Bibliographic Review of Sources Relevant to Development of Draft Ecosystem Flow Recommendations for the Savannah River below Thurmond Dam

January 2003

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This document is a review of the priority information sources previously identified by the UGA research team (see report of 31 October 2002). It is in the form of an annotated bibliography in four sections: (1) Hydrology, water quality, and geomorphology; (2) Floodplain ecosystems; (3) Aquatic biota; and (4) Estuarine processes. The following outline is included to provide an overview of the organization of this report.

(1) Hydrology, water quality, and geomorphology
- General hydrologic data (streamflow and peakflow statistics; river forecasting; water withdrawal and discharge; dam operations)
- Lake data
- Dredging and cross-section data
- Water quality data
- Recent maps and aerial photography
- Map for April workshop
- Historical maps and aerial photography
- Climate data

(2) Floodplain ecosystems
- Savannah River floodplain studies (effects of flooding on seed dispersal, germination and establishment in cypress-tupelo forests; seed banks; winter floods; importance of substrate heterogeneity in seedling recruitment; effects of water level fluctuations on growth of swamp forest trees; seedling recruitment and growth; dynamics of mature forests; comparison of wetland forest communities in response to hydrologic regime; experimental studies of effects of flooding; remote sensing of SRS floodplain vegetation; Pen Branch restoration; invasive species; bivalves; insects; birds; herpetofauna)
- Related studies, not necessarily on Savannah River floodplain (effects of river flow management on floodplain systems; tree seedling recruitment and physiological tolerances; forest dynamics and productivity; floodplain nutrient cycling processes; coastal issues/sea level rise; general river floodplain references; floodplain wetland restoration; miscellaneous)

(3) Aquatic biota
- Atlantic and shortnose sturgeon
- Shad and herring
- American eel
- Striped bass

(1) HYDROLOGY, WATER QUALITY, AND GEOMORPHOLOGY
(compiled by Rhett Jackson and Cody Hale)

There are many sources of information on the hydrology, water quality, and geomorphology of the Savannah River system as outlined below. There appears to be only one effort to create a comprehensive summary of water quality information, and that is the Savannah River Basin Management Plan (GA EPD, 2001). In evaluating and analyzing this information, our primary areas of focus will be hydrologic modification by the reservoir system (as determined from pre- and post-project USGS flow data from the Augusta and Clyo gages), dredging modifications to the river channel, water demands (such as lake evaporation and water withdrawals from the Savannah River), current water quality conditions, and hydraulic analysis of floodplain connectivity. Below are listed the hydrologic data sources we believe to be most relevant to an evaluation of ecological flow restoration on the Savannah.

General Hydrologic Data

GA Department of Natural Resources, Environmental Protection Division. 2001. Savannah River Basin Management Plan 2001. Section 2.1.4, 4.1.3. Atlanta, GA.
Section 2 gives a general overview of the Savannah River and its basin's physical characteristics. Section 4 gives a brief evaluation of the temperature and flow modifications to the Savannah River and their affects.

Meade, Robert H. May 1982. Sources, Sinks, and Storage of River Sediment in the Atlantic Drainage of the United States. The Journal of Geology. Vol. 90. No 3. The University of Chicago Press. Chicago, IL.
This article addresses the issue of sediment transport from the point of erosion to its final storage point (salt marshes in the Lower Piedmont). Emphasizes the fact that a large amount of eroded material has yet to reach a water body and is being stored on the landscape. Thurmond Dam is mentioned directly as it notes it has a sediment trap efficiency of 80-90%. In the decade following the dam installation it was found that the sediment concentrations at the Augusta gage had decreases from pre-dam levels, however concentrations measured at the Clyo gage remained at the same levels. This has been attributed to the sediment previously stored in the lower reaches of the channel.

Pearlstine, L.G., R. Bartleson, W.M. Kitchens, and P.J Latham. 1989. Lower Savannah River Hydrological Characterization. Technical Report No. 35. Florida Cooperative Fish and Wildlife Research Unit. Gainesville, FL.
Paper has yet to be obtained.

US Army Corps of Engineers, Savannah District, South Atlantic Division. April 1992. Lower Savannah River Environmental Restoration: Reconnaissance Report. pp. 12-13, 17 and 47.
These pages contain descriptions of the Savannah River's physical attributes, water quality classifications, statistical analyses on streamflow characteristics, and information on water releases during low flows. Flow regime as it pertains to water quality, wetlands, and fisheries is also addressed.

Streamflow Statistics for the Savannah River @ …

Stevens Creek: http://waterdata.usgs.gov/nwis/discharge/?site_no=02196000
Period of Record: 1929-Present (gaps from 1931-40 and 1978-83)
Augusta: http://waterdata.usgs.gov/nwis/discharge/?site_no=02197000
Period of Record: 1883-Present (continuous since 1925)
Burton's Ferry: http://waterdata.usgs.gov/nwis/discharge/?site_no=02197500
Period of Record: 1939-70 and 1982-Present
Clyo: http://waterdata.usgs.gov/nwis/discharge/?site_no=02198500
Period of Record: 1929-Present (gap from 1933-37)
The streamflow data from these sites has been used to develop pre and post-dam flow recurrence curves, flow duration curves, 7-day low flow curves, hydrographs, and mean monthly flow graphs.

Peak Flow Statistics for the Savannah River @ …
Stevens Creek: http://waterdata.usgs.gov/nwis/peak/?site_no=02196000
Augusta: http://waterdata.usgs.gov/nwis/peak/?site_no=02197000
Burton's Ferry: http://waterdata.usgs.gov/nwis/peak/?site_no=02197500
Clyo: http://waterdata.usgs.gov/nwis/peak/?site_no=02198500
These data give the annual maximum flow for the period of record at each gage. It is used to compare peak flows from before and after dam installation.

River Forecasting
Augusta: http://www.srh.noaa.gov/serfc/hydroweb/AUGUSTA.gif
Millhaven: http://www.srh.noaa.gov/serfc/hydroweb/BURTONS_FERRY.gif
Clyo: http://www.srh.noaa.gov/serfc/hydroweb/CLYO.gif
These sites give flood stage and flood of record for each gage. Also, it includes a hydrograph and precipitation data for the past five days and forecasts this information through the next five days.
Water Withdrawal/ Discharge Data

GA Department of Natural Resources, Environmental Protection Division. 2001. Savannah River Basin Management Plan 2001. Figures and Tables. Atlanta, GA.
Table 3-1: Community Public Water Systems in the Savannah River Basin
Table 3-2: Permits for Surface Water Withdrawals in the Savannah river Basin
Table 3-4: Historical Agricultural Water Use in the Savannah River Basin, 1980-1995
Table 3-5: Projected Water Use in the Savannah River Basin, 1995-2020
Table 3-6: Permits for Groundwater Withdrawals from the Savannah River Basin
Table 4-1: Major Municipal Wastewater Treatment Plant Discharges in the Savannah River Basin
Table 4-2: Summary of NPDES Permits in the Savannah River Basin
Table 4-3: Major Industrial and Federal Wastewater Treatment Facilities in the Savannah River Basin
Figure 3-2: Surface Water Intakes, Savannah River Basin, HUC 03060103
Figure 3-4: Surface Water Intakes, Savannah River Basin, HUC 03060105

Figure 3-5: Surface Water Intakes, Savannah River Basin, HUC 03060106
Figure 3-7: Surface Water Intakes, Savannah River Basin, HUC 03060109
Figure 4-1: Location of Municipal Wastewater Treatment Plant Discharges in the Savannah River Basin
Figure 4-3: NPDES Sites Permitted by GAEPD, Savannah River Basin, HUC 03060103
Figure 4-5: NPDES Sites Permitted by GAEPD, Savannah River Basin, HUC 03060105
Figure 4-6: NPDES Sites Permitted by GAEPD, Savannah River Basin, HUC 03060106
Figure 4-8: NPDES Sites Permitted by GAEPD, Savannah River Basin, HUC 03060109

Dam operations

Water Control Plan: http://water.sas.usace.army.mil/manual.zip
Manual outlines the operating procedures for the three dams on the Savannah River. Also, includes thorough specifications of the dams and reservoirs.

Lake Data

GA Department of Natural Resources, Environmental Protection Division. 2001. Savannah River Basin Management Plan 2001. Section 2.1.4. Figure 2.4-5. Atlanta, GA.
This section outlines the history, location, size, and drainage area of the Savannah River reservoirs. Included are maps that show the reservoirs on a basin scale.

US Army Corps of Engineers, Lake data page: http://water.sas.usace.army.mil/hist.htm
This site has both climate and lake data for the three reservoirs on the Savannah River.

Dredging and Cross-section Data

US Army Corps of Engineers, Savannah District, South Atlantic Division. April 1992. Lower Savannah River Environmental Restoration: Reconnaissance Report. pp. 20-32.
This section deals with the types of improvement alternatives suggested for the cut-off bends. Dredging plans and fate of the dredged materials is included.

US Army Corps of Engineers, Savannah District, South Atlantic Division. 1990. Navigation Charts: Savannah River Below Augusta.
Black and White aerial photography of the river (from river mile 22-203) with cross-sections superimposed every tenth of a mile.

US Army Corps of Engineers, Savannah District, South Atlantic Division. 1947-1951. Cross-sections for river miles 28-219: Savannah to Augusta.
Blueprint format of the river channel with approximately twenty-five cross-sections per mile.

Water Quality Data

Alber, M. and J. Florey. 2002. The effects of changing freshwater inflow to estuaries: A Georgia perspective. Georgia Coastal Research Council. 45 p.
This recent review summarizes the scientific information available regarding the connections between freshwater inflow, estuarine conditions and resources. It explores the different approaches to estuarine inflow management being used in the US and puts

the current Georgia approach in perspective. It has an extensive list of sources for water quality and estuarine resource data.

Clarke, J.S., and Krause, R.E., 2000. Design, revision, and application of ground-water flow models for simulation of selected water-management scenarios in the coastal area of Georgia and adjacent parts of South Carolina and Florida: U.S. Geological Survey Water- Resources Investigations Report 00-4084, 93 p.
This report outlines revisions made to ground-water flow models of the Floridan aquifer system in the coastal area of Georgia and adjacent parts of South Carolina and Florida. The updated models were then used to facilitate evaluation of the effects of pumping on the ground-water level near areas of saltwater contamination. Thirty-two pumping scenarios were analyzed. Maps showing simulated ground-water-level decline and diagrams presenting changes in simulated flow rates are presented for each scenario.

Clarke, J.S., and Krause, R.E. 2001. Coastal Ground Water at Risk - Saltwater Contamination at Brunswick, GA and Hilton Head Island, SC: U.S. Geological Survey Water Resources Investigations Report 01-4107, 1 oversize sheet.
Saltwater contamination is restricting the development of ground-water supply in coastal Georgia and adjacent parts of South Carolina and Florida. This report outlines the coastal Georgia geologic setting, pre and post-development groundwater flow behavior, the differing mechanisms of saltwater intrusion at Hilton Head Island, SC and Brunswick, GA, and addresses the need for a water management plan to sustain growth in these areas.

Clarke, J.S., 2000. Georgia's coastal sound science initiative--evaluation of ground-water flow, saltwater contamination, and alternative water sources: in Geological Society of America, Abstracts with Programs, v. 32, no. 2, p. 11.
The GA EPD has developed a series of studies, the Coastal Sound Science Initiative, in which they are reviewing feasible alternatives for supporting the EPA's strategy to protect the Upper Floridan Aquifer. The USGS is working in conjunction with GA EPD to help simulate management alternatives that could help reduce saltwater contamination.

Clarke, J.S., and Krause, R.E. 2000. Use of ground-water flow models for simulation of water-management scenarios in the coastal area of Georgia and adjacent parts of South Carolina: in Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia, Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia, p. 627-630.
This report reviews the use of ground-water flow models for the coastal area of Georgia and adjacent parts of South Carolina and Florida, by the USGS, to simulate various water-management scenarios. Results of these simulations were used by the GA EPD to help develop an interim water-management strategy for coastal Georgia. Results of selected model simulations are presented in this paper.

Clarke, J.S., and Krause, R.E. 2001. Saltwater contamination of ground water at Brunswick, Georgia and Hilton Head Island, South Carolina: in Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia, Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia, p. 756-759.

This paper addresses the problem of saltwater intrusion into the Upper Floridan aquifer in the coastal areas of Georgia and adjacent South Carolina due to the excessive pumping of water from this resource. Understanding the conditions under which these intrusions occur is important to developing management strategies for the coastal area's water resources.

Fanning, J.L., 1999. Water use in coastal Georgia by county and source, 1997; and water-use trends, 1980-97: in Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at The University of Georgia, Athens, Georgia, Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

This paper reports water use during 1997 for the 24-county area of coastal Georgia, by water-use category, using data obtained from various Federal and State agencies. Categories of offstream water use include public supply, domestic, commercial, industrial, mining, irrigation, livestock, and thermoelectric power generation. Also included is an evaluation of water use trends in these counties from 1980-97.

GA Department of Natural Resources, Environmental Protection Division. 2001. Savannah River Basin Management Plan 2001. Section 4.1.1-3, Table 4-5. Atlanta, GA.

These sections address NPDES permitted municipal and industrial storm water and wastewater discharge, nonpoint source pollution by type (agricultural, residential/commercial, animal, and forestry), and modifications that have affected flows and temperature.

GA Department of Natural Resources, Environmental Protection Division. 2000. Georgia 2000 305 (b) Report:
http://www.state.ga.us/dnr/environ/gaenviron_files/watrqual_files/305b00_rpt.pdf

This report outlines how and when water quality monitoring programs were established. It lists water quality standards for individual water bodies of GA and explains how streams and lakes are classified in accordance to these standards.

US Army Corps of Engineers, Savannah District, South Atlantic Division. April 1992. Lower Savannah River Environmental Restoration: Reconnaissance Report. pp. 16, 17.

Addresses water quality as it pertains to the Savannah Water Intake Facility, point sources of pollution, and low dissolved oxygen and high temperatures due to low flows separating cut-off bends and oxbows from the river. Increasing flows in the lower Savannah River can mitigate the negative impacts associated with these issues.

Online water quality data from USGS gages (Savannah River @…)
Clyo:
http://waterdata.usgs.gov/ga/nwis/qwdata?site_no=02198500&agency_cd=USGS&begin_date=&end_date=&inventory_output=0&rdb_inventory_output=file&format=rdb&date_format=YYYY-MM-DD&rdb_compression=&qw_sample_wide=0&submitted_form=brief_list

Contains data on a variety of water quality parameters. One useful parameter not included is dissolved oxygen.

* Other gages have very limited water quality data

Recent Maps & Aerial Photography

EnviroMapper: http://maps.epa.gov/
An interactive mapping tool that can be used to identify items of interest such as NPDES permit locations, nutrient stations, and watershed boundaries.

GA Department of Natural Resources, Environmental Protection Division. 2001. Savannah River Basin Management Plan 2001. Figures. Atlanta, GA.
Hydrography: Figures 2-1 through 10
Hydrogeology: Figure 2-10
Land Use: Figures 2-13 through 19
Land Cover: Figures 2-20 through 26
Surface Water Intakes: Figures 3-1 through 7
Water Treatment Plants: Figure 4-4
NPDES Permits: Figures 4-2 through 8
Gaging Stations: Figure 5-12

US Army Corps of Engineers, Savannah District, South Atlantic Division. April 1992. Lower Savannah River Environmental Restoration: Reconnaissance Report. Figures 1 and 2.
Figure 1 is a map of the basin including bridges, dams, and the City of Savannah water intake. Figure 2 maps the basin with cut-off bends under consideration for restoration highlighted.

US Army Corps of Engineers, Savannah District, South Atlantic Division. 1990. Navigation Charts for the Savannah River Below Augusta.

USGS has DOQQ (Digital Orthophoto Quarter Quadrangle, 1992) and some CIR (Color Infrared, 1999) photography. It is available at UGA, Institute of Ecology, GIS lab.

USGS Quadrangle Maps, 1:24,00 as follows:
Sheet Name Date
North Augusta 1980
Augusta 1995
Mechanic Hill 1981
Jackson 1989
Shell Bluff Landing 1989
Girard NW 1989
Girard 1989
Millett 1989
Burton's Ferry Landing 1987
Bull Pond 1987
Brier Creek Landing 1987
Blue Springs Landing 1987
Kildare 1987
Brighton 1987
Pineland 1988
Hardeeville NW 1987
Rincon 1979
Hardeeville 1987

Port Wentworth 1993
Limehouse 1980
Savannah 1978

Map for April Workshop

We have hired a GIS professional to combine the following information into maps usable at the workshop. We plan to have her put it on a CD as well as provide large format printed maps, perhaps of the three sections of the river. It would be helpful to get some feedback from TNC on what would be most useful.

Soils - Map of soil types clipped at 5 or 10 miles on either side of the river; this may allow us to delineate the floodplain
1:250,000 GA soils map
1:24,000 SC soils maps

Drainages - This map should show detail of the river including oxbows and cut-off bends (and should also include tributaries?). We currently have two datasets that include this information. One is very detailed and includes other information such as gaging sites, roads, towns, county boundaries, and land cover. Its drawback is that it onlycovers GA. The other dataset includes just the drainages with no state discrimination. Ideally, we'd like to take the useful information from the GA dataset and couple it with SC drainage data for the final map.

River channel: We have downloaded B&W aerial photos of the river. These have good detail of the river, cut-off bends, and oxbows.

Wetlands - Available but not yet downloaded: National Wetlands Inventory has GIS data that classifies forest types by quadrangle(forested wetland, non-forested wetland, upland deciduous, and so on). We have a list of the quadrangles necessary to get coverage of the corridor and adjacent landscape. In addition, there are datasets available from FEMA that map the 100-yr and 500-yrfloodplains by county. However, the only counties that we were able to pull up in ArcView are Richmond and Chatham.

Land Cover - Don't know if it's necessary, but seems that it may be useful. Map would cover the river and surrounding landscape. Several land cover datasets are available at different scales and containing different classifications.

Historical Maps and Aerial Photography

USGS Topographic Maps, 1:62,500 as follows:
Sheet Name Date
Augusta 1921
Greens Cut 1920
Ellenton 1921
Hilltonia 1920
Peeples 1920
Shirley 1919
Pineland 1919
Hardeeville 1920
Savannah 1920
Bluffton 1920

U.S. Forest Service- Savannah River. 1948. Black and white aerial photography of the Savannah River Site.

1888 Army maps from Andersonville SC to Augusta GA showing extent of shoals from Augusta to the Tugaloo River (Will Duncan received from Prescott Brownell).

Aerial photos from USGS: http:\\terraserver.homeadvisor.msn.com\
These show sandbars, floodplain habitats, and oxbows.

Climate Data

GA Department of Natural Resources, Environmental Protection Division. 2001. Savannah River Basin Management Plan 2001. Section 2.1.2. Atlanta, GA. General overview of the Savannah River basin climate.

Southeast Regional Climate Center- Historical Climate Records:
Augusta WSO Airport- http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?ga0495
Period of Record: 1948-2000
Millhaven-Wade- http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?ga5896
Period of Record: 1956-1986
Newington- http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?ga6323
Period of Record: 1956-2000
Savannah WSO Airport- http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?ga7847
Period of Record: 1948-2000

These sites list average monthly maximum and minimum temperatures along with average monthly precipitation and snowfall for the period of record.

Present conditions

Cody Hale motored down the river over a 2.5 day period this autumn, stopping every 15 minutes to take pictures of bank conditions and water quality measures with a Hydrolab.

Sources identified at TNC workshop that are not on this list

There are additional USACE data (e.g. historical inflow data being compiled by Lamar Sanders) that are not yet included here. We have sent a letter requesting information on several topics to our hydrologist contact, Stan Simpson, at the Savannah office and are awaiting a response.

We have not included data from the USGS gages at Brier Creek because they are such a small fraction of the total river flow at that point.

(2) FLOODPLAIN ECOSYSTEMS

(compiled by Rebecca R. Sharitz, Elizabeth A. Richardson, and Monica Palta)
NOTE: This section was updated 2/28/03. Hence this material is updated from what was originally sent out in January 2003.

The following bibliographic information is divided into two major categories. The first includes data specific to the Savannah River floodplain, and the second is similar research on comparable systems. Papers on closely related topics are grouped into subcategories, and in some cases a paper may be listed more than once. Annotations are provided for all references in category 1, and for selected references in category 2.

Category 1: Savannah River Studies

Dynamics of mature forests on the Savannah River floodplain and a tributary

Good, B. and S. Whipple (1982). "Tree spatial patterns: South Carolina bottomland and swamp forests." Bulletin of the Torrey Botanical Club 109: 529-536.

Jones, R., R. Sharitz, S. James and P. Dixon (1994). "Tree population dynamics in seven South Carolina mixed-species forests." Bulletin of the Torrey Botanical Club 121: 360-368.

These papers describe a study of seven 1-ha mixed-species forest plots distributed along a soil moisture gradient. Two of the plots are on the floodplain of the Savannah River; the other five are along Upper Three Runs Creek. All trees were tagged and measured in 1979, and have been remeasured in 1989, 1995 and 2000. In all plots, small stem density decreased and large stem density increased, an indication that the forests are in mid-succession phases where competition is expected to be intense. Note: the 1995 and 2000 data on these forests have not yet been published.

Effects of flooding on seed dispersal, germination and seedling establishment in cypress-tupelo forests, including both natural recruitment processes and recovery from disturbance

De Steven, D. and R. Sharitz (1997). "Differential recovery of a deepwater swamp forest across a gradient of disturbance intensity." Wetlands 17(4): 476-484.

Schneider, R., N. Martin and R. Sharitz (1989). Impact of dam operations on hydrology and associated floodplain forest of Southeastern rivers. DOE Symposium Series No. 61, Oak Ridge, TN.

Sharitz, R. and L. Lee (1985). Recovery processes in southeastern riverine wetlands. Riparian Ecosystems and Their Management: Reconciling Conflicting Uses, U.S. Forestry Service.

These papers describe studies conducted in cypress-tupelo forests on the floodplain of the Savannah River on the SRS, in which recovery following long-term chronic disturbance and natural recruitment are examined. In each of these, it is either demonstrated or suggested that flooding during the growing season limits seedling survival during early phases of recruitment. Floods during the winter months are shown to be important in seed dispersal, but summer floods of more than a few days are likely to cause mortality of newly germinated seeds. Comparisons of Savannah River discharges for ten-year periods prior to upstream reservoir construction and post-construction suggest that extensive periods of low summer water levels no longer provide

opportunity for extensive seedling recruitment. The Schneider et al. paper examines impacts to hydrology in other southeastern river floodplains, using USGS records.

Sharitz, R., L. Lee, R. Johnson, C. Ziebell, D. Paton and P. Ffolliott (1985). Limit on regeneration process in southeastern riverine wetlands. North American Riparian Conference, Tucson, AZ.

Effects of water level fluctuations (and/or altered hydrologic conditions) on growth of swamp forest trees on the Savannah River floodplain

Keeland, B. and R. Sharitz (1995). "Seasonal growth patterns of Nyssa sylvatica var. biflora, Nyssa aquatica, and Taxodium distichum as affected by hydrologic regime." Canadian Journal of Forest Research 25: 1084-1096.

Keeland, B. and R. Sharitz (1997). "The effects of water level fluctuations on weekly tree growth in a southeastern USA swamp." American Journal of Botany 84: 131-139.

Young, P., B. Keeland and R. Sharitz (1994). "Growth response of baldcypress [Taxodium distichum (L.) Rich.] to an altered hydrologic regime." American Midland Naturalist 133: 206-212.
These three studies examine the growth responses of canopy and subcanopy cypress and tupelo trees to fluctuations or alterations in the hydrologic regime. In the first two, Keeland used dendrometer bands to examine weekly responses of over 600 mature trees to variations in hydrologic regime at five sites on the Savannah River floodplain throughout two growing seasons. Significant relationships between weekly changes in water levels and tree diameter were found for N. sylvatica and T. distichum trees growing in sites with periodic shallow flooding. The Young et al. study used tree cores to assess growth of canopy T. distichum trees following impoundment of an area as a result of road construction. Tree growth was accelerated for several years immediately following impoundment, followed by a long-term (approximately 16 year) decline.

Experimental studies of the effects of flooding (and other factors such as salinity) on seedling growth of swamp forest species

Hardegree, W., D. Wenner, J. Dowd and K. McLeod (1995). "Using super(18)O/super(16)O data to examine the mixing of water masses in floodplain wetlands." Wetlands Ecology and Management 3(3): 189-194.
Using oxygen isotopic differences, the extent to which Savannah River flood water inundates tributaries and surrounding floodplains was determined to be significantly greater than visual turbidity indicates. Visual estimates indicated inundation to 300 m up the tributary, whereas isotopic data revealed mixing of water 1100 m up the tributary. Differing water quality in the river (suspended solids, agricultural and industrial runoff)compared to the tributary can affect ecological processes.

Conner, W., J. Bryant and L. Inabinnette (1996). Impact of complete submergence upon three common wetland species. Proceedings of the Southern Forested Wetlands Ecology and Management Conference, Clemson University, Clemson, SC, Consortium for Research on Southern Forested Wetlands.

Conner, W., K. McLeod and J. McCarron (1997). "Flooding and salinity effects on growth and survival of four common forested wetland species." Wetlands Ecology and Management 5: 99-109.

Conner, W., K. McLeod and J. McCarron (1998). "Survival and growth of four bottomland oak species in response to increased flooding and salinity." Forest Science 44(4): 618-624.

Jones, R., B. Allen and R. Sharitz (1997). "Why do early-emerging tree seedlings have survival advantages?: A test using Acer rubrum (Aceraceae)." American Journal of Botany 84: 1714-1718.

Jones, R. and R. Sharitz (1989). "Potential advantages and disadvantages of germinating early for trees in floodplain forests." Oecologia 81: 443-449.

McCarron, J., K. McLeod and W. Conner (1998). "Flood and salinity stress of wetland woody species, buttonbrush (Cephalanthus occidentalis) and swamp tupelo (Nyssa sylvatica var. biflora)." Wetlands 18: 165-175.

McLeod, K., L. Donovan, N. Stumpff and K. Sherrod (1986). "Biomass, photosynthesis and water use efficiency of woody swamp species subjected to flooding and elevated water temperature." Tree Physiology 2: 341-346.

McLeod, K., J. McCarron and W. Conner (1999). "Photosynthesis and water relations of four oak species: impact of flooding and salinity." Trees 13: 178-187.

Megonigal, J. and F. Day (1992). "Effects of flooding on root and shoot production of bald cypress in large experimental enclosures." Ecology 73: 1182-1193.

These studies characterize experimental research that evaluates seedling tolerances to environmental conditions, including flooding with freshwater and with water of increased salinity, exposure to continuous vs. periodic flooding, and effects of root competition. These studies include species characteristic of the Savannah River floodplain and its tributaries. The papers by Conner, McCarren and McLeod reveal susceptibility of species to increases in flooding and salinity that could lead to shifts in species composition of coastal forests under climate change scenarios. Megonigal and Day found that 3-year baldcypress saplings grown under periodically flooded conditions had greater belowground production and deeper roots than did saplings grown under continuous flooding, although total productivity did not differ between the two treatments. Jones and Sharitz reported advantages to early germinating seedlings, including increased light, but noted that late spring floods caused mortality of early germinants.

Importance of substrate heterogeneity (microsites) in tree seedling recruitment in cypress-tupelo and mixed bottomland hardwood forests

Collins, B. and L. Battaglia (2002). "Microenvironmental heterogeneity and Quercus michauxii regeneration in experimental gaps." Forest Ecology and Management 155: 618-624.

