Georgia Water Resources Institute
Annual Technical Report
FY 2005

Introduction

The GWRI mission is to foster the creation of partnerships, resources, and knowledge base necessary to address current water resources challenges in the state of Georgia, the U.S., and the world. Specific GWRI goals include:

a) Develop new research methods and scientific knowledge to support sustainable river basin planning and management; b) Educate scientists, engineers, and water professionals in state-of-the-science methods and their potential applications; and c) Disseminate useful information to policy makers, water managers, industry stakeholders, citizen groups, and the general public.

In keeping with the above-stated mission and goals, during Fiscal Year 2004, the Georgia Water Resources Institute (GWRI) was involved in a wide range of activities at the state, national and international levels. The following sections summarize these activities as they pertain to research, education, technology transfer, and professional and policy impact.

RESEARCH PROJECTS:

1. Phosphorus Storage and Transport in Headwaters of the Etowah River Watershed; sponsored by GWRI/USGS104B; 2. A Strontium Isotope Investigation of Possible Sewage Influx to Stream Base Flow in the Atlanta Metropolitan Region; sponsored by GWRI/USGS104B; 3. Decision Support For Georgia Water Resources Planning and Management; sponsored by GWRI/USGS104G; 4. ACF-ACT River Basin Assessments; sponsored by the Georgia Environmental Protection Division; 5. A Decision Support System for Water Resources Planning in the Huaihe River: sponsored by the Chinese Ministry of Water Resources; 6. INFORM: Integrated Forecast and Reservoir Management System for Northern California; sponsored by NOAA, the California Energy Commission, and CalFed; 7. The Impact of Precipitation Measurement Missions on Hydrologic and Water Resources Predictions; sponsored by NASA.

EDUCATION AND TECHNOLOGY TRANSFER:

1. Hydrologic Engineering for Dam Design; continuing education course.

PROFESSIONAL AND POLICY IMPACT:

GWRIs continued involvement with the INFORM project brings together all relevant agencies and stakeholder groups associated with the Sacramento and American Rivers in Northern California and provides opportunities for significant policy impact. Participating agencies include the National Weather Service, the US Army Corps of Engineers, the US Bureau of Reclamation, the Sacramento Flood Control Authority, US EPA, California Department of Water Development, and the California Energy Commission. The project aims at developing the institutional framework and technical tools necessary to support integrated river basin management.

At the state level, the project sponsored by the Georgia EPD is the first step toward a closer relationship between GWRI and the state of Georgia. The plan is for GWRI to provide technical support for the state water resources planning effort currently underway and scheduled to be completed by 2009. To this end, GWRI will have the opportunity to contribute and influence key state water resources decisions. This partnership ushers in an important new chapter in the history of GWRI.

Research Program

Decision Support for Georgia Water Resources Planning and Management

Basic Information

Title:	Decision Support for Georgia Water Resources Planning and Management
Project Number:	2004GA57B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	12
Research Category:	Not Applicable
Focus Category:	Management and Planning, None, None
Descriptors:	
Principal Investigators:	Kathryn Hatcher

Publication

Support for

Water Resources Planning and Management in Georgia

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SECTION 1. INTRODUCTION

Georgia Water Resources Conference (1989 – 2005)

The Georgia Water Resources Conference was begun in 1989 as a collaborative effort, with funding under the Water Resources Research Act of 1984, through the Georgia Water Resources Institute at Georgia Tech. The statewide conference has been held biennially since 1989, growing from the initial 87 presentations to over 240 presentations and panels, with a third day added in 2005 to include training courses. The nine volumes of proceedings (1989 – 2005) were originally published in printed form before each conference and are now available in electronic format, with approximately 1400 papers, on the website of the Georgia Water Resources Institute.

2005 Georgia Water Resources Conference

The ninth biennial Georgia Water Resources Conference was held April 25-27, 2005, to provide a forum for discussion of Georgia water resources and information relevant to the state's initiative to prepare a comprehensive statewide water resources management plan. Over 25 government, professional, and citizen organizations served to co-sponsor the conference and organize sessions and panels with over 250 speakers in these general tracks: State water plan and policy, Atlanta area water issues, water conservation, instream flow and restoration, watershed protection and TMDLs, flood mapping and stormwater, groundwater, coastal water issues, and river basins including Savannah, Etowah, Flint, and Chattahoochee Rivers.
Over 40 students from University of Georgia and Georgia Tech provided assistance for the conference sessions, policy panels and training courses.

The third day of the conference provided five all-day training courses on topics of interest to participants in the statewide water planning process:
(1) Shared Vision Planning Approach – Linking Participation and Water Planning through a Technical Systems Model, by U.S. Army Corps of Engineers' Institute for Water Resources;
(2) ArcHydro – Geographic Information System for Water Resources, by David Maidment, University of Texas;
(3) Introduction to the Clean Water Act for Watershed Stakeholders, by U.S. Environmental Protection Agency, Region IV staff;
(4) Water Quality Modeling using WASP software, by U.S. Environmental Protection Agency – Environmental Research Laboratory in Athens; and
(5) Stormwater Management using Locally-Based Planning and Management Tools, by University of Georgia, Biological and Agricultural Engineering; as well as
(6) Workshop on government programs with technical assistance and funding for water resources planning and management, organized by U.S. Army Corps of Engineers, Mobile District.

Policy Panels for Five State Water Issues

The Georgia Water Resources Conference included five panels, composed of stakeholders, experts and state program staff, organized to discuss five state water policy issues important for the statewide water planning process:
(1) protection of instream and downstream flows,
(2) water quantity allocation/reallocation among users,
(3) minimum aquifer levels protection policy,
(4) water quality allocation (TMDL allocation policy), and
(5) water conservation/efficiency and reuse policy.

Recommendations for Erosion and Sedimentation Control in Georgia

This section provides recommendations for improving the effectiveness of the Georgia Erosion and Sedimentation Control program as implemented under the Georgia Erosion and Sedimentation Control Act and the federal NPDES Georgia Stormwater General Permit for Construction Activities.

Best Practices in Water Resources Planning

A guide to best practices in water resources planning is needed for professionals involved in the developing the regional plans for Georgia. This project provides an interactive website with a guide to the current best professional procedures in water resources planning. It is interactive to allow users to easily contribute to and expand the scope of the online information.

Graduate Education in Water Resources Planning

The curriculum and requirements for a proposed masters degree in water resources planning are outlined here, to be offered jointly with University of Georgia and Georgia Institute of Technology. The courses match the content of the curriculum developed by the Universities Council on Water Resources and the U.S. Army Corps of Engineers for water resources planners.

SECTION 2. GEORGIA WATER RESOURCES CONFERENCE

2.1. Conference History

The Georgia Water Resources Conference was begun in 1989 as a collaborative effort of representatives from five organizations: U.S. Geological Survey, Georgia DNR Environmental Protection Division, University of Georgia, Georgia Institute of Technology, and Georgia State University. The first conference was initiated with funding under the Water Resources Research Act of 1984, through the Georgia Water Resources Institute at Georgia Tech. The Georgia Water Resources Institute continued to fund this biennial conference as it grew over the 1990s, and provided primary funding for the 2005 conference. From 1989 to 2005, the conference grew from 87 presentations and panels to over 240 presentations and panels, and added a third day to include training courses. The proceedings were published, for each conference listed below, in bound volumes for all years and also published in electronic format on compact disk for the 2003 and 2005 conferences.

Table 2.1. List of Published Proceedings of the Georgia Water Resources Conference

Proceedings of the 1989 Georgia Water Resources Conference
May 16 and 17, 1989
ISBN: 0-935835-01-6 LOC# 89-84386 (245 pages)

Proceedings of the 1991 Georgia Water Resources Conference
March 19 and 20, 1991
ISBN: 0-935835-02-4 LOC# 91-70247 (356 pages)

Proceedings of the 1993 Georgia Water Resources Conference
April 20 and 21, 1993
ISBN: 0-935835-03-2 LOC# 92-76060 (412 pages)

Proceedings of the 1995 Georgia Water Resources Conference
April 11 and 12, 1995
ISBN: 0-935835-04-0 LOC# 95-68015 (412 pages)

Proceedings of the 1997 Georgia Water Resources Conference
March 20, 21 and 22, 1997
ISBN: 0-935835-05-9 LOC# 97-71355 (550 pages)

Proceedings of the 1999 Georgia Water Resources Conference
March 30 and 31, 1999
ISBN: 0-935835-06-7 LOC# 99-61857 (604 pages)

Proceedings of the 2001 Georgia Water Resources Conference
March 26 and 27, 2001

ISBN: 0-935835-07-5 LOC# 2001087837 (793 pages)

Proceedings of the 2003 Georgia Water Resources Conference
April 23 and 24, 2003
ISBN: 0-935835-08-3 LOC# 2003104494 (900 pages)

Proceedings of the 2005 Georgia Water Resources Conference
April 25, 26 and 27, 2005
ISBN: 0-935835-09-1 LOC# 2005926249 (931 pages)

2.2. Electronic Proceedings (1989-2005)

As part of this project, the earlier bound volumes have now been converted into electronic format and are being made available on the website of the Georgia Water Resources Institute (www.gwri.org). The website has a combined Table of Contents for all the volumes (1989-2005) which can be electronically searched by author, organization, and keyword in the paper's title, for over 1200 papers. Each paper is hyperlinked to its page number in the Table of Contents; the user can click on the hyperlinked page number to bring up the corresponding paper (in pdf file format) on his computer screen.

2.3. The 2005 Georgia Water Resources Conference

The ninth biennial Georgia Water Resources Conference was held April 25-27, 2005, at the Georgia Center for Continuing Education, Athens, Georgia. In addition to its traditional purpose of providing a biennial forum for presentation and discussion of major water projects, issues, programs and research in Georgia, the 2005 conference was designed with an additional purpose -- to provide information relevant to the state's initiative to prepare a comprehensive statewide water resources management plan by 2008.

The conference steering committee, which sets the goals and theme for the conference, consisted of representatives from the five main sponsors including U.S. Geological Survey, USDA Natural Resources Conservation Service, University of Georgia, the director of the Georgia Water Resources Institute and the director of the Georgia Environmental Protection Division. The Georgia EPD director selected the conference theme, "Creating Georgia's Sustainable Water Future," and gave the plenary session presentation on Georgia's initiative to develop a comprehensive statewide water resources management plan. Governor Sonny Perdue gave the keynote conference address on Georgia water resources.

In addition to the five main sponsors, the conference was supported by over 20 co-sponsoring organizations and a program committee of co-sponsor representatives, who organized 36 of the 70 sessions and panels presented at the conference, and provided exhibits and conference promotion.

Conference Co-Sponsors

The conference is sponsored by: U.S. Geological Survey, Georgia Department of Natural Resources, University of Georgia, Georgia Institute of Technology – Georgia Water Resources Institute, and USDA Natural Resources Conservation Service.

Additional co-sponsors include Georgia offices of:
- American Society of Civil Engineers
- American Water Resources Association
- American Water Works Association
- Association County Commissioners of Georgia
- Georgia Municipal Association
- Georgia Department of Community Affairs
- Georgia Forestry Commission
- Georgia Soil and Water Conservation Commission
- Georgia Pollution Prevention Assistance Division
- Georgia Water & Pollution Control Association
- Georgia Ground Water Association
- Georgia Lake Society
- Georgia Water Wise Council
- National Weather Service, SE River Forecast Center
- Natural Resources Conservation Service (SCS)
- Soil and Water Conservation Society
- Soil Science Society of Georgia
- The Georgia Conservancy
- Upper Chattahoochee River Keeper
- Water Environment Federation
- U.S. Army Corps of Engineers, Mobile/Atlanta/Savannah
- U.S. Environmental Protection Agency, Region 4
- U.S. Environmental Protection Agency, ERL
- U.S. Fish and Wildlife Service

Student Participation

Over 40 students from the University of Georgia and Georgia Institute of Technology provided volunteer assistance to the conference. Thirty-six students served as moderator assistants during the conference sessions, operating the A/V equipment and lighting. Three students provided technical and computer assistance for the all-day training course on the ArcHydro software. Ten students provided research assistance during spring semester for the five water policy panels. The student chapter of American Water Resources Association organized the Monday evening event with speaker for the conference, and also organized the team of students who served as moderator assistants. One graduate student, funded by a research assistantship, helped with editing and peer reviewer correspondence for 200+ papers published in the conference proceedings.

Conference Technical Program

The conference agenda included over 250 speakers in 70 sessions, with sessions on the Etowah River, Savannah River, Chattahoochee River Basin, Flint River Basin, and Coastal Georgia. The session and panel topics, each with 3-5 speakers, are listed below with the session organizer indicated.

Note: Each technical session listed below included 3-5 speakers. Over 200 papers from these sessions are published in the printed conference proceedings and all are available online for viewing or download from the website of the Georgia Water Resources Institute.

TRACK 1. STATE WATER PLAN AND POLICY
+ Water Allocation Legal Issues
+ Regional Water Plans in Georgia (GaEPD)
+ Plenary Session: Carol Couch, GaEPD Director
+ Panel: Perspectives on State Water Plan Process (GWC)
+ Panel: Policy on Water Allocation/Reallocation (UGA)
+ Poster and Exhibit Session (USDA-NRCS)
- Low Impact Development
- Integrated Water Resources Planning
- Legislative Update and Water Law
- Panel: Indicators of Sustainability (GaDNR-P2AD)
- Conflict Resolution
^ Technical and Financial Assistance Programs (USACE-SAM)
^ Technical and Financial Assistance Programs II (USACE-SAM)
^ Adopt-A-Stream Monitoring field demonstrations (GaEPD)

TRACK 2. ATLANTA AREA WATER ISSUES
+ Public Education and Awareness (ARC)
+ Atlanta Area Stream Quality
+ Metro District Water Plans Development (MNGWPD)
+ Metro District Water Plans Implementation (MNGWPD)
- Panel: ACF River Federal Water Requirements
- ACF River Basin Water Negotiations
- Sustainable Mgt w/Lake Lanier Reuse (GW&PCA)
- Atlanta Water Supply Issues
- Sewage Overflow and Infrastructure
^ Full-day Course on Basin Planning (USACE-IWR)

TRACK 3. INSTREAM FLOW AND RESTORATION
+ Instream Flow Guidelines for Georgia (TNC)
+ Instream Flow Studies (Entrix Inc.)
+ Panel: Policy on Instream/Downstream Flow Protection (UGA)
+ Streamflow vs Fish Distribution
- Aquatic Ecosystems
- Imperiled Aquatic Species (USFWS)
- Etowah River Habitat Conservation Plan (USFWS)

- Stream Restoration (USACE-SAD)
- Ecosystem Restoration
^ Full-day Course on Clean Water Act (USEPA Region4)

TRACK 4. FLOOD MAPPING, WATER CONSERVATION
+ Floodplain Mapping using GIS (AWRA-Ga)
+ GIS Applications in Water Resources (GaEPD)
+ River Flood Forecasting (NWS-SERFC)
+ Watershed Assessment
- Georgia Sustainability Initiative (GaDNR-P2AD)
- Water Conservation in Landscape (GWWC)
- Water Conservation
- Potable Water Reuse (GW&PCA)
- Panel: Policy on Water Conservation and Reuse (UGA)
^ Full-day Course on GIS Use for Water Resources (GaEPD)

TRACK 5. WATERSHED PROTECTION
+ Stream Riparian Buffers
+ Runoff Impacts to Stream Quality
+ Stream Quality Studies
+ Stream Data for TMDL Models
- Watershed Alliances and Education
- Watershed Management (USEPA Region4)
- Water Quality Permit Trading
- Panel: Policy on TMDL Allocation/Reallocation (UGA)
- TMDL Plans Development (USEPA Region4)
^ Full-day Course on Water Quality Modeling (USEPA-ERL)

TRACK 6. STORMWATER, SAVANNAH RIVER
+ Stream Channel Restoration
+ Adequacy NPDES Stormwater Regulations
+ Panel: Erosion & Sediment Control (ASCE-Ga)
+ BMPs for Runoff Control (ASCE-Ga)
- Gwinnett County Stormwater Program I (Gwinnett Co)
- Gwinnett County Stormwater Program II (Gwinnett Co)
- Savannah River Basin Models (USACE-SAV)
- Panel: Savannah River Basin Water Use GA/SC (USACE-SAV)
^ Full-day Course on Stormwater Management (UGA-Engr)

TRACK 7. GROUND WATER ISSUES
+ Conservation Tillage (SWCS-Ga)
+ Piedmont Ground Water Supply I (GGWA)
+ Piedmont Ground Water Supply II (GGWA)
- Education for Private Well Owners I (UGA-CES)
- Education for Private Well Owners II (UGA-CES)
- Irrigation Water Use in Georgia
- Flint River Basin Models

^ Surface and Ground Water Interactions
^ Coastal Ground Water Levels and Management
^ Panel: Policy on Minimum Ground Water Levels (UGA)
^ Savannah Harbor Dredging Effects on Ground Water
^ Ground Water Contamination

Workshops and Training Courses

The third day of the conference consisted of workshops and one-day training courses. The agenda and contact information for each workshop are available in the online version of the conference proceedings on the website of Georgia Water Resources Institute.

* Workshop on Multiple Agency Programs with Technical Assistance and Funding for Water Resources Planning and Management, hosted by US Army Corps of Engineers-Mobile District.

* Workshop on Adopt-A-Stream Monitoring (field demonstrations), by Georgia Environmental Protection Division, Adopt-A-Stream program www.riversalive.org/aas.htm

* Course on the Shared Vision Planning Approach - Linking Participation and Water Planning through a Technical Systems Model, by US Army Corps of Engineers, Institute for Water Resources www.iwr.usace.army.mil

* Course on ArcHydro: GIS for Water Resources, with application for the Upper Ocmulgee watershed in Georgia, by Dr. David Maidment, University of Texas, and Jack Hampton, PBSJ [48 seats in computer lab] Organized by Georgia Environmental Protection Division. http://www.ce.utexas.edu/prof/maidment/

* Course on Introduction to Clean Water Act for Watershed Stakeholders, by US Environmental Protection Agency Region IV. www.epa.gov/r5water/cwa.htm

* Course on Water Quality Modeling using WASP software package, by US EPA Environmental Research Laboratory, Athens. www.epa.gov/AthensR/research/modeling/wasp.html

* Course on Stormwater Management using Locally-Based Planning and Management Tools, by University of Georgia, Biological and Agricultural Engineering Department.

SECTION 3. POLICY PANELS FOR FIVE STATE WATER ISSUES

The conference program plans, which were outlined in summer 2004 to support the state's comprehensive water plan process, were modified in fall 2004 by the conference steering committee after Governor Perdue expressed his wish that the state water plan process would emphasize resolving state water policy issues which were discussed leading up to the legislation mandating the state water plan. To adjust to this new direction, five water policy panels were added to the conference agenda to foster discussion of several of the key state water policy issues:

1. Protection of Instream and Downstream Flows
2. Water Quantity Allocation/Reallocation among Users
3. Minimum Aquifer Levels Protection Policy
4. Water Quality Allocation (TMDL allocation policy)
5. Water Conservation/Efficiency and Reuse Policy

These five topics were selected for the conference by the chair of the Georgia Water Council (the director of the Georgia Environmental Protection Division), responsible for developing the state water plan (www.georgiawatercouncil.org). Each panel consisted of five panelists: a DNR-EPD representative (nominated by the EPD director) to summarize Georgia's current policy and procedures; three panelists representing diverse stakeholder groups to summarize their group's desired policy choice and view of the pros/cons for the policy choices; and a technical or legal expert. The purpose of the panels was to begin a policy dialogue and provide information useful as background for the Georgia Water Council in considering several of the key state water policy issues facing Georgia. The panels were not intended to reach consensus or to make recommendations, only to provide useful background information about the difficult water policy issues, the policy choices available, and the pros/cons of each choice from the perspectives of the major groups concerned with the issue. The five panels discussions were held during the conference, with four of the interim panel papers included in the conference proceedings (see list under publications) and available online from website of the Georgia Water Resources Institute.

Student Participation

Teams of graduate students provided research assistance for topics related to each panel's water issue. The students were grouped into five interdisciplinary teams, one for each panel, with each team assigned a student from ecology, economics, and public administration. The students also served as assistant moderators or moderators for the panel discussions during the conference, with their contributions recognized in the panel papers in the conference proceedings.

Publications

These publications are available online.

Hatcher, Kathryn J. (editor), Proceedings of the 2005 Georgia Water Resources Conference, Volumes I and II, April 25-27, 2005, Athens, Georgia; sponsored by U.S. Geological Survey, Georgia Department of Natural Resources, USDA Natural Resources Conservation Service, Georgia Institute of Technology – Georgia Water Resources Institute, and The University of Georgia, Athens GA, 931 pages.

Bomar, Robert, Joel Cowan, Ciannat Howett, Kevin Farrell, David Newman, Michael Wald, Kathryn Hatcher, "State Water Policy Alternatives for Water Allocation and Reallocation," in: Proceedings of the 2005 Georgia Water Resources Conference, The University of Georgia, Athens GA, pp. 37-43.

Biagi, John, Jerry Ziewitz, Brian Richter, Bob Scanlon, Billy Turner, Kathryn Hatcher, "State Water Policy Alternatives for Instream and Downstream Flow Protection," in: Proceedings of the 2005 Georgia Water Resources Conference, The University of Georgia, Athens, GA, pp. 270-278.

Keyes, Alice Miller, Cindy Daniel, Shana Udvardy, Brian Skeens, David Bennett, Kathryn Hatcher, "State Water Policy Alternatives for Water Conservation/Efficiency and Reuse," in: Proceedings of the 2005 Georgia Water Resources Conference, The University of Georgia, Athens GA, pp. 459-468.

Williams, Vince, Curry Jones, Shana Udvardy, Bill White, Matt Harper, Candace Connell, Kathryn Hatcher, "State Water Policy Alternatives for TMDL Allocation and Reallocation," in: Proceedings of the 2005 Georgia Water Resources Conference, The University of Georgia, Athens GA, pp. 567-575.

SECTION 4.

RECOMMENDATIONS FOR GEORGIA EROSION AND SEDIMENTATION CONTROL

This section provides recommendations for improving the effectiveness of the Georgia Erosion and Sedimentation Control program as implemented under the Georgia Erosion and Sedimentation Control Act and the federal Stormwater General Permit for Construction Activities.
The document is intended to be read online so that the embedded hyperlinks can be used.

4.1. Public Website on Georgia Erosion and Sediment Control

An interactive public website describing the Georgia Erosion and Sediment Control Program has been set up in the form of an online guide at
http://en.wikibooks.org/wiki/Georgia_Erosion_and_Sedimentation_Act
The website includes a description of the relevant laws and the Georgia management program, with hyperlinks to the key references for the program.

4.2. Georgia's Erosion and Sedimentation Control Program

The legal authority guiding Georgia's erosion and sedimentation control program is given by:

(1) Georgia Erosion and Sedimentation Control Act of 1975 (OCGA 12-7-1), amended in 2003 by HB 285, with the Rules adopted by the Georgia Board of Natural Resources,

(2) U.S. Clean Water Act (Federal Water Pollution Control Act of 1972, as amended 1987 to add stormwater regulation) section 402, administered by the U.S. Environmental Protection Agency with delegated authority to the Georgia Environmental Protection, with USEPA oversight, and

(3) NPDES Georgia Stormwater General Permit for Construction Activities (GAR100003) of August 2003 issued by the U.S. Environmental Protection Agency under the U.S. Clean Water Act, to the Georgia EPD, with required consistent state Rules adopted

under the Georgia Water Quality Control Act by the Georgia Board of Natural Resources.

