South Atlantic Landscape Conservation Cooperative

SARP Aquatic Resource Management Project

Assessment of Hydrologic Model Availability

Submitted by

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1. Introduction

The waterways of the SALCC are delicately balanced ecosystems linking diverse habitats and the people, plants and animals that rely on clean and abundant water supplies to thrive. The importance of natural flow regimes to the ecological integrity of rivers has been established for decades, but more specific information is needed to develop and implement scientifically credible instream flow standards and management recommendations (Richter 2009). The type of science needed to support instream flow standards has recently been described under the Ecological Limits of Hydrologic Alteration framework (ELOHA; Figure 1; Poff et al. 2009).

Under contract with the SALCC, SARP is following the ELOHA framework to development science-based instream flow information for water resource managers and policy makers of the region. SARP is working with partners to develop the baseline information, including the following products:

- Compilation of existing hydrologic foundations
- Compilation and summary of existing studies of ecological responses to flow alteration and other relevant information sources
- A regional river classification framework
- Priority aquatic conservation areas where altered flow is a threat
- A map of ecologically significant flow alterations in the SALCC that are amenable to management

The outcome of this work will help inform water resource managers and policy makers about flow requirements of streams, rivers, and estuaries of the SALCC region.

The primary objective of this portion of the SARP project is to develop baseline information on hydrologic alteration and ecological responses to alteration in rivers and streams across the SALCC. The regional hydrologic foundation will integrate with the other products under development by SARP, for example, by,:

- providing estimates of flow alteration for studies of ecological responses to magnitude of flows (e.g., converting Virginia DIF fish monitoring studies of Young-of-Year response to average June flows to response to altered June flows);
- extending river classes determined from gaged locations to ungagged locations in support of the regional river classification framework;
- quantifying altered flows at priority aquatic conservation areas; and
- substantiating estimates of flow alterations due to consumption, impervious surface, and dam operations across the region.

An initial step in developing flow-ecology relationships is to quantify the degree of hydrologic alteration by comparing baseline hydrologic conditions with current conditions at sites where ecological data is available. Various state and federal watershed hydrologic models have been developed or are under development in the SALCC region. This report surveys the extent, resolution, and availability of these hydrologic models, identifies information gaps, and assesses their applicability to serve as a hydrologic foundation for instream flow policy and management practices.

2. **Hydrologic Foundations** (taken from Kendy 2009, www.conserveonline.org/workspaces/eloha)

ELOHA is built on a "hydrologic foundation" of information about water resources in a region. This information is used to classify river types based on flow characteristics and to assess ecological responses to hydrologic alteration (Figures 1 and 2), as well as to evaluate the status of sites relative to environmental flow standards. To provide an adequate foundation for ELOHA, hydrologic information needs to:

- be spatially comprehensive so as to include both locations where water managers may want to make allocation or other water management decisions, as well as sites where ecological data have been collected;
- represent historical (unaltered), current, and future conditions;
- include the range of ecologically-relevant flow characteristics; and
- address ground-water and estuarine flows where appropriate.

An ideal hydrologic foundation is a regional database of daily or monthly streamflow hydrographs for baseline (unaltered), current, and future conditions over a common time period that represents variability in climate (generally 20 years or more). The database needs to have enough spatial detail to resolve reaches with different streamflow characteristics (e.g., because of an intervening tributary) and small streams that nonetheless provide significant habitats and may have altered hydrology because of ground-water pumping, diversions, or regulation.

Hydrologic modeling is a comprehensive approach to address all of the criteria for ELOHA's hydrologic foundation. Hydrologic modeling can extend the periods of streamflow data for gauged analysis nodes and synthesize data for ungauged analysis nodes as needed for unaltered, current, and future conditions. To achieve these objectives, unaltered streamflow data are needed for model calibration, data on current water management and uses must be incorporated into the model, and the model must be capable of representing changes in climate, land use, and water management. Existing hydrologic model or decision support system for water management may be adapted to build a hydrologic foundation for ELOHA

3. **Hydrologic Models** (based on Konrad 2008, www.conserveonline.org/workspaces/eloha)

There are many different types of models available for constructing a hydrologic foundation for ELOHA. Hydrologic models differ in terms of required inputs, representation of hydrologic process, algorithms for calculating fluxes, outputs, and incorporation of management actions. These include statistical and process hydrologic models and decision support systems.

Statistical hydrologic models are based on associations between streamflow and basin characteristics. Statistical models can be developed quickly for gaged and ungaged streams, but have limitations for hydrologic foundations in precision of predictions, efficiency for analyzing many different of potentially significant ecologically-significant flow characteristics, and ability to assess hydrologic alteration and future conditions.

Process hydrologic models account for the flux of water through different parts of the hydrologic cycle (precipitation, evapotranspiration, infilitration, ground-water recharge, runoff, and ground-water discharge). These models are generally more complex to construct than statistical models, but can be used to simulate many different types of scenarios (climate change and variability, water use and regulation, land development). A technical background and training are generally required for using process models. Examples of process models used in the southern US are: US EPA BASINS (HSPF) and Lancaster University TOPMODEL .

> **The HSPF Model, Hydrologic Simulation Program Fortran,** is a U.S. EPA program for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The HSPF model uses information such as the time history of rainfall, temperature and solar radiation; land surface characteristics such as land use patterns; and land management practices to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. HSPF includes an internal database management system to process the large amounts of simulation input and output. (source: http://www.epa.gov/ceampubl/swater/hspf/ accessed 03/07/2011)
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> **TOPMODEL** is a physically based watershed model that simulates hydrologic fluxes of water (infiltration-excess overland flow, saturation overland flow, infiltration, exfiltration, subsurface flow, evapotranspiration, and channel routing) through a watershed. The model simulates explicit groundwater/surface-water interactions by predicting the movement of the water table, which determines where saturated land-surface areas develop and have the potential to produce saturation overland flow (http://smig.usgs.gov/). TOPMODEL was originally developed to simulate catchment hydrology under humid conditions in the U.K, eastern US and Scotland. The model has provided good simulation of discharge rates and dynamic saturated areas. (http://www.bae.ncsu.edu/www3/acad/Regional-Bulletins/Modeling-Bulletin/TOPMODEL.html accessed 03/07/2011)

Hydrologic decision support systems (DSS) are spatial representations of rivers that integrate flow information with management infrastructure such as dams, withdrawals, and discharges. They enable water managers to model impacts of various alternative practices and rules on management goals and objectives. DSS have various levels of integration with hydrologic models. HSPF and TOPMODEL, for example, can be used to generate streamflow baseline hydrographs as well as generate streamflow under current and future management. DSS can also be separate from the source of hydrographs. The streamflow information for some DSS is obtained from gage records or statistical and process hydrologic models. These DSS generally use spreadsheets or other accounting tools to route water through a river system. They can be used to estimate baseline streamflow hydrographs by removing human influences from flow records. They can also be used to model current and future streamflow hydrographs under various management alternatives. Examples of the latter type of DSS used in the southern US are HEC ResSim and OASIS.

> The Hydrologic Engineering Center's Reservoir Simulation (**HEC ResSIM**) computer program is the successor to the "HEC-5, Simulation of Flood Control and Conservation Systems" program. ResSim is comprised of a graphical user interface (GUI), a computational program to simulate reservoir operation, data storage and management capabilities, and graphics and reporting facilities. The Data Sotrage System, HEC-DSS is used for storage and retrieval of input and output time-series data. (source: http://www.hec.usace.army.mil/software/hec-ressim/index.html accessed 03/08/2011)

> The Operational Analysis and Simulation of Integrated Systems (**OASIS**) with Operations Control Language is proprietary software developed by Hydrologics, Inc. (www.hydrologics.net). It has application in river basin management, water supply, hydropower, and conflict resolution. The software analyzes operating rules that can yield large savings for managers faced with system expansion decisions or operating compliance. Rules can be developed with a planning model and then operators can use the very same software as a decision-support model to ensure that the rules are properly implemented. OASIS can be customized to suit clients' needs and is supported with training and free upgrades.

4. Hydrologic Models of the SALCC

Hydrologic modeling is undertaken in the SALCC for many reasons and at all scales. Counties and municipalities model local water resources, for example, to plan for water supply and waste management. Water management districts and dam managers model watersheds and manage regional water resources for water supply, waste management, navigation, hydropower production, flood control, and other large river services. With rampant population growth and recent extreme drought conditions all highlighting the need to plan for use of limited water resources, many SALCC states are using hydrologic models to plan and manage their resources. Regional modeling is being done by federal agencies, as well, to predict impacts of climate change and human influences on future water resources. These models have varying applicability to serve as hydrologic foundations.

Ideally, a hydrologic foundation for the SALCC would interface with the other products under development by SARP. It would be comprised of a single, regional modeling effort that could generate a minimum of a 20-year daily streamflow hydrograph at each stream segment (i.e., NHD+) for baseline, current, and future conditions. A researcher or water manager could 'point-and-click' on a map for the streamflow hydrographs for any watershed location of interest. This does not exist yet. The survey information given below outlines the various hydrologic modeling efforts in the SALCC region by state (Table 1). For the purposes of this report, emphasis is placed on statewide and regional efforts that would simplify access, compilation, and maintenance of the models for a SALCC hydrologic foundation. This report is concluded with recommendations for how to use these existing efforts to support a hydrologic foundation and the scientific basis for protection of instream flows.

ALABAMA

Statewide - Office of Water Resources, Department of Economic and Community Affairs
(based on conversations with Ken Odum, USGS)

> Act No. 2008-164 was enacted by the Alabama Legislature during the 2008 Regular Session. The Act created the Alabama Permanent Joint Legislative Committee on Water Policy and Management. The purpose of this committee is to develop the Alabama Water Management Plan to recommend to the Governor and Legislature courses of action to address the long-term and short-term water resource challenges of the State (www.legislature.state.al.us/joint_committees/water-resources.html). As this committee does it work, the Office of Water (OWR) of the Alabama Department of Economics and Community has been proactively gathering water resource information to inform water planning and management decisions. Among their accomplishments, OWR engaged the US Geological Survey (USGS) to develop statewide hydrologic models.
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> The USGS used TOPMODEL to develop daily flow records in over 2300 HUC12 (Hydrologic Unit Code) for 54 HUC8 basins statewide (Figure 3). Output is daily unimpaired flows based on 2001 land cover. A scenario generator is available to add withdrawals and discharges to generate current and future flows.