Huenneke, L. and R. Sharitz (1986). "Microsite abundance and distribution of woody seedlings in a South Carolina cypress-tupelo swamp." American Midland

Naturalist 115(2): 328-335.

Huenneke, L. and R. Sharitz (1990). "Substrate heterogeneity and regeneration of a swamp tree, Nyssa aquatica." American Journal of Botany 77: 413-419.
These studies, conducted in the Savannah River floodplain on the SRS, demonstrate the importance of substrate heterogeneity in providing safe sites for seed germination and seedling establishment and growth. In cypress-tupelo forests, such microsites are especially important to recruitment when water levels are managed in such a way that the forest floor remains inundated for prolonged times during the growing season, as was the case in the sites of the Huenneke study. Microsite heterogeneity (pit and mound topography caused by windthrown trees) also provides an array of soil moisture and temperature conditions that may enhance establishment of bottomland hardwood species such as oaks.

Importance of winter flood events in seed dispersal

Liu, E., E. Iglich, R. Sharitz and M. Smith (1990). "Population genetic structure of baldcypress (Taxodium distichum) in a thermally affected swamp forest." Silvae Genetica 39: 129-133.

Schneider, R. and R. Sharitz (1988). "Hydrochory and regeneration in a bald cypress-water tupelo swamp forest." Ecology 69(4): 1055-1063.

These two studies, conducted on the Savannah River floodplain on the SRS, demonstrate the importance of floods as a vector of dispersal in cypress-tupelo forests. The Schneider and Sharitz paper measures hydrochory (water dispersal) directly by the release and recapture of marked seeds. The Liu et al. paper demonstrates the importance of dispersal in maintaining genetic variability within cypress populations but suggests that a few trees shedding seeds during periods of low water and suitable conditions for seedling establishment may be responsible for spatial heterogeneity in allele frequencies.

Invasive species (Chinese tallow)

Jones, R. and R. Sharitz (1990). "Effects of root competition and flooding on growth of Chinese tallow tree seedlings." Canadian Journal of Forest Research 20: 5730578.
Chinese tallow is an invasive tree species in the Savannah River floodplain. Highly flood and shade tolerant, the Chinese tallow has been successful in low wet areas of the floodplain.

Conner, W., L. Inabinnette and C. Lucas (2001). "Effects of flooding on early growth and competitive ability of two wetland tree species and an exotic." Castanea 66(3): 237-244.

Invertebrates

Thorp, J., E. McEwan, M. Flynn and F. Hauer (1985). "Invertebrate colonization of submerged wood in a cypress-tupelo swamp and blackwater stream." American Midland Naturalist 113(1): 56-68.
This article investigates the wetland characteristics that influence the colonization of wood snags by invertebrates. Uniform sections of tupelo logs were submerged in a swamp tributary, swamp, and swamp outflow locations. The logs were rapidly colonized and most reached a steady-state in

1 week. By comparing the diversity and richness of species, length of submergence, current velocity, and seston particle size, the investigators propose that current velocity, oxygen availability, and seston particle size are likely to influence the invertebrate assemblages present at the different locations. This study was conducted on the SRS.

Mulvey, M., H.-P. Liu and K. Kandl (1998). "Application of molecular genetic markers to conservation of freshwater bivalves." Journal of Shellfish Research 17(5): 1395-1405.

Freshwater bivalves have experienced reductions in population, population fragmentation, and extinction as a result of dam construction, channelization, pollution, commercial exploitation, and introduction of exotic species. This article describes the use of molecular genetics techniques to explore the ecology, population structure, gene-flow, systematics and taxonomy, bivalve-fish host relationship, and many other aspects of bivalve conservation. The bivalve-fish host relationship is integral to conservation efforts. The life cycle of the bivalve requires a fish host in the glochidial stage. The fish host has been identified for only about 25% of the North American bivalves. So any habitat modifications that affect fish populations also has the potential to affect bivalve populations.

Floyd, M., J. Morse and M. JV (1993). "Aquatic insects of Upper Three Runs Creek, Savannah River Site, South Carolina. Part IV: caddisflies (Trichoptera) of the lower reaches." Journal of Entomological Science 28(1): 85-95.

This article details the results of a survey of caddisflies from two locations on Upper Three Runs Creek, a tributary of the Savannah River. Collected specimens of 93 species represented 14 families. Three species are new distributional records. Two species are new to science, and 8 species are endemic to Three Runs Creek, rare outside the drainage, or of limited distribution. The South Carolina Department of Wildlife and Marine Resources have listed 4 of the species found as "Species of Special Concern." When data from previous work is considered, Upper Three Runs Creek supports 123 species of caddisflies and can be said to have the largest reported caddisfly fauna of any stream its size in North America.

Lackly, M. and J. McArthur (2000). "Macroinvertebrate recovery of a post-thermal stream: habitat structure and biotic function." Ecological Engineering 15: S87-S100.

Morse, J., J. Chapin, D. Herlong and R. Harvey (1980). "Aquatic insects of Upper Three Runs Creek, Savannah River Plant, South Carolina. Part I: Orders other than Diptera." Journal of the Georgia Entomological Society 15(1): 73-101.

Morse, J., J. Chapin, D. Herlong and R. Harvey (1983). "Aquatic insects of Upper Three Runs Creek, Savannah River Plant, South Carolina. Part II: Diptera." Journal of the Georgia Entomological Society 18(3): 303-316.

Remote sensing of vegetation and disturbance (thermal stress) on the SRS Savannah River floodplain

Brewster, S. J. and L. Tinney (1984). Vegetation classification of the Savannah River floodplain, United States Department of Energy, Office of Nuclear Safety: 30.

This survey was conducted using multispectral scanners to delineate the floodplain extent by vegetation and water level. Vegetation was classified within the floodplain. Ten vegetation types were identified and the most common throughout the images were swamp and deciduous forest.

Christensen, E. (1987). Digital change detection: A quantitative evaluation of image registration and wetland phenological characteristics using high resolution multispectral scanner data. Columbia, SC.

Christensen, E., J. Jensen, E. Ramsey and H. J. Mackey (1988). "Aircraft MSS data registration and vegetation classification for wetland change detection." International Journal of Remote Sensing 9(1): 23-38.

Jensen, J., A. Hale and H. J. Mackey (1986). Vegetation stress detection in a southeastern swamp floodplain using remote sensing and in situ spectral measurements. Freshwater Wetlands and Wildlife Symposium, Charleston, SC.

Jensen, J., M. Hodgson, E. Christensen, H. Mackey and L. Tinney (1985). Remote sensing inland wetlands: A multispectral approach. Columbia, SC, South Carolina Univ., Dep. of Geography: 36.

Mackey, H. (1989). Monitoring seasonal and annual wetland changes in a freshwater marsh with SPOT HRV data, WSRC.

Mathews, N. and K. Dyer (1990). "Floodplain vegetation phenology in the Southeastern USA: Optimizing the timing of aerial imagery acquisition." Wetlands Ecology and Management 1(2): 65-72.

These studies, performed in the 1980 mostly by EG&G, used multispectral imagery and other techniques to evaluate the extent of the thermal disturbance on the SRS Savannah River floodplain and vegetation recovery. With the exception of the Matthews and Dyer study, ground-truthing was rather minimal, and the vegetation discrimination was limited to major types.

Restoration of the thermally impacted Pen Branch ecosystem –
a tributary of the Savannah River on the SRS

Barton, C., E. Nelson, R. Kolka, K. McLeod, W. Conner, M. Lakly, D. Martin, J. Wigginton, C. Trettin and J. Wisniewski (2000). "Restoration of a severely impacted riparian wetland system- The Pen Branch Project." Ecological Engineering 15(S): 3-15.

Bowers, C., H. Hanlin, D. J. Guynn, J. McLendon and J. Davis (2000). "Herpetofaunal and vegetational characterization of a thermally-impacted stream at the beginning of restoration." Ecological Engineering 15(supplement 1): S101-S114.

Nelson, E., N. Dulohery, R. Kolka and W. J. McKee (2000). "Operational Restoration of the Pen Branch bottomland hardwood and swamp wetlands- the research setting." Ecological Engineering 15(Supplement 1): S23-S33.

Wigginton, J., B. Lockaby and C. Trettin (2000). "Soil organic matter formation and sequestration across a forested floodplain chronosequence." Ecological Engineering 15(Supplement 1): S141-S155.

Pen Branch is one of several streams on the SRS that received thermally hot cooling waters from nuclear reactor operations for an extended period of years prior to the late 1980s. There is a vast body of literature from the Savannah River Ecology Laboratory on the effects of these hot water inputs to the Savannah River floodplain and its tributaries, and on the recovery of these systems following reactor shut-down. Most of this literature is not considered especially pertinent to the issues of altered river discharges, and is not included. The papers in this summary of Pen Branch may provide some insight into natural (and enhanced) recovery/restoration processes in thermally disturbed parts of the Savannah River floodplain.

Seed banks of cypress-tupelo and bottomland hardwood forests within the Savannah River Floodplain

Schneider, R. and R. Sharitz (1986). "Seed bank dynamics in a southeastern riverine swamp." American Journal of Botany 73(7): 1022-1030.

This study compares the seed banks (surviving seeds in the soil) of a cypress-tupelo forest and an adjacent hardwood island on the Savannah River floodplain on the SRS. Comparisons were made of seed bank composition before peak seed fall (September), following peak seed fall (December) and following recession of winter floods (April). In general, woody seed banks underrepresented the composition of the forest vegetation, and sediments in the cypress-tupelo community contained an unexpectedly large pool of nonviable seeds. Floods decreased seed densities in the hardwood community but not in the cypress-tupelo community. Germination from the seed bank may not be a major factor in recruitment of woody species in floodplain communities, and seed survival may be affected by prolonged inundation.

Seedling recruitment and growth in mixed bottomland forests on the Savannah River floodplain

Jones, R. and R. Sharitz (1990). Dynamics of advance regeneration in four South Carolina bottomland hardwood forests. Sixth Biennial Southern Silviculture Research Conference, Asheville, NC.

Jones, R. and R. Sharitz (1998). "Survival and growth of woody plant seedlings in the understory of floodplain forests in South Carolina." Journal of Ecology 86: 574-587.

These papers describe a 15-year study of natural seedling recruitment in bottomland hardwood forests on the floodplain of the Savannah River and along one of its tributaries (Upper Three Runs Creek) on the SRS. Sites included areas of higher and lower elevation (hence, more flooded and less flooded). Individually marked seedlings (total ~12,000 over the course of the study) were tallied at the beginning and ending of each growing season, and height and mortality noted. Significant differences in general survival patterns were found among species, sites, and years of establishment. In some sites, weak relationships were noted between mortality and peak river discharge during summer (negatively correlated) and winter (positively correlated). For most species, taller seedlings had greater survival, but very few seedlings grew over 1 m in height during the study. Note: the 1995-2001 data have not yet been published.

Jones, R., R. Sharitz, P. Dixon, D. Segal and R. Schneider (1994). "Woody plant regeneration in four floodplain forests." Ecological Monographs 64: 345-367.

Vertebrates

Kennamer, R. (2001). "Relating climatological patterns to wetland conditions and wood

duck production in the southeastern Atlantic coastal plain." Wildlife society Bulletin 29: 1193-1205.
Wetland hydrologic conditions were positively associated with wood duck productivity. Wet years provided a longer breeding season and reduced predation.

Straney, D., L. Briese and M. Smith (1974). "Bird diversity and thermal stress in a cypress swamp." Thermal Ecology: 572-578.
Birds respond to the structural changes bought on by aquatic stress. Formation of canopy gaps, presence or absence of underbrush, or standing deadwood influence the bird species diversity and abundance. Burke, V. J., J. E. Lovich and J. W. Gibbons. 2000. Conservation of freshwater turtles. Turtle Conservation. M. Klemens. Washington, DC, Smithsonian Institution Press. pp. 156-179.
This chapter in the book Freshwater Turtles discusses conservation of turtles in regards to life cycle, describes the status of freshwater turtles, and provides recommendations for future conservation efforts. Preservation of habitat is a critical factor in maintaining a population. Freshwater turtles frequently require upland habitat for nesting, overwintering, and foraging so protection of land adjacent to the wetland is essential. Juvenile turtles have different prey items and change habitat as they grow in size. As a result, a spatially heterogeneous freshwater environment is needed to provide the various requirements for the maturing turtles. Recommendations include ending human exploitation (recreational shooting and wild capture for the pet trade,) preservation of lentic waters, and educational programs for the public.

Gibbons, J., V. Burke, J. Lovich, R. Semlitsch, T. Tuberville, J. Bodie, J. Greene, P. Niewiarowski, H. Whiteman, D. Scott, J. Pechmann, C. Harrison, S. Bennett, J. Krenz, M. Mills, K. Buhlmann, J. Lee, R. Seigel, A. Tucker, T. Mills, T. Lamb, M. Dorcas, J. Congdon, M. Smith, D. Nelson, M. Dietsch, H. Hanlin, J. Ott and D. Karapatakis (1997). "Perceptions of species abundance, distribution, and diversity: lessons from four decades of sampling on a government-managed reserve." Environmental Management 21(2): 259-268.
This article reviews data compiled on over one million captures or observations of 98 species over a 44-year study period on the SRS. Perceptions of species diversity are dependent on level of effort during data collection. Short-term databases used for management decisions could result in serious error. Recommendations include training data collectors in field recognition of more than one taxonomic species. Efforts should be made to measure the status of populations quantitatively using consistent and reliable methodologies.

Lee, J., V. Burke and J. Gibbons (1997). "Behavior of hatchling Alligator mississippiensis exposed to ice." Copeia 1997(1): 224-226.
This study on the SRS indicates that alligators are able to survive temporary icing by maintaining a breathing hole and taking advantage of water temperature gradients. Water depth must be sufficient for the animals to submerge in an inclined position with only their snouts above the water.

Mills, M., C. Hudson and H. Berna (1995). "Spatial ecology and movements of the brown water snake (Nerodia taxispilota)." Herpetologica 51: 412-423.
This article reveals movement patterns and habitat preferences for the brown water snake. A preference was identified for the steep, outside bends of the river. A majority (70%) of recaptures were found within 250 m of their previous capture site and only the largest snakes actually crossed the river. These results are significant to the Savannah River ecological flow study because portions of the river have been straightened and the preferred habitat of these snakes destroyed.

Pechmann, J., D. Scott, J. Gibbons and R. Semlitsch (1989). "Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians." Wetlands Ecology and Management 1(1): 3-11.

Altering the hydroperiod of a wetland was directly related to increases or decreases in the number and species diversity of amphibians in and around a wetland. Five salamander species and 11 anuran species were studied. A longer hydroperiod provided more time for larvae to develop and metamorphose to the terrestrial juvenile stage. In addition, only the natural wetland in the study occasionally refilled for a period in the fall to allow late breeding species a chance to reproduce. Variable results from year to year emphasized the necessity of conducting multi-year studies. This study was conducted on the SRS.

Tuberville, T., J. Gibbons and J. Greene (1996). "Invasion of new aquatic habitats by male freshwater turtles." Copeia 1996(3): 713-715.

Turtles travel overland for several reasons: to and from overwintering sites, females in search of nesting sites, and males in search of females. Ten species of aquatic turtles were caught at Ellenton Bay on the Savannah River Site. Six of those species were resident populations evidenced by presence of hatchlings. Adults represented the remaining four species and of the 41 individuals captured only 2 were female. These long overland excursions by males may be explained as a method to increase interaction with females and improve chances of mating. Fragmentation or development of wetland habitats could affect the movement and reproductive success of these turtles.

Category 2: Comparative Floodplain Studies

Coastal issues/sea level rise

McLeod, K., J. McCarron and W. Conner (1996). "Effects of inundation and salinity on photosynthesis and water relations of four southeastern coastal plain forest species." Wetlands Ecology and Management 4(1): 31-42.

Brinson, M. and K. Moorhead (1990). "Sea level rise and fringe wetlands in North Carolina: recommendations from a workshop on management and research." Journal of the Elisha Mitchell Scientific Society 105: 149-157.

Conner, W. and J. Day Jr. (1989). Response of coastal wetland forests to human and natural changes in the environment with emphasis on hydrology. Orlando, FL, U.S. Department of Agriculture, Forest Services, Southeastern Forest Experimental Station: 34-43.

Comparisons of forest community structure and wetland tree growth in response to hydrologic regime in South Carolina and Louisiana

Conner, W., I. Mihalia and J. Wolfe (2002). "Tree community structure and changes form 1987 to 1999 in three Louisiana and three South Carolina forested wetlands." Wetlands 22: 58-70.

Keeland, B., W. Conner and R. Sharitz (1997). "A comparison of wetland tree growth response to hydrologic regime in Louisiana and South Carolina." Forest Ecology

and Management 90(2,3): 237-250.

Megonigal, J., W. Conner, S. Kroeger and R. Sharitz (1997). "Aboveground production in southeastern floodplain forests: a test of the subsidy-stress hypothesis." Ecology 78(2): 370-384.
Paired plots were established across a soil moisture gradient (dry, periodically flooded, flooded) in three forested wetland watersheds in Louisiana, and South Carolina. The SC sites included one on the Savannah River and one on Upper Three Runs Creek, a tributary. All trees greater than 10 cm diameter at breast height were tagged and measured annually. The greatest changes in density occurred in those sites where water-level changes were occurring or where windstorms struck. Mortality rates are typically low in areas that have not been altered hydrologically. Flooded sites in both states had the greatest basal area, and dry and periodically flooded sites had similar basal areas.

Effects of river flow management on floodplain systems

Dudgeon, D. (1995). "River Regulation in Southern China - Ecological Implications, Conservation and Environmental-Management." Regulated Rivers-Research & Management 11(1): 35-54.
The importance of floods as an incentive for river regulation is apparent from the fact that 10% of China's area, inhabited by 65% of the population and responsible for 70% of the agricultural and industrial output, is below the flood level of major rivers. Large-scale water-transfer projects and the planned construction of the biggest dam in the world (the Three Gorges High Dam) on the Chang Jiang have the potential to affect fisheries stocks and endangered fish species, to alter inundation patterns in wetlands of international conservation significance and may contribute to the extinction of the endemic and highly endangered Chinese alligator (Alligator sinensis) and Chinese river dolphin (Lipotes vexillifer). In addition, deforestation and soil erosion in the Chang Jiang basin have given rise to siltation and degradation of floodplain habitats. In the Zhujiang, dam construction has caused reductions in fisheries stocks but here, as elsewhere in China, the ecologically damaging consequences of river regulation are exacerbated by overfishing and increasing pollution of rivers by sewage, pesticides and industrial wastes.

Kingsford, R. T. (2000). "Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia." Austral Ecology 25(2): 109-127.
Australian floodplain wetlands are sites of high biodiversity that depend on flows from rivers. Dams, diversions and river management have reduced flooding to these wetlands, altering their ecology, and causing the death or poor health of aquatic biota. Four floodplain wetlands (Barmah-Millewa Forest and Moira Marshes, Chowilla floodplain, Macquarie Marshes, Gwydir wetlands) illustrate these effects with successional changes in aquatic vegetation, reduced vegetation health, declining numbers of water birds and nesting, and declining native fish and invertebrate populations. Plans exist to build dams to divert water from many rivers, mainly for irrigation. These plans seldom adequately model subsequent ecological and hydrological impacts to floodplain wetlands. To avoid further loss of wetlands, an improved understanding of the interaction between river flows and floodplain ecology, and investigations into ecological impacts of management practices, is essential.

Nilsson, C. and K. Berggren (2000). "Alterations of riparian ecosystems caused by river regulation." Bioscience 50(9): 783-792.

Richter, B. D., J. V. Baumgartner, R. Wigington and D. P. Braun (1997). "How much water does a river need?" Freshwater Biology 37(1): 231-249.Effects of river flow management on floodplain systems

This paper introduces a new approach for setting streamflow-based river ecosystem management targets and this method is called the 'Range of Variability Approach' (RVA). The proposed approach derives from aquatic ecology theory concerning the critical role of hydrological variability, and associated characteristics of timing, frequency, duration, and rates of change, in sustaining aquatic ecosystems. The RVA uses as its starting point either measured or synthesized daily streamflow values from a period during which human perturbations to the hydrological regime were negligible. The RVA targets and management strategies should be adaptively refined as suggested by research results and as needed to sustain native aquatic ecosystem biodiversity and integrity.

Richter, B. D. and H. E. Richter (2000). "Prescribing flood regimes to sustain riparian ecosystems along meandering rivers." Conservation Biology 14(5): 1467-1478.

The composition and structure of native riverine ecosystems are tightly linked to natural hydrologic variability. By managing river flows for water supplies and power generation water management agencies have inadvertently caused considerable degradation of riverine ecosystems and associated biodiversity. New approaches for meeting human needs for water while conserving the ecological integrity of riverine ecosystems are greatly needed We describe an approach for identifying the natural flooding characteristics that must be protected or restored to maintain riparian (floodplain) ecosystems along meandering rivers. Model simulations enabled us to tentatively identify a threshold of alteration of flood duration that could lead to substantial changes in the abundance of forest patch types over time should river flows be regulated by future water projects. Based on this analysis, we suggest an ecologically compatible water management approach that avoids crossing flood alteration thresholds and provides opportunity to use a portion of flood waters for human purposes.

Sparks, R. E., P. B. Bayley, S. L. Kohler and L. L. Osborne (1990). "Disturbance and Recovery of Large Floodplain Rivers." Environmental Management 14(5): 699-709.

Disturbance is defined as, "an unpredictable, discreet or gradual, event (natural or manmade) that disrupts structure or function at the ecosystem, community, or population level." This article presents case studies along the Mississippi and Illinois Rivers. Emphasis is placed on recognizing control mechanisms at the ecosystem level and identifying critical thresholds where system state and behavior will change. The authors also encourage the use of man-made and natural disturbances and environmental restoration as experiments to measure thresholds and test models.

Ward, J. V. and J. A. Stanford (1995). "Ecological Connectivity in Alluvial River Ecosystems and Its Disruption by Flow Regulation." Regulated Rivers-Research & Management 11(1): 105-119.

The dynamic nature of alluvial floodplain rivers is a function of flow and sediment regimes interacting with the physiographic features and vegetation cover of the landscape. During seasonal inundation, the flood pulse forms a 'moving littoral' that traverses the plain, increasing productivity and enhancing connectivity. The range of spatio-temporal connectivity between different biotopes, coupled with variable levels of natural disturbance, determine successional patterns and habitat heterogeneity that are responsible for maintaining the ecological integrity of floodplain river systems. Flow regulation by dams, often compounded by other modifications such as levee construction, normally results in reduced connectivity and altered successional trajectories in downstream reaches. Flood peaks are typically reduced by river regulation, which reduces the frequency and extent of floodplain inundation. To counter the influence of river regulation, restoration efforts should focus on reestablishing dynamic connectivity between the channel and floodplain water bodies.

Floodplain nutrient cycling

Clawson, R., B. Lockaby and B. Rummer (2000). "Changes in production and nutrient cycling across a wetness gradient within a floodplain forest." Ecosystems 4: 126-138.

This article compares multiple indexes of productivity, nutrient cycling, and hydroperiod. Somewhat poorly drained soil had the greatest belowground biomass and the most efficient retranslocation of nitrogen. Poorly drained soil had the greatest woody biomass current annual increment and overall had the greatest net primary productivity. Hydroperiod affected the allocation of nutrient and biomass resources for trees growing on the floodplain.

Kemp, W. M., M. T. Brooks and R. R. Hood (2001). "Nutrient enrichment, habitat variability and trophic transfer efficiency in simple models of pelagic ecosystems." Marine Ecology-Progress Series 223: 73-87.

We developed 4 simple numerical models of plankton dynamics to explore how nutrient enrichment and habitat variability might influence the efficiency by, which phytoplankton (P) production is transferred to growth of zooplankton (Z) consumers in coastal ecosystems. Numerical and analytical studies also showed that, regardless of resource variability, these model formulations produce a trend of initial enhancement of trophic efficiency with increasing nutrient levels, followed by a marked reduction inefficiency beginning at moderately eutrophic conditions. This precipitous drop in trophic efficiency is attributable to a saturation of the ability of zooplankton to utilize the increased primary production associated with nutrient enrichment. Under these conditions, an increasing fraction of the primary production is shunted to microbial food chains and associated respiratory losses. The steepness of this reduction in trophic efficiency with nutrient enrichment is related to the strength of predation (or disease) control at upper trophic levels. We speculate that these model results may help to explain how observed reductions in relative fish yield (per unit primary production) in many shallow nutrient-enriched estuaries and lakes are related to interacting effects of cultural eutrophication and intense fisheries exploitation. Furthermore, we surmise that these relationships are robust characteristics of most existing aquatic ecosystem models.

Anderson, R., J. Grubaugh and R. Sparks (1986). Macrophyte beds and floodplain forests; A source or sink for organic matter in a large river. Freshwater Wetlands and Wildlife Symposium, Charleston, SC.

Baker, T., III, W. Conner, B. Lockaby, J. Stanturf and M. Burke (2001). "Fine root productivity and dynamics on a forested floodplain in South Carolina." Soil Science Society of America Journal 65(2): 545-556.

Baker, T., III, B. Lockaby, W. Conner, C. Meir, J. Stanturf and M. Burke (2001). "Leaf litter decomposition and nutrient dynamics in four southern forested floodplain communities." Soil Science Society of America Journal 65(4): 1334-1347.

Brinson, M. M. (1977). "Decomposition and Nutrient Exchange of Litter in an Alluvial Swamp Forest." Ecology 58(3): 601-609.

Brinson, M. M. (1993). "Changes in the Functioning of Wetlands Along Environmental Gradients." Wetlands 13(2): 65-74.

One of the prevalent gradients in wetlands is the continuum of depth and frequency of flooding. While much emphasis has been placed on the importance of hydrology as a driving force for wetlands, few other perspectives have emerged to demonstrate unifying patterns and principles. Landscape-based continua include the transition from upstream to downstream in riverine wetlands and between aquatic and terrestrial ecosystems within a wetland. Along the upstream-downstream continuum, sources of flood-water delivery change dominance from ground-water discharge and overland runoff, as in low order streams, to dominance by overbank flooding, as in high order streams. Resource-based continua include the extremes of (1) sources of water to wetlands (precipitation, overland flow, and ground water) and (2) the variation in inflows and outflows of nutrients and sediments. A broader view of biogeochemical functioning is gained by categorizing wetlands into groups based on the exchange of nutrients and sediments among landscape units rather than on serving as a sink or source for a particular element. Based on this analysis, the less frequently flooded or saturated portions of wetlands are no less functionally active than wetter portions; the functions are simply different. Efforts to classify wetlands according to their hydroperiod do little to reveal their fundamental properties.

Brinson, M. M., H. D. Bradshaw and E. S. Kane (1984). "Nutrient Assimilative-Capacity of an Alluvial Floodplain Swamp." Journal of Applied Ecology 21(3): 1041-1057.

Burke, M., B. Lockaby and W. Conner (1999). "Aboveground primary production and nutrient circulation across a flooding gradient in a South Carolina coastal plain forest." Canadian Journal of Forest Research 29: 1402-1418.

Conner, W. (1994). "Effects of forest management practices on southern forested wetland productivity." Wetlands 14(1): 27-40.

Conner, W. and J. Day Jr. (1992). "Water level variability and litterfall productivity of forested freshwater wetlands in Louisiana." American Midland Naturalist 128: 237-245.