The state Act (1) and the federal Clean Water Act (2) are both implemented by requiring permits for land-disturbing construction activities which, if not properly managed, could cause impairment of stream water quality due to sediment in stormwater runoff from the site. The permits specify conditions for protecting the stream water quality. Two general administrative approaches for protecting stream quality are: prohibit bad results (prohibit site discharges which cause violation of stream quality standards), or prohibit bad procedures (prohibit improper site erosion control methods). The 2003 NPDES Georgia Stormwater General Permit (3) uses a combination approach; it prohibits bad results if bad procedures have been used. The state Act was amended in 2003, partly to provide consistency with the 2003 federal General Permit and partly to remedy widespread criticism about the ineffectiveness of the state Act and its administrative program.

Provisions of the Stormwater General Permit for Construction Activities

The Georgia Stormwater General Permit was issued to the state in 2003 by the U.S. Environmental Protection Agency under the provisions of the U.S. Clean Water Act and after negotiations to reduce water quality monitoring requirements (to detect bad results) in exchange for increased inspections (to detect bad procedures). The General Permit provides coverage (from prosecution for causing violation of stream quality standards) for the permittee if the permittee has properly designed, installed and maintained erosion controls for the construction site. The General Permit's provisions and administrative background are summarized in the EPD Fact Sheet (Appendix C here). Table 4-2 provides a list of steps for permittees to meet requirements of the Georgia Stormwater General Permit for Construction Activities (GAR100001).

Provisions of Georgia Erosion and Sedimentation Act of 1975 (as amended 2003)

The state Act requires operators of land-disturbing activities to obtain a permit from the local government or EPD, to design a pollution prevention plan (an erosion and sedimentation control plan using best management practices according to state manual guidance), to install and maintain the erosion control plan, to inspect the plan installation. But the state Act does not penalize a permittee when stormwater runoff from his site causes stream water quality impairment if he has correctly designed, installed and maintained the erosion control plan.

The Act requires a permit for land-disturbing activities of greater than 1.0 acre, particularly land development (construction) activities, while exempting several other types of land-disturbing activities listed here:

- surface mining and granite quarrying
- minor activities such as home gardens and landscaping
- agricultural operations (exempt per CWA 502(14); see EPA website, BMP manual)
- projects conducted under supervision of USDA-NRCS
- projects of the Georgia Department of Transportation (NRC BMP manual)
- county road construction and maintenance (see EPA website guides)

- public water utility reservoirs

With partial exemptions for

- forestry activities (see Forestry guides on EPA website)
- utility company's activities
- state road and tollway authorities
- projects less than one acre of disturbed soil area.

Administration of the Georgia Erosion and Sedimentation Control Act

The responsibility for administering the state Act is spread among several state and local agencies. A brief list of duties for each agency is given below, based on the summary from the State Performance Audit Report (2001, and 2004 follow-up) and from House Bill 285 (2003).

Local governments may request to be designated by Georgia EPD as a "local issuing authority" (LIA) for the permits. The LIA's responsibilities include:

- adopt an approved comprehensive ordinance for land-disturbing activities
- employ qualified personnel for implementing the ordinance
- review and approve permittees' erosion control plans within 45 days (OCGA 12-7-9)
- review and approve permit applications
- deny permit applications from two-time violators (optional, OCGA 12-7-7(f))
- require permittee to post a bond of $3000 per acre (optional), if LIA has hearing statute
- inspect permittees' project sites
- enforce the permits it issues (OCGA 12-7-7(b))
- respond to complaints

The regional State Soil and Water Conservation District's responsibilities include:

- approve erosion control plans within 35 days (12-7-10)(or delegate approval to LIA)
- approve an LIA's request for authority to approve erosion control plans (12-7-7(e))
- periodically review the ESC programs of the LIA (12-7-8)
- notify the EPD and request investigation if any deficient LIA program is found (required)
- provide technical assistance to any county or municipality for its ESC program

The State Soil and Water Commission, in Athens, responsibilities include:

- review permittees' erosion control plans
- periodically review the ESC programs of the LIA (12-7-8)
- notify the EPD and request investigation if any deficient LIA program is found (required)
- provide technical assistance to any county or municipality for its ESC program
- respond to complaints

- implement training and exam program for certification of qualified professionals (2003)
- approve trainers and instructor qualifications
- establish requirements for renewing certification (12-7-19)
- establish procedures for revoking certification, with EPD and Stakeholder Advisory Board
- publish and update the "Manual for Erosion and Sediment Control in Georgia"

Georgia Environmental Protection Division

- issue permits in jurisdictions having no certified LIA
- inspect project sites
- review the ESC programs of the LIA (12-7-8) (authorized, not required)
- approve or revoke the certification of a local government as a LIA
- enforce an action if the LIA has failed to secure compliance (12-7-8)
- issue a Stop Work order for certain offenses (12-7-12)
- respond to complaints
- administer the permit fee system ($80 per acre of disturbed land)
- develop (with P2AD) an electronic filing and reporting system for the program

Table 4.1. Guidance for Permittees to meet Requirements of the Georgia Stormwater General Permit for Construction Activities (GAR100001)

Source: Excerpts, with modifications, from powerpoint presentation, "NPDES Construction Stormwater Permits," by Georgia DNR Pollution Prevention Assistance Division, http://www.gadnr.org/p2ad/Assets/ppt_files/Construction_SW_Permits.ppt

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Obtaining Permit Coverage

- Determine which permit is required for your project. (The land owner or operator of a land disturbing activity over 1.0 acre is required to obtain permit coverage.)
- Obtain copy of Notice of Intent (NOI) form for that permit and permit fee form from EPD's website at www.gaepd.org – click on "Technical Guidance" and then "Storm Water"
- Submit NOI form by return receipt certified mail, at least 14 days before beginning construction
- Copy of NOI to Local Issuing Authority (LIA, which is local government)
- Pay permit fee of $80 per acre of disturbed land. Send half to EPD and half to LIA.

Erosion and Sedimentation Control Plan

- An Erosion, Sedimentation and Pollution Control (ES&PC) Plan must be developed, implemented and maintained for all permitted construction sites

- Plan developed for entire project by the primary permittee
- Plan must be designed by a qualified professional (passed certification training exam)
- ES&PC Plan must include Best Management Practices (BMPs) consistent with the "Manual for Erosion & Sediment Control In Georgia"
- Plan must also identify all other potential sources of storm water pollution and appropriate BMPs for managing them
- ES&PC Plan requirements in Part IV of the permit
- For new sites, the ES&PC Plan must be completed <u>before</u> beginning construction
- Plan must be kept on site or at a readily available location

Plan Submittals

- For new projects that will disturb equal to or greater than 50 acres, submit a copy of the ES& PC Plan to the EPD District Office <u>with the NOI</u>
- For all projects located in a jurisdiction where there is no local issuing authority for LDA permits, submit a copy of the Plan to EPD's Water Protection Branch <u>and</u> copies of the NOI and the Plan to the appropriate local Soil & Water Conservation District Office for information / review

Inspections

- ES&C plan designer inspects plan installation within 7 days of construction start; notifies permittee who must remedy any installation problems within 2 days
- Inspections by qualified personnel only (must have passed the certification training exam)
- <u>Daily</u> at vehicle entrances & exits and areas where petroleum products are used, stored, or handled
- <u>Weekly</u> and <u>within 24 hours</u> of each ½ inch or greater storm event: disturbed areas, storage areas, structural BMPs, and outfall locations
- <u>Monthly</u> inspections of final stabilized areas
- If BMP deficiencies are found during an inspection, they should be corrected immediately and the Plan must be revised as appropriate <u>within seven days</u>

Sampling Requirements

- Note: A separate Comprehensive Monitoring Program (CMP) is not required by the new permits
- Two sampling events over the course of the project – sample all receiving waters and/or outfalls: (a) First ½ inch or greater rain event during normal business hours that occurs <u>after clearing and grubbing</u>, and (b) Second from a ½ inch or greater rain event that occurs <u>either 90 days after the first event or after all mass grading</u> operations have been completed

- When BMP deficiencies exist during one of the two required sampling events, corrective action must be defined and implemented within two days
- Additional sampling must be conducted for every ½ inch or greater rainfall event during normal business hours until deficiencies are corrected or turbidity standard is attained

Reporting

- Submit monitoring results by the 15th day of the month following the sampling event
- Reports should include name and location of project, name(s) of sampling personnel, sample locations, date and time of sampling, and sampling results
- Reports submitted to EPD District Office

Termination of Coverage

- Submit Notice of Termination (NOT) when entire project has undergone final stabilization, all storm water discharges associated with construction activity have ceased, and the site is in compliance with the permit
- Final Stabilization = ALL soil disturbing activities have been completed AND 100% of soil surface is covered in permanent vegetation with a density of 70% or more, or equivalent permanent stabilization measures have been used
- If change in Owner/Operator – notify next Owner/Operator; NOI submittal
- Copy of NOT to Local Issuing Authority

Likely Areas of Enforcement

- Failure to submit NOI to obtain permit coverage
- Failure to prepare, implement, or maintain ES&PC Plan
- Improper installation & maintenance of BMPs
- Failure to conduct turbidity sampling
- Incomplete record keeping and reporting
- Improper BMPs resulting in turbidity numbers exceeding Appendix B values
- Failure to pay fee

4.3. Previous Reviews of Georgia Erosion and Sedimentation Control Program

The state Act has been amended several times to attempt to remedy program deficiencies and controversial provisions, most recently in 2003 by HB 285 which noted:

> "12-7-2. It is found that soil erosion and sediment deposition onto lands and into waters within the watersheds of this state are occurring as a result of widespread failure to apply proper soil erosion and sedimentation control practices in land clearing, soil movement, and construction activities and that such erosion and sediment deposition result in pollution of state waters and damage to domestic, agricultural, recreational, fish and wildlife, and other resource uses. It is therefore declared to be the policy of this state and the intent of this chapter to strengthen and extend the present erosion and sediment control activities and programs of this state and to provide for the establishment and implementation of a state-wide comprehensive soil erosion and sediment control program to conserve and protect the land, water, air, and other resources of this state."

The 2003 amendments to the state Act provided several improvements to remedy some of the weaknesses which had been noted in earlier reviews of the state program's effectiveness.
In 2001, three groups reviewed the state's erosion and sedimentation control program; their reports are referenced here, with selected statements regarding program weaknesses and recommended improvements.

1) Georgia Department of Audits and Accounts (by request of the Chairman of the Senate Appropriations Committee and the Georgia Board of Natural Resources - resolution adopted 24 January 2001) with report: "Performance Audit - Erosion and Sediment Control Program, DNR Environmental Protection Division and State Soil and Water Conservation Commission, September 2001," by Performance Audit Operations Division, Georgia Department of Audits and Accounts; with follow-up 2004 Review.

2) The Erosion and Sedimentation Control Technical Study Committee (known as the Dirt II Panel) with report: Repairing the Chattahoochee - The Dirt II Technical Panel Completion Report, A Summary of the Work, Findings, Recommendations,and History of the Erosion and Sedimentation Control Technical Study Committee, published by the Chattahoochee-Flint Regional Development Center, Franklin, Georgia, July 2001.
http://www.gaepd.org/Files_PDF/techguide/wpb/dirt2/tpcr_published.pdf

3) Staff of the National Academy of Public Administration, under contract as part of the Dirt II Panel's project. Dirt II Panel Completion Report, Appendix A-
"Policies to Prevent Erosion in Atlanta's Watersheds: Accelerating the Transition to Performance," policy paper by the National Academy of Public Administration, January 2001, as Appendix A in the Dirt II Technical Panel Completion Report (online at EPD as the NAPA Report)
http://www.gaepd.org/Files_PDF/techguide/wpb/dirt2/napa_published.pdf

NAPA Report (2001)

Some quotes from the NAPA Report are given here:
http://www.gaepd.org/Files_PDF/techguide/wpb/dirt2/napa_published.pdf

"The system has the potential to work well, provided all of those licensed professionals are well trained in the standards and their professions, and fulfill their responsibilities honestly. EPD will have to enforce the system vigorously to make it clear from the start that the professionals will lose money, reputation, and possibly their license if they certify work that fails to perform as promised."

" Maintaining the integrity of that extended enforcement system will require a sufficient number of EPD personnel who can review plans, inspect construction sites, and monitor stormwater runoff. If EPD does not devote the personnel to "checking the checkers," the entire system will probably fail. The licensed professionals who certify the work must have confidence that their colleagues at other sites are adhering to the same high standards as they are. Otherwise, contractors or developers will push them to compromise on their standards in order save the developers a few out-of-pocket dollars. If the public loses confidence in the network of professionals, EPD will have to bear all of the responsibility of inspecting the projects and enforcing the permits, and that would take significantly more people than checking the checkers." (page 24 of NAPA report)

"If EPD simply stores the monitoring reports in a file, they will have no such impact. If EPD were to post the reports on a web site, or better yet, require all permit holders to post them there within 24 hours after a storm, the monitoring reports could become an effective driver for improvements in erosion prevention, sediment control, and water quality." (page 26 of NAPA report)

"If there are no negative financial or legal consequences to sloppy construction and the resulting degradation of the waters of the state, that is what the system will produce." (page 29 of NAPA report)   The report mentioned possibility of (a) state and local governments having provision to only contract with firms which have demonstrated good performance in past projects regarding erosion control, or (b) put cash bonuses into contracts to reward good performance, or (c) local government ordinances to require a bond ($3000 per acre) but refund part of it with refund amount depending upon performance in erosion control, based on monitoring result.

Dirt II Panel Completion Report (2001)

The Dirt II Panel provided a list of recommendations, targeted to the various organizations involved in the program. A few of those recommendations are listed here.

"The new permit system requires a series of licensed professionals involved in projects to certify that their work complies with the permit and state standards. That system can work efficiently, but only if EPD guarantees its integrity by exposing false certifications and deterring fraud."

"*Require frequent electronic reporting of monitoring results*. The federal permit requires developers to monitor stormwater runoff during construction and to report the results monthly to EPD. The permit gives EPD the authority to require more frequent reporting, however, and to specify the format of that reporting. EPD should require developers to post monitoring results on an EPD web page within a day or two of a storm."

“The Legislature will need to ensure that EPD has the qualified staff required to rigorously review the development permit applications and to effectively enforce them on the ground. The Legislature may have to lead the investments in enhanced water-quality monitoring and web-based reporting that will make a performance-driven system work.”

“Professional associations should teach the well-recognized state-of-practice techniques to their members and help EPD expose any irresponsible members who would make the entire industry or profession look bad.”

“Government agencies should write their bid specifications to ensure that only competent, committed firms compete, and then write their contracts to reward strong performance and penalize sloppiness or actions that result in failure to perform.”

4.5. Recommendations

The first six recommendations listed below are based on Wight’s (1981) “six basic principles involved in managing anything, be it a manufacturing company, a public library, or the United Fund Drive. They are:

(1) Defining Objectives
(2) Assigning Accountability
(3) Developing Understanding
(4) Providing the Tools
(5) Measuring Performance
(6) Providing Incentives.”

The principles can be used systematically for improving a program by first listing all significant program participants and then checking the six management elements for each participant to confirm that they are adequately covered. If not, then the program evaluator will need to identify a way to add or improve the management element, which is usually done by identifying an action to be taken by a higher level participant to improve coverage of the management element for his supervisee. Key groups in the erosion and sedimentation control program include (in hierarchical order of supervision): the public, elected officials, USEPA, GaEPD and GaSWCC, Conservation Districts, local government LIA, land development project owners, general contractors and their ESC plan designers and inspectors, construction workers.

(1) Defining Objectives - Clear Statement of Program Requirements and Expectations

Each participant in the Georgia Erosion and Sedimentation Control Program needs to understand the overall goal, his role in the program and the expectations for performing that role successfully.
The key participants include:

* Citizens (stewards of the environment)
* Property Owners
* Developers/ Builders/Contractors
* Bulldozer Operators
* Professionals (designers of erosion control plans)

* Site Inspectors
* Local Governments (certified local issuing authorities)
* Conservation Districts
* Georgia Soil and Water Conservation Commission
* Georgia Environmental Protection Division
* U.S. Environmental Protection Agency
* Elected officials

The Georgia EPD should develop and post on its website a document to clearly list the legal requirements and the professional expectations for each significant participant in the Georgia Erosion and Sedimentation Control program.
This information could be covered in the certification training program required of most program participants, per OCGA 12-7-19(b)(4): "An awareness seminar (Level 1) will be established which provides information regarding the erosion and sediment control practices and processes in the state and which will include an overview of the systems, laws, and roles of the participants" (underlining added).

U.S. Environmental Protection Agency, NPDES General Permit for Stormwater Discharges from Construction Activities – Fact Sheet, January 21, 2005, contains detailed information on permit requirements (http://www.epa.gov/npdes/pubs/cgp2003_fs.pdf). This outlines the requirements for permittees, but similar information about requirements and accountability is needed for each of the other program participants as well.

(2) Provide Understanding (Education) to Enable Participants to Meet Expectations

To be effective, each program participant needs to understand his role and also to have the skills needed to perform the role successfully.
The 2003 amendments to the state Erosion and Sedimentation Control Act provide that (OCGA 12-719) "(a) After December 31, 2006, all persons involved in land development design, review, permitting, construction, monitoring, or inspection or any land-disturbing activity shall meet the education and training certification requirements, dependent on their level of involvement with the process, as developed by the commission in consultation with the division and the Stakeholder Advisory Board created pursuant to Code Section 12-7-20."
The Commission and Stakeholder Advisory Board should compare and cross-check the list of legal requirements and professional expectations (in Recommendation 1) with the training modules covered in the certification training program. Any missing training elements, such as training needed for local government officials to conduct an effective administrative program, should be identified and then developed or referred. The Stakeholder Advisory Board should document this cross-checking in its report or minutes to include a table showing the participants list in Recommendation (1) with the corresponding training module. The Commission should post this table on its webpage for the training program.
The certification exam should include questions to test each participant's understanding of the legal requirements and professional expectations for his role in the program.

Some of the participants listed in Recommendation (1) are not required to attend the education and training certification courses of the ESC program. Other groups do provide educational programs for these participants. Extensive education for citizens is provided by the Upper Chattahoochee Riverkeeper's program on "Get the Dirt Out" (www.getthedirtout.org). The Vinson Institute of Government at University of Georgia provides training for elected officials (www.cviog.uga.edu).

(3) Assign Accountability for Meeting Requirements and Expectations

All participants in the program, and the public, need to know who is accountable for which parts of the program. This information, with names and contact information for the responsible individuals (not just the program offices) should be posted and available online, especially for the state and local government agencies, with link to description of their responsibilities.
Georgia EPD should post this information on its website for the following program participants: USEPA, GaEPD, GaSWCC, Conservation Districts, and list of local government LIAs with link to the LIA webpage for ESC program (not just the main city webpage). The local government LIA's should post the specific local information, with names of local government program participants and their responsibilities, and also include contact information for any citizen organizations which request to be so listed. The Georgia EPD should consider requiring a local government to provide this information as a prerequisite for being certified as a local issuing authority. At least, providing accountability to the public should be included on the list of professional expectations (or legal requirements) for a local government, per Recommendation (1) and should be covered in the certification training course.

(4) Provide Resources and Tools Needed

All program elements need sufficient funding and resources to perform effectively. The funds authorized under the 2003 amendment (HB 285) in amount of $80 per acre of disturbed land need to be fully and properly allocated to the state and local agencies.

Help Kits. For each program participant listed in Recommendation (1), there should be an online Help Kit with information to help the participant do the best job, including: resources, guides, standard forms, "go-bys", links to good examples. The contents for each Help Kit could be recommended by panels consisting of representatives from each participant category.
The Georgia Department of Community Affairs provides an online ToolKit for Local Governments; this webpage could be adapted with an extended subpage specifically for the erosion and sedimentation control program. Similar websites are needed for each participant category, in addition to local governments.

Funding Sources. The grant program under Section 319 (see Appendix D here) of the U.S. Clean Water Act, administered in Georgia by the EPD, is a potential source of funding for initiatives to further develop and implement improvements in erosion and sedimentation control for land-disturbing activities not regulated under the NPDES program. A list of funding and technical assistance sources for program improvements is needed for each participant category.

(5) Measure Performance

It would be helpful for each program participant listed in Recommendation (1) to have a self-assessment form, which would list each of his responsibilities and professional expectations, and provide a scale for indicating level of performance. Even a rough scale, such as indicating "high" or "medium" or "low" level, would be useful. It would also be helpful to have a good example listed for each role, such as recognizing a local government LIA which has an outstanding erosion and sedimentation control program (Gwinnett County's program has been mentioned as a good example), with a description of the features which make an outstanding example.

USEPA provides some helpful self-audit materials and technical guidance online at
http://www.epa.gov/compliance/resources/publications/assistance/sectors/constructmyer.html
The Construction Industry Compliance Assistance Center also provides materials; see "Managing Your Environmental Responsibilities, III. Permit Requirements for Construction Projects"
http://www.epa.gov/compliance/resources/publications/assistance/sectors/constructmyer/myer1c_stormwater.pdf

For some program elements, a formal evaluation method is needed, such as the exam for the certification training courses or the certification of a local issuing authority.

A formal written evaluation procedure and detailed evaluation form or checklist are recommended for the program tasks marked by asterisk (*):
a) design of low impact project to protect environmental quality including stream buffers
b) design of site erosion and sedimentation control plan (*)
c) design of site water quality monitoring plan and assessment method (*)
d) contract language to specify operator's performance regarding ESC program compliance (provide a model contract language for a construction project)
e) evaluation and approval of ESC site plan (*)
f) approval of ESC permit application (*)
g) site inspection and report by the permittee's agent to the permittee, and follow-up procedure
h) site inspection and report by the LIA or EPD, and follow-up procedure (*)
i) evaluation of site monitoring data by the permittee
j) evaluation of site water quality monitoring data by EPD (*)
h) evaluation of local government application for certification as local issuing authority (*)
i) response to citizen complaints by LIA
j) response to citizen complaints by EPD

Good examples for each program element should be provided or referenced on EPD's technical guidance website. Technical guidance and links to the relevant certification training module could also be provided for each program task listed above.
The written evaluation procedures and form should be cross-checked with the legal requirements of the General Permit, the Clean Water Act, and the Georgia Erosion and

Sedimentation Control Act, and the rules/regulations for each. EPD should prepare this material and post on its website.

Annual Reports. Each agency (USEPA, GaEPD, GaSWCC, Conservation Districts, and each LIA) should prepare an annual report to summarize its activities, accomplishments and future plans for this program. The annual reports should be made available online, and linked from the GaEPD website. The outline and expectations for contents of annual reports should be specified, by the Governor for state agency programs and by the County/City Commissions for the local government programs. Citizen stewards are advised to contact their county/city commission to request to review the annual report specifications for the local erosion and sedimentation program and the permit fees. EPD should prepare a separate annual report regarding the permit fee system, to cover its administrative program and describing accountability of local governments for this program.