Alabama-Coosa-Tallapoosa (ACT) River Basin - US Army Corps of Engineers, Mobile District

> The ACT Basin (Figure 4) provides water resources for multiple purposes from just north of the Tennessee-Georgia border, extending into central north Georgia, crossing the Georgia-Alabama state line into north Alabama, continuing across central and south Alabama before terminating in Mobile Bay. The Coosa and Tallapoosa join to form the Alabama River about two-thirds of the way downstream in the basin. Eighteen dams are in the ACT basin, which form 16 major reservoirs. Six dams are federally owned by the Corps and 12 are privately owned projects.
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> The US Army Corps of Engineers, Mobile District, manages the six federal dams and coordinates water management with the privately owned projects. To meet NEPA requirements and support daily water management decisions, the Corps has developed a basinwide HEC-ResSim hydrologic model. The model generally routes water between reservoirs on the three river main stems. The model is based on unimpaired flows for > 50 years. Outputs are hourly reservoir levels and river flows.

FLORIDA

Georgia-Florida Coastal Plain - US Environmental Protection Agency, Office of Research and Development, Global Change Research Program (GCRP)

The GCRP works to build the capacity of EPA program and regional offices, water managers, and other decision-makers to assess and respond to global change impacts on water quality and aquatic ecosystems. Research and assessment activities in the GCRP Water Quality focus area broadly support EPA's mission and responsibilities as defined by the Clean Water Act and the Safe Drinking Water Act. Water quality is a complex outcome of watershed hydrologic, biogeochemical, and ecological processes coupled with the impacts of human use and disturbance. Accordingly, although the GCRP's research and assessments have a primary focus on water quality, research and assessment activities in this area also include watershed hydrologic processes (e.g. streamflow), aquatic ecosystems, and linked terrestrial ecosystems. Watershed modeling will be conducted in demonstration watersheds across the nation (Figure 5) using 2 watershed models, HSPF and SWAT. The resulting hydrologic and water quality change scenarios will contribute, in part, to a comprehensive Water Quality Assessment Report to be prepared by the EPA GCRP in 2013. (source: www.aquaterra.com/projects/)

Water Management Districts (Based on www.dep.state.fl.us/secretary/watman/; Figure 6)

Under the Water Resources Act of 1972, water in Florida is managed by the Florida Department of Environmental Protection through its relationship with the state's five water management districts: Northwest Florida Water Management District, Suwannee River Water Management District, St. Johns River Water Management District, South Florida Water Management District and Southwest Florida Water Management District. The SALCC falls within the three northern districts.

- The water management districts administer several water quantity programs including flood protection programs, water management plans for water shortages in times of drought and regulatory programs to manage the consumptive use of water, aquifer recharge, well construction and surface water management. The districts rely on hydrologic modeling for all of these programs, especially for select areas within the district boundaries where water resources are threatened. The level of modeling is related to the level of funding received by each WMD. Suwannee River WMD and Northwest Florida WMD are the least well-funded of the five districts. They have extensive coastal zones and relatively small threats to surface freshwater resources due to abundant groundwater availability from the Floridan Aquifer. Their modeling focus has been more on effects of sea level rise and groundwater use than hydrologic process models for their surface freshwater resources. These WMD do have, however, decision support models (HecRes) for mainstem rivers. The St Johns River WMD contains Jacksonville and the northern Atlantic coastal areas of Florida where freshwater water resources are threatened. It is better funded and is using a GIS based model to investigate effects of land use change scenarios. As the districts operate independently, the modeling of the three districts in the SALCC are discussed below.

GEORGIA

Statewide - Environmental Protection Division, Department of Natural Resources
(based on information at www.georgiawaterplanning.org)

The 2004 Comprehensive State-wide Water Management Planning Act mandates the development of a state-wide water plan that supports a far-reaching vision for water resource management (O.C.G.A. 12-5-522(a)). Georgia Environmental Protection Division (EPD) and its contractors is using the "River Basin Planning Tool," developed by the Georgia Water Resources Management Institute at Georgia Tech, to model flows in Georgia's river systems. The River Basin Planning Tool allows EPD to convert existing data on the 14 river basins in Georgia into smaller planning units or sub-basins (Figure 7), and measure the quantity of water available for consumptive use in each sub-basin. Consumptive use refers to the amount of water used but not returned without undue delay from either surface water or groundwater.

The Surface Water Availability assessment measures the amount of water that can be used from the rivers and lakes of Georgia without substantially altering the desired hydrologic flow regime and the opportunities for use of water supported by that flow regime. Together with the Groundwater Availability assessment, they form the "consumptive use assessment" described in the State Water Plan. The assessments include modeling, monitoring, and the compilation and management of data. Assessments are being provided to each of the 10 regional water planning councils as a starting point for the development of a recommended Regional Water Plan and are not intended for use for individual permit decisions. Critical inputs for the surface water availability model include: the desired flow of the river system, expected return of treated wastewater to the system, the desired water supply, and the desired reliability of the water supply.

The GA Surface Water Quantity Assessment models are based on unimpaired or "natural" flow data representing natural hydrologic conditions over a period of nearly 70 years. Flows are calculated on a daily basis for 70 basic nodes and 40 planning nodes in 14 basins. Nodes are located at existing gages.

In addition to water availability assessments, the EPD is assessing water quality statewide. The water quality models are based on hydrologic models developed using the Loading Simulation Program C++ (LSPC), which is similar to the HSPF(v12). Hydrologic models are developed at a subHUC12 scale and produce daily flows and calibrated for 1997-2007.

Apalachicola-Chattahoochee-Flint (ACF) River Basin -

The ACF River Basin (Figure 8) originates in northeast Georgia, crosses the Georgia-Alabama border into central Alabama, and follows the state line south until it terminates in Apalachicola Bay, Florida. The Chattahoochee and Flint Rivers join at the Georgia-Florida state line to form the Apalachicola River. The Corps Water Management Section of the Mobile District operates five federal reservoir projects as components of the ACF system. These are multi-purpose projects for which operations have been congressionally authorized either through the original project authorizations, or by subsequent congressional authorizations that apply generally to all Corps reservoir projects. In addition the ACF, supplies 3 million people in metro Atlanta with drinking water, cooling water for thermal power generation and nuclear power generation, irrigation water for SW Georgia, and one of the region's most productive commercial seafood industries. Water allocation among the three states in this basin has been very contentious for more than 15 years. Several hydrologic modeling efforts have focused on this basin.

US Army Corps of Engineers, Mobile District - As for the ACT, to meet NEPA requirements and support daily water management decisions, the Corps has developed a basinwide HEC-ResSim hydrologic model. The model generally routes water between reservoirs on the Chattahoochee River main stem. The model is based on unimpaired flows for > 50 years. Outputs are hourly reservoir levels on the Chattahoochee River and river flows for all three rivers.

US Geological Survey – Aquatic habitat is sensitive to streamflow, so under the Southeast Resource Assessment Program (SERAP) the USGS is assessing how climate change can affect land cover and flow in river systems. The project team will experiment with a variety of resolutions for linking hydrology and land-cover data for analyzing streams in the Apalachicola–Chattahoochee–Flint watershed to improve the ability to detect and project the condition of aquatic habitats. Modelers are using the Precipitation-Runoff Modeling System (PRMS; http://water.usgs.gov/software/PRMS/) to model daily flows throughout the basin at stream segment scale. (source: http://serap.er.usgs.gov/)

US Environmental Protection Agency – The EPA Office of Research and Development Global Change Research Program (GCRP) works to build the capacity of EPA program and regional offices, water managers, and other decision-makers to assess and respond to global change impacts on water quality and aquatic ecosystems. Research and assessment activities in the GCRP Water Quality focus area broadly support EPA's mission and responsibilities as defined by the Clean Water Act and the Safe Drinking Water Act. Water quality is a complex outcome of watershed hydrologic, biogeochemical, and ecological processes coupled with the impacts of human use and disturbance. Accordingly, although the GCRP's research and assessments have a primary focus on water quality, research and assessment activities in this area also include watershed hydrologic processes (e.g. streamflow), aquatic ecosystems, and linked terrestrial ecosystems. Watershed modeling will be conducted in demonstration basins across the nation (Figure 5) using 2 watershed models, HSPF and SWAT. The resulting hydrologic and water quality change scenarios will contribute, in part, to a comprehensive Water Quality Assessment Report to be prepared by the EPA GCRP in 2013. (source: http://www.aquaterra.com/projects/)

Atlanta Regional Commission – The ARC relies on the ACF for water supply and waste assimilation for more than half of its residents. Certainty for future water resource availability is critical for planning purposes. The ARC has developed an OASIS model for the three river main stems.

Savannah River – US Army Corps of Engineers, Savannah District

The Savannah River watershed begins in the mountains of North and South Carolina as the Tugaloo and Keowee Rivers. These rivers join in Lake Hartwell on the Georgia-South Carolina border and form the Savannah River. The river forms the 300+ mile border between these states. Lake Hartwell is one of three major reservoirs in this system and are managed by the Corps.

As for the ACT and ACF, to meet NEPA requirements and support daily water management decisions, the Corps has developed a basinwide HEC-ResSim hydrologic model. The model generally routes water between reservoirs on the Savannah River main stem. The model is based on unimpaired flows for > 50 years. Outputs are hourly reservoir levels and river flows.

NORTH CAROLINA

Statewide - Division of Water Resources , Department of Environment and Natural Resources (based on 02/01/2011 conversation with Steve Reed and information at www.ncwater.org)

On July 8, 2010, NC House Bill 1743 was passed. It directs DENR to develop basinwide hydrologic models for the state (access a copy of the bill at www.southeastaquatics.net/programs/sifn/documents). This law gives DENR approval for watershed hydrologic modeling that has been under development for water resource planning and management. DENR is using OASIS on main stem rivers in each watershed. Models are being developed now on the Broad, Cape Fear, Neuse, Roanoke, and Tar Rivers (Figure 9). They will release a schedule in late summer 2011 for model development for all the state's 17 watersheds. Descriptions of the basin models and the stakeholder process can be found at www.ncwater.org.

