stage and discharge. In the absence of automated systems of data collection, a stage-flow curve can be generated to make inferences about the relative flows at different stages. For information on how to create a stage-flow curve, see Appendix B.

### **Inventory and Flow Analysis**

This section combines land cover, water inventory, and flow analysis for the SECN. Because of the important and established linkages between basin land cover and streamflow, land cover was included as a part of this analysis. Land cover analysis for each park is reported first within each section followed by the water inventory and flow analysis. Maps of land cover types (including dam and gage locations) and tables of percentages of each type are reported at 3 spatial scales for each property: park boundary, 5-km buffer, and HUC watershed level. The water inventory provides a summary of relevant gage data and flow analysis where data were available.

The land cover analysis was created using ArcMap version 9.3. The National Land Cover Data (NCLD) 2001 layers were utilized, downloaded with the Geospatial Data Gateway available online at <http://datagateway.nrcs.usda.gov/GatewayHome.html>. The land cover data is differentiated into 16 different classes as follows: open water, perennial ice/snow, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, and emergent herbaceous wetland. A detailed description of each class is available online at <http://www.epa.gov/mrlc/definitions.html>.

Each cell in the GIS layer represents 30m by 30m of ground data. The tables were created to show the land cover within the park, a 5-km buffer around the park and the entire HUC (Hydrologic Unit Code) 8 watershed encompassing the park. This was done to illustrate how landcover upstream and surrounding the park may affect flow characteristics within the park.

This section provides an inventory of gages at or near SECN parks and lists the dates of available data for flow history (Table 3). The majority of this information was collected via automated data logging available through the USGS website (<http://waterdata.usgs.gov/nwis/rt>) and analyzed using the program RIVER2 (Dowd 2009) A detailed description of this program is provided in Appendix A).

Trend analysis was performed for non-coastal parks with available discharge data. These parks included: CHAT, CONG, HOBE, KEMO, and OCMU. For each park, graphs of the average daily flow and flow duration were created if data were available. High and low flows were analyzed with the Log Pearson III estimation technique to estimate the return interval for high and low-flow events (regional skew coefficients were applied when long-term data was lacking).

The Log Pearson III distribution fits frequency distribution data in order to predict the return period of high-flow and low-flow events of a particular magnitude.

The Log Pearson III technique is the standard technique used by federal agencies and has been shown to produce unbiased estimates as long as adjustments to the expected probability (regional skew coefficients) have been appropriately employed (Beard 1974). For some streams, data is only available for recent years and therefore no flood record exists for that site. In this instance, other nearby stations were used to create nationally recognized regional skew coefficients to substitute for the lack of information in a particular area. In these cases, in order to account for the small sample size of particular gage, regional data were used as a substitute to make predictions about the return frequency of particular flow events. Other methods of analysis can be applied and examined (e.g. Gumbel I and Gumbel III) using RIVER2 (see Appendix A), however these methods generally do not reduce uncertainty any more than the Log Pearson III method (Beard 1974).

In the event streamflow was altered due to dam construction, the data were analyzed pre- and post-dam construction if preliminary analysis suggested a change in flow characteristics. This enabled the comparison of changes in flow parameters. Typically, if a park contained more than one gage, only data from one gage were analyzed unless multiple streams with gages influence the park. For coastal parks heavily influenced by tides, flow data were not analyzed and the gage height is reported instead of flow, since tidal action prevents meaningful analysis of flow. Maximum, minimum, and mean gage heights are reported where available. However, many USGS stations only report one parameter (often mean height), which may be of little use if understanding maximum heights during surge events is desired.

For more information on various flow analysis techniques, the following web sites may be useful:

<http://www.epa.gov/waterscience/models/dflow/flow101.htm#methods>

<http://water.oregonstate.edu/streamflow/analysis/floodfreq/index.htm>

### **CHAT: Chattahoochee National Recreation Area**

Within the recreation area approximately 17% is classified as open water, but the dominant land cover class is deciduous forest (Figure 2; Table 4). Low intensity development and developed open space dominates much of the land cover within a 5-km buffer of CHAT. At the watershed level, however, deciduous forest is the dominant land cover class (Table 4).

There are currently five USGS gaging stations located within CHAT (Table 3), the oldest of which is located near Norcross, GA, and represents data going back to 1903. Prior to the construction of Buford Dam and the creation of Lake Lanier, peak-flow events exceeded 30,000 cfs on several occasions between 1915 and 1946 (Figure 3). After the construction of the dam, peak flow events have rarely exceeded 10,000 cfs (Figure 3). As would be expected, the construction of the dam decreased the magnitude of all peak-flow events downstream within CHAT (Figures 4-5). Also as expected, the 7-day low-flow magnitude increased following the construction of the dam, although the increase was not substantial (Figures 6-7).

Similarly, flow duration curves indicate that the probability of high-flow events decrease, while the probability of extreme low-flow events also decrease (Figures 8-9). For example, there was a 1-5% chance that a single or seven-day flow event would exceed 10,000 cfs prior to the construction of Buford Dam (Figure 8). However, after the construction of the dam, the probability that a similar event would occur dropped well below 1% (Figure 9). By contrast, extreme low-flow events occurred with lower frequency after the construction of the dam (Figures 8-9). Overall, there are sufficient data covering much of the historical flows downstream of Buford Dam for the past 100 years and no additional monitoring is needed within CHAT.

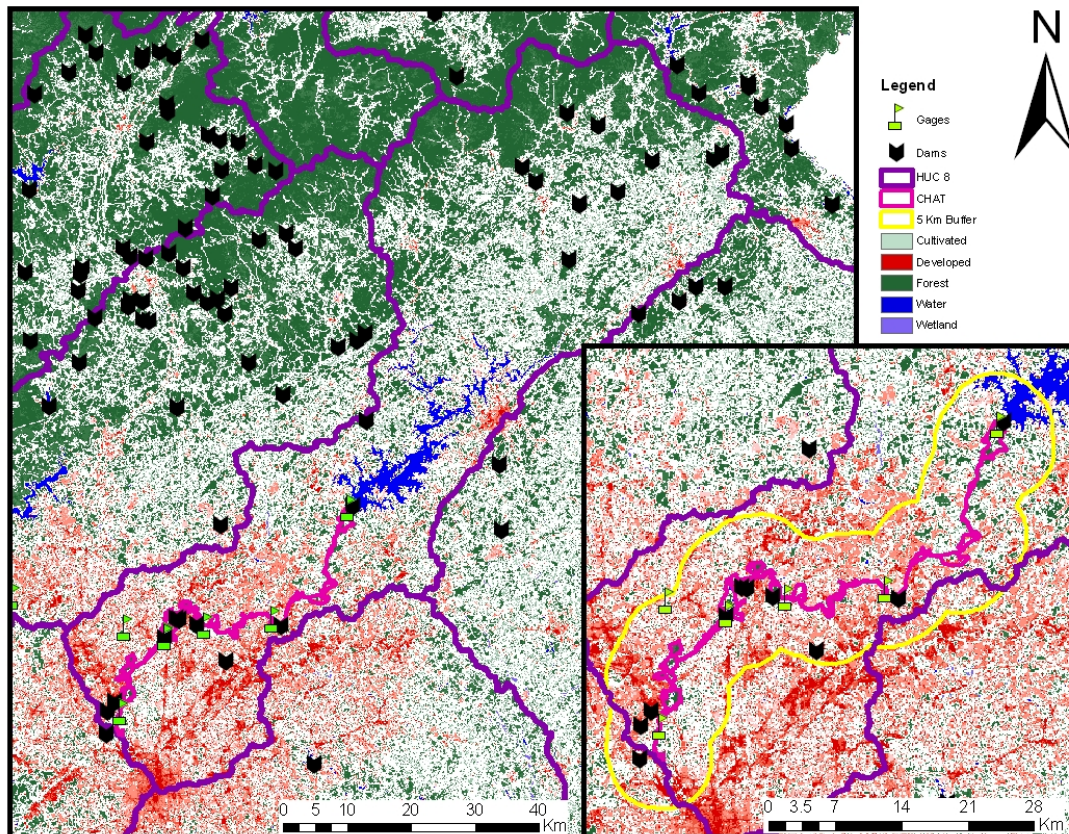


**Figure 2.** Land cover and watershed map for Chattahoochee National Recreation Area (CHAT).

**Table 5.** Chattahoochee National Recreation Area (CHAT) landcover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 1450.90     | 16.67   | 8391.62     | 4.10    | 42715.38        | 4.21    |
| Developed Open Space        | 668.30      | 7.68    | 52274.58    | 25.51   | 145173.79       | 14.29   |
| Developed Low Intensity     | 634.94      | 7.29    | 46667.56    | 22.78   | 96106.37        | 9.46    |
| Developed Medium Intensity  | 119.43      | 1.37    | 15000.98    | 7.32    | 34515.23        | 3.40    |
| Developed High Intensity    | 6.00        | 0.07    | 7047.03     | 3.44    | 19524.49        | 1.92    |
| Barren Land                 | 48.04       | 0.55    | 2205.04     | 1.08    | 6937.38         | 0.68    |
| Deciduous Forest            | 4143.66     | 47.60   | 37453.52    | 18.28   | 400111.67       | 39.39   |
| Evergreen Forest            | 645.17      | 7.41    | 22650.91    | 11.06   | 97805.03        | 9.63    |
| Mixed Forest                | 97.41       | 1.12    | 1013.45     | 0.49    | 17601.88        | 1.73    |
| Shrub/Scrub                 | 13.57       | 0.16    | 302.23      | 0.15    | 5182.24         | 0.51    |
| Grassland/Herbaceous        | 111.86      | 1.29    | 2347.60     | 1.15    | 31171.97        | 3.07    |
| Pasture/Hay                 | 288.89      | 3.32    | 7276.76     | 3.55    | 112759.97       | 11.10   |
| Cultivated                  | 0.00        | 0.00    | 19.79       | 0.01    | 71.39           | 0.01    |
| Woody Wetland               | 476.59      | 5.48    | 2227.95     | 1.09    | 6054.03         | 0.60    |
| Emergent Herbaceous Wetland | 0.00        | 0.00    | 2.89        | 0.00    | 12.23           | 0.00    |

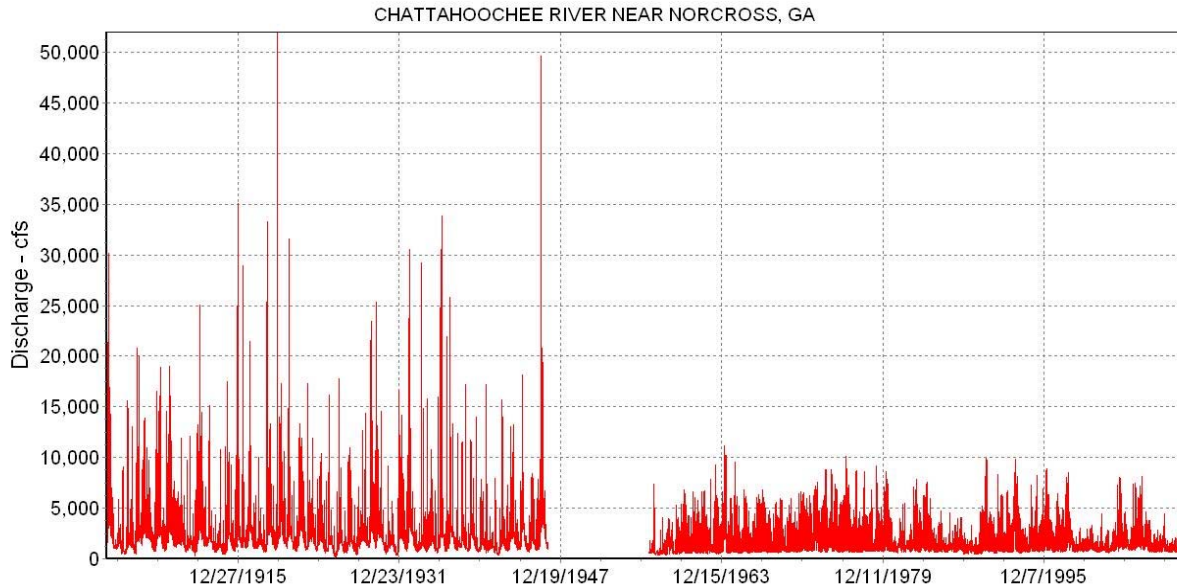


**Figure 3.** USGS Gage 02335000. Average daily flow of the Chattahoochee River pre- and post-construction of Buford Dam near Norcross, GA.

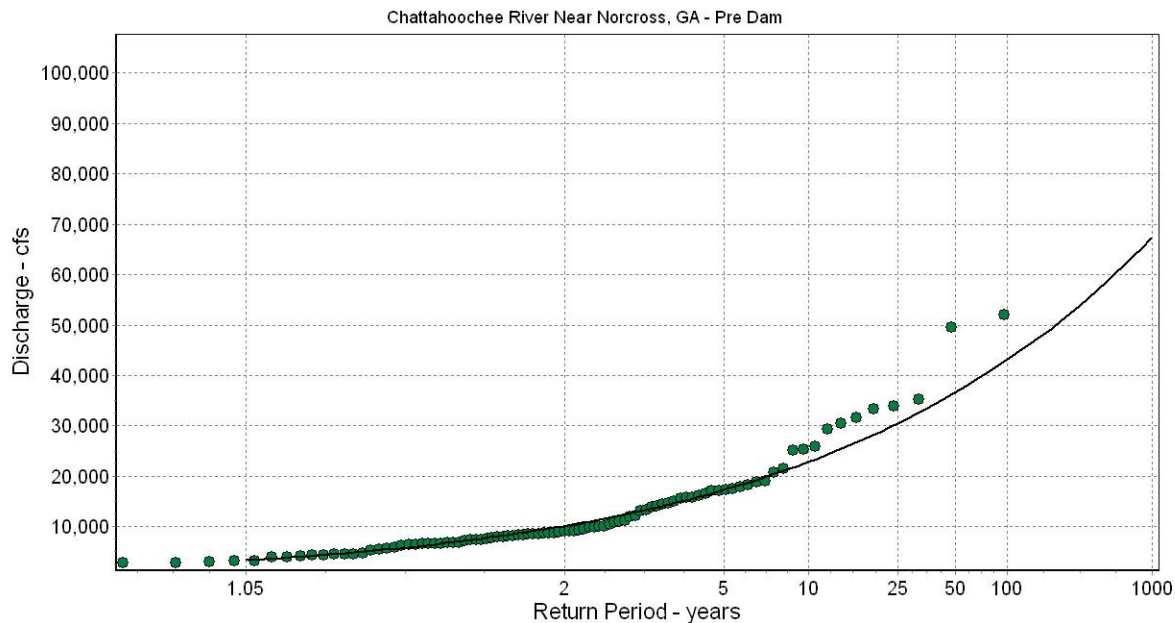


**Figure 4.** USGS Gage 02335000. Log Pearson III graph of high-flow return frequency for the Chattahoochee River near Norcross, GA, prior to the construction of Buford Dam.

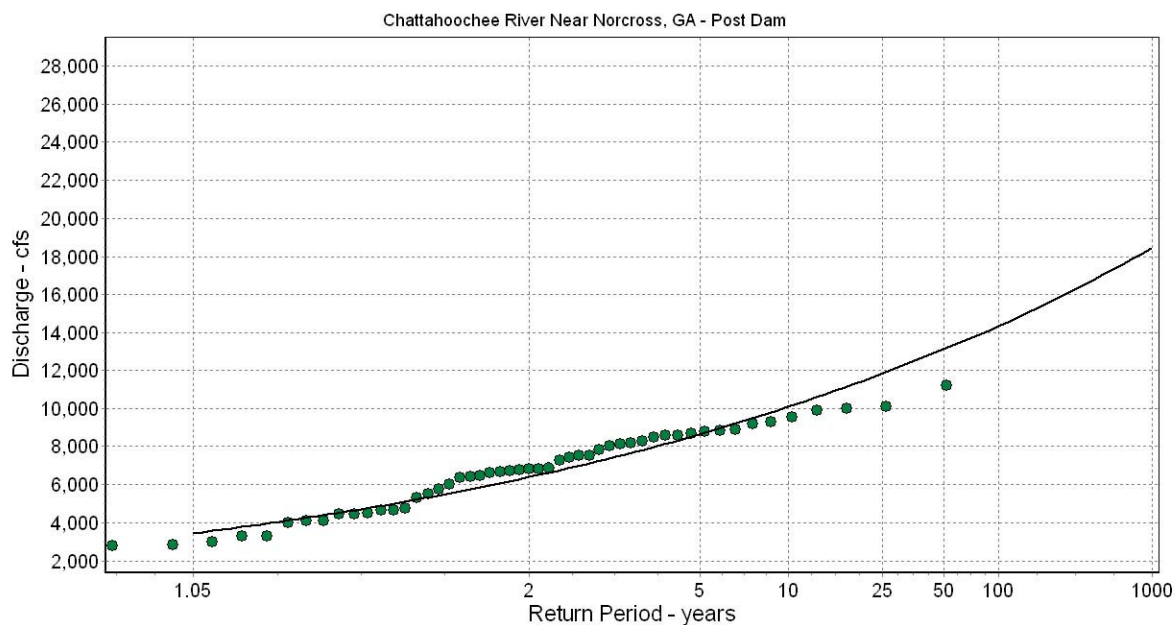


**Figure 5.** USGS Gage 02335000. Log Pearson III graph of high-flow return frequency for the Chattahoochee River near Norcross, GA, after the construction of Buford Dam.

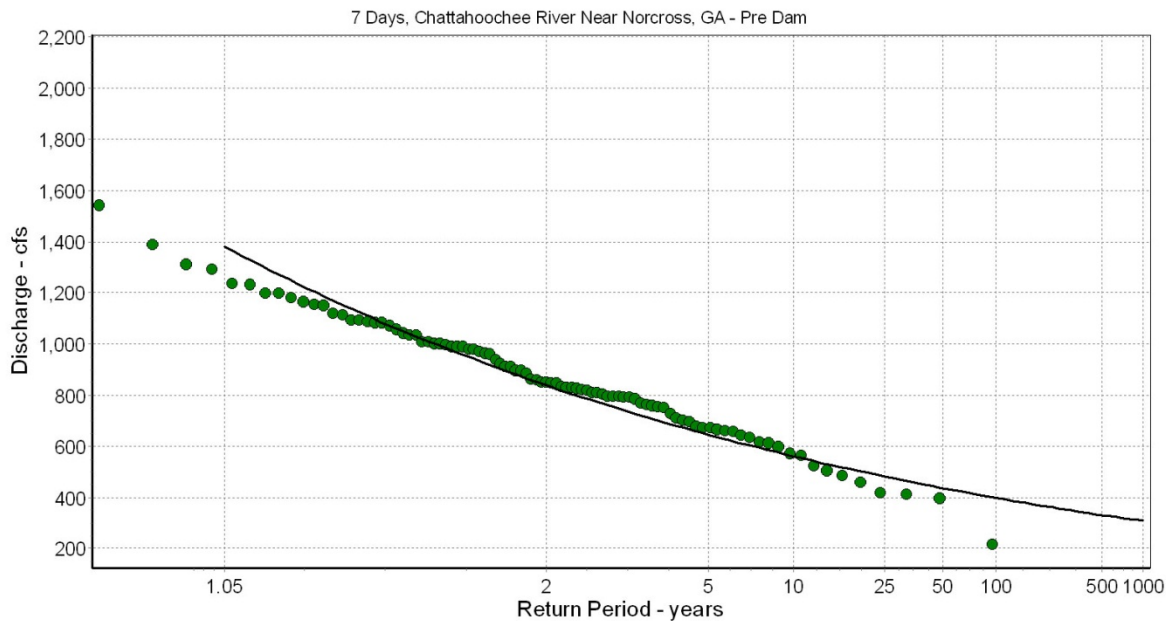


**Figure 6.** USGS Gage 02335000. Log Pearson III graph of the seven-day low-flow return frequency for the Chattahoochee River near Norcross, GA, prior to the construction of Buford Dam.

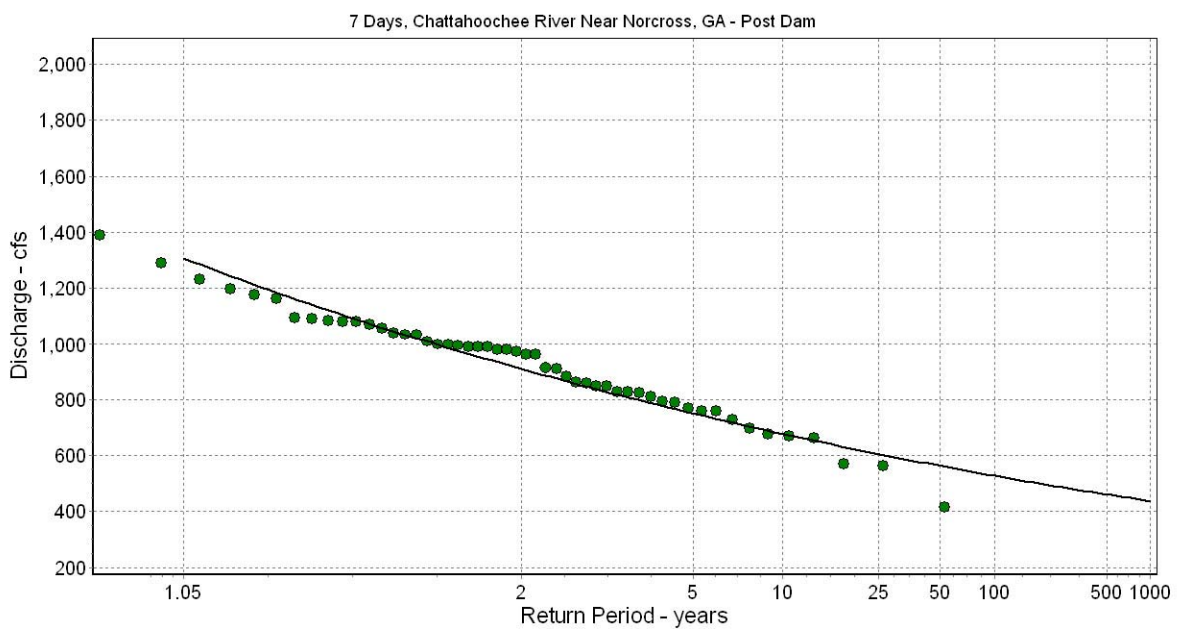


**Figure 7.** USGS Gage 02335000. Log Pearson III graph of the seven-day low-flow return frequency for the Chattahoochee River near Norcross, GA, after the construction of Buford Dam.

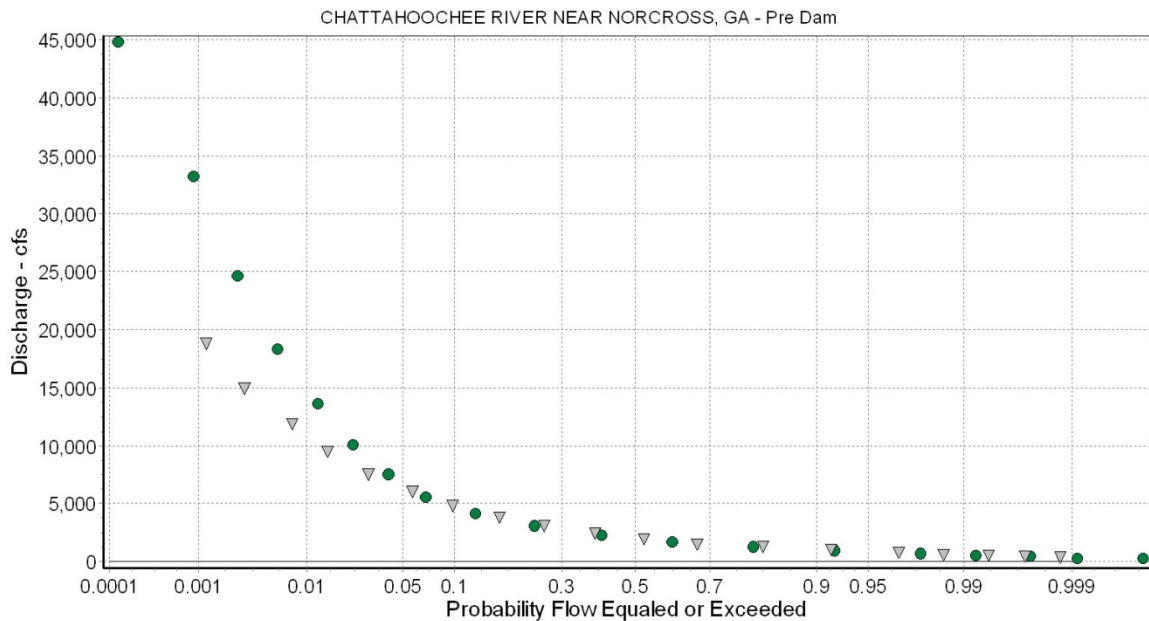


**Figure 8.** USGS Gage 02335000. Single day (dots) and seven-day (triangles) flow duration curves for single-day flow on the Chattahoochee River near Norcross, GA, prior to the construction of Buford Dam.

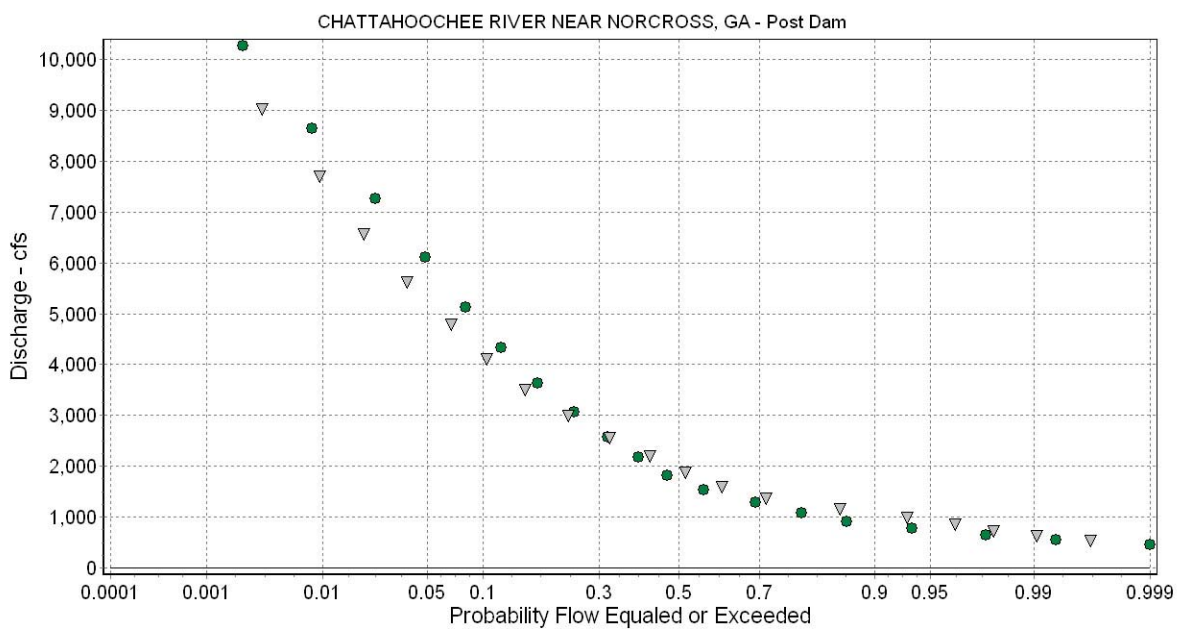


**Figure 9.** USGS Gage 02335000. Single day (dots) and seven-day (triangles) flow duration curves for single-day flow on the Chattahoochee River near Norcross, GA, after to the construction of Buford Dam.

## **CONG: Congaree National Park**

Within the Congaree National Park, less than 1% is classified as open water, but the majority of the land cover is dominated by forested (woody) wetlands (Figure 10; Table 5) which are inundated several times each year. Forested wetlands also surround much of the land cover within a 5-km buffer of CONG, but at the watershed level, deciduous forest and evergreen forests are the dominant land cover class (Table 5).

Two rivers have a major influence on the surface water hydrology at CONG; the Congaree River (formed by the Broad and Saluda Rivers just upstream from CONG) and the Wateree River. Although not located directly in the park, USGS 02169500 (see Table 3) near Columbia, SC, has the longest flow data history and was therefore used to assess trends and extreme flow events for this river. While discharge data is unavailable within the park, the USGS maintains a gaging site (USGS 02169625) that only provides river stage. This is because streamflow exchanges with nearby CONG wetlands, precluding accurate discharge measurements. For the Wateree, gage 02148315 (Table 3) below Eastover, SC, was examined. Extensive hydrologic modeling beyond the scope of this report has been conducted on CONG and should be used to supplement the analysis presented here (see Conrads et al. 2008; Doyle 2009; Merdun 1996; Merdun 2003)

The Congaree River gage (2169500) is located 8,200 ft upstream of Granby Dam, which has little impact on the flow of the stream since water flows freely through an unused shipping lock adjacent to the dam. Two-thirds of the daily flow on the Congaree River is due to flow from Broad River and therefore is primarily responsible for the patterns observed in the average daily flow (Figure 11). Two gages do exist within the park (02169625 and 02169672), and relationships between gage height and streamflow within the Congaree River have been established previously (e.g. Patterson et al. 1985).

Examination of high-flow return frequency indicates that events exceeding 100,000 cfs occur almost every 5 years and the Congaree did exceed 150,000 cfs in the late 1970s (Figure 12). Log Pearson III projections indicate that the 7-day low-flow will only dip below 1,000 cfs every 100 years (Figure 13); however, the data indicate that it has happened at least twice since records have been kept. The flow duration curve indicates that the probability that the flow will exceed 60,000 cfs is less than 1% and that there is a greater than 50% chance that the flow will be less than 10,000 cfs (Figure 14).

The Wateree River has a similar pattern of flow that is also heavily influenced by an upstream dam at the base of Wateree Lake. This results in highly variable flows, but does not exceed 10,000 cfs (Figure 15). The high-flow return frequency indicates that flow events greater than 10,000 cfs do occur every four to five years, however they rarely go much higher (Figure 16). Seven-day low-flow events dipping below 1,000 cfs could occur as frequently as < 10 years, however no 7-day events much lower than 1,000 cfs are on record for this gage (Figure 17). The flow duration curve illustrates that there is a less than 30% probability that the flow will exceed 8,000, indicating that the flow is highly controlled since it does not exceed 10,000 cfs (Figure 18).

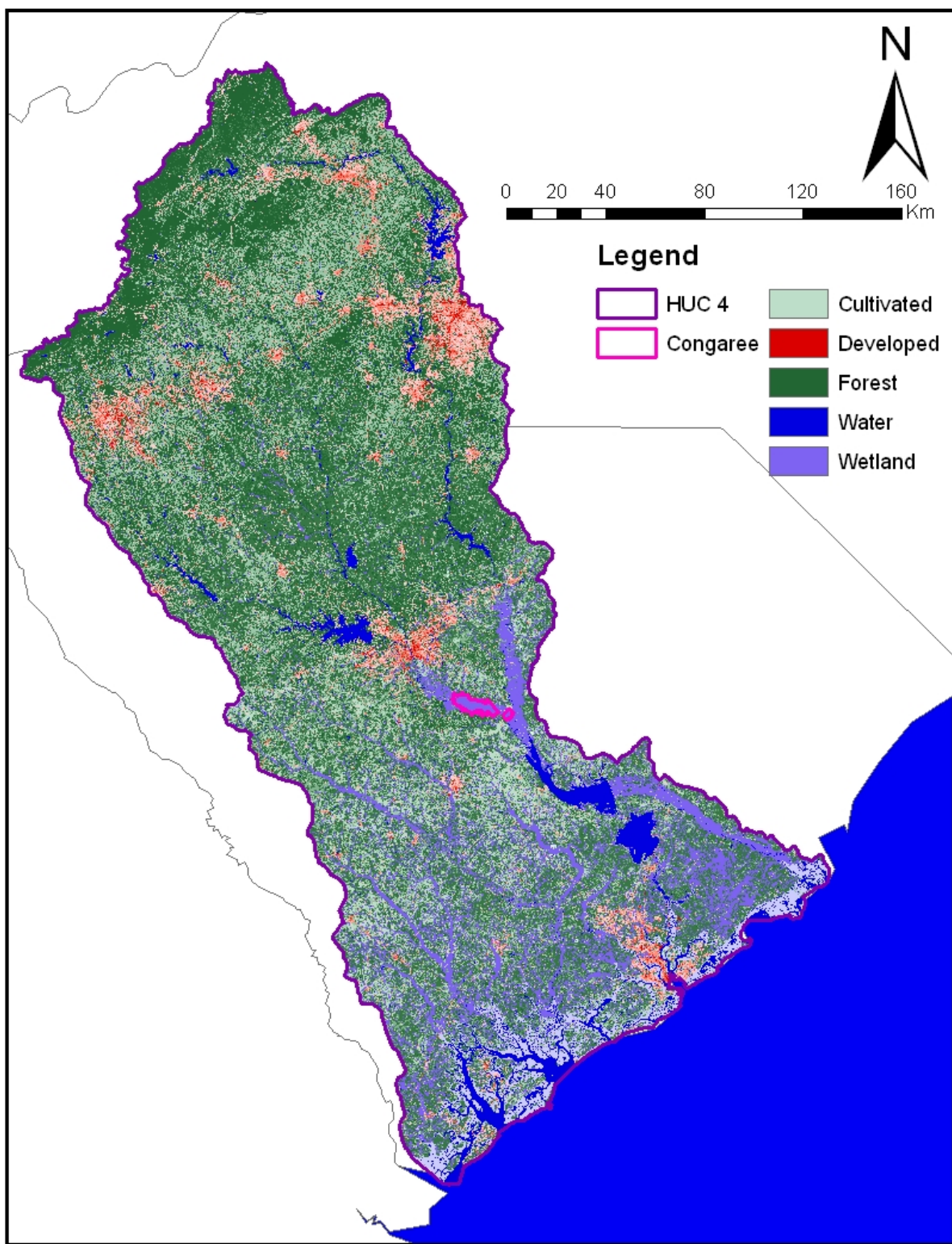


**Figure 10.** Land cover and watershed map (HUC 4) for Congaree National Park (CONG).

**Table 6.** Congaree National Park (CONG) landcover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 142.56      | 0.59    | 1892.14     | 1.61    | 24486.34        | 1.98    |
| Developed Open Space        | 40.03       | 0.17    | 3061.04     | 2.60    | 69362.06        | 5.60    |
| Developed Low Intensity     | 4.45        | 0.02    | 607.58      | 0.52    | 41935.22        | 3.38    |
| Developed Medium Intensity  | 2.22        | 0.01    | 47.15       | 0.04    | 14300.88        | 1.15    |
| Developed High Intensity    | 0.22        | 0.00    | 2.22        | 0.00    | 5253.86         | 0.42    |
| Barren Land                 | 0.00        | 0.00    | 0.00        | 0.00    | 7723.55         | 0.62    |
| Deciduous Forest            | 133.44      | 0.55    | 10453.45    | 8.89    | 181725.28       | 14.66   |
| Evergreen Forest            | 1226.95     | 5.06    | 19062.80    | 16.21   | 340332.83       | 27.46   |
| Mixed Forest                | 137.88      | 0.57    | 1133.32     | 0.96    | 41905.42        | 3.38    |
| Shrub/Scrub                 | 10.01       | 0.04    | 620.48      | 0.53    | 8499.04         | 0.69    |
| Grassland/Herbaceous        | 8.45        | 0.03    | 12299.32    | 10.46   | 180231.45       | 14.54   |
| Pasture/Hay                 | 10.01       | 0.04    | 2592.23     | 2.20    | 55559.35        | 4.48    |
| Cultivated                  | 8.45        | 0.03    | 7310.12     | 6.22    | 63310.25        | 5.11    |
| Woody Wetland               | 22488.12    | 92.81   | 57940.08    | 49.27   | 201583.58       | 16.26   |
| Emergent Herbaceous Wetland | 30.25       | 0.12    | 576.67      | 0.49    | 3351.27         | 0.27    |

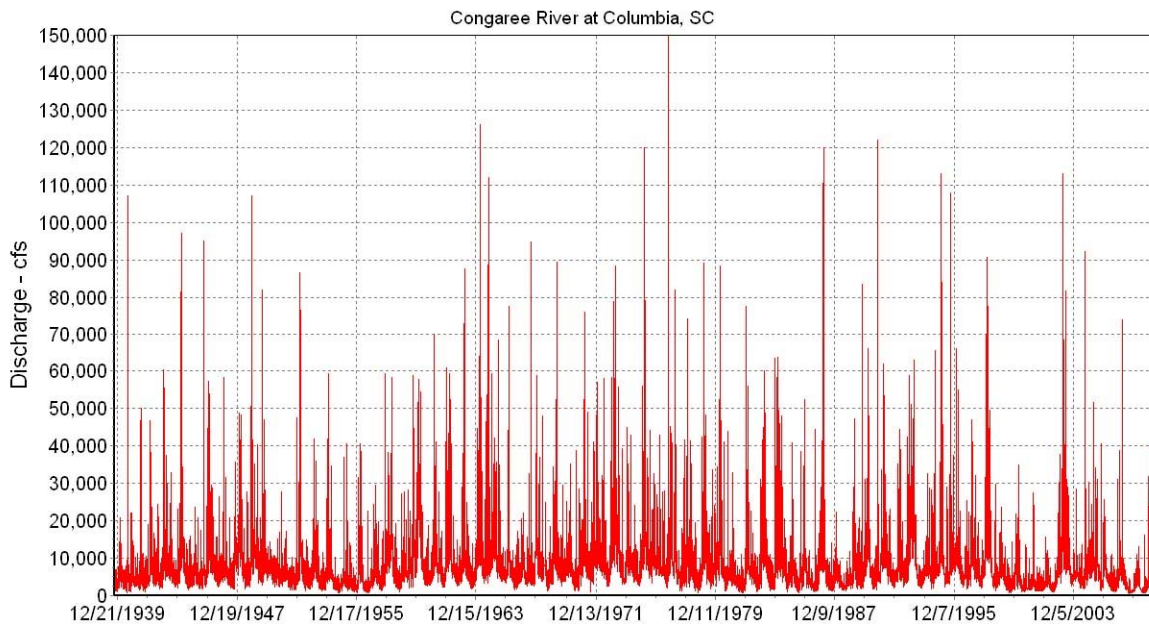


**Figure 11.** USGS Gage 02169500. Average daily flow of the Congaree River at Columbia, SC.

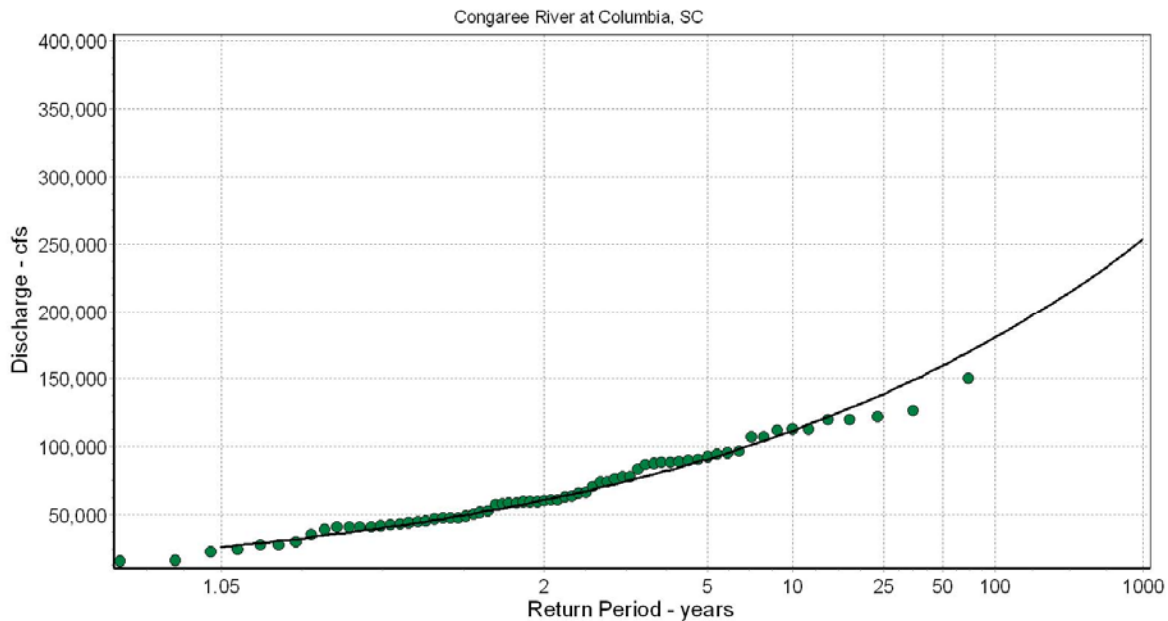


**Figure 12.** USGS Gage 02169500. Log Pearson III graph of high-flow return frequency for the Congaree River at Columbia, SC.