(6) Provide Incentives

Each program participant listed in Recommendation (1) needs sufficient incentives and recognition for good work, as well as penalties for inadequate work, with a clear understanding of this information. This information, along with procedures for distributing incentives and disincentives, should be summarized for each participant category, particularly the land-disturbance permittees, and posted online on websites appropriate for each participant category, and with a central directory with links to each external website.

Examples of existing programs which provide incentives and recognition include:
a) Georgia Department of Community Affairs, WaterFirst program
b) Georgia Department of Community Affairs, Signature Communities program
c) Keep America Beautiful provides community assessment and certification recognition.

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(7) Develop Prioritization Procedures for Major Time-Consuming Tasks
The following tasks in the program are major time-consumers for the overworked staff:

a) reviewing ESC site plans
b) site inspections
c) review of local goverments' LIA certification.

Procedures for streamlining and setting priorities for each task should be written and posted online. The prioritization scheme (who gets priority for inspection or audit) could also serve as motivation for permittees, if it is developed in concert with citizen complaint and response procedures.

Reviewing ESC Site Plans. This task could be done under contract with funds from the permit fee system. Now that all ESC plan designers are required to receive training and certification, there should be fewer cases of poor ESC plan designs. A written procedure is needed for handling cases where the submitted ESC plan is found to be inadequate, beyond simply returning the site plan as inadequate. The ESC plan designer should receive a warning after submitting one inadequate site plan design, and should have certification revoked after two inadequate plan designs. Land developers who submit more than two inadequate ESC plans (who persist in hiring poor ESC plan designers) should also be penalized, to prevent their shopping for plan designers who are most willing to compromise on the quality of the ESC plan design.

Prioritizing Site Inspections. The 2003 Stormwater General Permit requires that the ESC plan designer, who shall be a qualified professional, will visit the site within seven days of construction start to inspect the installation of the plan components for consistency with the plan specifications, and will report the inspection results to the permittee, who then has two days to correct any deficiencies. The plan designer is not required to report this inspection result to anyone else. The LIA or EPD could offer a voluntary program whereby the qualified plan designer, with permittee concurrence, certifies the inspection result and provides it to the LIA or EPD. Permittees who provide this voluntary information become a low priority for site inspections by LIA or EPD. High priority project sites are those which receive the most citizen complaints.

Electronic Filing and Reporting System. The last section of HB 285 added a provision authorizing the EPD to develop an electronic filing and reporting system to help reduce the manual workload. http://www.legis.state.ga.us/cgi-bin/gl_codes_detail.pl?code=12-7-22
"12-7-22. In order to achieve efficiencies and economies for both the division and the regulated community by the use of electronic filing for certain application and reporting requirements of this chapter and National Pollution Discharge Elimination System permits, the division and the Pollution Prevention Assistance Division of the department shall jointly work toward implementing such an electronic filing and reporting system as soon as practicable and allowable under federal regulations."

The EPD is currently working on the first stage of the electronic filing system, which will be an electronic version of the present NOI form. The electronic filing system can be used by EPD and local governments for cross-checking the permits (and acreages) filed under the state ESC Act and under the General Permit. A user can log in as a guest and print out a list of all active permits by county, for example. EPD is also considering a second stage of the electronic filing system which would include additional input and summary data fields.

Recommendations: (1) Ask the DNR Pollution Prevention Assistance Divsion (P2AD) staff to review the draft project and provide suggestions for how to make the system most helpful, from a pollution prevention perspective.

(2) The electronic filing system should be developed with attention to concerns about privacy of Georgia's citizens, particularly citizens who are operating on private property and who are not guilty of any offense.

(3) The electronic system should be developed to automate the citizen complaint and response procedures. Post a list of LIA's with online list of the complaint record (number complaints per number of active permits) for each LIA. Use this information in setting priorities for site inspections and local government audits.

(8) Recommendations Regarding Local Governments

Local governments have an important role in erosion and sedimentation control. This section outlines those responsibilities and provides recommendations for improving local government function.

Model Local Ordinance. Under the Georgia Erosion and Sedimentation Control Act, OCGA 12-7-4(a), "the governing authority of each county and each municipality shall adopt a comprehensive ordinance establishing the procedures governing land-disturbing activities which are conducted within their respective boundaries." The 2003 amendments added a statement encouraging the local governments to integrate the provisions of this ordinance with other local ordinances which address land development and environmental protection.
Recommendation: The model local ordinance (provided on EPD's website) should include the required provisions of the state Act for construction activities, as well as recommended optional provisions for managing additional categories of land disturbing activities which are exempt under the state Act, particularly road maintenance and forestry activities within the county. The counties already obtain notices of forestry activities for tax purposes. Local ordinances could provide for citizens to recover damages from erosion causing activities, possibly from permittee bonds up to $3000 per acre, which local governments are authorized (but not required) to collect under the Georgia Erosion and Sedimentation Control Act. For example, the concept of environmental damage recovery is used in the EPA and NOAA damage assessment and recovery programs, http://www.epa.gov/superfund/programs/nrd/primer.htm).

Local Government Contracting. From Dirt II panel: "Government agencies should write their bid specifications to ensure that only competent, committed firms compete, and then write their contracts to reward strong performance and penalize sloppiness or actions that result in failure to perform." Recommendation: Georgia Department of Community Affairs could post an example of a bid specification and model contract on their website in the Water Toolkit.

Enforcement of Local Ordinances – Environmental Courts.
Keep America Beautiful (www.kab.org) has an online toolkit for citizens to use in improving their communities, including model ordinances and guidelines for setting up an environmental court for localities where court support for enforcing local ordinances has been weak.
The Georgia Uniform Codes Act (1991) requires local governments to adopt administrative procedures, ordinances, and penalties to enforce. See ACCG notes on Uniform Codes Act and local communities.

Reviewing LIA Certification. Written procedures and checklists are needed for review of local governments for LIA certification and recertification. Note that the Districts and SWCC are required to report any deficiencies to EPD and are required to request EPD to investigate if any deficiencies are found in the LIA program. The Board of Natural Resources has developed rules for this certification and decertification; the rules need to be strengthened.

Assistance for Failing LIAs. The Georgia DCA, with participation of EPD and P2AD and SWCC, should develop a written procedure for providing assistance and remediation for local governments which are not meeting the legal requirements and professional expectations for their erosion and sedimentation control programs.

(9) Georgia Compliance with the NPDES Stormwater General Permit

The requirements for the Georgia Stormwater General Permit (2003), which were approved by the U.S. Environmental Protection Agency, provided some flexibility to the state, in allowing decreased stormwater quality monitoring at construction sites but with increased site inspections by the GaEPD. The regulated community in Georgia accepted the permit fee system of $80 per acre of disturbed land area, set up by HB 285, in exchange for reduced required stormwater quality monitoring which was estimated to save the development community about $20-$40 million per year. The collected permit fees would support, in part, the hiring of 80 additional site inspectors by the Georgia Environmental Protection Division. However, due to state revenue shortfalls, the State of Georgia used part of the collected permit fees for other purposes, and the Georgia EPD did not have sufficient funds to hire the expected number of site inspectors. EPD currently has 23 site inspectors.

Recommendation: The U.S. Environmental Protection Agency should determine whether the provisions of the Georgia Stormwater General Permit, as implemented rather than as promised, are sufficient to meet the requirements of the federal Clean Water Act. The citizen environmental organizations are advised to monitor what procedures USEPA uses to ensure that the provisions of the General Permit are being met.

(10) Well-Qualified and Well-Intentioned Personnel

The Georgia DNR and EPD should make an effort to hire the most qualified people for the positions in this program. The minimum qualifications should be specified appropriately and the position announcements should be posted on the state jobs website and widely distributed. EPD should have a written procedure for actively recruiting qualified applicants, posted online, and for selecting applicants. Citizen stewardship programs, such as the UCR's Get the Dirt Out program and the Keep Georgia Beautiful program and the Georgia Water Coalition, are advised to monitor the hiring program which is not under the State Merit System.

4.5. Related Presentations at Georgia Water Resources Conference

The following papers were presented at the 2005 Georgia Water Resources Conference on sediment and erosion control topics, covering technical and management methods as well as government and citizen initiatives. The papers are available in the printed and online conference proceedings at the Georgia Water Resources Institute (http://www.ce.gatech.edu/research/gwri/).

Growth Readiness for Georgia: Water Quality Matters, by Randy Hartmann, Georgia Department of Community Affairs; and Joel Haden, Sustainable Development Project Manager, Tennessee Valley Authority (p. 47). Presentation described the Non-point Source Education Project for Municipal Officials (NEMO), the Tennessee Growth Readiness program for local governments (with consensus review of local codes and ordinances), and also the new program for Georgia communities, called the Georgia Urban Nonpoint Source Reduction Program, by the Georgia Department of Community Affairs.

The Upper Flint River Watershed Alliance: Finding Solutions to Common Goals, by Leigh Askew and Corinne Blencoe, Office of Environmental Management, Georgia Department of Community Affairs (p. 533). Presentation described a coalition of city and county governments, landowners, regional and state agencies, environmental advocacy groups, and economic development and tourism representatives, to protect the unique resources of the Upper Flint River Watershed.

Achieving the WaterFirst Designation - Highlights of Five Communities, by Leigh Askew, Environmental Management, Georgia Dept of Community Affairs (p. 536). Presentation described the WaterFirst Community Program of the Georgia Department of Community Affairs, which provides recognition and reward for communities which go beyond the requirements of the law in managing and protecting water resources.

Water Education Tools For Specific Audiences, by Joseph A. Krewer, Georgia Department of Community Affairs (page 540). Describes the Water Resources Toolkit for Local Government and activity of Keep America Beautiful affiliates in educating citizens and local officials. http://www.georgiaplanning.com/watertoolkit/main.asp?PageID=24

FLOW: Forging Leadership in our Watershed, Garden Club of Georgia, by Becky Champion, Columbus State University, online at http://www.uga.edu/gardenclub/flow.html Describes a program of the Garden Club of Georgia for community-based watershed protection.

Coastal Region Training Center for the Georgia Adopt-A-Stream Program at Savannah State University, by Joseph P. Richardson, Marine Sciences Program, Savannah State University (p. 816)

Initiative for Watershed Excellence, by William L. Cox and Mark Nuhfer, U..S Environmental Protection Agency, Region IV (p. 543) Describes a project, funded by US EPA Region IV at University of Georgia, setting up a Watershed Management Support Institute to provide technical, organizational and legal assistance to watershed stakeholders and local goverments for activities such as permitting, enforcement, land use planning. See: http://www.rivercenter.uga.edu/service/iwe.htm

Controlling Construction Stormwater Runoff, by Alice J. M. Champagne, Upper Chattahoochee Riverkeeper (p. 586) Describes the Upper Chattahoochee Riverkkeeper's project, "Get the Dirt Out", funded by USEPA, to monitor the implementation and effectiveness of Georgia NPDES Stormwater General Permit in five watersheds, and to educate citizens, developers and local officials about the requirements. See extensive education and legal materials on website: www.getthedirtout.org

Panel: Erosion and Sediment Control, sponsored by Georgia Section of American Society of Civil Engineerr, Environmental Tech Group (p. 605)

Greenscapes and Greenbuilding: Integrating AEngineered Soils@ as a Stormwater Best Management Practice in Sustainable Landscape Construction, by Wayne King, Sr., ERTH Products LLC (p. 617)

Field Evaluation of Compost and Mulches for Erosion Control, by L. Mark Risse et al., University of Georgia (p. 621)

Land Use Effects on Suspended Sediment Yield in Six Small Georgia Watersheds, by J. Kenneth Bradshaw, et. al., University of Georgia (p. 486).

Phosphorus, Sediment, and E.coli Loads in Unfenced Streams of the Georgia Piedmont, USA, by Harris L. Byers, et al., University of Georgia (poster, p. 494)

Hydrologic and Sediment Transport Response to Forestry; Southwest Georgia Headwater Stream, by William B. Summer et al., University of Georgia (p. 858)

4.6. References

Georgia General Assembly, full text of 2003 HB 285 (as passed) which amends the Georgia Erosion and Sedimentation Act.
http://www.legis.state.ga.us/legis/2003_04/fulltext/hb285.htm

Georgia General Assembly, Georgia Erosion and Sedimentation Control Act (as amended 2003)
http://www.gaepd.org/Files_PDF/rules/rules_exist/ocga12-7-1.pdf
OCGA 12-7-1 Full text of Georgia Erosion and Sedimentation Control Act (as amended 2003)
http://gaswcc.georgia.gov/vgn/images/portal/cit_1210/18/53/56818622ocga12-7-1.pdf

Georgia Environmental Protection Division, Rules for Erosion and Sedimentation Control

Georgia Environmental Protection Division, NPDES Georgia Stormwater General Permit (GAR100003) under the U.S. Clean Water Act
http://www.getthedirtout.org/pdf/8a_GA_GenPermit.pdf
http://www.gaepd.org/Files_PDF/techguide/wpb/cnstrct_swp_commondev.pdf

Georgia Environmental Protection Division, Fact Sheet about the NPDES Georgia Stormwater General Permit for Construction Activities (GAR100003), June 26, 2003.
http://www.gaepd.org/Files_PDF/techguide/wpb/cnstrct_swp_factsheet.pdf

Georgia Environmental Protection Division, "Erosion and Sedimentation Control Procedures", technical guidance document, January 10, 2006. Online at:
http://www.gaepd.org/Files_PDF/
techguide/wpb/20060110_Erosion_and_Sedimentation_Control_Procedures_Final.pdf

Georgia Environmental Protection Division, Model Ordinance for Erosion and Stormwater http://www.gaepd.org/Files_PDF/forms/wpb/modelsoil.pdf

National Academy of Public Administration, staff policy paper, “Policies to Prevent Erosion in Atlanta's Watersheds: Accelerating the Transition to Performance**,”** 2001. (Online at Georgia EPD website as the NAPA Report), Appendix A of the Dirt II Panel Completion Report.
http://www.gaepd.org/Files_PDF/techguide/wpb/dirt2/napa_published.pdf

Dirt II Panel project completion report: Repairing the Chattahoochee - The Dirt II Technical Panel Completion Report, A Summary of the Work, Findings, Recommendations,and History of the Erosion and Sedimentation Control Technical Study Committee, published by the Chattahoochee-Flint Regional Development Center, Franklin, Georgia, July 2001.
http://www.gaepd.org/Files_PDF/techguide/wpb/dirt2/tpcr_published.pdf

Georgia Department of Audits and Accounts, Performance Audit Operatiions Division, “Performance Audit - Erosion and Sediment Control Program, DNR Environmental Protection Division and State Soil and Water Conservation Commission, September 2001” http://www.audits.state.ga.us/rptSearch/report/1518 with a follow-up review conducted in 2004: 2004 Review http://www.audits.state.ga.us/rptSearch/report/1749

Georgia Department of Community Affairs, Water Resources ToolKit for Local Governments, http://www.georgiaplanning.com/watertoolkit/main.asp?PageID=24

Georgia Stormwater Management Manual, Vol. I – Stormwater Policy Guidebook, and Vol. II – Technical Handbook, website from Atlanta Regional Commission: http://www.georgiastormwater.org/

U.S. Environmental Protection Agency, “National Management Measures to Control Nonpoint Source Pollution from Agriculture, EPA 841-B-03-004, July 2003
http://www.epa.gov/owow/nps/agmm/index.html

U.S. Environmental Protection Agency, Stormwater Permitting Program
http://cfpub1.epa.gov/npdes/home.cfm?program_id=6

U.S. Environmental Protection Agency, National Pollutant Discharge Elimination System - Regulations for Revision of the Water Pollution Control Program Addressing Storm Water Discharges; Final Rule, Federal Register Vol. 64, No. 235, pp. 68721-68851 (12/08/1999), CFR Title: 40, Part 9, 122 , 123, 124. “Phase II regulations expand the existing NPDES stormwater program (Phase I) by addressing stormwater discharges from small MS4s and construction sites that disturb 1 to 5 acres.”
http://cfpub.epa.gov/npdes/regresult.cfm?program_id=6&view=all&type=1

U. S. Environmental Protection Agency, Model Ordinances to Protect Local Resources - Erosion and Sediment Control, http://www.epa.gov/owow/nps/ordinance/erosion.htm

U.S Environmental Protection Agency**,** list of “Best Nonpoint Sources Documents” (2001)
http://www.epa.gov/owow/nps/bestnpsdocs.html

Upper Chattahoochee Riverkeeper, project on "Get the Dirt Out", Stormwater Permitting Guide to Land Disturbance Activities (a guide for developers), http://www.getthedirtout.org/pdf/GTDO_Permbroc_v03.pdf

Upper Chattahoochee Riverkeeper, project on Get The Dirt Out, Site Inspection Report Card (for use by citizens), http://www.getthedirtout.org/pdf/ReportCard_v5.pdf

Wight, Oliver W. "Chapter 6. The Old Principles of Management," in MPR II: Unlocking America's Productivity Potential, CBI Publishing Co., Boston, Massachusetts, 1981.

4.7. Appendix A - Organizations

Georgia Secretary of State, Construction Industry Licensing Board

Georgia Department of Community Affairs
* Construction Codes Program and State Codes Advisory Committee
* Georgia Uniform Codes Act (1991) requires local governments to adopt administrative procedures, ordinances, and penalties to enforce.
* Government Management Initiative Survey (uses electronic filing)
* Georgia Planning and Quality Growth Program http://www.georgiaplanning.com/
* Sample Local Ordinance for Sediment and Erosion Control http://www.dca.state.ga.us/development/PlanningQualityGrowth/programs/downloads/SoilErosionOrd.pdf
* Signature Communities Program, http://www.dca.state.ga.us/DCANews/PressReleaseDetail.asp?view=218

US Department of Agriculture, Rural Development
* State Staff: http://www.usda.gov/rus/water/states/ga.htm

Georgia Department of Transportation
* Transportation Online Policy and Procure System, by subject name http://www.dot.state.ga.us/topps/subname.shtml
* TOPPS, Appendix S - Erosion, Sedimentation and Pollution Control Plan, NPDES Phase I http://www.dot.state.ga.us/topps/pre/dir/4050-29.htm

Training Materials (webcast by TetraTech Inc. sponsored by EPA Office of Water) Stormwater Phase II: Developing an Effective Municipal Stormwater Management Program For Construction Sites (Construction 101)
http://cfpub.epa.gov/npdes/courseinfo.cfm?program_id=0&outreach_id=284&schedule_id=927

Atlanta Regional Commission, Stormwater Regulations

Metropolitan North Georgia Water Resources Management District
www.northgeorgiawater.org

Upper Chattahoochee Riverkeeper, program on "Get the Dirt Out"
www.getthedirtout.org

Nonpoint Source Education for Municipal Officials - Coastal Georgia NEMO Program
http://nemonet.uconn.edu/programs/about_members/ga/georgia.htm

Nonpoint Education for Municipal Officials (NEMO), University of Georgia Marine Extenstion Service. http://nemonet.uconn.edu/programs/about_members/ga/georgia.htm

Southeast Watershed Forum, with assistance for local governments including consensus review of local codes and ordinances.
http://www.southeastwaterforum.org/training/growthreadiness.asp

4.8. Appendix B – Georgia EPD Fact Sheet on NPDES Stormwater General Permit

Fact Sheet (June 26, 2003), Georgia Environmental Protection Division
http://www.gaepd.org/Files_PDF/techguide/wpb/cnstrct_swp_factsheet.pdf

NPDES Georgia Stormwater General Permit for Construction Activities (GAR100003)

The 1972 amendments to the Federal Water Pollution Control Act (FWPCA, also referred to as the Clean Water Act or CWA) prohibit the discharge of any pollutant to waters of the United States from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. Efforts to improve water quality under the NPDES program have focused traditionally on reducing pollutants in discharges from industrial and municipal wastewater treatment plants. Prior to 1990, efforts to address storm water discharges under the NPDES program have generally been limited to a few industrial categories with storm water effluent limitations.

In response to the need for comprehensive NPDES requirements for discharges of storm water, Congress amended the CWA in 1987 to require the U. S. Environmental Protection Agency (USEPA) to establish phased NPDES requirements for storm water discharges. To implement these requirements, USEPA published the Phase I permit application and other requirements for certain categories of storm water discharges associated with industrial activity, including construction activities, on November 16, 1990 (50 FR 47990) and April 2, 1992 (57 FR 11394). In conjunction with the federal regulations, the Georgia Environmental Protection Division (EPD) amended the Georgia Rules and Regulations for Water Quality Control (Rules) in April 1990 to allow the issuance of general NPDES permits. In January 1991, USEPA granted authority to EPD to issue general NPDES permits.

In September 1992, EPD issued the first of five different general NPDES permits for construction activities. Each of these permits was administratively appealed and did not become effective. The Phase I general NPDES permit developed during the course of settlement negotiations with the participating parties became effective on August 1, 2000, and regulated construction activity disturbing between five and 250 acres. This permit is set to expire on July 31, 2003.

The USEPA established the Phase II storm water regulations on December 8, 1999, in order to regulate construction sites that disturb between 1 and 5 acres. In conjunction with the federal regulations, the Georgia Environmental Protection Division (EPD) amended the Georgia Rules and Regulations for Water Quality Control (Rules) in April 2001 to incorporate all Phase II regulations.

EPD proposes to issue three NPDES general permits that will authorize the discharge of storm water from three distinct types of construction activity. These permits are expected to become effective on or about August 1, 2003, and will regulate all construction activity disturbing 1 or more acres. The first permit regulates stand-alone construction activity (GAR100001); the second regulates infrastructure (i.e., linear) construction sites (GAR100002); the third regulates common development construction (GAR100003). Each permit will contain significant common language and requirements as well as individual differences specific to each type of activity. In preparing the proposed permits, the Director of the EPD considered the goals, objectives, and public policies embodied in the Georgia Water Quality Control Act, O.C.G.A. §§ 12-5-20 *et seq.*, and the Erosion and Sedimentation Act, O.C.G.A. §§ 12-7-1 *et seq.*, the authority contained therein to promulgate the proposed permits, the methodologies available to insure compliance with the provisions of the proposed permits, and the important public policy of reducing sedimentation in the waters of the State from construction activities.

The proposed permits are being issued pursuant to the authority contained in O.C.G.A. §§ 12-5-27 and 12-5-30. As required, the permits incorporate the applicable provisions of O.C.G.A. §§ 12-7-6. The proposed permits include the requirement that regulated activities perform turbidity sampling on all receiving water(s), or all storm water outfalls, or a combination of receiving water(s) and outfall(s). The numbers applicable to the alternative outfall monitoring were established as estimated surrogates for the otherwise applicable in-stream turbidity levels using factors applicable on average basis statewide.

The proposed permits define construction activities as those disturbing a land area of 1 acre or greater, or tracts of less than 1 acre that are part of a larger overall development with a combined disturbance of 1 acre or greater (i.e., common plan of development or sale). EPD can require an applicant to submit an NPDES permit application for an individual NPDES permit upon written notification to the applicant. In addition to storm water discharges, the proposed general NPDES permits authorizes certain non-storm water discharges such as fire fighting water and uncontaminated groundwater. The proposed general permits will be valid for a term of five (5) years.