The NC hydrologic models are generally based on a > 50 year period of record for gages on the river main stem. Nodes are located at gages, points of withdrawal and discharge > 100,000 gpd, large dams, and selected points for environmental flow studies. Basins contain more than 100 nodes each (e.g., Figure 10). The model is flexible. Additional nodes can be added where there is flow input. The model can use output from other models, such as rainfall-runoff inputs. Computations are on a daily time step.

HB 1743 specifies that hydrologic models of interstate basins will be coordinated with neighboring states. DENR is extending the OASIS models into neighboring states with the use of water withdrawal and discharge information provided by the appropriate water resource agencies (e.g., VA DEQ is providing information for the Virginia portion of the Roanoke River). Stakeholders in neighboring states are asked for input into the models for node location and other important features.

Statewide - Research Triangle Institute (Bob Dykes and Michelle Cutrofello 919-990-8458)
As part of a larger research effort, RTI has developed hydrologic modeling software based on the Generalized Watershed Loading Function (GWLF). This is a process hydrologic model that is intermediate in data requirements between HSPF and TOPMODEL. The output is daily baseline flows at a NHD+ scale for any period of record. RTI has applied this model to several watersheds in NC and will expand coverage to the entire state. This modeling effort develops flows for ungaged stream segments and can be applied to the DSS that NC is using for water management (i.e., OASIS). RTI will make the model available to other areas on a contractual basis.

Albermarle-Pamlico Sound - US Environmental Protection Agency, Office of Research and Development, Global Change Research Program (GCRP)

The GCRP works to build the capacity of EPA program and regional offices, water managers, and other decision-makers to assess and respond to global change impacts on water quality and aquatic ecosystems. Research and assessment activities in the GCRP Water Quality focus area broadly support EPA's mission and responsibilities as defined by the Clean Water Act and the Safe Drinking Water Act. Water quality is a complex outcome of watershed hydrologic, biogeochemical, and ecological processes coupled with the impacts of human use and disturbance. Accordingly, although the GCRP's research and assessments have a primary focus on water quality, research and assessment activities in this area also include watershed hydrologic processes (e.g. streamflow), aquatic ecosystems, and linked terrestrial ecosystems. Watershed modeling will be conducted in demonstration watersheds across the nation (Figure 5) using 2 watershed models, HSPF and SWAT. The resulting hydrologic and water quality change scenarios will contribute, in part, to a comprehensive Water Quality Assessment Report to be prepared by the EPA GCRP in 2013. (source: www.aquaterra.com/projects/)

Yadkin, Cape Fear, Neuse, and Roanoke Rivers - US Army Corps of Engineers, Wilmington District

The Corps manages reservoirs and navigation on four watersheds in North Carolina. As for the ACT and ACF, to meet NEPA requirements and support daily water management decisions, the Corps has developed basinwide HEC-ResSim hydrologic models. The models generally route water between reservoirs on the main stems of each river. The models are based on unimpaired flows for the period of record. Outputs are hourly reservoir levels and river flows.

Catawba, Roanoke, and Yadkin-PeeDee Rivers – Progress and Duke Energy companies

Several dams on these rivers are operated by energy companies for hydropower production. This activity is licensed under the Federal Energy Regulatory Commission (FERC). DSS hydrologic models (CHEOPS, OASIS, and others) have been developed to meet FERC requirements as well as support daily water management decisions. These models have been linked with intensive aquatic habitat models to assess potential impacts to species of concern due to various water management alternatives. The models are based on unimpaired flows for the period of record. Outputs are hourly reservoir levels and river flows.

Roanoke River – The Nature Conservancy, Durham

The Roanoke River begins in Virginia and flows across northern North Carolina to the Albemarle Sound. TNC identified the Roanoke River and Albemarle Sound as high conservation priorities. Management of river by the Corps and energy companies for hydropower production was a major threat to the natural hydrologic regime and functions of this ecosystem. TNC initiated a major research project on the river to demonstrate ecological impacts of altered flows. An OASIS model was developed for the mainstem below Kerr Dam and linked with floodplain ground surface elevations. This model is now being expanded upstream and updated under the statewide hydrologic modeling effort described above.

SOUTH CAROLINA (Figure 11)

Statewide – no models are available at this time

Edisto River – USGS TOPMODEL (see Alabama)

Santee-Cooper, Catawba, and Yadkin-PeeDee Rivers – Progress and Duke Energy companies

Several dams on these rivers are operated by energy companies for hydropower production. This activity is licensed under the Federal Energy Regulatory Commission (FERC). DSS hydrologic models (CHEOPS, OASIS, and others) have been developed to meet FERC requirements as well as support daily water management decisions. These models have been linked with intensive aquatic habitat models to assess potential impacts to species of concern due to various water management alternatives. The models are based on unimpaired flows for the period of record. Outputs are hourly reservoir levels and river flows.

VIRGINIA (Figure 12)

Statewide – Va Department of Environmental Quality (source: http://southeastaquatics.net/states/VA)

Although instream flow protection is not well defined in VA other than 7Q10 for water quality, state water permitting regulations require that all beneficial uses, instream and off stream be protected, including aquatic resources. While there are exceptions, such as for agricultural operations, projects involving surface water withdrawals from state waters and related permanent structures and fill are permitted under the Virginia Water Protection Permit (VWPP) Program. The VWPP Program is administered by the DEQ Division of Water Quality Programs. For the full regulation concerning water withdrawals and structures permitted under the Virginia Water Protection Permit Program, please refer to: http://leg1.state.va.us/000/reg/TOC09025.HTM#C0210 and http://www.deq.virginia.gov/wetlands/permitfees.html. Surface water withdrawals regulated under the Surface Water Management Act of 1989, which establishes Surface Water Management Areas, require different permits from the Office of Surface and Ground Water Supply Planning.

VA DEQ is evaluating water supply use for instream and human purposes. Building off hydrologic modeling efforts for the Chesapeake Bay program, VA has HSPF statewide coverage that produces daily baseline and current steam flow hydrographs at sub-HUC12. Through an USEPA grant, VADEQ work with partners to apply this information to an ELOHA process.

Virginia has what may be the most sophisticated DSS model in the region. They have developed WOOOMM, which is an Online Object Oriented Meta-Model (WOOOMM). It is a modular, object-oriented time series executable system that contains a variety of components that can access online environmental data repositories (such as USGS NWIS, and NOAA databases), and also interact with certain environmental modeling environments (HSPF, CEQUALW2, GWLF). Made in the form of a "Systems Dynamics" model, the WOOOMM is completely extensible and user-programmable, all through a browser-based web interface. WOOOMM can be run on any timestep (defined in seconds), and native WOOOMM data access components have routines to interpolate/aggregate time series data based on user selected methods (mean, previous value, next value, median) to match the selected simulation timestep. For more information, see http://sifn.bse.vt.edu/sifnwiki/index.php/WOOOMM_Modeling.

Rivanna River – The Nature Conservancy, Charlottesville

> The Virginia TNC Chapter helped create the new Rivanna River Basin Commission, a collaboration among four local governments to address the threats facing the rivers and streams of the Rivanna River watershed—which harbor some of the finest freshwater habitats in the Piedmont of the Rappahannock River basin (Figure 12). As a part of that effort and to help determine good water supply reservoir management alternatives, an OASIS model was developed for the river.

SOUTHEAST REGION – US Forest Service , Southern Research Station & Eastern Forest Environmental Threat Assessment Center; http://www.fs.fed.us/ccrc/tools/wassi.shtml)

> The team that developed the Water Supply Stress Index Model (WaSSI) model has used it to predict water availability and stress over the next 20 years across 13 southeastern states. The WaSSI model is an online modeling tool that allows a user to generate estimates of the historical, current, or future predicted water stress index for a particular zipcode. In reality, the water stress index outputs represent the predominant Hydrologic Unit Code (HUC) within a particular zipcode. The primary model output consists of a value which represents the "Water Supply and Stress Index" (WaSSI). This value is essentially a water balance (e.g. a ratio of water demand to water supply) for a particular zipcode, which is linked to a single Hydrologic Unit Code (HUC). Also available from WaSSI is monthly streamflow for HUC8 basins for historic, current, and future climate change scenarios.

5. Status of modeling to meet hydrologic foundation requirements

An assessment of information to support a hydrologic foundation in the SALCC is more than the presence or absence of hydrologic models across the region. The hydrologic foundation must support the needs of researchers, managers, and regulators. The information must be useful across spatial scales and timeframes. It must reflect accurate and up-to-date water use information and be reasonably accessible. The following review considers these aspects of support for a hydrologic foundation for the SALCC.

a. Coverage – The SALCC is fortunate that there is good coverage of hydrologic process models across the region as this is probably the most expensive part of developing a hydrologic foundation. With the exception of South Carolina, every state has the capacity to develop baseline daily streamflow hydrographs statewide using HSPF, TOPMODEL, or similar models. As a result, baseline conditions can be estimated for gaged and ungaged locations throughout the region. All states define baseline as pre-impact or natural baseline with the exception of Georgia, which used the recent gage record as baseline. With the models in place, discrepancies such as these can be addressed.

The extent of hydrologic DSS models to develop current and future daily stream flow hydrographs is more limited. Most major watersheds in the SALCC (i.e., those that begin in the Appalachian Mountains) have DSS models, however, most of these models are designed for main stems and major tributaries to rivers (e.g., Corps or state water management plans). Modeling for hydrologic foundations is in place in these areas. There is currently limited coverage of DSS models to generate daily current and future hydrographs in

- headwater and other streams,
- small and medium rivers within the major watersheds,
- watersheds that originate in the coastal plain, and
- locations downstream of DSS model nodes (e.g., tidal and estuarine reaches).

b. Timeframes – Development of streamflow hydrographs that represent baseline, current and future time frames often depends on the availability and reliability of information about human and climate influences through time. For example, the hydrologic process models initially estimate runoff based on a natural, forested landscape. Once validated with observed flows, this can serve as the baseline hydrograph for undisturbed watersheds. Adjustments of the baseline hydrograph must be made for increased runoff, consumption (i.e., withdrawals – returns), and storage for the modeled hydrographs to represent altered conditions at any point in time. It is the information about these sources of impacts on the hydrograph that must be developed and maintained in addition to the hydrologic process and DSS models themselves.