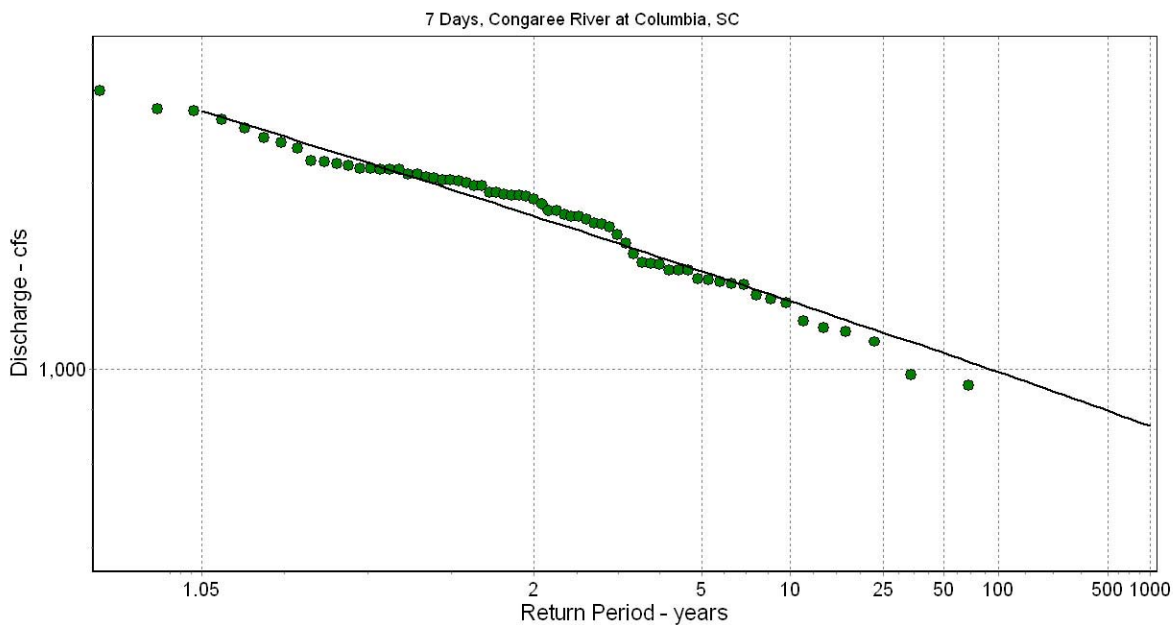


**Figure 13.** USGS Gage 02169500. Log Pearson III graph of the seven-day low-flow return frequency for the Congaree River at Columbia, SC.

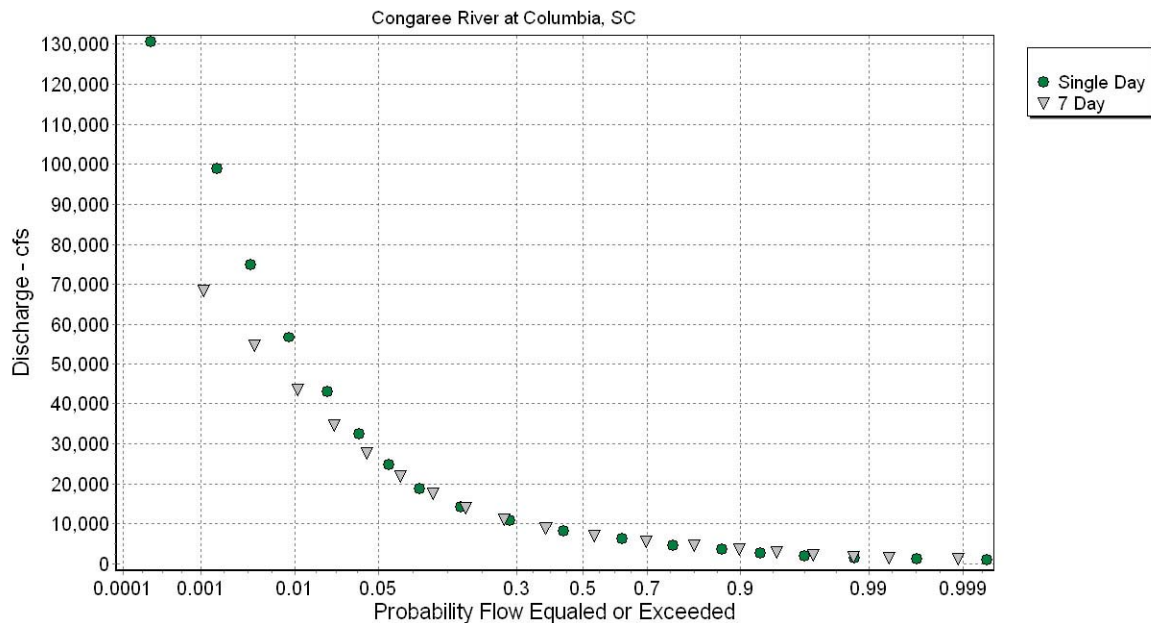


**Figure 14.** USGS Gage 02169500. Flow duration curves for seven-day (triangles) and single day (dots) flow duration for the Congaree River at Columbia, SC.

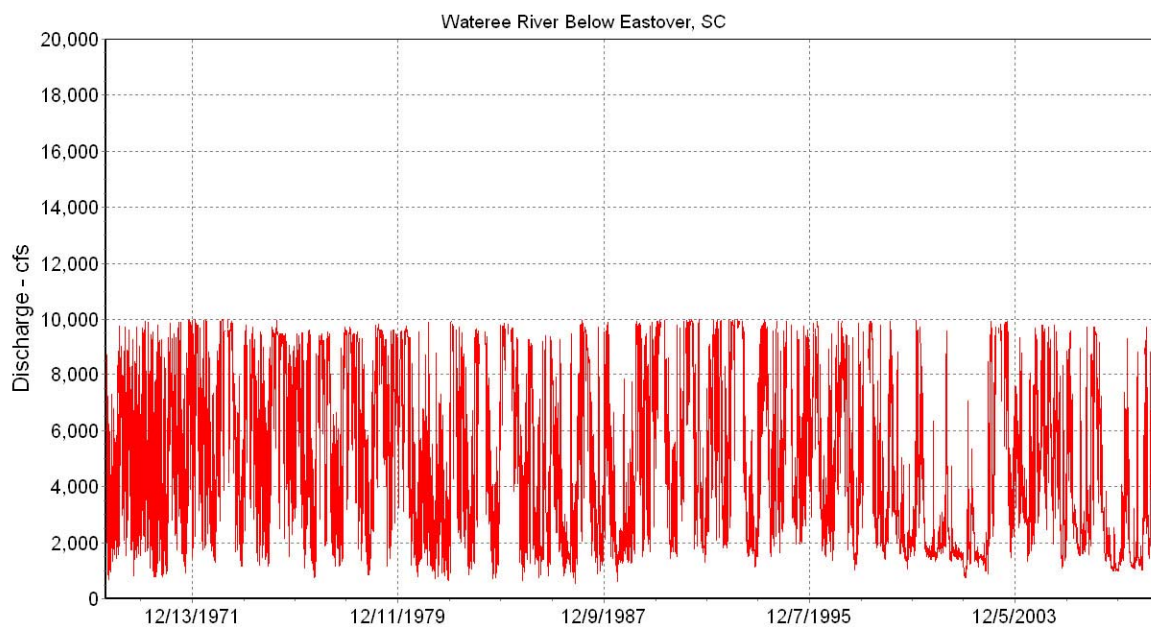


**Figure 15.** USGS Gage 02148315. Average daily flow for the Wateree River below Eastover, SC.

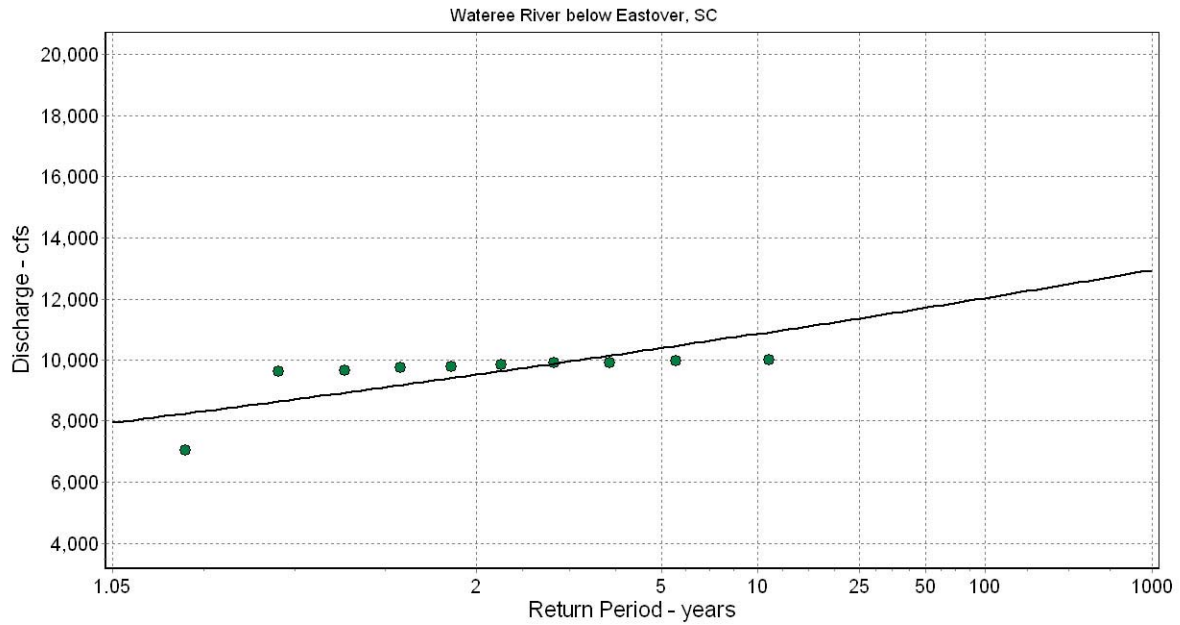


**Figure 16.** USGS Gage 02148315. Log Pearson III graph of high-flow return frequency for the Wateree River below Eastover, SC.

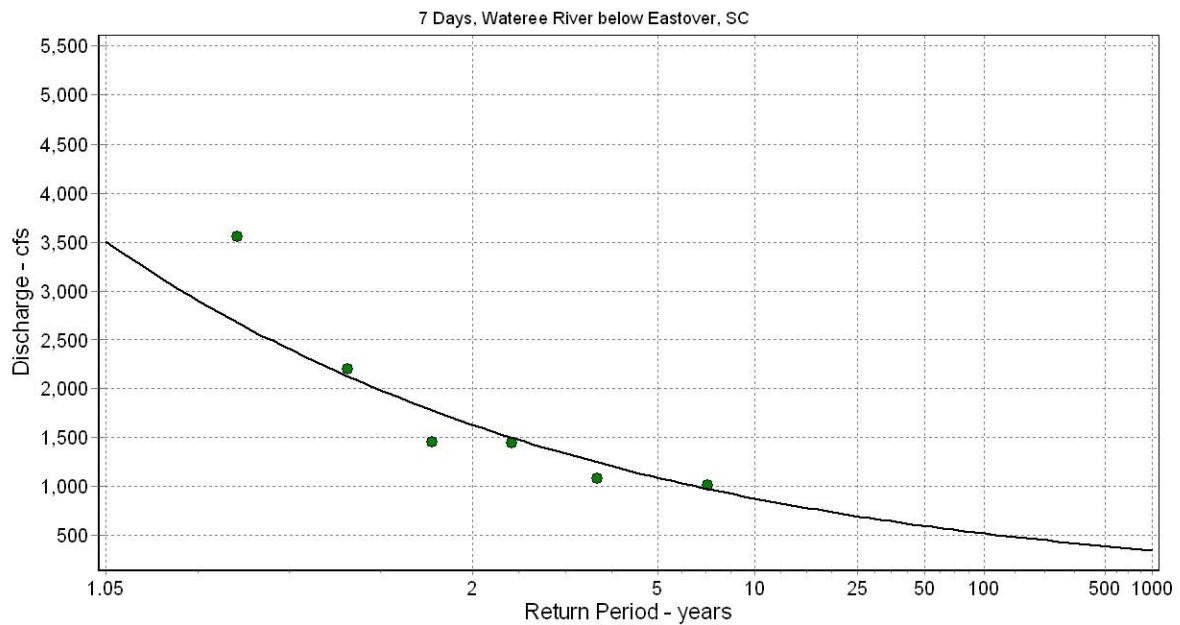


**Figure 17.** USGS Gage 02148315. Log Pearson III graph of seven-day low-flow return frequency for the Wateree River below Eastover, SC.

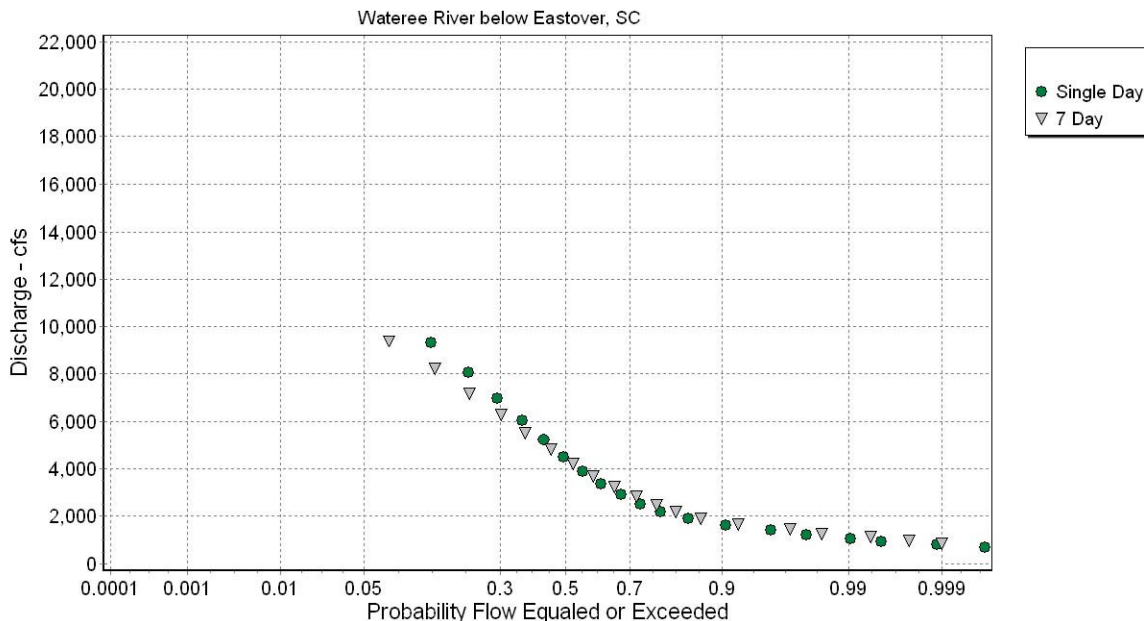


**Figure 18.** USGS Gage 02148315. Flow duration curves for seven-day (triangles) and single day (dots) flow duration for the Wateree River at Columbia, SC.

### FOFR: Fort Frederica National Monument

Despite its coastal location, less than 1% of the land is classified as open water within the monument. The majority of the land cover is considered emergent herbaceous wetland (Figure 19; Table 6). Within a 5-km buffer surrounding FOFR, emergent herbaceous wetlands also dominate. At the watershed level, however, the majority of the landscape is evergreen forest, but wetlands are also widespread (Table 6).

No gages are found within the boundaries of Fort Frederica, however three gages are located nearby, but only one contains data up to 2009 (0226180; Table 3). As of the time of writing this report, this data only runs through 6/17/2009. None of the gages contain discharge data, although this would be of little use in a coastal system that is mostly dominated by tidal action. Maximum gage height rarely exceeds 6 feet, although direct impact from a major storm would likely push the maximum much higher (Figure 20). Minimum gage heights reached nearly -8 feet in 2009 and no mean was reported, but can easily be inferred from examination of the graph. If trends are to be assessed at this location, it will require a long-term data set to determine what types of impact tropical systems may impart to Fort Frederica, especially in conjunction with sea level rise (see Appendix C).

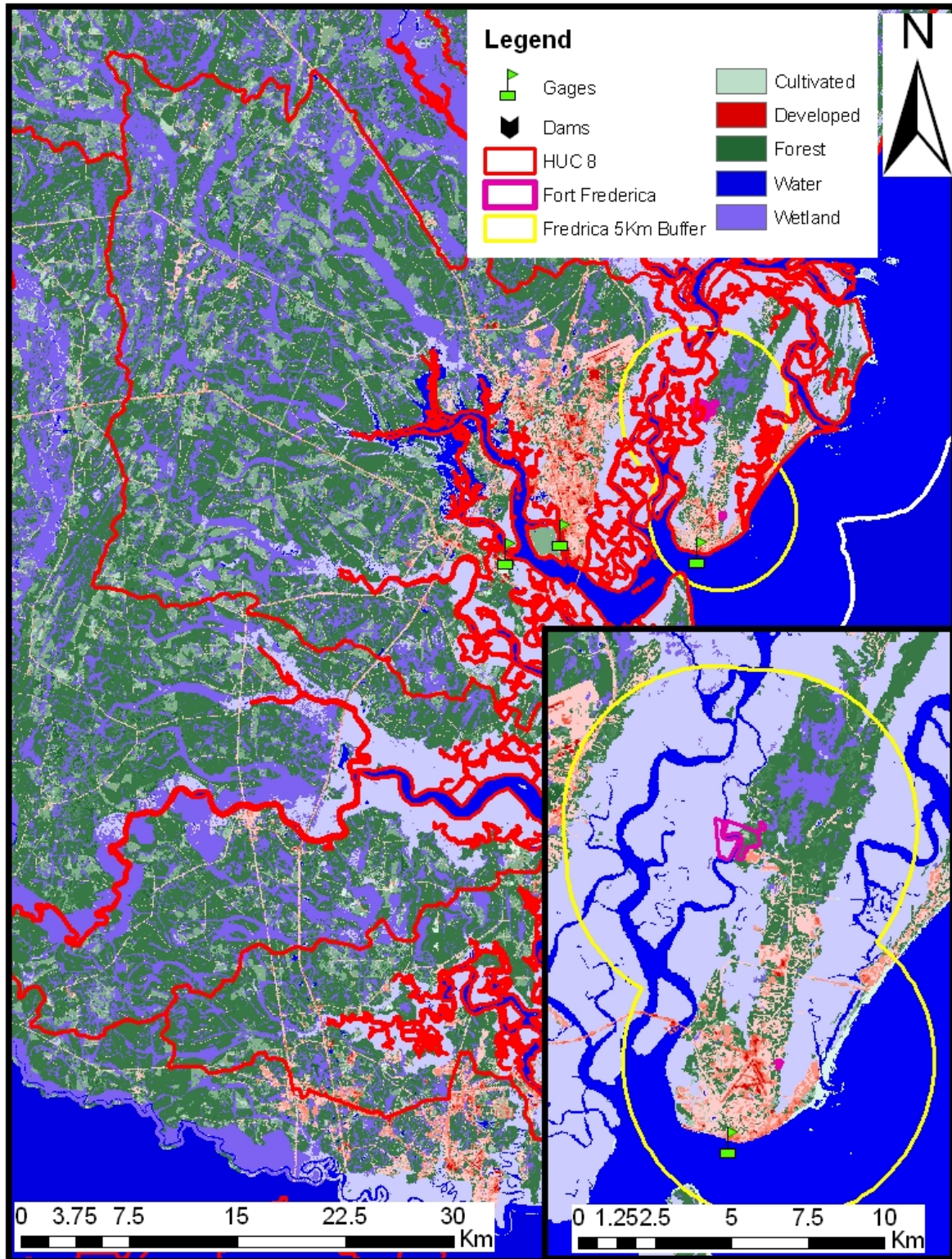


**Figure 19.** Land cover and watershed map for Fort Frederica National Monument (FOFR).

**Table 7.** Fort Frederica National Monument (FOFR) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 1.78        | 0.63    | 5067.04     | 14.60   | 54548.56        | 10.95   |
| Developed Open Space        | 4.23        | 1.50    | 2461.02     | 7.09    | 26249.49        | 5.27    |
| Developed Low Intensity     | 0.00        | 0.00    | 1071.50     | 3.09    | 9715.10         | 1.95    |
| Developed Medium Intensity  | 0.00        | 0.00    | 275.99      | 0.80    | 2724.78         | 0.55    |
| Developed High Intensity    | 0.00        | 0.00    | 85.84       | 0.25    | 1440.45         | 0.29    |
| Barren Land                 | 0.00        | 0.00    | 322.69      | 0.93    | 4568.88         | 0.92    |
| Deciduous Forest            | 0.00        | 0.00    | 81.84       | 0.24    | 7736.89         | 1.55    |
| Evergreen Forest            | 86.73       | 30.88   | 5135.32     | 14.80   | 143480.26       | 28.79   |
| Mixed Forest                | 2.67        | 0.95    | 758.81      | 2.19    | 13670.39        | 2.74    |
| Shrub/Scrub                 | 9.56        | 3.40    | 23.13       | 0.07    | 3603.69         | 0.72    |
| Grassland/Herbaceous        | 0.00        | 0.00    | 323.14      | 0.93    | 37179.75        | 7.46    |
| Pasture/Hay                 | 9.56        | 3.40    | 165.91      | 0.48    | 3719.11         | 0.75    |
| Cultivated                  | 0.00        | 0.00    | 0.00        | 0.00    | 1501.83         | 0.30    |
| Woody Wetland               | 0.89        | 0.32    | 1260.53     | 3.63    | 79270.64        | 15.91   |
| Emergent Herbaceous Wetland | 164.13      | 58.43   | 17665.49    | 50.91   | 108973.25       | 21.87   |

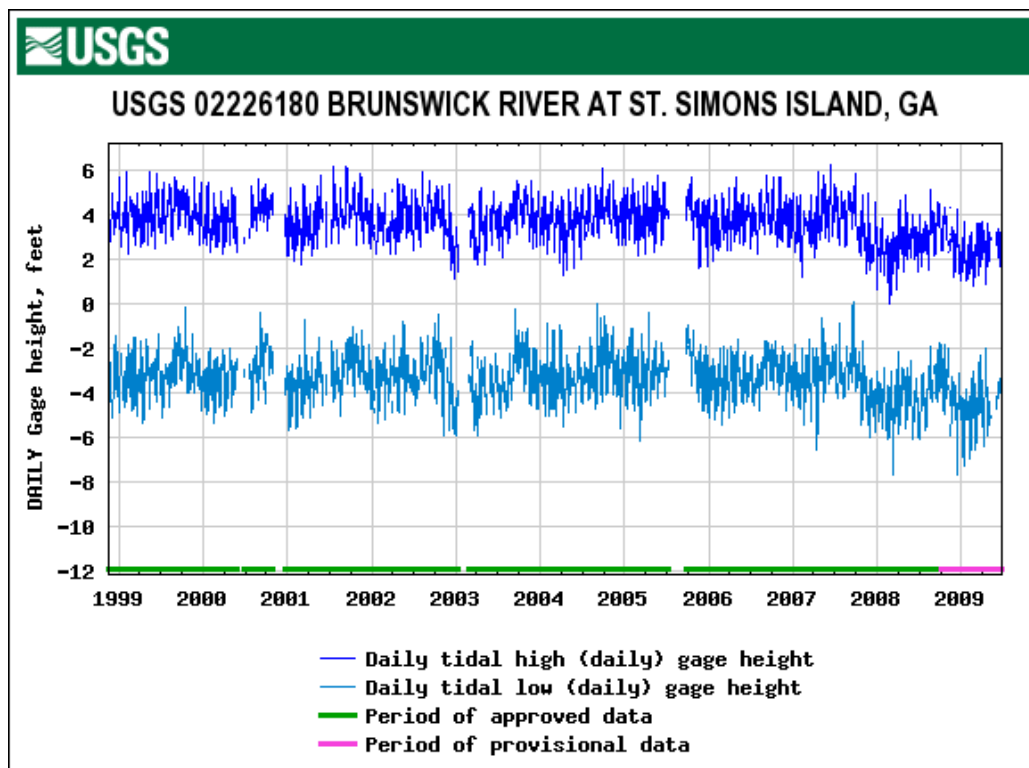


**Figure 20.** USGS 0226180. Daily stream height located near Fort Frederica.

### FOMA: Fort Matanzas National Monument

Fifteen percent of the land is classified as open water within FOMA. The majority of the land cover is considered emergent herbaceous wetland, followed by evergreen forest (Figure 21; Table 7). Within a 5-km buffer surrounding FOMA, emergent herbaceous wetlands and evergreen forests also dominate. At the watershed level, however, the dominant wetland type shifts from herbaceous wetlands to woody wetlands (Table 7).

The nearest gage with data that may be relevant to Fort Matanzas is located on the St. John's River near Satsuma, FL, and not located within the park's boundaries (Table 3). It contains current and historical data on discharge and gage height back to 1992 and 1990 respectively. However, this is a short period of time from which to assess flood potential. Additionally, there are many gaps in the data since that time (Figure 22). Additionally, only mean height is reported; therefore, there is no indication of what the maximum and minimum heights could be. Mean height ranged from a low of 8.5 ft in the early 1990s to a high of nearly 14 ft occurring at various times since record keeping began (Figure 22). Storm surge, combined with potential sea-level rise, could inundate the majority of FOMA (see Appendix C). Therefore, long-term monitoring, including maximum and minimum gage height, is recommended.

**Table 8.** Fort Matanzas National Monument (FOMA) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 43.81       | 14.65   | 2168.57     | 13.77   | 25811.15        | 5.32    |
| Developed Open Space        | 3.78        | 1.26    | 296.01      | 1.88    | 54084.20        | 11.14   |
| Developed Low Intensity     | 13.57       | 4.54    | 421.66      | 2.68    | 51976.57        | 10.71   |
| Developed Medium Intensity  | 11.12       | 3.72    | 124.76      | 0.79    | 12857.09        | 2.65    |
| Developed High Intensity    | 2.45        | 0.82    | 16.68       | 0.11    | 3071.50         | 0.63    |
| Barren Land                 | 43.81       | 14.65   | 837.32      | 5.32    | 7201.81         | 1.48    |
| Deciduous Forest            | 0.00        | 0.00    | 49.59       | 0.31    | 1840.76         | 0.38    |
| Evergreen Forest            | 59.38       | 19.85   | 3328.36     | 21.13   | 115504.32       | 23.80   |
| Mixed Forest                | 30.91       | 10.33   | 48.70       | 0.31    | 1840.76         | 0.38    |
| Shrub/Scrub                 | 15.79       | 5.28    | 73.61       | 0.47    | 2876.90         | 0.59    |
| Grassland/Herbaceous        | 0.00        | 0.00    | 2420.10     | 15.36   | 55078.53        | 11.35   |
| Pasture/Hay                 | 15.79       | 5.28    | 94.74       | 0.60    | 8998.76         | 1.85    |
| Cultivated                  | 0.00        | 0.00    | 8.45        | 0.05    | 2387.19         | 0.49    |
| Woody Wetland               | 0.00        | 0.00    | 1996.44     | 12.67   | 95586.64        | 19.70   |
| Emergent Herbaceous Wetland | 74.50       | 24.91   | 3867.00     | 24.55   | 46180.96        | 9.52    |

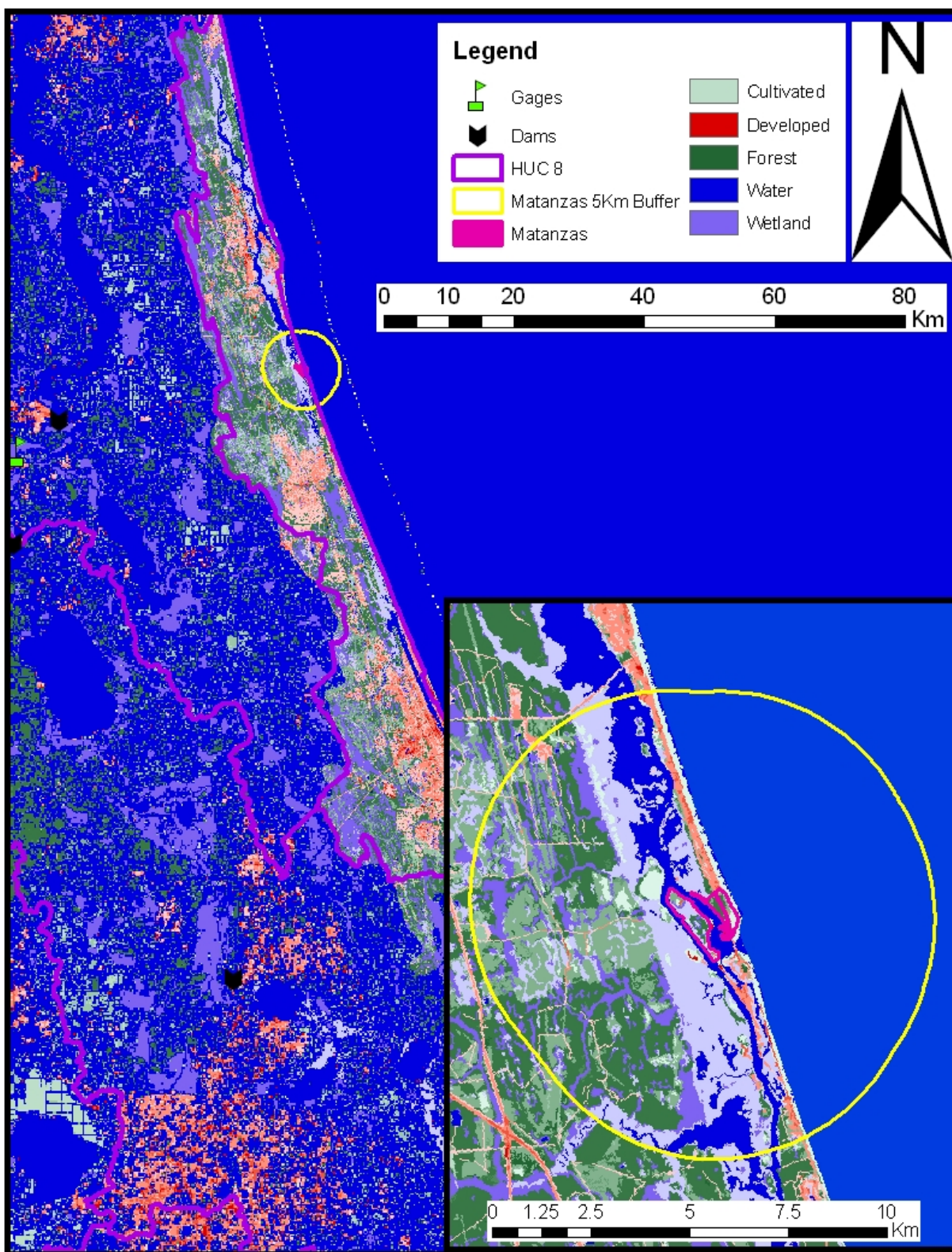


**Figure 21.** Land cover and watershed map for Fort Matanzas National Monument (FOMA).

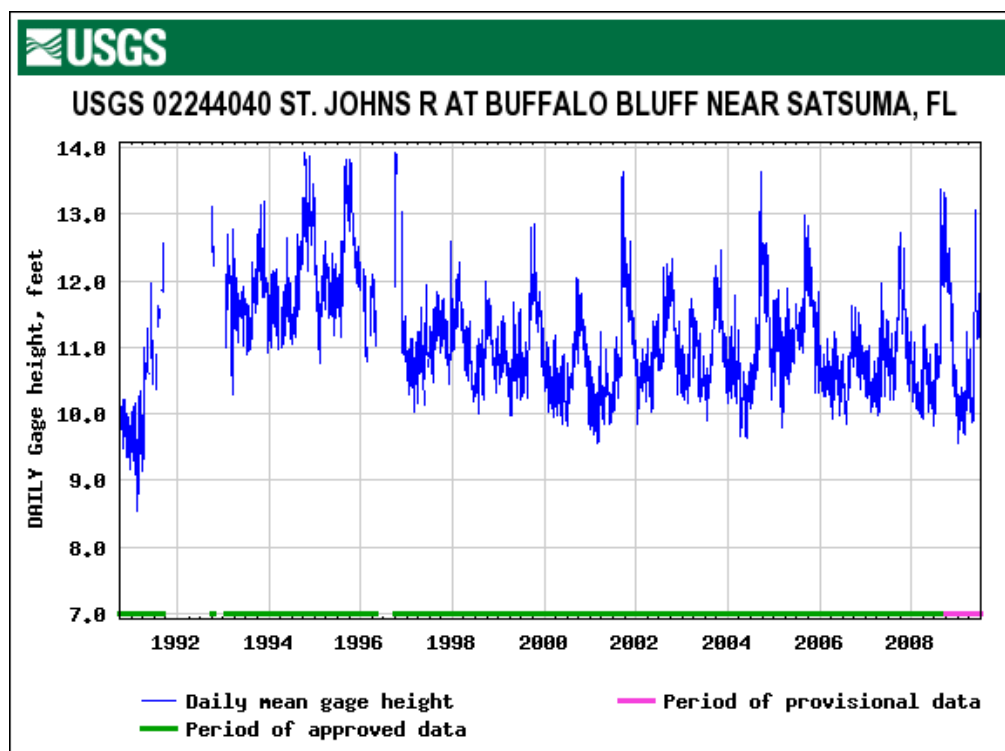


**Figure 22.** USGS 02244040. Daily stream height located near Fort Matanzas (FOMA).

### FOPU: Fort Pulaski National Monument

Open water and emergent herbaceous wetlands make up over 90% of the land cover types within FOPU (Figure 23; Table 8). Within a 5-km buffer surrounding FOMA, > 80% of the land cover is also comprised of open water and herbaceous wetlands. At the watershed level, however, the dominant wetland type begins to shift from herbaceous wetlands to woody wetlands and evergreen forests make up 25% of the landscape (Table 8).

Until 2006, Fort Pulaski appears to have had adequate monitoring of gage height that included daily maximum, minimum, and mean height (Table 3; Figure 24). Nearby gages include USGS 021989773 located on the Savannah River at US Army Corps of Engineers (USACE) dock at Savannah, GA, and USGS 02198840 on the Savannah River near Port Wentworth, GA. Both gages are presently reporting gage height at the USGS website; however, USGS 02198840 summary tables indicate that historical gage height data is only available through 2005.

For USGS gage 2198980, maximum gage height was recorded at approximately 10 ft on multiple occasions from 1993 - 2001, however an abnormality in the data appears in the mean height in the fall of 1993 and indicates a height over 25 feet. This does not appear to be associated with any tropical system, but it is unclear why this abnormality occurred. Maximum, minimum, and mean height appear to have all dropped three to four ft in late 2001, however this was not due to an actual change in height, but a change in the datum used for this gage. As of December 2005, gage height is no longer being recorded at this station. Since Fort Pulaski is located in a highly dynamic system susceptible to tropical systems, potential sea level rise (see

Appendix C), and changes caused due to dredging operations, it would be prudent to re-instate monitoring at this location.