The major provisions of the proposed permits are: notification of the facility/site's intent to comply with the permit by submitting a Notice of Intent (NOI); the preparation of an Erosion, Sedimentation and Pollution Control Plan (Plan); and the implementation of this Plan. Coverage under the proposed permits is achieved by submitting a NOI to EPD by the permittee(s). A permittee structure for common developments remains similar to the previous permit. A primary permittee is the facility/site owner or operator. A secondary permittee is a home builder, a utility contractor, or similar entity conducting land disturbance activities within a common development. Both stand-alone and infastructure construction activities have primary permittees only. NOIs are required to be submitted to EPD by all permittees at least fourteen (14) days prior to the commencement of the construction activity, with certain exceptions specified in the permits. The NOI will include basic information about the facility/site including the specific waters of Georgia where the discharges will occur, except in the case of Blanket NOIs for utility companies and utility contractors that are secondary permittees. Specific forms will be available from EPD and must be used for the NOI. NOIs are required to be submitted to EPD by return receipt certified mail or similar service. Coverage by the general NPDES permit is provided without acknowledgment from EPD. When final stabilization of the facility/site is achieved, the permittee must notify EPD they are terminating coverage under the general NPDES permit by submitting a Notice of Termination (NOT).

The Plan will detail those best management practices to be used at the facility/site to control erosion, sedimentation and other pollutants. The primary permittee is responsible for developing and implementing the Plan for the entire infastructure, stand-alone, or common development construction site. The Plan must be prepared, on the behalf of the primary permittee, by an individual licensed by the State of Georgia in the field of engineering, architecture, landscape architecture, forestry, geology or land surveying; or by a person that is a Certified Professional in Erosion and Sediment Control (CPESC) with a current certification by the International Erosion Control Association.

The Plan is also required to establish procedures to collect and analyze samples from the receiving stream(s) or the storm water outfall(s) based on the methodologies set forth in the proposed permits. Permittees are required to perform sampling of turbidity levels as a means of determining whether an additional violation of the permit terms and conditions has occurred in the event best management practices (BMPs) were not properly designed, installed or maintained. Sampling shall be performed during qualifying rain events following distinct points in the construction process as outlined in the permits.

As a result of work done by the Erosion and Sediment Control Overview Council and the stakeholders on the General Permit Advisory Committee during the last two years, House Bill 285 was passed by the Georgia General Assembly and signed by the Governor in 2003. This bill establishes the development of a mandatory education and training program for persons involved in the land disturbance process, and the establishment of an NPDES permit fee system to offset the costs of the state-wide implementation of the NPDES general permits for construction activities. The proposed permits include these provisions, as well as reduced monitoring requirements as compared to the current general permit.

Permittees must maintain records of their activities relative to compliance with the terms and conditions of the proposed general NPDES permits. These records include copies of the NOI, Plan, site inspections, sampling results and NOT. For new facilities/sites disturbing more than 50 acres, the Plan must be submitted to EPD with the NOI. For new facilities/sites disturbing between one and 50 acres and where there is no local issuing authority pursuant to the Georgia Erosion and Sedimentation Act, the Plan must be submitted to EPD with the NOI.

Public notice of the proposed general NPDES permits is being distributed by newspaper and mailing to all those persons who have requested notice of NPDES permits in order to satisfy requirements of the Georgia Administrative Procedures Act and the Georgia Water Quality Control Act.

4.9. Appendix C – UCR Guide to Stormwater General Permit

Upper Chattahochee Riverkeeper
Get the Dirt Out! http://www.getthedirtout.org/pdf/3b_NPDES%20permit.pdf

UNDERSTANDING PERMITS ASSOCIATED WITH CONSTRUCTION ACTIVITY FOR COMMON DEVELOPMENTS

Section 402 of the Clean Water Act prohibits the discharge of pollutants from a point source into waters of the United States without a National Pollutant Discharge Elimination System ("NPDES") permit or in violation of a NPDES permit. Discharges associated with construction and industrial activities, including clearing, grading, and excavation **of at least one acre** require a storm water discharge permit under the Clean Water Act's National Pollutant Discharge Elimination System. 40 C.F.R. §§ 122.26(b)(14)(x); 122.26(b)(15); 33 U.S.C. §§ 1311, 1342.

In Georgia, stormwater discharges associated with such construction activities are regulated by a general permit. The permit, "Georgia Environmental Protection Division Authorization to Discharge under the NPDES, Storm Water Discharges Associated With Construction Activity for Common Developments, General Permit No. GAR 100003," became effective as of August 13, 2003 (hereinafter referred to as the "General Permit"). A developer permitted under GAR 100003 has continuing liability for any violations of the General Permit until a Notice of Termination has been submitted to EPD. GAR 100003, Part(I)(E).

The General Permit requires the submittal of a Notice of Intent (NOI) at least fourteen days prior to the commencement of construction activities. GAR 100003 Part II (A). The General Permit also specifies that best management practices, to prevent or reduce pollution, must be properly implemented for all construction activities. GAR 100003, Part III(C)(1)&(2). Where best management practices have not been properly designed, installed, and maintained, it is a violation of the General Permit for each day that those BMPs are not properly designed, installed, and maintained. In addition, when BMPs are not properly designed, installed, or maintained, it is a second violation on each day that discharges increase turbidity by more than 25 nephelometric turbidity units. GAR 100003, Part III(C)(3). The General Permit also requires monitoring and reporting following qualifying events. GAR 100003, Part IV (D)(5) & (E).

In addition, the General Permit specifies that discharges shall not cause violations of water quality standards. GAR 100003, Part I(C)(4). The following are just some of the applicable state water quality standards:

* Ga. Comp. R. & Regs. 391-3-6-.03(5)(b), which states that "[a]ll waters shall be free from ... floating debris ... in amounts sufficient to be unsightly or to interfere with legitimate water uses";

* Ga. Comp. R. & Regs. 391-3-6-.03(5)(c), which states that "[a]ll waters shall be free from material ... which produce turbidity, color, odor or other objectionable conditions which interfere with legitimate water uses";

* Ga. Comp. R. & Regs. 391-3-6-.03(5)(d), which states that "[a]ll waters shall be free from turbidity which results in a substantial visual contrast in a water body due to man-made activity"; and

* Ga. Comp. R. & Regs. 391-3-6-.03(2)(b) and 40 C.F.R. § 131.12(a)(1), which state that "[e]xisting instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected."

The general permit further requires an Erosion, Sedimentation and Pollution Control Plan (ESPCP or the Plan) which shall include, at a minimum, best management practices, including sound conservation and engineering practices to prevent and minimize erosion and resultant sedimentation, which are consistent with the Manual for Erosion and Sediment Control in Georgia. GAR 100003, Part IV. The Plan must include provisions to retain sediments on site and preclude sedimentation of adjacent waters. GAR 100003, Part IV. The Plan must include provisions for adequate sediment control basins, with storage of at least 1800 cubic feet (67 cubic yards) per acre drained. GAR 100003, Part IV(D)(2)(a)(3).

There are layers of laws and regulations that govern construction activities in Georgia including federal law and regulations, state law and regulations and local ordinances. In addition, the Green Book is specifically incorporated into the General Permit and, as such, has the force of law. A developer must comply with *all* of these laws and regulations. However, in resolving ambiguities between these regulations and laws, **federal law always trumps state and local law, and state law always trumps local law. However, if local or state law is more stringent, then the developer must comply with *the most stringent* requirement.**

4.10. Appendix D – U.S. Clean Water Act, Section 319

Source: Federal Register / Vol. 64, No. 235 / Wednesday, December 8, 1999 / Rules and Regulations, page 68733. http://www.epa.gov/npdes/regulations/sw2-part1.pdf

"In 1987, section 319 was added to the CWA to provide a framework for funding State and local efforts to address pollutants from nonpoint sources not addressed by the NPDES

program. To obtain funding, States are required to submit Nonpoint Source Assessment Reports identifying State waters that, without additional control of nonpoint sources of pollution, could not reasonably be expected to attain or maintain applicable water quality standards or other goals and requirements of the CWA. States are also required to prepare and submit for EPA approval a statewide Nonpoint Source Management Program for controlling nonpoint source water pollution to navigable waters within the State and improving the quality of such waters. State program submittals must identify specific best management practices (BMPs) and measures that the State proposes to implement in the first four years after program submission to reduce pollutant loadings from identified nonpoint sources to levels required to achieve the stated water quality objectives.
State nonpoint source programs funded under section 319 can include both regulatory and nonregulatory State and local approaches. Section 319(b)(2)(B) specifies that a combination of ''nonregulatory or regulatory programs for enforcement, technical assistance, financial assistance, education, training, technology transfer, and demonstration projects' may be used, as necessary, to achieve implementation of the BMPs or measures identified in the section 319
submittals."

See also:
EPA website for the Section 319 program
http://www.epa.gov/owow/nps/cwact.html

See also: EPA website for the State-EPA Nonpoint Source Partnership which has information about management of Section 319 grants (and other important links)
http://www.epa.gov/owow/nps/partnership.html

SECTION 5. BEST PRACTICES IN WATER RESOURCES PLANNING

Guide for Best Practices in Water Resources Planning

The state of Georgia is currently developing a statewide water resources management plan which will include sub-state water resources plans for the major river basins or regions such as coastal Georgia. The sub-state planning is scheduled to begin in 2008, after the state level component of the plan has been approved by the General Assembly. The state component is the state policy guidance, with any needed revisions of Georgia water law, and the specified framework for the sub-state planning.

Developing a regional water resources plan is a highly complex and controversial task with multiple competing objectives and high stakes for the future of the region's inhabitants. It involves identifying a set of management policies (restrictions) and actions (projects) which will determine how the natural water resources assets will be distributed among competing water users in the region, and how public funds will be allocated for water related purposes. The challenges and pitfalls for regional water planning were highlighted in the preface to the National Research Council's report (2004) which evaluated federal water resources planning procedures:

"Effective water project planning in this new environment requires an approach that seeks to balance a diverse range of objectives that cannot be directly or easily compared and to forecast outcomes and impacts of water projects in the midst of the considerable uncertainty inherent in large and complex natural systems. Such efforts are difficult not only because of the complexity of the contemporary multi-objective, multi-stakeholder planning environment, but also because of the complex and conflicting mix of legislation, congressional committee language, administration guidance, and legal precedent that operates as our nation's water policy. The clear policy guidance and consistent funding and authority necessary for integrated planning at the scale of river basins and coastal systems do not presently exist. Integrated water resources planning must also be conducted in competition with strong pressures to build specific projects advocated by local interests and their congressional representatives. Further, even in cases where the need for a comprehensive regional analysis is widely supported, the funding necessary to carry out the analysis may not be available."

From the Preface to the NRC report on "River Basins and Coastal Systems Planning Within the U.S. Army Corps of Engineers, " Panel on River Basin and Coastal Systems Planning, Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning, National Research Council, 184 pages (2004). http://www.nap.edu/catalog/10970.html

A guide to best practices in water resources planning will be useful for professionals involved in the developing the regional plans for Georgia. This project provides an interactive website with a guide to the current best professional procedures in water resources planning. It is interactive to allow users to easily contribute to and expand the scope of the online information.
http://en.wikibooks.org/wiki/Water_Resources_Directory/Best_Practices/Planning

The professional planning process outlined on the website follows the process specified in the planning principles and guidelines (P&G) developed by the U.S. Water Resources Council for use by the federal water planning agencies (Corps of Engineers, USDA-NRCS, TVA, BOR), but with modifications to include procedures from the USACE-IWR's shared vision planning methods and the Watershed Approach advocated by the U.S. Environmental Protection Agency. (The 2005 Georgia Water Resource Conference included a one-day course on the shared vision planning method, presented by the USACE Institute for Water Resources staff.) The federal water resources planning guidelines have been developed, critiqued, and improved by some of the best minds in the water resources field over the past four decades, with the intention of providing clear guidance to water resources planners and accountability to the public.

The USACE Planning Process
http://www.usace.army.mil/inet/usace-docs/eng-regs/er1105-2-100/c-2.pdf

"The Corps planning process follows the six-step process defined in the P&G. This process is a structured approach to problem solving which provides a rational framework for sound decision making. The six-step process shall be used for all planning studies conducted by the Corps of Engineers. The process is also applicable for many other types of studies and its wide use is encouraged. The six steps are:
Step 1 - Identifying problems and opportunities
Step 2 - Inventorying and forecasting conditions
Step 3 - Formulating alternative plans
Step 4 - Evaluating alternative plans
Step 5 - Comparing alternative plans
Step 6 - Selecting a plan"

References

National Research Council, "Analytical Methods and Approaches for Water Resources Project Planning," 2004.

U.S. Environmental Protection Agency, "Handbook for Developing Watershed Plans to Restore and Protect Our Waters," EPA 841-B-05-005, October 2005. http://www.epa.gov/owow/nps/pubs.html. (Also see the USACE view of the EPA handbook: https://swwrp.usace.army.mil/portal/alias__swwrp/lang__enUS/tabID__3625/DesktopDefault.aspx)

U.S. Army Corps of Engineers, "Guidance for the Development of Watershed Management Plans," CESPD-CM-P, 31 August 2001
http://www.spd.usace.army.mil/cwpm/public/plan/pdguide/spd/watershed.htm

Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management (6 Fed. Reg. 62566, October 18, 2000). http://water.usgs.gov/owq/cleanwater/ufp/

SECTION 6. EDUCATION FOR WATER RESOURCES PLANNERS

Need for Education in Water Resources Planning

The state of Georgia is currently developing a statewide water resources management plan. The planning is being done in two phases: Phase I (due July 2007) includes review and revision of state water policy (laws, regulations) and outlining the framework for sub-state planning, while Phase II includes preparation of the regional water resources management plans. In order to participate successfully in this planning process, each sub-state region in Georgia and each major municipality needs staff with expertise in water resources planning. The state, major municipalities and 18 Regional Development Centers throughout Georgia have an ongoing need for staff with training in water resources planning.

Currently, there is no university degree program in Georgia to train water resources planners. A graduate degree program is needed to provide for the continuing long-term need for new professionals in this discipline. However, given the short time frame for statewide water resources planning in Georgia, there is also a need to provide immediate training for the mid-career professionals who will be involved in the regional planning efforts over the next 1-5 years. The Table 6.1. outlines a proposed graduate degree program in water resources planning, as a joint program at University of Georgia and Georgia Institute of Technology.

Note that another government agency, the U.S. Army Corps of Engineers, faced a similar problem of having major responsibilities for water resources planning but with loss of expertise from staff retirements and need to provide training for new hires. Their response was to set up a Planning Capabilities Task Force to assess the needs and to recommend solutions (see USACE Planning Capabilities Task Force and its report). The recommendations given below for Georgia are patterned after the recommendations for the USACE, but have been adapted to better fit the educational needs for regional water resources planning in Georgia and other southeastern states.

Table 6.1. Graduate Certificate or MS Degree in Water Resources Planning

Joint Graduate Program between UGA and Georgia Tech.

Student is admitted to either UGA or Georgia Tech, and may take courses for credit toward the degree at both schools.

Admission Requirements

* Bachelors Degree in any field, and following undergraduate courses:
* Biology, chemistry or physics (4 semester courses)
* Ecology
* Probability+statistics
* Economics

Graduate Certificate Requirements (18 semester hours):

* Six courses taken as 3 approved electives (from List B) and 3 core courses (from List C)
* The student must attain competency in 9 subject areas (List A) with 6 areas from the certificate coursework and 3 areas from other sources (undergraduate courses, other graduate coursework, experience, or competency demonstrated by exam).

MS Degree Requirements (30 semester hours):

* Ten courses taken as 6 electives, 3 core courses, and 1 independent project course. The 6 electives consist of 4 approved electives from List B and 2 electives from the student's selected area of specialization (List D). Students who already have an MS degree in an appropriate field may receive transfer credit for two courses toward the two free electives for the area of specialization.
* The student must attain competency in 9 subject areas (List A), with 6 areas from the MS degree coursework and 3 areas from other approved sources (undergraduate courses, other graduate coursework, experience, or competency demonstrated by exam).

Acknowledgment: This curriculum was developed based on an MS degree program of the US Army Corps of Engineers, with six participating universities. (http://www.water-resources.us/Advanced/corecourses.cfm)
The USACE degree program was recommended by a UCOWR-USACE team (see report).
We have adapted the USACE curriculum by adding a water quality course.

List A. Nine Basic Subjects for Water Resources Planners

1. Hydrology
2. Water Quality
3. Environmental Impact Assessment
4. Legal and Institutional Considerations
5. Social Decision-Making (policy analysis)
6. Economics and Finance
7. Water Resources Infrastructures (*)
8. Quantitative Methods (simulation, optimization) (*)
9. Planning Process (*)

*Note: These last three subjects are covered in the core courses (List C).

List B. Approved Electives

Certificate students select 3 courses, and MS degree students select 4 courses, with each course from different subject area.

(a) Click on the (notes) hyperlink to see our curriculum development notes for each subject area.
(b) Click on the GIT or UGA hyperlink to see the course syllabus.
(c) Status codes: +a = course fits objectives, +b = course needs modification, +c = new course is needed.

1. **Hydrology/Hydraulics/Climatology** (notes)
   - FORS 6120 - Quantitative Hydrology UGA++, Rasmussen
   - FORS 6110 - Hydrology and watershed management, UGA+, spring, Jackson
   - CEE 6221 - Physical hydrology, GIT, (spring and fall), Stieglitz, Webster or Fu
2. **Water Quality**
   - 1. ..
   - EHSC 6610 - Water Pollution and Human Health, UGA+b, Black
3. **Environmental Considerations in Water Resources Planning** (notes)
   - CEE 4620 - Environmental Impact Assessment (law) GIT+, Guensler
   - CP 6214 - Environmental planning and impact assessment, GIT+, (spring), Patton
   - ECOL 8420 - Watershed Conservation, UGA, (fall), Freeman
   - ECOL 8990 - Aquatic Ecosysystems (and water quality), UGA+, (spring), Rosemond
4. **Institutional/Legal Considerations in Water Resources Planning** (notes)
   - PUBP 6314 (also CP 6223) - Policy Tools for Envirionmental Management, GIT+, Elliott
   - CP 6261 - Environmental law, GIT+
   - ECOL 8700 - Environmental policy and management, UGA+, (fall), Kundell and Mumford
   - FORS 7820 - Natural resources law for managers, UGA (spring, 4hrs)
   - FORS 7800 - Forest Resources Policy UGA+, Newman
   - ECOL 8720 - Environmental Law for Design Professionals, UGA+, (spring), Fowler
5. **Social Decision Making** (notes)
   - PUBP 6010 - Ethics in Public Policy, GIT+, Norton
   - CP 6821 - Basic Methods of Policy Analysis and Planning GIT+
   - PADP 8650 - Public policy seminar, UGA
6. **Water Resources Planning** (philosophy and planning methods) (notes)
   - CP 6821 - Basic Methods of Policy Analysis and Planning GIT+b (ok if change to water cases)
   - CP 6214 - Environmental Planning and Impact Assessment, GIT+
   - CP 6241 - Water resources planning (stormwater management), GIT+, fall, Debo
   - AAEC 4800/6800 - Water resources economics, UGA+b (fall) Mullen, 2nd syllabus
7. **Economics for Water Resources Planning** (notes)
   - CP 6031 - Economic Analysis for Planning, GIT+, (spring), Contant (transportation oriented)
   - AAEC 8100 - Applied Resources Policy and Project Analysis, UGA++, (fall), Bergstrom
8. **Quantitative Methods for Water Resources Planning** (notes)
   - CEE 6241 - Water Resources Management I (LP) GIT+, (spring), Georgakakos
   - PUBP 6281 - Quantitative (decision) models in public policy, GIT, no instructor listed.
   - INTA 6004 - Modeling, forecasting and decision-making GIT+, (spring), Peter Brecke
   - EAS 8803 - Intro to Complex Environmental Systems, GIT, Chang
   - GEOL/FORS 8740 - Hydrologic Flow and Transport Modeling, UGA+, Dowd+Rasmussen
   - FORS 6150 - Control and systems theory for the environmental scientist, UGA+, Beck
   - FORS 8150 - System Identification for the Environment, UGA+, irregular, Beck (pre-req FORS 6150)
   - CSCI 6210 - Modeling and Simulation UGA, irregular
   - ECOL 6130 - GIS for Environmental Planning, UGA, (spring), Kramer

List C - Core Courses (MS degree and Certificate students take all three courses):

1. **Water Resources Infrastructure for Planners** (engineering, demand management)
   a) New course will be needed. (See outline: Infrastructure course.)
   b) CP 6831 - Urban Growth and Infrastructure Systems, GIT+
2. **River Basin Models** (water quantity and quality, social/economic interactions)
   CEE 6242 - Decision support systems for water resources planning, GIT, Georgakakos
   ENGR - new course to be taught by new faculty hire
3. **Capstone Course - Advanced Planning Practicum** (case studies and project)
   a) CEE 8902 - Special Problems (See outline: Capstone course.)
   b) JHU course outline at Johns Hopkins University.

List D - Area of Specialization (MS degree students take 2 courses from one area);

Take 2 courses in one area of specialization. Suggested areas of specialization and courses are listed below, but other specializations are possible if approved by the student's Graduate Committee.

* Public Health
* Coastal Issues
* Water Quality Modeling
* Groundwater Hydrology
* Environmental Impact Assessment
* Environmental Economics (see Joint Programs)
* Environmental Restoration
* Conservation Ecology and Sustainable Development (see Joint Programs)

A strontium isotope investigation of possible sewage influx to stream base flow in the Atlanta metropolitan region

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Publication

A Strontium Isotopic Investigation of Possible Sewage Influx to Stream Base Flow in the Atlanta Metropolitan Region

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Technical Completion Report

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EXECUTIVE SUMMARY

Major Findings of the Study: Strontium isotope ratios did *not* provide a meaningful indicator of sewage effluent pollution in the urbanized Atlanta portion of the Chattahoochee River Basin. Any degree of urbanization within the Chattahoochee Basin results in base flow solute concentrations that are significantly elevated above “background”. The basin-wide correlation between sodium, potassium, and chloride indicates pervasive low-level contamination from human waste effluent.

Abstract: The hydrochemistry (major ions concentrations, stable oxygen isotope ratios, tritium concentrations, strontium ion concentrations, strontium isotope ratios and hydrology) of base flow within the upper 6,940 km^2 of the Chattahoochee River Basin (CRB) in Georgia was investigated on a synoptic basis during a dry period in May, 2005. The primary objective of the study was to determine whether strontium ion concentrations and strontium isotope ratios when analyzed in conjunction with major ion trends could provide a “signature” of sewage effluent contamination within stream base flow. The 39 samples acquired for this study were representative of rural basins, semi-developed basins, the Chattahoochee River, urbanized basins within the Atlanta Metropolitan Region (AMR), sewered basins within the AMR, combined sewage overflow (CSO) basins, and sewage effluent.

Strontium ion concentrations were highly elevated (>75 µg/L) in those streams in which base flow solute concentrations were also elevated (TDS >100 mg/L), probably as the result of sewage effluent imposition. Although there is a very wide range of strontium isotope ratio variation ($0.709460 < {}^{87}Sr/{}^{86}Sr < 0.723274$), there is no unique “waste signature’ in that the range of natural variation within the rural basins that are not impacted by waste disposal encompasses virtually the total range of isotope ratios for the study area. There is also a wide range of geochemical variation and the general trend in terms of *increasing* solute concentrations is: rural basins < Chattahoochee River < semi-developed basins < AMR basins without a main sewer line < AMR basins with a main sewer line < CSO basins < sewage effluent. Major ion concentrations within base flow of the Chattahoochee River significantly increase within the AMR and remain above upstream levels far downstream of the AMR. The most likely source of the increased source of solutes within the impacted basins is contamination within the near-stream zone.