Information regarding water use impacts on hydrographs is usually maintained by various agencies, if it is gathered at all. Landuse changes, for example, have been captured remotely for a century, but are only available in digital form for the region since about 1970 (?). Therefore, reliable adjustments of hydrographs to account for impacts from urbanization and agriculture are fairly recent. Although returns are generally recorded as discharges under state water quality programs, most states do not collect specific information on surface and groundwater withdrawals. Often only large water users are certified to make withdrawals. This inconsistent availability of information makes adjustments of hydrographs difficult for consumption - particularly in upper watershed reaches where consumption may be small quantitatively and fall below regulatory limits, but relatively large for small streams and rivers. Finally, releases from dams are the purview of federal, state, local, and private dam management agencies and often vary from 'rule curves' on a daily basis. Therefore, adjusting baseline hydrographs to represent regulated conditions can be challenging as well. Hydrologic DSS modelers must have the best estimates of all of these factors to simulate current and future hydrographs from baseline hydrographs.

c. Spatial scale – With the near complete coverage of hydrologic process models in the region, baseline hydrographs at the sub-HUC12 or stream segment scale are available. Where DSS models are in place, baseline, current and future hydrographs can be developed at a fine scale, with the addition of nodes to the models as necessary. While most of the DSS models can be readily modified for additional nodes between existing nodes, extrapolating beyond the model boundaries requires more time and expense. Therefore, in most watersheds in the SALCC region, resources may need to be dedicated to extend the DSS models to obtain current and future hydrographs.

d. Temporal scale – The SALCC region is fortunate in that most of the hydrologic process models are based on a daily time step. This enables the analysis of the full suite of ecologically significant components of the hydrograph. For example, duration of low flows can be measured in number of days and compared directly between hydrographs for a stream representing different time frames. These hydrographs can be utilized by programs such as the Index of Hydrologic Alteration (IHA) and Hydrologic Integrity Program (HIP).

e. Accessibility – Finally, for these hydrologic models to be useful as the hydrologic foundation for instream flows and other water management issues, they must be accessible to the public. Accessibility takes two forms in this case. First, the developers of the existing models must make them available. Since most of these models have been developed by government agencies, this should not be an insurmountable problem. Secondly, users must be able to access the models to generate hydrographs at various time frames and for selected periods of time. Not all users are modelers, so the models must be able to be run via some relatively convenient interface. If output is required for sites in different states, the output generated by different models must be comparable.

6. Recommendations for SALCC region

Given the state of hydrologic modeling in the SALCC region, the following recommendations are intended to help guide efforts to establish a hydrologic foundation that can be used with the other products SARP is developing for the SALCC to assess instream flow and other water management issues.

The objective is to develop a hydrologic foundation to support the ELOHA framework. To repeat from the introduction of this report, an ideal hydrologic foundation is

- a regional database of
- daily or monthly streamflow hydrographs for
- baseline (unaltered), current (to the measurement or event), and future conditions
- over a common time period that represents variability in climate (generally 20 years or more),
- with spatial detail to resolve reaches with different streamflow characteristics.

Various alternatives can be chosen to develop a hydrologic foundation for the SALCC region. These include the following:

1) Access to and compilation of hydrologic process models to develop baseline hydrographs

   Alternative 1 - If using existing models in the region:

   a) Develop interagency agreements to gain access to the existing hydrologic process models.
   b) Standardize the baseline hydrograph time frame.

c) Standardize the output of different models overlapping in a watershed to eliminate discrepancies between models.

Alternative 2 – If developing a regional hydrologic process model:

a) Ensure that the alternative is cost effective in comparison with Alternative 1.
b) Ensure that the minimum spatial scale is HUC12 and the time step is daily.
c) Ensure that there is adequate model validation at nodes throughout the region.
d) Ensure that future use the model is not limited as proprietary information.

2) Access to and compilation of hydrologic DSS models to develop current and future hydrographs
   a) Develop interagency agreements to gain access to the existing hydrologic DSS models.
   b) Provide a mechanism to extend DSS hydrologic models to meet flow alteration threats basinwide.

3) Availability for users
   a) Develop a user-friendly interface to provide or generate stream hydrographs for selected locations and time frames.
   b) Locate the models and data that support the hydrologic foundation on a server with public access.

4) Maintenance of models and water management information
   a) Develop a mechanism to compile and maintain spatially and temporally explicit information on withdrawals, returns, storage, and dam releases.

Table 1. Hydrologic models in the SALCC region and their suitability for instream flow assessments.

Area of coverage	**Resolution**	**Time step**	**Platform**	**Agency**
Alabama (statewide)	HUC12	daily	TopModel	USGS
Alabama –Coosa-Tallapoosa (ACT)	main stem	hourly	ResSim	MD-USCOE
	Main stem	Hourly		AL Power
Georgia (statewide)	Sub-HUC12	daily	HSPF	GA-EPD/DNR
Apalachicola-Chattahoochee-Flint (ACF)	main stem	hourly	HEC ResSim	MD-USCOE
	Main stem	daily	OASIS	ARC
	Watershed	daily	PRMS	USGS
	watershed	daily	HSPF	USEPA
Savannah (SC)	main stem	hourly	ResSim	SD-USCOE
South Carolina (statewide)	none			
Catawba (NC)	main stem	hourly		Duke Energy
Edisto	Watershed	daily	TopModel	USGS
Pee Dee (NC)	main stem	hourly	Oasis/CHEOPS	Progress Energy
Santee-Cooper	Main stem	hourly	CHEOPS	Progress Energy
North Carolina (statewide)	Watershed	daily	GWLF	RTI
Statewide (17 watersheds)	main stem	daily	Oasis	NC-DENR
Albermarle-Pamlico Watershed	Watershed	daily	HSPF	USEPA
Yadkin, Cape Fear, Neuse, and Roanoke Rivers	Main stem	hourly	ResSim	WD -USCOE
Catawba, Roanoke, and Yadkin-PeeDee Rivers	Main Stem	hourly	OASIS/ CHEOPS	Duke and Progress Energy
Roanoke (NC)	Mainstem	daily	OASIS	TNC
Florida				
FL-GA Coastal Plain	Watershed	daily	HSPF	USEPA
St Johns River				SJRWMD
Suwannee River				SRWMD
Panhandle rivers				NWFWMD
Virginia (statewide)	watershed	daily	HSPF	VA-DEQ
Rivanna	Mainstem	Daily	OASIS	TNC
Southeast region	HUC8	monthly	WaSSI	USFS

Figure 1. Ecological Limits of Hydrologic Alteration (ELOHA). This schematic illustrates the information needed to establish a scientific basis for instream flow standards and management practices. It lays out the relationship between the flow alteration-ecological respons relationships with the social process of setting and testing instream flow standards. (Poff et al. 2009)

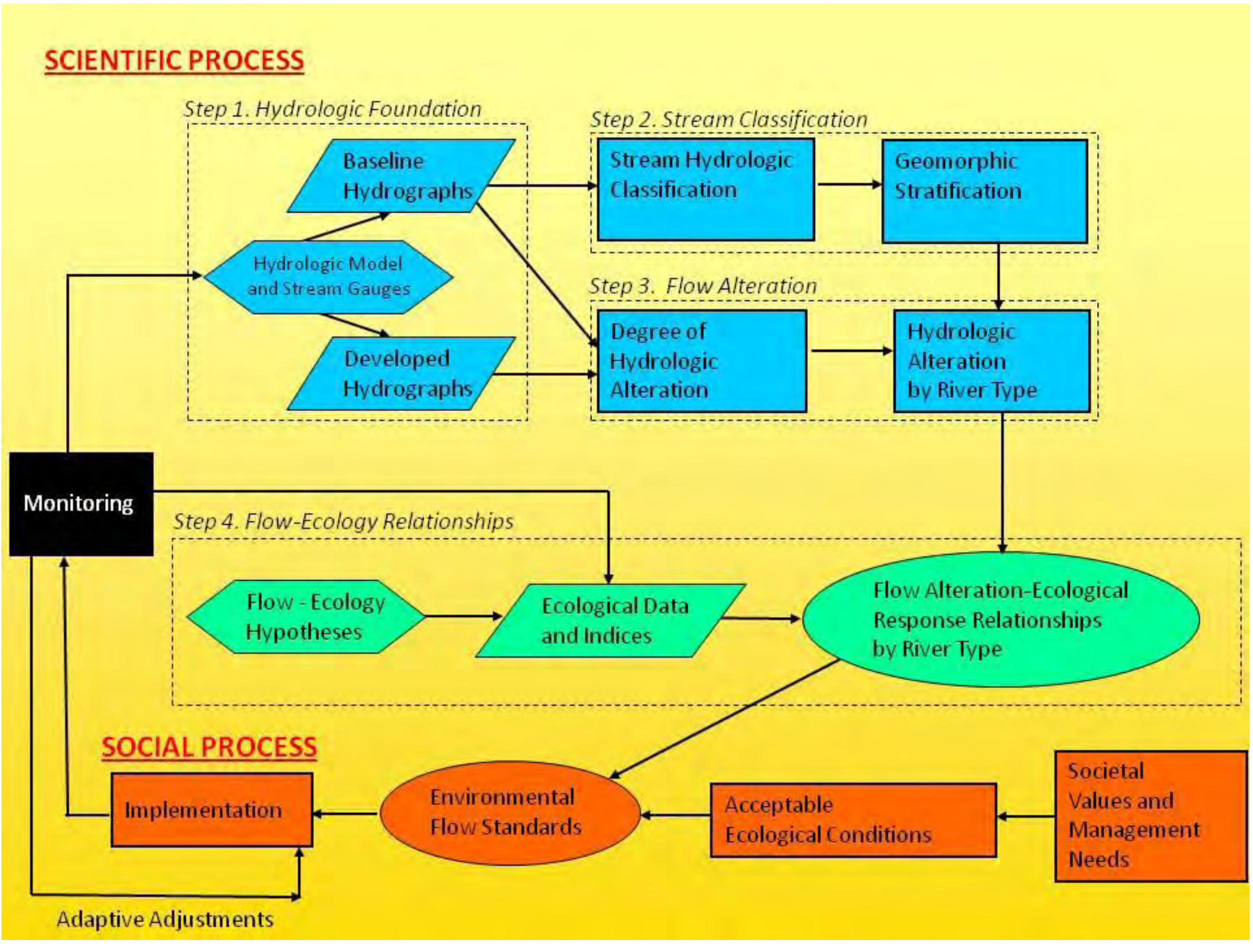


Figure 2. The Hydrologic Foundation of the Ecological Limits to Hydrologic Alteration (ELOHA). This schematic is an enlargement of a portion of Figure 1. It lays out how hydrologic models integrate information to classify rivers and analyze hydrologic alteration. This information is the foundation for the flow alteration-ecological response relationships necessary to support instream flow standards and management practices. (Poff et al. 2009)