**Table 9.** Fort Pulaski National Monument (FOPU) land cover within the park, within a 5-km buffer and its HUC 8 watershed.

|                             | <b>Within Park</b> |         | <b>5-km buffer</b> |         | <b>HUC 8 Watershed</b> |         |
|-----------------------------|--------------------|---------|--------------------|---------|------------------------|---------|
|                             | Acres              | Percent | Acres              | Percent | Acres                  | Percent |
| Open Water                  | 1430.22            | 25.82   | 23776.68           | 36.49   | 42220.55               | 2.90    |
| Developed Open Space        | 211.72             | 3.82    | 2322.02            | 3.56    | 67868.68               | 4.67    |
| Developed Low Intensity     | 73.17              | 1.32    | 1715.11            | 2.63    | 25996.62               | 1.79    |
| Developed Medium Intensity  | 0.00               | 0.00    | 513.51             | 0.79    | 9429.99                | 0.65    |
| Developed High Intensity    | 0.00               | 0.00    | 238.63             | 0.37    | 5873.89                | 0.40    |
| Barren Land                 | 26.24              | 0.47    | 2144.55            | 3.29    | 6903.36                | 0.47    |
| Deciduous Forest            | 0.00               | 0.00    | 394.97             | 0.61    | 59891.82               | 4.12    |
| Evergreen Forest            | 100.30             | 1.81    | 2417.43            | 3.71    | 375262.39              | 25.80   |
| Mixed Forest                | 39.14              | 0.71    | 389.86             | 0.60    | 53772.63               | 3.70    |
| Shrub/Scrub                 | 23.57              | 0.43    | 52.49              | 0.08    | 15063.25               | 1.04    |
| Grassland/Herbaceous        | 0.00               | 0.00    | 1444.01            | 2.22    | 129556.78              | 8.91    |
| Pasture/Hay                 | 23.57              | 0.43    | 214.61             | 0.33    | 24885.76               | 1.71    |
| Cultivated                  | 0.00               | 0.00    | 62.27              | 0.10    | 45500.43               | 3.13    |
| Woody Wetland               | 25.35              | 0.46    | 921.16             | 1.41    | 334220.09              | 22.97   |
| Emergent Herbaceous Wetland | 3599.91            | 65.00   | 28560.39           | 43.83   | 258291.37              | 17.76   |

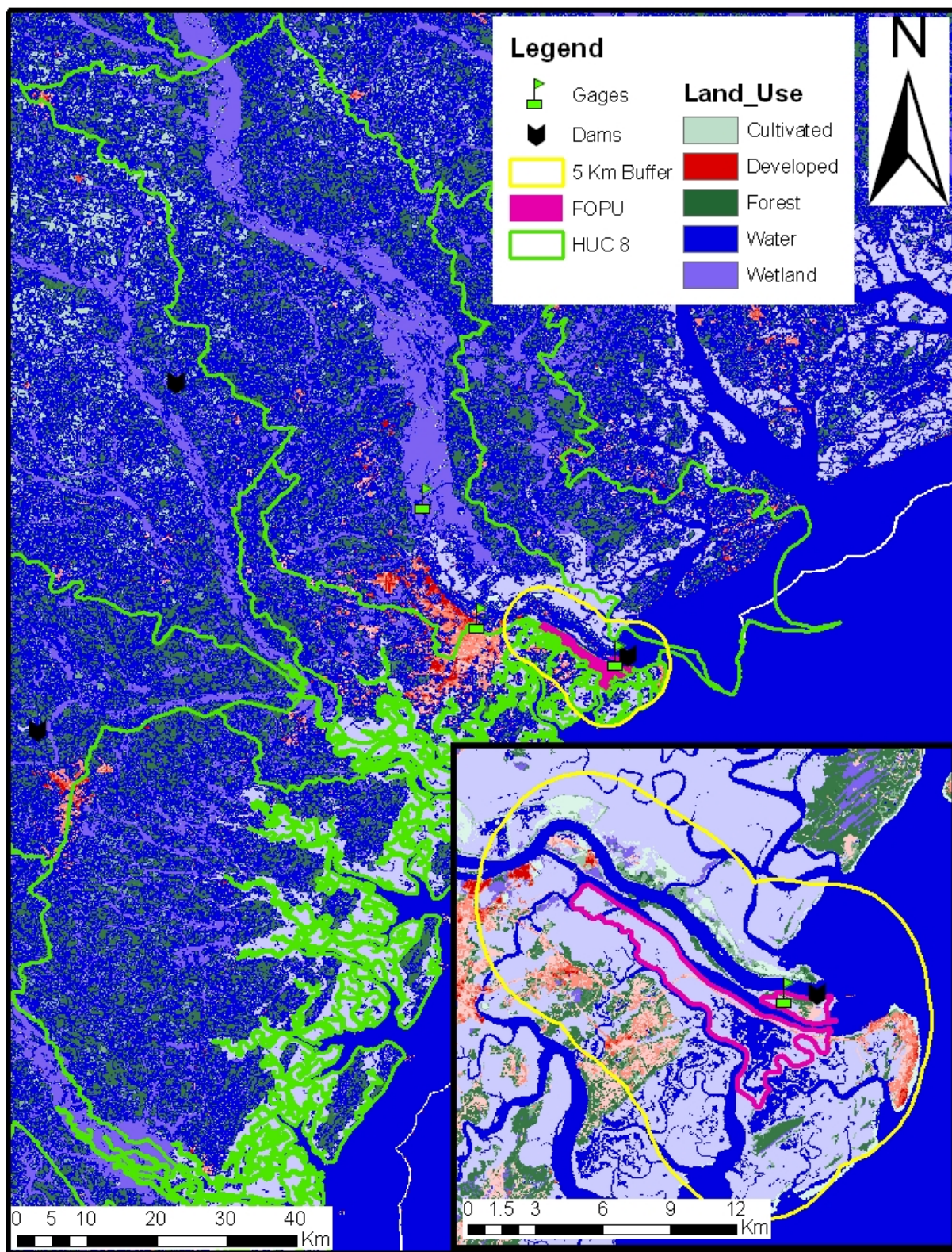


**Figure 23.** Land cover and watershed map for Fort Pulaski National Monument (FOPU).

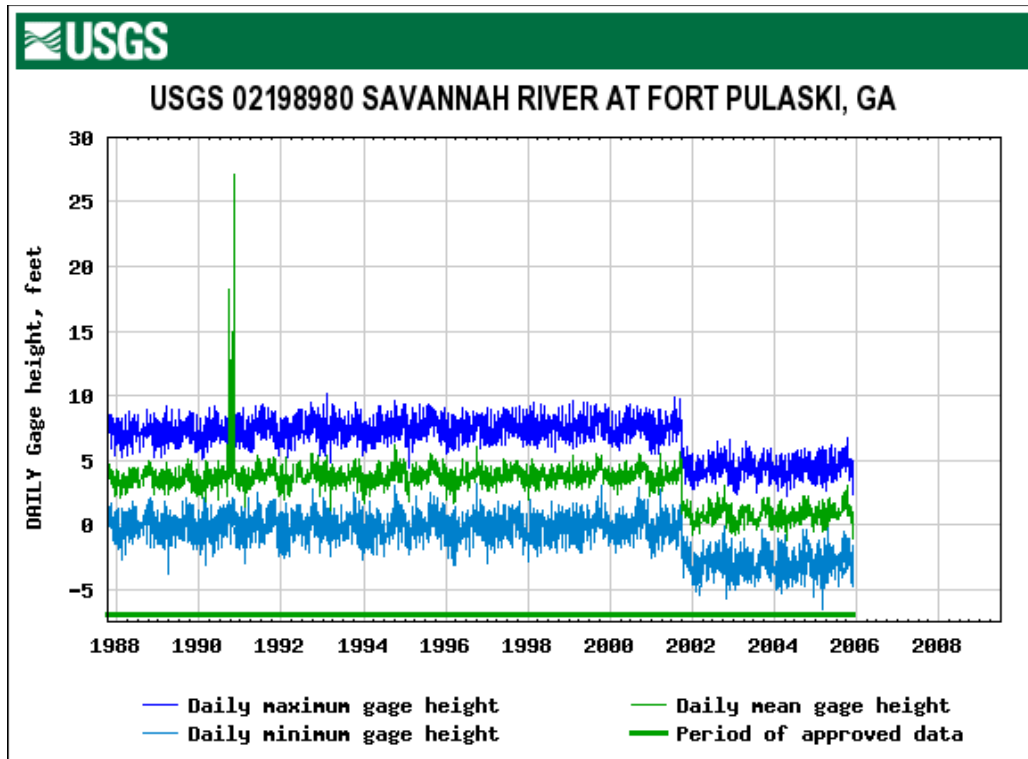


**Figure 24.** USGS gage 02198980. Gage height on the Savannah River at Fort Pulaski, GA. Spike in the early 1990s appears to be an unexplained data anomaly, as is the downward shift in height in 2001.

### FOSU: Fort Sumter National Monument

Fort Sumter National Monument is comprised mainly of developed land cover types that make up over 50% of the land area within the park (Figure 25; Table 9). Within a 5-km buffer surrounding FOSU, herbaceous wetlands dominate the landscape, followed by various intensities of development. At the watershed level, however, woody wetlands and evergreen forests are the primary land cover types and comprise over 50% of the area (Table 9).

There are eight USGS gaging stations near Fort Sumter, but only four are currently active (Table 3). USGS 02172100 was located on Fort Sumter and contains historical data for gage height from 1992 – 2005 (Figure 26). Nearby, USGS 021720711 (Figure 27) located on the Cooper River at Customs house at Charleston, SC, contains maximum and minimum gage height data beginning in August 1984 and is still currently active. However, much of the historical data from the Cooper River gage is still provisional.

For USGS 02172100 located on Fort Sumter, maximum and minimum gage heights were reported between 14 – 16 ft and approximately 6 – 10 ft respectively. However, this record is very brief, running for a short time during the 1990s and again from late 2004 – 2005, with large gaps in the data between the two time periods. However, when you compare the gage height at Fort Sumter to nearby USGS 021720711 (Figure 27), it reports a minimum gage height that is nearly equivalent to the maximum gage height ever reported at Fort Sumter. This indicates that although there is monitoring being conducted nearby, the tidal behavior at each location appears to affect each site differently. Further monitoring is probably required to determine how each

gage reflects the water height at the other location. Once this is accomplished, it can be determined if long-term monitoring is necessary. Additionally, like other coastal parks within the SECN, vulnerability to storm surge and sea level rise (see Appendix C) warrants the collection of accurate, long-term data.

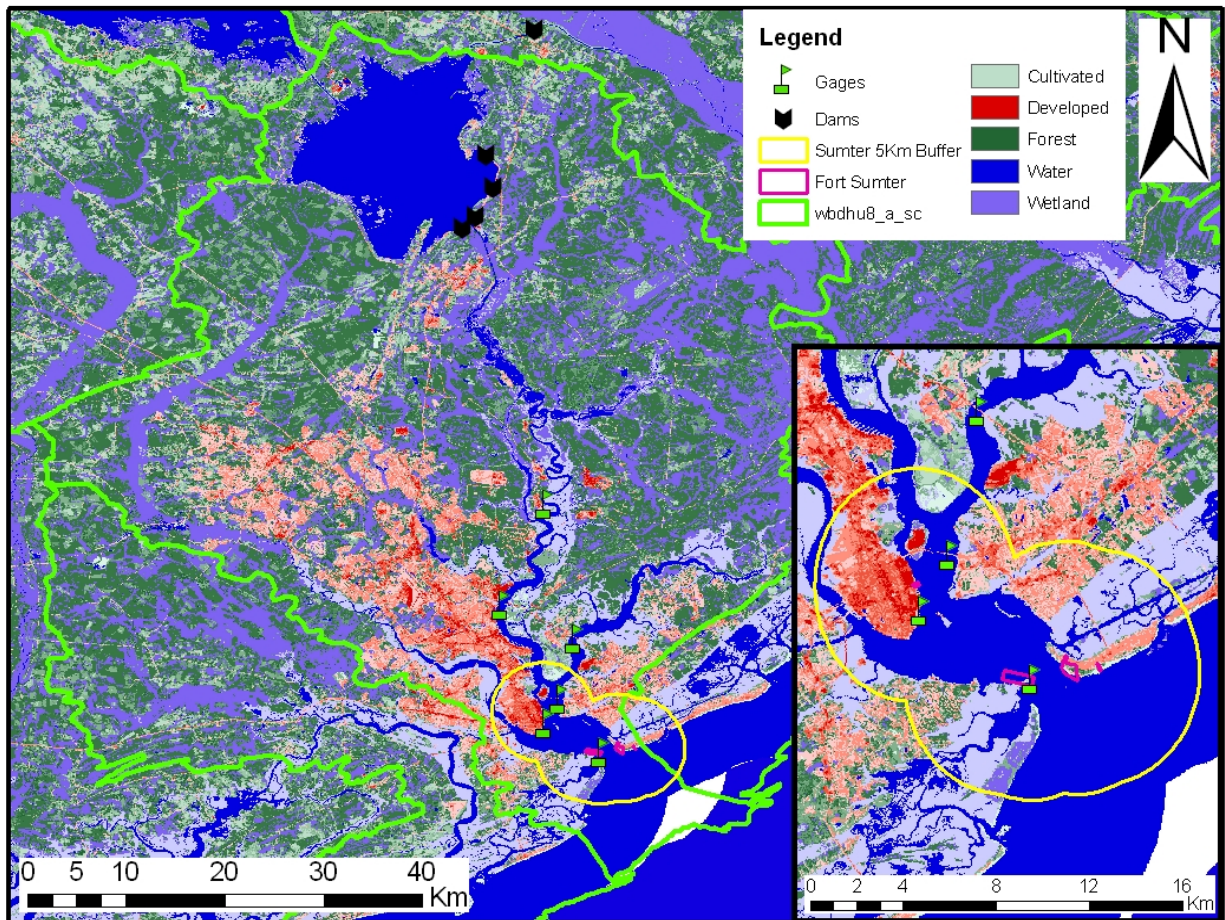


**Figure 25.** Land cover and watershed map for Fort Sumter National Monument (FOSU).

**Table 10.** Fort Sumter National Monument (FOSU) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 2.00        | 2.63    | 4146.33     | 17.25   | 104413.71       | 13.02   |
| Developed Open Space        | 16.90       | 22.22   | 2543.53     | 10.58   | 47533.78        | 5.93    |
| Developed Low Intensity     | 21.13       | 27.78   | 3569.66     | 14.85   | 38415.15        | 4.79    |
| Developed Medium Intensity  | 1.78        | 2.34    | 1960.86     | 8.16    | 12826.40        | 1.60    |
| Developed High Intensity    | 0.00        | 0.00    | 826.64      | 3.44    | 5240.51         | 0.65    |
| Barren Land                 | 2.45        | 3.22    | 362.06      | 1.51    | 1581.23         | 0.20    |
| Deciduous Forest            | 2.67        | 3.51    | 104.75      | 0.44    | 21957.04        | 2.74    |
| Evergreen Forest            | 6.67        | 8.77    | 877.79      | 3.65    | 205565.11       | 25.63   |
| Mixed Forest                | 18.24       | 23.98   | 42.92       | 0.18    | 16130.52        | 2.01    |
| Shrub/Scrub                 | 0.00        | 0.00    | 279.77      | 1.16    | 28622.22        | 3.57    |
| Grassland/Herbaceous        | 0.89        | 1.17    | 977.87      | 4.07    | 37078.11        | 4.62    |
| Pasture/Hay                 | 0.00        | 0.00    | 114.09      | 0.47    | 25448.20        | 3.17    |
| Cultivated                  | 0.89        | 1.17    | 227.07      | 0.94    | 13270.75        | 1.65    |
| Woody Wetland               | 1.11        | 1.46    | 783.72      | 3.26    | 200190.05       | 24.96   |
| Emergent Herbaceous Wetland | 0.00        | 0.00    | 7224.50     | 30.05   | 43863.38        | 5.47    |

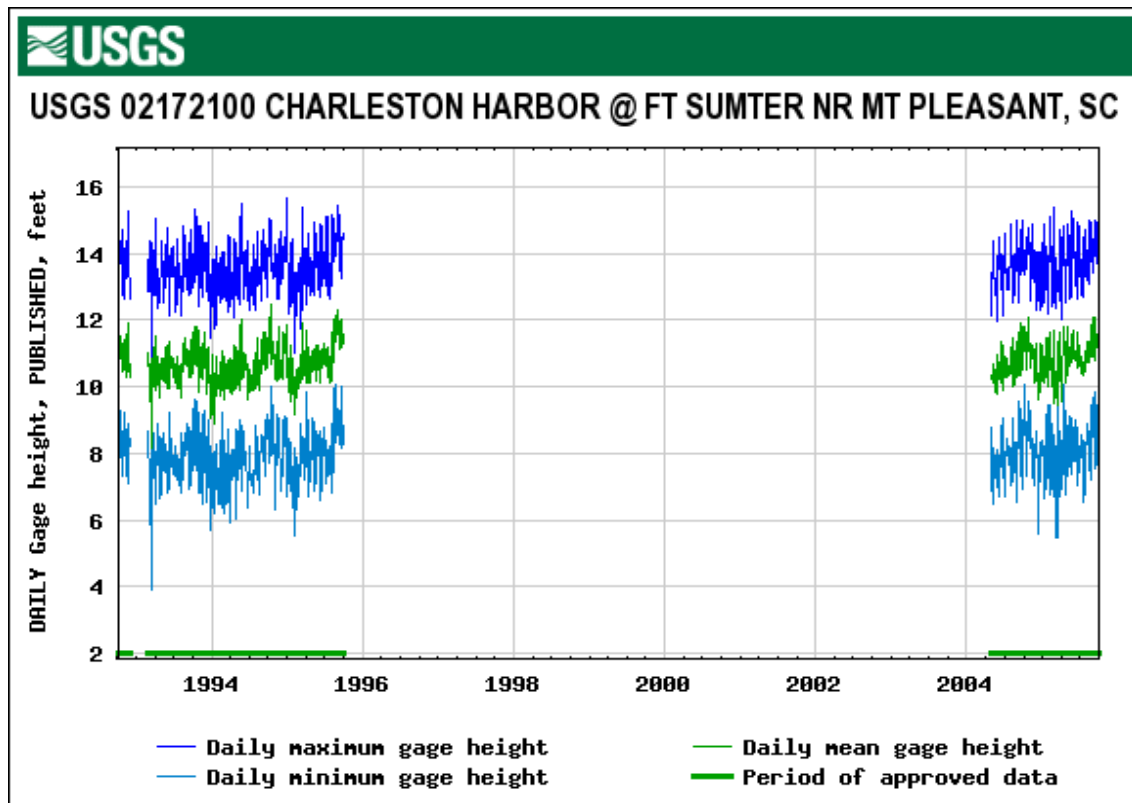


**Figure 26.** USGS 02172100 located at Fort Sumter near Mt. Pleasant, SC.

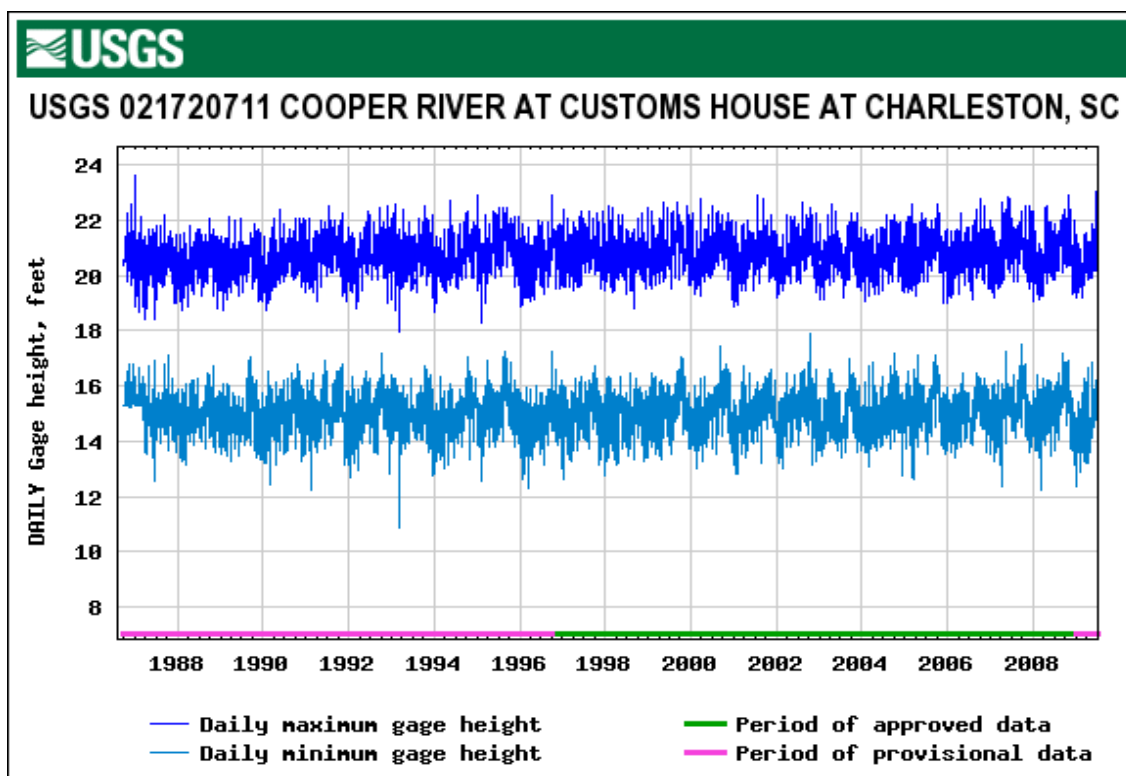


**Figure 27.** USGS 021720711 on the Cooper River at Customs House at Charleston, SC, near Fort Sumter.

## HOBE: Horseshoe Bend National Military Park

Land cover within Horseshoe Bend is primarily deciduous and evergreen forest and comprises approximately 85% of the landscape (Figure 28; Table 10). Within a 5-km buffer surrounding the park and at the watershed level, these same land cover types dominate, however, within the buffer more open space is developed (Table 10).

Two gages contain data relevant the surface water hydrology of Horseshoe bend (Table 3). USGS 02414715 is located at Horseshoe Bend and USGS 02414500 is located at Wadely, AL, on the Tallapoosa River. The gage located at Wadely, AL, contains historical data beginning in 1923 and is still being monitored at the time of writing (Table 3). USGS 02414715 located at Horseshoe Bend contains historical data beginning in 1985 and therefore contains no data prior to the construction of the R.L. Harris Dam.

The flow of the Tallapoosa River is primarily controlled from water released by the R.L. Harris Dam located below Lake Wedowee to the north and is controlled by the Alabama Power Company. Prior to the construction of the dam, the maximum discharge recorded at Wadely, AL, was approximately 67,000 cfs (Figure 29), but since its completion, a maximum discharge

exceeding 100,000 cfs was recorded only once in May, 2003 (Figure 30). The maximum discharge recorded at Horseshoe bend also exceeded 100,000 cfs that same month (Figure 31).

Since the USGS Gage at Wadely, AL, contained the longer time series for discharge data, pre- and post- dam data were analyzed at this location instead of at Horseshoe Bend. The Log Pearson III estimation of the return frequency for high-flow projects that a discharge event exceeding 100,000 cfs should have only occurred less than one time every 1000 years prior to the construction of the dam (Figure 32). After the construction of the dam, the Log Pearson III estimation for high-flow return frequency projects that a discharge event exceeding 100,000 cfs should occur at a similar rate, however the data do not fit distribution nearly as well and high-flow events such as those observed in 2003, may occur much more frequently than the model suggests (Figure 33), possibly as frequently as every 25 years.

The Log Pearson III estimation for the return frequency for seven-day low-flow projects that low flows below 100 cfs occurred every 40 – 50 years prior to the construction of the dam (Figure 34). However, after the construction of the R.L. Harris Dam, seven-day low flows falling below 100 cfs are projected to occur every 25 years (Figure 35). However, data for the seven-day low flow prior to dam construction (Figure 34) do not fit the distribution as well as data after the construction of the dam (Figure 35).

Monitoring efforts at Horseshoe Bend are adequate and there appears to be a large degree of similarity between events observed upstream of Horseshoe Bend at Wadely, AL. However, there are some discrepancies that are worth noting. For example, high-flow events occurring between 1987 and 1991 reached a maximum discharge of 60,000 cfs at Wadely, AL, but approached 80,000 cfs at Horseshoe Bend. This pattern is seen for other high-flow events along the Tallapoosa and underscores the importance of maintaining a long-term gage at Horseshoe Bend since the amount of the land area drained at HOBE is substantially higher than upstream near Wadely, AL.

Flow duration curves indicate that prior to dam construction there was a less than 1% probability that the average daily flow would exceed 40,000 cfs and that there was a greater than 50% probability that the average daily flow would be less than 5,000 cfs (Figure 36). After the construction of the dam there was a less than 1% probability that the average daily flow would exceed 20,000 cfs and a greater than 50% probability that the average daily flow would be less than 5,000 cfs (Figure 37). As mentioned earlier however, the high-flow event observed in 2003 may indicate that these types of events occur at higher probabilities than indicated since the data fall outside of the distribution (Figure 38).

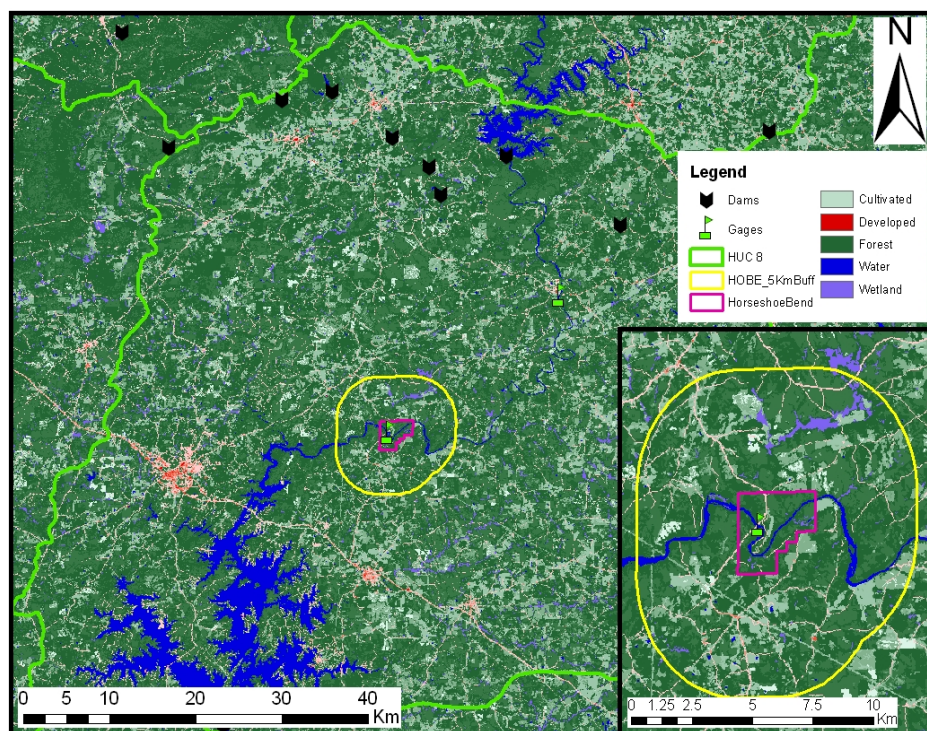


**Figure 28.** Land cover and watershed map for Horseshoe Bend National Military Park (HOBE).

**Table 11.** Horseshoe Bend National Military Park (HOBE) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

| Land Use/Land Cover         | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 134.77      | 6.59    | 675.19      | 2.10    | 60469.38        | 3.15    |
| Developed Open Space        | 82.95       | 4.06    | 1148.67     | 3.57    | 87220.59        | 4.54    |
| Developed Low Intensity     | 0.00        | 0.00    | 40.92       | 0.13    | 22266.62        | 1.16    |
| Developed Medium Intensity  | 0.00        | 0.00    | 6.23        | 0.02    | 4532.18         | 0.24    |
| Developed High Intensity    | 0.00        | 0.00    | 0.00        | 0.00    | 1612.81         | 0.08    |
| Barren Land                 | 0.00        | 0.00    | 432.34      | 1.34    | 20020.87        | 1.04    |
| Deciduous Forest            | 1072.17     | 52.41   | 13269.41    | 41.27   | 707828.97       | 36.87   |
| Evergreen Forest            | 657.84      | 32.16   | 10157.44    | 31.59   | 504559.64       | 26.28   |
| Mixed Forest                | 14.46       | 0.71    | 161.68      | 0.50    | 13041.90        | 0.68    |
| Shrub/Scrub                 | 0.00        | 0.00    | 349.83      | 1.09    | 43206.87        | 2.25    |
| Grassland/Herbaceous        | 16.90       | 0.83    | 3033.02     | 9.43    | 152030.00       | 7.92    |
| Pasture/Hay                 | 31.80       | 1.55    | 2259.98     | 7.03    | 272338.50       | 14.19   |
| Cultivated                  | 0.00        | 0.00    | 0.00        | 0.00    | 413.21          | 0.02    |
| Woody Wetland               | 34.69       | 1.70    | 620.26      | 1.93    | 30330.65        | 1.58    |
| Emergent Herbaceous Wetland | 0.00        | 0.00    | 0.00        | 0.00    | 8.23            | 0.00    |

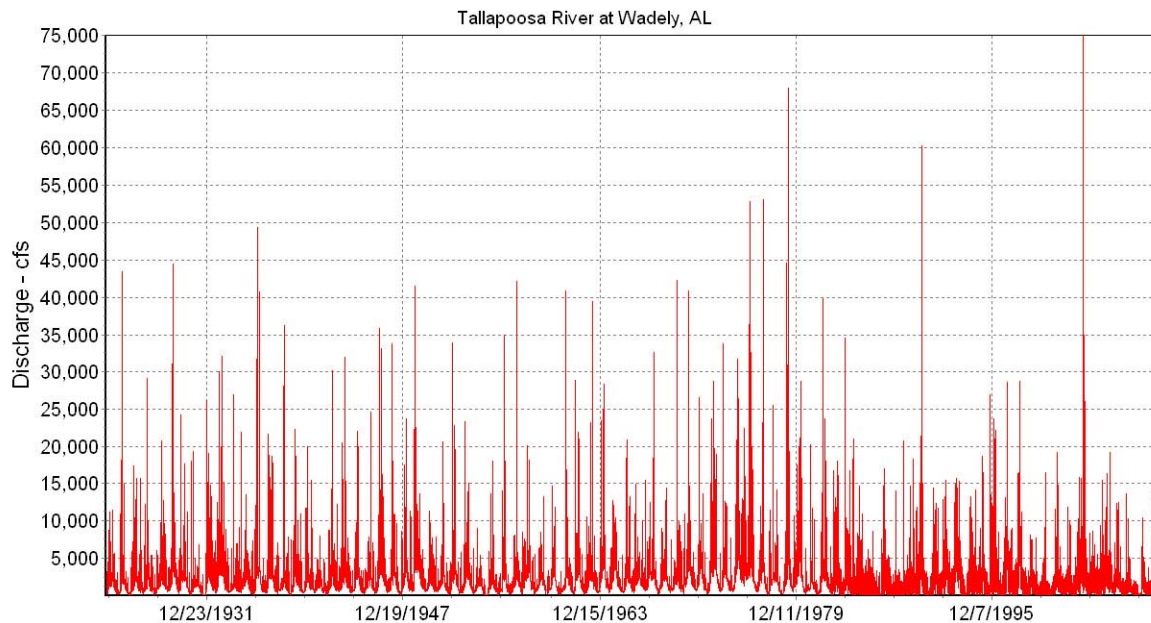


**Figure 29.** USGS 02414500. Average daily flow for the Tallapoosa River at Wadely, AL.

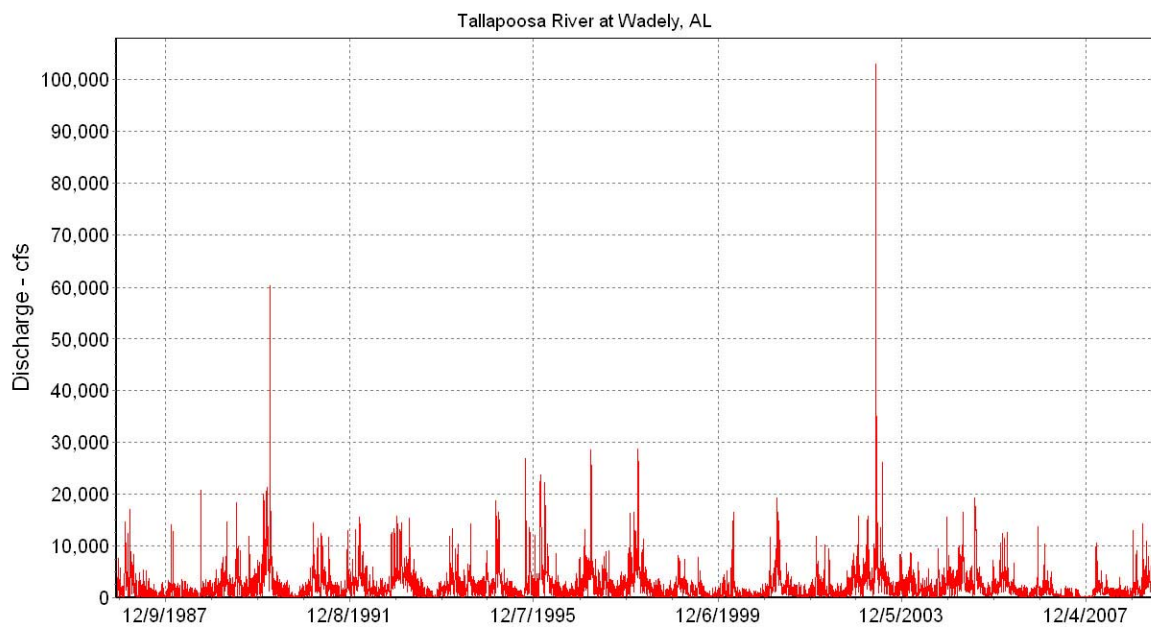


**Figure 30.** USGS 02414500. Average daily flow for the Tallapoosa River at Wadely, AL, after the construction of the R.L. Harris Dam.

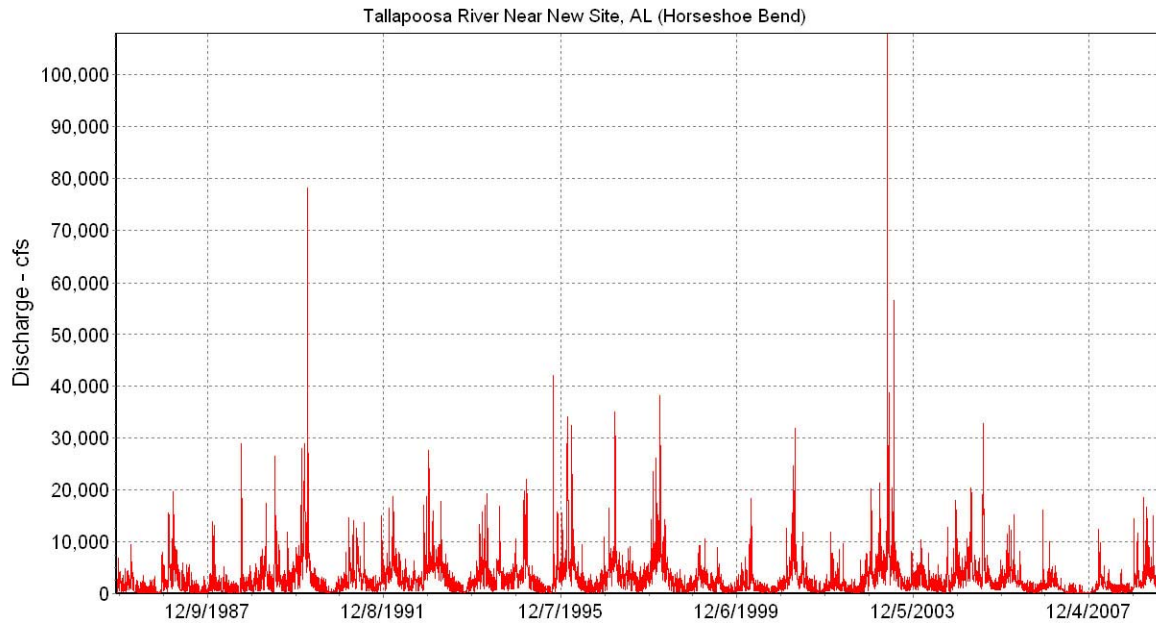


**Figure 31.** USGS 2414715. Average daily flow for the Tallapoosa River near New Site, AL, (Horseshoe Bend).

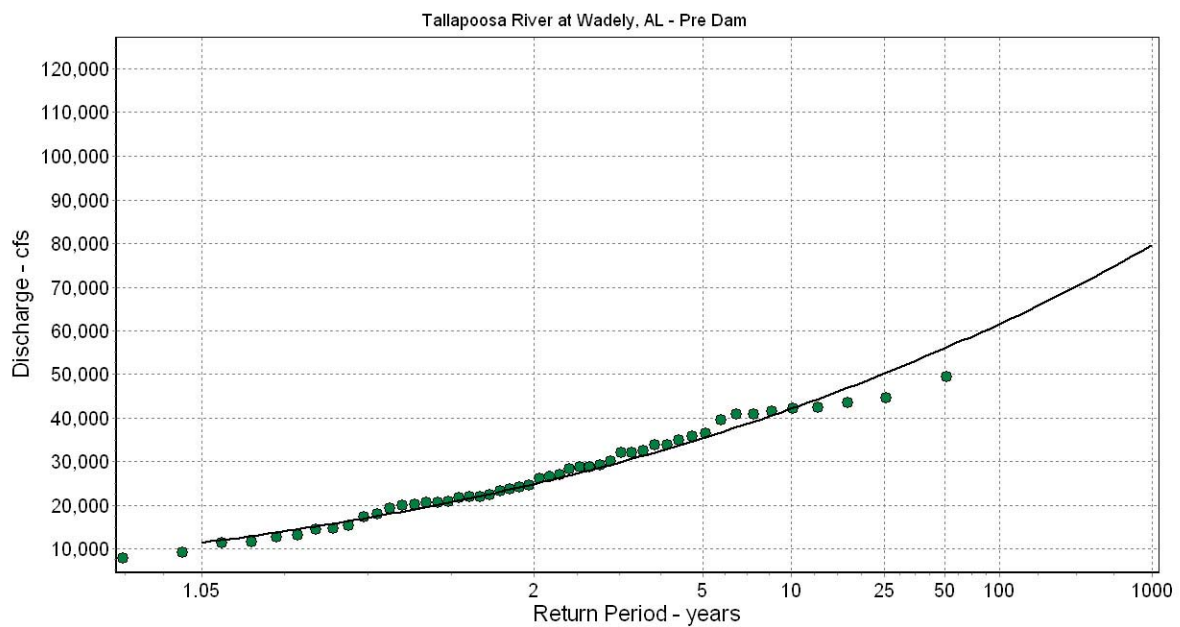


**Figure 32.** USGS 02414500. Log Pearson III graph of the high-flow return frequency for the Tallapoosa River at Wadely, AL, prior to the construction of R.L. Harris Dam.