The highest degree of correlation ($r^2 > 0.80$) for the major ions in base flow was between chloride, sodium, and potassium which are all concentrated within sewage effluent and are dominant ions present in human electrolytes and household cleaning fluids. These correlations would *not* be expected if aluminosilicate weathering was the sole control upon the major ion geochemistry of base flow (which is ground water). The relatively high sulfate concentrations (mean SO_4 = 27.8 mg/L) for the group of basins which include a main sewage line parallel and proximal to a stream suggests that some ground water pollution originates from leaky buried conveyance pipes in that sulfate is concentrated within sewage effluent. However, the major ion chemistry as a whole is equivocal in this regard in that all urban and semi-urban basins other than the rural basins are characterized by relatively high chloride, alkalinity, Sr ion, and TDS concentrations. Any degree of urbanization or development results in solute concentrations that are significantly greater than “background”. The sources of these solutes are not always clear and are likely diffused throughout the developed and developing Atlanta Metropolitan Region.

KEY WORDS: Chattahoochee River Basin, Atlanta Metropolitan Region, base flow, major ion geochemistry, Piedmont Province hydrochemistry, strontium ion concentrations, strontium isotope ratios, urban hydrology

PROJECT DESCRIPTION

Introduction: Overview of Water Quality Problems in the Atlanta Metropolitan Region:

The Chattahoochee River is the most utilized water resource in Georgia (Frick and Gregory, 2000) and provides the principal water resource for more than 4.5 million people who currently live within the Atlanta Metropolitan Region (AMR). The Chattahoochee River Basin (CRB) is virtually totally urbanized from Roswell, GA (~20 miles north of the City of Atlanta) to approximately 20 miles south of the city. The AMR occupies a 12-county, 1,200 square mile region and hence has a potentially large impact upon water quality within the Chattahoochee River well downstream of Atlanta.

The most important water quality problem faced by residents of the CRB and its water managers is the imposition of sewage wastes to the Chattahoochee River and its tributaries. On average ~6.0×10^5 cubic meters of sewage is conveyed daily to treatment facilities in the City of Atlanta (Seabrook, 1997) and is eventually discharged to the Chattahoochee River. The City of Atlanta is underlain by 3,400 km (2,100 miles)of sewage discharge pipe and the average age of these pipes is 75 years (Q. Aslami, City of Atlanta Bureau of Sewer Operations, 2001, personal communication). This is an antiquated system that periodically backs up and overflows through manhole covers. These pipes likely discharge polluted effluent into the subsurface at various locations; however, the extent of this problem is not well known. In some cases contaminants are directly flushed through this system as storm flow; while in other cases a given pollutant might accumulate within the riparian zone, pollute the ground water below a stream and subsequently contaminate base flow (i.e. stream flow that occurs between storms). The controls upon base flow contamination have been far less studied and are less understood than those related to surface water pollution. This is true with respect to the Chattahoochee River Basin (CRB), urban basins, and watersheds in general.

The major problem associated with sewage wastes from leaky pipes as well as from untreated sewage effluent is coliform bacteria contamination which is the most common reason that the Chattahoochee River and its tributaries at times do not meet designated standards for drinking water supply (Gregory and Frick, 2000). In various small urban basins within the AMR such as Proctor Creek and Clear Creek the problem is exacerbated by combined sewage overflow (CSO) facilities that discharge sewage effluent into these tributaries of the Chattahoochee River. During periods following intense storms, sewage is frequently discharged to stream basins through overflowing manhole covers. Gregory and Frick (2000) observed an inverse relationship between bacteria concentrations and discharge in several highly urbanized watersheds. These authors inferred a possible ground water source for these contaminants and the origin of this contamination was from CSOs or leaky sewage pipes. Another possible source of bacterial contamination within the urban environment include wastes generated by domestic pets (Center for Watershed Protection, 1999).

In addition to the sewage problem, rapid growth (*urban sprawl*) into the northern suburbs such as Forsyth and Cherokee County is placing additional stress upon the limited water and land resources of the Upper Chattahoochee Basin. The NAWQA Program of the U.S. Geological Survey has documented that the AMR is a major source area responsible for elevated pesticide, fertilizer, polycyclic aromatic hydrocarbons (PAHs), metal and suspended sediment concentrations within the Apalachicola - Chattahoochee - Flint River Basin. Most of the load of these contaminants can not be attributed to specific source areas and is associated with storm runoff rather than base flow (Frick et al., 1998).

Major ion concentrations within the urban tributaries of the Chattahoochee River Basin (CRB) are often greater than less urbanized Piedmont basins; however, are typically below Maximum Concentration Limits (MCLs) for drinking water (Rose, 2002). Therefore the major ion geochemistry of these basins has been given relatively little attention in comparison to the study of bacteria, pesticides, metals and other contaminants associated with storm runoff (i.e. Frick et al., 1998). Nonetheless, total dissolved solid (TDS) solid concentrations within the Chattahoochee River downstream of the Atlanta region have been elevated for many decades (McConnell and Buell, 1994). The source(s) and source area(s) for these wastes remains poorly understood but in some cases is related to sewage effluent problems (Rose, 2002).

Objectives of the Research Project:

Given the ongoing concern with sewage contamination in the CRB, the objective of the research summarized in this report was to analyze possible new "tracers" for sewage effluent in stream base flow. Specifically, strontium isotope ratios ($^{87}Sr/^{86}Sr$) and strontium ion concentrations were analyzed in conjunction with *environmental* isotopic data (tritium concentrations and stable oxygen isotope ratios) and the major ion geochemistry of base flow in streams and waste water facilities within the 2,680 square mile (6,940 km^2)area of the Chattahoochee River Basin upstream of Franklin, Georgia in Heard County. A related objective of this investigation was to derive and interpret a large *synoptic* (i.e. that representative of the same sampling period) hydrogeochemical and isotopic data set that can be used to better interpret the sources and extent of base flow contamination within the CRB. This multiple-parameter approach allowed for the comparative analysis of the effects of land use and waste disposal activity in this very large study basin.

BACKGROUND: UTILIZATION OF STRONTIUM ISOTOPE RATIOS IN STREAM BASIN STUDIES

Some prefatory explanation regarding the utilization of strontium isotopes is necessary in that this is not a universally utilized "tracer" in watershed hydrology. Strontium isotope ratios have been utilized in previous watershed studies primarily to trace water pathways and define weathering reactions that control the major ion chemistry of stream flow (Bullen and Kendall, 1998). Strontium isotope ratios have also been used for many other purposes including the analysis of: 1) mixing dynamics between saline and fresh water in sedimentary basins (Banner et al., 1989 and Musgrove and Banner, 1993); 2) fluvial contributions of strontium to sea water (Goldstein and Jacobsen, 1987; Waldeigh et al., 1985; and Palmer and Edmond, 1992); 3) source rock contributions to the solute load of river water (Miller et al., 1993, Krishnaswami et al., 1992; and Aubert et al., 2002); 4) ground water - surface water interactions (Katz et al., 1997) and leakage processes in aquifers

(Woods et al., 2000); 5) the paleohydrology of the proposed Yucca Mountain tuff nuclear waste repository (Stuckless et al., 1991 and Johnson and DePaolo, 1994); 6) tracing of hydrologic flow paths in watersheds (Hogan and Blum, 1993) and 7) the sources of waters to lakes, playas, and peat bogs (Neumann and Dreiss, 1995; Lyons et al., 1995 and Hogan et al., 2000).

The first-order control upon the $^{87}Sr/^{86}Sr$ ratio in natural waters is the relative abundance of aluminosilicate minerals versus carbonate minerals comprising either a watershed or aquifer (Bishop et al., 1994; Douglas et al., 2002 and Krishnaswami et al., 1992). Strontium isotopes do not significantly fractionate as a result of biological or low-temperature abiotic chemical reactions and hence their ratio will be a function primarily of weathering reactions (Hunt et al., 1998). In general, waters that derive their strontium from carbonate minerals will be characterized by lower $^{87}Sr/^{86}Sr$ ratios and higher Sr concentrations than those waters in which strontium evolves from the Rb-rich aluminosilicates (McNutt et al., 1990; Bullen and Kendall, 1998; and Palmer and Edmond, 1992). Biotite is the most of the common source of Sr-87 that is derived from the beta decay of rubidium-87 and rubidium is a common substitute for potassium in this mineral(Bullen and Kendall, 1998). Other potential sources of Sr-87 within aluminosilicate watersheds include K-feldspar, garnet and hornblende (Bailey et al., 1996). Strontium isotopic ratios of natural waters typically better reflect the ratios of individual minerals rather than whole rock ratios because of the variability inherent in weathering rates for minerals (Aubert et al., 2002).

There are numerous controls upon $^{87}Sr/^{86}Sr$ ratios in addition to source minerals that when properly interpreted can lead to a better understanding of the hydrodynamics of watersheds and aquifers. The $^{87}Sr/^{86}Sr$ ratio of rainwater is usually much different from that of a solution derived from mineral weathering and therefore the isotopic composition might indicate the relative contribution of recent precipitation to a natural water source (Bailey, 1996; Hogan et al., 2000 and Douglas et al., 2002). There is often a strong correlation between the rate of discharge or water flux and strontium isotope composition. Aubert et al. (2002) found that strontium isotope ratios correlated positively with discharge rates in the Strengbach catchment of the Vosges mountains of France and attributed this relationship to a variable source area effect (i.e. the relative contribution from hillslopes). Variable discharge rates are often controlled by soil water-ground water mixing processes and other factors that also control the isotopic composition of strontium (Land et al., 2000 and Négrel and Lachassagne, 2000). The age of minerals is another control upon the $^{87}Sr/^{86}Sr$ ratio in that the isotopic composition of strontium within minerals has changed with time and the susceptibility to weathering of various minerals is also a function of time (Goldstein and Jacobsen, 1987 and Blum et al., 1994).

Cation exchange reactions represent still another control upon the isotopic composition of stream water. Miller et al. (1993) concluded that cation exchange reactions contributed to an average of 30% of the strontium exported in stream water in a high elevation watershed in New York and showed that there is a $^{87}Sr/^{86}Sr$ gradient in soil columns within this study area. In addition to providing a variable isotopic pool of strontium in the upper soil horizons, such gradients may result in variable strontium isotope ratios in stream water. Finally, pollutant influxes from sewage, mining tailings, waste dumping, and fertilizer may affect the magnitude and variability of the $^{87}Sr/^{86}Sr$ ratio in stream water (Tricca et al., 1999 and Soler et al., 2002). However, the utilization of strontium isotopes to detect waste water pollution in ground water or surface water has not received a great of prior attention. Typically wastewater is enriched in potassium concentrations (as well as other major ions, notably sodium, chloride and sulfate) and rubidium substitutes for potassium in alkaline earth-bearing salts. Hence it is likely that rubidium concentrations are higher in waste water. Since rubidium-87 is the radioactive progenitor or "parent" of strontium-87, the $^{87}Sr/^{86}Sr$ may be higher in water impacted by sewage waste.

This investigator previously undertook what is likely the first systematic basin study of strontium isotope variation within base flow in the southeastern Piedmont Province (summarized in Rose, 2004 and Rose and Fullagar, 2005). $^{87}Sr/^{86}Sr$ ratios, along with Sr ion and major ion concentrations were measured in four streams on a monthly basis between March, 2003 and March 2004 within the Middle Oconee River basin, located approximately 50 miles east of the Chattahoochee River basin. The results of this investigation indicated that the strontium isotope ratio was by far the best "tracer" of base flow within this hydrological system because it was significantly different in each basin and remained constant throughout the year in any one location.

STUDY AREA

The study area chosen for this investigation encompasses the upper 6,940 km^2 (2,650 mi^2) of the Chattahoochee River Basin in Georgia (Figure 1). Samples were acquired from upstream of Helen, Georgia located in the Blue Ridge Mountains to Franklin, Georgia which is approximately 125 kilometers (80 miles) south of Atlanta in Heard County. Most of the study area is within the Georgia Piedmont Province and is characterized by hilly terrain and clay rich soils. The Chattahoochee Basin is narrow (less than 30-40 kilometers) throughout most of the study area and therefore drains only a limited but important area within Georgia. The upper basin above Lake Lanier and Buford Dam remains relatively rural and is characterized by steep topography. The area immediately downstream of Lake Lanier has been urbanized to some extent and the Atlanta Metropolitan Region (AMR) occupies approximately 30-40% of the entire study area. The CRB's densely urbanized core coincides approximately with the middle of the study area and the lower 20-30% of the study area remains mostly rural. In its most urbanized locations (e.g. the Peachtree Creek watershed within Atlanta), the population density approaches 2,400 people per square kilometer. In the less urbanized regions of the AMR, such as the region west of the City of Atlanta in Douglas County, population densities are less than 250 people per square kilometer (Atlanta Regional Commission, 2000).

Stream flow is by far the dominant water resource within the Chattahoochee Basin as it is throughout the Piedmont Province in northern central Georgia. The Chattahoochee River supplies the water resource needs of most of the greater than 4.5 million people who now live within the AMR and it also provides the major water source for numerous other upstream and downstream users; hence it is the most important single water resource within the state. Stream runoff that is generated per unit rainfall decreases within this region from higher elevation to lower elevation. In the mountainous Blue Ridge Province a unit of rainfall generates approximately 0.54 units of runoff

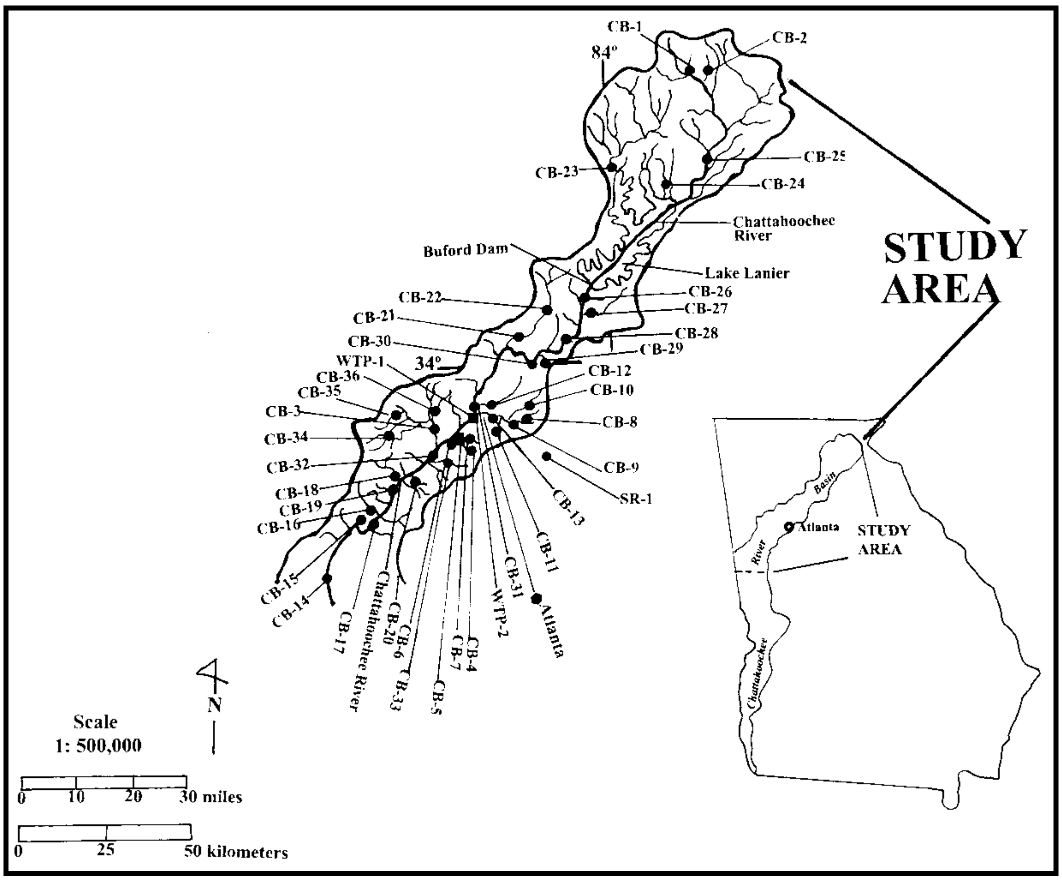

Figure 1: Map of the study area showing sampling locations within the Chattahoochee Basin

while in the southern Piedmont (i.e. downstream within the Chattahoochee River Basin) a unit of rainfall produces only 0.28 units or approximately one half as much runoff (Rose and Peters, 2001).

Previous regional studies have calculated that base flow (i.e. stream flow that occurs between storm periods) accounts for nearly one half of the total stream flow (Rose and Fullagar, 2005 and Nelms et al., 1997). During dry years it provides between 70-80% of the total yearly runoff (Rose and Fullagar, 2005). A typical yearly hydrograph includes approximately 20-30 storms per year; however, within urban basins such as Peachtree Creek there can be almost twice as many distinct hydrographic storm peaks per year (Rose and Peters, 2001). Mean monthly runoff is typically greatest during March, coinciding with the end of the period of a net water surplus (Rose, 1993). Rates of base flow decline as a result of increased evapotranspiration during the summer months (Rose and Peters, 2001) when the synoptic samples were acquired for this present study (see details that are given in the following section).

Stream flow within the Piedmont Province (as described by Rose, 2002) is generated by direct surface runoff (particularly in the urban areas) and from the release of shallow ground water stored within the soils and saprolite (collectively termed the "residuum") overlying the bedrock. The residuum is on average 20 meters thick and is underlain by Paleozoic metamorphic rock. Evidence from the Panola Mountain Research Watershed, east of the study area, suggests that stream flow in non-urban settings within the Piedmont Province is generated from multiple subsurface "reservoirs", as a mixture of water from the shallow organic-rich soil layer and deeper hillslope ground water, particularly from the bedrock-soil contact (McDonnell et al., 1996). Intensively urbanized basins produce less base flow per unit area, likely as the result of reduced infiltration within these paved watersheds (Rose and Peters, 2001).

The dominant weathering reactions that contribute to the natural solute load within the Piedmont and Blue Ridge streams include the carbonic acid weathering of biotite to both kaolinite and vermiculite (Cleaves et al., 1970), the weathering of feldspar to form kaolinite (White et al., 2001) and the relatively rapid weathering of ferro-magnesium minerals, notably hornblende (Velbel, 1992). Much of the solute load has been interpreted to originate from the near-stream or "riparian" zone (Burns et al., 2003); however the mechanisms responsible for generating the higher solute loads inherent within urban base flow are as of yet poorly understood.

METHODS

<u>Sampling Plan, Sample Locations and Hydrological Conditions During Sampling:</u>

Thirty-seven stream locations (36 within the CRB and one in the adjoining South River basin; Figure 1) were chosen as the sampling network for this study (see Appendix 1 and Table 1 for a description of the sampling locations and sample types). Two additional samples were acquired from the R.N. Clayton Treatment Plant (untreated sewage effluent) and Utoy Creek Waste Water Treatment Plant (treated sewage) that are located within Fulton County. These sewage samples represent a key "end-member" from which the stream samples can be compared with. One "out-of-basin sample" (SR-1) was acquired from the South River which is approximately 20 miles east of the CRB. This location in Dekalb County is directly downstream from the Snapfinger Creek Advanced Waste Water Treatment Facility which treats a high volume of sewage effluent that is generated in the AMR.[It should be noted that the access to sewage treatment plants is now limited and the logistics of acquiring effluent samples has been made quite difficult in this "post- 9/11"era].

Table 1
Classification of Stream Samples

Group I — Rural Basins:

1	CB-1	Chattahoochee River near Helen
2	CB-2	Smith Creek
3	CB-15	Acorn Creek
4	CB-16	Snake Creek
5	CB-18	Dog Creek
6	CB-20	Pea Creek
7	CB-23	Chestatee River
8	CB-24	Bear Creek

Group II — Semi-Developed Basins

1	CB-3	Sweetwater Creek near Austell
2	CB-21	Big Creek
3	CB-22	Big Creek
4	CB-27	Sewanee Creek
5	CB-34	Sweetwater Creek near Villa Rica
6	CB-35	Lick Log Creek
7	CB-36	Olley Creek

Group III — Developed Basins in the Atlanta Metropolitan Region

1	CB-8	Burnt Fork Creek
2	CB-9	South Fork of Peachtree Creek
3	CB-10	North Fork of Peachtree Creek
4	CB-29	Crooked Creek
5	CB-33	Camp Creek

Group IV — Developed Basins in the Atlanta Metropolitan Region with Streams on Main Sewage Lines

1	CB-4	South Utoy Creek
2	CB-5	North Utoy Creek
3	CB-6	Utoy Creek
4	CB-12	Nancy Creek
5	CB-13	Peachtree Creek

Table 1
Classification of Stream Samples (continued)

Group V Basins Directly Receiving Treated Effluent or Used for CSOs

1	CB-7	Proctor Creek	(CSO) in Atlanta
2	CB-11	Clear Creek	(CSO) in Atlanta
3	SR-1	South River	(stream receiving treated effluent; basin is east of the CRB)

Group VI Chattahoochee River Sites

1	CB-14	near Franklin, furthest downstream sample
2	CB-17	downstream of the Atlanta metropolitan region
3	CB-19	downstream of the Atlanta metropolitan region
4	CB-25	immediately upstream of Lake Lanier
5	CB-26	downstream of Lake Lanier
6	CB-28	most upstream Atlanta metropolitan region site
6	CB-30	northern Atlanta metropolitan region site
7	CB-31	within the Atlanta metropolitan region
8	CB-32	immediately downstream of the Atlanta metropolitan region

VII Waste Water (Sewage Effluent)

1	WTP-1	R.N. Clayton Waste Water Treatment Plant (non-treated effluent)
2	WTP-2	Utoy Creek (treated effluent)

The objective in choosing sampling locations (shown in Figure 1 and described in Table 1) was to acquire an adequate number of samples which were as representative of as wide of a spectrum of land uses (i.e. degrees of urbanization) and affinity to sewage waste disposal facilities as possible. Obviously not all CSO and waste facilities within the AMR were sampled as part of this investigation. The stream samples were collected during a restricted time interval as possible in order to acquire a "synoptic" set which is representative of very similar, if not identical, hydrological conditions. Most all of the stream samples (CB-3 through CB-36) were acquired during a very dry period between May 9 through May 24, 2005. An *Environmental Monitoring Network* rain gage in Fulton County recorded two days of rainfall totaling 1.57 inches during this sampling period (University of Georgia, 2005). Sample collection dates are shown on a hydrograph representing average runoff from five gages [Chestatee River, Peachtree Creek, Chattahoochee River at Atlanta, Utoy Creek, and Chattahoochee River at Whitesburg] within the CRB (Figure 2); USGS (2005). The slight spike shown on Figure 2 for the sample collection date of May 13 does not reflect the actual base flow conditions that existed for the stream samples that were acquired on that date. In short, the samples that were acquired from these streams are thought to be representative of "base flow" conditions and were not influenced at all by surface water runoff.