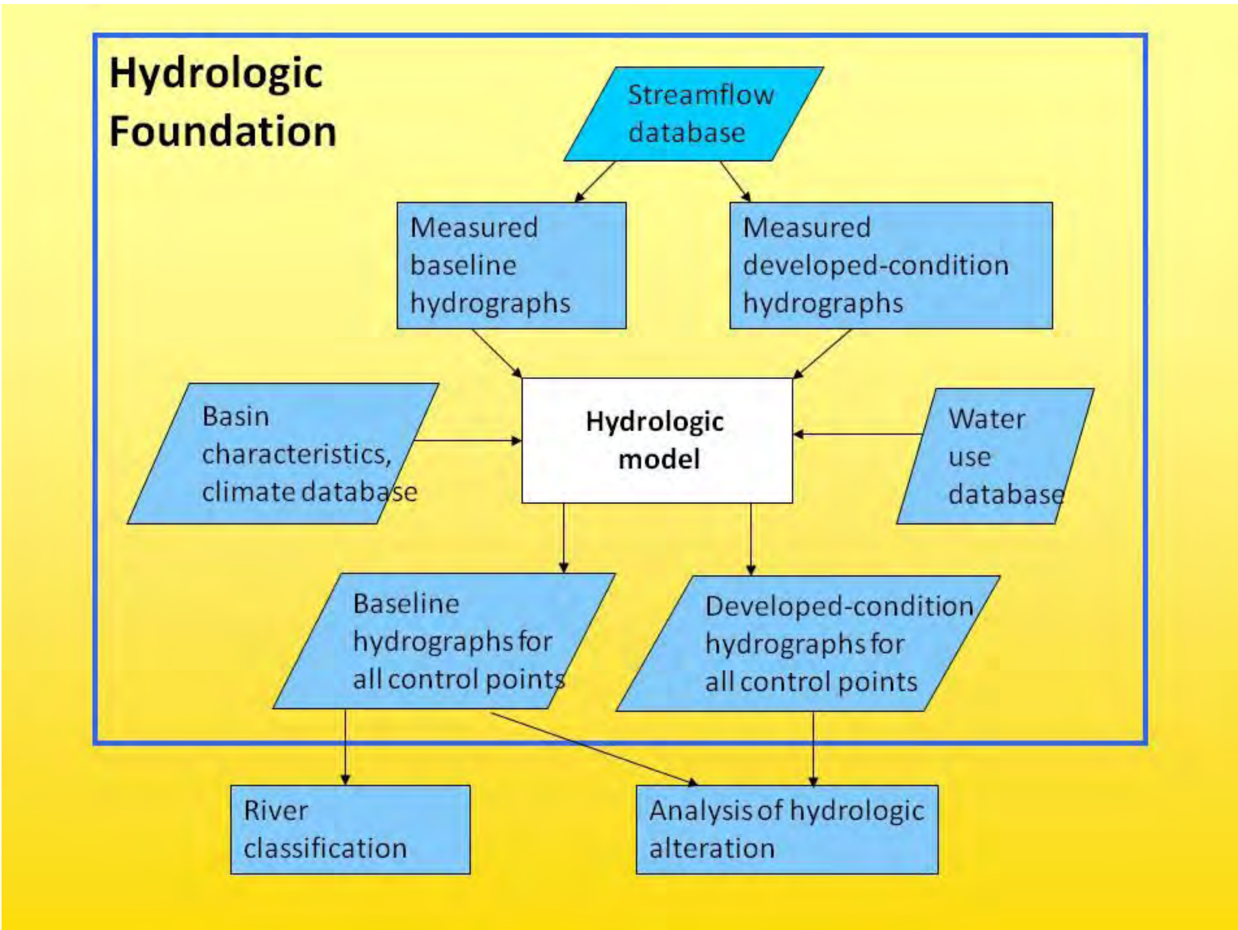


Figure 3. Coverage of TOPMODEL hydrologic models for Alabama. USGS has developed statewide coverage of TOPMODEL to support Alabama's water availability assessment program.

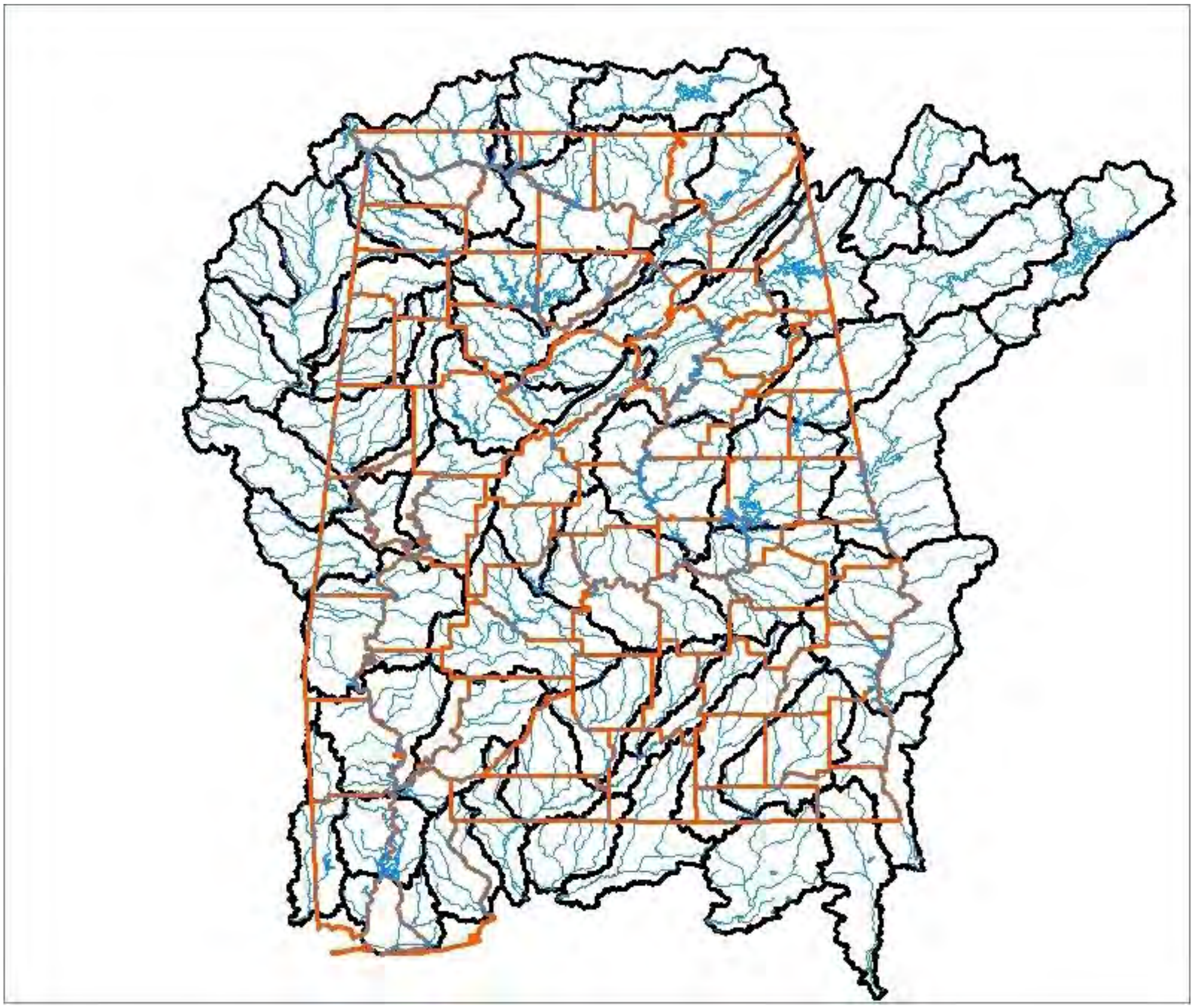


Figure 4. Alabama-Coosa-Tallapoosa (ACT) River basin. The US Army Corps of Engineers and Alabama Power have developed hydrologic decision support systems for their management activities in this basin.