Darke, A., M. Walbridge and B. Lockaby (1997). "Changes in Al and Fe crystallinity and P sorption capacity in a floodplain forest soil subjected to artificially manipulated flooding regimes in field mesocosms." Wetlands Ecology and Management 4: 235-244.

Dosskey, M. and P. Bertsch (1994). "Forest sources and pathways of organic matter transport to a blackwater stream: a hydrologic approach." Biogeochemistry 24: 1-19.

This study determines the contribution of upland forest and wetland forest to organic matter transported to aquatic systems. The organic matter is a key nutrient source in the aquatic ecosystem. Upland forest, although it covers 94% of the watershed, only contributed 2.0 tonnes C per year to stream flow. Wetland forest, which covers the other 6% of the watershed contributed 26.9 tonnes C per year to stream flow. Loss of wetland habitat has a greater potential for impacting the aquatic system.

Jurgensen, M., D. Richter, M. Davis, M. McKevlin and M. Craft (1997). "Mycorrhizal relationships in bottomland hardwood forests of the southern United States." Wetlands Ecology and Management 4: 223-233.

Lockaby, B. and W. Conner (1999). "N:P balance in wetland forests: productivity across a biogeochemical continuum." Botanical Review 65(2): 171-185.

Rader, R., J. McArthur and J. Aho (1994). "The relative importance of mechanisms determining decomposition in a southeastern blackwater stream." The American Midland Naturalist 132: 19-31.

Segal, D., R. Jones and R. Sharitz (1990). "Release on NH sub(4)-N and PO sub(4)-P from litter in two bottomland hardwood forests." American Midland Naturalist 123(1): 160-170.

Floodplain wetland restoration

Brinson, M. M. (1988). "Strategies for Assessing the Cumulative Effects of Wetland Alteration on Water-Quality." Environmental Management 12(5): 655-662.

Brinson, M. M. and R. Rheinhardt (1996). "The role of reference wetlands in functional assessment and mitigation." Ecological Applications 6(1): 69-76.
By establishing standards from reference wetlands chosen for their high level of sustainable functioning, gains and losses of functions can be quantified for wetlands used in compensatory mitigation. Advantages of a reference wetland approach include (1) making explicit the goals of compensatory mitigation through identification of reference standards from data that typify sustainable conditions in a region, (2) providing templates to which restored and created wetlands can be designed, and (3) establishing a framework whereby a decline in functions resulting from adverse impacts or a recovery of functions following restoration can be estimated both for a single project and over a larger area accumulated over time.

Brooks, R. P., T. J. O'Connell, D. H. Wardrop and L. E. Jackson (1998). "Towards a Regional Index of Biological Integrity: The example of forested riparian ecosystems." Environmental Monitoring and Assessment 51(1-2): 131-143.
Our premise is that measures of ecological indicators and habitat conditions will vary between reference standard sites and reference sites that are impacted, and that these measures can be applied consistently across a regional gradient in the form of a Regional Index of Biological Integrity (RIBI). Six principles are proposed to guide development of any RIBI: 1) biological communities with high integrity are the desired endpoints; 2) indicators can have a biological, physical, or chemical basis; 3) indicators should be tied to specific stressors that can be realistically managed; 4) linkages across geographic scales and ecosystems should be provided; 5) reference standards should be used to define target conditions; and 6) assessment protocols should be efficiently and rapidly applied. By providing a reliable expression of environmental stress or change, a RIBI can help managers reach scientifically defensible decisions.

Conner, W., K. McLeod and E. Colodney (2002). Restoration methods for deepwater swamps. Conference on sustainability of wetlands and water resources: how well can riverine wetlands continue to support society into the 21st century, Asheville, NC, U.S. Department of Agriculture, Forest Service, Southern Research Station.

Fairey, D. (1975). Flood plain management in South Carolina, South Carolina Land Resources Conservation Commission: 95.
This report describes flood characteristics and frequency within South Carolina. The advantages

and disadvantages of floodplain occupance are identified. Advantages include proximity to the water source, agriculturally rich soil, and lower taxes. Disadvantages include misperceptions of the danger from floodwaters and extensive or repeated damage to man-made structures. A comprehensive planning strategy is presented that includes both corrective and preventive measures. Site specific data is provided for the major river basins in South Carolina; Savannah, ACE, Santee, and Pee Dee. Soil interpretations, maximum floods of record, and area of damage are included. The report concludes with the environmental significance of different riverine ecosystems and recommendations for continued management.

Fletcher, D., S. Wilkins, J. McArthur and G. Meffe (2000). "Influence of riparian alteration on canopy coverage and macrophyte abundance in southeastern USA blackwater streams." Ecological Engineering 15(S): 67-78.

McLeod, K. (2000). "Species selection trials and silviculture techniques for the restoration of bottomland hardwood forests." Ecological Engineering 15(S): 35-46.

This article describes characteristics of trees suitable for reforestation of impacted wetlands. Site characteristics such as elevation, groundwater level, and plant competition were considered. Flood tolerance and shade tolerance of 24 species are identified and survival rates helped to determine the species suitable for reintroduction. Successful silviculture techniques included bare root plantings, tree shelters, and maintaining a minimum seedling height.

McLeod, K. and T. Ciravolo (1999). Species selection and seedling establishment for restoration of bottomland forests, Raleigh, NC.

McLeod, K., M. Reed and L. Wike (2000). "Elevation, competition control, and species affect bottomland forest restoration." Wetlands 20: 162-168.

Baldcypress, water tupelo, willow oak, nuttall oak, and overcup oak were successfully established when planting elevation and flood tolerance were used to determine planting location. Species diversity can be established by exploiting the variations in flood and shade tolerance with planting elevation.

Molles, M. C., C. S. Crawford, L. M. Ellis, H. M. Valett and C. N. Dahm (1998). "Managed flooding for riparian ecosystem restoration - Managed flooding reorganizes riparian forest ecosystems along the middle Rio Grande in New Mexico." Bioscience 48(9): 749-756.

This article discusses how managed flooding reorganizes riparian forest ecosystems along the middle of the Rio Grande River in New Mexico. Although the river still has a peak flow in May, dams and levees have eliminated most flooding. Patches of riparian forest exist which have been disconnected from the river. Managed flooding of one of these patches revealed alterations in biotic response. Soil biological activity doubled as abundance of bacteria, fungi, and cellulose decomposers increased. Population of a native floodplain cricket increased, whereas the populations of two non-native isopods decreased. Small mammal populations were not affected. Initial measures of forest floor respiration and mass loss by leaves and logs were greater than the same measures at the control site, but levels decreased as the annual flood repeated. Although the different measures are responding at different rates, continued annual flooding is expected to return the disconnected patch to a near natural state.

O'Neill, M. P., J. C. Schmidt, J. P. Dobrowolski, C. P. Hawkins and C. M. U. Neale (1997). "Identifying sites for riparian wetland restoration: Application of a model to the Upper Arkansas River basin." Restoration Ecology 5(4): 85-102.

We present a conceptual model for identifying restoration sites for riparian wetlands and discuss its application to reaches within the Upper Arkansas River basin in Colorado. The model utilizes a Geographic Information System (GIS) to analyze a variety of spatial data useful in characterizing geomorphology, hydrology, and vegetation of riparian wetland sites. The model focuses on three basic properties of riparian wetland sites: relative soil moisture, disturbance regime, and vegetative characteristics. Restoration potential is evaluated as a combination of nominal scores from wetness, land cover, and disturbance indices. Application of these methods to field sites within the Upper Arkansas River basin identifies a wide range of riparian wetland sites for preservation or restoration. Potential sites within identified reaches are prioritized using size and proximity criteria.

Rheinhardt, R. D., M. M. Brinson and P. M. Farley (1997). "Applying wetland reference data to functional assessment, mitigation, and restoration." Wetlands 17(2): 195-215.

This study demonstrates the hydrogeomorphic (HGM) assessment procedure by identifying ecological functions performed by mineral soil wet flats, obtaining quantitative field data from 19 wet Bats (reference sites) in southeastern North Carolina, and modeling wetland functions using variables derived from those field data. We chose a subset of the 19 reference sites to demonstrate how HGM assessment can be used to measure ecosystem functions before and after a project site is altered and the degree to which ecosystem restoration can compensate for a reduction in functions caused by a project's impact. HGM assessment can be used to determine the minimum area over which restoration should be applied to achieve a no-net-loss in function objective. The ratio of wetland area restored to wetland area altered by a project impact (compensatory mitigation ratio) varies among functions and is influenced by (1) the magnitude to which any given function occurs at a project site both before and after the site is altered, (2) the magnitude to which any given function occurs at a compensatory mitigation site both before and after restoration is applied, and (3) the rate at which any given function is restored.

Schmidt, J. C., R. H. Webb, R. A. Valdez, G. R. Marzolf and L. E. Stevens (1998). "Science and values in river restoration in the Grand Canyon - There is no restoration or rehabilitation strategy that will improve the status of every riverine resource." Bioscience 48(9): 735-747.

Forest dynamics and productivity

Allen, B. and R. Sharitz (1999). Post-hurricane vegetation dynamics in old-growth forests of Congaree Swamp National Monument. On the Frontiers of Conservation: 10th Conference on Research and Resource Management in Parks and on Public Lands, Asheville, NC, The George Wright Society, Inc.

Bates, R. and J. Williams (1986). Estimation of biomass and primary productivity of an early successional forest site on the Santee River floodplain. Freshwater Wetlands and Wildlife Symposium, Charleston, SC.

Conner, W. (1995). "Woody plant regeneration in three South Carolina Taxodium/Nyssa stands following Hurricane Hugo." Ecological Engineering 4: 277-287.

Hesse, I., W. Conner and J. Day Jr. (1996). Herbivory impacts on the regeneration of forested wetlands in Louisiana. Proceedings of the Southern Forested Wetlands Ecology and Management Conference, Clemson University, Clemson, SC,

Consortium for Research on Southern Forested Wetlands.

Pederson, N., R. Jones and R. Sharitz (1997). "Age structure and possible origins of old Pinus taeda stands in a floodplain forest." Bulletin of the Torrey Botanical Club 124(2): 11-123.

Sharitz, R., M. Vaitkus and A. Cook (1992). Hurricane damage to an old-growth floodplain forest in the southeast. Seventh Biennial Southern Silviculture Research Conference, Mobile, AL.

General river floodplain reference

Lydeard, C. and R. Mayden (1995). "A diverse and endangered aquatic ecosystem of the Southeast United States." Conservation Biology 9(4): 800-805.
Freshwater ecosystems are a valuable ecological resource that has been overlooked by many conservationists. Biodiversity in temperate freshwater environments is comparable to tropical terrestrial environments but receive less attention. Biodiversity in these habitats depends on the interaction between species, such as predator-prey or host-parasite, so the loss of a species impacts many other species. Dams, channel modification, siltation, reduced water quality, and invasive species are destroying these freshwater habitats.

Bayley, P. B. (1995). "Understanding Large River Floodplain Ecosystems." Bioscience 45(3): 153-158.
This article discusses the economic advantages and increased biodiversity and stability, which would result from the restoration of impaired river systems. The flood-pulse concept defines the dynamic interaction between water and land as the natural process that has adapted and maintained the native biota. The absence of flood-pulse is a disturbance to the system. Inundation of the floodplain allows nutrient cycling as minerals are dissolved, nutrients are replenished, and detritus decomposes. Animals such as fish, mammals, and invertebrates are adapted to the flood-pulse of the river. Their cycle of reproduction and growth is timed to the flood pulse to take advantage of the floodplain's size and nutrient availability.

Beasley, B., W. Marshall, A. Miglarese, J. Scurry and C. Vanden Houten (1996). Managing Resources for a sustainable future: the Edisto River Basin Project. Columbia, SC, South Carolina Department of Natural Resources.

Bedient, P. and W. Huber (2002). Hydrology and floodplain analysis. Upper Saddle River, NJ, Prentice Hall.

Benke, A. C., I. Chaubey, G. M. Ward and E. L. Dunn (2000). "Flood pulse dynamics of an unregulated river floodplain in the southeastern US coastal plain." Ecology 81(10): 2730-2741.
We used aerial photography to delineate the degree of floodplain inundation and GIS to quantify flooded areas on the forested floodplain of a 6.3-km reach of the Ogeechee River, an unregulated sixth-order river in the southeastern USA. A regression was used to quantify the relationship between discharge and percentage floodplain inundation. Using 58 years of daily discharge data obtained from a U.S. Geological Survey gauging station, we converted daily discharge into daily percentage inundation and produced an inundation-duration curve, which describes the percentage of time that a particular inundation level is exceeded. The long term pattern over a period of 58 years (1938-1995) showed considerable fluctuation in inundation and recession occurring

throughout most years, with the highest peaks found during winter and spring. Description of inundation dynamics is critical to understanding how plants and animals adapt to a habitat that shifts from dry to lentic to lotic, and in quantifying production of aquatic organisms and ecosystem processes.

Brinson, M. M. and A. I. Malvarez (2002). "Temperate freshwater wetlands: types, status, and threats." Environmental Conservation 29(2): 115-133.

This review examines the status of temperate-zone freshwater wetlands and makes projections of how changes over the 2025 time horizon might affect their biodiversity. Loss of biodiversity is a consequence both of a reduction in area and deterioration in condition. The information base for either change is highly variable geographically. Factors responsible for losses and degradation include diversions and damming of river flows, disconnecting floodplain wetlands from flood flows, eutrophication, contamination, grazing, harvests of plants and animals, global warming, invasions of exotics, and the practices of filling, dyking and draining. An observation is that countries with both protection and restoration programs do not necessarily enjoy a net increase in area and improvement in condition. Consequently, both reductions in the rates of wetland loss and increases in the rates of restoration are needed in tandem to achieve overall improvements in wetland area and condition.

Flynn, K. and W. Conner (1997). "Ecology and Management of southern forested wetlands." Wetlands Ecology and Management 4(special).

Wharton, C. (1978). The natural environments of Georgia, Georgia Department of Natural Resources, Environmental Protection Division, Geologic Survey Branch.

This book details the hydric systems present throughout the state of Georgia, including the Savannah River. Flora and fauna for the various systems are presented as well as soil structure and the inherent natural and cultural values. Appendices provide listings of native plants and animals and the systems where they are found.

General river floodplain references

Gosselink, J., L. Lee and T. Muir (1990). Ecological processes and cumulative impacts: illustrated by bottomland hardwood wetland ecosystems. Chelsea, MI, Lewis Publishers.

Sharitz, R. and W. Mitsch (1993). Southern Floodplain Forests. Biodiversity of the Southeastern United States/Lowland Terrestrial Communities. W. Martin, S. Boyce and A. Echternacht, John Wiley & Sons, Inc.: 311-371.

Sharitz, R., H. Shealy Jr. and W. Marshall (1998). Wetland resource evaluation in the Edisto River Basin, USA. INTECOL's V International Wetlands Conference, Adelaide, Australia, Geneagles Publishing.

Stanford, J. A. and J. V. Ward (1993). "An Ecosystem Perspective of Alluvial Rivers - Connectivity and the Hyporheic Corridor." Journal of the North American Benthological Society 12(1): 48-60.

Floodplains of large alluvial rivers are often expansive and characterized by high volume hyporheic flow through lattice-like substrata, probably formed by glacial outwash or lateral migration of the river channel over long time periods. River water downwells into the floodplain at the upstream end; and, depending on bedrock geomorphology and other factors, groundwater from the unconfined aquifer upwells directly into the channel or into floodplain springbrooks at rates determined by head pressure of the water mass moving through the floodplain hydrologic system. These large scale (km3) hyporheic zones contain speciose food webs, including specialized insects with hypogean and epigean life history stages (amphibionts) and obligate groundwater species (stygobionts). The landscape-level significance and connectivity of processes along the hyporheic corridor must be better understood if river ecosystems, especially those involving large floodplain components, are to be protected and/or rehabilitated.

Ward, J. V., K. Tockner and F. Schiemer (1999). "Biodiversity of floodplain river ecosystems: Ecotones and connectivity." Regulated Rivers-Research & Management 15(1-3): 125-139.

A high level of spatio-temporal heterogeneity makes riverine floodplains among the most species-rich environments known. Fluvial dynamics from flooding play a major role in maintaining a diversity of lentic, lotic and semi-aquatic habitat types, each represented by a diversity of successional stages. We propose a hierarchical framework for examining diversity patterns in floodplain rivers. Without ecologically sound restoration of disturbance regimes and connectivity, these remnants of biodiversity will proceed on unidirectional trajectories toward senescence, without rejuvenation. Principles of ecosystem management are necessary to sustain biodiversity in fragmented riverine floodplains. Copyright (C) 1999 John Wiley & Sons, Ltd.

Welcomme, R. (1979). fisheries ecology of floodplain rivers. New York, NY, Longman Group Limited.

Wharton, C., W. Kitchens, E. Pendleton and T. Sipe (1982). The ecology of bottomland hardwood swamps of the Southeast: A community profile. Washington, D.C., U.S. Fish and Wildlife Service, Biological Services Program: 133.

This report focuses on bottomland hardwood swamps of riverine floodplains in the Southeast. The biology, geomorphology, and hydrology of the floodplains are described in detail. The ecological zone concept is used to organize and explain the structural complexity of the resident flora and fauna.

Gosselink, J. and L. Lee (1989). "Cumulative impact assessment in bottomland hardwood forests." Journal of the Society of Wetlands Scientists 9(Wetlands, special issue): 174.

Thoroughly discusses the role of wetlands for the maintenance of biotic diversity and abundance. Provides examples of modifications and the resulting impacts on the ecosystem. Stresses the significance of many small and seemingly insignificant changes and the cumulative effect of those changes. Identifies mammal species dependent on the floodplain environment.

Invertebrates

Benke, A. C. (2001). "Importance of flood regime to invertebrate habitat in an unregulated river-floodplain ecosystem." Journal of the North American Benthological Society 20(2): 225-240.

Unlike most large rivers of the northern hemisphere, several medium-sized rivers in the southeastern USA Coastal Plain remain unregulated. These smaller rivers possess 2 habitat types (snags and floodplain) that were historically important for invertebrate assemblages in many rivers and are strongly dependent on flood regime. I reviewed and compared 2 models of habitat inundation (snags and floodplain) that were developed for the Ogeechee River (Georgia, USA) to understand the ecological significance of these habitats. Habitat-specific invertebrate biomass was highest on snags (mostly aquatic insects), followed by the main channel (dominated by Corbicula), and then the floodplain (oligochaetes, crustaceans, aquatic insects). After correction for total amount of habitat surface area, invertebrate biomass contributions were highest in the floodplain > main channel > snag. However, arthropods and oligochaetes, the most likely prey of higher trophic levels, were clearly dominant on snags and in the floodplain. In many rivers around the world, invertebrate productivity from snags and floodplains is likely to have been significantly diminished because of snag removal, channelization, and floodplain drainage for >2 centuries. Understanding the interaction between flood regime and invertebrate habitat in unregulated rivers like the Ogeechee River can serve as a benchmark in restoration efforts.

Batzer, D. P. and S. A. Wissinger (1996). "Ecology of insect communities in nontidal wetlands." Annual Review of Entomology 41: 75-100.
Published research about wetland insects has proliferated, and a conceptual foundation about how wetland insect populations and communities are regulated is being built. Here we review and synthesize this new body of work. Our review begins with a summary of insect communities found in diverse wetland types, including temporary pools, seasonally flooded marshes, perennially flooded marshes, forested floodplains, and peatlands. Next, we critically discuss research on the population and community ecology of wetland insects, including the importance of colonization strategies and insect interactions with the physical environment, plants, predators, and competitors. Results from many of the experimental studies that we review indicate that some commonly held beliefs about wetland insect ecology require significant reevaluation. We then discuss the importance of wetland insect ecology for some applied concerns such as efforts to manage wetland insect resources as waterfowl food and development of ecologically sound strategies to control pest mosquitoes. We conclude with a discussion of wetland conservation, emphasizing insect aspects.

Daniels, S. and J. Morse (1992). "Mayflies (Ephemeroptera), stoneflies (Plecoptera) and other interesting biota of Wildcat Creek, South Carolina, a biodiversity reference stream." Entomological News 103(2): 44-52.

Davis, J., M. Delaney, J. Adkins, TR, J. Morse, J. Patti and R. Hack (1984). "Preimpoundment distribution of mosquitos within the Richard B. Russel Dam and Lake area of South Carolina and Georgia." Journal of the Georgia Entomological Society 19(2): 143-151.

Morse, J. (1981). "Aquatic insect investigations in South Carolina, USA." Victorian Entomologist 2(6): 62-64.

Morse, J., B. Stark, W. McCafferty and K. Tennessen (1997). Southern Appalachian and other Southeastern streams at risk: Implications for mayflies, dragonflies and damselflies, stoneflies and caddisflies. Aquatic Fauna in Peril: The southeastern Perspective. G. Benz and D. Collins. Decatur, GA, Southeast Aquatic Research Institute, Lenz Design Communications.

Hillman, T. J. and G. P. Quinn (2002). "Temporal changes in macroinvertebrate assemblages following experimental flooding in permanent and temporary wetlands in an Australian floodplain forest." River Research and Applications 18(2): 137-154.
The River Murray, Australia, is a highly regulated river from which almost 80% of mean annual flow is removed for human use, primarily irrigated agriculture. Consequent changes to the pattern and volume of river flow are reflected in floodplain hydrology and, therefore, the wetting/drying patterns of floodplain wetlands. To explore the significance of these changes, macroinvertebrate samples were compared between permanent and temporary wetlands following experimental

flooding in a forested floodplain of the River Murray. Weekly samples from two permanent wetlands and four associated temporary sites were used to track changes in macroinvertebrate assemblage composition. Non-metric multidimensional scaling was used to ordinate the macroinvertebrate data, indicating consistent differences between the biota of permanent and temporary wetlands and between the initial and later assemblages in the temporary sites. There were marked changes over time, but little sign that the permanent and temporary assemblages were becoming more alike over the 25-week observation period. The apparent heterogeneity of these systems is of particular importance in developing river management plans which are likely to change flooding patterns. Such plans need to maintain a mosaic of wetland habitats if floodplain biodiversity is to be supported. Copyright (C) 2002 John Wiley Sons, Ltd.

Quinn, G. P., T. J. Hillman and R. Cook (2000). "The response of macroinvertebrates to inundation in floodplain wetlands: A possible effect of river regulation?" Regulated Rivers-Research & Management 16(5): 469-477.
A large number of permanent and temporary wetlands are associated with the lowland rivers in south-eastern Australia. Regulation of these rivers for irrigated agriculture has probably increased the temporary nature of some wetlands because the reduced frequency of overbank flows causes them to remain dry for longer. The responses of macroinvertebrate assemblages(species composition and abundance) to inundation in permanent and temporary wetlands on the floodplain of the unregulated Ovens River were examined, and these responses were compared with those from permanent and temporary wetlands in the Barmah-Millewa forest of the regulated River Murray. The compositions of macroinvertebrate assemblages in permanent wetlands could not be distinguished from those of temporary wetlands on the Ovens after inundation, although changes in abundance of some taxa (especially chironomids) meant that the assemblages in permanent wetlands differed significantly before and after flooding. In contrast, after inundation permanent and temporary wetlands in the Barmah-Millewa forest differed significantly and this difference was sustained through time. This different response of macroinvertebrate assemblages on the two floodplains may be an effect of regulation, although other explanations, such as differences between the floodplains in the mechanism of inundation and historical water regimes, or climatic differences between years, may also be important. Copyright (C) 2000 John Wiley & Sons, Ltd.

Shannon, J. P., D. W. Blinn, T. McKinney, E. P. Benenati, K. P. Wilson and C. O'Brien (2001). "Aquatic food base response to the 1996 test flood below Glen Canyon Dam, Colorado River, Arizona." Ecological Applications 11(3): 672-685.
We examined the impact of the 1996 test flood released from Glen Canyon Dam (GCD) on the aquatic food base in the Colorado River through Grand Canyon National Park, Arizona, USA, Benthic scour and entrainment of both primary and secondary producers occurred at all study sites along the 385-km river corridor. The majority of the organic drift occurred within the first 48 h of the test flood with the arrival of the hydrostatic wave. Recent macrophyte colonizers (Chara, Potamogeton, and Elodea) of fine sediment in the tailwaters were scoured from the channel bottom, with recovery to pre-flood estimates within 1-7 months depending on taxa. Macroinvertebrates and filamentous algae recovered within three months depending on taxa. The test flood removed suspended particles from the water column and increased water clarity, which enhanced benthic recovery. The test-flood hydrograph was designed primarily as an experiment in sand transport and occurred during a period of sustained high releases from GCD starting in June 1995 due to above-average inflow into Lake Powell. We discuss the implications of the hydrograph shape, pre- and post-riverine conditions, and the slow response time of biological resources for design of aquatic ecosystem experiments.

Management of river discharges/flows, and effects on floodplain systems

Hochman, E. (1999). Lower Roanoke River optimum hydroperiods: Part I. Altered hydrology and implications for forest health. Chapel Hill, NC, University of

North Carolina: 23.

Irwin, E. and M. Freeman (2002). "Proposal for adaptive management to conserve biotic integrity in a regulated segment of the Tallapoosa River, Alabama (U.S.A.)." Conservation Biology 16(5): 1212-1222.

Middleton, B. (2002). Flood Pulsing in wetlands: restoring the natural hydrological balance. New York, NY, Wiley.

Pearlstine, L., H. McKellar and W. Kitchens (1985). "Modeling the impacts of a river diversion on bottomland forest communities in the Santee River floodplain, South Carolina." Ecological Modelling 29: 283-302.

The first and third references in this group are noteworthy. In the first, effects of altered flows in the Roanoke River and potential implications for woody species recruitment are considered. This may serve as something of a model for the report to be developed for the Savannah River. The third reference, Middleton's book, addresses the overall importance of the flood pulse in river floodplain systems.

Mapping and modeling flood inundation in the Roanoke River floodplain

Townsend, P. (2001). "Mapping seasonal flooding in forested wetlands using multi-temporal Radarsat SAR." Photogrammetric Engineering and Remote Sensing 67: 857-864.

Townsend, P. (2002). "Relationships between forest structure and the detection of flood inundation in forested wetlands using C-band SAR." International Journal of Remote Sensing 23(3): 443-460.

These papers describe in detail the use of Radarsat scenes for delineating and mapping flood inundation in the forests of the Roanoke River floodplain. Images from both leaf-on and leaf-off periods were acceptable for detecting flooding, although leaf-off were classified with higher accuracy. Through the use of radar and optical remote sensing in conjunction with GIS modeling, the authors delineated potential inundation in area of subtle topographic relief. Biophysical data reveal that certain features of the forest structure (basal area, height to the bottom of the canopy) affected detection of inundation, whereas other features (leaf area index, canopy height, canopy depth, crown closure) did not.

Townsend, P. and J. Foster (2002). "A synthetic aperture radar-based model to assess historical changes in lowland floodplain hydroperiod." Water Resources Research 38(10): 1029-2001.

This paper presents a model for the Roanoke River floodplain to simulate flood extent and duration based on a power law correlation between inundation area, as mapped from synthetic aperture radar (SAR) imagery and river discharge. SAR imagery is used to map flood extend under different river discharges. Hydrology simulated for pre-dam and post-dam periods was compared, and spatial changes in hydroperiod regime in these two time frames are identified. Following dam construction, topographically wet areas are flooded longer than before damming, and dry areas are drier. Similarly, hydrologically wet years experience longer floods, whereas the driest years are drier. Most importantly, spring hydroperiod regimes are wetter than prior to damming. this study and model have direct applicability to issues of altered flow regimes in the Savannah River, although the data to apply this model directly to the Savannah floodplain are likely not available.