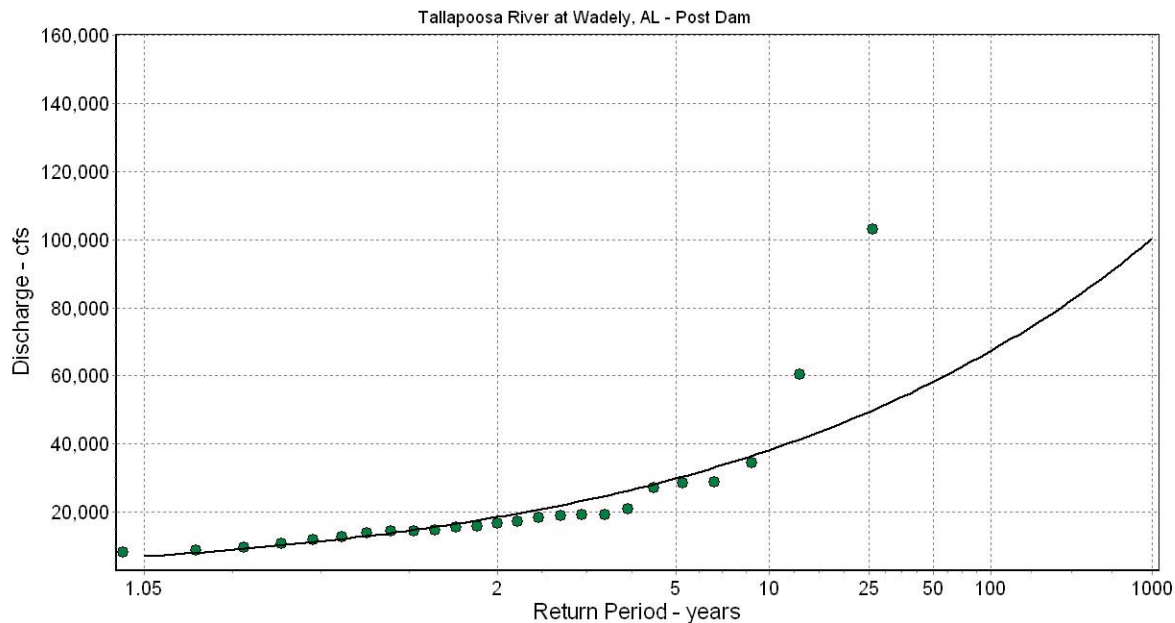


**Figure 33.** USGS 02414500. Log Pearson III graph of the high-flow return frequency for the Tallapoosa River at Wadely, AL, after the construction of R.L. Harris Dam.

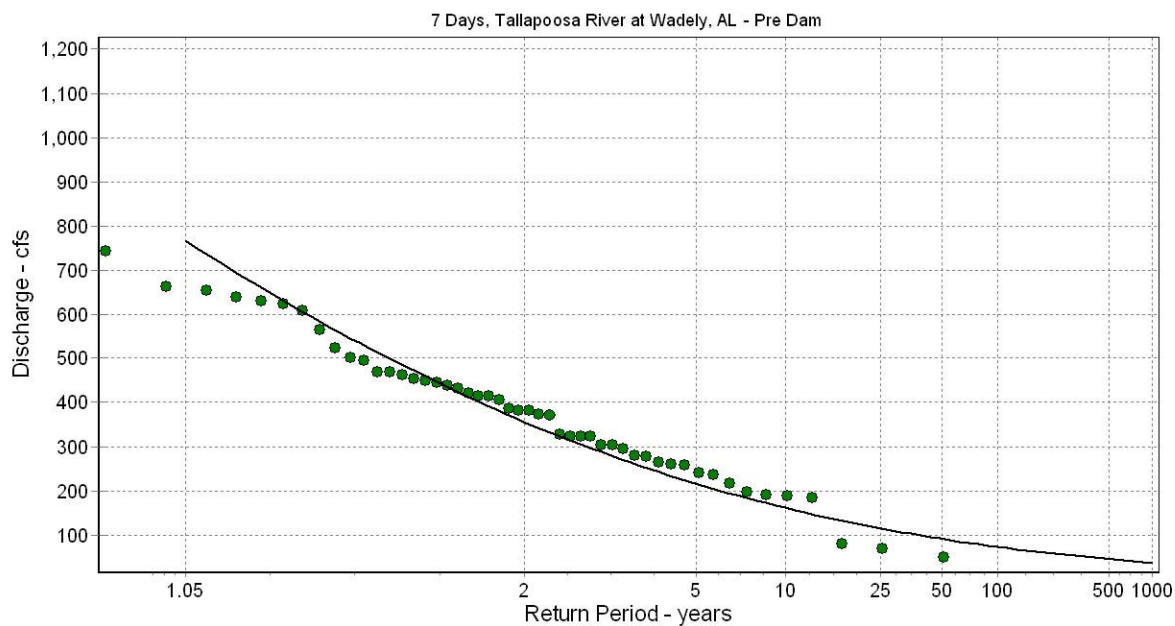


**Figure 34.** USGS 02414500. Log Pearson III graph of the seven-day low-flow return frequency for the Tallapoosa River at Wadely, AL, prior to the construction of R.L. Harris Dam.

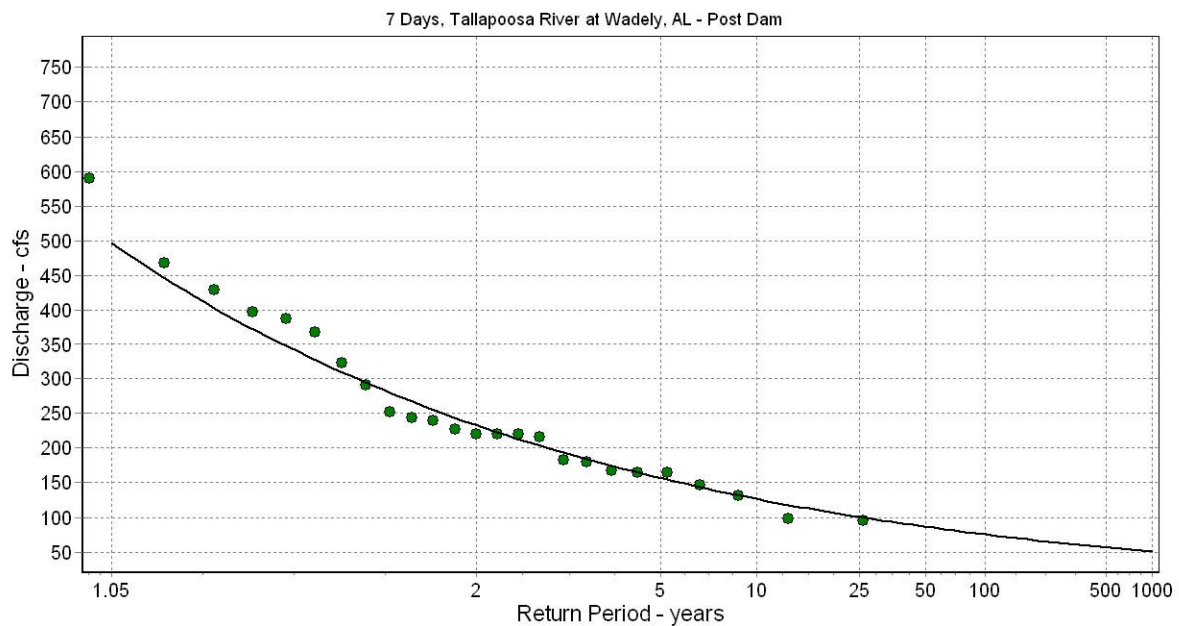


**Figure 35.** USGS 02414500. Log Pearson III graph of the seven-day low-flow return frequency for the Tallapoosa River at Wadely, AL, after the construction of R.L. Harris Dam.

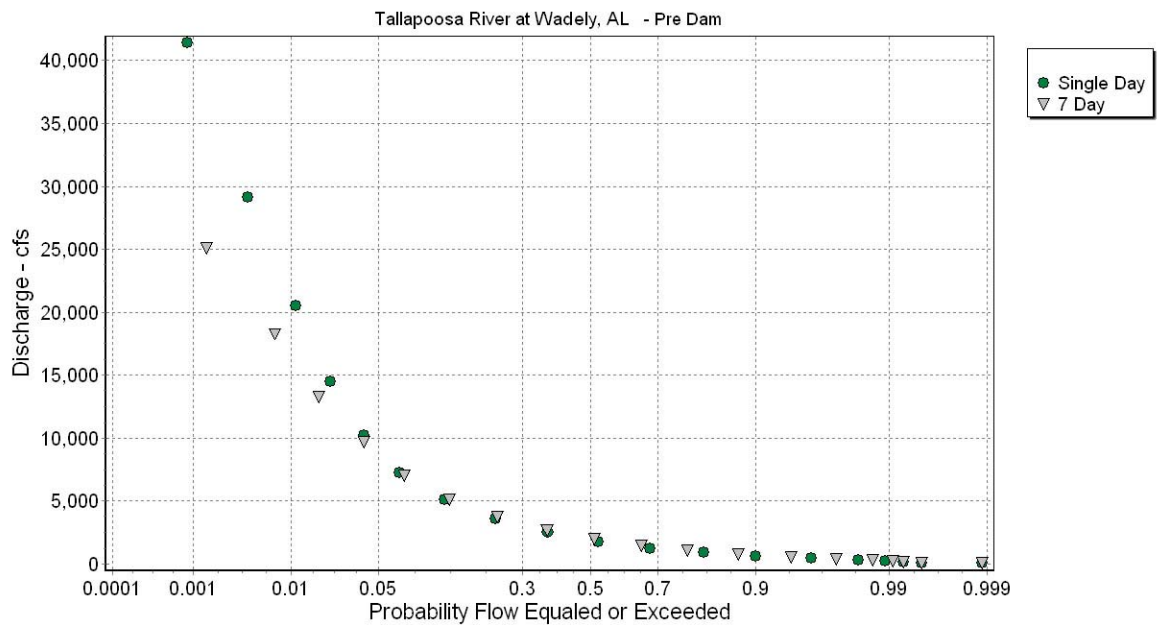


**Figure 36.** USGS 02414500. Flow duration curves for seven-day (triangles) and single day (dots) flow duration for the Tallapoosa River at Wadely, AL, prior to the construction of R.L. Harris Dam.

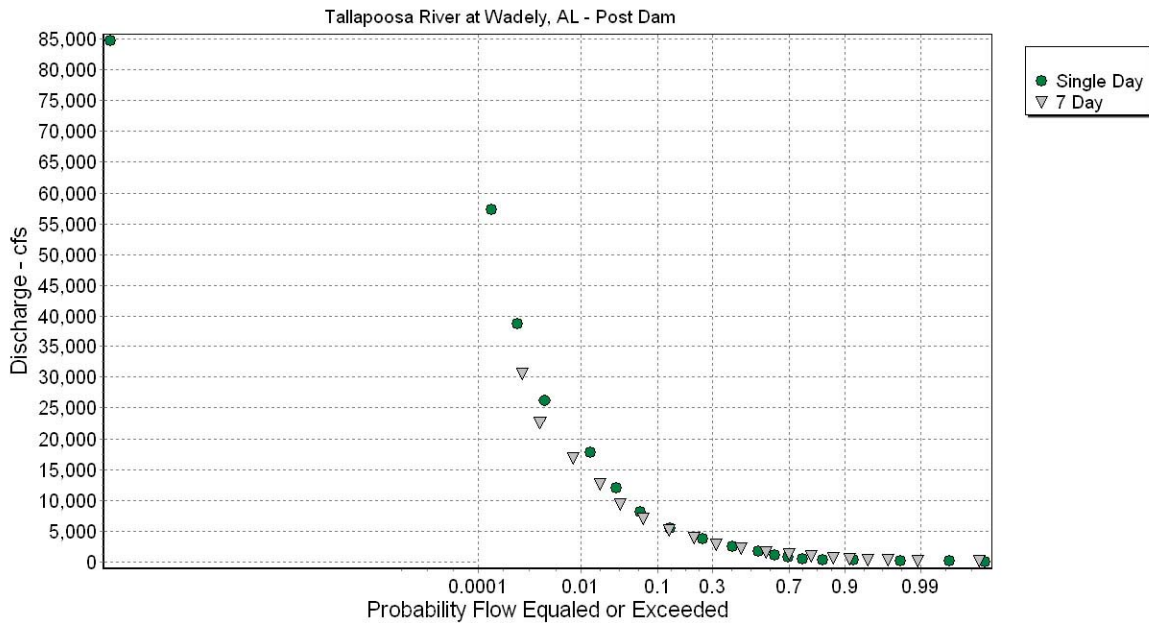


**Figure 37.** USGS 02414500. Flow duration curves for seven-day (triangles) and single day (dots) flow duration for the Tallapoosa River at Wadely, AL, after the construction of R.L. Harris dam. In 2003, a large flood event increased the single day average to approximately 85,000 cfs, the highest on record.

### KEMO: Kennesaw Mountain National Battlefield Park

Land cover within Kennesaw Mountain NBP is primarily deciduous and evergreen forest and less than 1% is classified as open water (Figure 38; Table 11). Within a 5-km buffer surrounding the park, over 60% of the area is developed. At the watershed level, deciduous and evergreen forests dominate, although in slightly smaller proportions to those within the park (Table 11).

The nearest USGS gage with discharge data (02336968) relevant to KEMO is located in Powder Springs, GA, on Noses Creek and contains current and historical data going back to 1998. An additional gage, USGS 02393377, is located on Butler Creek at Mack Dobbs near Kennesaw, GA, however it only contains data relevant to gage height and began recording data in 2007. Therefore, to project high-flow frequency and low-flow frequency, the Powder Springs gage data were analyzed.

The maximum flow recorded on Noses Creek at Powder Springs occurred in 2004 and exceeded 2,800 cfs (Figure 39). Examining the Log Pearson III projections based on the short term data and adjusted using the regional skew coefficient, a flow of this magnitude should occur, on average every 100 years (Figure 40). That is, there is a 1% chance that this type of event will happen in any given year. However, the amount of data available is limited, so this estimate should be interpreted with caution. Gage height data indicated that the flow observed on Noses Creek in 2004 corresponded to a gage height of nearly 16 ft. Minor flood stage level for Noses Creek is 11 ft.

The lowest flow recorded on Noses Creek was < 1 cfs and has occurred multiple times since record keeping began. Log Pearson III projections indicate that this type of event could occur every 4–5 years and is a common event in this stream (Figure 41).

The flow duration curves for single and seven-day average flows indicate that the probability of average daily and seven-day flows will exceeding 800 cfs is less than 1% (Figure 42) and there is only a 5% chance that it will exceed 200 cfs. However, since multiple creeks, other than just Noses Creek, flow through KEMO more monitoring is advised since the surrounding metropolitan landcover likely increases the flash flooding potential especially as the level of development increases and encroaches on the park.

**Table 12.** Kennesaw Mountain National Battlefield Park (KEMO) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 1.56        | 0.05    | 379.63      | 0.87    | 77282.21        | 2.44    |
| Developed Open Space        | 198.82      | 6.84    | 10329.57    | 23.73   | 263516.09       | 8.32    |
| Developed Low Intensity     | 15.35       | 0.53    | 10159.22    | 23.34   | 134372.97       | 4.24    |
| Developed Medium Intensity  | 0.89        | 0.03    | 3188.92     | 7.33    | 29727.74        | 0.94    |
| Developed High Intensity    | 0.22        | 0.01    | 1916.38     | 4.40    | 14614.23        | 0.46    |
| Barren Land                 | 0.89        | 0.03    | 404.54      | 0.93    | 22762.78        | 0.72    |
| Deciduous Forest            | 1388.63     | 47.77   | 6696.31     | 15.38   | 1116497.28      | 35.26   |
| Evergreen Forest            | 1072.83     | 36.91   | 6979.19     | 16.03   | 737785.55       | 23.30   |
| Mixed Forest                | 25.80       | 0.89    | 235.96      | 0.54    | 69057.38        | 2.18    |
| Shrub/Scrub                 | 161.46      | 5.55    | 59.16       | 0.14    | 58009.03        | 1.83    |
| Grassland/Herbaceous        | 0.00        | 0.00    | 512.40      | 1.18    | 168338.00       | 5.32    |
| Pasture/Hay                 | 161.46      | 5.55    | 2045.37     | 4.70    | 386901.87       | 12.22   |
| Cultivated                  | 0.00        | 0.00    | 0.00        | 0.00    | 16159.21        | 0.51    |
| Woody Wetland               | 23.13       | 0.80    | 619.81      | 1.42    | 71755.25        | 2.27    |
| Emergent Herbaceous Wetland | 0.00        | 0.00    | 0.00        | 0.00    | 38.70           | 0.00    |

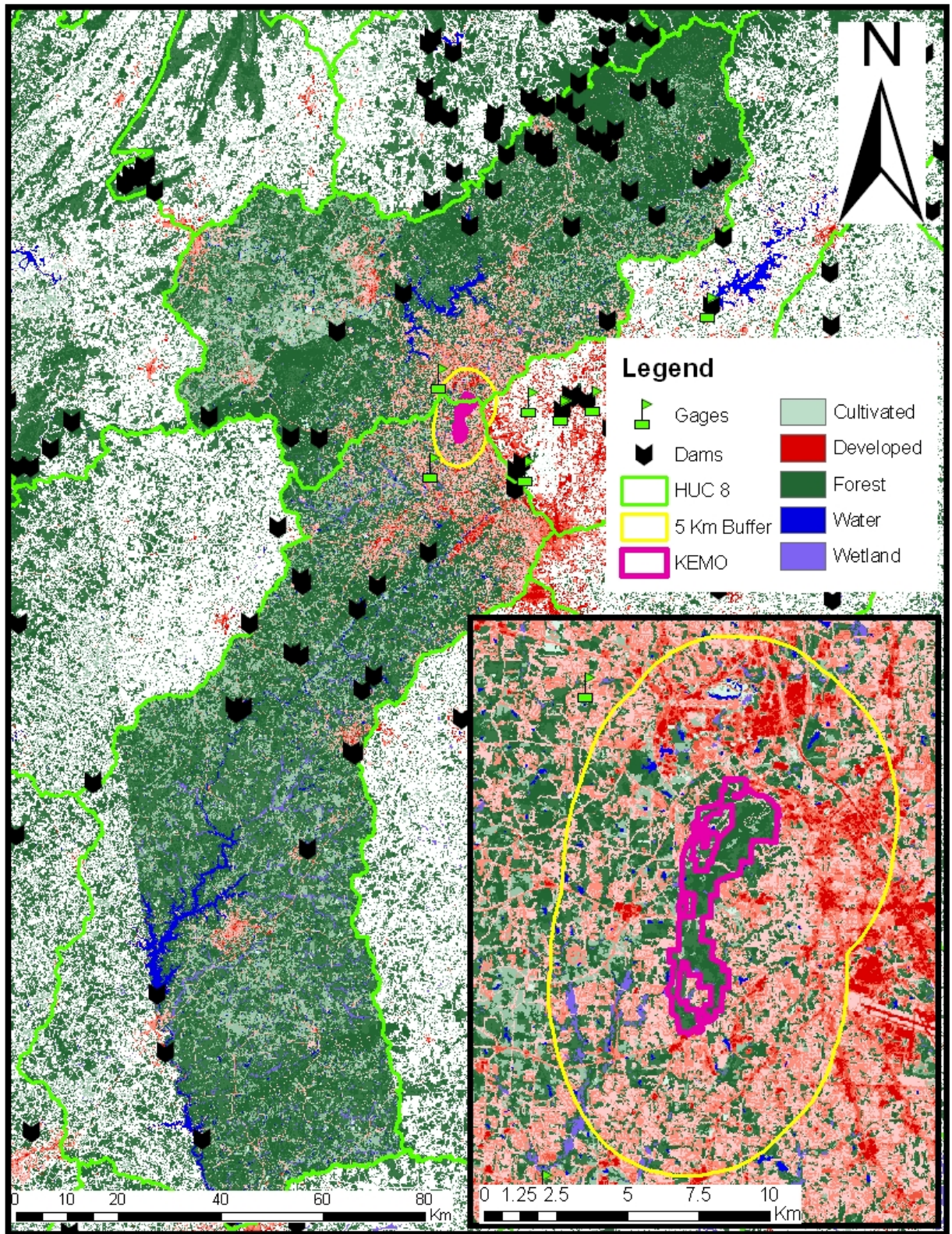


**Figure 38.** Land cover and watershed map for Kennesaw Mountain National Battlefield Park (KEMO).

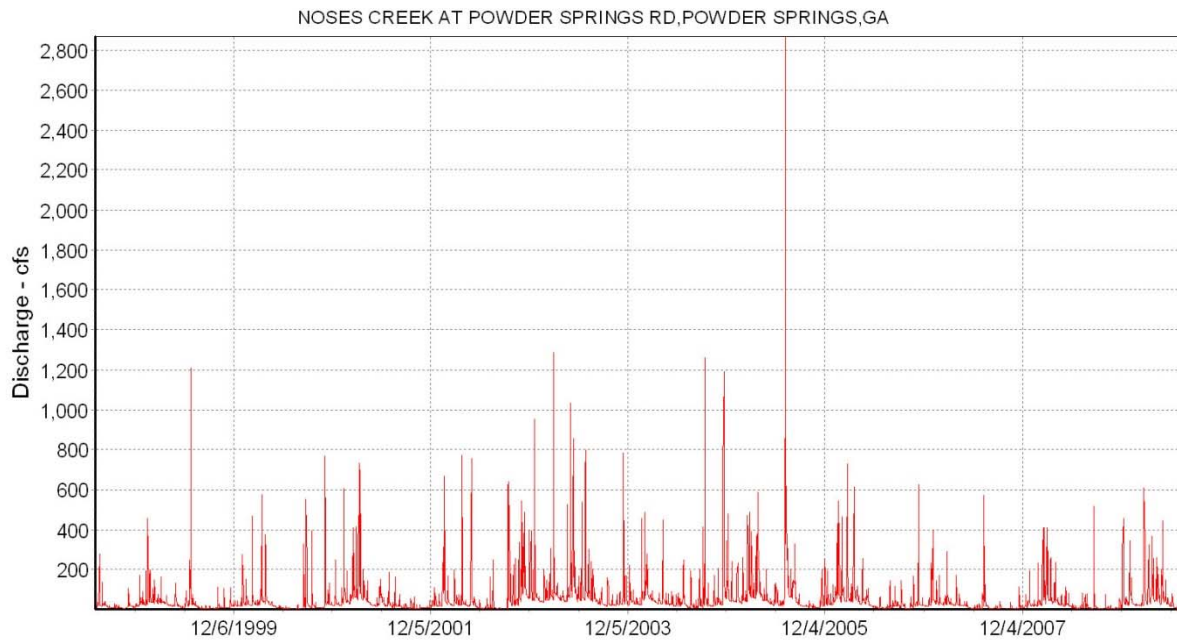


**Figure 39.** USGS 02336968 on Noses Creek at Powder Springs Road in Powder Springs, GA, south of Kennesaw Mountain National Battlefield Park.

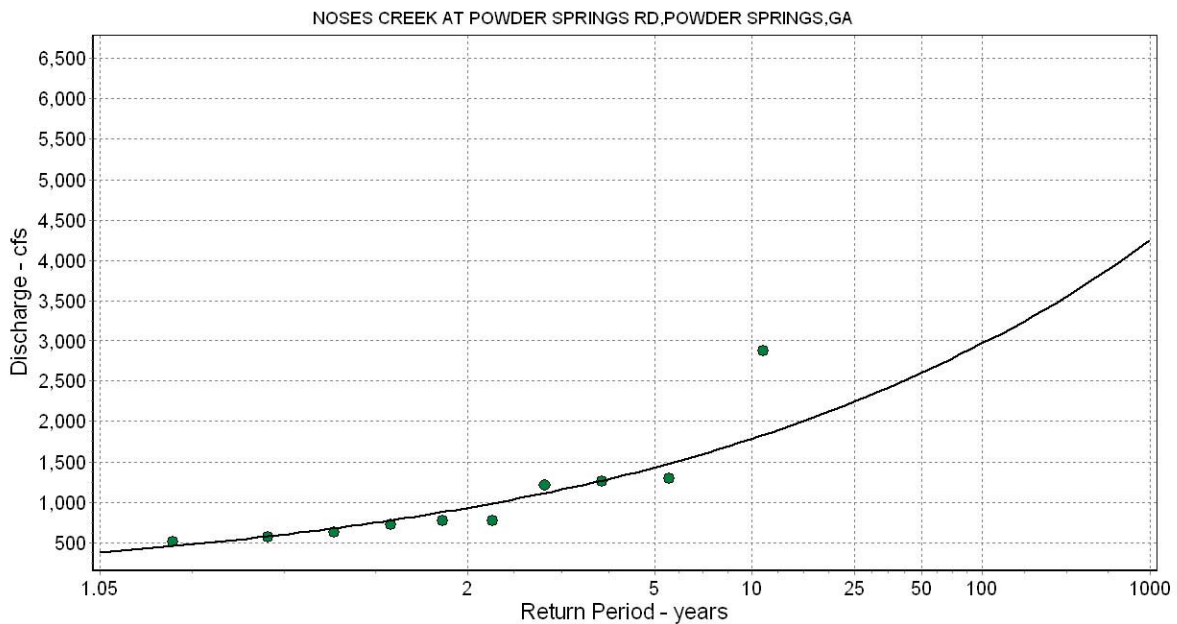


**Figure 40.** USGS 02336968. Log Pearson III for high-flow events on Noses Creek at Powder Springs Road in Powder Springs, GA, south of Kennesaw Mountain National Battlefield Park.

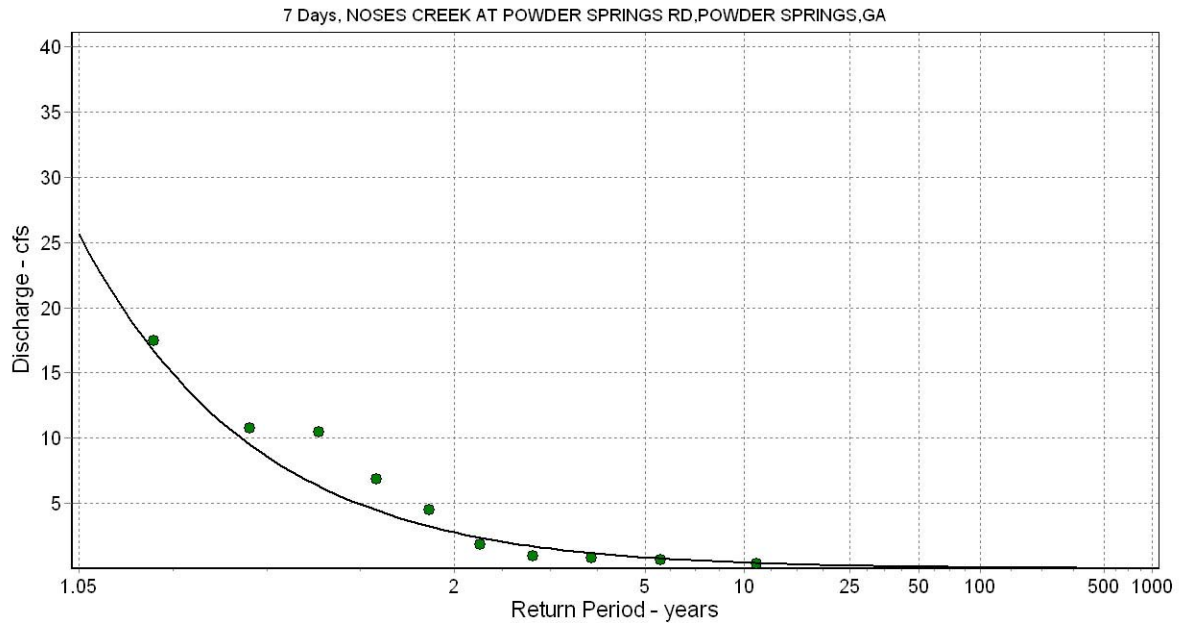


**Figure 41.** USGS 02336968. Log Pearson III for low-flow events on Noses Creek at Powder Springs Road in Powder Springs, GA, south of Kennesaw Mountain National Battlefield Park.

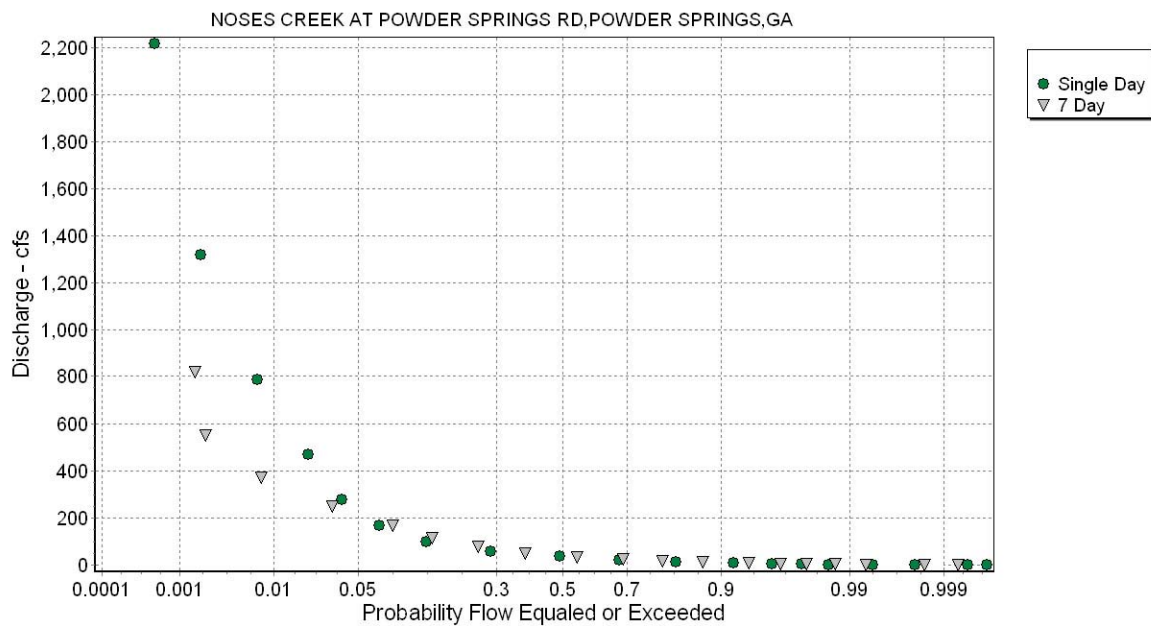


**Figure 42.** USGS 02336968. Flow duration curves for 7-day (triangles) and single day (dots) flow duration for Noses Creek at Powder Springs Road in Powder Springs, GA, south of Kennesaw Mountain National Battlefield Park.

**MOCR: Moores Creek National Battlefield**

Within Moores Creek National Battlefield, woody wetlands are the dominant land cover class and makes up 28% of the land area. However, the majority of landscape is made up of the two land cover classes of deciduous and evergreen forest (Figure 43; Table 12). Within a 5-km buffer surrounding MOCR, woody wetlands and evergreen forests dominate. At the watershed level, however, over 28% of the landscape is cultivated, with the remaining majority comprised primarily of woody wetlands and evergreen forest (Table 12).

No USGS gages are located within Moores Creek National Battlefield. However, 3 gages are located on nearby rivers including USGS 02105769 on the Cape Fear River at Lock #1 near Kelly, NC; USGS 0217544 on the Black River near Currie, NC; and USGS 02108566 on the Northeast Cape Fear River near Burgaw, NC. However, it is unlikely that these gages accurately reflect the behavior of Moores Creek.

The only flow data available are from Mallin and McIver (2007) and were collected between 3/21/96 and 6/14/96 (see literature review). The following is information summarized from this report. The maximum surface water elevation ranges from 12 ft above mean sea level for a two-year frequency storm, to 32 ft for a 100-year storm (USACOE 2000). Maximum stream discharge ranges from 1,150 cfs for a two-year storm up to 5,940 cfs for the 100-year storm (USACOE 2000). Several tropical systems have affected Moores Creek including flooding from Hurricanes Fran (1996), Bonnie (1998), and Floyd (1999).

Because the creek (Moores Creek) within MOCR is prone to frequent flooding and no long-term data are available, it is recommended that a long-term monitoring system be employed.

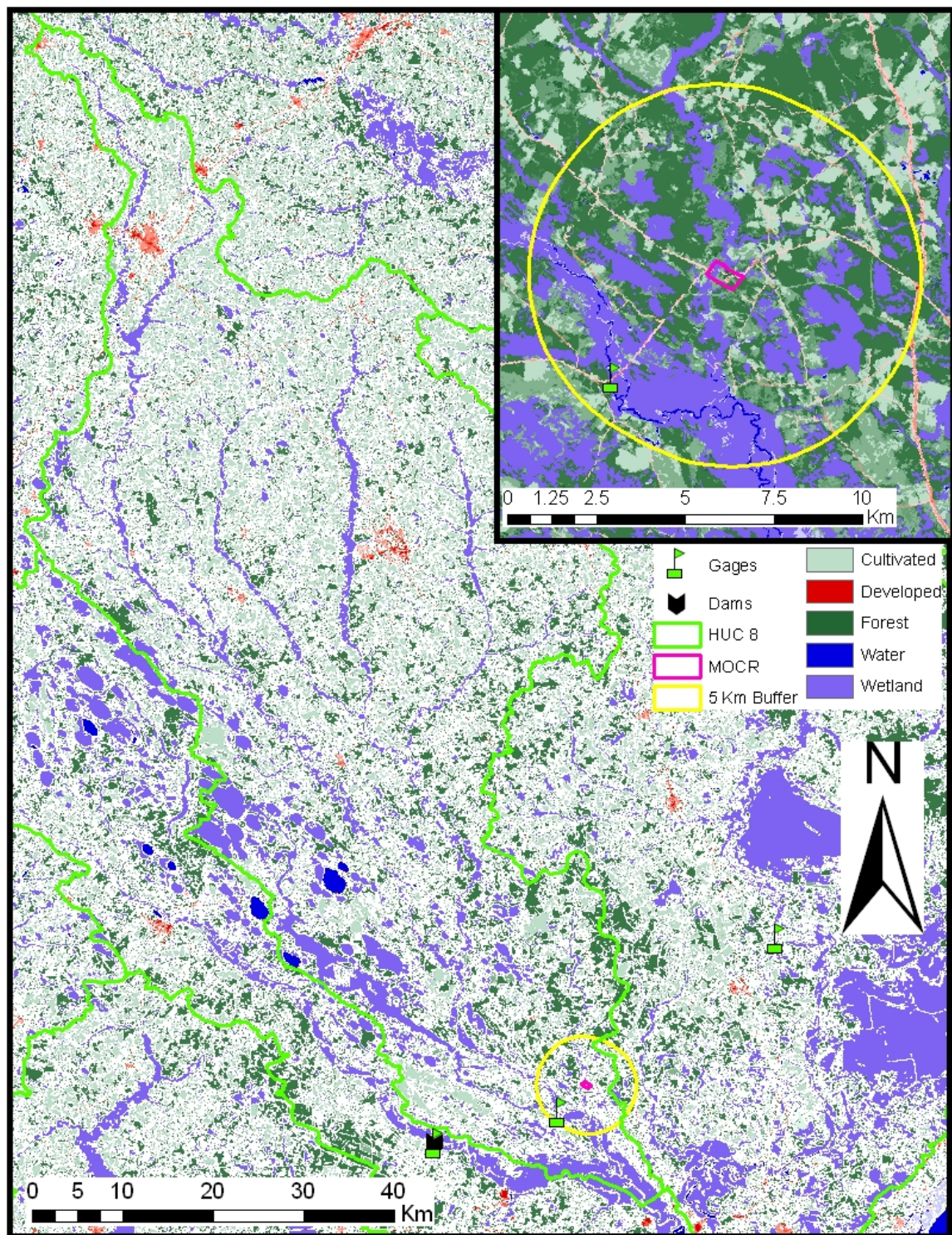


**Figure 43.** Land cover and watershed map for Moores Creek National Battlefield (MOCR).

**Table 13.** Moores Creek National Battlefield (MOCR) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 0.00        | 0.00    | 182.14      | 0.80    | 5421.99         | 0.54    |
| Developed Open Space        | 13.57       | 13.65   | 684.75      | 3.01    | 41186.19        | 4.09    |
| Developed Low Intensity     | 2.00        | 2.01    | 101.63      | 0.45    | 11713.76        | 1.16    |
| Developed Medium Intensity  | 0.00        | 0.00    | 0.67        | 0.00    | 2101.63         | 0.21    |
| Developed High Intensity    | 0.00        | 0.00    | 0.89        | 0.00    | 472.14          | 0.05    |
| Barren Land                 | 0.00        | 0.00    | 0.00        | 0.00    | 448.35          | 0.04    |
| Deciduous Forest            | 6.00        | 6.04    | 280.00      | 1.23    | 30191.43        | 3.00    |
| Evergreen Forest            | 23.57       | 23.71   | 7084.39     | 31.13   | 185947.00       | 18.45   |
| Mixed Forest                | 20.24       | 20.36   | 644.06      | 2.83    | 47928.09        | 4.76    |
| Shrub/Scrub                 | 0.00        | 0.00    | 1558.10     | 6.85    | 53969.22        | 5.35    |
| Grassland/Herbaceous        | 0.89        | 0.89    | 2792.83     | 12.27   | 108765.76       | 10.79   |
| Pasture/Hay                 | 0.00        | 0.00    | 73.61       | 0.32    | 13849.86        | 1.37    |
| Cultivated                  | 0.89        | 0.89    | 2082.51     | 9.15    | 290619.80       | 28.83   |
| Woody Wetland               | 27.80       | 27.96   | 7025.23     | 30.87   | 208074.62       | 20.64   |
| Emergent Herbaceous Wetland | 0.00        | 0.00    | 248.86      | 1.09    | 7260.52         | 0.72    |

### OCMU: Ocmulgee National Monument

Within the Ocmulgee National Monument, woody wetlands and deciduous forests make up nearly 50% of all land cover classes (Figure 44; Table 13). Within the 5-km buffer surrounding OCMU, over 35% of the area is classified as developed, 15% is woody wetlands, and 25% is forested. At the HUC 8 watershed level, 20% is developed and approximately 50% is forested (Table 13).

No USGS gages have been located within Ocmulgee National Monument. The nearest gage station with relevant data for the Ocmulgee River is located at Macon, GA (USGS 02213000). It contains historical data from 1893 – present (Table 3). Other nearby gages include USGS 02213050 located on Walnut Creek, near Gray, GA, which runs through OCMU and , and has historical data from 1961 – 1994. Additionally, USGS 02210500 on the Ocmulgee River near Jackson, GA, contains historical data from 1906 – present. However, this gage is located much farther upstream than the Macon, GA, gage so only data from the Macon, GA, gage were analyzed.

The nearest hydroelectric dam upstream on the Ocmulgee River is located on Jackson Lake and was created in 1910. An additional reservoir, Lake Juliette (on Rum Creek), is located between Jackson Lake and OCMU, but is only used for cooling Scherer’s coal power plant. Although water is pumped directly from the Ocmulgee River to augment lake levels it has little effect on the net flow the Ocmulgee River. Therefore, to predict high and low-flow events we analyzed the data as a single time series although there is a substantial gap in the earlier portions of the data’s history (Figure 45).