Any grouping of samples into sub-populations has to be considered somewhat arbitrary and biased. However, the designated land uses shown on Table1are believed to be reasonable and reflective of the varying states of development within the Chattahoochee Basin. The groupings were based upon surveying the basins upstream of the sample collection point (during the sampling period) and also upon land use designations given in Geographic Information Systems data summarized on CD-ROM by Alhadeff et al. (2001). The sub-groups of stream samples shown on Table 1 consisted of eight *rural basins* both upstream and downstream of the Atlanta metropolitan region (designated as Group I). Two of the sites (the Chattahoochee River near Helen and Smith Creek) were headwater streams within the Blue Ridge Province. All of the other samples, with the exception of the Chestatee River (a larger Blue Ridge basin) were located within Georgia's Piedmont Province.

Group II consisted of seven stream basins that were designated as *semi-developed basins*. While, not quite rural, the population density within these basins was far lower than within urbanized Atlanta and vicinity (i.e. typically fewer than 250 people/km^2 as is the case for the Sweetwater Ck. basin near Austell; Sample CB-3). Groups III and IV consisted of 10 basins within the *urbanized* AMR. Five of these streams ran parallel and adjacent to the main sewer line for Atlanta (Group III) as determined from the City of Atlanta *Sewer Basin Map* and the remaining five basins were not on the main sewage line. The purpose of this designation was to investigate the possible effects of leaky sewage lines and it seemed reasonable that a main sewer line might contribute more effluent than smaller lines throughout the metropolis. Group V was an *ad hoc* group of three basins either directly receiving treated effluent or streams used as a Combined Sewage Overflow (CSO)facility maintained by the City of Atlanta. The Chattahoochee River (Group VI) was sampled in eight locations (other

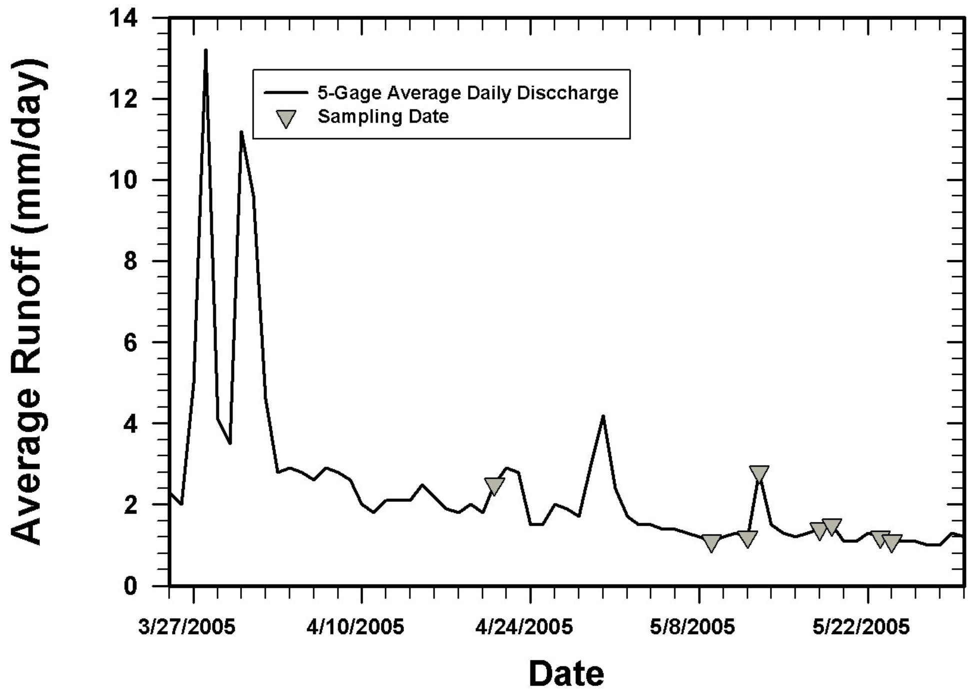

Figure 2. Average study area runoff during sample collection period. Triangles indicate date when a sample was collected.

than the site at Helen which has been included in Group I) both upstream and downstream of the Buford Dam on Lake Lanier and upstream and downstream of the AMR. Group VII includes the two sewage effluent samples previously described. In total, this sampling set provides a range of diversity that is representative of most basin-types within the Chattahoochee Basin.

Hydrology:

Long-term rainfall records (1961-1990) for the study area were obtained from the *Georgia Automated Environmental Monitoring Network*, a service of the University of Georgia. Long-term discharge records for five streams (all of which were sampled as part of this present study) that varied in basin area between 44.7 square miles (116 km^2) and 2,430 square miles (6,249 km^2) were used to compute average base flow runoff, total runoff and runoff/rainfall ratios within the study area. The five gauging stations used for this analysis were: Chattahoochee River at Helen (USGS gauge number: 023304500); Snake Creek (02337500); Sweetwater Creek (02337000); Peachtree Creek (02336300) and Chattahoochee River at Whitesburg (02338000). These basins are thought to be representative of a wide range of basin areas and land uses within the Chattahoochee Basin. The 22-year period of record used for this analysis was between 1980-2003 and is believed to be suitable to derive representative averages.

In another analysis of long-term hydrological conditions (between 1970-2003), records from nine gaging locations on the Chattahoochee River from successively larger drainage areas [Helen, Cornelia, Buford Dam, Norcross, Atlanta, GA 280, Fairborn, Whitesburg, and West Point] were used to determine the relationship between the percentage of total yearly discharge and percentage of total basin area. In this manner, the effects of urbanization on runoff can be assessed (i.e. to answer the question whether urban streams produce proportionally more runoff per unit area than their less-developed counterparts). All hydrographic data for these analyses were obtained from United States Geological Survey records available from their internet web sites (USGS, 2005).

Water Sampling, Sample Handling, and Analytical Methods:

Samples were collected at mid-stream (where possible) using a weighted polypropylene water collector. In most cases, samples were acquired from a bridge enabling mid-stream sampling. The 1 liter polyethlene bottles used to store the unfiltered stream samples were pre-rinsed with nitric acid (pH<2.0), 18 Ωohm DI water, and then finally with sample water before the final stream sample was acquired. Temperature and specific conductance were determined at the time of collection with a YSI 85 probe.

Alkalinity and pH were determined on unfiltered samples usually within 24 hours of collection at the Georgia State University Hydrochemistry Laboratory. Alkalinity was determined by titration with 0.02N sulfuric acid and pH was determined on an Orion 720 pH meter buffered at pH 4.0 and 7.0. Alkalinity was determined with a precision that was better than 6% and is reported as *bicarbonate alkalinity* (mg/L). Samples were filtered through a 0.45µ polymer membrane, stored in polyethylene bottles and refrigerated until the chemical and isotopic analyses could be performed. Those samples used for cation analyses were acidified at a pH<2 using trace metal grade nitric acid.

Samples used for the determination of anions were additionally filtered through a 0.2µ membrane immediately prior to analysis.

Aqueous silica concentrations (reported as SiO_2) were determined colorimetrically using a molybdosilicate reagent. Cation (Ca, Mg, Na, K) concentrations were determined by conventional flame atomic absorption (AA) analysis using a Perkin Elmer 3110 spectrophotometer. The precision associated with these analyses was typically better than 5% as determined by calculating the relative standard deviation (standard deviation/mean) on repeated analysis of a sample when the analyses were performed. Anion (Cl and SO_4) concentrations were determined by ion chromatography using a Lachat 5000 instrument. The precision associated with these analyses was better than 10%. The total charge balance error (summarized in the formula given below) for these determinations averaged 4.8% for the sample set although in some cases the error associated with individual samples was significantly higher. The total set of major ion concentrations are given in Appendix 2.

$$\text{Charge Balance Error (\%)} = \frac{\sum \text{equivalence of cations} - \sum \text{equivalence of anions}}{\sum \text{equivalence of cations} + \sum \text{equivalence of anions}} \times 100$$

Stable oxygen ratios ($\delta^{18}O$) were measured on all of the Chattahoochee Basin stream waters samples by the Environmental Isotope Laboratory at the University of Waterloo (Canada) using a standard carbon dioxide-sample equilibration method, followed by mass spectrometry. Stable oxygen isotope ratios are reported relative to Standard Mean Ocean Water (SMOW) as follows:

$$\delta^{18}O_{sample}\text{ (per mil)} = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 1{,}000$$

The precision associated with these analyses was 0.2 $^{o}/_{oo}$ ($^{o}/_{oo}$ = per mil = per thousand) or better.

Tritium (^3H) concentrations were determined in seven Chattahoochee River Basin stream water samples. These analyses were performed by the Environmental Isotope Laboratory at the University of Waterloo using electrolytic concentration methods followed by beta particle detection. The precision of these measurements as determined by replicate analyses of the same sample is typically 1.0 T.U. or better [where 1 T.U. = 1 "Tritium Unit" = 1 atom of ^3H in 10^{18} H atoms in water].

Strontium (Sr) ion concentrations and strontium isotope ratios ($^{87}Sr/^{86}Sr$) were determined by thermal ionization mass spectrometry (TIMS) at the University of North Carolina-Chapel Hill. Uncertainties in accuracy and precision for the reported Sr concentrations are estimated to be less than 1%. A VG (Micromass) Sector thermal ionization mass spectrometer was used for the $^{87}Sr/^{86}Sr$ determinations. Internal precision as percent standard error was typically better than 0.0008% for these strontium isotope analyses.

RESULTS

Hydrology:

The three hydrological issues of interest to this investigation were determination of: 1) the percentage of rainfall in the CRB that is translated into runoff; 2) the percentage total runoff that occurs as base flow (i.e. flow between storm periods, assumably from ground water) and 3) the effect of urbanization that occurs within the AMR downstream from Lake Lanier upon total runoff within the CRB.

Average annual runoff (total yearly discharge/basin area) varied between 480-1,000 millimeters/year in the five study basins (Table 2). The highest runoff (1,001 mm/year) for the 22-year period of record (1982-2003) was recorded for the Chattahoochee River at Helen, a headwater stream within the Blue Ridge Mountains. This, however, is not representative of most of the Chattahoochee Basin due to its high slopes, limited soil development, and high annual rainfall totals. Runoff rates are approximately 520 mm (20 in) per year throughout most of the Piedmont portion of the Chattahoochee River Basin. This rate of runoff is approximately 40% of the annual rainfall (1320 mm or 52 inches) within this region of Georgia. Total runoff rates were slightly higher in Peachtree Creek which was one of the of the most urbanized watersheds within the AMR, than elsewhere. These results are consistent with previous analyses (Rose and Peters, 2002).

Rates of base flow within the five CRB streams shown on Table 2 varied widely between 164-770 mm/year. This represents between 30-70% of the total yearly runoff. The percentage of base flow was highest in the rural streams and lowest in the highly urbanized Peachtree Creek watershed. The relatively low rates of base flow associated with urban streams is likely the result of reduced infiltration rates - a condition brought about by the high percentage of impervious surfaces and the rapid removal of storm runoff within densely populated urban areas (Rose and Peters, 2002). Base flow assumes a significantly higher percentage of total annual runoff within Piedmont basins during dry years and typically base flow is the most reliable water resources within this region (Rose and Fullagar, 2005).

Table 2
Summary of Runoff in the Chattahoochee River Basin:
Period of Record (1982-2003)

Stream Name	Upstream Watershed Area (km^2)	Average Annual Runoff (mm)	Average Annual Storm Flow Runoff (mm)	Average Annual No. of Days of Storm Runoff	Average Annual Base Flow Runoff (mm)	Average Annual Percent Base Flow
Chattahoochee River @ Helen[1]	116	1,001	231	37	770	78%
Snake Creek[2]	92	483	140	26	343	74%
Sweetwater Creek[3]	637	501	247	59	254	52%
Peachtree Creek[4]	225	549	385	76	164	30%
Chattahoochee River @ Whitesburg[5]	6,249	540	226	84	314	59%

Stream Information

[1] U.S.G.S. gage no:023304500; Gage Elev. = 1404 ft. msl; Lat.:34° 24' 03"; Long.: 83° 43' 44"; small Blue Ridge watershed upstream

[2] U.S.G.S. gage no:02337500; Gage Elev. = 833 ft. msl; Lat.:33° 31' 46"; Long.: 84° 55' 42" small Piedmont rural watershed downstream of Atlanta Metropolitan Region

[3] U.S.G.S. gage no:02337000; Gage Elev. = 857 ft. msl; Lat.:33° 46' 22"; Long.: 84° 36' 53" semi-developed Piedmont watershed downstream west of Atlanta

[4] U.S.G.S. gage no:02336300; Gage Elev. = 764 ft. msl; Lat.:33° 49' 10"; Long.: 84° 24' 28" highly urbanized Piedmont watershed in Atlanta

[5] U.S.G.S. gage no:02338000; Gage Elev. = 682 ft. msl; Lat.:33° 28' 37"; Long.: 84° 54' 03" large watershed near terminus of the study area

All data are from USGS web site: http://ga.water.usgs.gov/

Stable Oxygen Isotopes:

Stable oxygen isotope ratios ($\delta^{18}O$ values) in stream water typically resemble an integration or weighted average of the stable isotopic composition of precipitation that is input to a stream basin. Widely variable $\delta^{18}O$ values would indicate that the source of that particular stream water is storm water runoff, rather than seasonally averaged precipitation. Stable oxygen ratios within the CRB and two waste water samples varied only between -6.10$^o/_{oo}$ and -3.72$^o/_{oo}$. The average $\delta^{18}O$ value for the base flow samples was -4.64$^o/_{oo}$ ± 0.48$^o/_{oo}$ (1 std.dev.). The average value of CRB base flow closely resembles the stable oxygen isotope composition of average yearly rainfall for north central Georgia (as can be inferred from Figure 14-2 in Drever, 1997). This average $\delta^{18}O$ value and the relatively low standard deviation strongly indicates that the base flow samples collected for this study are yearly average precipitation values, rather than some form of temporally variant water. However, the isotopic composition of Piedmont Province base flow may vary at a given location by a small degree when sampled monthly during the course of a year (Rose, 1996).

Stable oxygen isotope ratios in the Chattahoochee River itself systematically increase from -5.8$^o/_{oo}$ in the Blue Ridge headwaters to -4.4$^o/_{oo}$ at Buford Dam on Lake Lanier which is upstream of the AMR (Figure 3). The contributions of tributary base flow within the Atlanta Metropolitan Region do not systematically alter the stable isotopic composition of water in that values remain near the average value of -4.4$^o/_{oo}$. Stable oxygen ratios become slightly heavier downstream of Atlanta (Figure 3), increasing to -4.0$^o/_{oo}$ at Franklin, Georgia at the terminus of the study area. This trend of increasing values is consistent with yearly-average continental precipitation trends (shown on Figure 14-2 in Drever, 1997) which increase from the polar regions to the equator (i.e. in a generally southern direction). The trends towards increasing downstream $\delta^{18}O$ values shown on Figure 3 provides another line of evidence that these base flow samples collected in this study represent truly integrated yearly-precipitation, rather than isolated temporally variant storm water. This is the trend that would be expected if base flow was derived from ground water, rather than some poorly-mixed source of water in the shallow subsurface.

Tritium Concentrations:

The source of environmental tritium (^3H) within natural waters is from the thermonuclear bomb tests that occurred over North America during the late 1950's and early 1960's. Atmospheric bomb tests were curtailed by treaty in the mid-1960's and since that time the massive "bomb pulse" of tritium has radioactively decayed. Tritium has a half-life of 12.3 years and therefore three to four half-lives have passed since leaving only "residual" concentrations in most natural waters. Tritium concentrations have been measured within Piedmont Province surface water and ground water since the early 1990's (Rose, 1993). During this period tritium concentrations were typically between 20-30 T.U. in this region. Tritium concentrations in the seven samples analyzed for this present study varied only between 5.5 and 9.1 T.U. (Table 3). Tritium concentrations in regional precipitation within the southeastern United States averaged ~4.5 T.U. during the period between 2000-2002 and 5.6 T.U. during the period between 1990-1999 (R.L. Michel, USGS.,written communication).

Using an average tritium concentration of 7.6 T.U., some information can be inferred regarding the residence time of base flow within CRB watersheds. First, there is definitely some "bomb-tritium" present within all of the waters or else tritium concentrations would be lower (i.e.

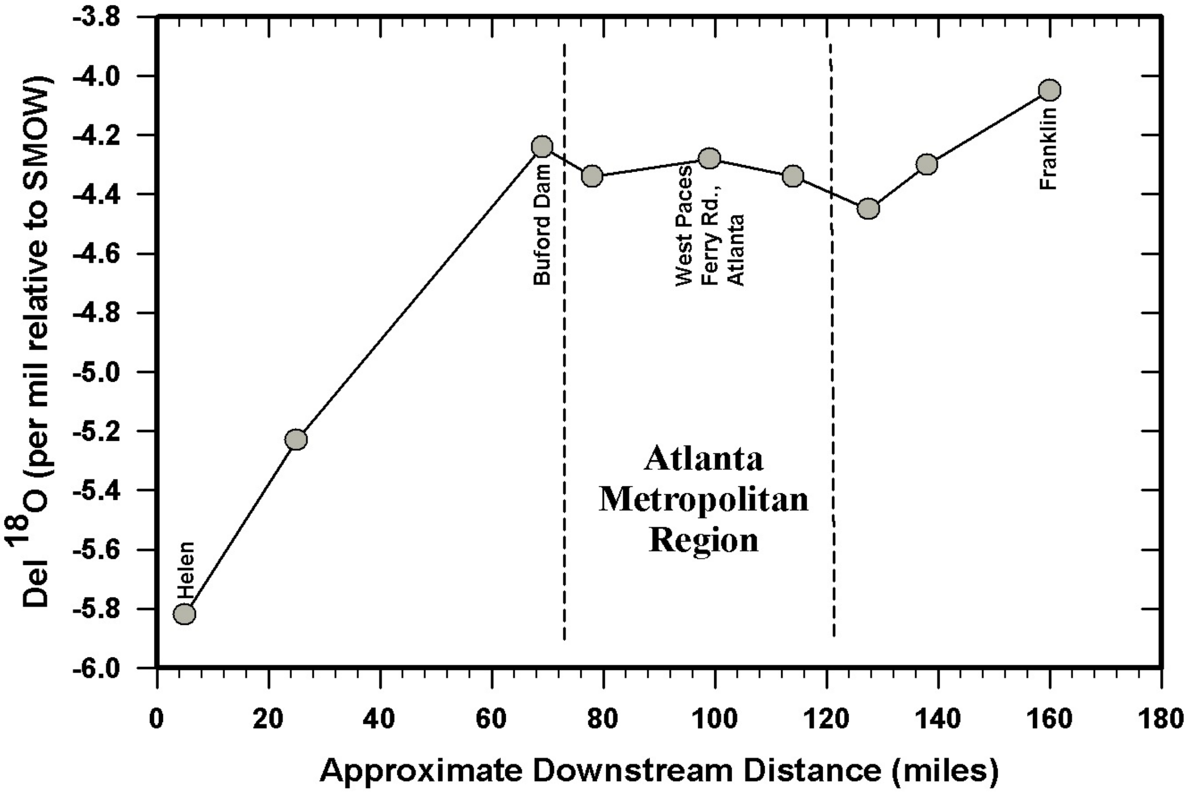

Figure 3. Profile of stable oxygen isotope ratio trends within the Chattahoochee River

4-5 T.U. or the concentrations found in regional rainfall for the past ten years). In contrast, if the base flow was composed predominantly of pre-bomb age water, tritium concentrations would approach zero. Tritium concentrations in CRB base flow are 10-20 T.U. less than tritium concentrations within Piedmont basins were during the 1990s. This is the result of radioactive decay and possibly mixing of older ground water which makes up base flow with younger precipitation. In short, the tritium concentrations measured in CRB base flow within this study are consistent with average residence times of 15-40 years which were interpreted in previous regional studies (i.e. Rose, 1993) and directly measured by tritium-helium measurements within the small Panola Mountain experimental catchment, approximately 35 miles east of the CRB (Burns et al., 2003).

Table 3
Summary of Stable Oxygen Isotope Ratios and Tritium Concentrations in Chattahoochee River Basin Base Flow

Sample No.	Stable Oxygen Ratio $\delta^{18}O$ per mil ($^o/_{oo}$) relative to SMOW[a]	Stable Oxygen Ratio $\delta^{18}O$ per mil ($^o/_{oo}$) relative to SMOW (repeat analysis)	Tritium (^3H) Concentration (in T.U.)[b]
CB-1	-5.83	-5.82	
CB-2	-6.10		
CB-3	-4.59		
CB-4	-4.87	-4.72	
CB-5	-5.00		
CB-6	-5.01		
CB-7	-4.69	-4.40	
CB-8	-4.60		
CB-9	-4.45		7.3±0.7
CB-10	-4.48		
CB-11	-4.65		
CB-12	-4.49		7.4±0.8
CB-13	-4.54	-4.42	9.1±1.0
CB-14	-4.05		7.2±0.7
CB-15	-4.61		
CB-16	-3.94		6.6±0.8 & 5.5±0.7
CB-17	-4.30		
CB-18	-4.54	-4.68	
CB-19	-4.45		
CB-20	-4.66		
CB-21	-4.60	-4.51	
CB-22	-4.60		

Sample No.	Stable Oxygen Ratio $\delta^{18}O$ per mil ($^o/_{oo}$) relative to SMOW[a]	Stable Oxygen Ratio $\delta^{18}O$ per mil ($^o/_{oo}$) relative to SMOW (repeat analysis)	Tritium (^3H) Concentration (in T.U.)[b]
CB-23	-5.45		
CB-24	-5.42	-5.43	
CB-25	-5.23		
CB-26	-4.24		
CB-27	-4.96		
CB-28	-4.54		
CB-29	-4.40		
CB-30	-4.34		
CB-31	-4.28		
CB-32	-4.34		8.3±0.8
CB-33	-4.42	-4.38	
CB-34	-4.17		
CB-35	-3.72		
CB-36	-4.64		8.0±0.7
WTP-1	-4.53	-4.40	
WTP-2	-4.44		
Average Stream Water Composition = -4.64 $^o/_{oo}$ ± 0.48 $^o/_{oo}$ (1 std. dev.) [a]) SMOW = Standard Mean Ocean Water [b]) T.U. = Tritium Unit (1 tritium atom in 10^{18} H atoms)			

Major Ion Geochemistry:

General Trends and Comparison of Sub-Groups: The major ion chemistry of stream base flow in the Chattahoochee Basin (as summarized in Table 4 and Appendix 2) is extraordinarily diverse and this diversity can not be solely attributed to lithological variation. There is assumably a reasonably varied assemblage of minerals and rocks within the rural basins that were sampled both north and south of the AMR; however, there was only a fairly narrow range of hydrochemical variation (i.e. TDS < 50 mg/L) within these basins. Therefore the effects of anthropogenic contamination must be considered. The term '*contamination*' as used in this study refers to solute that is input as a result of some human activity that results in ionic concentrations that are significantly greater than "*background*" or *lithogenic* concentrations. The term "*contamination*" does not necessarily imply that the concentration of a given parameter is elevated above Maximum Concentration Levels (MCLs) for drinking water and in fact major ion concentrations for all the stream water is below the MCLs for drinking water (i.e. <250 mg/L chloride, <250 mg/L sulfate, and < 500 mg/L for total dissolved solids [TDS]).