Townsend, P. and S. Walsh (1998). "Modeling floodplain inundation using an integrated GIS with radar and optical remote sensing." Geomorphology 21: 295-312.

Miscellaneous

Gehrke, P. C., P. Brown, C. B. Schiller, D. B. Moffatt and A. M. Bruce (1995). "River regulation and fish communities in the Murray-Darling river system, Australia." Regulated Rivers-Research & Management 11(3-4): 363-375.

Fish communities from four catchments in the Murray-Darling river system were analyzed in relation to climate, hydrology and river regulation. There was a significant trend for reduced species diversity in increasingly regulated catchments. River regulation may alter the relative abundance of native and alien fish by desynchronizing environmental cycles and the reproductive cycles of native species. Ordination of species abundances showed discrete fish communities that reflect the geographical separation between catchments. Differences between communities are related to opportunities for dispersal, the environmental tolerances of dominant species and the modifying effects of river regulation. Fish communities in lakes exhibited less seasonal variation than riverine communities within the same catchment, indicating the greater seasonal stability of lakes compared with regulated and unregulated river reaches. Management of fish resources needs to include catchment-specific strategies within current State and basin-wide management programs.

Kiuchi, M. (2002). Multiyear-Drought impact on hydrological conditions in South Carolina, water years 1998-2001, South Carolina Department of Natural Resources.

The effect of the multi-year drought on the lake, river, and groundwater levels in the state of South Carolina are quantified. Declines in the groundwater level in Aiken and Barnwell counties represent the loss of water recharge due to the drought. Groundwater flow influences the hydrologic conditions in the wetlands and reduction of this water source would have additional effects on ecological processes.

Remote sensing

Kingsford, R. T. and R. F. Thomas (2002). "Use of satellite image analysis to track wetland loss on the Murrumbidgee River floodplain in arid Australia, 1975-1998." Water Science and Technology 45(11): 45-53.

Demonstrating the extent of wetland loss and its causes are essential for policy makers and managers. We used Landsat satellite imagery to show major wetland loss in the Lower Murrumbidgee.. floodplain on the Murrumbidgee River in and Australia. Stratification of the floodplain according to hydrology, use of imagery from the same time of year and the separation of developed areas, using ancillary information were essential. There was considerable loss of floodplain area over a 23 year period (1975-1998), mainly in the Nimmie-Caira stratum (59% loss), as wetland areas were replaced by irrigation bays.-There was also a significant increase in fragmentation. For floodplain areas distant from the river, flooding patterns were more difficult to identify because of infrequent flooding and primary reliance on rainfall Landsat imagery provided a powerful tool for demonstrating long-term changes in wetland area, even in highly variable environments. Such information can demonstrate the ecological costs of water resource development on floodplains, forming a basis for policy and management of rivers.

Townsend, P. and J. Foster (2002). Comparison of EO-1 Hyperion to AVIRIS for mapping forest composition in the Appalachian Mountains, USA. 2002

International Geoscience and Remote Sensing Symposium, Toronto, Canada.

Townsend, P. and J. Foster (2002). Terrain normalization of AVIRIS and Hyperion imagery in forested landscapes. Eleventh JPL Airborne Earth Science Workshop, Pasadena, CA.

Tree seedling recruitment and physiological tolerances

Battaglia, L., S. Fore' and R. Sharitz (2000). "Seedling emergence, survival and size in relation to light and water availability in two bottomland hardwood species." Journal of Ecology 88: 1041-1050.

Battaglia, L., R. Sharitz and P. Minchin (1999). "Patterns of seedling and overstory composition along a gradient of hurricane disturbance in an old-growth bottomland hardwood community." Canadian Journal of Forest Research 29: 144-156.

Conner, W. and K. Flynn (1989). "Growth and survival of baldcypress (Taxodium distichum [L.] Rich.) planted across a flooding gradient in a Louisiana bottomland forest." Wetlands 9: 207-217.

Jansson, R., C. Nilsson, M. Dynesius and E. Andersson (2000). "Effects of river regulation on river-margin vegetation: A comparison of eight boreal rivers." Ecological Applications 10(1): 203-224.

Regulation and fragmentation by dams belong to the most widespread deliberate impacts of humans on the world's rivers, especially in the Northern Hemisphere. We evaluated the effects of hydroelectric development by comparing the flora of vascular plants in 200-m-long reaches of river margin distributed along eight entire rivers in northern Sweden. Four of these rivers were free-flowing, and four were strongly regulated for hydroelectric purposes. First, we compared species diversity per site between entire free-flowing and regulated rivers. To reduce the effects of natural, between-river variation, we compared adjacent rivers.

Run-of-river impoundments had higher proportions of long-floating species and species with mechanisms for vegetative dispersal, suggesting that water dispersal may still be important despite fragmentation by dams. Plant species richness and cover varied with both local factors, such as water-level regime, and regional factors, such as length of the growing season. Presence of clay and silt in the river-margin soil, pre-regulation position of the contemporary river margin, non-reservoir sites, low altitudes, and long growing seasons were associated with high plant species richness and cover.

Pezeshki, S. and P. Anderson (1997). "Responses of three bottomland species with different flood tolerance capabilities to various flooding regimes." Wetlands Ecology and Management 4: 245-256.

This article examines the effect of prolonged flooding on the seedlings of baldcypress, nuttall oak, and cherrybark oak. Prolonged flooding produces a reduced soil deficient in oxygen. The seedlings have varying tolerances for these conditions which affect their growth and survival.

Use of Remote Sensing to Determine Hydroperiod and Vegetation on the Roanoke River

Townsend, P. (2001). "Relationships between vegetation patterns and hydroperiod on the Roanoke River floodplain, North Carolina." Plant Ecology 156: 43-58.

Townsend, P. (2002). "Estimating forest structure in wetlands using multitemporal SAR." Remote Sensing of Environment 79: 288-304.

The first study quantified relationships between forest composition and flooding gradients on the Roanoke River floodplain. The second study assesses the capabilities of multispectral radar imagery for estimating biophysical characteristics of forested wetlands. In the first, the author tested the importance of spring vs. yearly flood duration, as well as flood duration during hydrologically wet vs. dry years, both before and following dam construction. Results suggest that inundation during extremely wet years strongly controls species composition, and that spring hydroperiod is an important mechanism that may drive competitive sorting along the flooding gradient, especially during periods of species establishment. Annual hydroperiod affects the relative dominance of species as the forests mature. These findings are directly applicable to the forest communities on the Savannah River floodplain. Appendix I provides species optimal hydroperiod durations for annual and spring hydroperiods and should be useful in estimating species responses to hydroperiod change in the Savannah River.

Townsend, P. and S. Walsh (2001). "Remote sensing of forested wetlands: application of multitemporal and multispectral satellite imagery to determine plant community composition and structure in southeastern USA." Plant Ecology 157: 129-149.

In this study, a hierarchical classification of forested wetland communities was developed for the lower Roanoke River floodplain, through the use of multitemporal and multispectral satellite digital data, including Landsat TM images from different seasons to capture the phonological variability of the vegetation. Field data supported the classification and were used to describe and validate the compositional characteristics of the mapped plant communities. Vegetation classes included 21 forest communities and several other ecologically important classes.

Vertebrates

Burke, V. J., J. E. Lovich and J. W. Gibbons. 2000. Conservation of freshwater turtles. Turtle Conservation. M. Klemens. Washington, DC, Smithsonian Institution Press. pp. 156-179.

This chapter in the book Freshwater Turtles discusses conservation of turtles in regards to life cycle, describes the status of freshwater turtles, and provides recommendations for future conservation efforts. Preservation of habitat is a critical factor in maintaining a population. Freshwater turtles frequently require upland habitat for nesting, overwintering, and foraging so protection of land adjacent to the wetland is essential. Juvenile turtles have different prey items and change habitat as they grow in size. As a result, a spatially heterogeneous freshwater environment is needed to provide the various requirements for the maturing turtles. Recommendations include ending human exploitation (recreational shooting and wild capture for the pet trade,) preservation of lentic waters, and educational programs for the public.

Kingsford, R. T. (1999). "Aerial survey of waterbirds on wetlands as a measure of river and floodplain health." Freshwater Biology 41(2): 425-438.

This study highlights the use of waterbird communities as potential measures of river and floodplain health at a landscape scale. The abundance and diversity of a waterbird community (54 species) was measured over 15 trips with four aerial and three ground counts per trip on a 300-ha lake in arid Australia. River system health encompasses the state of floodplain wetlands. Waterbirds on an entire wetland or floodplain may be estimated by aerial survey of waterbirds; this is a coarse but effective measure of waterbird abundance. Aerial survey is considerably less costly than ground survey and potentially provides a method for measuring river and floodplain health over long periods of time at the same scale as river management.

Townsend, P. and D. Butler (1996). "Patterns of landscape use by beaver on the lower Roanoke River floodplain, North Carolina." Physical Geography 17(3): 253-269.

(3) AQUATIC BIOTA

(compiled and annotated by Will Duncan, Tavis McLean, Mary Freeman, Cecil Jennings

The annotated bibliography below is divided into ten sections: Atlantic and shortnose sturgeon, Shad and Herring, American eel, striped bass, robust redhorse, habitat, flow and other fish, mussels, floodplain fish, estuaries and general information sources. They are ordered by the authors last name, not relevance.

Atlantic and Shortnose Sturgeon

Buckley, J., and B. Kynard. 1985. Habitat use and behavior of prespawning and spawning shortnose sturgeon, *Acipenser brevirostrum*, in the Connecticut River. Pages 111-117 *in* F.P. Binkowski and S.I. Doroshov, eds. North American sturgeons: biology and aquaculture potential. Developments in Environmental Biology of Fishes 6. Dr. W. Junk bv Publishers, Dordrecht, Netherlands. 163 pp.

Collins, M.R., S.G. Rogers, T.I.J. Smith, and M.L. Moser. 2000a. Primary factors affecting sturgeon populations in the southeastern United States: fishing mortality and degradation of essential habitats. Bulletin of Marine Science. 66, 917-928. Reviews sources of mortality and habitat degradation for anadromous (Atlantic) and nearly anadromous (shortnose) sturgeon. Some life stages are restricted to or concentrated in estuaries and deterioration of dissolved oxygen levels in these areas has degraded these habitats. Protecting these areas from human induced DO drops and creating habitat preserves to eliminate bycatch may benefit these species. Although the spawning habitat for the Atlantic sturgeon is unknown, shortnose appear to spawn at limestone outcrops or deep, scoured channels with hard substrate. Nursery habitat for both species appears to be the interface between fresh and brackish water. For the Savannah River, Collins et al. make three management recommendations: halt degradation of nursery habitat (salinity and DO), establish riverine reserve to the first dam at rkm 300, and maintain adequate flow from dam during spawning season.

Collins, M.R., T.I.J. Smith, W.C. Post, and O. Pashuk. 2000b. Habitat utilization and biological characteristics of adult Atlantic sturgeon in two South Carolina rivers. Transactions of the American Fisheries Society 129, 982-988.
Radio telemetry studies revealed seasonal movement patterns of the Atlantic sturgeon in nearby South Carolina rivers. All fish were between the ages of 7 and 20 years old, but fewer females were found in the rivers. Additionally, females were older (aged 15-20). All fish moved out to sea between October and November. Some data suggest upstream spawning runs in October. Nearly half returned in March. Fall and spring spawning was documented. Summer habitats included upper and lower estuaries, tidal freshwater, river, and perhaps the ocean. This study suggest little differentiation between rivers in the ACE basin. Some WQ data related to habitat use is available.

Collins, M.R., W.C. Post, D.C. Russ, and T.I.J. Smith. 2002. Habitat use and movements of juvenile shortnose sturgeon in the Savannah River, Georgia- South Carolina. Transactions of the American Fisheries Society. 131, 975-979.

Juvenile shortnose sturgeon *Acipenser brevirostrum* were implanted with acoustic transmitters in the Savannah River. Nets were set between rkm 29 (the Kings Island Turning Basin) and rkm 60, but juveniles were only found between 31.2 and 47.5 rkm. This study indicates that juveniles are not using previously identified nursery habitats at the KITB, probably as a result of hydrology and water quality changes associated with harbor modification. Juveniles congregated near rkm 31.2 (the confluence of Front and Middle rivers) when water temperatures were below 22C, and rkm 47.5 when temperatures were above 22C. This study also suggests that abundance of juvenile shortnose sturgeon has declined despite stocking and that proposed modifications to the Savannah Harbor will contribute to further declines. The same information is presented in Collins et al. (SCDNR; see sysconn.com)

Collins, M.R., W.C. Post, and D.C. Russ. (SCDNR) Distribution of Shortnose Sturgeon in the lower Savannah River. Results of research conducted 1999-2000. Final Report to the Georgia Ports Authority. http://www.sysconn.com/harbor/SEG/Study%20Reports/SNS%20Field%20Study/SCDNR%20SNS%20Final%20Report%20text%20and%20figures_7-24-01.pdf In this study, 15 juvenile and 17 adult sturgeon were tagged and tracked with acoustic transmitters and their habitat use patterns were determined. Juveniles used to relatively small areas very intensively. When water temp < 22°C, they concentrated in the vicinity of the Front and Middle rivers and moved about in both. When water temp > 22°C, they moved well upriver from the area of proposed deepening, concentrating around river km 47.5. Adult movement patterns are also documented in this paper. Paper also discusses how harbor modifications have caused changes in habitat use patterns.

Cooke, D.W., S.D. Leach, and J. Isely. 2000. Behavior and Lack of upstream passage of shortnose sturgeon at a hydroelectric facility/navigation lock complex. Pages 101-110 in W. Van Winkle, P.J. Anders, D.H. Anders, D.H. Secor, and D.A. Dixon, editors. Biology, management, and protection of North American Sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Crance, J.H. 1986. Habitat suitability index models and instream flow suitability curves: shortnose sturgeon. U.S. Fish and Wildlife Service Biological Report. 82(10.129). 31 pp. [accessible at http://www.wes.army.mil/el/emrrp/emris/EMRIS_PDF/] Habitat Suitability Index Models were developed for the American shad and shortnose sturgeon were modified and used in the Savannah River Instream Flow study (ENTRIX, 2002b) to examine spawning, egg and larval drift, and adult habitat suitability under various flows.

Dadswell, M.J., B.D. Taubert, T.S. Squires, D. Marchette, and J. Buckley. 1984. Synopsis of biological data on shortnose sturgeon, Aciperser brevirostrum Lesueur 1818. NOAA Tech. Rep. NMFS 14 (FAO Fish. Synopsis 140). U.S. Dep. Commerce. iv + 45 pp. [for purchase in microfiche from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Phone 1-800-553-NTIS. Web site: http://www.ntis.gov.]

Gilbert, C.R. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic Bight) – Atlantic and shortnose sturgeons. U.S. fish and Wildlife Service Biological Report 82(11.122). U.S. Army

Corps of Engineers TR EL –82-4. 28 pp. [available at http://www.nwrc.gov/wdb/pub/0123.pdf]
Species profiles for both Atlantic and shortnose sturgeon indicate that both species spawn in strong current but are usually found in little to no current. Temperature around 20C stimulates movement by Atlantic sturgeon. Shortnose sturgeon are found in water temperatures as high as 34C in the Altamaha River. Additional information on growth, food, diel movement patterns, salinity, and catch data are provided.

Hall, J.W., T.I.J. Smith, and S.D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon, *Acipenser brevirostrum* in the Savannah River. Copeia. 1991, 695-702.
Seasonal movements and habitat use of adult and juvenile shortnose sturgeon was studied in the Savannah River with a few notes on Atlantic sturgeon. Their study indicates that upstream migration takes place from mid-Feb to mid-Mar when river temperatures ranged from 9-12C (mean 9.2). Downstream migrations begin in mid-Mar with all adults leaving freshwater by early May. Spawning sites and habitats were identified with high bottom velocities averaging 82 cm/sec (compare to Connecticut River 36-120 cm/sec). Interface of salt and freshwater heavily used by adults and juveniles fall and winter. Probable nursery area identified downstream of interface.

Heidt, A.R., and R.J. Gilbert. 1978. The shortnose sturgeon in the Altamaha River drainage, Georgia. pages 54-60 *in* Proceedings of the rare and endangered wildlife symposium. Georgia Department of Natural Resources.

Kynard, B. 1997. Life history, latitudinal patterns, and status of the shortnose sturgeon, *Acipenser brevirostrum*. Environmental Biology of Fishes. 48, 319-334.
Life history and latitudinal patterns of the shortnose sturgeon *Acipenser brevirostrum* were reviewed by. Adult abundance is below 1000 for all southern populations, the minimum estimated size to maintain population viability. Most remain in their natal river or estuary, although there is some evidence of emigration, most notably in the north. In the Savannah River, adults forage in the fresh/saltwater interface during the spring and summer and move briefly, or for a long period, into high salinity in the fall (lower estuary). Some adults remain in freshwater after spawning in Altamaha River. But during the summer, adults and juveniles remain in the deep, cool water refuges and avoid river temperatures that exceed 28-30C. They have a long 1-step migration, spawn in the late winter when river temperatures exceed 9C. Spawning ceases at 12-15C. Spawning habitats in the SR are channel curves with rocks, gravel/sand/logs. Larvae tolerate a max of 9ppt salinity and require more than 3mg/l O2, but salinity tolerance increases with age. YOY probably prefer and remain in freshwater. One-year old juveniles and adults use the same fresh/saltwater interface and use sand and mud substrate of deep channels.

Kynard, B., M. Horgan, M.Kieffer, D. Seibel. 2000. Habitats used by shortnose sturgeon in two Massachusetts rivers, with notes on estuarine Atlantic sturgeon: A hierarchical approach. Transactions of the American Fisheries Society 129, 487-503.
Seasonal shifts in habitat use for both Atlantic and shortnose sturgeon were studied in Massachusetts. Describes varying shoal use in two rivers. In the summer, Atlantic juveniles used a narrow range of habitat: run with island, the channel portion of the

cross section, and sand substrate. All ages of shortnose selected a range of habitats. Showed a preference for curves with sand or cobble substrate and avoided runs, especially in fall, probably because of slow water velocity. Winter habitat selection patterned the fall, but was less variable.

Kynard, B., and M. Horgan. 2002. Ontogenetic behavior and migration of Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus*, and shortnose sturgeon, *A. brevirostrum*, with notes on social behavior. Environmental Biology of Fishes. 63, 137-150. Laboratory studies of embryo and larva temporal and spatial movement patterns of Hudson River Atlantic sturgeon and Connecticut River shortnose sturgeon were examined as well as the foraging relationship to body size. Atlantic sturgeon embryos sought cover in gravel substrate until day eight of development and shortnose sturgeon emerged as larva at 16-17 days old. Atlantic sturgeon spawn at rkm 136-182 and larva have a long 1-step migration of 6-12 days. Shortnose sturgeon spawn at rkm 192-194 and have a long 2 step migration downstream for 3 days. A good review of life history and early life movement patterns is given.

Smith, T.I.J. 1985. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrhynchus*, in North America. Environmental Biology of Fishes. 14,61-72. The decline of the Atlantic sturgeon and the shortnose sturgeon is described here and landings/ year and landings/ year/ state are presented. A good summary of the biology at various life stages is presented here. Timing of Atlantic sturgeon spawning migrations are temperature dependent and adults arrive in inland waters in February- March. Probable spawning areas for Atlantic sturgeon is in running water over bottoms containing rocks, rubble, and other hard objects and in pools below waterfalls. There is evidence that juveniles move progressively into saline waters in time.

Smith, T.I.J., and J.P. Clugston. 1997. Status and management of Atlantic sturgeon, *Acipenser oxyrinchus*, in North America. Environmental Biology of Fishes. 48, 335-346.
The status and management of Atlantic sturgeon are given a thorough review. They state that spawning migrations begin in Feb-Mar in the south. Spawning locations are assumed to be flowing water over hard substrates (rocks, rubble, shale, and sand). In culture studies, incubation times range from 94 h (20C) to 140 h (18C). There is some movement of juveniles between river systems. Most juveniles stay in brackish water near river mouth/ estuarine zone for a number of months or years. Outlines reasons for decline. In 1982, SC and GA ranked number 1 and 2 respectively in sturgeon harvesting (58 mt total).

Van Den Avyle, M.J. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) – Atlantic sturgeon. U.S. Fish and Wildlife Service. FWS/OBS-82/11.25 U.S. Army Corps of Engineers, TR IL-82-4. 17 pp.[available at http://www.nwrc.gov/wdb/pub/1048.pdf] Additional information in the Atlantic sturgeon species profile suggests that they gather food off soft bottom substrates. The non-adhesive nature of the eggs suggests that low-velocity water is necessary for egg development.

Shad and Herring

Bailey, M.M., J.J. Isely, and D.C. Cooke. (AFS abstract) Movement and passage of American shad at the New Savannah Bluff Lock and Dam.
American shad movement was examined by radio telemetry below. Nearly half of the 50 tagged shad moved upstream of the New Savannah Bluff Lock and Dam during lock cycles. The authors conclude that an aggressive locking schedule with a one-half hour period of attractant flow will facilitate upstream passage of American shad

Boltin, W.R. 1999. New Savannah Bluff Lock and Dam American Shad Mark/Recapture Report, April 1999 to July 1999. South Carolina Department of Natural Resources. Wildlife and Freshwater Fisheries Section.Abbeville, South Carolina.

Cooke, D.W., and S.J. Chappelear. Santee-Cooper Blueback Herring Sudies, Rediversion Project, Annual Report, January 16, 1994 to Septermber 30, 1994. South Carolina Department of Natural Resources. Division of Wildlife and Freshwater Fisheries. 1994.

Cooke, D.W., and S.D. Leach. 2001. The effects of increased river flow and implementation of upstream fish passage on alosid stocks in Santee River, South Carolina. Proceedings of Shad 2001: A conference on the status and conservation of shads worldwide. American Fisheries Society. Bethesda, Md. (In Review)

Eager, R. 1987. Central Savannah River American Shad Study: 1986-1987. Draft Report. U.S. Fish and Wildlife Service.

As juvenile American shad approached 95 mm, they shifted from shallow water habitats (<5ft) to deeper water. Most of the outmigration (late Sept. to early Dec.) over New Savannah Bluff Lock and Dam was from 2300 to 0600 hrs.

Facey, D.E., and M.J. Van Den Avyle. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)— American shad. U.S. Fish and Wildlife Service Biological Report. 82(11.45) U.S. Army Corps of Engineers, TR EL-82-4. 18 pp.
http://www.nwrc.gov/publications/specindex.htm
The American shad profile indicates that spawning runs peak at about 20C. Substrate appears unimportant for this species given that it releases its eggs into the water column. They spawn in velocities ranging from 9.5-132 cm/sec, normally 30-90 cm/sec. Some temperature preference data are also provided. Oxygen in headponds for American shad must remain above 4-5 mg/L and dissolved oxygen for egg viability must remain above 5.0 mg/L (MacKenzie, 1985).

McDonald, M. 1884. The shad- *Clupea sapidissima in* Goode, G.B. The fisheries and fishery industries of the United States. United States Commission of Fish and Fisheries.
This source describes the American shad fishery in the late 1800's as well as some attributes of shad life history. Individuals once ranged throughout Savannah River ascending to the Falls of Tallula. It also implicates dams in the reduction of spawning area and sets forth evidence that disproves the theory of instinct locality. Spawning grounds are described as sandbars and areas near sandy flats.

Goodwin, W.F., and Adams, J.G. (1969). Young Clupeids of the Altamaha River, Georgia. Georgia Game and Fish Division. Marine Fisheries Division. Brunswick, Georgia.

In the Altamaha River, juvenile American shad were first collected in April. Juveniles migrated out of the river by January and blueback herring migrated out by October. American shad migrations out of the river system do not correlate with decreasing water temperatures. Shad migration is probably size dependent. Hickory shad probably don't use the river as nursery area, but migrate to offshore waters following hatching. A good review of juvenile clupeid movement in the Altamaha River is presented here.

O'Leary, J.A. 1984. Characteristics of the Downstream Migration of Juvenile American Shad (*Alosa sapidissima*) and Blueback Herring (*Alosa aestivalis*) in the Connecticut River. University of Massachusetts Master's Thesis. 58p.

Downstream migration of juvenile American shad and blueback herring was studied in the Connecticut River. Migration peaked during the new moon phase in October. American shad diel patterns showed a peak in the late afternoon to evening of both years and blueback herring during the daytime.

Paller, M.H., and B.M. Saul. 1996. Effects of temperature gradients resulting from reservoir discharge on *Dorosoma cepedianum* spawning in the Savannah River. Environmental Biology of Fishes. 45, 151-160.

Hypolimnetic release from Strom Thurmond Reservoir created a downstream temperature gradient in the Savannah River. Gizzard shad *Dorosoma cepedianum* spawned earlier in the season in the warmer reaches of the river downstream and later upstream. Gizzard shad larvae peaked when water temperatures reached approximately 19 C. Temperature range for spawning is 10-29 C. When water levels were high and low in the floodplain swamps and backwaters (April and May of 1983 and 1984), larval densities were high. However, declining water levels and emigration may have influenced densities. Floodplain swamp water levels were high in April, 1983 and low by May 1983 (see floodplain innundation in fig 6.).

Probst, W. 1988. Evaluation of Successive Year Class Strength of Juvenile American Shad in the Ogeechee River. Georgia Department of Natural Resources. Game and Fish Division. Altanta Georgia.

In Georgia the American shad spawning run begins in January and continues into April. Young shad remain in their natal rivers the first summer and migrate to the sea in late summer. Juvenile shad appeared to be more active in the daylight. Outmigration may be triggered by temperature.

Stier, D.J., and J.H. Crance 1985. Habitat suitability index models and instream flow suitability curves: American Shad. U.S. Fish and Wildlife Service Biological Report. 82(10.88). [accessible at http://www.wes.army.mil/el/emrrp/emris/EMRIS_PDF/ other riverine species available at this site, too.]

The Habitat Suitability Index Models developed by Crance (1986) and Stier and Crance (1985) for the American shad and shortnose sturgeon were modified and used in the Savannah River Instream Flow study (ENTRIX, 2002b) to examine spawning, egg and larval drift, and adult habitat suitability under various flows. The habitat suitability index model for the American Shad has life history information as well as habitat and flow requirements. Spawning runs begin as early as November in the southern part of its range, but as late as June in the north (see Hildebrand, 1963 summary in Fishes of the Northern Atlantic). They sometimes migrate hundreds of miles into headwaters, and spawn over a variety of substrates, at a variety of depths, and in optimal velocities from 1-3 ft/sec. Eggs are initially adhesive, but then become nonadhesive. The eggs are slightly heavier than water, gradually sink, and are carried downstream. Larvae are carried passively; juveniles school and migrate downstream in current to estuary nursery area, usually migrating when temperatures drop below 15.5 C. Spawning temperatures occur between 8-26 C, but peak from 14-21 C. Peak movement into rivers occurs at 18.5 C and upstream migrations discontinue at 20 C, stopping to spawn at optimal temperatures. Water temperatures between 15.5 and 26.0 C are optimal for egg and larva development.

American Eel

American Eel Plan Development Team. 2000. Interstate fishery management plan for American eel (*Anguilla rostrata*). Atlantic State Marine Fisheries Commission, Washington D.C. Fishery Management Report. No. 36, 93 pp. [available at www.asmfc.org]

There has been a dramatic decline in the amount of river available for American eel migration. The historic length of available riverine habitat in the Savannah-Ogeechee was 34604 km. However, a total of 1028 dams, ranging from less than 10 feet to hydroelectric size (30), fragment the river system leaving only 4508 km available. Stream use is important to elvers and yellow eel.