The maximum average daily flow on the Ocmulgee River at Macon, GA, reached 97,000 cfs in the 1994. Based on Log Pearson III predictions for high-flow events, it is predicted that this flow would occur less than once every 500 years (Figure 46). That is, for any given year there is less

than 0.05% chance that a high-flow event such as the one that occurred in 1994 will happen. The 7-day Log Pearson III prediction for minimum flow indicate that discharge less than 500 cfs will occur at least once every 10 years (Figure 47). Single day flows well below 200 cfs have been recorded as recently as 1988.

The flow duration curves for single and seven-day average flows indicate that there is a less than 1% probability that the flow will exceed 25,000 cfs (Figure 48). It also predicts a greater than 50% chance that both the daily and seven-day average flows will be less than 5,000 cfs (Figure 48).

Assuming that the gage located in Macon, GA, continues to operate, no further monitoring of the Ocmulgee River at OCMU is necessary. However, given that there are several creeks present in the park, the installation of staff gages that are monitored by park employees is recommended (see Appendix B).

**Table 14.** Ocmulgee National Monument (OCMU) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 2.22        | 0.32    | 826.86      | 2.37    | 32191.43        | 1.69    |
| Developed Open Space        | 38.47       | 5.52    | 5370.61     | 15.40   | 192502.09       | 10.11   |
| Developed Low Intensity     | 37.81       | 5.42    | 4367.17     | 12.53   | 129924.85       | 6.82    |
| Developed Medium Intensity  | 7.56        | 1.08    | 2620.70     | 7.52    | 36869.28        | 1.94    |
| Developed High Intensity    | 0.00        | 0.00    | 1105.75     | 3.17    | 19991.96        | 1.05    |
| Barren Land                 | 0.00        | 0.00    | 307.35      | 0.88    | 20078.92        | 1.05    |
| Deciduous Forest            | 120.98      | 17.35   | 6412.98     | 18.39   | 488905.04       | 25.67   |
| Evergreen Forest            | 43.37       | 6.22    | 2438.78     | 7.00    | 417144.90       | 21.90   |
| Mixed Forest                | 32.91       | 4.72    | 1990.21     | 5.71    | 69815.75        | 3.67    |
| Shrub/Scrub                 | 37.14       | 5.33    | 131.88      | 0.38    | 19146.86        | 1.01    |
| Grassland/Herbaceous        | 3.78        | 0.54    | 2202.82     | 6.32    | 130792.19       | 6.87    |
| Pasture/Hay                 | 37.14       | 5.33    | 717.00      | 2.06    | 250007.39       | 13.13   |
| Cultivated                  | 3.78        | 0.54    | 243.30      | 0.70    | 9036.35         | 0.47    |
| Woody Wetland               | 219.95      | 31.55   | 5329.69     | 15.29   | 85894.89        | 4.51    |
| Emergent Herbaceous Wetland | 43.14       | 6.19    | 797.73      | 2.29    | 2501.27         | 0.13    |

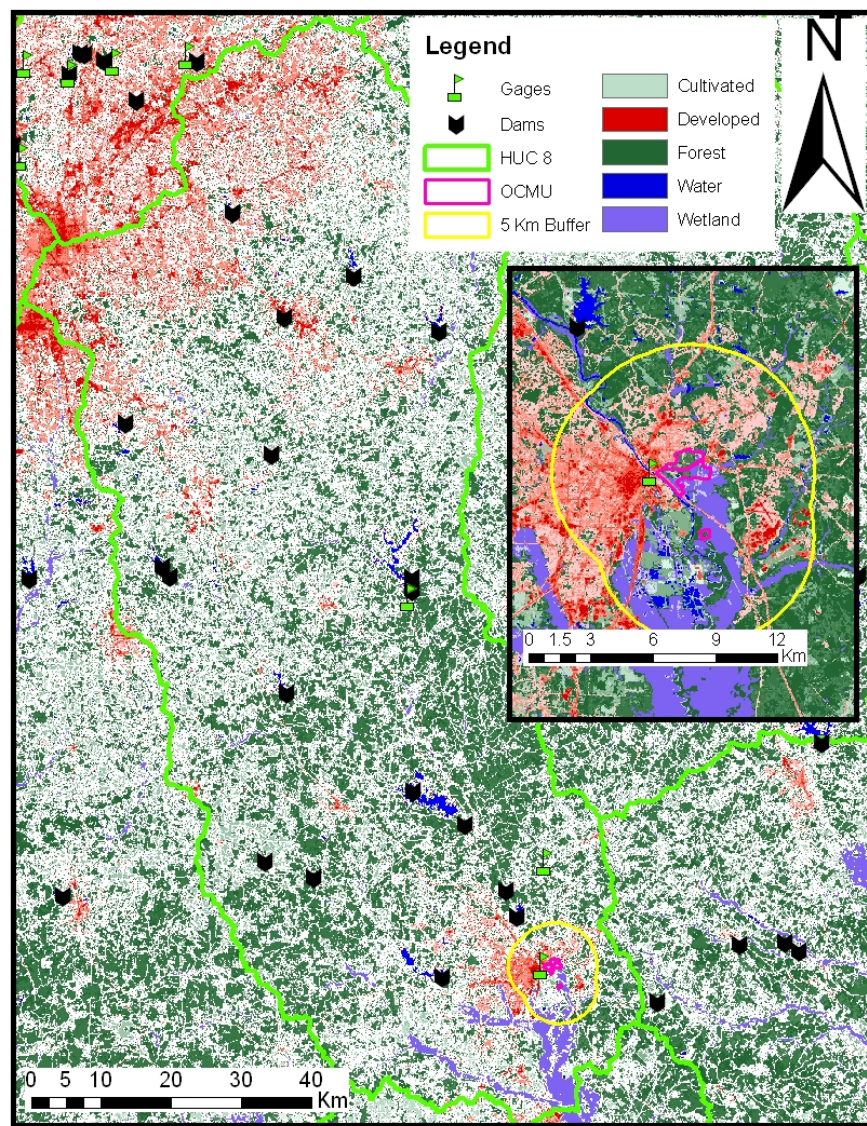


**Figure 44.** Land cover and watershed map of Ocmulgee National Monument (OCMU).

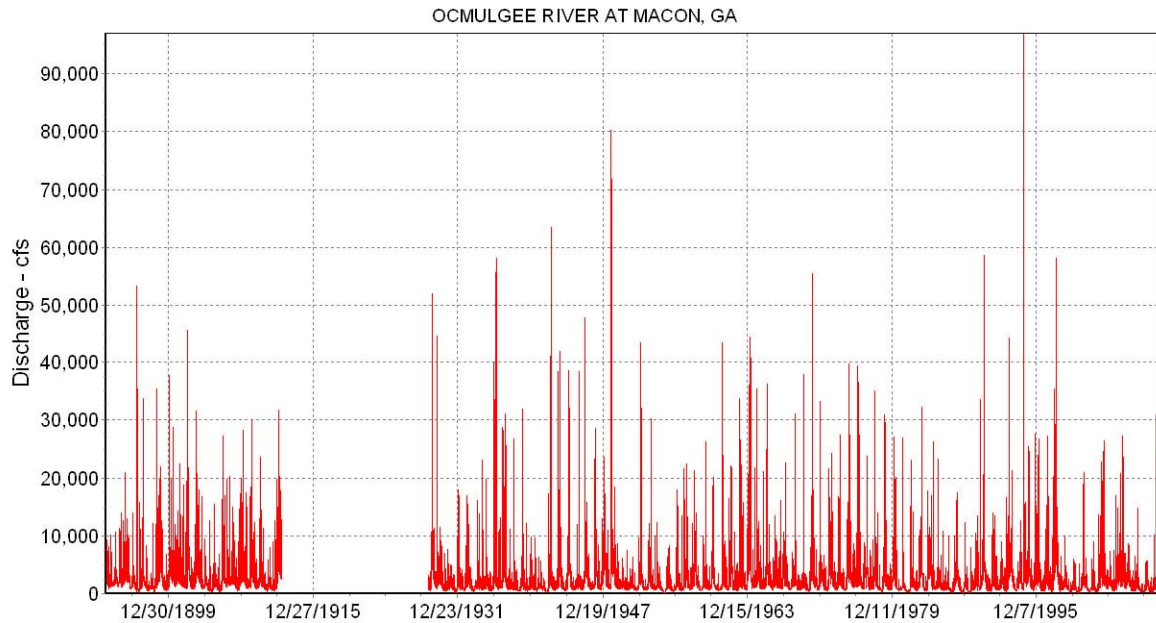


**Figure 45.** Average daily flow for USGS 02213000 located on the Ocmulgee River at Macon, GA, south of Ocmulgee National Monument.

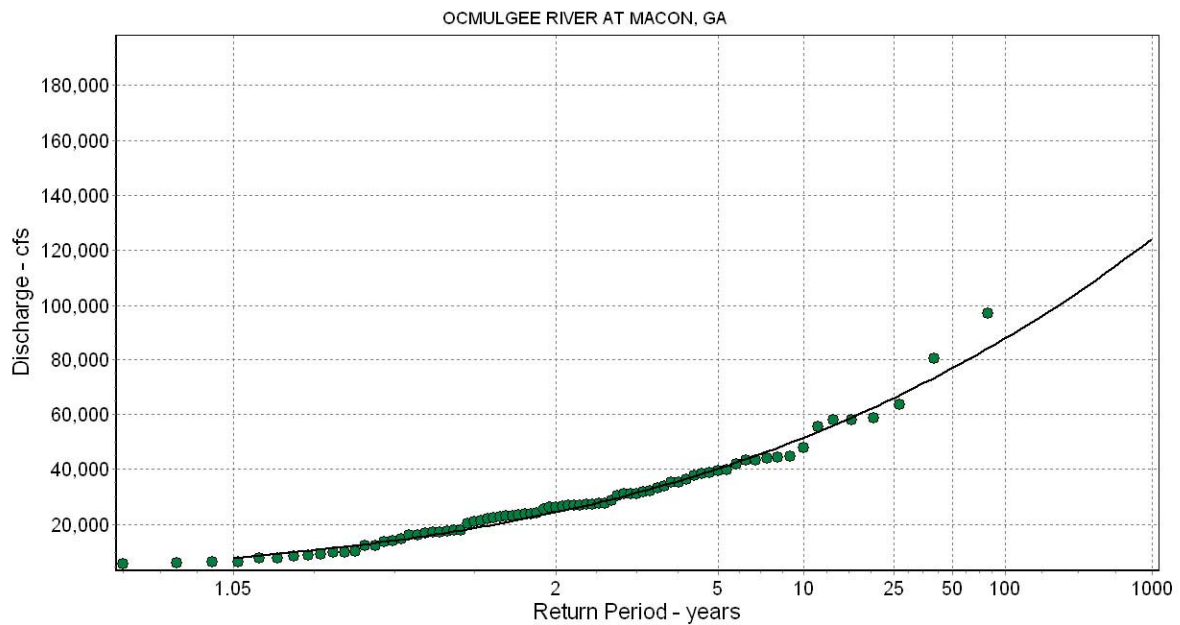


**Figure 46.** Log Pearson III graph of high-flow return frequency for USGS 02213000 located on the Ocmulgee River at Macon, GA, south of Ocmulgee National Monument.

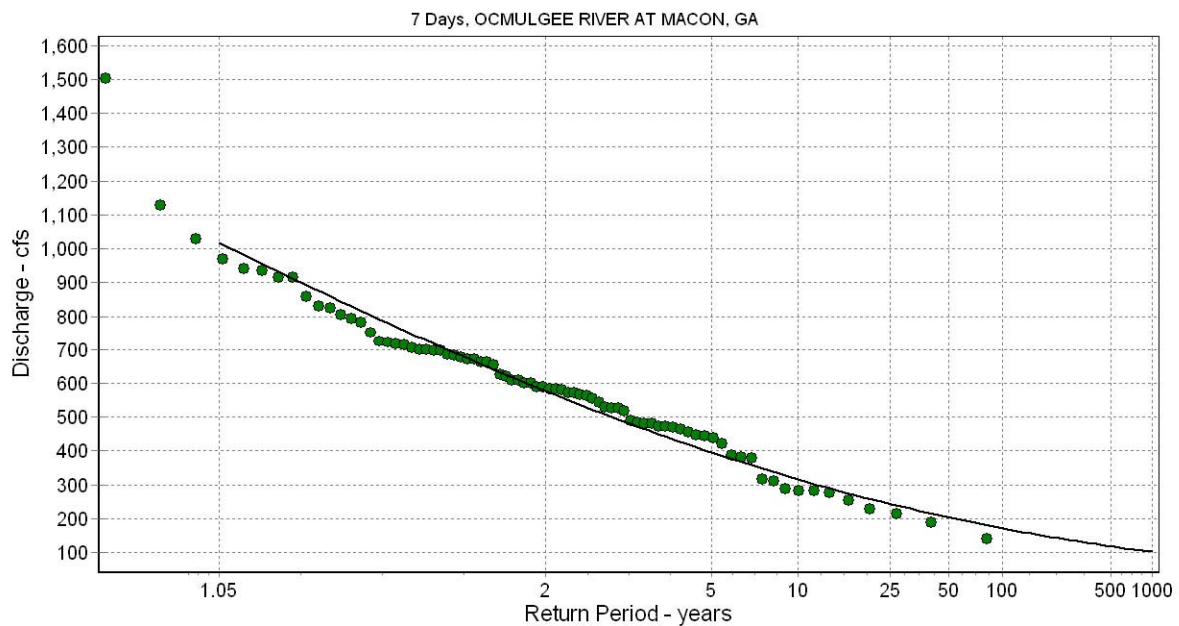


**Figure 47.** Log Pearson III graph of low-flow return frequency for USGS 02213000 located on the Ocmulgee River at Macon, GA, south of Ocmulgee National Monument.

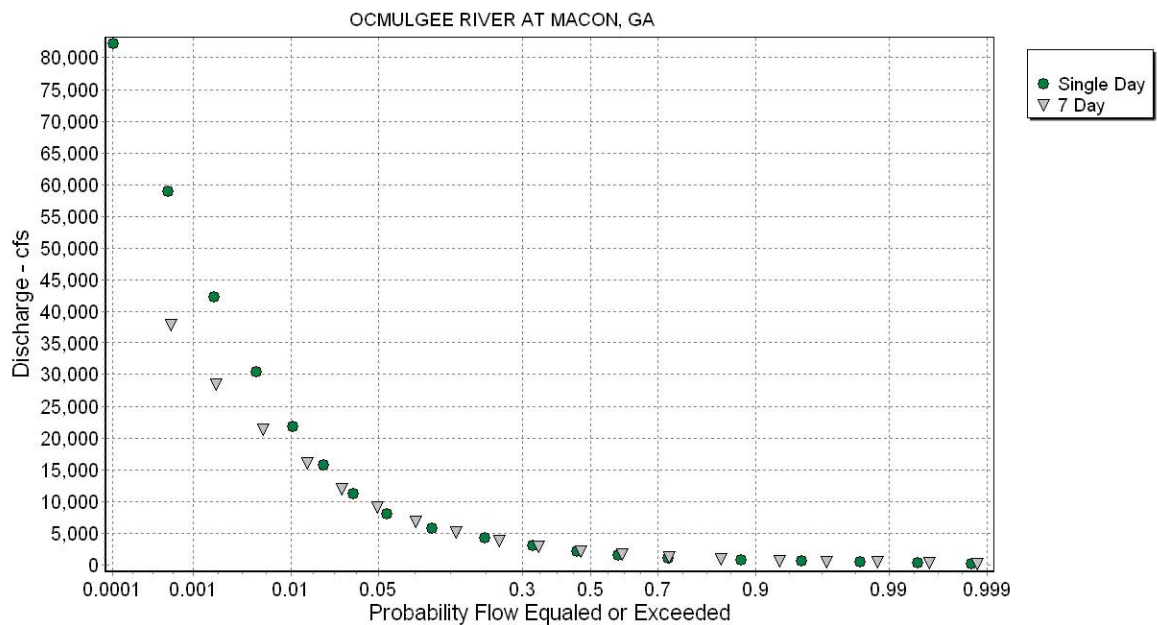


**Figure 48.** Flow duration curves for seven-day (triangles) and single-day (dots) flow duration for USGS 02213000 located on the Ocmulgee River at Macon, GA, south of Ocmulgee National Monument.

### **TIMU: Timucuan Ecological and Historic Preserve**

Land cover within Timucuan Ecological and Historic Preserve is over 50% emergent herbaceous wetland and 22% open water (Figure 49; Table 14). Within a 5-km buffer surrounding TIMU, wetlands and evergreen forest dominate, but only 14% is open water. At the watershed level, wetlands and evergreen forest are found at slightly higher proportions and only 7% of the landscape at the watershed scale is classified as open water (Table 14).

Two USGS gages are relevant to TIMU; USGS 02231289 on the Nassau River just outside the park boundary and USGS 02246500 on the St. Johns River at Jacksonville, FL. However, data collection on the Nassau River gage in the park ceased in 2004 (Table 3, Figure 50). Data collection on the St. Johns River is current and contains historical data back to 1971 (Figure 51). Daily mean, minimum, and maximum height data are available for both gages.

The maximum gage height observed at TIMU recorded at gage 02231289 rarely exceeds 15 ft (Figure 50). Historical gage heights observed between the formerly active gage located within the boundary of TIMU, and the currently active gage on the St. Johns River, are similar in maximum and minimum heights observed (although heights at TIMU appear to be slightly higher). Since the St. Johns River gage closely mirrors what was actually measured within the boundary of TIMU, it is probably not necessary to incorporate additional monitoring. However, in the event that the St. Johns River gage is discontinued and considering the preserve's vulnerability to storm surge and sea level rise (see Appendix C), re-instating the gage at TIMU is recommended.

**Table 15.** Timucuan Ecological and Historic Preserve (TIMU) land cover within the park, within a 5-km buffer, and its HUC 8 watershed.

|                             | Within Park |         | 5-km buffer |         | HUC 8 Watershed |         |
|-----------------------------|-------------|---------|-------------|---------|-----------------|---------|
|                             | Acres       | Percent | Acres       | Percent | Acres           | Percent |
| Open Water                  | 10160.11    | 22.25   | 23852.29    | 13.82   | 147938.38       | 7.20    |
| Developed Open Space        | 635.60      | 1.39    | 13202.69    | 7.65    | 204020.14       | 9.93    |
| Developed Low Intensity     | 779.27      | 1.71    | 9931.71     | 5.75    | 103904.43       | 5.06    |
| Developed Medium Intensity  | 218.84      | 0.48    | 3067.27     | 1.78    | 31595.19        | 1.54    |
| Developed High Intensity    | 180.81      | 0.40    | 2174.35     | 1.26    | 14430.76        | 0.70    |
| Barren Land                 | 452.57      | 0.99    | 2240.85     | 1.30    | 9456.67         | 0.46    |
| Deciduous Forest            | 24.24       | 0.05    | 678.53      | 0.39    | 18437.20        | 0.90    |
| Evergreen Forest            | 5130.43     | 11.24   | 38271.26    | 22.17   | 595030.75       | 28.96   |
| Mixed Forest                | 721.00      | 1.58    | 3284.77     | 1.90    | 37643.89        | 1.83    |
| Shrub/Scrub                 | 14.23       | 0.03    | 468.81      | 0.27    | 26100.70        | 1.27    |
| Grassland/Herbaceous        | 0.22        | 0.00    | 9632.59     | 5.58    | 249804.79       | 12.16   |
| Pasture/Hay                 | 14.23       | 0.03    | 1540.97     | 0.89    | 68719.78        | 3.34    |
| Cultivated                  | 0.22        | 0.00    | 208.61      | 0.12    | 44904.19        | 2.19    |
| Woody Wetland               | 2531.30     | 5.54    | 21506.69    | 12.46   | 429835.41       | 20.92   |
| Emergent Herbaceous Wetland | 24442.53    | 53.53   | 42588.61    | 24.67   | 73066.71        | 3.56    |

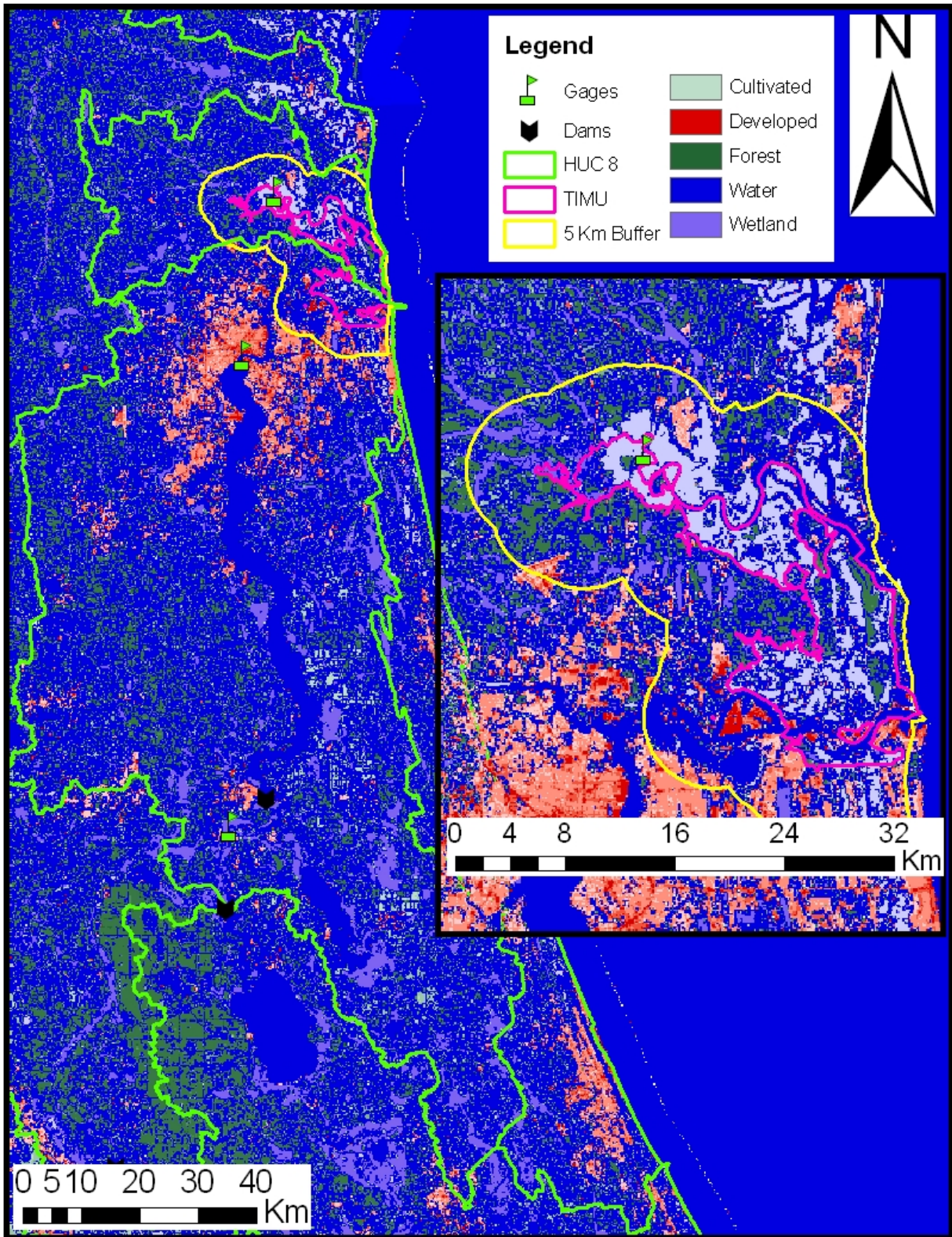


**Figure 49.** Land cover and watershed map for Timucuan Ecological and Historic Preserve (TIMU).

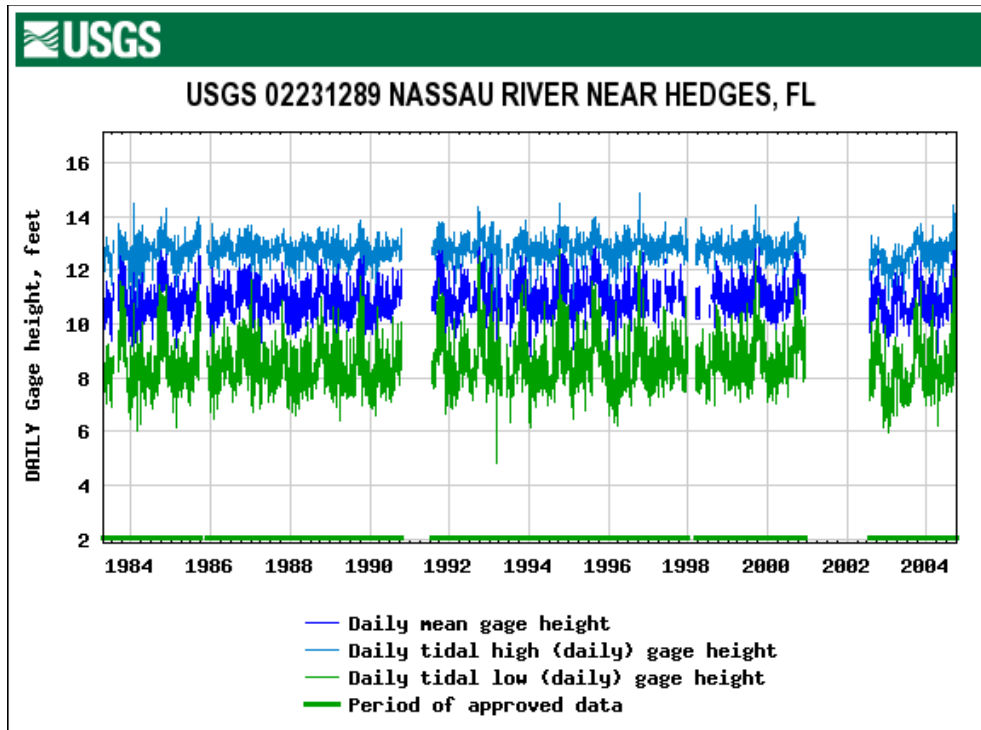


**Figure 50.** USGS 02231289 on the Nassau River near Hedges, FL, and within the boundary of Timucuan Ecological and Historic Preserve.

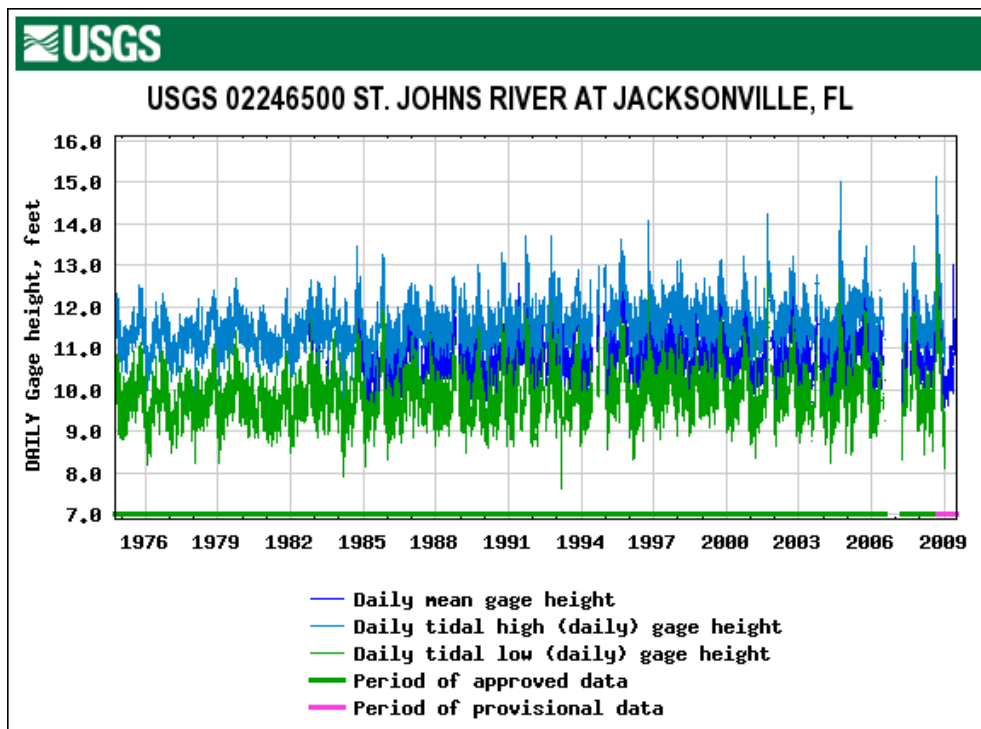


**Figure 51.** USGS 02246500 on the St. Johns River at Jacksonville, FL, near Timucuan Ecological and Historic Preserve.



## Summary of Water Quantity Monitoring at SECN Parks

All flow data analyzed for this report is maintained by the USGS and is easily accessed via the Internet. Program River2 and UpdateSW can be used to analyze historical flows to develop models of flow regimes.

For CHAT, five currently active gaging stations with flow data are available with pre- and post-dam construction. Construction of Buford Dam decreased the frequency, duration, and magnitude of peak events and increased the magnitude of seven-day low flows. Sufficient monitoring is currently in place.

Both the Congaree and Wateree Rivers influence CONG, and each are influenced by upstream dams. Previous examinations have related gage heights within the park to streamflow on the Congaree River. Additional monitoring is likely needed within the park to predict future effects of development and dam re-licensing.

No gages are located within FOFR, but three are located nearby. However, only one gage contains data up to 2009 (but no reporting since 6/17/2009 as of this report).

No gages are located within FOMA boundaries, but one is located at Satsuma, FL, on the St. Johns River. However, this data only goes back to early 1990s and many gaps in the data are present. Additionally, only mean height is reported which may be of little use in predicting the height of storm surges.

Adequate monitoring was available until 2006 on FOPU. Nearby gages were active until as recently as March 2009, but data collection appears to have been discontinued. Further monitoring is likely needed.

Four gages near FOSU are currently active; there are no active gages within the FOSU (ceased in 2005). Differences in nearby gages and historical gage heights collected on Fort Sumter indicate that tidal behavior may differ on Fort Sumter and the nearest currently active gage on the Cooper River.

There are two currently active gages providing relevant flow data for HOBE, one located upstream at Wadely, AL, and one located on HOBE itself. High-flow events occurred in 2003 and were higher than those projected by Log Pearson III models. This may indicate that either the data poorly fit the model or this was an extremely rare event.

No gages are located within KEMO, however there is a gage located on Noses Creek at Powder Springs, but only contains data going back to 1998. Multiple creeks, other than Noses Creek, influence the surface water hydrology at KEMO so further monitoring may be necessary given that increases in development around the park may increase the flash flood potential in this area.

No USGS gages are located within MOCR and frequent flooding has been observed. Only a single study has been conducted which collected surface water elevation and discharge, but the data were collected over a short period of time (< four months). Further monitoring is likely necessary.

No gages are found on OCMU, however long-term data is available at Macon, GA, on the Ocmulgee River. Adequate data is available for analysis, however OCMU is also influenced by other creeks that run through the park, so further monitoring may be necessary.

Gage height monitoring ceased within TIMU in 2004, however data for the nearby St. Johns River is available. Comparison of gage heights observed at TIMU and at the St. Johns River gage, indicate a large degree of similarity, so further monitoring may not be needed unless the St. Johns River gage is discontinued.

## Surface Water Concerns and Suggested Methods for Analysis

This section provides a brief overview of possible concerns related to SECN parks. Table 15 provides a summary of likely stresses to the surface hydrologic system at these parks. Note that the list of concerns was based on the proximity to coastal waters, as well as the proximity of potential stresses. Three tools are presented that were used for the analysis of surface water disturbances, as well as for the management of surface water data. UpdateSW and River2 are programs created by Dr. John Dowd at the University of Georgia to automatically retrieve current and historical data from USGS databases and run similar analyses to those presented in this report as well as others. Detailed instructions and examples for how to use these programs are provided in Appendix A.

Indicators of Hydrologic Alteration (IHA) is a program developed by the Nature Conservancy (TNC) in conjunction with Totten Software Design and Smythe Scientific Software to quantify the characteristics of natural and altered hydrologic systems (TNC 2007). Mathews and Richter (2007) suggest using IHA in conjunction with other statistics, such as those generated by River2, and organism specific statistics when making environmental flow recommendations.

The primary purpose of presenting these tools within this document is to provide park employees, researchers, and managers with simple-to-use tools that will enable comparisons of hydrologic characteristics for different scenarios other than those presented in this report. This is important since it is most often the case that different NPS lands have varying interests in surface water hydrology for different reasons. Additionally, urban development, changes in landcover, salt water intrusion, local climate changes, and projected rises in sea level will all impact each park in a different manner.

**Table 16.** Potential surface water management concerns at SECN parks.

|      | Dams | Point Source | Non-Point Source | Drought | Erosion | Dredging | Tidal Influence | Hurricanes | Withdrawals |
|------|------|--------------|------------------|---------|---------|----------|-----------------|------------|-------------|
| CONG | X    | X            | X                | X       | X       |          |                 | X          | X           |
| CHAT | X    | X            | X                | X       | X       |          |                 |            | X           |
| FOMA |      | X            |                  |         |         | X        | X               | X          |             |
| FOFR |      | X            |                  |         |         | X        | X               | X          |             |
| FOPU |      | X            | X                |         |         | X        | X               | X          |             |
| FOSU |      | X            |                  |         | X       | X        | X               | X          |             |
| HOBE | X    |              | X                | X       | X       |          |                 |            | X           |
| KEMO |      |              | X                | X       | X       |          |                 |            |             |
| MOCR |      |              | X                | X       |         |          | X               | X          |             |
| OCMU | X    | X            | X                | X       | X       |          |                 |            | X           |
| TIMU |      | X            |                  | X       | X       | X        | X               | X          | X           |

Indicators of Hydrologic Alteration software, was developed in order allow hydrologic processes to be rapidly assessed. The advantage of this software is its ability to utilize any form of hydrologic data including streamflows, river stages, ground water levels, and lake levels. The disadvantage is the long-term data sets typically required to run useful analysis. This, however, is also an advantage of the program since examining long-term data in a meaningful way is often a daunting task. As a general rule, 20 years of daily data are recommended for estimating many of the parameters for analysis (TNC 2007), but this requirement varies depending on the goal of the analysis and variability within the system being characterized.

IHA calculates a total of 67 statistical parameters divided into two groups: Environmental Flow Component (EFC) parameters and the Indicators of Hydrologic Alteration (IHA) (Table 16). Many of these parameters are correlated with each other (Olden and Poff 2003), so caution should be exercised when examining the output and the parameters should typically be chosen *a priori*. A brief example analysis of the Chattahoochee River below Buford Dam is provided below.

One of the most useful tools in program IHA is the Range of Variability analysis (Richter et al. 1997). The purpose of RVA analysis is to compare flows from one time period to another and determine the range of variability that was present prior to the “disturbance” of the natural regime. The goal of the analysis is to quickly identify what the range of variability is in order to set goals for management that may have an impact on flow. Once these have been identified, then biological and/or water quality changes can be monitored. If, for example, it is determined that any decrease below 30% of the natural range of variability of the original streamflow results in lethally low water levels resulting in mass die-offs of native mussels, then adaptive management recommendations can be made. Richter et al. (1997) provides a 6-step adaptive approach for setting management goals and provides additional examples of RVA analysis. Additionally, Mathews and Richter (2007) provide a detailed description of prescribing flows within an adaptive framework.

For this example, the time period prior to the creation of Buford Dam on the Chattahoochee is compared to post-dam flows. This analysis is for illustrative purposes only and is only meant to show some of the capabilities of the IHA program and is not intended as a management recommendation. The RVA analysis indicates that for October monthly flows prior the construction of Buford Dam yielded a Low Hydrologic Alteration Factor (HA) of -0.8814, a Middle HA of -0.6368 and a High HA of 1.609 (Figure 52). HA is calculated as:

$$HA = (OF - EF) / EF$$

Where OF is the observed frequency and EF is the expected frequency. The statistic is estimated for three categories: Low HA (0-33<sup>rd</sup> percentile), Middle HA (34<sup>th</sup> – 67<sup>th</sup> percentile) and High HA (>67<sup>th</sup> percentile). Therefore, a negative Low HA indicates that the frequency of values falling within the 33<sup>rd</sup> percentile for the range of variability has decreased substantially. While a positive High HA indicates that the frequency of values > 67<sup>th</sup> percentile has increased.