The relatively large amount of diversity observed within this synoptic sample set is summarized in the *Stiff diagrams* shown in Figure 4. The variable shapes of each polygon in this figure represent different proportions of the major ions (Ca, Na, K, Mg, HCO_3, Cl, and SO_4) while the area of the polygon corresponds to the total ionic load or TDS of the individual sample. The most obvious observation that can be inferred from Figure 4 is that the stream chemistry of all the other groups (as represented by these particular individual streams) is far more concentrated in solute than the rural streams (represented by Acorn Creek which is a small watershed south of the AMR). Furthermore, it can be inferred from Figure 4 that Chattahoochee River water more closely resembles the geochemistry of rural basin water (considered to represent "background" or uncontaminated conditions) than it does waters from the urban areas. We can also infer from Figure 4 that stream flow in the semi-developed basins (represented by Olley Creek - west of Atlanta) much more closely resembles the major ion geochemistry of stream water in the developed basins (i.e. South Peachtree Creek) than base flow in the rural basins. Further details on these observations will be forthcoming.

The highest TDS concentrations in stream water were 236 mg/L for Proctor Creek which is directly downstream from a CSO facility and the lowest value was 16 mg/L for Smith Creek which is a head water stream in the Chattahoochee National Forest in the Blue Ridge Mountains (Table 4). For purposes of comparison, TDS concentrations in sewage effluent were between 250 and 350 mg/L in the two samples that were obtained from R.N. Clayton and Utoy Creek water treatment plants. The variability with respect to specific conductance (a readily measurable proxy for total solute concentrations or TDS) is shown on Figure 5. The patterns of groupings observed on Figure 5 are common to most all of the major ions in that it shows that urban sub-groups (i.e. semi-developed basins, developed basins, basins with main sewage line basins, and basins with CSOs) are characterized by higher solute concentrations than both rural base flow and Chattahoochee River base flow.

Bicarbonate (as determined by alkalinity titration)was the most concentrated of the ions which is typically the case in aluminosilicate watersheds such as the Chattahoochee River basin and other watersheds within the Blue Ridge and Piedmont Provinces. Bicarbonate concentrations were

Table 4
Summary of Chemical Data by Groups

Specific Conductance (values in µS/cm)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	33.2	34.1	17.9	10.2	56.1
II	Chattahoochee River	9	77.4	74.6	34.6	37.1	136.3
III	Semi-Developed Basins	7	95.2	105.9	41.3	70.5	167.9
IV	Developed Basins in the AMR[1]	5	109.5	116.2	20.5	91.0	143.9
V	AMR Basins with Streams on Main Sewage Line	5	131.1	136.3	16.7	121.9	160.1
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	224.3	245.8	53.3	206.5	306.5
VII	Sewage Effluent	2	------	430.1	42.3	400.2	460.2
pH							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	6.1	6.1	0.1	5.9	6.3
II	Chattahoochee River	9	6.3	6.3	0.3	5.8	6.7
III	Semi-Developed Basins	7	6.4	6.4	0.2	6.1	6.7
IV	Developed Basins in the AMR[1]	5	6.5	6.4	0.1	6.4	6.6
V	AMR Basins with Streams on Main Sewage Line	5	6.5	6.5	0.1	6.4	6.8
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	6.7	6.7	0.4	6.2	7.1
VII	Sewage Effluent	2	------	6.7	0.2	6.5	6.8
[1]AMR= Atlanta Metropolitan Region							

Table 4
Summary of Chemical Data by Groups (continued)

Bicarbonate Alkalinity (values in mg/L)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	9.2	12.2	7.0	3.9	22.7
II	Chattahoochee River	9	22.4	20.2	6.9	10.7	31.5
III	Semi-Developed Basins	7	32.5	32.7	2.5	27.7	35.0
IV	Developed Basins in the AMR	5	41.7	42.0	6.8	34.3	52.5
V	AMR Basins with Streams on Main Sewage Line	5	43.1	44.5	8.0	35.4	56.9
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	67.1	68.6	21.0	48.3	90.3
VII	Sewage Effluent	2	------	110.4	64.6	64.7	156.1
Chloride (values in mg/L)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	5.4	5.4	2.2	1.7	8.2
II	Chattahoochee River	9	11.4	11.5	5.9	4.5	21.9
III	Semi-Developed Basins	7	12.1	17.0	15.4	4.7	49.3
IV	Developed Basins in the AMR	5	13.2	14.7	5.2	8.5	22.0
V	AMR Basins with Streams on Main Sewage Line	5	14.5	14.9	2.5	12.0	18.2
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	28.9	31.7	6.6	27.1	39.2
VII	Sewage Effluent	2	-----	66.2	1.5	65.1	67.3

Table 4
Summary of Chemical Data by Groups (continued)

Sulfate (values in mg/L)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	1.9	1.9	0.4	1.1	2.7
II	Chattahoochee River	9	5.6	5.6	2.8	1.8	10.4
III	Semi-Developed Basins	7	4.1	6.6	6.0	2.2	19.0
IV	Developed Basins in the AMR	5	4.9	5.3	1.4	3.7	7.6
V	AMR Basins with Streams on Main Sewage Line	5	11.9	14.2	5.0	11.1	23.1
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	27.9	27.8	14.0	13.8	41.8
VII	Sewage Effluent	2	------	27.3	2.7	25.4	29.2
Calcium (values in mg/L)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	1.2	2.3	2.2	1.3	6.3
II	Chattahoochee River	9	3.2	4.3	2.5	1.4	9.1
III	Semi-Developed Basins	7	6.9	6.7	1.9	6.9	10.1
IV	Developed Basins in the AMR	5	10.4	10.4	3.4	5.9	13.8
V	AMR Basins with Streams on Main Sewage Line	5	10.9	12.0	3.2	9.4	17.5
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	25.4	25.0	5.7	19.1	30.5
VII	Sewage Effluent	3	-----	20.3	8.6	14.2	26.4

Table 4
Summary of Chemical Data by Groups (continued)

Magnesium (values in mg/L)							
Group	**Description**	**No.**	**Media n**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	0.7	0.7	0.4	0.2	1.4
II	Chattahoochee River	9	1.2	1.1	0.3	0.7	1.6
III	Semi-Developed Basins	7	2.0	2.4	1.2	1.8	5.1
IV	Developed Basins in the AMR	5	1.9	2.0	0.1	1.9	2.1
V	AMR Basins with Streams on Main Sewage Line	5	2.4	2.5	0.3	2.2	3.1
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	3.8	3.7	1.4	2.3	5.1
VII	Sewage Effluent	2	-----	2.6	0.2	2.4	2.8
Sodium (values in mg/L)							
Group	**Description**	**No.**	**Media n**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	4.1	3.8	1.8	1.3	6.3
II	Chattahoochee River	9	7.5	8.4	5.2	3.1	19.5
III	Semi-Developed Basins	7	6.1	9.6	5.4	6.7	17.6
IV	Developed Basins in the AMR	5	7.9	9.3	3.4	5.9	13.8
V	AMR Basins with Streams on Main Sewage Line	5	10.0	10.5	2.1	9.0	14.1
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	19.8	19.0	2.1	16.6	20.5
VII	Sewage Effluent	2	-----	57.6	9.5	40.9	50.4

Table 4
Summary of Chemical Data by Groups (continued)

Potassium (values in mg/L)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	1.3	1.2	0.5	0.5	2.1
II	Chattahoochee River	9	2.3	2.4	0.8	1.3	3.7
III	Semi-Developed Basins	7	2.3	2.6	1.7	1.0	5.7
IV	Developed Basins in the AMR	5	2.5	2.6	0.2	2.3	2.8
V	AMR Basins with Streams on Main Sewage Line	5	2.7	2.7	0.4	2.5	3.3
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	4.7	4.9	0.5	4.5	5.4
VII	Sewage Effluent	2	------	9.3	2.1	7.8	10.7
Dissolved Silica (values in mg/L)							
Group	**Description**	**No.**	**Median**	**Mean**	**Standard Deviation**	**Low**	**High**
I	Rural Streams	8	10	10	2	6	13
II	Chattahoochee River	9	7	7	1	5	9
III	Semi-Developed Basins	7	13	13	2	11	15
IV	Developed Basins in the AMR	5	13	14	2	12	17
V	AMR Basins with Streams on Main Sewage Line	5	17	16	3	13	19
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	13	18	7	13	26
VII	Sewage Effluent	2	-----	13	1	12	14

Table 4
Summary of Chemical Data by Groups (continued)

Total Dissolved Solids (mg/L)							
Group	**Description**	**No**	**Median**	**Mean**	**Std. Dev.**	**Low**	**High**
I	Rural Streams	8	38.9	43.7	10.4	16.1	58.4
II	Chattahoochee River	9	63.7	60.8	24.3	31.4	106.6
III	Semi-Developed Basins	7	84.9	90.8	26.5	65.8	138.3
IV	Developed Basins in the AMR	5	96.1	100.5	16.8	82.1	123.7
V	AMR Basins with Streams on Main Sewage Line	5	118.6	117.5	12.4	106.2	136.3
VI	Combined Sewage Overflow Basins/Basins Receiving Treated Effluent	3	192.2	198.9	34.9	167.9	236.7
VII	Sewage Effluent	2	------	296.7	65.3	250.5	342.9

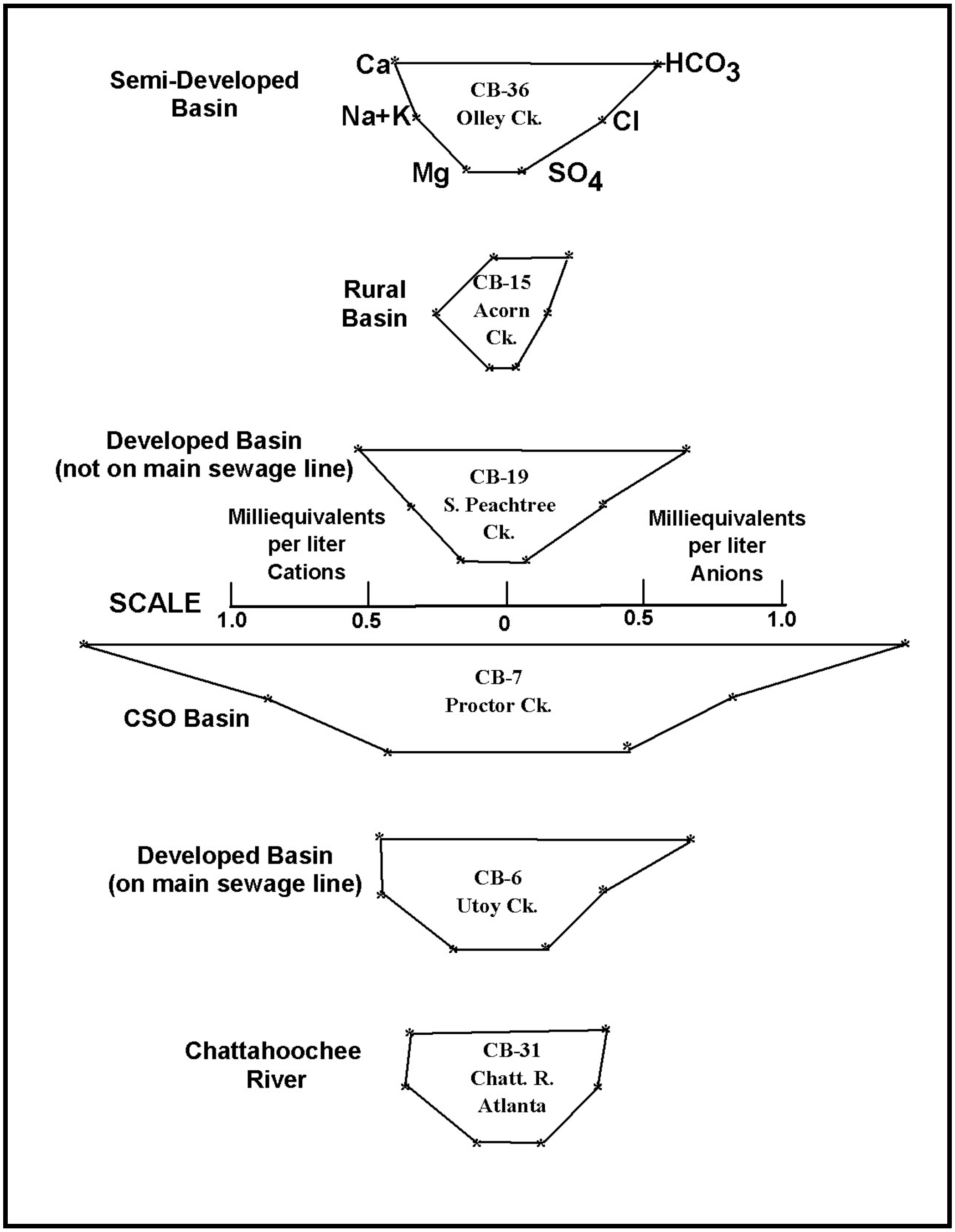

Figure 4. "Stiff" Diagrams for representative samples. Diagrams show relative proportions of cations and anions (in meq/L) for selected samples. See top polygon for position of ions.

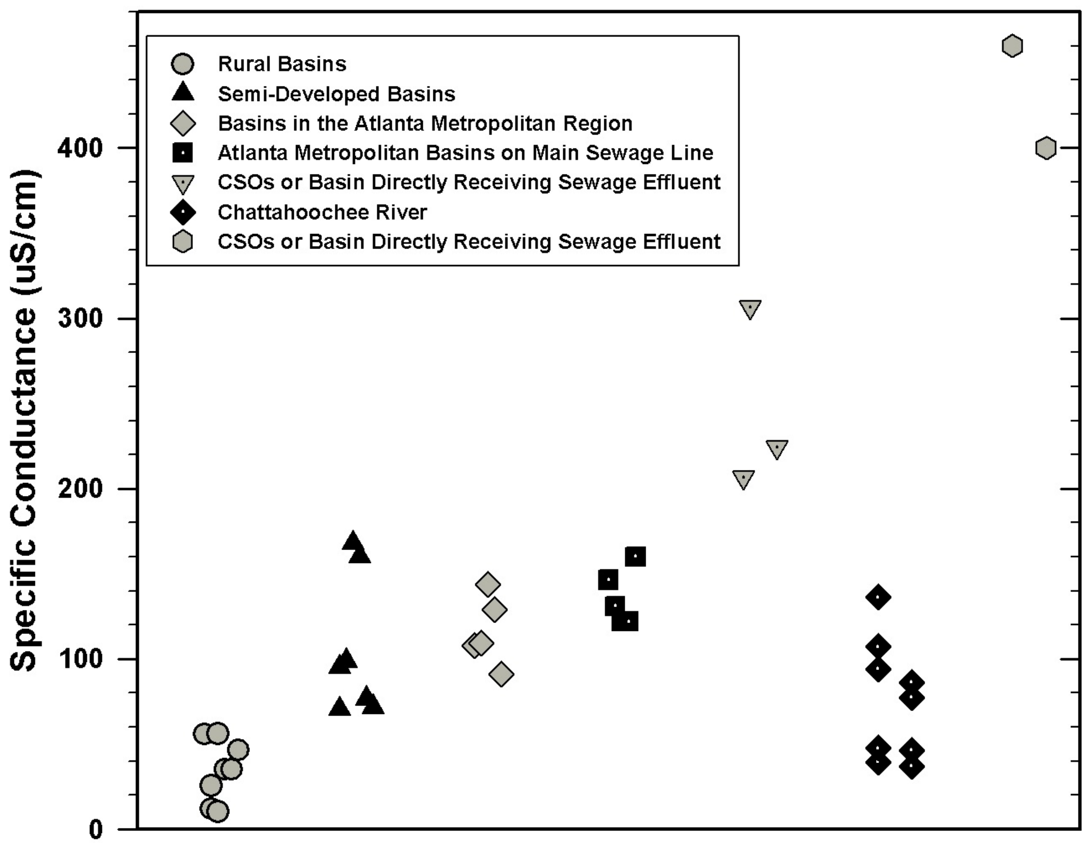

Figure5. Specific Conductance values for the various groups of waters

also the most concentrated within the sewage-impacted CSO basins (Figure 4) and within the sewage effluent itself (mean alkalinity = 110.4 mg/L; Table 4). Bicarbonate alkalinity averaged ~12 mg/L and were 3-4 times greater within base flow in the urban areas than in the rural streams, most likely indicative of a contaminant source for this ion. Comparative bicarbonate alkalinity concentrations for the various Chattahoochee basin sub-groups are shown in Figure 6 which shows similar trends to specific conductance (Figure 5).

Chloride and sulfate concentrations are also very revealing geochemical parameters within Chattahoochee Basin stream flow in that although both these ions can be derived from atmospheric and lithological sources, their presence in high concentrations is likely from an anthropogenic source. Chloride is a concentrated electrolyte in human wastes and is also present within household cleaning fluids. Sulfate can be derived from the oxidation of organic sulfur present in sewage wastes. The mean concentrations of chloride and sulfate within the two sewage effluent samples were 66.2 and 27.3 mg/L, respectively, compared to 5.4 and 1.9 mg/L within rural stream flow (Table 4 and Figure 5). In other words, waste water is approximately 13 times more concentrated with respect to sulfate and chloride than the more pristine waters found in the rural basins. Comparisons of sulfate within the urban waters are also revealing. Median sulfate concentrations were 2.4 greater for AMR basins adjacent to main sewage lines (Group V, Table 4) than urban basins *not* adjacent to the main sewage line (Group IV waters). The results for sulfate stands in contrast to bicarbonate, chloride, sodium, and TDS which were less than 1.3 greater in the *sewage line basins* than within the other developed AMR watersheds. Median sulfate concentrations in Group VI waters (CSO and sewage effluent-receiving basins) were >20 times more concentrated than in the rural basins (Table 4). In contrast, bicarbonate alkalinity, sodium, TDS, and chloride were only 5-7 times more concentrated in the Group VI than Group I (rural basin) waters. The median sulfate concentration within the Chattahoochee River base flow is 5.6 mg/L and ranges between1.8 and 10.4 mg/L; approximately twice as high as rural base flow but much lower than in most of the other urban basins (Table 4).

Sulfate and chloride concentrations for base flow within the various sub-groups of basins are shown on Figures 7 and 8. The sulfate and chloride concentrations (as well as specific conductance and other major ion concentrations) in Big Creek (at Cumming) base flow are quite elevated in relation to the other samples in this group (semi-developed basins outside of the Atlanta metropolitan basin; Group III, Table 4). The specific conductance of this sample (CB-22) was 168 μS/cm (Appendix 2), approximately 77% higher than median base flow for this group. The chloride concentration in this sample was 49 mg/L, clearly reflecting some waste contribution from sewage effluent disposal upstream of where the sample was taken. In short, these data show that base flow in basins outside of the AMR under some circumstances can become as contaminated or more contaminated than base flow in stream basins within the main metropolitan area.

The ternay diagrams shown on Figures 9 and 10 show the entire set of study area base flow samples grouped by their relative percentage equivalence of cations (Figure 9) and anions (Figure 10). These diagrams do not, however, give any specific information about the magnitude of solute concentrations within any of the samples. As can be observed on Figure 9, most of the base flow samples are either dominated by sodium or are a mixed sodium-calcium type. The rural basins and base flow from the Chattahoochee River tend to be more sodium-dominated and the CSO basins are more calcic. The bicarbonate ion comprises between 50-70% of the total equivalence of base