Facey, D.E., and M.J. Van Den Avyle. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)—American eel. U.S. Fish and Wildlife Service Biological Report. 82(11.74) U.S. Army Corps of Engineers, TR EL-82-4. 28 pp. [available at http://www.nwrc.gov/publications/specindex.htm http://216.239.51.100/search?q=cache:2fkM5QfJWEMC:www.nwrc.usgs.gov/wdb/pub/0113.pdf+U.S.+Fish+and+Wildlife+Service+Biological+Report.+82(11.74)&hl=en&ie=UTF-8]

Radio telemetry of eight yellow eels in a tidal creek indicated that they remain in the main channel in the daytime. At night, however, they either move to the mouth of feeder creeks, probably for foraging purposes, or during high tides they will move into the flooded marshes. Their movement is also tidally influenced. Undisturbed bottom sediments and plant matter is important to migrating elvers. Temperature requirements are also outlined in this species profile.

Helfman, G.S., E.L. Bozeman, E.B. Brothers. 1984. Size, age, and sex of American eels in a Georgia River. Transactions of the American Fisheries Society. 113, 132-141.

This study related length and weight, age, and sex information of the American eel to spatial and temporal occurrence in the Altamaha River and estuary. Smallest reported individuals were reported in freshwater in the summer, and the estuary in the spring. Average age in the estuary was younger (4.6 compared to 6.2 years). Males were much more abundant in the estuary.

Krueger, W.H., and K. Oliveira. 1999. Evidence for environmental sex determination in the American eel, *Anguilla rostrata*. Environmental Biology of Fishes. 55, 381-389.
Field studies and experiments on the American eel Anguilla rostrata indicated environmental sex determination (ESD). High population densities result in the high proportion of males; the converse is true, as well. ESD may be adaptively significant and an explanation for this is provided.

Martin, M.H. 1995. The effects of temperature, river flow, and tidal cycles on the onset of glass eel and elver migration into fresh water in the American eel. Journal of Fish Biology. 46, 891-902.
The onset of *Anguilla rostrata* elver migration into freshwater was examined and related to environmental factors in a Rhode Island River. Increased river temperatures and reduced flow increased elver migration early in the season (March), but tidal stage appeared to be more important in May-June. Thermal or oldfactory cues that accompanied the increase in water flow may have played a role in elver migration. Other studies suggest that elvers prefer higher temperatures in long-term experiments and selective tidal stream transport.

Striped Bass

Bain, K.B. and J.L. Bain. 1982. Habitat suitability index models: Coastal stocks of striped bass. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-82/10.1. 29 pp.
This HSI model may be useful for developing flow recommendations as several of the suitability index variables measured in the model pertain to river flow rates. The model was located at the following web address:
http://www.nwrc.usgs.gov/wdb/pub/hsi/hsi-001.pdf

Dudley, R.G., A.W. Mullis, and J.W. Terrell. 1977. Movement of Adult Striped Bass (Morone saxatilis) in the Savannah River, Ga. Transactions of the American Fisheries Society. 106: 314-322.
After spawning in March-May, striped bass move as far as 301 km upstream and remained there throughout the summer (Dudley et al., 1977).

Dudley, R.G., and K.N. Black. 1978. Distribution of striped bass eggs and larvae in the Savannah River estuary. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 32: 561-570.

Dudley, R.G., and K.N. Black. 1979. Effects of the Savannah River Tidegate on Striped Bass Eggs and Larvae. Final Report to the U.S. Army Corps of Engineers on contract DACW21-78-C-0073, 46 pp.

Jennings, C. A., B.J. Hess, and C. Jackson. 1999. Use of Cool-Water Springs as Thermal Refuge by Striped Bass in the Ogeechee River, Georgia. Georgia Journal of Science. 57 (2): 123-130.
This study was a two-year telemetry study conducted to determine whether or not summertime cool water refuge area was limiting to striped bass in the Ogeechee River, Ga. The conclusion was that Ogeechee River striped bass were not limited to upstream cool water springs and may meet most of their thermal requirements in the estuary or the mainstem of the Ogeechee River.

Jennings et al. 2001. Assessment of spawning sites and reproductive status of striped bass, *Morone saxatilis*, in the Savannah River Estuary. Ga. Port Authority Website.
This study focused on several objectives: 1. Validating egg detection thresholds for standardized egg collection methods and determining sampling efficiency by sampling known amounts of striped bass egg surrogates, 2. Quantify spatial and temporal egg abundances in the Savannah River Estuary, and 3. Estimate total egg abundance in the SRE, 4. Evaluate an existing fecundity model for striped bass, and 5. Assess temporal changes in maturation and fecundity from 1999-2000. Study results showed an increase in overall egg abundance from previous years. This study may be found at the following web address:
http://www.sysconn.com/harbor/#Sci

Larson, S.C. 1985. The distribution and abundance of striped bass eggs in the lower Savannah River. Masters thesis. University of Georgia, Athens.

Mooneyhan, D.M. and M.J. Van Den Avyle. 1995. Distribution and Habitat Requirements of Adult Striped Bass in the Savannah River. Final Report, Ga. Coop. Fish and Wildlife Research Unit, Warnell School of Forest Resources, Athens, Ga. 30602.
Larger fish seek cool-water refugia in small, spring-fed creeks and in the tailwaters of the NSBL&D. Smaller fish were located in the estuary in the late winter and early spring and throughout the river in the summer and fall (Mooneyhan and Van den Avyle, 1995).

Morgan, R.P., V.J. Rasin, Jr., and R.L. Coop. 1981. Temperature and salinity effects on development of striped bass eggs and larvae. Transactions of the American Fisheries Society. 110: 95-99.

Manooch, C.S. III., and R. A. Rulifson, editors. 1989. Roanoke River Water Flow Committee Report: a recommended water flow regime for the Roanoke River, North Carolina, to benefit striped bass and other below-dam resources and users. NOAA (National Oceanic and Atmospheric Administration) Technical Memorandum NMFS (National Marine Fisheries Service), SEFC (Southeast Fisheries Center) 216, Beaufort, North Carolina.

Reinert, T.R., K.L. Jefferson, and C.A. Jennings. 1998. Abundance and distribution of striped bass eggs and larvae in the Savannah River estuary-Implications for channel dredging window, 1996-1998. Final Report, U.S. Army Corps of Engineers Savannah District. USGS, Biological Resources Division, Georgia Cooperative Fish and Wildlife Research Unit, Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, Ga. 30602.
Objectives of this study were to determine the temporal and spatial distribution of striped bass spawning in the S.R. estuary, the abundance of eggs in the estuary, and to evaluate the spatial and temporal location of salinity levels harmful or lethal to striped bass ichthyoplankton. The amount of suitable hatchling and rearing habitat for striped bass eggs and larvae were measured under high (>27,000 cfs) and low (~5700 cfs) river flows. Under high flow conditions: The Back River was suitable throughout the observed stations (upriver of the Tide Gate). Suitable salinity existed in at least half of the water column as far down the Front River as the Talmadge Bridge (river mile 14.9), but below that, salinity quickly became toxic. All of the

Middle River was considered suitable. Under low flow conditions: Portions of the Back River (up to 6.5 miles upriver of the Front River confluence) became unsuitable for striped bass eggs and larvae. Most of the Middle River except for the lowest reaches were suitable. The Front River had mostly toxic levels up to the Hoolihan Bridge (river mile 21.5). These flow levels are unlikely during the striped bass spawning season but serve as a 'worst-case scenario'.

Reinert, T.R., J. Wallin, and M.J. Van Den Avyle. 1996. Abundance and distribution of striped bass eggs and larvae in the Savannah River estuary-Implications for channel dredging window, 1994-1996. Final Report, U.S. Army Corps of Engineers Savannah District. Georgia Cooperative Fish and Wildlife Research Unit, Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, Ga. 30602.
The general objectives of this study were to determine the timing of striped bass spawning, define the spatial distribution of eggs and larvae, and examine how water-mass transport affects distribution of spawned eggs throughout the estuary. Most eggs (86%) were collected in the upper Front River (river miles 24-31). Most eggs (99.5%) were captured from March 23 to May 10 each year. Based on float study results, eggs spawned in the upriver areas (river miles 24-31) would be jeopardized by rapid transport to the harbor area, where they could be exposed to dredging and maintenance activities and areas of high salinity. Conversely, eggs spawned in the Back River area (Back River miles 10 and above) would, during periods of low river discharge, remain in the Back River.

Rulifson, R. A. and C. S. Manooch III. 1990. Recruitment of Juvenile Striped Bass in the Roanoke River, North Carolina, as Related to Reservoir Discharge. North American Journal of Fisheries Management. 10: 397-407.
Juvenile abundance index (JAI) values for young-of-year striped bass in Abermarle Sound (1955-1987) were compared to preimpoundment and post-impoundment flows of the Roanoke River during the spawning season. Recruitment was best (JAI > 5.0) for years in which river flows were low to moderate (5,000-11,000 ft3/s) and was poor (JAI < 5.0) when flows were very low (3.900-8,100 ft3/s) or high (10,000 ft3/s or greater) during spawning season. Additionally, the average flow pattern for good recruitment years (JAI > 5.0) most closely resembled preimpoundment flow conditions. Preimpoundment flow patterns were used to develop a recommended flow regime for the lower river.

Secor, D.H., T.E. Gunderson, and K. Karlsson. 2000. Effect of temperature and salinity on growth performance in anadromous (Chesapeake Bay) and nonanadromous (Santee-Cooper) strains of striped bass *Morone saxatilis*. Copeia. 2000, 291-296.
Growth rates of striped bass *Morone saxatilis* were compared between anadromous (Chesapeake Bay) and nonanadromous (Santee-Cooper) stocks. Early growth rates are probably inversely related to latitude. Growth rates for both stocks at given temperatures and salinities are provided.

Stevens, D.E. 1977. Striped bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 106: 34-42.

Turner, J. L., and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, Morone saxatilis, in relation to river flow in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society. 101: 442-452.

U.S. Army Corps of Engineers. 2002. Current status of information on striped bass in the Savannah River Estuary

This document provides a thorough review of Savannah River striped bass studies. Egg density, abundance, and transport, stocking programs, reproductive status, distribution, and water quality related to striped bass are all considered.

Van Den Avyle, M.J., and M.A. Maynard. 1994. Effects of saltwater intrusion and flow diversion on reproductive success of striped bass in the Savannah River Estuary. Transactions of the American Fisheries Society. 123, 886-903.

Striped bass *Morone saxatilis* reproduction following recruitment failure was studied in the late 1980's. Their study suggests that egg and larval dispersal and transport to areas with harmful salinity levels was responsible for reproduction failure. Maintenance of freshwater on the spawning grounds and prevention of rapid flushing of eggs and larvae into saline areas may restore reproduction conditions. Discussion section presents the following historic flow/salinity information from Pearlstine et al. (1990) : At a discharge of 170 m3/sec., the salt wedge extended upriver only to about km 32, whereas in the 1980's, the salt wedge extended to km 37 without tidegate operation and with discharges of 165-180 m3/sec. (Pearlstine 1990). Under average tidal conditions, salinity at km 38 of the Savannah River exceeded 0.5 ppt. When flow was less than 230 m3/sec. and the tide gate was operating (Pearlstine et al. 1990). VanDenAvyle recommends managing salinity at the estuarine spawning grounds by regulation of water releases from J. Strom Thurmond Dam, and mentions that freshwater conditions needed for spawning could probably be assured by maintaining flows above 230 m3/sec. He does however, note concern over possible acceleration of egg and larval transport downstream to harmful salinities.

Van Den Avyle, M.J., M.A. Maynard, R.C. Klinger, and V.S. Blazer. 1990. Effects of Savannah Harbor development on fishery resources associated with the Savannah National Wildlife Refuge. Final Report. U.S. Fish and Wildlife Service, Atlanta, GA. 169 pp.

Van den Avyle, M.J., Wallin, J.E., and C. Hall. 1995. Restoration of the Savannah River striped bass population. Uses and Effects of Cultured Fishes in Aquatic Ecosystems., American Fisheries Society, Bethesda, Md. 15: 572.

Wallin, J., M.J. Van Den Avyle, and T. Sinclair. 1995. Juvenile striped bass nursery habitat and abundance index in the lower Savannah River. Final report. Georgia Department of Natural Resources, Atlanta, GA. 61pp.

Will, T.A., T.R. Reinert, and C.A. Jennings. 2000. Assessment of the reproductive status of striped bass, Morone saxatilis, in the Savannah River Estuary, 1999-2000, Final Report, U.S. Army Corps of Engineers Savannah District. USGS, Biological Resources Division, Ga. Coop. Fish and Wildlife Res. Unit, Warnell School of Forest Resources, Athens, Ga. 30602.

Ultrasonic imaging data was used to predict total fecundity. Maturational status was believed to be progressing normally. Environmental cues needed for spawning seemed to be sufficient to allow the development and release of striped bass oocytes into the Savannah River Estuary.

Will, T.A., T.R. Reinert, and C.A. Jennings. 2002. Maturation and fecundity of a stock-enhanced population of striped bass in the Savannah River Estuary, U.S.A. Journal of Fish Biology. 60, 532-544.

A recent study on striped bass *Morone saxatilis* in the Savannah River Estuary indicate that maturation appears to be progressing normally and spawning is occurring. Cues necessary for oocyte development and release are present. Study suggests a time lag of 8-10 years for post-stocking recovery (Will et al., 2002).

Winger, P.V., and P.J. Lasier. 1994. Effects of salinity on striped bass eggs and larvae from the Savannah River, Georgia. Transactions of the American Fisheries Society. 123, 904-912.

The effects of varying salinities on stripped bass eggs and larvae was studied. Egg mortality occurs in salinities greater than 18%. Survival and length of larvae is reduced in 15% salinity. The 10 day LC50 for 2 day old post hatch larvae was 10%. Salinities over 9% are judged to be critical to S. R. striped bass eggs and larvae.

Robust Redhorse

Dilts, W.D. 1999. Effects of fine sediment and gravel quality on survival to emergence of larval robust redhorse *Moxostoma robustum*. Masters Thesis. The University of Georgia.

Survival to emergence (STE) of robust redhorse was inversely related to percent fine sediment in laboratory studies. Treatments containing <25% fine sediment probably caused larval entrapment and treatments >50% probably depressed dissolved oxygen. Because sedimentation is related to flow, both should be considered in flow recommendations for the robust redhorse.

ENTRIX, Inc. 2002a. Protected Species Resource Report for the Augusta Canal Hydropower Project-Appendix A. Special concern animals list from GADNR. FERC No. 11810

Freeman, B.J. and M.C. Freeman. 2001. Criteria for Suitable Spawning Habitat for the Robust Redhorse *Moxostoma robustum*. A Report to the U.S. Fish and Wildlife Service, January 2001.

Robust redhorse data were collected over several years in the Savannah River to determine habitat suitability criteria. Criteria for spawning habitat are water depth of .29-1.1m, velocity of .26-.67 m/s, and substrate of coarse gravel.

Ruetz, C.R. III., and C.A. Jennings. 2000. Swimming performance of larval robust redhorse *Moxostoma robustum* and low-velocity habitat modeling in the Oconee River, Georgia. Transactions of the American Fisheries Society. 129, 398-407.

Larval robust redhorse *Moxostoma robustum* were tested to see if they could tolerate water velocities commonly found during hydropower generation in the Oconee River. They concluded that low-velocity habitats were available in the Oconee River, but they were dynamic during fluctuating discharge. The ability of these fish to access these areas, either through lateral or downstream movement, is unknown

and this may contribute to the population decline in the Oconee River. This paper also gives a brief review of related flow-habitat-species papers.

Walsh, S.J., D.C. Haney, C.M. Timmerman, and R.M. Dorazio. 1998. Physiological tolerances of juvenile robust redhorse, *Moxostoma robustum*: conservation implications for an imperiled species. Environmental Biology of Fishes. 51, 429-444.

Mean lower temperature tolerances range between 5.3C and 19.4 C, depending on prior thermal acclimation. Mean critical thermal maxima ranged between 34.9-37.2 C and was dependent on prior thermal conditioning. This paper may be useful in relating Savannah River temperatures and DO requirements to early life intervals of the robust redhorse.

Weyers, R.S., C.A. Jennings, M.C. Freeman. Effects of pulsed, high-velocity water flow on larval robust redhorse and v-lip redhorse. Transactions of the American Fisheries Society. In Press.

This laboratory experiment demonstrated that pulsed flows impede larve swim-up ability and gas bladder inflation. Growth rates were higher in more stable conditions. This paper also emphasized the point suitable habitats should not just simply exist during early life stages, but habitat must be accessible to these fish.

Habitat, Flow, and Other Fish

Aadland, L.P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management. 790-806.

Habitat preferences for over 70 species of fishes were studied, summarized, and divided into habitat guilds. Although studies were based on six MN streams, velocity and depth preferences, habitat strategy, and habitat consistency are probably applicable, with varying degrees, to the Savannah River. Preferences are also divided by life stage.

Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. Ecology. 69, 382-392.

Fish assemblages were compared in an unregulated and a regulated river in Vermont. The guild of fish that occur in shallow, slow habitat had higher densities in the unregulated West River. Fewer species that inhabit shallow, slow habitats were found as proximity to the dam decreased. American eel (130-670 mm), small-mouth bass, and other habitat generalists associated with deep fast portions of rivers showed an increase in species richness with an increase in flow fluctuations. They theorize that rapid decreases in flow threaten fish not able to move with the receding shoreline. Rapid flows may expose fish to increased predation. Results suggest that extreme flow fluctuation impose functional habitat homogeneity.

Bowen ZH, M.C. Freeman, and K.D. Bovee. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. Transactions of the American Fisheries Society. 127, 455-468.

Hydropeaking reduced the persistence of shallow water habitats and year to year variation in persistence. Cyprinids are positively correlated with availability of deep-fast habitats, Catostomids with shallow slow in spring, Percids negatively with deep fast, and fish density positively with shallow slow. Annual variation in key-habitat availablity is important for maintaining diverse assemblages. Excellent study that should be reviewed in more detail.

ENTRIX, Inc. 2002b. Savannah River Instream Flow Study for the Augusta Canal Hydropower Project. FERC No. 11810, September 2002.
This is particularly useful in that it used hydraulic modeling and the PHABSIM model to relate flow conditions to usable area for a variety of species, including anadromous species and the robust redhorse *Moxostoma robustum*, at various life stages. Duration of habitat persistence for various flows and species was evaluated as well as the effects of low flows on recreational boating in the shoals.

Freeman, M. C., Z. H. Bowen, K. D. Bovee, E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications. 11, 179-190.
The availability, persistence, and seasonal timing of nursery habitats largely determines YOY abundance for any given species. Habitat persistence was reduced by flow fluctuations resulting from pulsed water releases for hydropower generation on the Tallapoosa River. Shallow water habitat persistence and availability in the regulated site was highest in the summers of 1995 and 1996, which corresponded to higher abundance of YOY from summer spawners.

Kinsolving, A.D., and M. B. Bain. 1993. Fish assemblage recovery along a riverine disturbance gradient. Ecological Applications. 3, 531-544.
Kinsolving and Bain (1993) investigated whether a spatial recovery gradient in fish assemblage structure existed below a hydropower dam and if recovery could be identified by the presence and abundance of fluvial specialists. They compared an unregulated river (Cahaba River, AL) to a regulated river (Tallapoosa River below Thurlow dam, AL) and determined that fish abundance and species distribution was highly variable on the Tallapoosa River, habitat generalists abundance did not change as a function of river section, and fluvial specialists increased abundance with decreasing proximity to the dam. They cited several sources by which they determined which species were generalists and fluvial specialists.

Marchetti, M.P., and P.B. Moyle. 2001. Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications. 11, 530-539.
Altered flow regimes from dams on Putah Creek, CA have created a compression of the natural longitudinal gradient of physical and ecological factors within the stream, consequently compressing fish assemblages into narrow zones. In this study, there were large differences in community response between wet and dry years, especially for native and nonnative species.

Parasiewicz, P., S. Schmutz, and O. Moog. 1998. The effect of managed hydropower peaking on the physical habitat, benthos, and fish fauna in the River Bregenzerach in Austria. Fisheries Management and Ecology. 5, 403-417.
Mitigation measures were developed that reduced the adverse effects of hydropower peaking in an Austrian river (Parasiewicz et al., 1998). Although benthic biomass showed significant recovery, fish biomass did not improve, possibly as a result of the unaltered ramping rate of the acceleration phase. Shallow, littoral areas, which were often unavailable to fish, were subjected to rapid reductions in depth, possibly stranding fish.

Scheidegger, K.J., and M.B. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia. 1995, 125-135.
Microhabitat attributes and fish larval assemblages were measured in flow regulated sites on the Tallapoosa River and an unregulated site on the Cahaba River. Maximum current velocity for each nursery area sampled was 8.4 cm/sec (i.e. 7 body lengths times 12 mm long larvae). Cahaba river produced a majority of the larvae and near shore samples produced more larvae that offshore (drift). Larvae abundance and diversity increased with decreasing proximity to Thurlow Dam in the Tallapoosa River. Cyprinids were most often found in near-shore samples. Means and ranges of microhabitat attributes (flow, depth, velocity substrate, etc) are provided in tables for study areas for Catostomidae, Cyprinidae, Centrarchidae, Percidae, Fundulidae, Poeciliidae, and Clupeidae.

Schlosser, I.J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. Ecology. 66, 1484-1490.
Abundance of juvenile fish and assemblage structure was studied and related to varying interannual flow regimes. High stream discharge had little influence on juvenile northern hogsuckers *Hypentilium nigricans* and several darter species *Etheostoma spp.* Large increases in juvenile abundance were observed for bluegill Lepomis macrochirus and various cyprinids including the striped shiner *Notropis chrysocephalus* and bluntnose minnow *Pimephales notatus* when spring and early summer flows were lower and more stable. Animals with prolonged breeding seasons (minnows) showed great intraannual increases in juvenile abundance

Taylor, C.M., and M.L. Warren, Jr. 2001. Dynamics in species comosition of stream fish assemblages: Environmental variability and nested subsets. Ecology. 82, 2320-2330.
Both immigration and extinction rates are highly associated with mean abundance. They cite that variation in flow regime is the predominant natural disturbance that can alter stream community structure.

Travnichek, V. H., M. B. Bain, and M. J. Maceina. 1995. Recovery of a warmwater fish assemblage after the initiation of a minimum-flow release downstream from a hydroelectric dam. Transactions of the American Fisheries Society. 124, 836-844.
Initiation of a minimum flow release increased species richness and fluvial specialist richness below Thurlow Dam on the Tallapoosa River, AL. However, community response was not as great farther down the river, but more fluvial specialists were collected after flow enhancement. Frequency of flow fluctuations did not change, but magnitude of flow fluctuations did. Similar to Kinsolving and Bain (1993), they found that a longitudinal recovery gradient did exist.

van Snik Gray, E., J.R. Stauffer, Jr. 1999. Comparative microhabitat use of ecologically similar benthic fishes. Environmental Biology of Fishes. 56, 443-453.
Microhabitat use was compared for three benthic fishes in Pennsylvania. The tessellated darter *Etheostoma olmstedi* occcupied deeper water and adult and YOY *Cottus bairdi* and *cognatus* occupied faster, shallower water. A more detailed description of habitat preferences, including flow, depth, and substrate size, is provided.

Mussels

ENTRIX, Inc. 2002c. Protected Species Resource Report for the Augusta Canal Hydropower Project. Appendix C- Mussel observations. FERC No. 11810-000

Fuller, S.L.H. 1971. A brief field guide to the freshwater mussels (Mollusca: Bivalvia: Unionacea) of the Savannah River System. ASB Bulletin 24(2): 52.

Thomas, R.L., S.L.H. Fuller, R.W. Bouchard, J.W. Littrell, P.F. Overbeck, and R.W. Bouchard, Jr. 2001. A fifty-year history of the mussel fauna of the Savannah River in the vicinity of the U.S. Department of Energy Savannah River Site, Goergia and South Carolina. (Abstract) North American Benthological Society NABStracts. [abstract available at http://www.benthos.org/database/allnabstracts.cfm/db/lacrosse2001abstracts/id/498]

Mussel surveys near the Savannah River Site have been taking place since the 1950's. They note numerous mussel species and changes in the mussel community with time. Numbers for several species have increased and decreased, but *Lampsilis cariosa* has probably had the most significant decline since 1972.

Floodplain fish

Bain, M.B., and J.M. Boltz. 1989. Importance of floodplain wetlands to riverine fish diversity and production: study plan and hypothesis. Report prepared by Alabama Cooperative Fish and Wildlife Research Unit for National Ecology Research Center, U.S. Fish and Wildlife Service, Auburn University, AL.

Baker, J.A., K.J. Killgore, and R.L. Kasul. 1991. Aquatic habitats and fish communities in the lower Mississippi River. Reviews in Aquatic Sciences. 3, 313-356.

This paper synthesizes fish collections from a large number of floodplain studies and presents species distribution and relative abundance in each habitat. This paper will be valuable in comparing floodplain fish fauna to oxbow fauna. It may justify using oxbow fish collections from the Fisheries Survey of the Savannah River to describe Savannah River floodplain fish.

Benke, A.C., I. Chaubey, G.M. Ward, and E.L. Dunn. 2000. Floodpulse dynamics of an unregulated river floodplain in the Southeastern U.S. Coastal Plain. Ecology. 81, 2730-2741.

Finger, T.R., and E.M. Stewart. 1987. Response of fishes to flooding regime in lowland hardwood wetlands. Pages 86-92. in W.J. Matthews and D.C. Heins, eds. Community and ecolutionary ecology of North American stream fishes. University of Oklahoma Press.

In a Missouri floodplain dominated by hardwood habitats, flooding was delayed in 1981 but inundation was continual and widespread. In 1982, however, winter rains caused floodplain inundation, but water levels receded earlier than in 1981. Changes in species assemblages appear to be related to the timing of flooding and spawning season for each species (early-mid-spring spawners [E. zonatum and C. macropterus] vs. late-spring to summer spawners [*Fundulus dispar and G. affinis*]. Duration of flooding is tied to reproductive success. Some late spawning species such *as F. dispar* and *G. affinis*, take advantage of nutrient rich early spring flooded areas, thus increasing energy available for spawning and resulting in higher reproductive

success. Continual inundation of a neighboring floodplain had a much different composition, favoring *M. salmoides* and *I. nebulosus*. A list of species and CPUE are available.

Schmidt, D.N., and J.H. Hornsby. 1985. A fisheries survey of the Savannah River. Georgia Department of Natural Resources, Game and Fish Division, Atlanta, Georgia. Federal Aid in Fish Restoration Acts, Dingell- Johnson Project F-30.
This report summarizes probably the most intensive sampling conducted in the Savannah River floodplain. Flowing and static oxbows as well freshwater tidal oxbows were sampled with rotenone. Fishing pressure was highest in oxbows compared to the mainstem. This study can probably be used to characterize Savannah River floodplain fish.

Guillory, V. 1979. Utilization of an inundated floodplain by Mississippi River fishes. Florida Scientist. 42, 222-228.
This study examines the seasonal occurrence of fish to the seasonal inundation of floodplain habitat along the Mississippi River. It notes which species were observed as YOY or adults in spawning condition. It also cites several sources that indicate that fish production is related to the extent of inundation.