**Table 16. (Continued)**

|                                                         |                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>3. Timing of annual extreme water conditions</p>     | <p>Julian date of each annual 1-day maximum</p> <p>Julian date of each annual 1-day minimum</p> <hr/> <p><i>Subtotal 2 parameters</i></p>                                                                                                                                                                                   | <ul style="list-style-type: none"> <li>• Compatibility with life cycles of organisms</li> <li>• Predictability/avoidability of stress for organisms</li> <li>• Access to special habitats during reproduction or to avoid predation</li> <li>• Spawning cues for migratory fish</li> <li>• Evolution of life history strategies, behavioral mechanisms</li> </ul>                                                                                                                                                                                                        |
| <p>4. Frequency and duration of high and low pulses</p> | <p>Number of low pulses within each water year</p> <p>Mean or median duration of low pulses (days)</p> <p>Number of high pulses within each water year</p> <p>Mean or median duration of high pulses (days)</p> <hr/> <p><i>Subtotal 4 parameters</i></p>                                                                   | <ul style="list-style-type: none"> <li>• Frequency and magnitude of soil moisture stress for plants</li> <li>• Frequency and duration of anaerobic stress for plants</li> <li>• Availability of floodplain habitats for aquatic organisms</li> <li>• Nutrient and organic matter exchanges between river and floodplain</li> <li>• Soil mineral availability</li> <li>• Access for waterbirds to feeding, resting, reproduction sites</li> <li>• Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)</li> </ul> |
| <p>5. Rate and frequency of water condition changes</p> | <p>Rise rates: Mean or median of all positive differences between consecutive daily values</p> <p>Fall rates: Mean or median of all negative differences between consecutive daily values</p> <p>Number of hydrologic reversals</p> <hr/> <p><i>Subtotal 3 parameters</i></p> <hr/> <p><b>Grand total 33 parameters</b></p> | <ul style="list-style-type: none"> <li>• Drought stress on plants (falling levels)</li> <li>• Entrapment of organisms on islands, floodplains (rising levels)</li> <li>• Desiccation stress on low-mobility streamedge (varial zone) organisms</li> </ul>                                                                                                                                                                                                                                                                                                                |

**Table 16. (Continued)**

| <b><u>EFC Type</u></b> | <b><u>Hydrologic Parameters</u></b>                                                                                                                                                                                                                                                                                                        | <b><u>Ecosystem Influences</u></b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Monthly low flows   | <p>Mean or median values of low flows during each calendar month</p> <hr/> <p><i>Subtotal 12 parameters</i></p>                                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>• Provide adequate habitat for aquatic organisms</li> <li>• Maintain suitable water temperatures, dissolved oxygen, and water chemistry</li> <li>• Maintain water table levels in floodplain, soil moisture for plants</li> <li>• Provide drinking water for terrestrial animals</li> <li>• Keep fish and amphibian eggs suspended</li> <li>• Enable fish to move to feeding and spawning areas</li> <li>• Support hyporheic organisms (living in saturated sediments)</li> </ul> |
| 2. Extreme low flows   | <p>Frequency of extreme low flows during each water year or season</p> <p>Mean or median values of extreme low flow event:</p> <ul style="list-style-type: none"> <li>• Duration (days)</li> <li>• Peak flow (minimum flow during event)</li> <li>• Timing (Julian date of peak flow)</li> </ul> <hr/> <p><i>Subtotal 4 parameters</i></p> | <ul style="list-style-type: none"> <li>• Enable recruitment of certain floodplain plant species</li> <li>• Purge invasive, introduced species from aquatic and riparian communities</li> <li>• Concentrate prey into limited areas to benefit predators</li> </ul>                                                                                                                                                                                                                                                       |

Table 16. (Continued)

|                            |                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>3. High flow pulses</p> | <p>Frequency of high flow pulses during each water year or season</p> <p>Mean or median values of high flow pulse event:</p> <ul style="list-style-type: none"> <li>• Duration (days)</li> <li>• Peak flow (maximum flow during event)</li> <li>• Timing (Julian date of peak flow)</li> <li>• Rise and fall rates</li> </ul> <hr/> <p><i>Subtotal 6 parameters</i></p> | <ul style="list-style-type: none"> <li>• Shape physical character of river channel, including pools, riffles</li> <li>• Determine size of streambed substrates (sand, gravel, cobble)</li> <li>• Prevent riparian vegetation from encroaching into channel</li> <li>• Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants</li> <li>• Aerate eggs in spawning gravels, prevent siltation</li> <li>• Maintain suitable salinity conditions in estuaries</li> </ul>                                                                                                                                           |
| <p>4. Small floods</p>     | <p>Frequency of small floods during each water year or season</p> <p>Mean or median values of small flood event:</p> <ul style="list-style-type: none"> <li>• Duration (days)</li> <li>• Peak flow (maximum flow during event)</li> <li>• Timing (Julian date of peak flow)</li> <li>• Rise and fall rates</li> </ul> <hr/> <p><i>Subtotal 6 parameters</i></p>         | <p>Applies to small and large floods:</p> <ul style="list-style-type: none"> <li>• Provide migration and spawning cues for fish</li> <li>• Trigger new phase in life cycle (i.e insects)</li> <li>• Enable fish to spawn in floodplain, provide nursery area for juvenile fish</li> <li>• Provide new feeding opportunities for fish, waterfowl</li> <li>• Recharge floodplain water table</li> <li>• Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances)</li> <li>• Control distribution and abundance of plants on floodplain</li> <li>• Deposit nutrients on floodplain</li> </ul> |

**Table 16. (Continued)**

|                        |                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>5. Large floods</p> | <p>Frequency of large floods during each water year or season</p> <p>Mean or median values of large flood event:</p> <ul style="list-style-type: none"> <li>• Duration (days)</li> <li>• Peak flow (maximum flow during event)</li> <li>• Timing (Julian date of peak flow)</li> <li>• Rise and fall rates</li> </ul> <hr/> <p><i>Subtotal 6 parameters</i></p> <hr/> <p><b>Grand total 34 parameters</b></p> | <p>Applies to small and large floods:</p> <ul style="list-style-type: none"> <li>• Maintain balance of species in aquatic and riparian communities</li> <li>• Create sites for recruitment of colonizing plants</li> <li>• Shape physical habitats of floodplain</li> <li>• Deposit gravel and cobbles in spawning areas</li> <li>• Flush organic materials (food) and woody debris (habitat structures) into channel</li> <li>• Purge invasive, introduced species from aquatic and riparian communities</li> <li>• Disburse seeds and fruits of riparian plants</li> <li>• Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes)</li> <li>• Provide plant seedlings with prolonged access to soil moisture</li> </ul> |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

The RVA analysis allows the user to specify what percentiles each category can be set. By default, it will divide the three categories as they are presented here, but this is arbitrary. Examining the graph of the pre-impact flows (Figure 52), it is evident that there was quite a bit of variation prior to the construction of the dam, therefore the RVA boundaries could be widened to capture more of the variation if desired. Additionally, when balancing human demands (hydropower and recreation) with environmental issues, fine tuning is often required.

The RVA analysis only considers the 33 parameters that are related to IHA not the EFC parameters, so separate analyses are required if the EFC parameters are of interest. There are numerous components that can be examined (see Table 16), but for this example extreme low flows will be examined.

To begin, a hydrograph delineating extreme low flows, low flows, high-flow pulses, small floods and large floods was graphed pre- and post-dam construction (Figure 53). It is obvious from the graph (and would be obvious from a standard hydrograph as well) that the creation of Buford Dam dampened the erratic flow of the Chattahoochee and virtually eliminated all large flood events. Program IHA allows you pick from any of the EFC parameters and examine them individually to determine to what degree each has been altered.

To examine the frequency of extreme low flows, the frequency of occurrence was graphed (Figure 54). It appears from the graph that the creation of Buford Dam substantially increased the number of extreme low-flow events in the Chattahoochee River. However, it is important to

consider how the program defines extreme low flow. Program IHA defines the extreme low-flow threshold at the 10<sup>th</sup> percentile of all low flows. In order to make sure the program is appropriately defining low flows for the stream of interest, the EFC algorithm should be calibrated properly and details for doing this can be found in the IHA manual (TNC 2007).

In addition to graphing the parameters of interest for both the IHA parameters and the EFC parameters, program IHA also creates a series of tables that include: an annual summaries table, a scorecard table, RVA table, box-and-whisker table (for creating box-and-whisker plots), regression table, percentile table, EFC table, and a message report. A detailed description for interpretation of the values can be found in the IHA manual (TNC 2007), but a few are highlighted below.

The scorecard table contains a collection of statistics for pre- and post-impact time periods for each parameter examined. Some of these include mean annual flow, mean annual flow/watershed area, annual coefficient of variation, flow predictability, flow constancy, maximum proportion of floods occurring during any common 60 day period, and length of flood free period in addition to also displaying the values used for calculating the EFC parameters.

The RVA table displays the results that were used for the RVA analysis and displays information for each parameter examined. These include: mean or median coefficient of dispersion for pre- and post-impact parameters, minimum and maximum of each pre- and post- impact parameter, RVA boundaries (set by user or default), and the HA factor for the middle HA category, and then provides a second section that compares the distributions of data found within each category.

It isn't always the case that two well-defined time periods are necessary for analysis and this is not a prerequisite to calculating many of the parameters in the IHA program. In some instances, it may be of interest to simply characterize the flow for reports or biological assessments. It would also be possible to characterize and examine multiple, but similar streams to compare differences in ecosystem function that may be driven by differences in flow characteristics.

Dams are the classic example of flow alteration; however analyses can be applied in more subtle ways. For example, it could be applied to flows in an area before and after development of a nearby shopping center on the flow of smaller streams (like those associated with CHAT or OCMU). It could also be used to examine the changes in flow due to increases in the percentages of urban areas near larger streams or changes in gage heights within CONG. Simulated data can also be incorporated to test future water management scenarios (Mathews and Richter 2007). For locations with limited amounts of data, this is probably the most useful way to employ the use of the IHA program.

This is just a brief examination of some of the functions of program IHA. For a complete explanation and more details on how the program can be used and has been used in the past consult the IHA manual (TNC 2007) as well as the many of the publications mentioned above (e.g. Mathews and Richter 2007, Richter et al. 2003, Richter et al. 1997).

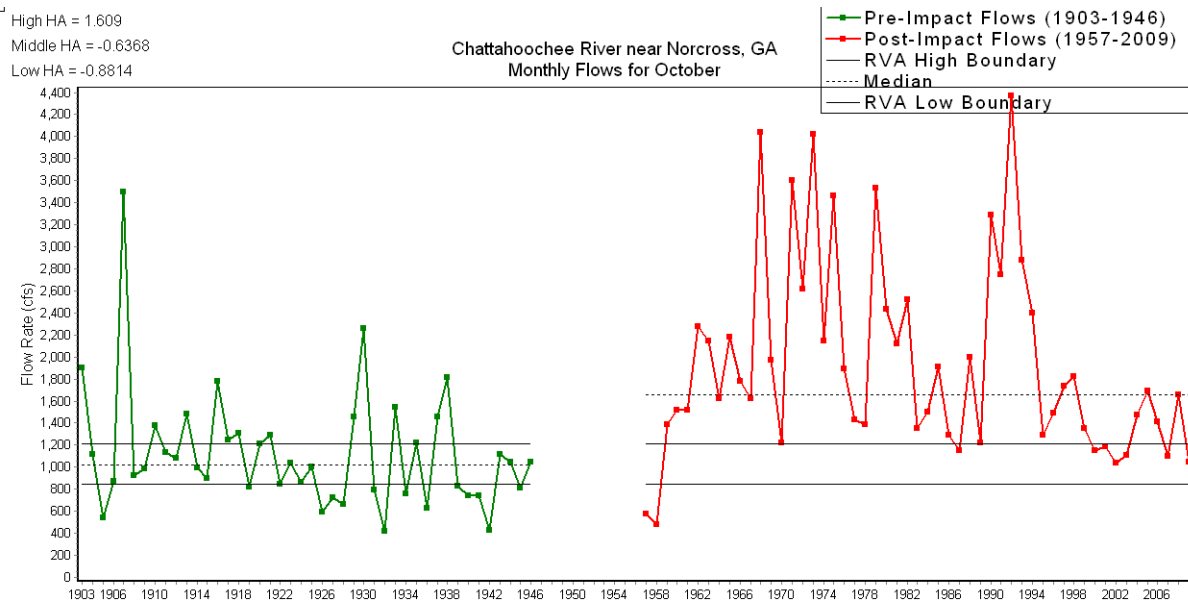


**Figure 52.** Range of Variability analysis for the Chattahoochee River near Norcross, GA.

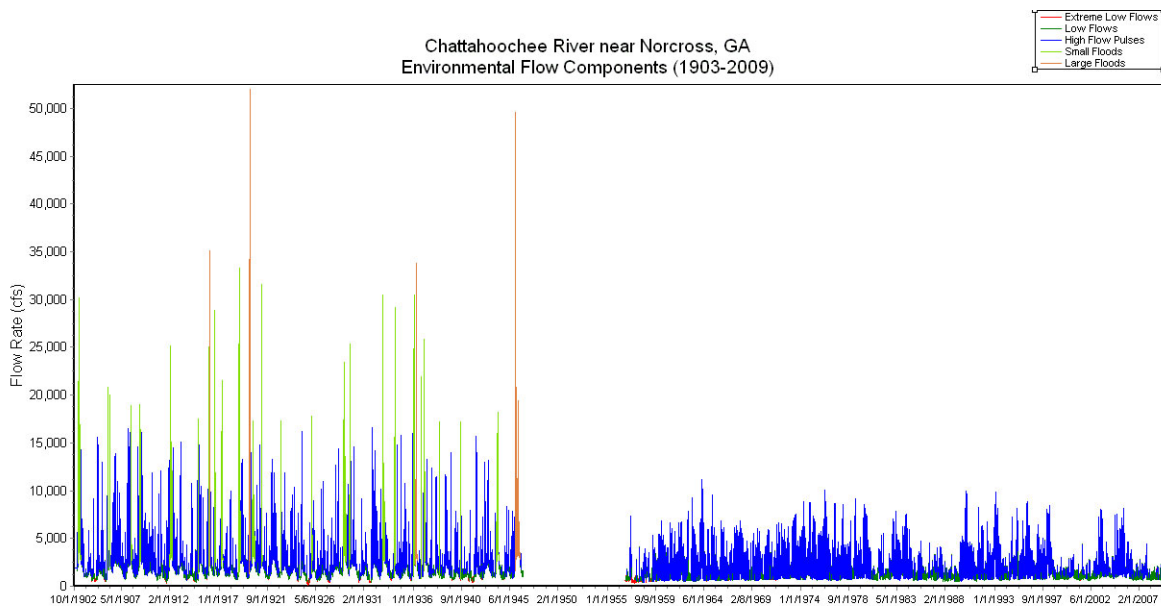


**Figure 53.** Graph of the frequency of extreme low flows, low flows, high-flow pulses, small floods, and large floods near Norcross, GA, before and after the construction of Buford Dam.

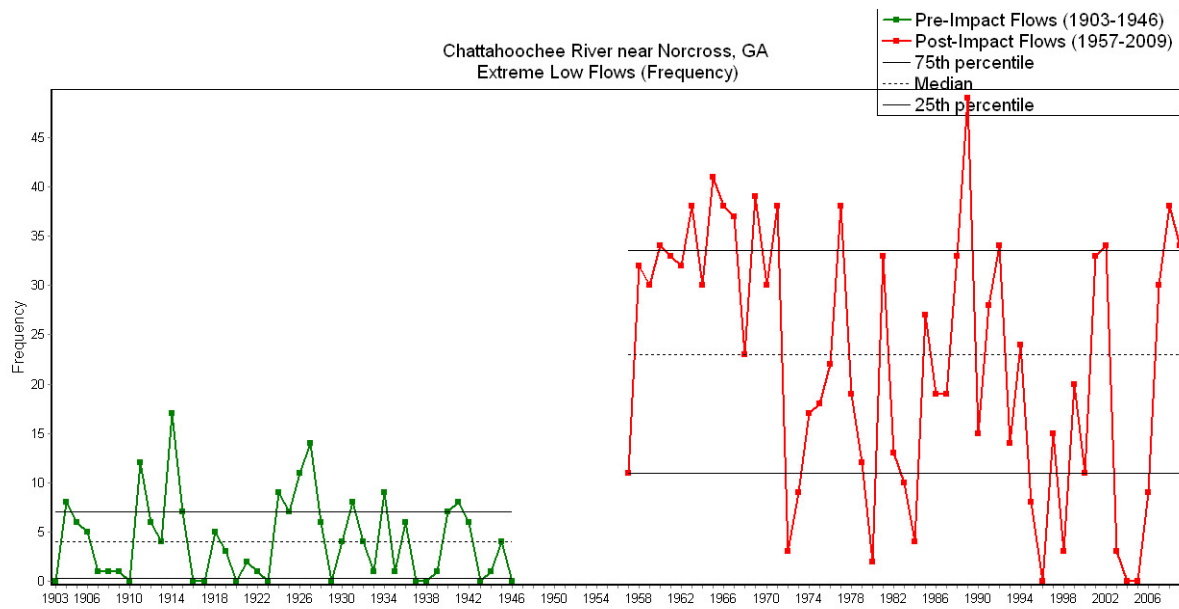


**Figure 54.** Graph of the frequency of extreme low-flow events on the Chattahoochee River near Norcross, GA, before and after the construction of Buford Dam.

## Recommendations

Table 17 summarizes monitoring recommendations for each park based on the above assessments. For most parks in the SECN, some form of water-quantity monitoring is available. The recommendations assume that the NPS desires to understand how flows may impact the integrity of their park and the safety of their visitors. Alternatively, if more detailed information is desired such that the park requires an understanding of how flow may impact the biological systems within the park, then tools are available (IHA, RIVER2) to examine flow data in this manner and a brief description and example analysis has been provided. In general, however, to understand the impact of surface water availability and flow on biological systems, long-term data sets are needed to document both hydrologic requirements of the biotic components of interest. Therefore, if there is any chance that the NPS may need this type of data at some point in the future, now is the time to begin monitoring.

### **Parks impacted by anthropogenic disturbances (dams, withdraws, etc.):**

- Congaree National Park
- Chattahoochee River National Recreational Area
- Horseshoe Bend National Military Park
- Timucuan Ecological & Historic Preserve
- Ocmulgee National Monument

### **Parks with limited surface water monitoring resources:**

- Congaree National Park
- Kennesaw Mountain National Battlefield Park
- Moores Creek National Battlefield

### **Parks with greater surface water monitoring resources:**

- Timucuan Ecological & Historical Preserve
- Fort Matanzas National Monument
- Fort Frederica National Monument

**Parks with adequate flow monitoring provided by USGS:**

- Horseshoe Bend National Military Park
- Chattahoochee River National Recreational Area
- Fort Sumter National Monument
- Fort Frederica National Monument
- Ocmulgee National Monument

**Table 18.** Recommendations for SECN parks for future surface water monitoring needs.

| <b>Park</b> | <b>Current Monitoring?</b> | <b>Recommendation</b>                                                                                                                                                                                                                              |
|-------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CHAT        | Yes                        | none                                                                                                                                                                                                                                               |
| CONG        | Yes                        | Recommend adding discharge monitoring to gages within the park. Additional monitoring needed to assess influence of nearby development and dam re-licensing.                                                                                       |
| FOFR        | No                         | Gage height monitoring and records maintained by USGS.                                                                                                                                                                                             |
| FOMA        | No                         | No data is currently being kept for FOMA and there are large gaps in the historical data which only reports the mean height. Recommend gage height monitoring that includes, min/max and mean height.                                              |
| FOPU        | No                         | Although there are not any gages on FOPU, the current issues of the dredging of Savannah Harbor have revealed a large amount of data. However, to adequately monitor what happens at FOPU, min/max and mean gage height monitoring is recommended. |
| FOSU        | No                         | Nearby gage (USGS 021720711) is currently recording min/max and mean gage height, however heights are much greater than the data collected at the same time previously on FOSU. Recommend re-instating the gage height monitoring.                 |
| HOBE        | Yes                        | none                                                                                                                                                                                                                                               |
| KEMO        | Yes                        | Monitor discharge in addition to gage height                                                                                                                                                                                                       |
| MOCR        | No                         | Implement staff gage to record peak flood events.                                                                                                                                                                                                  |
| OCMU        | No                         | Nearby gage (USGS 02213000) in Macon provides sufficient monitoring of the Ocmulgee River, however staff gages recommended for Walnut Creek.                                                                                                       |
| TIMU        | No                         | Nearby gage (USGS 02246500) on the St. Johns may provide sufficient monitoring as data previously collected at TIMU shows similarities in gage heights. However, the best information will come from re-instating gage height monitoring at TIMU.  |



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## Appendix A – Surface Water Data Analysis Support Programs

Two programs were developed by Professor John Dowd in the Geology Department of the University of Georgia to support surface water analyses and can be obtained upon request (jdowd@uga.edu). The two programs are *UpdateSW*, and *River 2* which are described below.

### Program *UpdateSW*

This program is designed to assist in the management and interpretation of surface water data. The program updates daily or real time USGS streamflow or groundwater data by using the internet to update chosen gage sites, and saving the data in an *Excel* format. The program can also be used to graph the data, and to evaluate whether temporal trends are present in the data. Surface water data (discharge and stage) is used for a trend analysis for each park. The trend analysis was completed by retrieving all discharge or water level data for a list of gaging stations that were determined to be representative of the surface water conditions in the SECN NPS parks of interest.

UpdateSW can be used to download data from the National Water Information System (NWIS) database, which is the national archive for hydrologic data (<http://nwis.waterdata.usgs.gov/nwis>). NWIS combines local databases with the centralized National Water Data Storage and Retrieval System (WATSTOR) database to create a single, distributed-information processing and management system (Dzurik, 2002).

Surface water and groundwater data collected is accessed from the NWIS database using:

<http://water.usgs.gov/waterwatch/>

<http://ogw01.er.usgs.gov/AWLSites.asp?S=<stationid>>

where <stationid> is the USGS station identification. *UpdateSW* stores data as an *Excel* file.

## Running UpdateSW

1. Double-click setup\_UpdateSW1200.exe and run InstallShield Wizard to install UpdateSW (Figure A-1). Then repeat the process for setup\_River2V2013.exe to install River2. Both programs will be downloaded to C:\Program Files\HOTL\

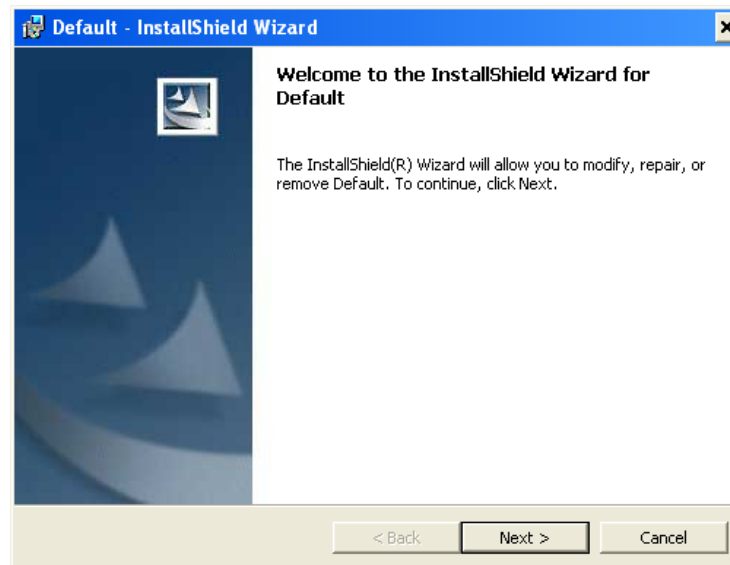


**Figure A-1.** Program *InstallShield Wizard* - Sample screen showing the installation process

2. Navigate to C:\Program Files\HOTL\ and open UpdateSW.exe (Figure A-2).

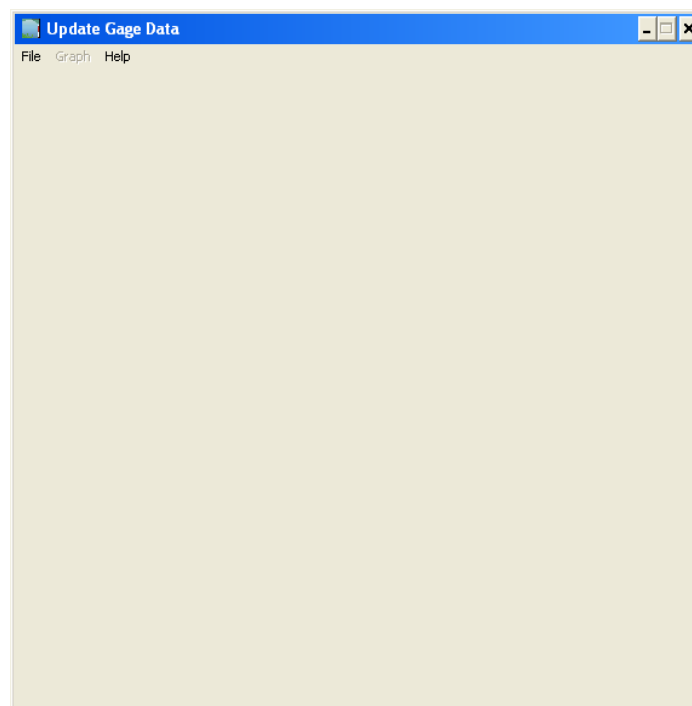


**Figure A-2.** Program *UpdateSW* - Sample screen showing how *UpdateSW* appears when first opened.

3. Click File on the Menu Bar then Read.
4. In the Open window navigate to the UpdateSW folder and select the .txt file that corresponds to the state in which the gage station of interest is located (Figure A-3). For instance GA\_SW\_UV.txt will extract the data for the USGS gage stations in Georgia. NC\_SW\_UV.txt will extract the data for the USGS gage station in North Carolina. Then click Open.

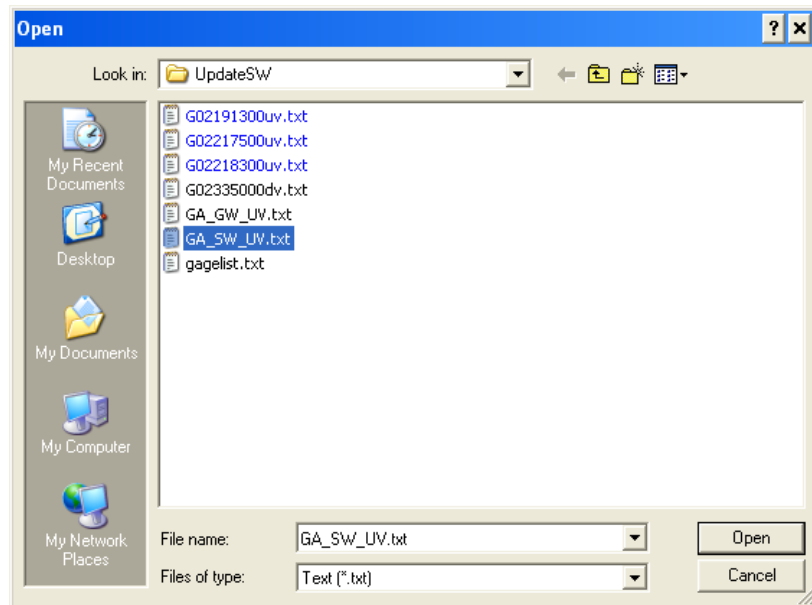


**Figure A-3.** Program *UpdateSW* - Sample screen showing how *UpdateSW* appears when first opened.

5. In the Update Gage Data frame all of the gage station for the state will appear (Figure A-4). Here select the gage stations of interest and the Data Type. Daily values extract the average daily values for the site for the entire period of collection. Real time extracts the 15-minute data but only for the past 60 days.

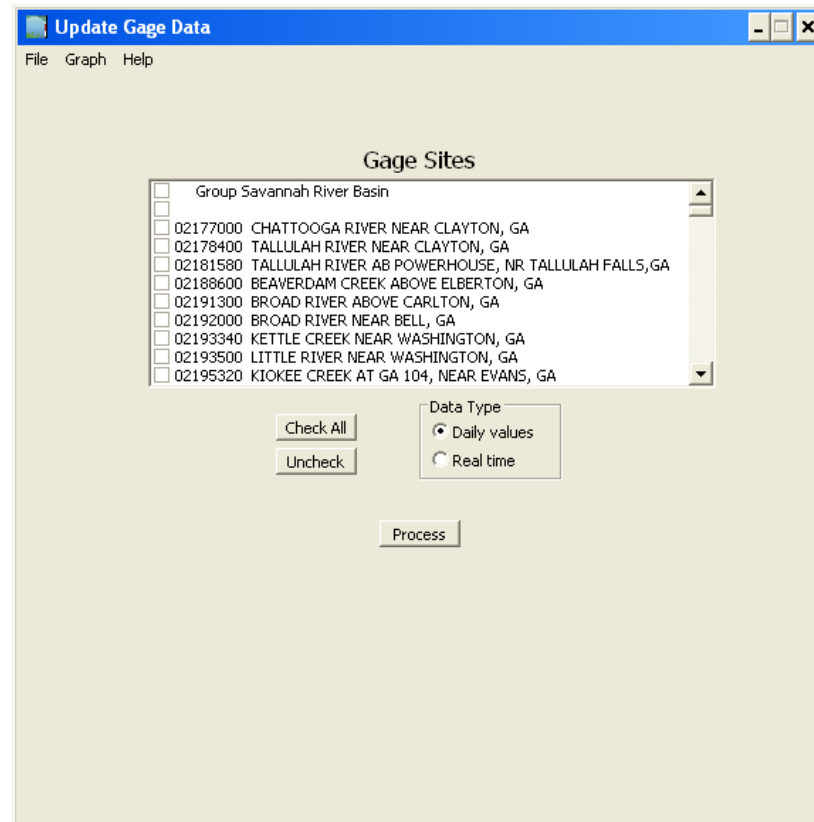


**Figure 55.** Program *UpdateSW* - Sample screen showing the display using the **Read** option.

6. Click on Process
7. After the data is processed you can close UpdateSW.

*UpdateSW* has a number of other functions, below is a detailed description of them.

### **File Command**

- **Read:** Initially, this option will allow the user to navigate to the appropriate file. When re-starting the program, it will open the last gage list file read, containing a list of sites. The first time the program is run, the user must navigate to the input file. A list of sites to be updated must be in a text file in the following format:

02191300 BROAD RIVER ABOVE CARLTON, GA

02192000 BROAD RIVER NEAR BELL, GA

with the site identification number first, followed by a description of the site. An example file, *filelist.txt*, is supplied with the program.

A mixture of surface water and groundwater sites is acceptable. The file *GageList.txt* is supplied as an example. The list can be modified with the **Add** command. It is preferable to use the **Add** option to maintain the list because an improper site number will cause uncertain results from the website.

- **New:** This option allows the user to navigate to a new text file that contains a list of site names to be maintained. The file *GageList.txt* is supplied as an example. The list can be modified with the **Add** command. It is preferable to use the **Add** option to maintain the list because an improper site number will cause uncertain results from the website. This command allows the user to navigate to a new file name and/or location.
- **Filenames:** This form allows the user to change the filenames associated with the sites (Figure A-5). The default name is a “G” followed by the site number. Names can be modified by typing a new name (without extension) and pressing the <enter> key. The list will be saved with the **Update** option, or discarded with the **Cancel** option located in the drop-down menu below File in the Gage File Names window. Default names can be obtained with the **Default** option. The **Filename** option allows the user to specify the filename that contains the list of names associated with the sites in the gage list.

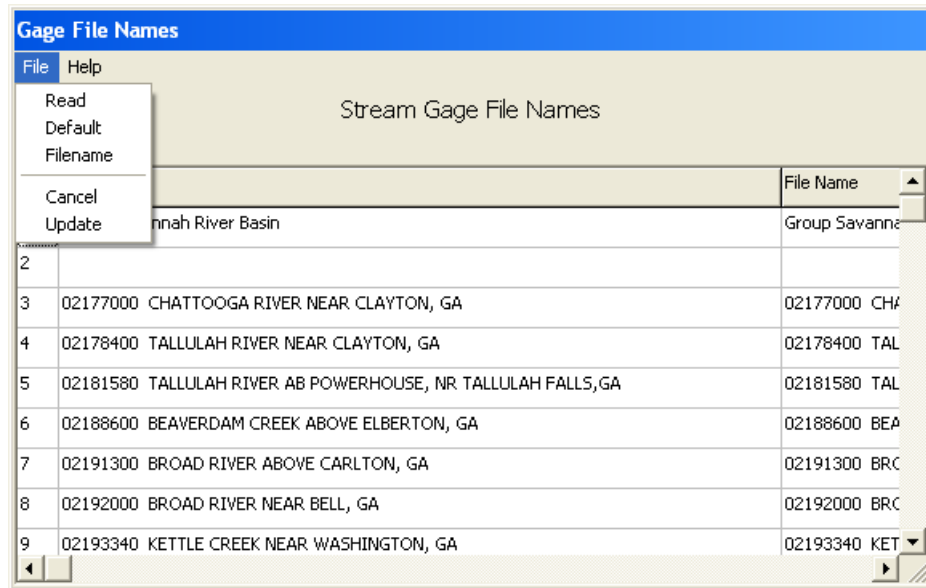


**Figure 56.** Program *UpdateSW* - Sample screen showing the display using the **FileNames** option.

- **Add:** The current file list can be modified with this form, and appears in the right panel (Figure A-6). A Master List can be loaded to the left side with the **Load** option located in the drop-down menu under File in the Add Station window. The real-time surface water sites for Georgia, for example, are contained in *GA\_SW\_UV.txt*, and real-time groundwater sites for Georgia are contained in *GA\_GW\_UV.txt*. Sites can be added to the operational list by dragging sites to the right. Only valid sites can be dragged. Sites can be removed by dragging sites from the operational list to the left. The Master List will not be permanently modified by this action. Upon return, if the file list is modified, the program will display the filenames form.

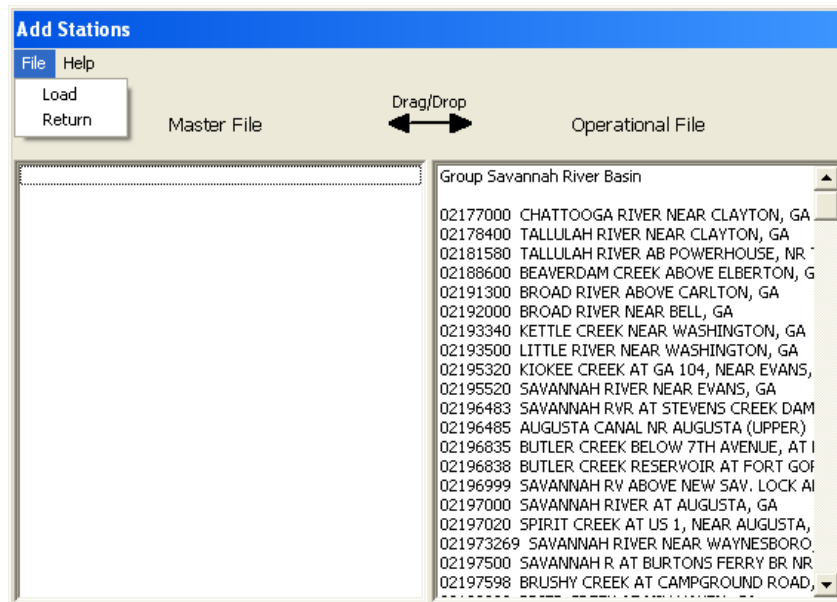


**Figure 57.** Program *UpdateSW* - Sample screen showing the display using the **Add** option.

- **View:** This option allows the user to inspect the last file downloaded and the full *Excel* spreadsheet (Figure A-7). The site is selected from the list at the bottom; the daily values or real-time values are selected with the adjacent button. The *Excel* file can be modified by the following sequence: select a cell with the mouse, change the value, press the <enter> key. If the file is changed, the user can select to save the changes when the **View** form is closed. A sample screen showing the program operation is provided below.

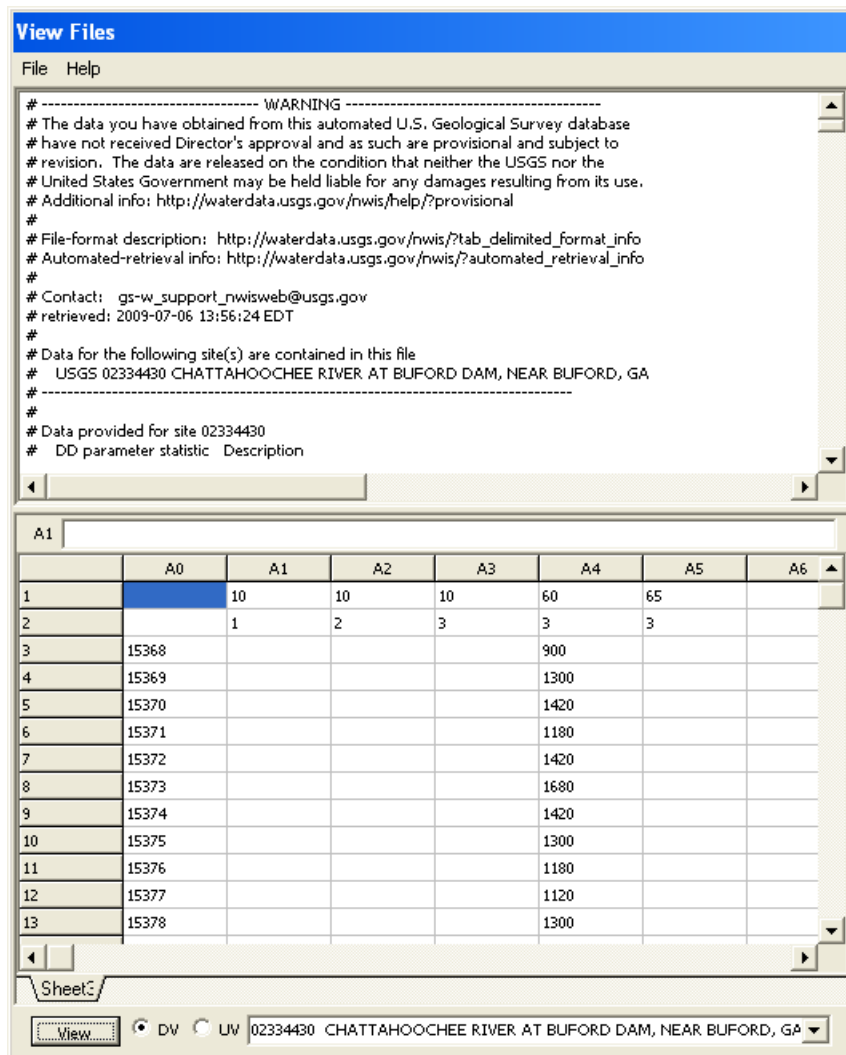


**Figure 58.** Program *UpdateSW* - Sample screen showing the display using the **View** option.

- **Exit:** Exit the program. Various defaults are set when exited in this manner. If the "x" is used to exit the program, these defaults will not be set.

## Graph Command

- **Graph:** To view a Cartesian plot of the data in the Update Gage Data window click Graph from the menu bar (Figure A-8). When the Graph window appears a site is selected from the drop down list box at the bottom of the Form. A button is used to select between daily and real-time values. The **Plot** button will display the selected site. If both discharge and gage height data exists then discharge will be plotted on the left axis and gage height will be plotted on the right axis. For groundwater, depth below surface will be plotted. The **Graph > Options** menu item allows other data to be plotted.

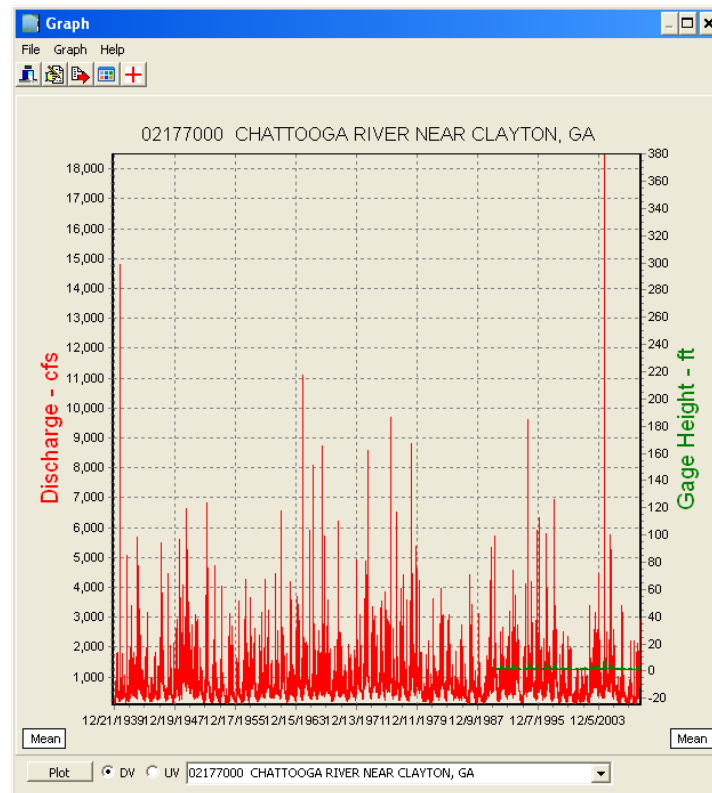


**Figure 59.** Program *UpdateSW* - Sample screen showing the display using the **Graph** option.

- **Edit:** This option allows the user to manually change most aspects of the plot, including line color and axis labels (Figure A-9). Printing can also be accomplished from this option.