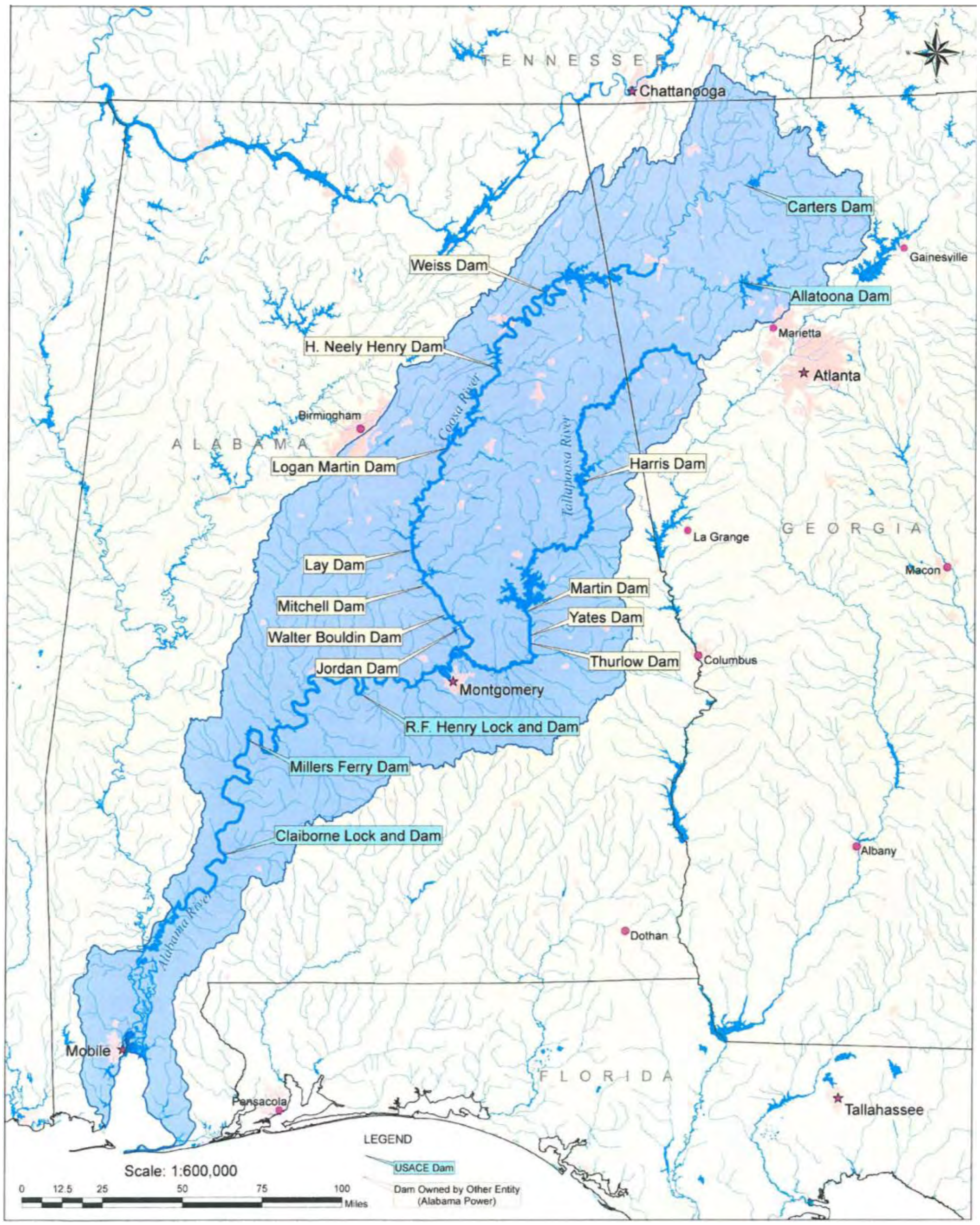


Figure 5. Selected watersheds for the US Environmental Protection Agency Global Change Research Program. HSPF models will be developed for all selected watersheds. See text for an explanation of the program for the watersheds in the SALCC. (source: http://www.aquaterra.com/projects/)

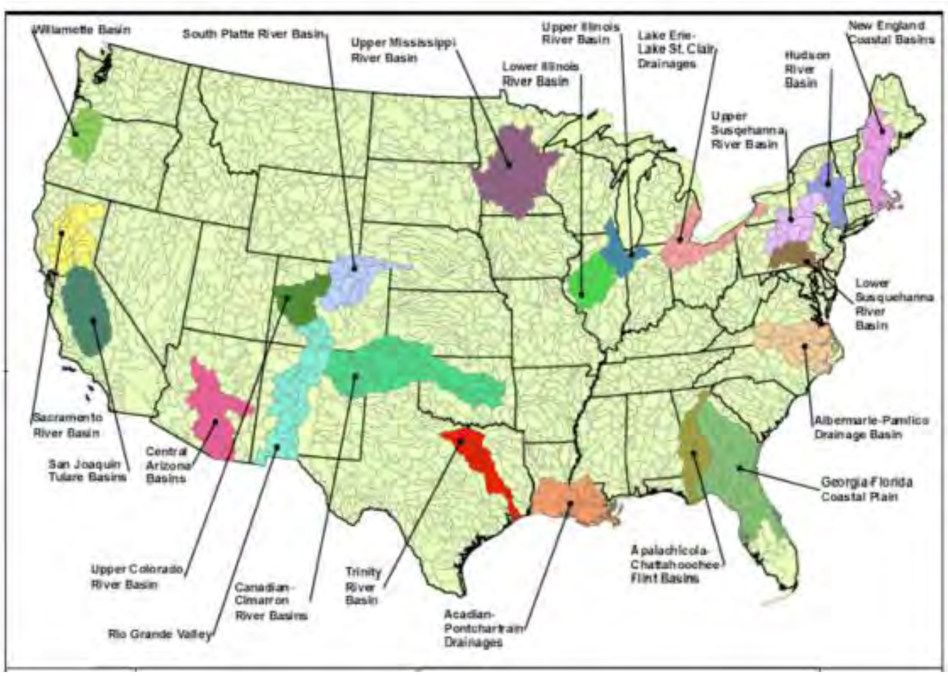


Figure 6. Florida Water Management Districts. Boundaries generally follow major watershed boundaries. (source: www.dep.state.fl.us/secretary/watman/)

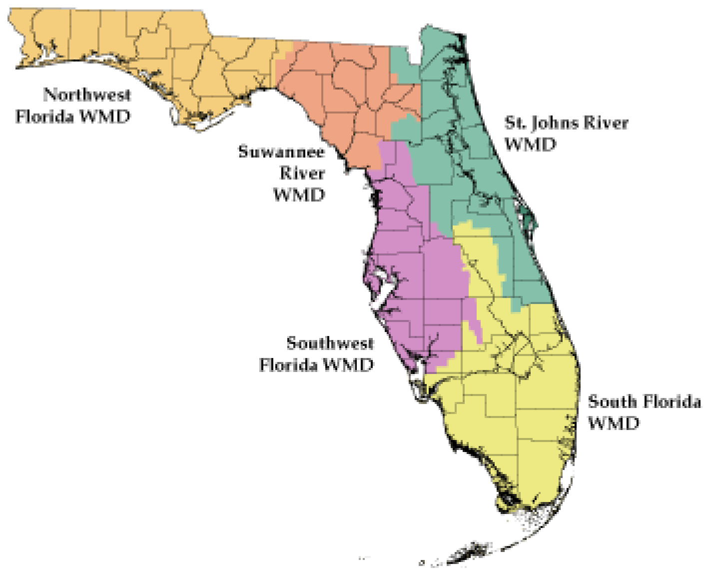


Figure 7. Watersheds used in Georgia's Statewide Comprehensive Water Management Plan. LSPC models have been developed statewide to support assessments of water quality. (source: www.georgiawaterplanning.org)

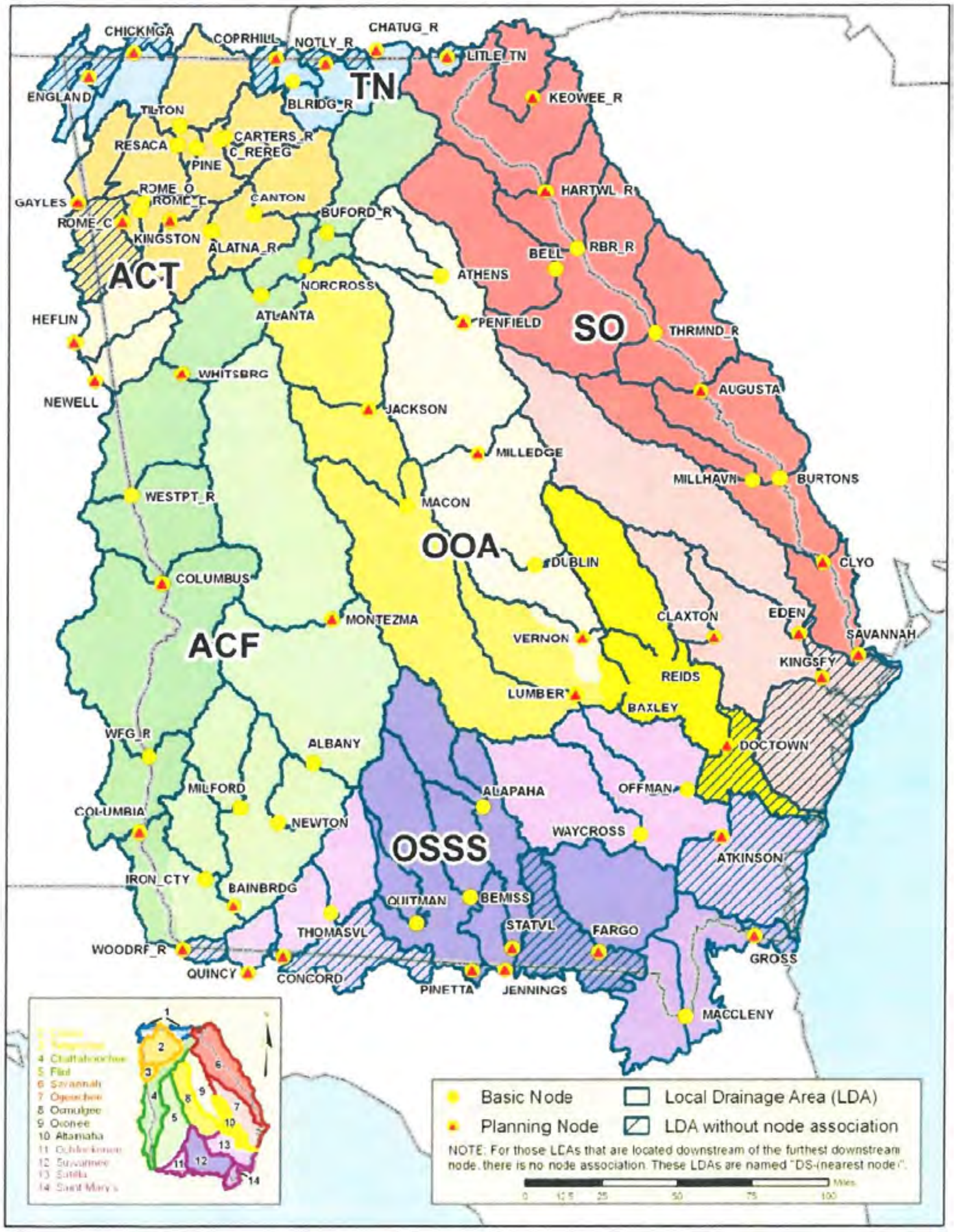


Figure 8. The Apalachicola-Chattahoochee-Flint (ACF) River basin. The US Army Corps of Engineers, Atlanta Regional Commission, US Geological Survey, and US Environmental Protection Agency have all developed hydrologic models for this basin.