Killgore, K.J., and J.A. Baker. 1996. Patterns of larval fish abundance in a bottomland hardwood wetland. Wetlands. 16, 288-295.
Larval fishes were collected over two years in the channel and floodplain of the Cache River, Arkansas. Large catches corresponded to high floodplain water levels through the winter and spring, compared to that of the previous year when levels were high only in the winter. Habitat use and characteristics were assessed. Seasonal abundance of larval fish is presented by family and habitat type. All species were flood exploitative species with the exception of one quiescent group, suckers. Abundance increases with decreasing proximity to the main channel, especially during the period of prolonged inundation (1989).

Kwak, T.J. 1988. Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois. The American Midland Naturalist. 120, 241-249.
As water level dropped in an ephemeral ditch nearby the Kankakee River, fish migrated out and crawfish migrated into the ditch. Lateral migration to floodplains is probably seasonal and unlikely the result of daily patterns as evidenced by recapture data. Number of fish trapped per day is significantly correlated with river discharge and declines exponentially with decreasing discharge. This study also lends evidence to support the significance of floodplains as nursery areas.

Light, H.M., M.R. Darst, and J.W. Grubbs. 1998. Aquatic habitats in relation to river flow in the Apalachicola River floodplain, FL. U.S. Geological Survey Professional Paper 1594.
A good review of floodplain habitats and the changes in quantity and type of floodplain habitat in relation to Apalachicola River flow is provided. Aquatic floodplain habitat connected to the main river is related to sill elevation and pre- and post-entrenchment conditions. A literature review of eastern U.S. floodplain fishes is also provided.

Light, H.M., M.R. Darst, and J.W. Grubbs. 1995. Hydrologic conditions, habitat characteristics, and occurrence of fishes in the Apalachicola River Floodplain, Florida: Second Annual Report of Progress, October 1993- September 1994. U.S. Geological Survey, Open-File Report 95-167.

Paller, M.H. 1987. Distribution of larval fish between macrophyte beds and open channels in a southeastern floodplain swamp. Journal of Freshwater Ecology. 4, 191-200.

Larval fish distribution in macrophyte beds and open channels in a floodplain swamp of the Savannah River system was investigated. Although all life stages occurred here, a number of species use macrophyte beds heavily as nursery areas. The occurrence of nearly 20 species in this area is described here as using these habitats, as well as diel changes in drift and reasons for the occurrence of drift for several species.

Paller, M.H., and B.M. Saul. 1996. Effects of temperature gradients resulting from reservoir discharge on *Dorosoma cepedianum* spawning in the Savannah River. Environmental Biology of Fishes. 45, 151-160.

Floodplain swamp water levels were high in April, 1983 and low by May 1983 as a result of releases from Thurmond Dam (see floodplain inundation in fig 6. Note that this is the same source that is cited in the shad section.

Ross, S.T., and J.A. Baker. 1983. The response of fishes to periodic spring floods in a Southeastern stream. The American Midland Naturalist. 109, 1-14.

In a comparison of a Mississippi floodplain and main channel, fish were grouped as either flood quiescent or exploitative. Both adults and juveniles used the floodplain (see Table 1). There is a significant relationship between high stream discharge and exploitative species (*Notropis texanus*), but no relationship could be found for quiescent species (Percina nigrofasciata). The floodplain provides a nursery area for juvenile fishes, especially centrarchids. Nutrient availability through floodplain inundation may increase energy available for reproduction when energy demands of gonadal development and rising water temperatures are increasing.

Turner, T.F., J.C. Trexler, G.L. Miller, and K.E. Toyer. 1994. Temporal and spatial dynamics of larval and juvenile fish abundance in a temperate floodplain river. Copeia. 1994, 174-183.

Floodplains are important nursery areas for a wide variety of fishes. In the regulated Tallahatchie River, MS, floodplains became inundated in the late winter-early spring. Larval, juvenile, YOY, and adult fish were collected in slough, low flow tributary, moderate flow tributary, and main channel habitats. Two peaks in larval fish recruitment were observed in all locations, the first around mid May and the second in mid July to August. Relative abundance and peak abundance dates are provided for a wide range of fish and life stage. Early spring spawners, such as gizzard shad, crappie, and darters were dominant from spring to midsummer and then abruptly disappeared. Temperature probably plays a role in abundance, but temperature is related to flow regime. Mid- late summer spawners, like sunfish and shiners, were on the floodplain from May to October. More larval and juvenile fishes were collected in the floodplain than in the river channel. A number of potentially useful sources are cited.

Ward, J.V., and J.A. Stanford. 1995. The serial discontinuity concept: extending the model to floodplain rivers. Regulated Rivers. 10, 159-168.

The serial discontinuity concept (SDC) was originally applied along a longitudinal profile but later incorporated the lateral dimension of floodplains. The SDC conceptually explains how impoundments disrupt biotic and abiotic processes, the degree of which is dependent upon dam position on a river profile. Plankton, substrate size, nutrient availability/spiraling, environmental heterogeneity, and biodiversity are all considered. This source cites several other potentially useful sources.

Ward, J.V., K. Ockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regulated Rivers: Research and Management. 15, 125-139.

Zalumi, S.G. 1970. The fish fauna of the lower reaches of the Dnieper: its present composition and some features of its formation under conditions of regulated and reduced river discharge. Journal of Ichthyology. 12, 249-259.

Estuarine biota

Collins, M.R., B.M. Callahan, and W.C. Post. 2001. Spawning Aggregations of Recreationally Important Sciaenid Species in the Savannah Harbor: Spotted Seatrout *Cynoscion nebulosus*, Red Drum *Sciaenops ocellatus*, Weakfish *Cynoscion regalis*, and Black Drum *Pogonias cromis*. Ga. Port Authority Website.
The purpose of this study was to determine if, where, and when spawning of these species occurred in areas where the proposed harbor expansion and maintenance activities would take place. Six large spawning aggregations of spotted seatrout, one of weakfish, and one of black drum were located. Although large aggregations of red drum were not located, individuals were located in the mouth of the river and plankton tow captures of red drum indicate these fish do spawn in the Savannah River estuarine system. This study may be found at the following web address: http://www.sysconn.com/harbor/#Sci

Ingram, R.G., B.F. D'Anglejan, S. Lepage, and D. Messier. 1986. Changes in current regime and turbidity in response to a freshwater pulse in the Eastmain Estuary. Estuaries. 9 (4B): 320-325.

Jones, K. K., C.A. Simenstad, D.L. Higley, and D. L. Bottom. 1990. Community structure, distribution, and standing stock of benthos, epibenthos, and plankton in the Columbia River Estuary. Progress in Oceanography. 25 (1-4): 211-241.

Jennings et al. 2002. Temporal and Spatial Distribution of Estuarine-Dependent Species in the Savannah River Estuary (First Year Report). Ga. Port Authority Website.
This study focused on quantifying the temporal and spatial distribution of fish species that use the main channel, marsh-edge, and tidal creek habitat in the Savannah River estuary in different salinity zones. This study may be found at the following web address: http://www.sysconn.com/harbor/#Sci (Savannah Harbor expansion website).

Lamar, W.L. 1940. Salinity of the lower Savannah River in relation to stream flow and tidal action. Transactions, American Geophysical Union. 21: 463-470.
Haven't located this paper. However, some of the historic information in this paper is presented in (Van Den Avyle, 1994).

Latham, P.J., L.G. Pearlstine, and W. M. Kitchens. 1993. Species association changes across a gradient of fresh, oligohaline, and mesohaline tidal marshes along the lower Savannah River. Wetlands. 14 (3): 174-178.

Latham, P.J., and W.M. Kitchens. 1996. Changes in vegetation and interstitial salinities in the lower Savannah River: 1986-1994. Final Report. U.S. Fish and Wildlife Service, Charleston, SC. 16pp.

Liu, R., F. Xu, D. Sun, Y. Cui, and H. Wang. 1992. Benthic fauna in the Changjiang River estuary and prediction of the influence on the Three Gorges Project on it. Studia marina sinica/ Haiyang Kexue Jikan. 33: 237-247.

Mao, Z. and H. Shen. 1994. Effects of freshwater discharge at the Datong Station on saltwater intrusion in the South Channel of the Changjiang Estuary. Marine Sciences. 2: 60-63.

Pearlstine, L., P. Latham, W. Kitchens, and R. Bartelson. 1990. Development and application of a habitat succession model for the wetland complex of the Savannah National Wildlife Refuge, volume 2. Final report. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville.

Pearlstine, L. G., W.M. Kitchens, P.J. Latham, and R. D. Bartleson. 1993. Tide Gate Influences on a Tidal Marsh. Water Resources Bulletin. 29 (6): 1009-10019.
This study discusses changes in salinities associated with operation of the tide gate. Influences of tide gate operation on the marsh were modeled in a GIS. With the tide gate out of operation, the model predicts that freshwater marsh would increase by 340%.

Pearlstine, L.G., W.M. Kitchens, and P. Latham. 1993. Modeling tidal marsh succession in the coastal Savannah River, Ga. In: Landin, M. C., ed. Wetlands: Proceedings of the 13th Annual Conference of the Society of Wetlands Scientists, New Orleans, LA. Utica, MS.

Rozas, L.P. 1995. Hydroperiod and its influence on nekton use of the salt marsh: A pulsing ecosystem. Pages 579-590 in Pulsed Ecosystems: A New Paradigm? Proceedings Of A Symposium Held in Hilton Head, November 1993. Estuaries. 18: (4).

Strydom, N.A., A.K. Whitfield, and A.W. Patterson. 2002. Influence of altered freshwater flow regimes on abundance of larval and juvenile Gilchristella aestuaria (Pisces : Clupeidae) in the upper reaches of two South African estuaries. Marine And Freshwater Research. 53 (2): 431-438.

General Information Sources

ALDEN Research Laboratory, Inc. 2002. Fish passage and protection plan for the Augusta Canal hydropower project. FERC Project No. 11810-000.
This source evaluates various upstream and downstream fish passage alternatives exclusively for anadromous species. It also describes water quantity use by the city, pumping station, and hydropower facilities as well as fish entrainment at those facilities. The composition of species (40 species) netted at the King Mill Hydropower Plant is similar to the list found in the Fisheries report (ENTRIX, 2002d).

Applied Technology and Management, Inc. (ATM). 2000. Hydrodynamic and Water Quality Monitoring of the Lower Savannah River Estuary, Aug. 2nd- Oct. 9th, 1999. Report to Ga. Ports Authority
This project may be found at the following web address:
http://www.nwrc.usgs.gov/wdb/pub/hsi/hsi-001.pdf

Barwick, D.H. and J.L. Oliver. 1982. Fish Distribution and Abundance below a Southeastern hydropower dam. Proceedings of the 36th annual conference: Southeastern association of fish and wildlife agencies. Vol. 36: 135-145.

Brown, J.D., E.M. EuDaly, and J.P. Davis. 1987. An innovative analysis of port development impacts on a coastal National Wildlife Refuge. Pages 2269-2281 in Coastal zone'87. American Society of Civil Engineers, Seattle, Washington.

Dames and Moore, Inc. 1991. Stevens Creek hydroelectric project: environmental report. Final Exhibit E, Sections 1-8.

ECS (Environmental and Chemical Sciences, Inc.). 1984. A Survey of Adult Fish and Icthyoplankton of the Savannah River and Augusta Canal in the Vicinity of a Proposed Hydroelectric Plant. Prepared for the City of Augusta.

ENTRIX, Inc. 2002d. Fisheries Resource Report for the Augusta Canal Hydropower Project. FERC No. 11810, March 2002.
ENTRIX prepared a series of reports related to the Augusta Canal hydropower projects in partial fulfillment of the Federal Energy Regulatory Commission's (FERC) requirements for a new license. A detailed map depicting the Augusta Canal project and a list of 77 species that are found in the Savannah River near the canal and the Augusta Canal. The Fisheries report describes the species composition and habitat of both and a description of how the project is operated.

ENTRIX, Inc. 2002e. Water Use and Quality Resource Study Report. Augusta Canal Hydropower Project (FERC No. 11810).
It includes a river map from New Savannah Bluff Lock and Dam (RM 187) to Thurmond Dam (RM 221; Fig 1-2), a description of the USGS streamflow gages and their period of record (Table 2-1). It provides an analysis of streamflow over the diversion dam, into the canal, and below the confluence of the canal and river at NSBL&D.

GADNR. 2001. Savannah River Basin Management Plan.
www.dnr.state.ga.us/environ/plans_files/plans/savannah-pdf/savannah.pdf.
Point source discharge locations, a list of NPDES permits, water quality and water quantity assessments, land use by HUC, land cover statistics, Georgia water quality standards, and a fish list is provided for the entire Savannah River Basin.

Georgia Game and Fish. 1966. Savannah River Fish Population Studies, June and October 1966 (unpublished)

Osteen, D., J. O'Hara, and D. Hughes. 1984. A survey of adult fish and ichthyoplankton of the Savannah River and Augusta Canal in the vicinity of a proposed hydroelectric plant. Environmental and Chemical Sciences, Inc., Report prepared for the City of Augusta.

Parasiewicz, P. 2001. MesoHABSIM: A concept for application of instream flow models in river restoration planning. Fisheries. 26, 6-13.
The benefits of applying habitat modeling for a river reach at a meso scale (MesoHABSIM) rather than a micro scale is described. Larger spatial units of

habitat and fish measurements are probably more relevant and practical to large-scale management objectives.

Paller, M., J. O'Hara, V. Osteen, W. Specht, and J. Kania. 1984. Annual report on the Savannah River Aquatic Ecology Program, Sept. 1982- Aug. 1983. Volume 1. Environmental and Chemical Sciences, Inc., Aiken, S.C. ECS-SR-8-Vol.1. 275pp.

Paller, M.H., J. O'Hara, and D.V. Osteen. 1985. Annual report on the Savannah River Aquatic Ecology Program, Sept. 1983- Aug. 1984. Volume 2. Environmental and Chemical Sciences, Inc., Aiken, S.C. DPST-85-377, , 1985, 186pp.

Paller, M. 1990. Entrainment sampling at the Savannah River Site (SRS) Savannah River water intakes. (Couldn't locate this one except in Galileo-Aquatic Sciences and Fisheries Abstracts)

This paper presents an improved ichthyoplankton sampling plan designed to assess entrainment at the Savannah River Site intake canals and determine the percentages of ichthyoplankton removed from the Savannah River.

Quintrell, R.D. 1980. Effects of hypolimnial oxygenation on the fish populations and the water chemistry of the Clark Hill Reservoir tailwaters. Masters Thesis. University of Georgia. Athens, GA.

Quintrell's work focused primarily on examining the effects of oxygenation on tailwater fish populations below Clark Hill reservoir over a two-year span. He provides a list of 35 species, a description of the stratification in Clark Hill, a brief description of the reach below Clark Hill to Stevens Creek Reservoir, and the gradual reoxygenation that occurs downstream.

Smith, L.D. 1968. Notes on the Distribution, Relative Abundance and growth of Juvenile Anadromous Fish in the Altamaha River System Georgia with Specific Reference to Striped Bass. Georgia Game and Fish Commission. Sport Fisheries Division. Brunswick, Georgia. [summary available at sysconn.com].

Stickney, R.R., and D. Miller. 1974. Chemistry and Biology of Lower Savannah River. Journal of Water Pollution Control Federation. 46 (10): 2316-2326.

U.S. Army Corps of Engineers. 1982. Savannah harbor investigation: results from the tide gate operation study. COE, Savannah District, Savannah, Georgia.

U.S. Army Corps of Engineers. 2001. Draft Addendum and Draft Finding of No Significant Impact for New Savannah Bluff Lock and Dam Project, Savannah River, Georgia and South Carolina, Section 216 Disposition Report, May 2001.

U.S. Fish and Wildlife Service. 2000. Final Fish and Wildlife Coordination Act Report on New Savannah Bluff Lock and Dam Project, Section 216 Disposition Study, September, 2000.

U.S. Fish and Wildlife Service. 2001. Draft Elements of Consensus Relative to Development of a Fish Restoration Plan for the Mid-Savannah River, 1 page.

(4) ESTUARINE PROCESSES

(compiled and annotated by Merryl Alber and Joan Sheldon)

The following references may be useful in determining the relationship of streamflow below Thurmond Dam to characteristics of the Savannah River estuary including transit time of freshwater (and dissolved constituents) through the estuary, salinity zonation as an aspect of estuarine habitat, water quality, and biota. References primarily regarding fish are not included here because they are covered in the previous section.

Background

Flow Alteration

Alber, M. and J. Flory. 2002. The effects of changing freshwater inflow to estuaries: A Georgia perspective. White Paper. Georgia Coastal Research Council, Department of Marine Sciences, University of Georgia, Athens, Georgia.
Keywords: freshwater; inflow; estuary; Georgia; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; river discharge; water quality; salinity; transit time; management; nutrients; suspended solids; fishery; vegetation; policy; withdrawal
Summary: This paper is divided into three parts. Part One provides an overview of the scientific information available regarding the connections between freshwater inflow, estuarine conditions, and resources. Part Two presents a conceptual model for inflow management in terms of the types of regulation available and the societal values that must be considered. In this section we categorize management as inflow-based, condition-based, or resource-based, and use this structure as the basis to explore the differing approaches to estuarine inflow management that have been taken in various parts of the country. In Part Three we apply this perspective to Georgia. We describe the inflow policy currently in place in Georgia's rivers and summarize the scientific efforts being undertaken to understand the impact of changing freshwater flow to Georgia's estuaries.

Ardisson, P.-L. and E. Bourget. 1997. A study of the relationship between freshwater runoff and benthos abundance: a scale-oriented approach. *Estuarine, Coastal and Shelf Science* **45**: 535-545.
Keywords: benthos; abundance; biomass; freshwater; runoff; scaling; St. Lawrence Estuary; Gulf of St. Lawrence; variability; linear regression

Copeland, B. J. 1966. Effects of decreased river flow on estuarine ecology. *Journal Water Pollution Control Federation* **38**(11): 1831-1839.
Keywords: flow; river discharge; estuary; invertebrate; shellfish; primary production; Texas

Dynesius, M. and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* **266**: 753-762.
Keywords: flow; river discharge; management; regulation
Summary: The Savannah River is considered strongly affected by fragmentation and flow regulation. The longest main-channel segment without a dam constitutes less than 50% of the main channel length, and its largest tributary also includes one or more dams. Flow regulation is potentially high because reservoir gross capacity is 96% of the mean unregulated flow.

Flint, R. W. 1985. Long-term estuarine variability and associated biological response. *Estuaries* **8**(2A): 158-169.
Keywords: Corpus Christi Bay; estuary; variability; flood; production; benthos; sediment; nutrients; fishery; salinity; carbon; recycling

Halim, Y. 1991. The impact of human alterations of the hydrological cycle on ocean margins, p. 301-327. *In* Mantoura, R. F. C., J.-M. Martin and R. Wollast (eds.), Ocean Margin Processes in Global Change. John Wiley & Sons, Chichester, England.
Keywords: hydrological cycle; hydrology; dam; diversion; land use; hydropower; vegetation; erosion; siltation; flushing; nutrients; production; fishery; intrusion; salinity; sediment

Livingston, R. J., X. Niu, F. G. Lewis III and G. C. Woodsum. 1997. Freshwater input to a gulf estuary: long-term control of trophic organization. *Ecological Applications* **7**(1): 277-299.
Keywords: freshwater; estuary; inflow; Apalachicola; drought; fish; invertebrate; production; trophic organization
Summary: Propagation of changes in inflow through an ecosystem was observed in Appalachicola River estuary, Florida, where a two-year drought led to an approximately 50% reduction in river flow. This resulted in an initial increase in primary production (due to reduced turbidity), followed by a long-term decrease in production, which may have been due to decreased delivery of nutrients to the estuary. There were also dramatic effects on trophic structure: overall trophic diversity decreased and there were increases in some groups (herbivores, detritivorous omnivores, primary and secondary carnivores) and decreases in others (tertiary predators were virtually absent). The effects of the drought took several years to make their way through the food web of the estuary.

Montagna, P. A., R. D. Kalke and C. Ritter. 2002. Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. *Estuaries* **25**(6B): in press.
Keywords: restoration; freshwater; inflow; macrofauna; meiofauna; invertebrate; Rincon Bayou; diversion
Related papers: Palmer et al., 2002

Palmer, T. A., P. A. Montagna and R. D. Kalke. 2002. Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA. *Estuaries* **25**(6B): in press.
Keywords: restoration; freshwater; inflow; Rincon Bayou
Related papers: Montagna et al., 2002

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. *BioScience* **47**(11): 769-784.
Keywords: river discharge; management; dynamic; master variable; regulation; hydrology; environmental impact
Related papers: Sparks, 1992

Richter, B. D., J. V. Baumgartner, J. Powell and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* **10**: 1163-1174.
Keywords: model; hydrology; disturbance

Sklar, F. H. and J. A. Browder. 1998. Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. *Environmental Management* **22**(4): 547-562.
Keywords: environmental impact; river discharge; management; watershed; estuary; salinity; nutrients; topography; oxygen; policy; spatial overlap; model

Skreslet, S. 1986. Freshwater outflow in relation to space and time dimensions of complex ecological interactions in coastal waters, p. 3-12. *In* Skreslet, S. (ed.) The Role of Freshwater Outflow in Coastal Marine Ecosystems. Springer-Verlag, Berlin.
Keywords: freshwater; outflow; estuary; ecosystem

Sparks, R. E. 1992. Risks of altering the hydrologic regime of large rivers, p. 119-152. *In* Cairns, J., J., B. R. Niederlehner and D. R. Orvos (eds.), Predicting Ecosystem Risk. Princeton Scientific Publishing Co., Princeton, New Jersey.
Keywords: disturbance; ecosystem; flood; floodplain; hydrology; risk analysis
Summary: Factors that affect flow regime include climate, stream order, geological history of the basin, vegetative cover and soil of the drainage basin, groundwater inputs, tidal fluctuations, and dams. Alterations in these factors, such as climate change, land use, and water withdrawals and diversions, carry risks that must be considered in long-term planning. In terms of regulation, the "ideal" flow regime is often defined in terms of a single or limited number of water uses (human uses or species needs), and the needs of many uses may be contradictory. Maintaining a more natural water regime may preserve whole assemblages of species, but natural regimes may be difficult to define because there are virtually no undisturbed large rivers. The naturally fluctuating water regime and the spatial heterogeneity of large river-floodplains are both important to the preservation of species occupying these ecosystems. The species are adapted to a relatively predictable annual cycle in terms of seasonal timing, duration, and rate of rise and fall. Spatial heterogeneity ensures that some portion of the floodplain will meet the requirements for a species during the flood and low flow periods, if not the same location every year.
Related papers: Poff et al., 1997

Ward, G. H., M. J. Irlbeck and P. A. Montagna. 2002. Experimental river diversion for marsh enhancement. *Estuaries* **25**(6B): in press.
Keywords: river discharge; diversion; marsh
Summary: This paper describes a demonstration project done by the U.S. Bureau of Reclamation in the Nueces River in Texas. The Nueces River is the primary source of freshwater inflow to Corpus Christi Bay and virtually the only source of freshwater inflow to the Nueces Delta. Reservoir development and operation in the Nueces Basin has greatly reduced freshwater inflow to the Delta, causing increased salt concentrations in the soil and water. The Bureau excavated two overflow channels, significantly lowering the minimum threshold for flooding to the upper Delta without having to increase total flow through the main channel. As a consequence of the excavation, the amount of freshwater diverted to the upper Nueces Delta increased by a factor of seven and average salinity was greatly decreased, leading to a corresponding improvement in abundance and diversity of both intertidal vegetation and benthic communities. This study demonstrates that small changes in overflow can result in large changes in local salinity, and exploiting this might be an effective management strategy.

Flow Optimization

Aleem, A. A. 1972. Effect of river outflow management on marine life. *Marine Biology* **15**: 200-208.

Keywords: river discharge; streamflow; management

Chamberlain, R. H. and P. H. Doering. 1998. Preliminary estimate of optimum freshwater inflow to the Caloosahatchee Estuary: a resource-based approach. *In* Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor National Estuary Program.

Keywords: optimization; freshwater; inflow; Caloosahatchee River; estuary; salinity; river discharge; submerged aquatic vegetation

Flannery, M. S., E. B. Peebles and R. T. Montgomery. 2002. A percentage-of-streamflow approach for managing reductions of freshwater inflows from unimpounded rivers to southwest Florida estuaries. *Estuaries* **25**(6B): in press.

Keywords: river discharge; streamflow; management; Florida; estuary;

Summary: This paper describes studies that the Southwest Florida Water Management District (SFMWD) has undertaken to establish freshwater inflow relationships for estuaries in the region. The District uses a percent-of-flow approach that emphasizes the interaction of freshwater inflow with the overlap of stationary and dynamic habitat components in tidal river estuaries. Since the responses of key estuarine characteristics (e.g. isohaline locations, residence times) are frequently non-linear, the approach is designed to prevent impacts to estuarine resources during sensitive low-inflow periods and to allow water supplies to become gradually more available as inflow increases. A high sensitivity to variation at low flow extends to many zooplankton and fish that move upstream and downstream in synchrony with inflow. Total numbers of estuarine and estuarine-dependent organisms have been found to decrease during low inflow periods, including mysids, grass shrimp, and juveniles of the bay anchovy and sand sea trout. The interaction of freshwater inflow with seasonal processes, such as phytoplankton production and the recruitment of fishes to the tidal river nursery, indicates that withdrawal percentages during the springtime should be most restrictive. Ongoing efforts are oriented toward refining percentage withdrawal limits among seasons and flow ranges to account for shifts in the responsiveness of estuarine processes to reductions in freshwater inflow.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecological Applications* **5**(1): 272-289.

Keywords: fish; freshwater; flow; habitat; indicator; variability; mollusc; phytoplankton; Sacramento River; San Joaquin River; salinity; San Francisco Bay; statistical model

Summary: Populations of native and introduced aquatic organisms in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary ("Bay/Delta") have undergone significant declines over the past two decades. Decreased river inflow due to drought and increased freshwater diversion have contributed to the decline of at least some populations. Effective management of the estuary's biological resources requires a sensitive indicator of the response to freshwater inflow that has ecological significance, can be measured accurately and easily, and could be used as a "policy"

variable to set standards for managing freshwater inflow. Positioning of the 2 ppt (grams of salt per kilogram of seawater) bottom salinity value along the axis of the estuary was examined for this purpose.

The 2 ppt bottom salinity position (denoted by X_2) has simple and significant statistical relationships with annual measures of many estuarine resources, including the supply of phytoplankton and phytoplankton-derived detritus from local production and river loading; benthic macroinvertebrates (molluscs); mysids and shrimp; larval fish survival; and the abundance of planktivorous, piscivorous, and bottom-foraging fish. The actual mechanisms are understood for only a few of these populations.

X_2 also satisfies other recognized requirements for a habitat indicator and probably can be measured with greater accuracy and precision than alternative habitat indicators such as net freshwater inflow into the estuary. The 2 ppt value may not have special ecological significance for other estuaries (in the Bay/Delta, it marks the locations of an estuarine turbidity maximum and peaks in the abundance of several estuarine organisms), but the concept of using near-bottom isohaline position as a habitat indicator should be widely applicable.

Although X_2 is a sensitive index of the estuarine community's response to net freshwater inflow, other hydraulic features of the estuary also determine population abundances and resource levels. In particular, diversion of water for export from or consumption within the estuary can have a direct effect on population abundance independent of its effect on X_2. The need to consider diversion, in addition to X_2, for managing certain estuarine resources is illustrated using striped bass survival as an example.