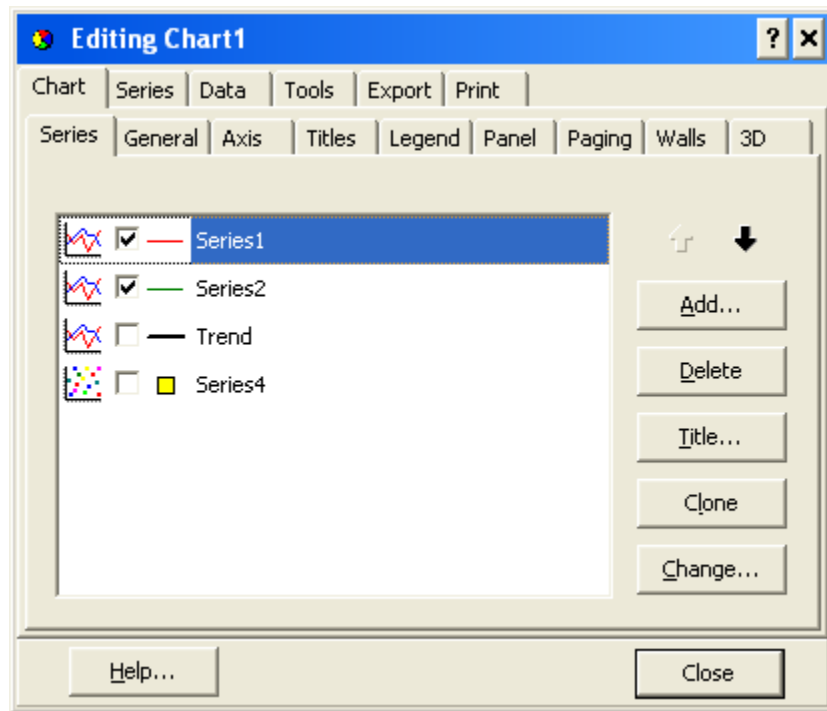


**Figure 60.** Program *UpdateSW* - Sample screen showing the display using the **Edit** option in the **Graph** window.

- **View:** This option allows the user to inspect the data in a full *Excel* spreadsheet. The site is selected from the list at the bottom; the daily values or real-time values are selected with the adjacent button. The *Excel* file can be modified by the following sequence: select a cell with the mouse, change the value, press the <enter> key. If the file is changed, the user can select to save the changes when the **View** form is closed.

- **Options:** This option, located in a drop-down menu under Graph, allows the user to select any data to be plotted on the left or right axis (Figure A-10). The list box for each axis lists all the data contained in the *Excel* file. This option also contains an edit box to change the time gap for plotting breaks in the data.

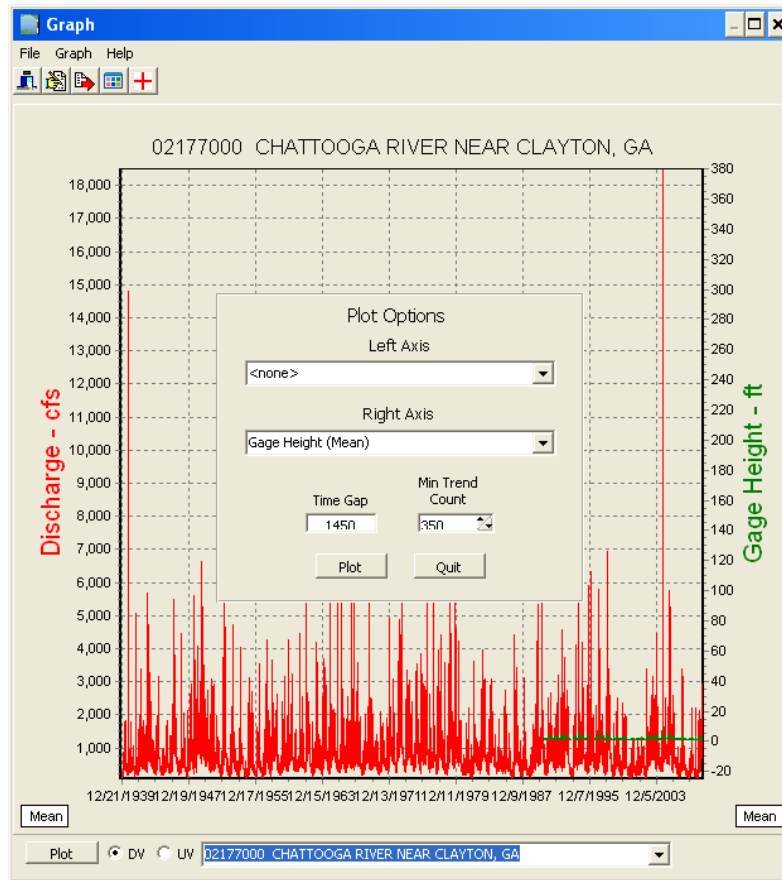


**Figure 61.** Program *UpdateSW* - Sample screen showing the display using **Options** in the Graph window.

- **Plot Fast:** The curves are broken if there is a gap in the data (default). The magnitude of the time gap can be changed in **Options** menu option. The **Plot Fast** option will plot the data without the breaks. It is not reliable if there is a large break in the data.
- **Cursor:** This option displays a mouse cursor, and shows the cursor position at the top of the plot. The x-axis is shown as Date/Time, and the y-axis is shown in units of either the left or right axis. T
- **Alternate:** This option allows the user to alternate the cursor between the left and right axis. Initially, the cursor points to the left y-axis. This option is only available when the cursor is turned on.
- **Flip Series:** the **flip** button will alternate between the two curves.

- **Show Point** : This command displays all the individual data points on the graph
- **Copy to Clipboard**: This option is the easiest way to save a copy of the plot. If a graphics capable program is also running, selecting this option will place a copy of the graph in the clipboard. In the other program, **paste** will place the copy in the program.
- **Trend**: For daily values of groundwater (depth below surface), the annual average depth and annual trend can be shown with the **Trend** option in the **Main** menu. The year is calculated from January 1. In order to provide a statistically significant result, the test requires a minimum number of daily observations per year, and a minimum number of years of monitoring data overall. These values can be modified on the **Options** menu.

## Program River 2

River2 is designed to display streamflow, and summarize the data using several statistical techniques. These procedures include flow duration curve using a log normal distribution, and high and low flows using several extreme value distributions. The annual series for these distributions is displayed in tables

The program reads data in an Excel spreadsheet that was produced by the UpdateSW program (daily data read from the USGS website). In addition, daily flow from the UK equivalent (National River Archive: [http://www.ceh.ac.uk/data/nrfa/river\\_flow\\_data.html](http://www.ceh.ac.uk/data/nrfa/river_flow_data.html)) can also be read. The file Tamar.xls is an example of this data type. Note that these data must be converted from the .csv format to the .xls format before they can be used. Daily data from other sources need to be put in one of these formats. If the data is in .cfs, use the USGS format; if the data is in cumecs (cubic meters per second), use the UK format.

After the data is read, all calculations are performed and the different views of the data can be selected with the tabs at the top. In most of the views, there are multiple plot options selected with a drop down menu. If options are changed on the Info page, the Update button must be selected to perform the recalculations.

## Files

- **USGS**: This program currently reads average daily flows from an Excel file produced by the UpdateSW program. It is an Excel file, with date/time (decimal format permissible) in one column, and discharge in the next column. Above the date column in row 1, the code 60 (USGS code) denotes flow. The program selects the column headed by this column, which need not be in column 1. The second code on row two must be there, but is not used by this program.
- **UK**: Data from the National River Archive ([http://www.ceh.ac.uk/data/nrfa/river\\_flow\\_data.html](http://www.ceh.ac.uk/data/nrfa/river_flow_data.html)) can also be read after it has been converted from the .csv format to the .xls format. The data on the first line is used to label the data, and the flow data is read starting at line 2. The data must be in the day, month, year, flow, code format.

- Other: If data is used from another source, it needs to be put in an Excel spreadsheet in the same form as one of the examples included with this program - either USGS or UK. Choose the one with the appropriate units, or change the units with the Edit option.

### ***Running River2***

1. Navigate to C:\Program Files\HOTL\ and click on River2.exe. The Open Gage Description File will open (Figure A-11).

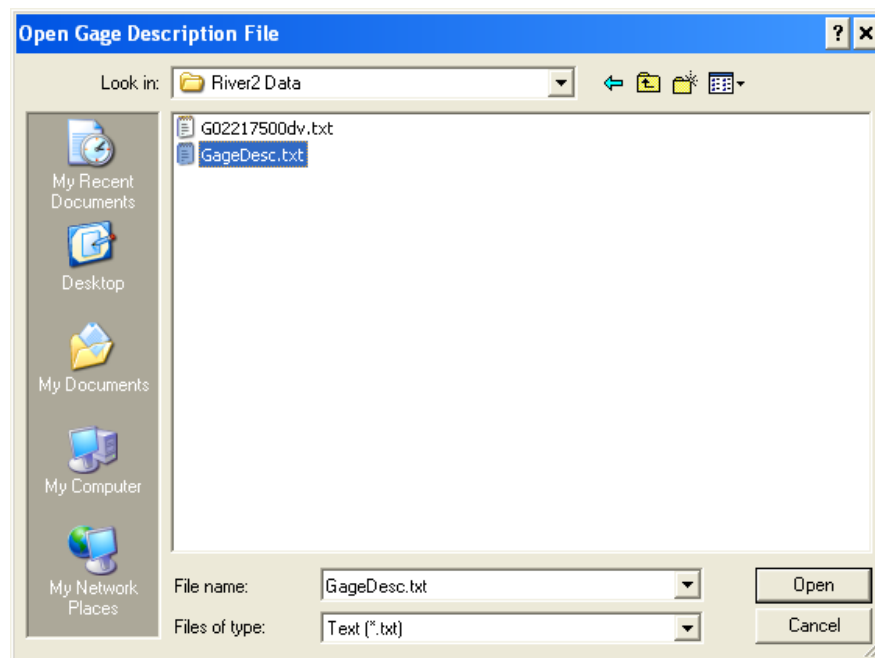


**Figure 62.** Program *River2* - Sample screen showing how to open the GageDesc.txt file.

2. Navigate to C:\Documents and Settings\administrator\My Documents\River2 Data and select GageDesc.txt. Click Open. The River II window should appear (Figure A-12).

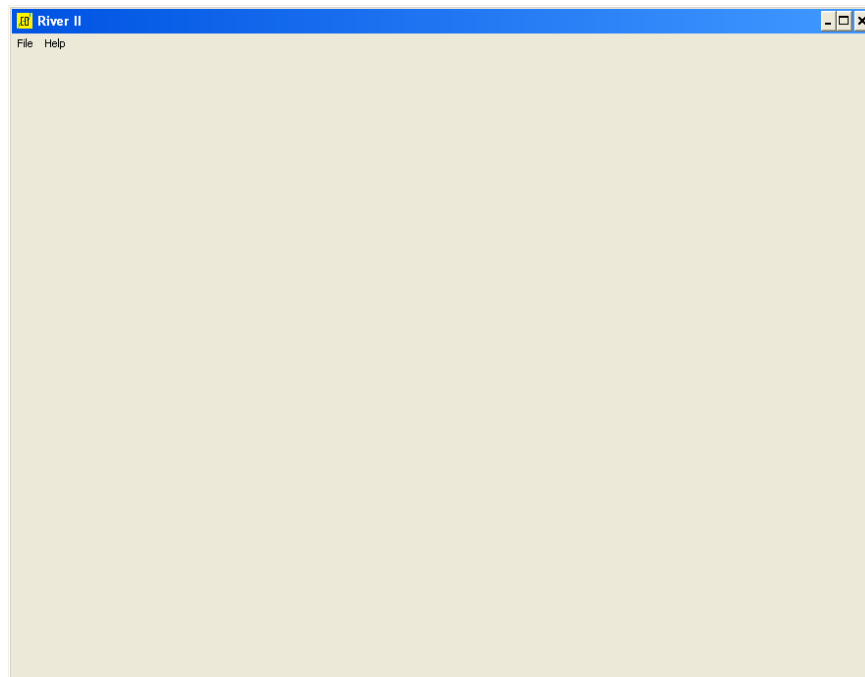


**Figure 63.** Program *River2* - Sample screen showing how *River2* appears when first opened.

3. In the River II window click File. In the drop-down menu click Read. The Open Gage File Window should appear (Figure A-13).

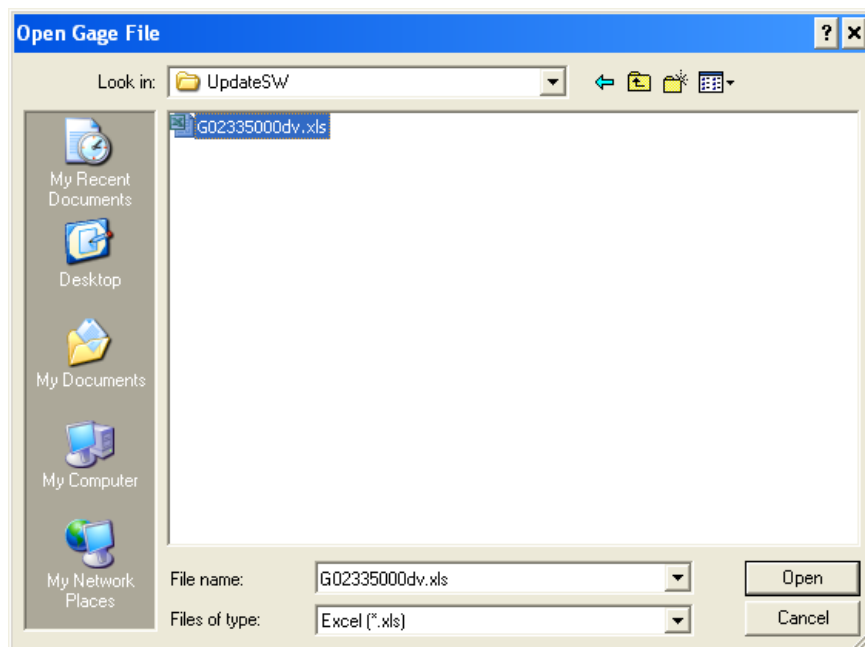


**Figure 64.** Program *River2* - Sample screen showing navigating to the gage xls files.

4. Select the .xls file associated with the gage you selected in *UpdateSW*. Then click open. The River II window will update with the gage data added and the Info tab will be selected.
5. Different views are selected with the tabs at the top of the page (Figure A-14). These include Info, Flow, Tables, High Flow, Flow Duration Curve, Low Flow, Seasonal, and Annual

**Figure 65.** Program *River2* - Sample screen showing the **Info** tab as *River2* appears after it has read the .xls file.

### **Info Tab**

The Info tab contains the calculation options that determine how the plots are created.

- **Gage Number/Description:** The USGS gage number, with accompanying description is shown in the Gage# and Description box at the top of the screen. The gage number is read in from the file name, and the gage description is found in the GageDesc.txt file. These are read only fields and cannot be edited.
- **Record Information:** In the Record Information box, the start date and end dates of the data collected by the USGS are shown. These are read only fields and cannot be edited.

- **Record Set:** In the Record Set box, the start date and end dates of the data analyzed with the program can be adjusted to a specific period of record.
  - **Start Time:** The start date for the data to be analyzed can be set with this field. This can be done by typing the desired date in the date field, or by using the calendar button. If a date is set that is before the Start Date in the Record Information box then the value is automatically reset to the Start Date in the Record Information box.
  - **End Time:** The end date for the data to be analyzed can be set with this field. This can be done by typing the desired date in the date field, or by using the calendar button. If a date is set that is after the End Date in the Record Information box then the value is automatically reset to the End Date in the Record Information box.
  - **Number of Multi-Days:** The number of days in a moving average multi-day calculation can be specified in this field.
- **Log-Pearson III Options Regional Skew:** Options for the Log-Pearson III calculations are set in this box.
  - **High-flow Regional Skew:** The regional skew for high flow is entered in this field. The skew map for the US can be shown with the speed button located beside the High-flow Skew Type drop down menu (Figure A-15).

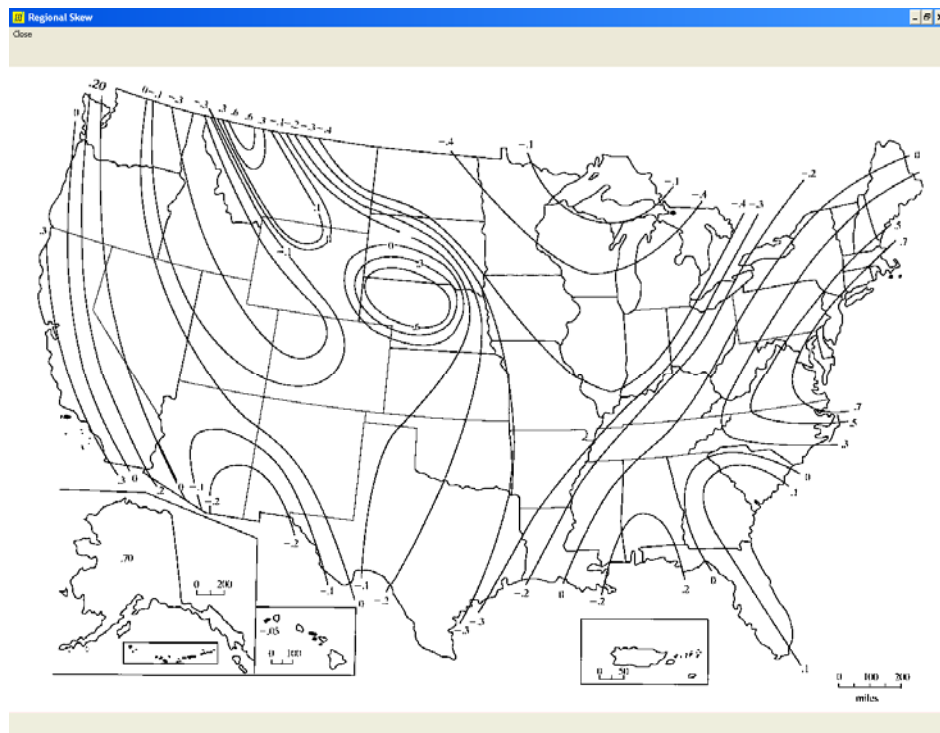


**Figure 66.** Program *River2* - Sample screen showing the high-flow regional skew map.

- o **High-flow Skew Type:** The skew calculation is set with this drop down menu.
  - **Station** skew will be the skew calculated from the data. This should be used for long datasets. It is generally used for datasets of over 100 years
  - The **Regional** skew entered in the field above will be used in calculations if this option is chosen. This option should be used for stations with a short record. It is generally used for datasets of less than 25 years.
  - The **Automatic** option will use a weighted average of the station and regional skews, depending on the length of record. For record lengths less than 25 years, the regional skew will be used, and for lengths longer than 100 years the station skew will be used. It is recommended that Automatic always be used and that the correct regional skew be entered into the Log Person Options Regional Skew box.
- o **Low-flow Regional Skew:** The regional skews for low flow are entered in this field. There is no US map available for low-flow skews.
- o **Low-flow Skew Type:** The skew calculation is set with this drop down menu.
  - **Station** skew will be the skew calculated from the data. This should be used for long datasets. It is generally used for datasets of over 100 years
  - The **Regional** skew entered in the field above will be used in calculations if this option is chosen. This option should be used for stations with a short record. It is generally used for datasets of less than 25 years.
  - The **Automatic** option will use a weighted average of the station and regional skews, depending on the length of record. For record lengths less than 25 years, the regional skew will be used, and for lengths longer than 100 years the station skew will be used.
  - **NOTE:** Low-flow regional skew maps are not available.
- **Annual Series:** Options for the annual series are set in this box.
  - o **Minimum Number of Days:** The minimum number of days entered in this field will be used to filter the annual series. If fewer days are available for the calculation of the annual series (high, low or multi-) than in this field, the year will be skipped.
    - **NOTE:** Single days missing in the record are interpolated with a linear interpolation of the adjacent days. Consequently they are not counted as missing days
  - o **High-flow Start Day:** This field sets the start date for the high-flow water year. It can be edited directly or with the adjacent calendar tool.

- o **Low-flow Start Day:** This field sets the start date for the low-flow water year. It can be edited directly or with the adjacent calendar tool.
- o **Plotting Formulas:** The plotting formulas for the high-flow and low-flow calculations are set with the appropriate drop down menu. Plotting formulas available are:

|            |                    |
|------------|--------------------|
| Weibull    | $n+1 / i$          |
| Hazen      | $n / i-0.5$        |
| Gringorten | $n+0.12 / i-0.44$  |
| Blom       | $n+0.25 / i-(3/8)$ |
| Bernard    | $n+0.4 / i-0.3$    |
| Beard      | $n+0.38 / i-0.31$  |

Where **n** is number of years of data in the annual series, and **i** is the rank. If in doubt, it is suggested you use the Weibull formula, which is set as the default.

- **Update Button:** This button must be "clicked" to recalculate the data with the choices made on this page. Therefore, it is important to Update after before looking at any graphs or tables if a change was made. No re-calculation is performed if this button is not selected.

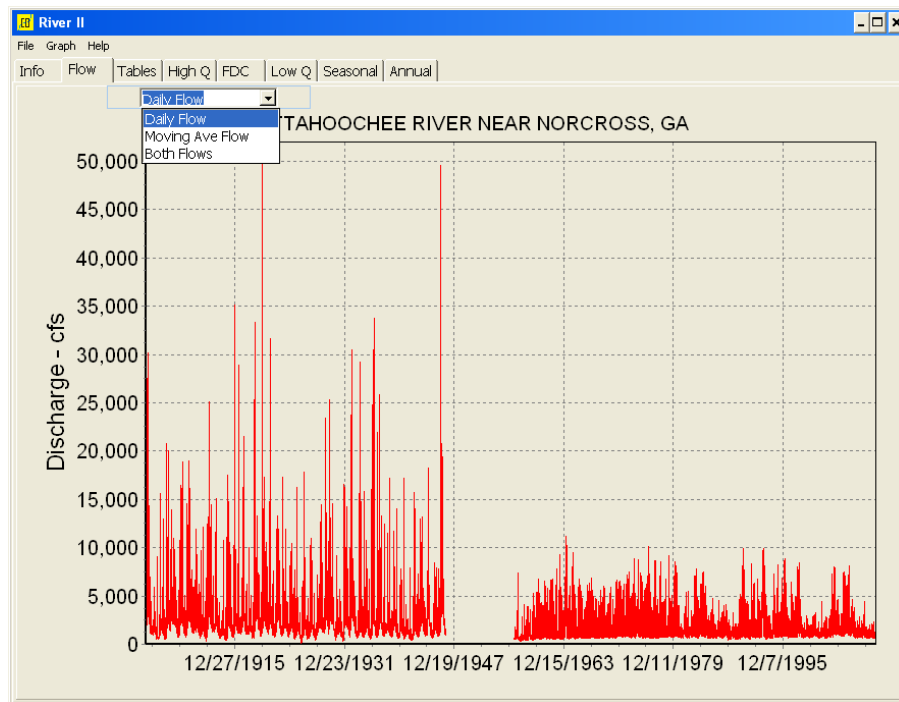
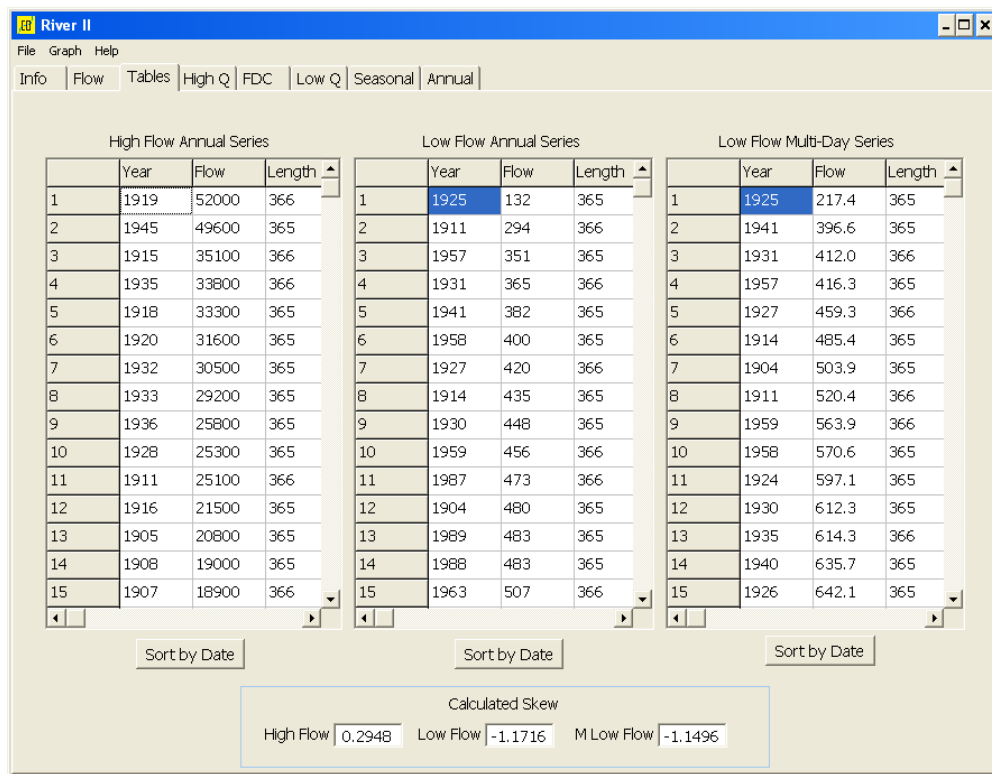


**Figure 67.** Program *River2* - Sample screen showing the **Flow** tab.

## Flow Tab

The Flow tab displays the daily flow (Figure A-16).

- **Flow:** Areas of interest can be selected with the Graph->Zoom X-Axis option. The desired start and end times can be set with the edit fields or with the (vertical) cursor, which is displayed if the appropriate radio button is selected. If the cursor is not found, double click with the mouse and the cursor will follow the mouse. Another double click will freeze the cursor, and it will have to be "grabbed" with the mouse to move it. The start date must be before the end date. After the ends are selected, the plot is rescaled with the **zoom** button. The resulting plot can be rescaled with the same procedure. The full button will re-plot all of the daily flows.
- **Daily Flow:** The daily flow option on the drop down menu at the top of the graph will plot the daily flows. The vertical scale can be reset with the Edit menu option. The time scale is most easily reset with the Zoom X-Axis menu item.
- **Multi-Day Flow:** The multi-day flow option on the drop down menu at the top of the plot will plot the moving average multi-day flows. The vertical scale can be reset with the Edit menu option. The time scale is most easily reset with the Zoom X-Axis menu item.
- **Both Flows:** Both flows can be shown with this option. The red line is the daily flow, and the black line is the multi-day flow.



|    | Year | Flow  | Length |
|----|------|-------|--------|
| 1  | 1919 | 52000 | 366    |
| 2  | 1945 | 49600 | 365    |
| 3  | 1915 | 35100 | 366    |
| 4  | 1935 | 33800 | 366    |
| 5  | 1918 | 33300 | 365    |
| 6  | 1920 | 31600 | 365    |
| 7  | 1932 | 30500 | 365    |
| 8  | 1933 | 29200 | 365    |
| 9  | 1936 | 25800 | 365    |
| 10 | 1928 | 25300 | 365    |
| 11 | 1911 | 25100 | 366    |
| 12 | 1916 | 21500 | 365    |
| 13 | 1905 | 20800 | 365    |
| 14 | 1908 | 19000 | 365    |
| 15 | 1907 | 18900 | 366    |

|    | Year | Flow | Length |
|----|------|------|--------|
| 1  | 1925 | 132  | 365    |
| 2  | 1911 | 294  | 366    |
| 3  | 1957 | 351  | 365    |
| 4  | 1931 | 365  | 366    |
| 5  | 1941 | 382  | 365    |
| 6  | 1958 | 400  | 365    |
| 7  | 1927 | 420  | 366    |
| 8  | 1914 | 435  | 365    |
| 9  | 1930 | 448  | 365    |
| 10 | 1959 | 456  | 366    |
| 11 | 1987 | 473  | 366    |
| 12 | 1904 | 480  | 365    |
| 13 | 1989 | 483  | 365    |
| 14 | 1988 | 483  | 365    |
| 15 | 1963 | 507  | 366    |

|    | Year | Flow  | Length |
|----|------|-------|--------|
| 1  | 1925 | 217.4 | 365    |
| 2  | 1941 | 396.6 | 365    |
| 3  | 1931 | 412.0 | 366    |
| 4  | 1957 | 416.3 | 365    |
| 5  | 1927 | 459.3 | 366    |
| 6  | 1914 | 485.4 | 365    |
| 7  | 1904 | 503.9 | 365    |
| 8  | 1911 | 520.4 | 366    |
| 9  | 1959 | 563.9 | 366    |
| 10 | 1958 | 570.6 | 365    |
| 11 | 1924 | 597.1 | 365    |
| 12 | 1930 | 612.3 | 365    |
| 13 | 1935 | 614.3 | 366    |
| 14 | 1940 | 635.7 | 365    |
| 15 | 1926 | 642.1 | 365    |

Sort by Date      Sort by Date      Sort by Date

Calculated Skew  
High Flow 0.2948    Low Flow -1.1716    M Low Flow -1.1496

Figure 68. Program River2 - Sample screen showing the Tables tab.

### Tables Tab

The Tables tab displays the high and low-flow annual series (Figure A-17). It also displays the skew used for the Log-Person III calculation for each annual series in a box at the bottom of the window.

- **High Flow:** The high-flow annual series is shown in the left table. Initially it is sorted in descending order. The left column is the year, the middle column is the maximum flow for that year, and the right column is the number of days examined for that year. The button at the bottom will toggle the table between sorting by year in ascending order and sorting by flow in descending order.
- **Low Flow:** The low-flow annual series is shown in the middle table. Initially it is sorted in ascending order. The left column is the year, the middle column is the minimum flow for that year, and the right column is the number of days examined for that year. The button at the bottom will toggle the table between sorting by year in ascending order and sorting by flow in ascending order.
- **Low-flow Multi-Day Series:** The moving average multi-day low-flow annual series is shown in the right table. The number of days used in the calculation is selected on the Info page. Initially it is sorted in ascending order. The left column is the year, the middle column is the minimum multi-day flow for that year, and the right column is the number of days examined for that year. The button at the bottom will toggle the table between sorting by year in ascending order and sorting by flow in ascending order.

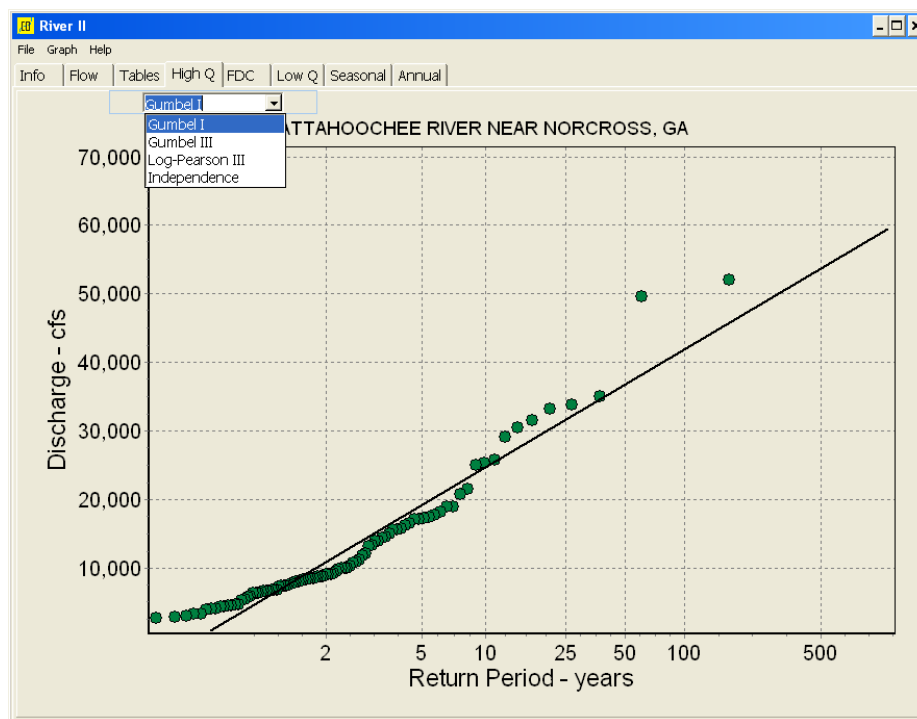


Figure 69. Program *River2* - Sample screen showing the **High Q** tab.

### High-Q Tab

The High Q tab shows the high-flow extremal analysis (Figure A-18).

- **High Flow:** The circles represent the flow of the annual series plotted with the Weibull plotting formula  $n+1/m$ , where  $n$  is the number of years in the series, and  $m$  is the rank. The solid line is the best fit of the statistical distribution chosen in the drop down menu in the upper left. (It is calculated by the method of moments.) The curve is best interpolated with the Cursor, enabled from the main menu. When enabled, the flow and the return period in years are shown in the upper right corner of the plot.
- **Gumbel I:** Gumbel I high-flow analysis.
- **Log-Pearson III:** Log-Pearson III high-flow analysis. The skew calculation is determined by choices on the Info page.
- **Independence:** The annual series verse the value for the next year is plotted in this view. Unacceptable serial correlation can be corrected by choosing another start date for the high flows on the Info page.

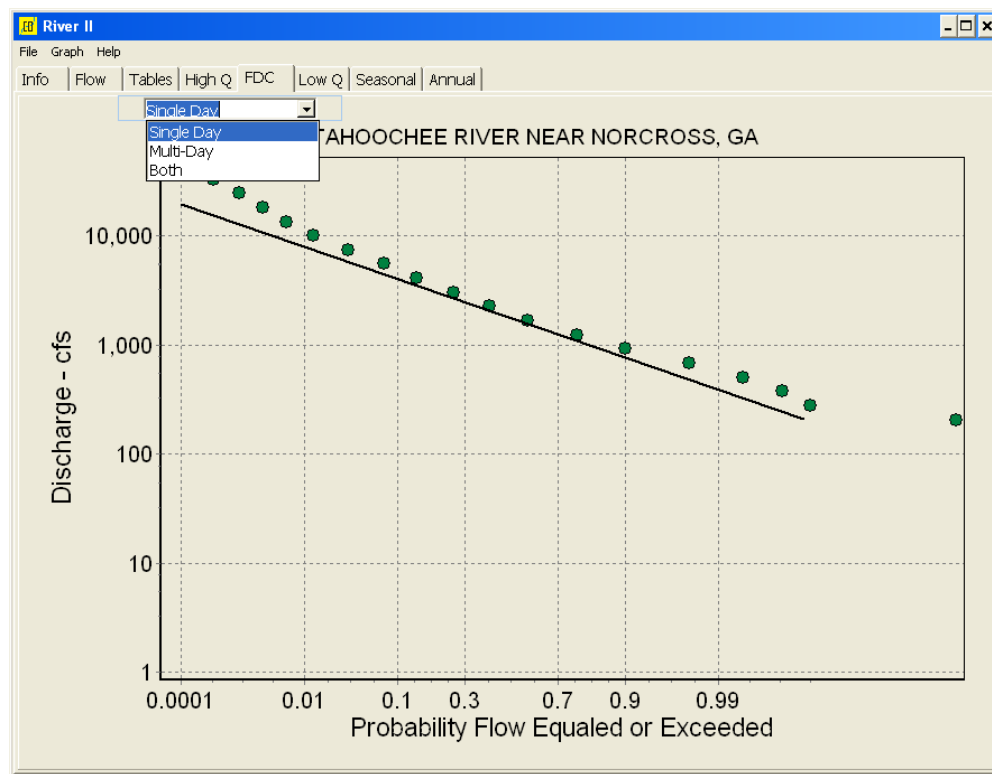


**Figure 70.** Program *River2* - Sample screen showing the **FDC** tab.

### FDC Tab

In the FDC tab the flow duration curves are plotted (Figure A-19). The squares are calculated from the daily flow, with twenty evenly spaced bins determined from the log of the flows. The straight line is the best fit of the log-normal distribution from the daily flow data using the maximum likelihood estimator.

- **Single Day:** Single day flows are used for the calculation in this view.
- **Multi Day :** Moving average multi-day flows are used for the calculation in this view. The number of days in the calculation is set on the Info page.
- **Both Plots:** Both single day and multi-day flows are shown in this view. The green values are from the single day flows, and the red values are from the multi-day flows. The number of days in the multi-day flow calculation is set on the Info page.