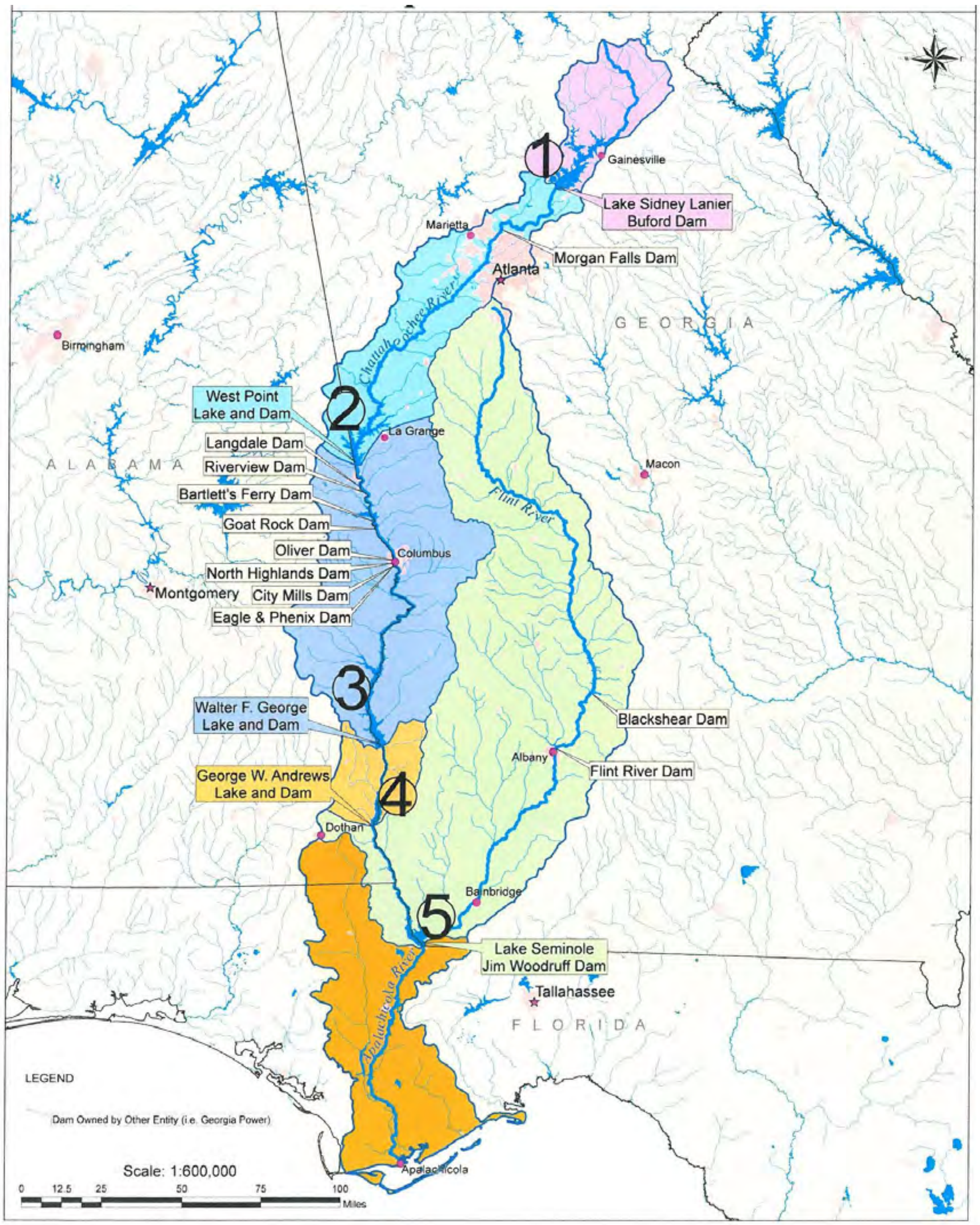


Figure 9. North Carolina watersheds. OASIS models are being develop for each of the 17 major watersheds under 2010 legislation. (source: www.ee.enr.state.nc.us/public/ecoaddress/riverbasins/)

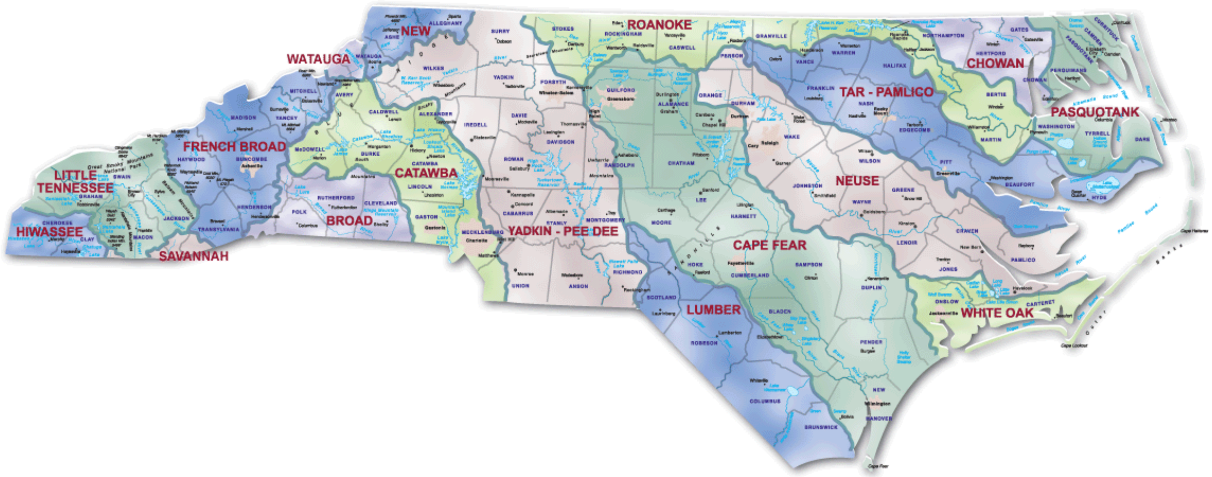


Figure 10. OASIS model of the Roanoke River. An example of the hydrologic decision support systems the state of North Carolina is developing for its 17 watersheds. These models will support water management planning statewide. (source: www.ncwater.org)

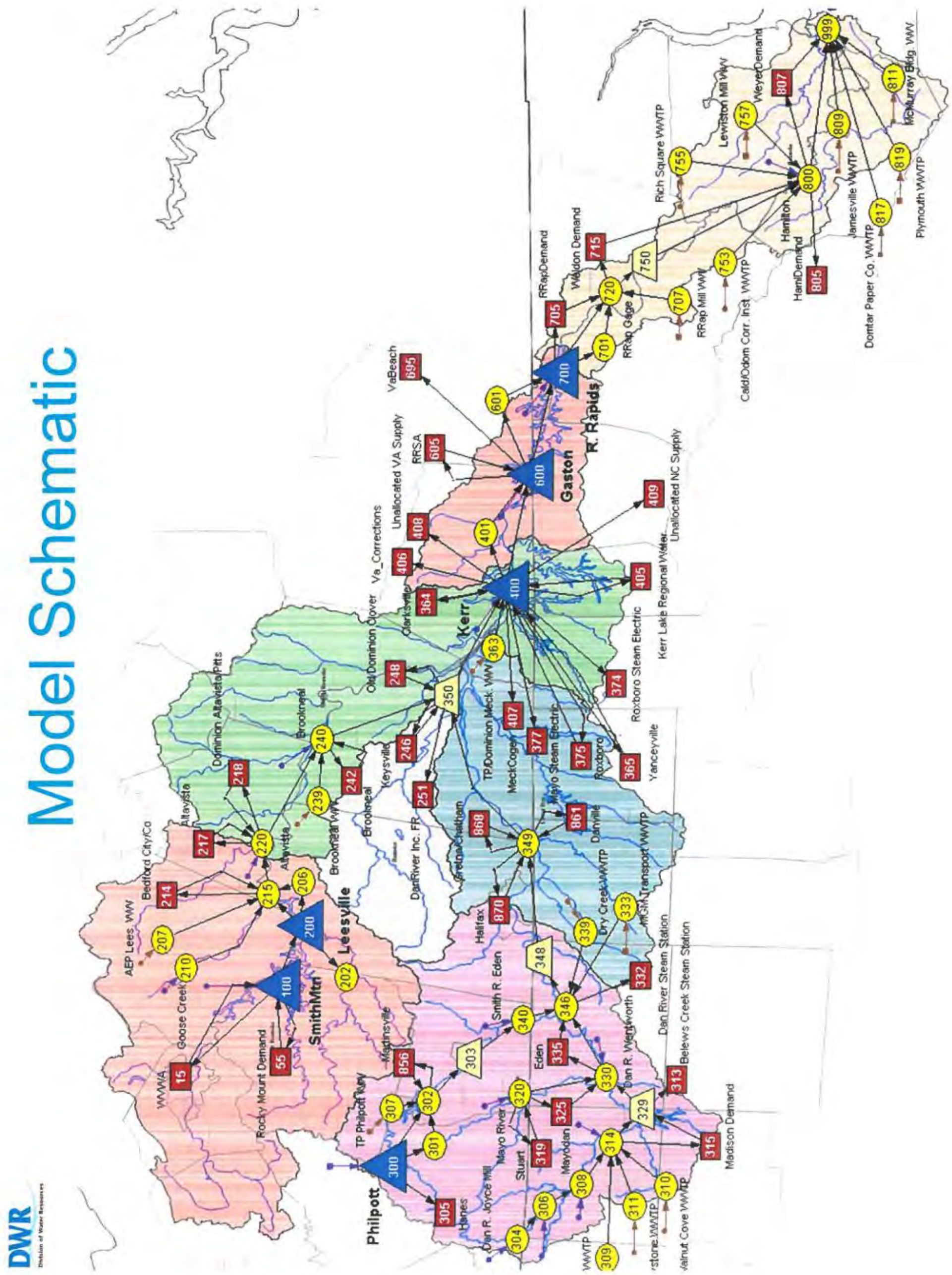


Figure 11. South Carolina major watersheds. (source: www.scdhec.gov/environment/water/)