The striped bass survival data were also used to illustrate a related important point: incorporating additional explanatory variables may decrease the prediction error for a population or process, but it can increase the uncertainty in parameter estimates and management strategies based on these estimates. Even in cases where the uncertainty is currently too large to guide management decisions, an uncertainty analysis can identify the most practical direction for future data acquisition.

Related papers: Kimmerer and Schubel, 1994

Kimmerer, W. J. and J. R. Schubel. 1994. Managing freshwater flows into San Francisco Bay using a salinity standard: results of a workshop, p. 411-416. *In* Dyer, K. R. and R. J. Orth (eds.), Changes in Fluxes in Estuaries: Implications from Science to Management. Olsen & Olsen, Fredensborg, Denmark.

Keywords: estuary; management; salinity; flow; freshwater; San Francisco Bay; Sacramento River; San Joaquin River;

Related papers: Jassby et al., 1995

Mattson, R. A. 2002. A resource-based framework for establishing freshwater inflow requirements for the Suwanee River Estuary. *Estuaries* **25**(6B): in press.

Keywords: freshwater; inflow; optimization; Suwanee River; flow; habitat; salinity;

Summary: This study describes the approach taken by the Suwanee River Water Management District in Florida to establish freshwater inflow requirements for the Suwanee River estuary. The approach involves maintaining a natural inflow regime (in terms of magnitude, frequency, duration and timing of freshwater flows) and identifying important habitat targets to be protected. The District uses salinity

ranges, limits of distribution of communities or habitats, and other characteristics to define the appropriate salinity and corresponding flow ranges needed to protect and maintain the resource targets. Habitats (and factors considered in setting salinity criteria) include tidal freshwater swamp (downstream limit of treeline; salinity tolerances of dominant species), low salinity SAV beds (downstream limit of SAV beds; salinity tolerances of dominant taxa), brackish tidal marshes (ratio of Cladium to Juncus; salinity tolerances of dominant plants), tidal creeks (fish habitat value; maintenance of low salinity SAV habitat), and oyster reefs and bars (spat settlement in spring/summer; mortality at high salinity). Subsequent monitoring and research is undertaken to evaluate the effectiveness of the river flow criteria in protecting the estuarine resource targets.

Related papers: Tsou and Matheson, 2002

Richter, B. D., J. V. Baumgartner, R. Wigington and D. P. Braun. 1997. How much water does a river need? *Freshwater Biology* **37**: 231-249.

Keywords: river discharge; optimization; flow

Swanson, H. S. and C. S. Beightler. 1970. A network flow analysis of water allocation decisions in a river system and their effect on estuarine ecology. Technical Report CRWR-63. Center for Research in Water Resources, The University of Texas at Austin, Austin, Texas.

Keywords: optimization; allocation; surface water; estuary; water use; river discharge; model; minimum cost circulation; network model; Out-of-Kilter algorithm; sensitivity

Summary: This report describes a network analysis method for optimizing surface water allocation in a theoretical river system to maximize net economic benefit and to estimate the benefit of various potential estuarine allocation levels. References for methods of estimating the relative benefits of different traditional water uses (e.g., domestic, industrial, agricultural) are provided. Both nonlinear benefits and seasonal variability in benefits (e.g., irrigation) are possible. The effects of the unknown benefit of instream flow for estuarine ecological needs are estimated by sensitivity analysis. This work provides a computational framework for organizing knowledge about the costs and benefits of water uses and optimizing the allocation of water among competing uses.

Physical Characteristics of the Estuary

Streamflow, Precipitation, and Water Use

Alber, M. and C. Smith. 2001. Water use patterns in the watersheds of the Georgia riverine estuaries, p. 752-755. *In* Proceedings of the 2001 Georgia Water Resources Conference, Athens, Georgia U.S.A. Institute of Ecology, University of Georgia.

Keywords: water use; watershed; estuary; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; ground water; surface water; water withdrawal

Summary: Data from the Georgia Water Use Program for the watersheds of the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys rivers in 1985, 1990, and 1995 were analyzed. For the most part, there were no large changes among years, so 1995 information was presented with notes on any interannual changes. Water withdrawal in the Savannah watershed was 3824 millions of gallons per day (mgd), with 3685 mgd withdrawn from surface water and 139 mgd from groundwater. The largest water use in the Savannah, 3325 mgd, is for thermoelectric power generation, but 97% of this is returned to the watershed (i.e. not consumed). Other large uses (in decreasing order) are industrial, domestic, irrigation, commercial, and livestock. When return flows are accounted for (95% of total withdrawals), water consumption is still highest for thermoelectric, industrial, irrigation, and domestic uses, in decreasing order. In this case, water use patterns have changed over time, with industrial use falling from 980 mgd in 1985 to 344 in 1995. Much of this reduction is the result of changes in the operation of the Savannah River Plant. However, total withdrawal in the watershed decreased less, due in large part to increases in thermoelectric withdrawals.

Alhadeff, S. J. and B. E. McCallum. 2001. Water Resources Data - Georgia, 2001. Compact Disk. United States Geological Survey.

Keywords: river discharge; streamflow; water level; water quality

Summary: In order to estimate river inflow into the Georgia estuaries, we routinely use the most downstream discharge gaging stations in the main channels and add, where possible, discharge from gaged tributaries that enter the estuary below the main gages. Discharge is then corrected for ungaged area within each basin by multiplying gaged discharge by a factor equivalent to the ratio of total to gaged area. For the Savannah River estuary, the most downstream discharge gage in the main channel is near Clyo, GA (USGS gage number 02198500), and the only discharge-gaged tributary entering below that is Ebenezer Creek at Springfield, GA (gage number 02198690). Periods of record for these gages begin in 1929 and 1990, respectively, and continue to the present. Ungaged area comprises 4% of the Savannah River watershed.

Cite this for compiled historic data outside annual reports

Blanton, J. O. and L. P. Atkinson. 1983. Transport and fate of river discharge on the continental shelf of the southeastern United States. *Journal of Geophysical Research* **88**(C8): 4730-4738.

Keywords: river discharge; continental shelf; wind; salinity; freshwater volume

Environmental Protection Division. 1986. Water availability and use report, Savannah River Basin. Department of Natural Resources, Atlanta, Georgia.

Keywords: water use; Savannah River

Summary: For each hydrologic unit within the Savannah River basin, this report includes a table and map of major facilities permitted for water withdrawal or waste discharge, an estimate of water use by users not required to have permits, and a text summary of water resources. For Hydrologic Unit 6 (Savannah), there is a discussion of salt water intrusion into the aquifer and a map of well restriction areas.

McCallum, B. E., J. F. Kerestes and A. C. Hickey. 2001. Water Resources Data - Georgia, 2001, Volume 1: Continuous water-level, streamflow, water-quality data, and periodic water-quality data, Water Year 2001. Compact Disk. United States Geological Survey.

Keywords: river discharge; streamflow; water level; water quality

For river discharge (streamflow) data through water year 2001: see the compilation by Alhadeff and McCallum, 2001

Plummer, G. L. 1983. Georgia Rainfall: Precipitation Patterns at 23 Places, 1734-1982. Georgia Academy of Science, Athens, Georgia.
Keywords: Georgia; rainfall; precipitation; historic data
Summary: This book contains precipitation data for Georgia from official records beginning in 1892. Analyses include annual and monthly trends statewide and broken down by crop-reporting divisions and cities.

Plummer, G. L. 1989. Outlook for precipitation in Georgia, p. 36-39. *In* Proceedings of the 1989 Georgia Water Resources Conference, Athens, Georgia U.S.A. Institute of Ecology, University of Georgia.
Keywords: precipitation; rainfall; climate; drought; periodicity; weather
Summary: Outlooks for climate changes in the next few decades must take into account all historic evidence for climatic changes in the past. Wet-dry periods are historic facts and evidence of cyclic periods is abundant. Thus, a century or more of historic patterns become precursors for patterns that project trends for several decades -- not precisely but generally.
Weather and climate in Georgia are governed primarily by two airmass systems: 1) the semi-permanent, Azores, high-pressure system affects Georgia's Coastal Plain area most directly, and 2) the continental polar airmasses affect the Southern Appalachian mountains. These airmasses cause droughts; they sometimes confront each other over Georgia as stationary frontal systems that cause much wet weather. Dry weather statewide occurred periodically at intervals of 7-yr, 9-yr, 11-yr, and others. Each cyclic pattern overlays the others.
Possible outlooks for rainfall from the comparatively dry decade of the 1980's are: 1) an up-trend that brings more precipitation, 2) a down-trend into yet drier weather, and 3) an extension, or continuation, of the relatively dry weather of the 1980s. History indicates that an up-trend in precipitation from 1986 until 1990 to 1993 is a reasonable expectation; but that trend was modified in June 1988, perhaps temporarily. Another series of dry weather periodically is expected from about 1994 through 1999. Two major dry-weather periods, similar to the decades of the 1930s, '50s and '80s, are expected about 2010-2015 throughout southeastern U.S. The outlook is bleak for the kind of wet-weather periods that occurred in the 1940's, '60s, and early '70s.

U. S. Army Corps of Engineers. Thurmond Project. Main: http://water.sas.usace.army.mil/thurmond.html; Historic Project Data: http://water.sas.usace.army.mil/hist.htm.
Keywords: Savannah River; Thurmond; dam; Clarks Hill; location; drainage area; reservoir; design floods; hydropower; historic data; elevation; inflow; outflow; pumpback; generation; rainfall; map
Summary: Main page includes descriptive measurements of project features. Historic Project Data includes monthly and annual averages and daily values in annual tables for lake elevation, various types of inflow, outflow, pumpback, and power generation for the period of record (1954-present). Monthly and annual average basin rainfall 1948-present. Also query and statistical capabilities.

Estuary Characterization

Dame, R., M. Alber, D. Allen, M. Mallin, C. Montague, A. Lewitus, A. Chalmers, R. Gardner, C. Gilman, B. Kjerfve, J. Pinckney and N. Smith. 2000. Estuaries of the south Atlantic coast of North America: Their geographical signatures. *Estuaries* **23**(6): 793-819.

Keywords: estuary; Atlantic; Zostera; salt marsh; community; structure; benthos; algae; dinoflagellate; macrophyte; production; organic matter; fishery

National Ocean Service. 1997. Environmental Sensitivity Index: Georgia. ESI Atlas Introduction. National Oceanic and Atmospheric Administration,, Seattle, Washington.

Keywords: sensitivity; Georgia; estuary; habitat; mammals; birds; reptiles; amphibians; fish; invertebrate; plants; rare; salinity; zonation; season; Savannah River; Wassaw Sound; Ossabaw Sound; St. Catherines Sound; Sapelo Sound; Doboy Sound; Altamaha River; St. Andrews Sound; St. Simons Sound; St. Marys River; Cumberland Sound; map

Summary: For estuarine systems with larger rivers (e.g., Savannah, Ossabaw, Altamaha, St. Andrew Sound, and St. Marys), freshwater input is typically highest from January-April and lowest during August-November. Accordingly, salinity is typically 5-15 ppt lower during February-April than during September-December. Freshwater also tends to set-up localized areas of vertical salinity stratification, especially during high inflow periods.

The Savannah River estuary includes the New River, Wright River, and several distributaries of the Savannah River (i.e., Front, Back, and Middle Rivers and South Channel). The average depth of the estuary is approximately 5m at mid-tide level, although deeper navigation channels (9-12m mean low water [MLW]) exist. The estuary receives most of its freshwater from the Savannah River; the head of tide is located about 5 km upstream of the Highway 17 bridge. During the 1970s and 1980s, a tide gate located in the Back River affected circulation and salinity in the upper estuary. The tide gate has not been operational since March 1989. Thus, salinity zones defined for this ESI map reflect conditions after March 1989. Salinity variability is dominated by seasonal fluctuations and controlled releases of freshwater from impoundments on the Savannah River and its tributaries. Throughout much of the estuary, salinity is about 5 ppt lower during February-April than during September-November, although these seasonal differences are less apparent upstream of Hutchinson Island. Salinities are often vertically homogeneous, except for moderate stratification in the lower Savannah River. Tides are semi-diurnal and range from 2.0m at the entrance to the estuary to 2.5m in the Savannah River above Elba Island.

Salinity zone maps showing locations of tidal fresh, mixing, and seawater zones during typical seasons of low, transitional, and high salinity are included.

The ESI maps themselves show shoreline habitats (e.g. structures, sand, gravel, mud, marshes, swamps) and occurrence of species considered sensitive to oil spills. Species categories include birds, fish, invertebrates, marine mammals, and reptiles. Human use resources such as industrial plants that would be affected by oil spills are also listed.

U. S. Study Commission: Southeast River Basins. 1963. Plan for Development of the Land and Water Resources of the Southeast River Basins. Appendix 1: Savannah Basin.
Keywords: drainage area; geology; soil; climate; ground water; surface water; rainfall; navigation; reclamation; irrigation; drainage; soil conservation; erosion; salinity; sediment
Summary: This Appendix describes the Savannah River basin (as it was in 1963) and includes sections on areal extent of the basin within 3 physiographic provinces, headwater sources, geology and soils, climate, water (surface and ground), navigation, reclamation, irrigation, drainage, soil conservation and utilization including agriculture, erosion and sediment control, and salinity intrusion.

Transit Time

Alber, M. and J. E. Sheldon. 1999. Trends in salinities and flushing times of Georgia estuaries, p. 528-531. *In* Proceedings of the 1999 Georgia Water Resources Conference, Athens, Georgia U.S.A. Institute of Ecology, University of Georgia.
Keywords: salinity; flushing time; estuary; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; variability; water withdrawal
Summary: This is an extension of Alber and Sheldon (1999 in Estuarine, Coastal and Shelf Science) with additional monitoring data from 1973-1992. At one station in the lower Savannah River estuary, salinity increased (0.2 PSU y^{-1}, p=0.005) while discharge to the estuary decreased (6.5 m^3 s^{-1} y^{-1}, p=0.029), although long cycles in the data may have influenced the analysis.
Related papers: Alber and Sheldon, 1999 in Estuarine, Coastal and Shelf Science

Alber, M. and J. E. Sheldon. 1999. Use of a date-specific method to examine variability in the flushing times of Georgia estuaries. *Estuarine, Coastal and Shelf Science* **49**: 469-482.
Keywords: flushing time; fraction of freshwater; transit time; model; river discharge; estuary; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; freshwater volume
Summary: Median flushing time of the Savannah River estuary over 30 years (1968-1997), calculated by a modified fraction of freshwater method, was 5.6 d. This is comparable to the flushing time of the Altamaha River estuary and much shorter than the flushing times of the Ogeechee, Satilla, and St. Marys estuaries. Flushing time is more sensitive to decreases in discharge than to increases, and the Savannah estuary flushing time is less sensitive to discharge changes than are those for the slower-flushing estuaries.
Related papers: Alber and Sheldon, 1999 in Proceedings of the 1999 Georgia Water Resources Conference

Atkinson, L. P., J. O. Blanton and E. B. Haines. 1978. Shelf flushing rates based on the distribution of salinity and freshwater in the Georgia Bight. *Estuarine and Coastal Marine Science* **7**: 465-472.
Keywords: flushing time; fraction of freshwater; continental shelf; salinity; freshwater volume; river discharge

Hayes, D. W. 1980. Tritium in the Savannah River Estuary and adjacent marine waters. *International Atomic Energy Agency* **SM 232**: 271-281.
Keywords: tritium; Savannah River; estuary; mixing; flushing time; fraction of freshwater; tidal prism model; freshwater volume; model
Summary: The tritium distribution in the Savannah River estuary and adjacent marine waters was measured to provide information on the dilution, mixing and movement of Savannah River water in this region. The Savannah River marine region was chosen because the average tritium concentration in this river is ~5 pCi/ml, whereas other rivers in the southeastern Unites States of America average less than 0.5 pCi/ml. The increased tritium concentration in the Savannah River is due to releases from the Savannah River Plant of the Department of Energy. Tritium measurements have proved particularly effective in estimating the flushing time of the Savannah River estuary (2.4 days) and in delineating the relative contribution to the water masses in Ossabaw and Port Royal Sounds from the river and from seawater. Ossabaw and Port Royal Sounds are located approximately 20 km south and north of the Savannah River estuary respectively.

Moran, M. A., W. M. Sheldon, Jr. and J. E. Sheldon. 1999. Biodegradation of riverine dissolved organic carbon in five estuaries of the southeastern United States. *Estuaries* **22**(1): 55-64.
Keywords: bacterial activity; carbon; estuary; respiration; continental shelf; flushing time; fraction of freshwater; transit time; light; photolysis; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Summary: The biological turnover of riverine dissolved organic carbon (DOC) discharged into five southeastern United States estuaries (Savannah, Ogeechee, Altamaha, Satilla, and St. Marys) was examined in long-term respiration bioassays. Measures of bacterial oxygen consumption indicated surprisingly large differences in the inherent biodegradability of DOC among the five estuaries, despite their close geographic proximity. Of the five rivers, those with Piedmont drainage (the Savannah and Altamaha) had the lowest average DOC concentrations but the highest carbon-normalized biodegradation rates in March and May 1996, indicating that DOC from Piedmont rivers was more biologically labile than that from Coastal Plain rivers. Combining these rates with estimates of estuary and shelf flushing times, maximum losses of 1-2% of DOC entering the Savannah estuary were predicted within the estuary and 18-28% on the adjacent shelf. Short exposures to natural sunlight increased the lability of the riverine DOC and enhanced biodegradation rates by over 3-fold for some estuaries, but not for the Savannah estuary.

Officer, C. B. 1976. Physical Oceanography of Estuaries (and Associated Coastal Waters). John Wiley & Sons, New York.
Keywords: estuary; mixing; flushing time; fraction of freshwater; freshwater volume; river discharge; advection; circulation; dispersion; tidal prism model; Savannah River

Modeling

Conrads, P. pers. comm. Data mining Savannah Wildlife Refuge gages: preliminary results.

Keywords: data mining; Savannah River; Savannah River National Wildlife Refuge; river discharge; flow; water level; specific conductance; model; conductivity; artificial neural networks
Preliminary results not publicly released

Conrads, P., W. M. Kitchens and Advanced Data Mining LLC. 2002. Lower Savannah River Water Level and Specific Conductivity Model: User Guide v. 061102. Advanced Data Mining LLC, Greenville, South Carolina.
Keywords: Savannah River; estuary; conductivity; streamflow; river discharge; water level; model; empirical model
Summary: The Lower Savannah River Water Level and Specific Conductivity Model was developed by USGS and Advanced Data Mining for the Georgia Ports Authority for use in their study for the proposed harbor deepening. It predicts water level and specific conductivity at several USGS gage locations within the Savannah River estuary based on a user-specified upstream flow regime and historical water levels (tidal forcing) downstream in the harbor.
The empirical relationships among flow, water level, and specific conductivity at these locations were determined using methods such as spectral analysis and artificial neural network models to analyze data from the USGS gages. The model provided is a simulator that uses those previously determined relationships to make predictions for a limited range of input manipulations. As provided, the model may be of limited use in evaluating the effects of potential flow regimes below Thurmond Dam on the salinity distribution in the estuary; however, the authors have indicated that future modifications may expand the input options for flow regimes and the specific conductivity coverage.

Singer, M. P., F. D. Arnold, R. H. Cole, J. G. Arnold and J. R. Williams. 1988. Use of SWRRB computer model for the National Coastal Pollutant Discharge Inventory, p. 119-131. *In* Proceedings of the Symposium on Coastal Water Resources, Wilmington, North Carolina. American Water Resources Association.
Keywords: SWRRB model; model; pollutant; runoff; sediment; rural; season; loading

Hydrography

McCarthy, J. E. 1979. Hydrographic observations off Savannah, Georgia : (Winter/Spring 1976). Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: hydrography; Savannah
Available at College of Charleston Marine Resources Library

Rhodes, R. F. 1949. The hydraulics of a tidal river as illustrated by Savannah harbor, Georgia. U.S. Army Corps of Engineers, Savannah, Georgia.
Keywords: hydraulics; tide; Savannah River; harbor; current
Available at College of Charleston Marine Resources Library

Singer, J. J. 1980. Hydrographic observations off Savannah and Brunswick, Georgia : (March, May, and September, 1977 and January, 1978). Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: hydrography; Savannah; Brunswick

Available at College of Charleston Marine Resources Library

U. S. Army Corps of Engineers. 2001. Channel Conditions, Atlantic Intracoastal Waterways, Norfolk, Virginia to St. Johns River, Florida: Savannah District, Skull Creek to St. Marys River. Savannah District, Savannah, Georgia.
Keywords: channel conditions; Georgia; law; regulation; tides; current; navigation; depth; bridges; map

Sediment

Alexander, C., J. Ertel, R. Lee, B. Loganathan, J. Martin, R. Smith, S. Wakeham and H. L. Windom. 1994. Pollution History of the Savannah Estuary. Skidaway Institute of Oceanography, University System of Georgia, Savannah, Georgia.
Keywords: sediment; sedimentation; Savannah River; estuary; trace elements; heavy metals; polycyclic aromatic hydrocarbons; pesticides; TBT; PCB; polychlorinated biphenyls; butyltins; coring
Summary: Pollution histories of the Savannah estuary for trace metals, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), pesticides, and butyltins were constructed using six sediment cores collected from various sites in the estuary. Silver, cadmium and zinc increased steadily over time, suggesting non-point sources associated with human population growth, while chromium showed a maximum in progressively more recent sediments going downstream, indicating a 1950s-era source up-estuary and subsequent movement of contaminated sediments downstream. Mercury was enriched in only two cores, and in those, maxima occurred in sediments of different age, indicating spatial and temporal variability in mercury contamination. Lead showed inconsistent distribution patterns among the cores that were attributed to local sources and downstream sediment transport. PAH concentrations were maximal in sediments from the 1950s and early 1960s in some cores, while PCB concentrations peaked in 1967. Pesticide and butyltin concentrations were very low. These data may be useful for evaluating potential pollutant recontamination in the event that a proposed flow regime is expected to result in significant sediment resuspension and transport.
Vol. 1 text, Vol. 2 tables and figures, Vol. 3 appendices

Howard, J. D. 1971. Investigation of the source and potential transport and depositional pattern of sediment in portions of coastal Georgia, part 3. United States Army Corps of Engineers.
Keywords: salinity; temperature; turbidity; current; sediment; water quality; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Excerpted in Winker et al., 1985

Meade, R. H. 1969. Landward transport of bottom sediments in estuaries of the Atlantic Coastal Plain. *Journal of Sedimentary Petrology* **39**(1): 222-234.
Keywords: transport; sediment; estuarine circulation; estuary; coastal plain; sediment; sand; continental shelf; minerals; sea level; Connecticut River; Hudson River; Delaware River; Susquehanna River; Potomac River; James River; Roanoke River; Cape Fear River; Pee Dee River; Santee River; Savannah River; Altamaha River; St. Johns River; river discharge

Meade, R. H. 1982. Sources, sinks, and storage of river sediments in the Atlantic drainage of the United States. *The Journal of Geology* **90**(3): 235-252.
Keywords: source/sink; sediment; drainage; model; erosion; soil conservation; reservoir; estuary; marsh; continental shelf; deep sea; flow; river discharge; streamflow; Juniata River; Merrimack River; Yadkin River; Edisto River; Pee Dee River; Potomac River; Susquehanna River; Delaware River; Monocacy River; Rappahannock River; Tar River; Oconee River; Savannah River; Clarks Hill

Biological Characteristics

Fish and Invertebrates

Brunswick Junior College. 1975-1983. Water quality investigations of estuaries of Georgia. Reports submitted to Environmental Protection Division, Georgia Department of Natural Resources.
Keywords: salinity; oxygen; pH; conductivity; redox potential; temperature; settling plates; estuary; water quality; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; Tybee Creek; Wilmington River; North Newport River; Turtle River
Summary: These annual reports include monthly data for dissolved oxygen, biological oxygen demand, pH, total alkalinity, conductivity, redox potential, temperature, chloride, turbidity, color, total and suspended solids, ammonia nitrogen, nitrate+nitrite nitrogen, phosphorus, total organic carbon, and total and fecal coliform bacteria for 1 station in the South Channel of the Savannah River (at Cockspur Island) from 1973-1982. In addition, settling on artificial substrates (plexiglas plates) was monitored quarterly. Sampling at this station was continued by the Georgia Environmental Protection Division's Coastal Monitoring Project.

Bulger, A. J., B. P. Hayden, M. E. Monaco, D. M. Nelson and M. G. McCormick-Ray. 1993. Biologically-based estuarine salinity zones derived from a multivariate analysis. *Estuaries* **16**(2): 311-322.
Keywords: principal component analysis; estuary; salinity; Chesapeake Bay; Delaware Bay; zonation; Venice salinity zone
Summary: Principal Component Analysis (PCA) was used to derive estuarine salinity zones based on field data on the salinity ranges of 316 species/life stages in the mid-Atlantic region (chiefly Chesapeake Bay and Delaware Bay species). Application of PCA to the data matrix showed that the structure underlying a diversity of salinity distributions could be represented by only five Principal Components corresponding to five overlapping salinity zones: freshwater to 4 ppt, 2-14 ppt, 11-18 ppt, 16-27 ppt, and 24 ppt to marine. The derived salinity zonation showed both differences and similarities to the Venice System of estuarine zonation. However, unlike the static and essentially descriptive Venice System, the new method will allow researchers to establish biologically-relevant local salinity zones, and then develop hypotheses about the processes that give rise to the resulting patterns. Examples of this procedure are given for the mid-Atlantic region. The method used here may also be useful for studying distributions across other environmental gradients, such as temperature, pH, substrate, turbidity, vegetation, or latitude.

Coastal Resources Division. pers. comm. Participation in Marine Recreational Fisheries Statistics Survey (MRFSS). Department of Natural Resources.
Keywords: total number of finfish harvested/released; species identification; length and weight of fish samples; mode of fishing; hours fished; county and state of residency
Available from DNR

Coastal Resources Division. pers. comm. Sportfish Carcass Recovery Project. Department of Natural Resources.
Keywords: angler name; address; number of anglers participating in trip; date of trip; estuary; species identification; length; gender; sagittal otolith
Available from DNR

Copeland, B. J. 1966. Effects of decreased river flow on estuarine ecology. *Journal Water Pollution Control Federation* **38**(11): 1831-1839.
Keywords: flow; river discharge; estuary; invertebrate; shellfish; primary production; Texas

Drinkwater, K. F. and K. T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Freshwater and Marine Ecosystems* **4**: 135-151.
Keywords: diversion; river discharge; fish; invertebrate; Nile River; Indus River; Black Sea; San Francisco Bay; James Bay; fishery
Summary: The effects of freshwater regulation and diversion on the adult and larval stages of fish and invertebrates in coastal marine waters are reviewed. Potential impacts of river modification are highlighted based on our present understanding of the role of fresh water on the physical, chemical and biological processes on the marine environment. These include effects on migration patterns, spawning habitat, species diversity, water quality and distribution and production of lower trophic levels. The effects of dams on anadromous and catadromous fish are also presented. We discuss in detail the marine response to specific river regulation projects on the Nile, Indus and rivers flowing into the Black Sea, San Francisco Bay and James Bay in Canada. A decline in some coastal fisheries with an overall negative impact on the biota is generally associated with reductions in freshwater flow. Extensive ecological considerations are needed during the planning stage of large-scale freshwater modification projects to minimize potential impacts.