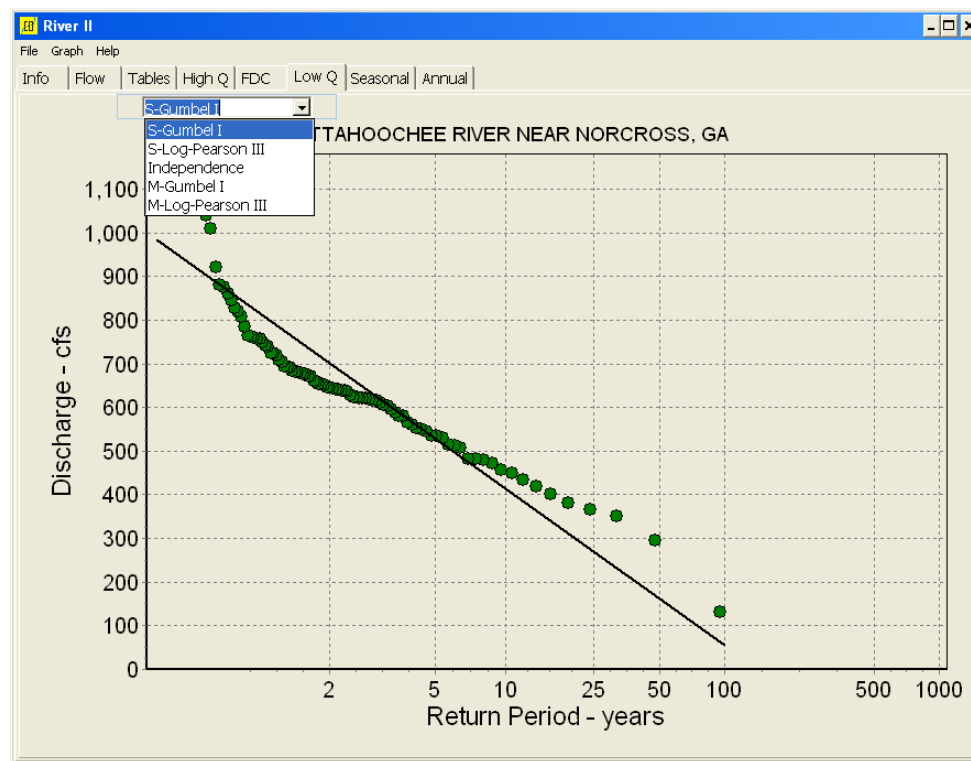


Figure 71. Program *River2* - Sample screen showing the **Low Q** tab.

### Low Q Tab

The Low Q tab shows the low-flow extremal analysis (Figure A-20).

- **Low Flow:** The circles represent the flow of the annual series plotted with the Weibull plotting formula  $n+1/m$ , where  $n$  is the number of years in the series, and  $m$  is the rank. The solid line is the best fit of the statistical distribution chosen in the drop down menu in the upper left. (It is calculated by the method of moments.) The curve is best interpolated

with the Cursor, enabled from the main menu. When enabled, the flow and the return period in years are shown in the upper right corner of the plot.

- o **Gumbel I- Single Day:** Gumbel I low-flow analysis using single day data.
- o **Log-Pearson III- Single Day:** Log-Pearson III low-flow analysis using single day data. The skew calculation is determined by choices on the Info page.
- o **Independence:** The annual series versus the value for the next year for the single day low-flow annual series is plotted in this view. Unacceptable serial correlation can be corrected by choosing another start date for the low flows on the Info page.
- o **Gumbel I- Multi-Day:** Gumbel I low-flow analysis using multi-day data. The number of days in the multi-day flow calculation is set on the Info page.
- o **Log-Pearson III- Multi-Day:** Log-Pearson III low-flow analysis using multi-day data. The skew calculation is determined by choices on the Info page. The number of days in the multi-day flow calculation is set on the Info page.

### Seasonal Tab

The seasonal tab shows the minimum seasonal flows for each year (Figure A-21).

- **Seasonal:** The minimum daily flow is show in the seasonal tab for January, February, June and July. The Lin Slope column is filled in form the accepted values decided upon by the user in Annual Tab

|    | Year | Jan  | Feb  | Jun  | Jul  | Lin Slope |
|----|------|------|------|------|------|-----------|
| 1  | 1903 | 1640 | 1970 | 2300 | 1640 |           |
| 2  | 1904 | 920  | 1220 | 515  | 560  |           |
| 3  | 1905 | 948  | 1120 | 1120 | 1220 |           |
| 4  | 1906 | 1720 | 1770 | 1460 | 1360 |           |
| 5  | 1907 | 2100 | 1990 | 1360 | 990  |           |
| 6  | 1908 | 1980 | 2240 | 1440 | 1120 |           |
| 7  | 1909 | 1640 | 1640 | 2520 | 1820 |           |
| 8  | 1910 | 1470 | 1510 | 1730 | 1640 |           |
| 9  | 1911 | 1080 | 850  | 910  | 790  |           |
| 10 | 1912 | 1560 | 1890 | 1890 | 1800 |           |
| 11 | 1913 | 1400 | 1890 | 1240 | 925  |           |
| 12 | 1914 | 930  | 995  | 538  | 460  |           |
| 13 | 1915 | 2020 | 2370 | 1060 | 832  |           |
| 14 | 1916 | 2120 | 1920 | 1220 | 1110 |           |
| 15 | 1917 | 1680 | 1840 | 1560 | 1080 |           |
| 16 | 1918 | 1080 | 1740 | 940  | 670  |           |

**Figure 72.** Program *River2* - Sample screen showing the **Seasonal** tab.

### Annual Tab

The Annual tab is used to look at all the data for a single year within the data record (Figure A-22).

- **Annual:** Looks at the data for a single year. The user can move between years with the left and right arrow buttons located under the graph.
  - **Pick:** Allows the user to select several data points. The data points that are selected should try and represent the base flow for the river during that year.
  - **Analyze:** This command plots a best-fit line for the points selected for the points that were selected.
  - **Line Slope:** The line slope is calculated from the best-fit line. If the user would like to save this as the line slope for the base flow for that year then the user can select 'Accept'. When the user hits 'Accept' the line slope value is added to Lin Slope column on the table in the Seasonal tab. If the user does not feel that the slope an accurate computation for the annual base flow then the user should click 'Reject' and select new points.

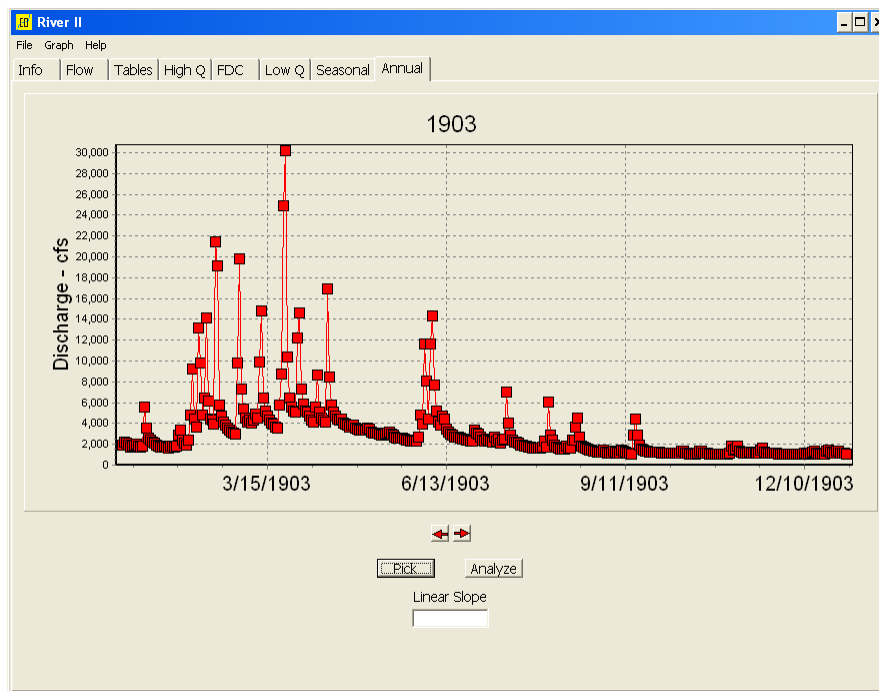


**Figure A-22.** Program *River2* - Sample screen showing the **Annual** tab.



## Appendix B – Streamflow Measurement Procedure

Measuring streamflow is important in understanding and predicting the probability of flood and drought conditions. The easiest way to measure streamflow is to install a gage and establish a stage-flow curve.

When selecting a gaging station site the hydrology of the area should be considered. An ideal site for a gaging station is an area where the stream is straight for 300 ft above and below the station and is easily accessible. It is also preferable that the flow be restricted to a single channel at all stages. Wetland areas are not ideal because there is so much subsurface flow that bypasses the channel. The banks should be stable and high enough to contain floods. This is important for maintaining a constant cross-section and it is for this same reason that sites where the streambed is prone to scour or fill are sought. If possible, there should be some natural channel controls such as bedrock outcrops with no aquatic growth. Artificial channel controls can be installed if natural ones are not present. The site should be selected far enough upstream of any confluence to avoid influences on the stage height. It is rare to find a stream location that meets all of these requirements within the park boundaries, therefore common sense must be used in selecting a site. Bridges make good gaging station sites because they are extremely accessible and often the embankments are paved so the cross section remains constant.

After a site has been selected, a datum plane must be established. The datum plane is established to verify that the channel morphology has not changed. If the stream-channel changes, then a new rating curve must be established or a coefficient can be applied to the old rating curve to account for the new channel cross-section. The datum can be arbitrarily set to when the streamflow is zero, the bottom of the channel, or the datum can be based on the elevation above sea level. In order to maintain a permanent datum at the gaging location at least 2 or 3 reference marks should be selected. Reference marks are permanent points, independent of the gage structure, with a known gage height elevation. Every so often the gage structure should be compared with the reference marks to ensure accurate data collection.

After a datum is established, the staff gage should be installed on a secure structure in the stream (Figure B-1). Staff gages look like large steel plated measuring tapes that are marked to hundredth of a foot for accuracy. At the selected cross-section where the gage is located the flow velocity must be measured. To get a precise streamflow velocity measurement the flow must be taken at several verticals across the stream using a current meter or a flow meter (Figure B-2). The general rule for determining the number of verticals to measure is based on stream width. The stream width is measured from bank to bank at right angles to the flow direction with a measuring tape. If the stream width is less than 5 ft, then verticals should be spaced .5 ft apart; if the stream is greater than 5 ft, 20 to 30 verticals are ideal but a minimum of 10 is required. To determine each location to use to measure the flow, take the entire stream length and divide it by the number of verticals to be measured to give the distance between verticals. Then take that distance and divide it by two. This will give you the distance from the bank for taking your first flow reading. For each additional flow reading add the distance between verticals. For instance, if your stream width is 10 ft and you decide to do 15 verticals, then the distance between verticals would be .67 ft and your first point would be at .33 ft from the bank. The second point would be at 1 ft from the shore. The third point would be at 1.67 ft from the shore and so on.

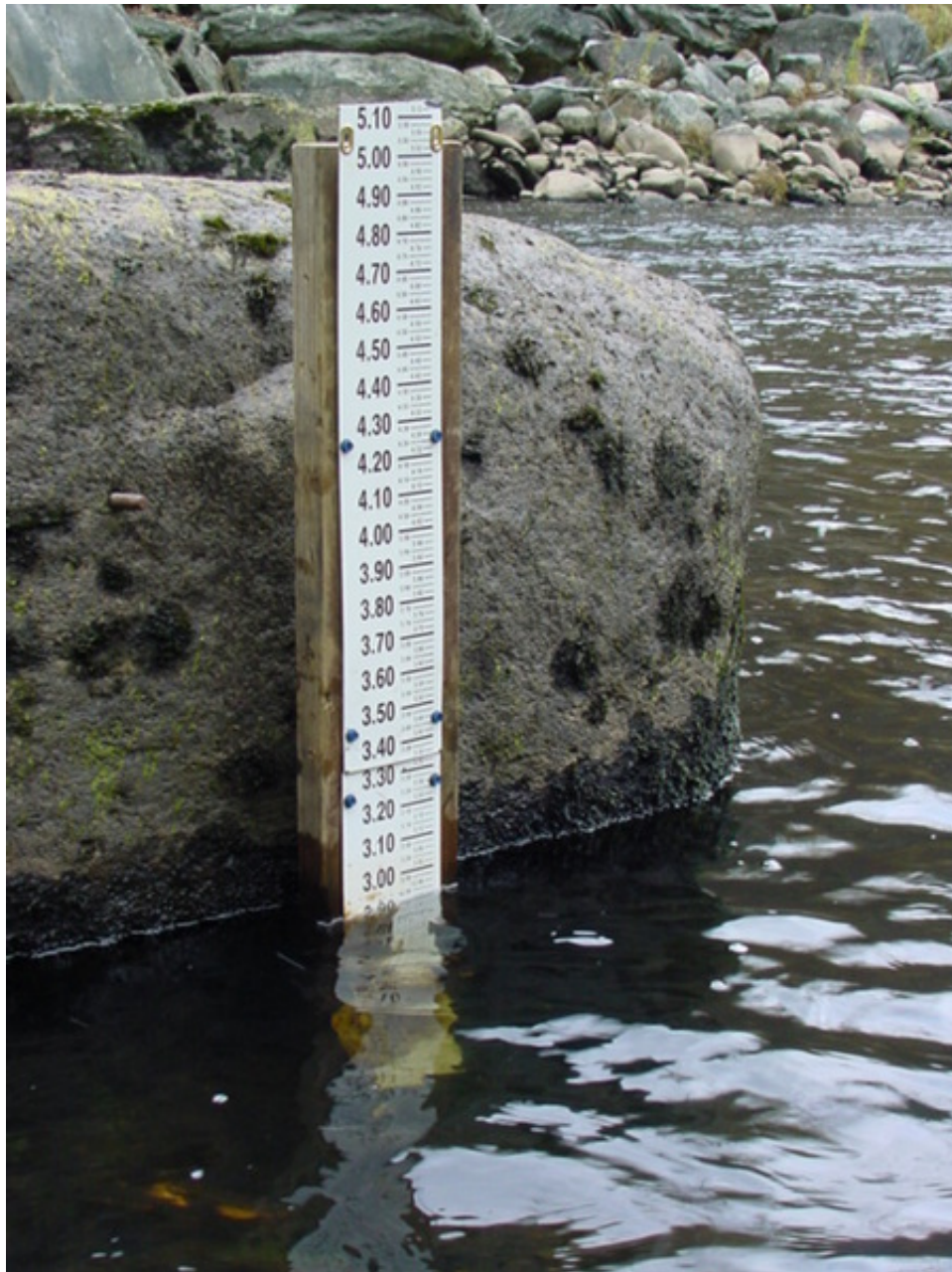


**Figure 73.** Staff gage positioned vertically to monitor river stage.

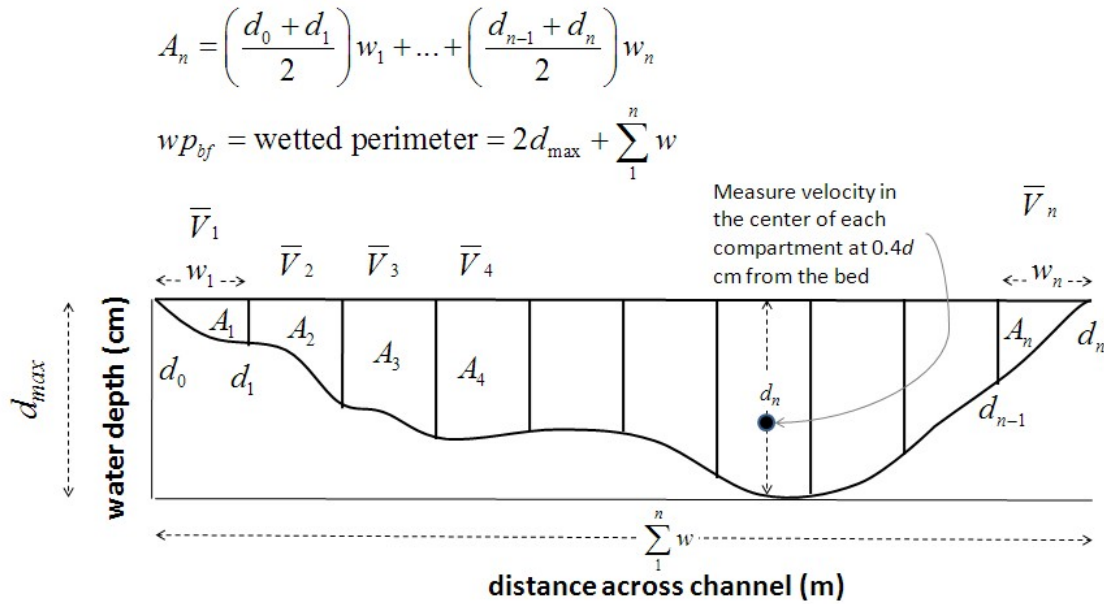


**Figure 74.** Channel measurements required for determining stream discharge.

The current meter or flow meter should be set to record the velocity at 60% of the stream depth, if the depth at that location is less than 2.5ft. If the depth is greater than 2.5 ft, then the velocity should be measured at 20% and 80% of the stream depth then the two velocity measurements are averaged together. Once velocity measurements are collected for each vertical the flow can be calculated. To determine area each vertical represents the sampling depth at each location and is multiplied by the distance between verticals. To get the discharge at each vertical, the velocity is multiplied by the corresponding area. The stream's total discharge is the sum of the discharges at each vertical.

$$Q = \left( \frac{D_1 + D_2}{2} \right) \left( \frac{V_1 + V_2}{2} \right) W_1 + \dots + \left( \frac{D_m + D_n}{2} \right) \left( \frac{V_m + V_n}{2} \right) W_m$$

$Q$  = discharge,  $D$  = depth,  $V$  = velocity,  $W$  = width (Rantz and others, 1982)

When the gage is first installed, record several flow measurements at different stages to establish a stage-flow curve (Figure B-3). Once the curve is established, the flow only needs to be measured monthly to make sure the cross section hasn't been altered. The stage however should be measured twice daily and during times of rapid change. Plotting the stage against the discharge for a variety of flows develops the stage-flow curve. Once this relationship is established, a discharge rate can be determined based on the stage measurements.

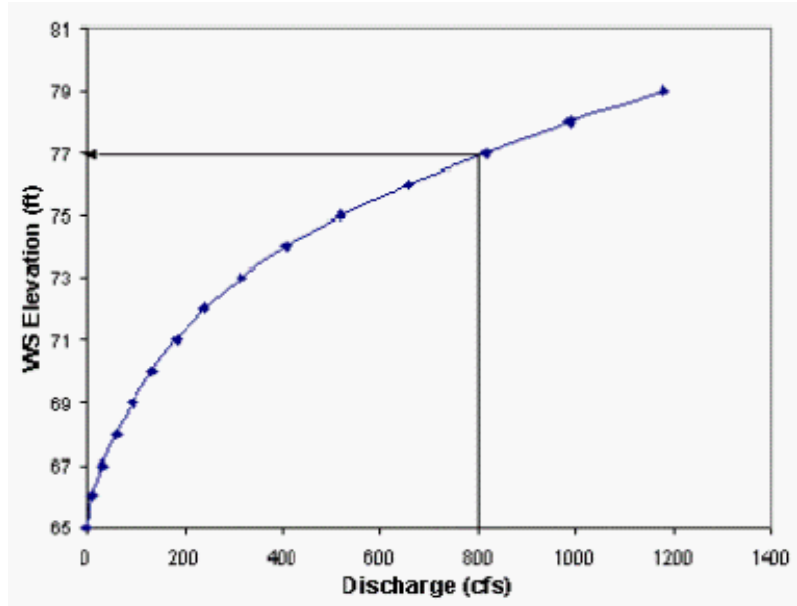


**Figure 75.** Rating curve used to relate stage to discharge.

## Appendix C- Sea Level Rise Scenarios

Presented below are maps (Figures C-1 through C-5) of hypothetical scenarios for the effect of sea level rise combined with storm surge projections on coastal parks within the SECN (FOFR, FOMA, FOPU, FOSU, and TIMU). The Digital Elevation Models (DEM) for each park were downloaded from the Geospatial Data Gateway (<http://datagateway.nrcs.usda.gov/>). The DEMs were used to illustrate changes in sea level resulting from climate change (Meehl et al. 2007) and storm surge estimations.

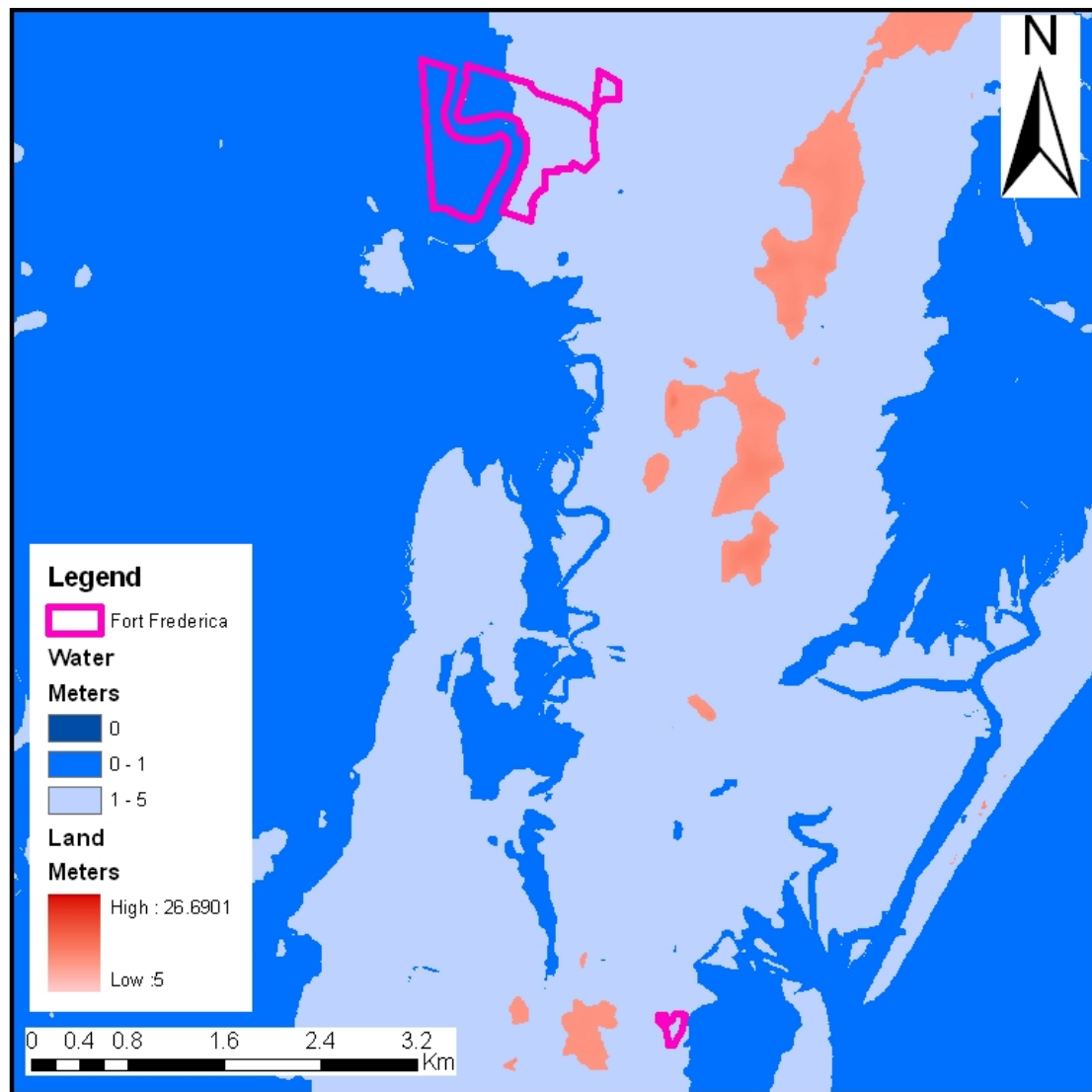


**Figure 76.** Projected effects of sea level rise combined with storm surge events of 1 – 5 meters on Fort Frederica National Monument (10 meter Digital Elevation Map cell size).

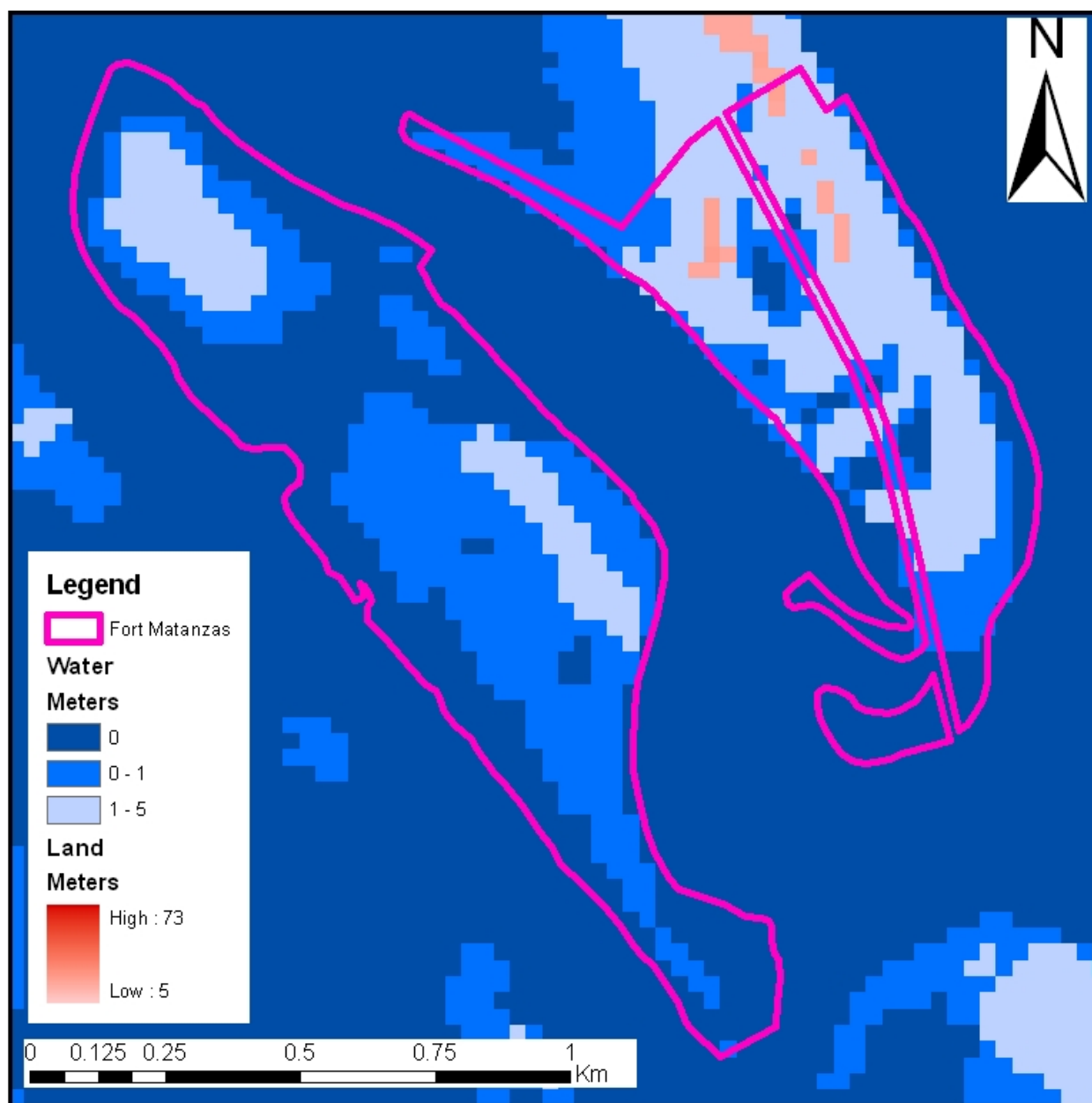


**Figure 77.** Projected effects of sea level rise combined with storm surge events of 1 – 5 meters on Fort Matanzas (30 meter Digital Elevation Map cell size).

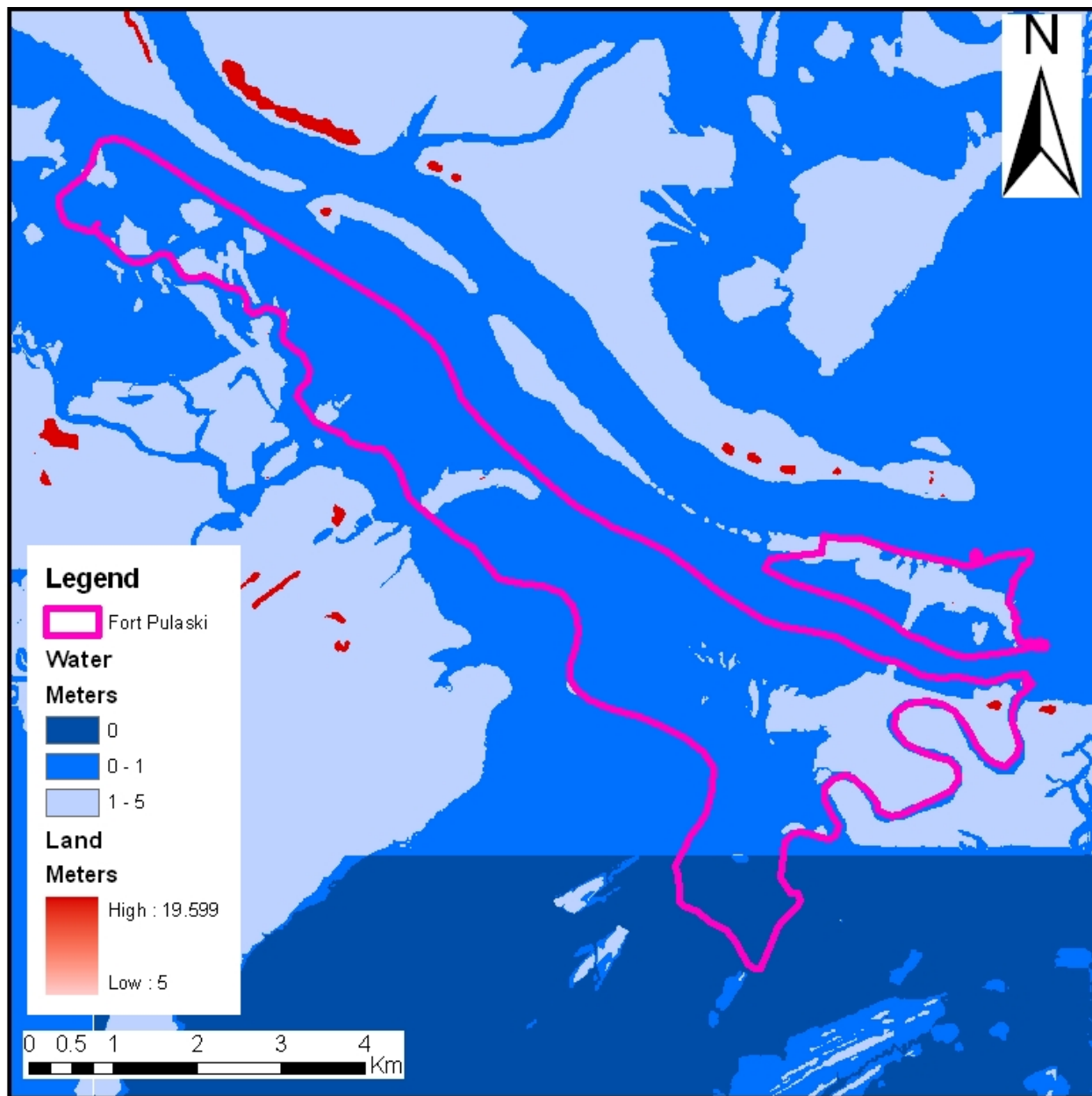


**Figure 78.** Projected effects of sea level rise combined with storm surge events of 1 – 5 meters on Fort Pulaski National Monument (10 meter Digital Elevation Map cell size).

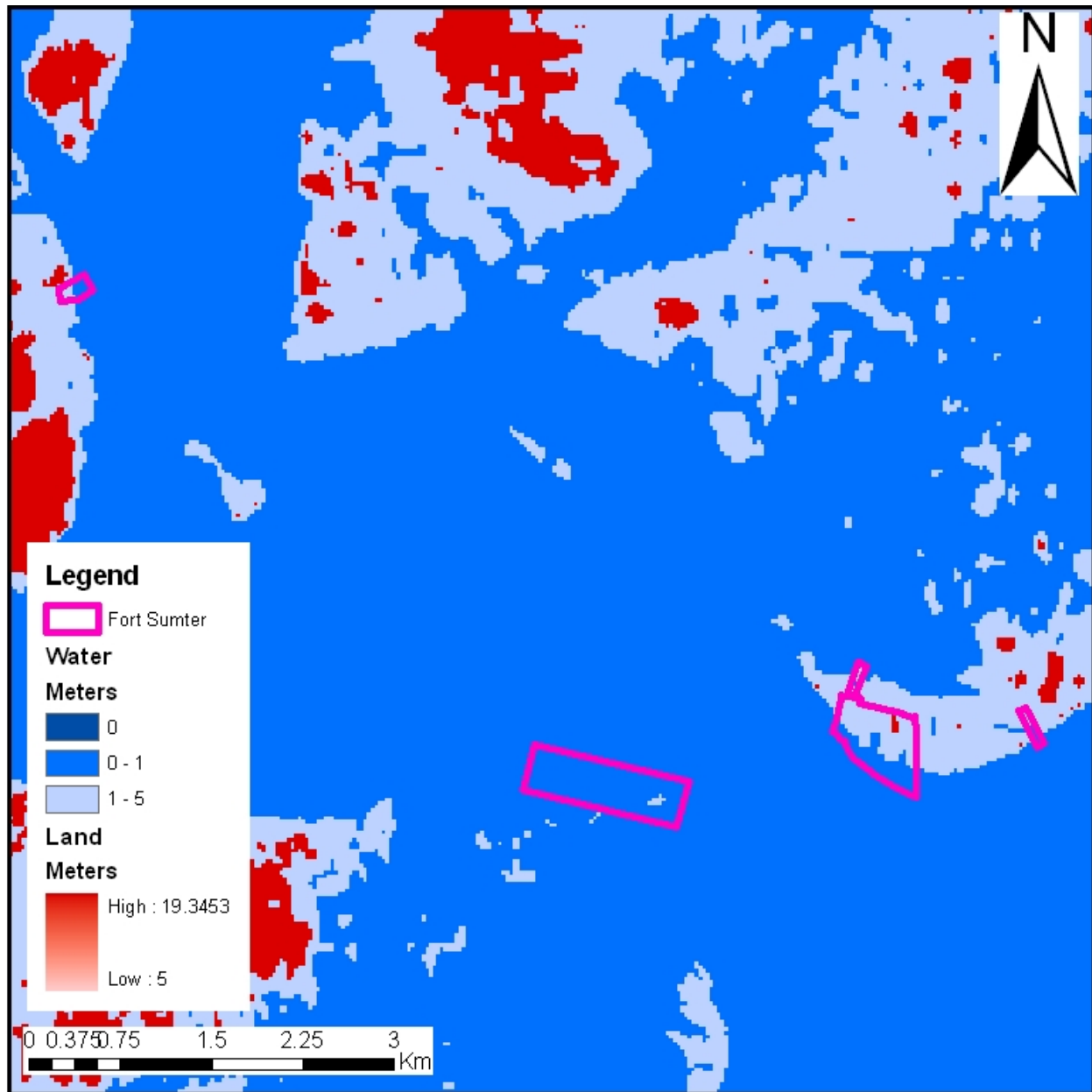


**Figure 79.** Projected effects of sea level rise combined with storm surge events of 1 – 5 meters on Fort Sumter National Monument (30 meter Digital Elevation Map cell size).

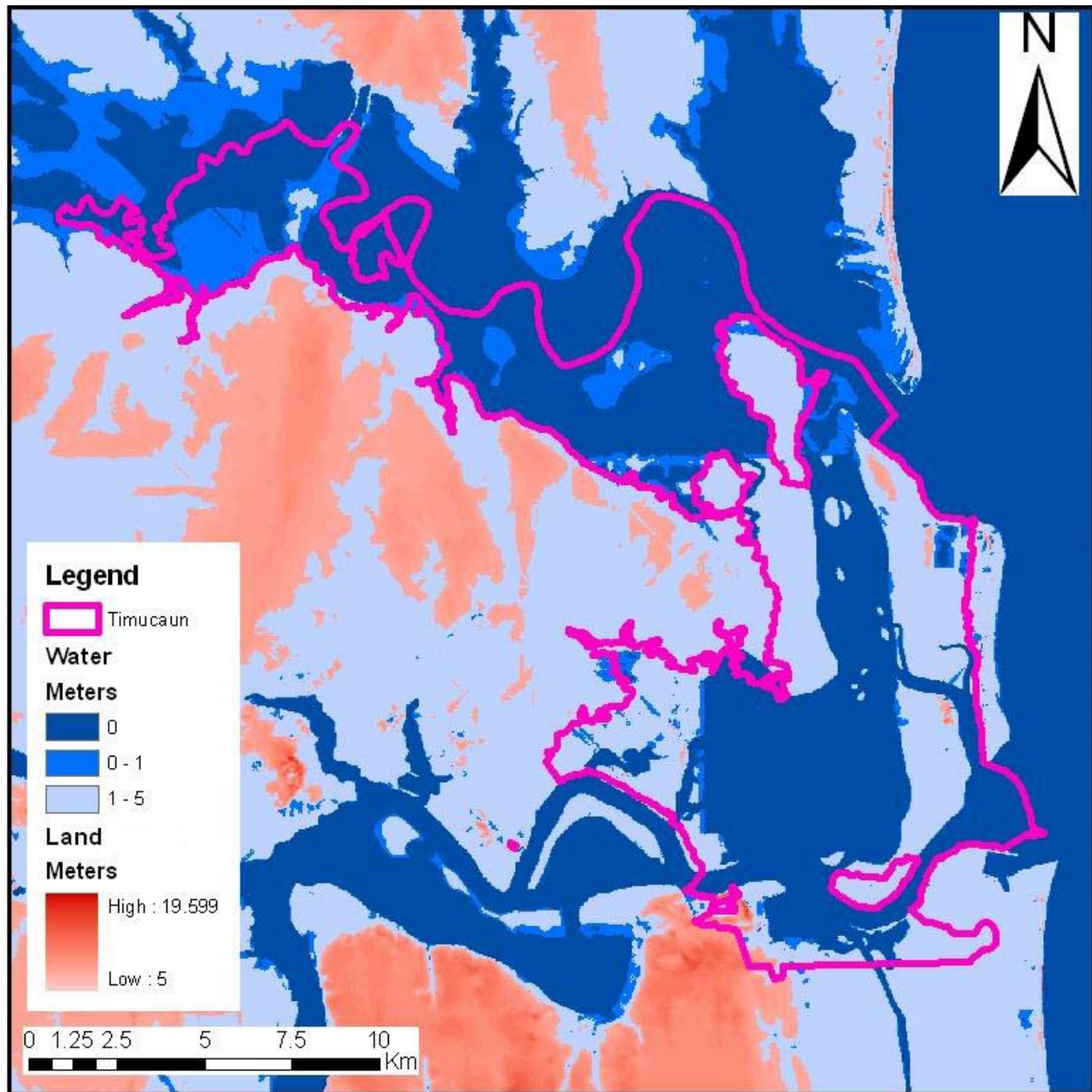


**Figure 80.** Projected effects of sea level rise combined with storm surge events of 1 – 5 meters on Timucuan Ecological and Historic Preserve (10 meter Digital Elevation Map cell size).



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