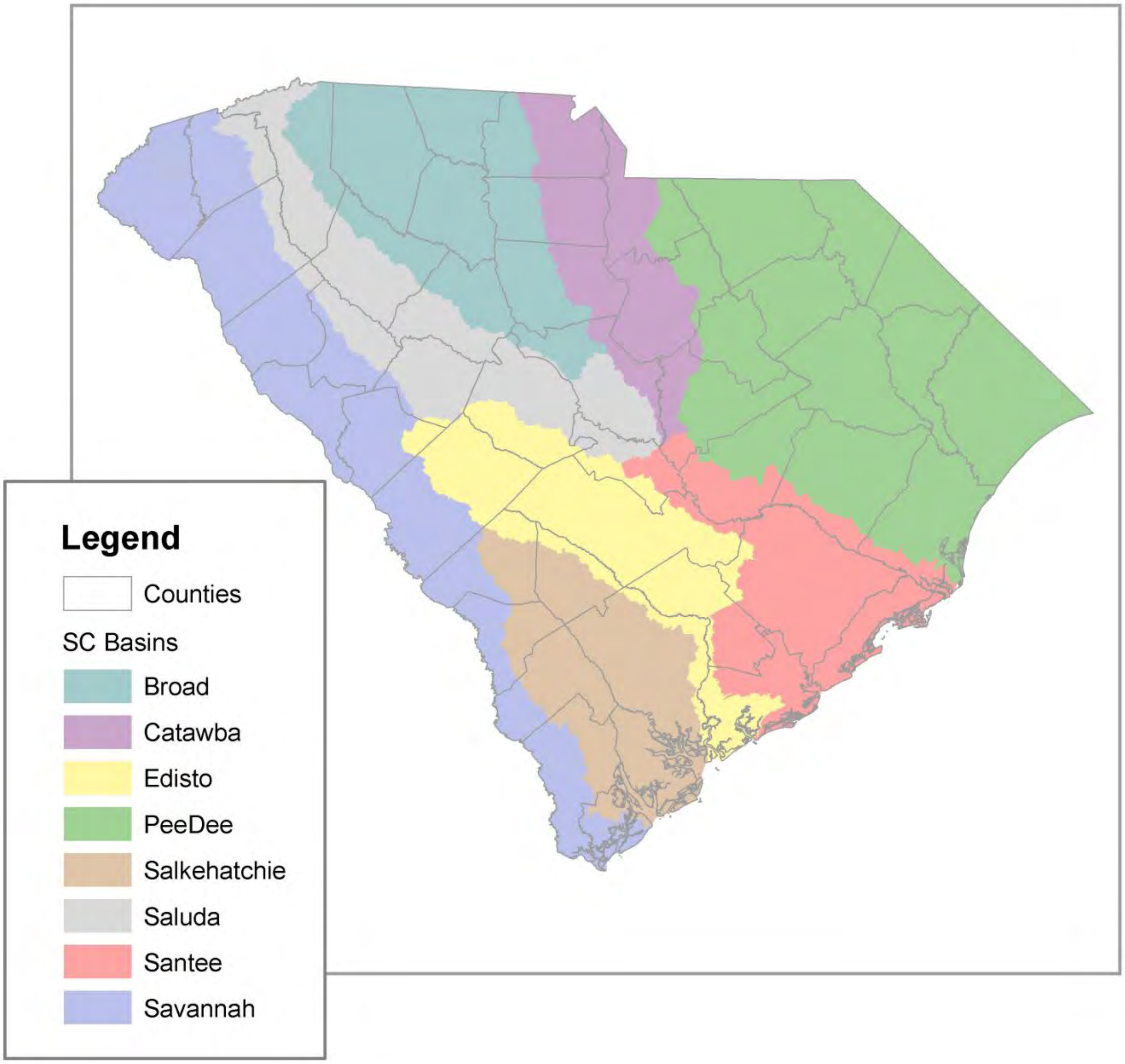


Figure 12. Virginia major watersheds. (source: web.wm.edu/geology/virginia/rivers/).

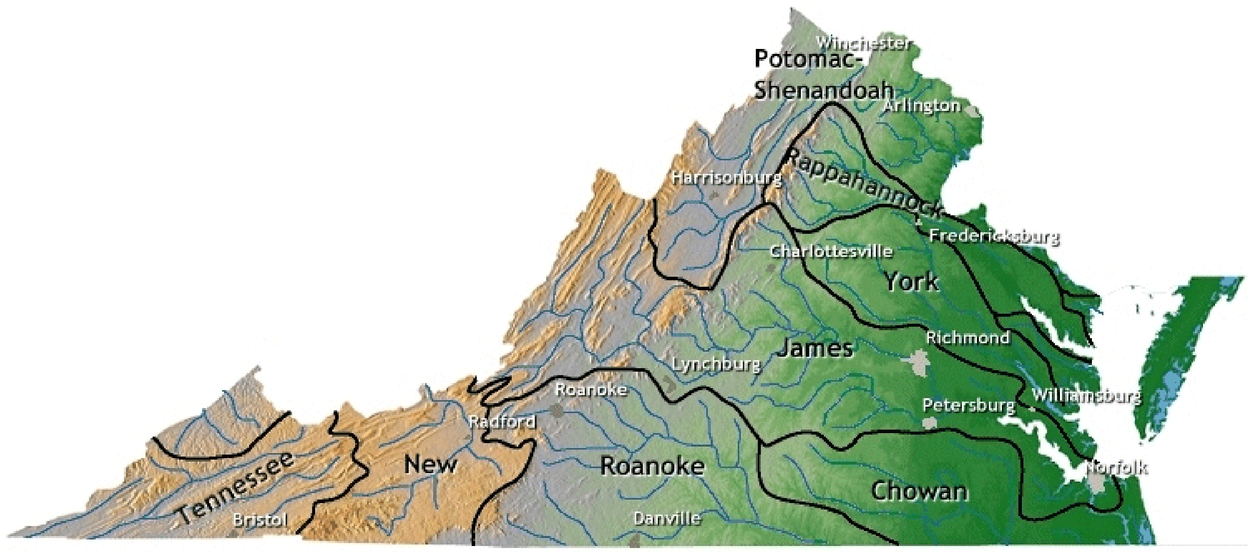
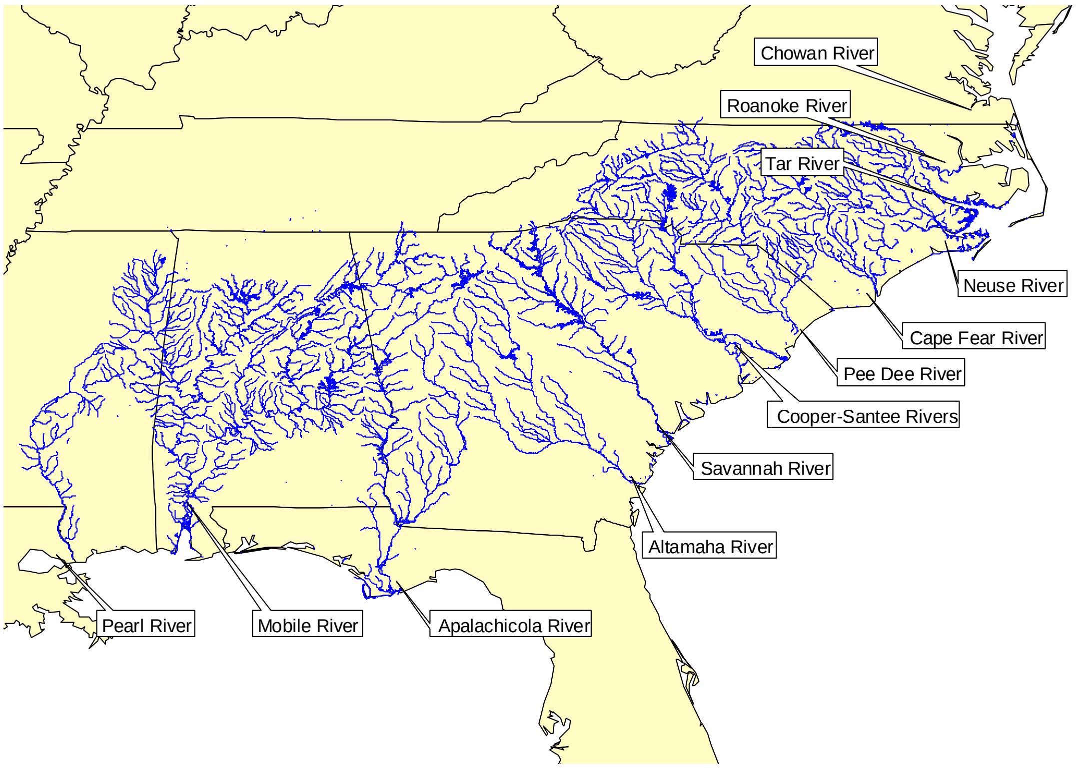


Figure 13. Major watersheds of the SALCC.



Appendix A - Hydrologic model contacts

Alabama (AL)

- Tom Littlepage, Alabama Office of Water (tom.littlepage@adeca.alabama.gov)

Florida (FL)

- Sonny Hall, St Johns River Water Management District
- John Good, Suwannee River Water Management District
- Ron Bartel, Northwest Florida Water Management District

Georgia (GA)

- Wei Zeng, GA-DNR Environmental Protection Division (Phone: 404.463.1425)
- Pat Stevens, Atlanta Regional Commission (pstevens@atlantaregional.com)

North Carolina (NC)

- Steve Reed, NC Department of Environment and Natural Resources (steven.reed@ncmail.net)

South Carolina (SC)

Virginia (VA)

- Scott Kudlas, VA Department of Environmental Quality (scott.kudlas@deq.virginia.gov)

US Army Corps of Engineers (USCOE)

- Stan Simpson, Savannah and Wilmington Districts – USCOE (Stanley.L.Simpson@sas02.usace.army.mil)
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US Environmental Protection Agency (USEPA)

US Fish and Wildlife Service (USFWS)

- John Faustini, USFWS – Southeast Region (john_faustini@fws.gov)

US Forest Service (USFS)

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US Geological Survey (USGS)

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