Montagna, P. A., R. D. Kalke and C. Ritter. 2002. Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. *Estuaries* **25**(6B): in press.
Keywords: restoration; freshwater; inflow; macrofauna; meiofauna; invertebrate; Rincon Bayou; diversion
Related papers: Palmer et al., 2002

Nelson, D. M., E. A. Irlandi, L. R. Settle, M. E. Monaco and L. Coston-Clements. 1991. Distribution and Abundance of Fishes and Invertebrates in Southeast Estuaries. ELMR Rep. No. 9. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, Maryland.
Keywords: distribution; abundance; fish; invertebrate; estuary; Albermarle Sound; Pamlico River; Pungo River; Neuse River; Bogue Sound; New River; Cape Fear River; Winyah Bay; Santee River; Charleston Harbor; St. Helena Sound; Broad

River; Savannah River; Ossabaw Sound; St. Catherines Sound; Sapelo Sound; Altamaha River; St. Andrews Sound; St. Simons Sound; St. Johns River; Indian River; Biscayne Bay; zonation; shellfish; shrimp; crab

Rees, R. A. 1972. A survey of the aquatic organism populations of the Savannah and Ogeechee River estuaries and their relationship in the diet of the striped bass, *Morone saxatilis*, (Walbaum). M.S., University of Georgia, Athens, Georgia.
Keywords: invertebrate; population; Savannah River; Ogeechee River; estuary; striped bass

Stickney, R. R. 1972. Effects of intracoastal waterway dredging on ichthyofauna and benthic macroinvertebrates. Skidaway Institute of Oceanography, University System of Georgia, Savannah, Georgia.
Keywords: intracoastal waterway; dredging; fish; benthos; invertebrate; estuary
Available at College of Charleston Marine Resources Library

Tsou, T.-S. and R. A. Matheson. 2002. Seasonal changes in the nekton community of the Suwanee River estuary and the potential impacts of freshwater withdrawal. *Estuaries* **25**(6B): in press.
Keywords: nekton; fish; Suwanee River; freshwater; withdrawal; cluster analysis
Summary: A report on nekton community structure in the lower Suwanee River estuary (1997-2000). Used multidimensional scaling ordination and cluster analysis to explore the relationship between environmental factors and the abundance of fisheries resources. Observed a strong seasonal pattern. Cold season fish: *Leiostomus xanthurus* and *Lagodon rhomboids*. Warm season: *Membras martinica* and *Anchoa hepsetus*. Species that contributed most to the dissimilarity in community structure between wet and dry seasons were abundant and generally preferred lower salinity (e.g. *L. xanthurus, Eucinostomus spp.,* and *Menidia* spp.)
Related papers: Mattson, 2002

Wagner, C. M. and H. M. Austin. 1999. Correspondence between environmental gradients and summer littoral fish assemblages in low salinity reaches of the Chesapeake Bay, USA. *Marine Ecology Progress Series* **177**: 197-212.
Keywords: nekton; estuary; gradient; tide; freshwater; Chesapeake Bay
Summary: Patterns in the assemblage structure of littoral fishes occupying the gradient between riverine and estuarine ecosystems were revealed through multivariate analysis of 5 annual summer seine surveys in 4 tributary systems of the lower Chesapeake Bay. Catch per unit effort of fishes was quantified and environmental variables measured to characterize assemblage structure and population responses along large-scale (km) environmental gradients. Results of two-way indicator species analysis (TWINSPAN), detrended correspondence analysis (DCA) and detrended canonical correspondence analysis (DCCA) suggested the presence of 4 intergrading assemblages of littoral beach fishes: permanent tidal freshwater, lower tidal freshwater, oligohaline estuary and mesohaline estuary. Littoral fish assemblages were ordered along a large-scale spatial gradient between tidal freshwater and mesohaline river reaches during summer, when relatively stable hydrological conditions create a well-defined salinity gradient. Large-scale distribution of these fishes along the river axis corresponded with salinity (and its correlates) up to the interface, and with structural attributes of the habitat (nearshore sediment grain size, presence of submerged aquatic vegetation, woody debris) in the

permanent tidal freshwater river reaches. The permanent tidal freshwater river reaches were more riverine in character, and were typified by speciose and relatively stable assemblages dominated by resident secondary division freshwater fishes and the juveniles of several diadromous species. Although the resident fauna is certainly derivative of more upland, non-tidal streams, patterns of association suggest distinct ecological relationships may exist for species co-occurring in tidal freshwater habitats.

Marsh

Alberts, J. J. a. and M. Takács. 1999. Importance of humic substances for carbon and nitrogen transport into southeastern United States estuaries. *Organic Geochemistry* **30**(6): 385-395.
Keywords: humic; carbon; nitrogen; transport; estuary; marsh; Pee Dee River; Black River; Edisto River; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Summary: Dissolved organic carbon (DOC) and nitrogen (DON) concentrations entering the Savannah River estuary were lower than those in the Ogeechee, Altamaha, Satilla, and St. Marys estuaries.

Alexander, H. D. and K. H. Dunton. 2002. Freshwater inundation effects on emergent vegetation of a hypersaline salt marsh. *Estuaries* **25**(6B): in press.
Keywords: freshwater; inundation; vegetation; hypersaline; salt marsh

Latham, P. J. and W. M. Kitchens. 1996. Changes in vegetation and interstitial salinities in the lower Savannah River: 1986-1994. Final Report. U.S. Fish and Wildlife Service, Charleston, South Carolina.
Keywords: vegetation; salinity; Savannah River
Related papers: others by Latham or Pearlstine

Latham, P. J., L. G. Pearlstine and W. M. Kitchens. 1993. Species association changes across a gradient of fresh, oligohaline, and mesohaline tidal marshes along the lower Savannah River. *Wetlands* **14**(3): 174-178.
Keywords: marsh; Savannah River
Summary: In the present study, plant species patterns and associated environmental factors of freshwater, oligohaline, and mesohaline marshes of the Savannah National Wildlife Refuge were compared. DECORANA, an ordination method, was used to group vegetation classes. Discriminant function analysis was applied to resulting classes to quantify differences in salinity, elevation, and distance from tidal channels among classes. Nine vegetation classes across freshwater and brackish marshes corresponded significantly to salinity differences between sites. Combinations of elevation and distance from tidal channel were significant in separating vegetation classes within sites. Scirpus validus (Vahl) was the only species to occur over the entire range of measured physical parameters and accounted for much of the overlap between vegetation classes. The proportion of correctly classified vegetation classes between sites was 70%. Within each site, the proportion of correct classification was lower in the freshwater marsh (77% correct classifications) when compared with the oligohaline (82%), strongly oligohaline (83%), and mesohaline (85%) sites. Although overlap among classes was greater in the more diverse freshwater marsh,

our results may reflect differences in the steepness of environmental gradients between sites and the scale at which physical parameters were measured rather than actual plant distribution overlap. Results suggest that resources are more finely divided among species in the freshwater marsh, resulting in a less distinct dominance hierarchy when compared with the mesohaline marsh.
Related papers: others by Latham or Pearlstine

McIntire, G. L. and W. M. Dunstan. 1975. The seasonal cycle of growth and production in three salt marshes adjacent to the Savannah River. Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: salt marsh; season; production; Savannah River
Available at College of Charleston Marine Resources Library

Pearlstine, L. G., W. M. Kitchens and P. J. Latham. 1993. Modeling tidal marsh succession in the coastal Savannah River, Ga. *In* Wetlands: Proceedings of the 13th Annual Conference of the Society of Wetlands Scientists, New Orleans, Louisiana. Utica, MS.
Keywords: model; marsh; succession; Savannah River
Related papers: others by Latham or Pearlstine

Pearlstine, L. G., W. M. Kitchens, P. J. Latham and R. D. Bartleson. 1993. Tide gate influences on a tidal marsh. *Water Resources Bulletin* **29**(6): 1009-1019.
Keywords: tide gate; marsh; Savannah River; salinity; community; soil; GIS; model; freshwater; harbor; development; Savannah River National Wildlife Refuge
Summary: Construction of a tide gate at the mouth of the north channel of the Savannah River in Georgia has resulted in significant changes in salinities influencing marsh community changes. The tide gate is directly responsible for a 2 to 6 mile upstream displacement of salt water in the river. In the marsh, soil salinities ranged from 0.0 ppt at upstream sites to 12 ppt at downstream sites when the tide gate was in operation. Within two months of taking the tide gate out of operation, interstitial salinities at the downstream sites dropped to 4 ppt. Influences of the tide gate on marsh vegetation were modeled in a geographic information system. With the tide gate out of operation, the model predicts that freshwater marsh would increase in area by 340 percent.
Related papers: others by Latham or Pearlstine

Ward, G. H., M. J. Irlbeck and P. A. Montagna. 2002. Experimental river diversion for marsh enhancement. *Estuaries* **25**(6B): in press.
Keywords: river discharge; diversion; marsh
Summary: This paper describes a demonstration project done by the U.S. Bureau of Reclamation in the Nueces River in Texas. The Nueces River is the primary source of freshwater inflow to Corpus Christi Bay and virtually the only source of freshwater inflow to the Nueces Delta. Reservoir development and operation in the Nueces Basin has greatly reduced freshwater inflow to the Delta, causing increased salt concentrations in the soil and water. The Bureau excavated two overflow channels, significantly lowering the minimum threshold for flooding to the upper Delta without having to increase total flow through the main channel. As a consequence of the excavation, the amount of freshwater diverted to the upper Nueces Delta increased by a factor of seven and average salinity was greatly decreased, leading to a corresponding improvement in abundance and diversity of

both intertidal vegetation and benthic communities. This study demonstrates that small changes in overflow can result in large changes in local salinity, and exploiting this might be an effective management strategy.

Windom, H. L. 1976. Geochemical interactions of heavy metals in southeastern salt marsh environments. Final report EPA-600/3-76-023. U.S. Environmental Protection Agency, Corvallis, Oregon.
Keywords: heavy metals; salt marsh; water column; sediment; organic matter; residence time; Pee Dee River; Black River; Santee River; Cooper River; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Johns River
Summary: Heavy metal pollution in industrialized rivers, including the Savannah River, was reflected in sediment rather than water column concentrations. Iron and manganese in the water column flocculate at the river-estuary interface, so that subsequent down-estuary transport is probably by bedload traction. Although cadmium and mercury tend to mix conservatively as freshwater is diluted with seawater, they are subject to scavenging during iron precipitation and organic matter flocculation so they also tend to accumulate in sediments. Compared to eight other southeastern rivers, in the early 1970s the Savannah River transported relatively large amounts of iron, manganese, and mercury, and moderate amounts of cadmium. Sediment containing heavy metals may accumulate in adjacent salt marshes.

Water Quality Monitoring

Historic Monitoring Programs

Blanton, J. O. pers. comm. Georgia Rivers LMER CTD data, 1994-1999. Skidaway Institute of Oceanography, University System of Georgia.
Keywords: salinity; temperature; fluorescence
Summary: During Georgia Rivers LMER program cruises, water column vertical profiles were taken approximately every 2-4 km between the estuary mouth and the head of seawater intrusion and included depth, temperature, salinity, density (sigma-t), chlorophyll-a fluorescence, and optical backscatterance. The Savannah River estuary was sampled in Nov. 1994, Apr. 1995, Oct. 1995, July 1996, and Feb. 1999.
Related data: Wiebe and Sheldon, unpubl.

Brunswick Junior College. 1975-1983. Water quality investigations of estuaries of Georgia. Reports submitted to Environmental Protection Division, Georgia Department of Natural Resources.
Keywords: salinity; oxygen; pH; conductivity; redox potential; temperature; settling plates; estuary; water quality; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; Tybee Creek; Wilmington River; North Newport River; Turtle River
Summary: These annual reports include monthly data for dissolved oxygen, biological oxygen demand, pH, total alkalinity, conductivity, redox potential, temperature, chloride, turbidity, color, total and suspended solids, ammonia nitrogen, nitrate+nitrite nitrogen, phosphorus, total organic carbon, and total and fecal coliform bacteria for 1 station in the South Channel of the Savannah River (at Cockspur Island) from 1973-1982. In addition, settling on artificial substrates

(plexiglas plates) was monitored quarterly. Sampling at this station was continued by the Georgia Environmental Protection Division's Coastal Monitoring Project.

Environmental Protection Division. 1973. Water quality monitoring data for Georgia streams, 1972. Annual Reports. Georgia Department of Natural Resources, Atlanta, Georgia.
Keywords: salinity; temperature; oxygen; pH; sediment; water quality; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Summary: Continued sampling at the same stations monitored in the volumes Water Quality Data, Lower Savannah River.
Excerpted in Winker et al., 1985

Environmental Protection Division. 1973-1983. Water quality monitoring data for Georgia streams. Annual Reports. Georgia Department of Natural Resources, Atlanta, Georgia.
Keywords: salinity; conductivity; temperature; oxygen; pH; turbidity; color; alkalinity; residue; nitrate; ammonium; phosphorus; total organic carbon; carbon; TOC; chloride; coliform; heavy metals; organic pollutants; sediment; water quality; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Summary: These annual reports contain monthly data on dissolved oxygen, turbidity, color, pH, alkalinity, hardness, suspended solids, dissolved solids, total organic carbon, conductivity, chloride, sulfate, phosphorus, nitrate+nitrite nitrogen, total kjeldahl nitrogen, ammonia nitrogen, calcium, iron, magnesium, manganese, sodium, potassium, and (in later years) heavy metals and organic toxins for 2-9 stations in the Savannah River estuary, many of which are the same stations as in the Water Quality Data, Lower Savannah River and earlier Water Quality Monitoring Data for Georgia Streams reports.
1972 data excerpted in Winker et al., 1985

Environmental Protection Division. 1974. Water quality investigation of the Savannah River basin in Georgia. Georgia Department of Natural Resources, Atlanta, Georgia.
Keywords: Savannah River; Wilmington River; water quality; headwaters; Hartwell Dam; Augusta Canal; estuary; temperature; pH; oxygen; total organic carbon; TOC; coliform; alkalinity; suspended solids; conductivity; salinity; chloride
Summary: Another presentation of the same data for the Savannah River estuary as in the report Water Quality Monitoring Data for Georgia Streams, 1973.

Environmental Protection Division. 1985-1992. Coastal Monitoring Project. Annual Reports. Georgia Department of Natural Resources, Atlanta, Georgia.
Keywords: salinity; oxygen; pH; conductivity; redox potential; temperature; settling plates; Secchi depth; BOD; alkalinity; sulfate; nitrate; phosphorus; coliform; chlorophyll; turbidity; chloride; ammonium; nitrogen; heavy metals; pesticides; organic pollutants; estuary; water quality; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River; Tybee Creek; Wilmington River; North Newport River; Turtle River; Medway River; Duplin River; Brunswick Harbor; Brunswick River; Sapelo River
Summary: Quarterly sampling continued at the same Savannah River station monitored by Brunswick Junior College for EPD. Chloride, redox potential, solids, total organic carbon and settling plates were no longer monitored, but sulfate,

chlorophyll, Secchi depth, total Kjeldahl nitrogen, heavy metals and organic toxin analyses were added.
Related papers: Brunswick Junior College, 1975-1983

Georgia Water Quality Control Board. 1970. Water quality data, lower Savannah River, Vol. 1 (1968-1969). Atlanta, Georgia.
Keywords: Savannah River; Back River; Wilmington River; temperature; oxygen; color; pH; alkalinity; suspended solids; conductivity; salinity; chloride; coliform
Summary: Monthly data on conductivity, chloride, temperature, dissolved oxygen, biological oxygen demand, pH, total alkalinity, turbidity, suspended solids, and total and fecal coliform bacteria for 8 stations in the Savannah River estuary during 1968-1969.
Excerpted in Winker et al., 1985

Georgia Water Quality Control Board. 1972. Water quality data, lower Savannah River, Vol. 2 (1970-1971). Atlanta, Georgia.
Keywords: Savannah River; Back River; Wilmington River; temperature; oxygen; color; pH; alkalinity; suspended solids; conductivity; salinity; chloride; coliform
Summary: Continued sampling at the same stations as the previous volume.
Excerpted in Winker et al., 1985

Wiebe, W. J. and J. E. Sheldon. unpubl. Georgia Rivers LMER nutrient data, 1994-1999. Dept. of Marine Sciences, University of Georgia, Athens, Georgia.
Keywords: nitrate; nitrite; ammonium; phosphate; silicate; total dissolved nitrogen; TDN; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Summary: During Georgia Rivers LMER program cruises, samples for dissolved nutrients were taken approximately every 4 km between the estuary mouth and the head of seawater intrusion. Analyses included ammonium, nitrate, nitrite, orthophosphate, and silicate. The Savannah River estuary was sampled in Nov. 1994, Apr. 1995, Oct. 1995, July 1996, and Feb. 1999. Total dissolved nitrogen was also analyzed for the first 3 cruises. Documentation files and fixed-column-width text data files are included.
Related data: Blanton, pers. comm.

Current Monitoring Programs

Alhadeff, S. J. and B. E. McCallum. 2001. Water Resources Data - Georgia, 2001. Compact Disk. United States Geological Survey.
Keywords: river discharge; streamflow; water level; water quality
Summary: Water quality data have been collected by USGS at the Clyo, Georgia station (see also **Streamflow, Precipitation, and Water Use**). A large number of parameters have been measured (e.g. nutrients, oxygen, suspended sediment, conductivity, pH, temperature), and data through 1994 are available online. Later data are available from printed and electronic reports. Periods of record for some parameters are: dissolved ammonium and dissolved nitrate+nitrite 1979-1994; dissolved orthophosphate 1981-1994; total suspended sediment 1974-1994. Inorganic nutrient and total suspended sediment concentrations were variable but did not show trends over time, nor were there obvious seasonal differences.

Nitrate+nitrite concentrations at the head of the Savannah River estuary were larger than those in the Ogeechee, Satilla, and St. Marys rivers, but ammonium and orthophosphate concentrations were similar among rivers. Despite the similarities in nutrient concentrations among rivers, the estimated nutrient loads to the Savannah River estuary from inflow were much higher due to its higher river discharge. Total suspended sediment loads to the Savannah River estuary were higher than to the Ogeechee, Satilla, and St. Marys estuaries but lower than to the Altamaha River estuary.

Cite this for compiled historic data outside annual reports

Coastal Resources Division. pers. comm. Nutrient Monitoring Program. Department of Natural Resources.

Keywords: nutrients; nitrate; nitrite; ammonium; phosphate; phosphorus; silicate

Available from DNR

Coastal Resources Division. pers. comm. Participation in Marine Recreational Fisheries Statistics Survey (MRFSS). Department of Natural Resources.

Keywords: total number of finfish harvested/released; species identification; length and weight of fish samples; mode of fishing; hours fished; county and state of residency

Available from DNR

Coastal Resources Division. pers. comm. Shellfish Monitoring Program. Department of Natural Resources.

Keywords: coliform; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River

Available from DNR

Coastal Resources Division. pers. comm. Sportfish Carcass Recovery Project. Department of Natural Resources.

Keywords: angler name; address; number of anglers participating in trip; date of trip; estuary; species identification; length; gender; sagittal otolith

Available from DNR

Coffin, R., S. C. Grams, A. M. Cressler and D. C. Leeth. 2001. Water Resources Data - Georgia, 2001, Volume 2: Continuous ground-water level data, and periodic surface-water- and ground-water-quality data, Calendar Year 2001 v. Water-Data Report GA-01-2. United States Geological Survey, Atlanta, Georgia.

Keywords: ground water; water level; surface water; water quality

For historic data through water year 2001: see the compilation by Alhadeff and McCallum, 2001

Environmental Protection Agency. pers. comm. National Coastal Assessment Program.

Keywords: water quality; oxygen; salinity; temperature; depth; pH; nutrients; chlorophyll; sediment; carbon; fish; benthos; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River

Available online soon

Environmental Protection Division. 1997-1998. Coastal Monitoring Project.

Keywords: Duplin River; Secchi depth; oxygen; pH; conductivity; temperature; salinity; Sapelo River; Medway River; Ogeechee River; Wilmington River; Tybee Creek; Savannah River; Altamaha River; Turtle River; Brunswick Harbor; Brunswick River; Satilla River; St. Marys River

Summary: Copies of field notebooks for continued quarterly sampling in 1997 at the Savannah River EPD station. Data include Secchi depth, oxygen, pH, conductivity, temperature, and salinity.
Related papers: Environmental Protection Division, 1985-1992, earlier Coastal Monitoring Project reports

McCallum, B. E., J. F. Kerestes and A. C. Hickey. 2001. Water Resources Data - Georgia, 2001, Volume 1: Continuous water-level, streamflow, water-quality data, and periodic water-quality data, Water Year 2001. Compact Disk. United States Geological Survey.
Keywords: river discharge; streamflow; water level; water quality
For river discharge (streamflow) data through water year 2001: see the compilation by Alhadeff and McCallum, 2001

Other Water Quality Data including Salinity

Dunstan, W. M. 1985. Savannah and Ogeechee estuaries, 1974-1975. *In* Winker, C. D., L. C. Jaffe and J. D. Howard (eds.), Georgia estuarine data 1961-1977, Volume 1. Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: salinity; Savannah River; Ogeechee River; estuary
Excerpted in Winker et al., 1985

Environmental Protection Division. 1975. Savannah River Basin water quality management plan. Department of Natural Resources, Atlanta, Georgia.
Keywords: Savannah River; water quality; management
Available at Skidaway Institute of Oceanography

Environmental Protection Division. 1981. Salinity study of the upper Savannah River estuary. Department of Natural Resources, Atlanta, Georgia.
Keywords: salinity; Savannah River; estuary; intrusion; ground water
Available at College of Charleston Marine Resources Library

Hydroscience Inc. 1970. Water quality analysis of the Savannah River estuary. Westwood, New Jersey.
Keywords: water quality; pollution; Savannah River; estuary
Available at College of Charleston Marine Resources Library

Jaffe, L. C. and L. P. Atkinson. 1985. Salinity and temperature measurements, Georgia estuaries, June-July 1975. *In* Winker, C. D., L. C. Jaffe and J. D. Howard (eds.), Georgia estuarine data 1961-1977, Volume 1. Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: salinity; temperature; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Excerpted in Winker et al., 1985

Nance, S. W. 1974. The role of suspended matter on trace metal transport in an estuarine environment. M.S., Georgia Institute of Technology, Atlanta, Georgia.
Keywords: suspended solids; trace elements; transport; estuary; sediment; Savannah River; Ogeechee River
Available at Skidaway Institute of Oceanography

National Oceanic and Atmospheric Administration (NOAA). 1996. NOAA's Estuarine Eutrophication Survey. Volume 1: South Atlantic Region. Office of Ocean Resources Conservation Assessment, Silver Spring, Maryland.
Keywords: estuary; eutrophication; algae; chlorophyll; turbidity; suspended solids; epiphytes; nutrients; nitrogen; phosphorus; oxygen; anoxia; hypoxia; salinity; primary production; plankton; benthos; submerged aquatic vegetation; wetlands; Albermarle Sound; Pamlico Sound; Pamlico River; Pungo River; Neuse River; Bogue Sound; New River; Cape Fear River; Winyah Bay; Santee River; Charleston Harbor; Stono River; Edisto River; St. Helena Sound; Broad River; Savannah River; Ossabaw Sound; Ogeechee River; St. Catherines Sound; Sapelo Sound; Altamaha River; St. Andrews Sound; St. Simons Sound; Satilla River; St. Marys River; Cumberland Sound; St. Johns River; Indian River; Biscayne Bay

Orlando, S. P., Jr., P. H. Wendt, C. J. Klein, M. E. Pattillo, K. C. Dennis and G. H. Ward. 1994. Salinity Characteristics of South Atlantic Estuaries. National Estuarine Inventory Series. National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation and Assessment, Silver Spring, MD.
Keywords: salinity; estuary; river discharge; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River

South Carolina Department of Health and Environmental Control. 1975. Savannah River Basin water quality management plan. Columbia, South Carolina.
Keywords: water quality; development; Savannah River; management
Available at College of Charleston Marine Resources Library

South Carolina Department of Health and Environmental Control. 1997. Watershed water quality assessment, Savannah and Salkehatchie river basins. Technical Report 003-97. Columbia, South Carolina.
Keywords: watershed; water quality; Savannah River; Salkehatchie River; eutrophication; ground water; invertebrate; fish; oxygen; pH; coliform; nutrients; turbidity; suspended solids; heavy metals; map
Summary: The portion of the Savannah River basin within South Carolina as described in Watershed Management Units (WMU) 0101, 0102 and 0103 encompasses 2,983,612 acres. Most (57%) of this area is forested; 15% is agricultural land, 14% is scrub land, 4% is forested wetland, 4% is urban land, 4% is water, 1% is barren land, and 1% is nonforested wetland. Urban land includes the Cities of Anderson, Aiken, and North Augusta. For each WMU, the report describes population growth, climate, fish consumption advisories, permitted discharges, and water quality monitoring including pesticides, dissolved oxygen, BOD, total nitrogen, ammonia, total phosphorus, turbidity, total suspended solids, pH, fecal coliform bacteria, and metals (cadmium, chromium, copper, lead, mercury, nickel, and zinc).

Southern Coastal Plains Expedition. 1985. Oceanographic study, National Ocean Survey, National Oceanic and Atmospheric Administration, March-May 1973, Savannah River to Ossabaw Sound. *In* Winker, C. D., L. C. Jaffe and J. D. Howard (eds.), Georgia estuarine data 1961-1977, Volume 1. Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: salinity; temperature; Savannah River
Excerpted in Winker et al., 1985

Stickney, R. R. and D. Miller. 1973. Chemical and biological survey of the Savannah River adjacent to Elba Island. Technical Report Series 73-3. Georgia Marine Science Center, University System of Georgia.
Keywords: salinity; temperature; oxygen; pH; tide
Excerpted in Winker et al., 1985

U. S. Department of the Interior. 1969. Proceedings : second session. *In* Conference in the Matter of Pollution of the Interstate Waters of the Lower Savannah River and its Estuaries, Tributaries and Connecting Waters--Georgia--South Carolina (1969 Oct. 29), Savannah, Georgia. U.S. Government Printing Office.
Keywords: Savannah River; pollution; estuary
Available at College of Charleston Marine Resources Library

West, A. W. 1964. Report on pollution of interstate waters of the mouth of the Savannah River, Georgia-South Carolina. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
Keywords: pollution; Savannah River; sewage
Available at College of Charleston Marine Resources Library

Windom, H. L. 1985. Heavy metal analysis of estuaries, southeastern U.S., 1973. *In* Winker, C. D., L. C. Jaffe and J. D. Howard (eds.), Georgia estuarine data 1961-1977, Volume 1. Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: salinity; temperature; oxygen; pH; Savannah River; Ogeechee River; Altamaha River; Satilla River; St. Marys River
Excerpted in Winker et al., 1985

Winker, C. D., L. C. Jaffe and J. D. Howard. 1985. Georgia estuarine data 1961-1977, Volume 1. Technical Report Series 85-7. Georgia Marine Science Center, University System of Georgia, Skidaway Island, Georgia.
Keywords: Savannah River; Ogeechee River; salinity; temperature; current; sediment; turbidity; oxygen; pH; tide phase
Summary: This compilation of papers, reports, theses, dissertations, and unpublished data contains salinity, temperature, current, sediment, turbidity, oxygen, and pH data for Georgia estuaries. Data for the Savannah River estuary, including the South Channel, Back River, and Middle River, span the years 1968-1975 and represent stations from 9 km outside the estuary mouth to 39 km upstream of the mouth.