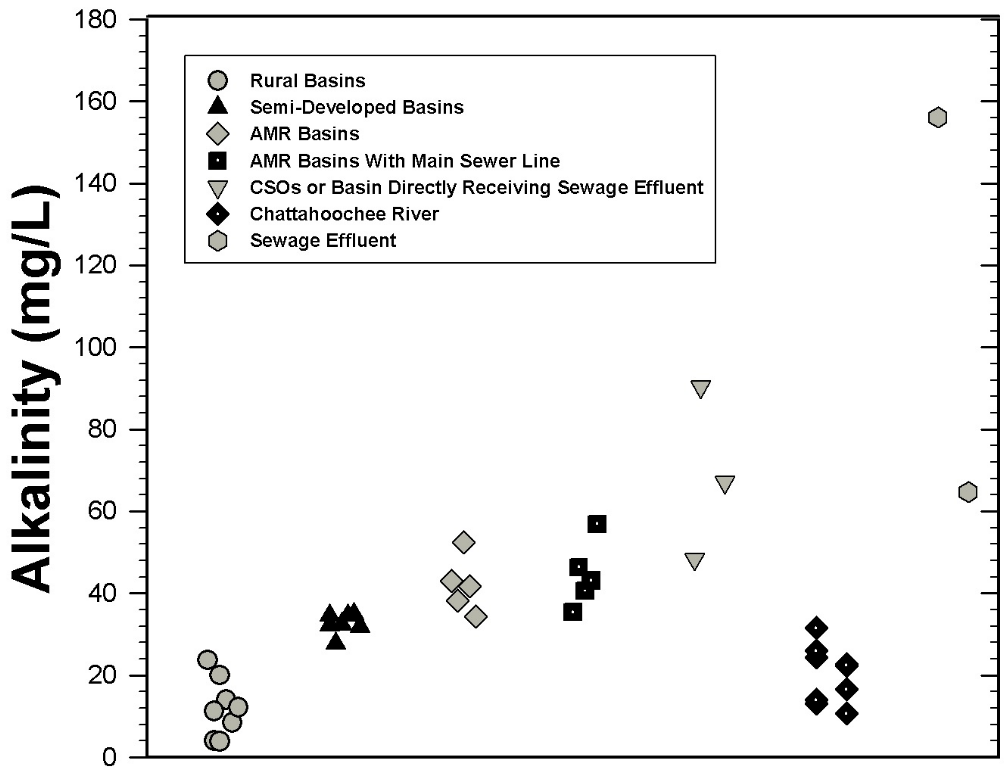

Figure 6. Alkalinity concentrations for the various groups of waters

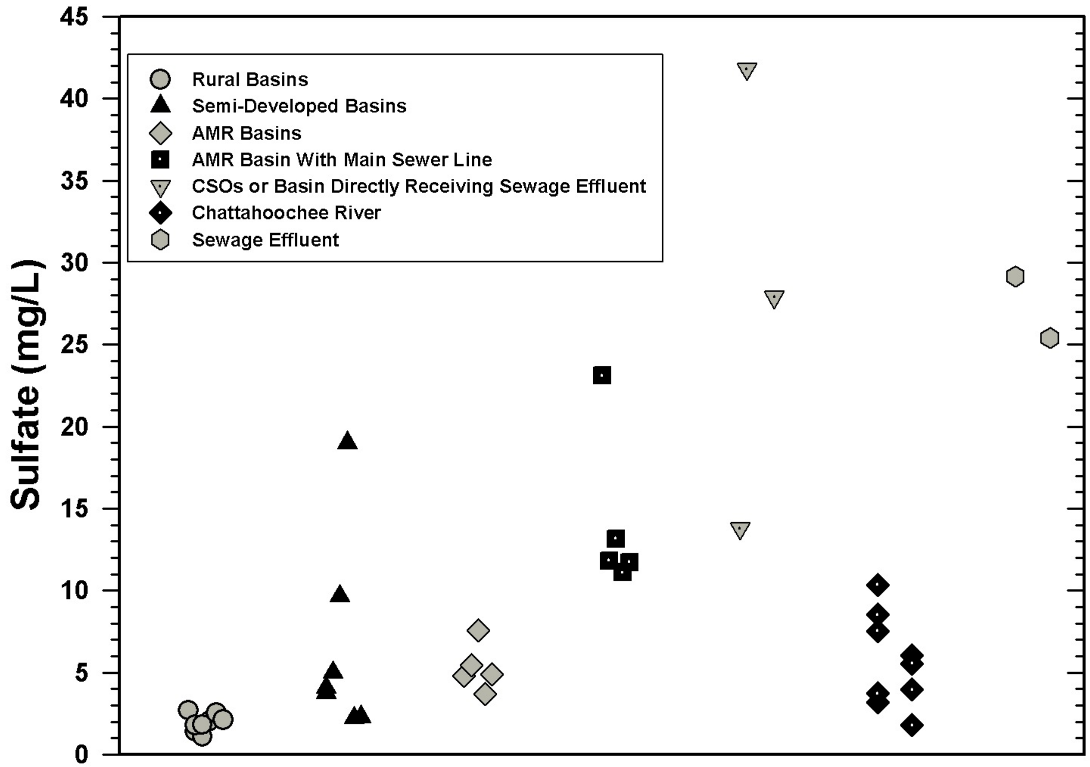

Figure 7. Sulfate concentrations for the various groups of waters

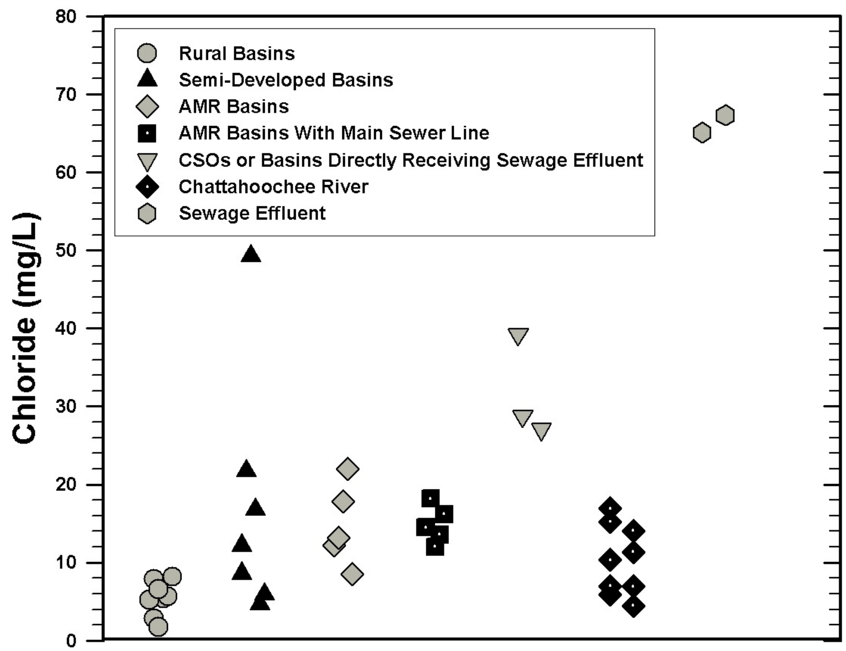

Figure 8. Chloride concentrations for the various groups of waters

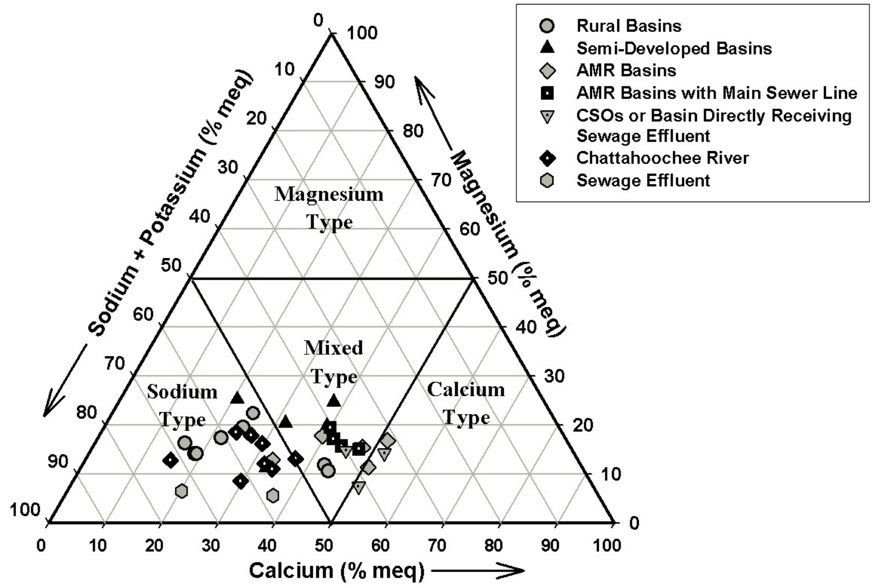

Figure 9. Ternary diagram showing the percentage of cations (in milliequivalents) for the various water groups

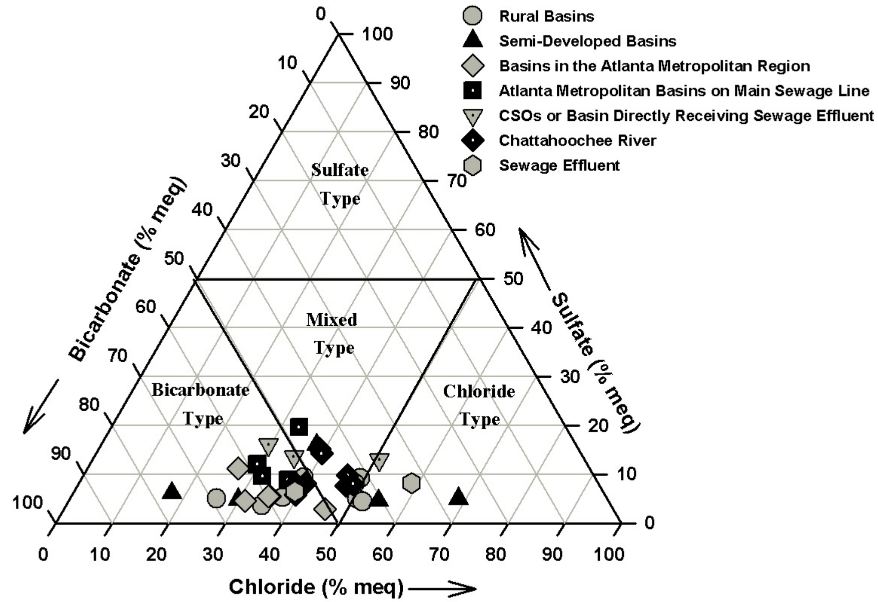

Figure 10. Ternary diagram showing the percentage of anions (in milliequivalents) for the various water groups

flow within the CRB and the chloride ion comprises between 30-40% of the total equivalence. It can also be deduced from Figure 10 that although the percentage of sulfate by equivalence is low (i.e. < 20%) in all of the base flow, there is a higher percentage of sulfate in those basins either on the main sewer line and those associated with CSO facilities.

Statistical Comparisons: T-tests were employed for a more statistically rigorous comparison of the major ion geochemistry of the sub-groups of Chattahoochee River stream basins that were designated within this study. The sets that were defined for the t-tests (summarized in Table 5) were slightly different but closely resembled the previously described sub-groups listed in Table 1. A 95% confidence interval ($\alpha = 0.05$) was used as the significance level to base a decision as to whether the mean of one population or group was greater than another group (i.e. Populations "A" and "B" on Table 5). However, in most cases the degree of statistical confidence associated with these tests is much greater than this 95% confidence interval.

In all cases (i.e. for specific conductance, alkalinity, chloride, sulfate, sodium, potassium, and strontium {which will be discussed later}) the urban and semi-developed basin base flow is characterized by significantly higher solute concentrations than the rural streams. Likewise, in all cases the four Chattahoochee River base flow samples collected downstream of Atlanta were characterized by greater mean concentrations of solutes than the four Chattahoochee River locations upstream of the AMR (these trends will be discussed further in the next section). The comparisons between urban ($n = 5$) versus the semi-developed basins ($n=7$) are not as clear or uniform. Mean specific conductance, alkalinity, and sulfate concentrations were greater in the urban base flow; however chloride, sodium and potassium concentrations (all parameters associated with sewage effluent) were not significantly greater in the urban population than within the non-urban population (Table 5). Similarly, the results of the t-tests between those basins located on the main sewage line in Atlanta versus those Atlanta basins that were not on the main lines were also mixed. Chloride and alkalinity concentrations were *not* significantly greater in base flow for those stream basins located on the main sewer line than those off the main line (Table 5). Sulfate concentrations were significantly greater in the urban base flow than in the non-urban base flow and greater in the urban basins with the main sewer lines than those without main sewer lines. Perhaps this indicates that sulfate is the most revealing indicator of sewage effluent impacts upon stream water chemistry. Nonetheless, the results are mixed and do not provide totally definitive evidence that Atlanta's aged sewage conveyance infrastructure is a source of ground water (base flow) contamination.

Major Ion Geochemical Trends Within Base Flow in the Chattahoochee River: Nine base flow samples from the Chattahoochee River upstream, downstream, and within the Atlanta region were chosen for this analysis (see Appendix 1 and Table 1). This corresponded to ~260 river kilometers (160 miles) and a watershed area of approximately 6,900 km^2 (or 2,660 mi^2) and extends from Helen to Franklin, Georgia. It was previously shown that concentrations of many of the major ion parameters within Chattahoochee River base flow more closely resemble "natural" or "background" concentrations than they do base flow sampled from the urban tributaries. In fact base flow from the Chattahoochee River closely resembles the chemistry of many of the major rivers of the world including the Ganges, Nile and Mississippi River. This is shown on Figure 10 which is known as a "Gibbs diagram" (after Gibbs, 1970 and Berner and Berner, 1987). The total dissolved

Table 5
Summary of T-Test Results for Key Geochemical Parameters in the Chattahoochee River Basin

Population A[1]	Population B[1]	Specific Conduct.	Alkalinity	Cl	SO_4	Na	K	Sr
Urban[3]	Rural[4]	S[2]	S	S	S	S	S	S
Semi-Developed[5]	Rural	S	S	S	S	S	S	S
Urban	Semi-Developed	S	S	NS[2]	S	NS	NS	S
Urban Basins on Main Sewage Line[6]	Urban Basins not on Main Sewage Line[7]	S	NS	NS	S	S	S	S
Chattahoochee River [8] (downstream of Atlanta)	Chattahoochee River [9] (upstream of Atlanta)	S	S	S	S	S	S	S

(1) Population "A:" has the greater mean value for the seven parameters than Population "B"

(2) "S" indicates positive T-test results; Means for populations A and B for the given parameter are significantly different from one another, at a 95% confidence interval or greater; "NS" = population means are not significantly different

(3) Urban Stream Basin Sites [n = 10]: CB-4, CB-5, CB-6, CB-8, CB-9, CB-10, CB-12, CB-13, CB-29, CB-33 (set does not include CSO basin)

(4) Rural Stream Basin Sites [n=8]: CB-1, CB-2, CB-15, CB-16, CB-18, CB-20, CB-23,CB-24

(5) Semi-Developed Basin Sites [n=7]: CB-3, CB-21, CB-22,CB-37, CB-34,CB-35,CB-36

(6) Urban Basins on Main Sewage Line Sites [n=5]: CB-4,CB-5,CB-6,CB-12,CB-13

(7) Urban Basins not on Main Sewage Line Sites [n=5]: CB-8,CB-9,CB-10,CB-29,CB-33

(8) Chattahoochee River (downstream of Atlanta) Sites [n=4]: CB-14,CB-17,CB-19,CB-30,CB-31

(9) Chattahoochee River (upstream of Atlanta) [n=4]: CB-1,CB-25, CB-26, CB-28

solids concentrations within the Chattahoochee River water samples average ~ 70 mg/L (slightly less than most of the other "rock weathering dominated" rivers shown on Figure 11); however, Chattahoochee River base flow apparently has a higher Na/Na+Ca ratio than the other major rivers that are "weathering dominated". The reason for this is not totally understood; however, it may be due to the negligible contribution of calcic minerals (e.g. calcite in limestones) within this aluminosilicate terrain and/or an additional input of sodium from a possible anthropogenic source.

As previously shown by the t-test analyses (Table 5), major ion concentrations in Chattahoochee River base flow downstream of Atlanta , while still relatively dilute, are greater than upstream of the Atlanta metropolitan reigon. The specific conductance, sulfate and chloride profiles on Figures 12, 13, and 14 show that solute concentrations in base flow increase by approximately a factor of three downstream of Lake Lanier (i.e. the upstream boundary of the AMR). Solute concentrations remain very low from the Blue Ridge mountain headwaters to the Buford dam in these relatively undeveloped headwater basins (i.e. $[SO_4]$ and [Cl] < 7 mg/L). Solute concentrations increase markedly within the AMR particularly between the Roswell area and the core metropolitan region around Atlanta. Specific conductance, chloride and sulfate concentrations decline by approximately 30-40% downstream of the AMR as the urban component of river base flow becomes "diluted" by a contribution from the rural basins south of and the relatively undeveloped basins west of the AMR. However, solute concentrations do not return to their upstream "background" levels (i.e. specific conductance ≈ 40 µS/cm) because there is not enough rural basin area downstream of Atlanta to generate sufficient runoff to accomplish this dilution.

Comparative Regression Analyses: Standard linear regression analyses were performed for the major ions, aqueous silica, strontium ion and strontium isotope ratios (which will be discussed later) on the 39 samples taken as part of this study (36 CRB base flow samples, two sewage effluent samples and one South River base flow sample). The linear regression coefficients (r^2 values) between each of the parameters were placed in a regression matrix (Table 6) to facilitate comparisons. Another comparative regression table (Table 7) summarizes similarly derived regression coefficients for the major ions within base flow from 32 stream samples derived from previous studies of the Flint, Oconee, and Ocmulgee basins (Rose, unpublished data and Rose, 2002). These basins are located generally no greater than 150 kilometers from Atlanta and samples were deliberately taken from relatively undeveloped parts of these basins located within the southern Georgia Piedmont Province.

The highest correlations (r^2 values > 0.80) for the Chattahoochee Basin base flow (Table 6) were between sodium and potassium, sodium and chloride, and potassium and chloride. A second group of relatively high regression coefficients ($0.60 < r^2 < 0.79$)were between calcium and bicarbonate, calcium and sulfate, potassium and bicarbonate, and sulfate and bicarbonate. These results are initially hard to explain in that one would expect to find the highest correlations between sodium and bicarbonate, sodium and calcium, calcium and bicarbonate in aluminosilicate watersheds. These high correlations would result from the *incongruent* or partial dissolution of

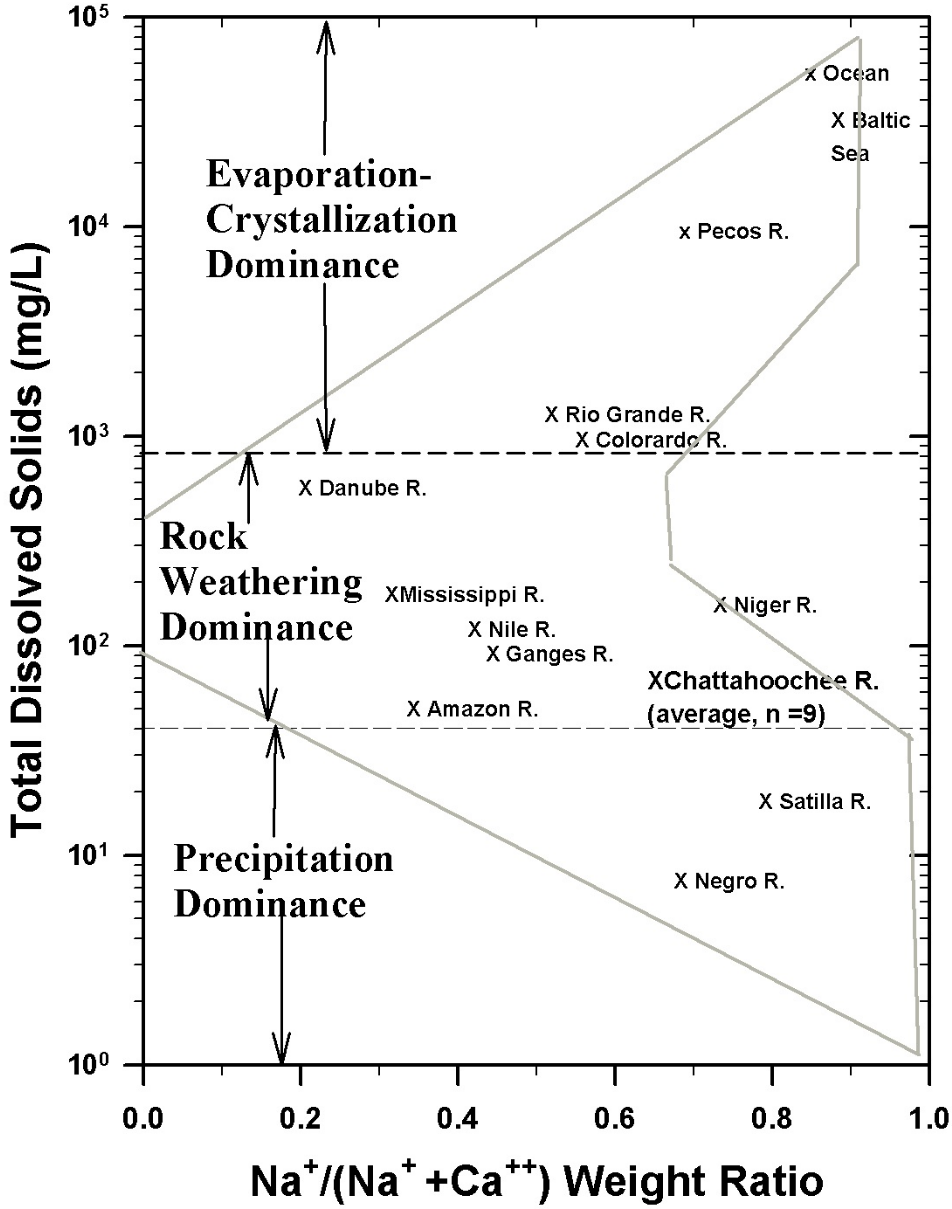

Figure 11. Gibbs Diagram showing comparison of the hydrochemistry of the Chattahoochee River with other rivers

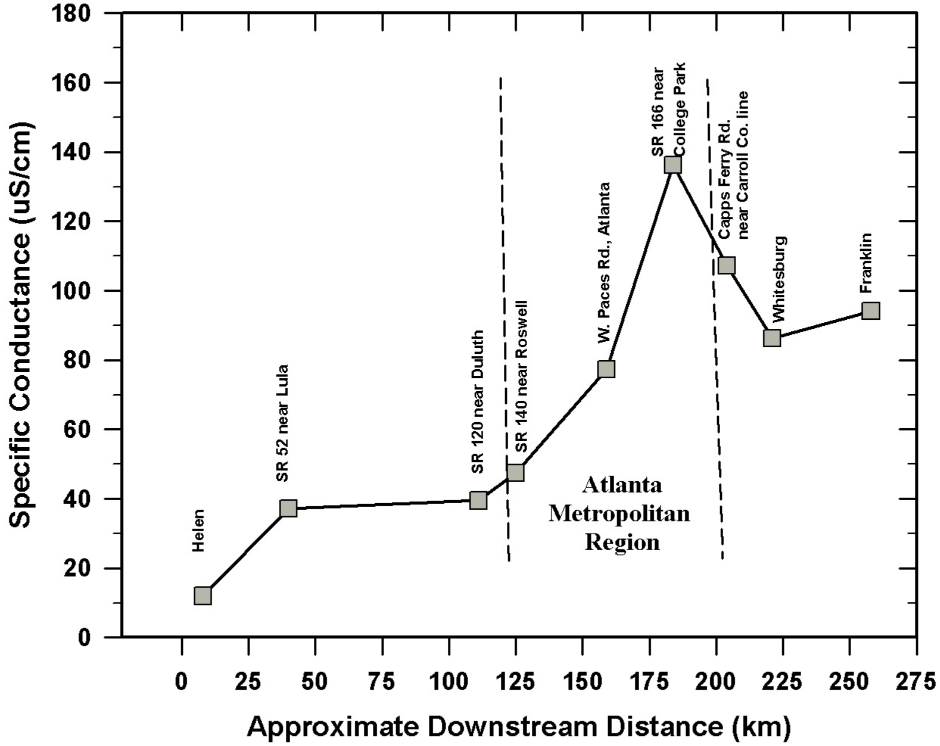

Figure 12. Profile of specific conductance within the Chattahoochee River

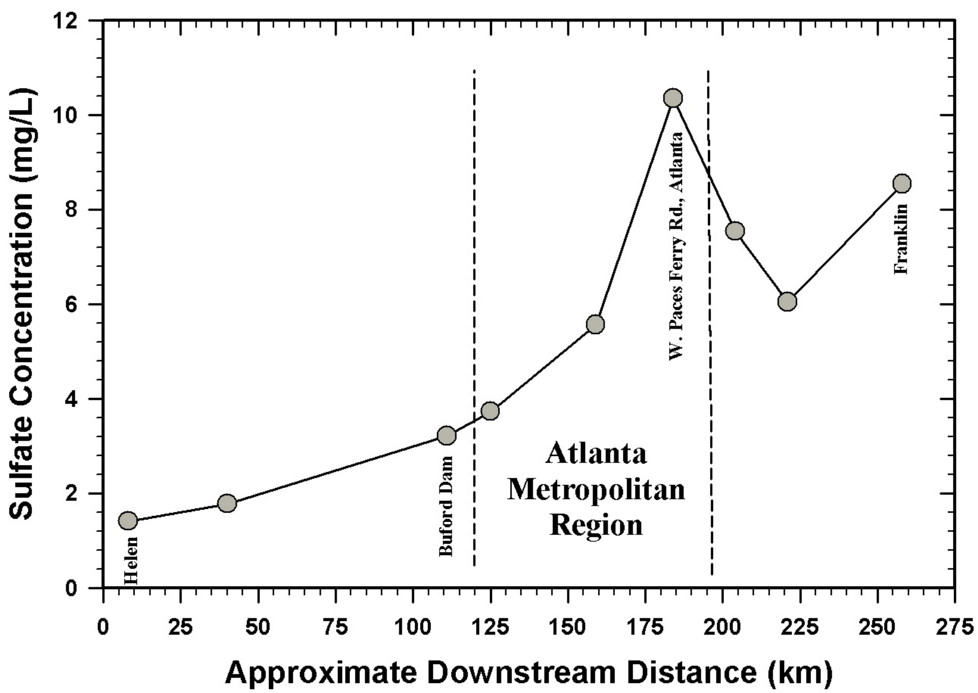

Figure 13. Profile of sulfate concentrations within the Chattahoochee River

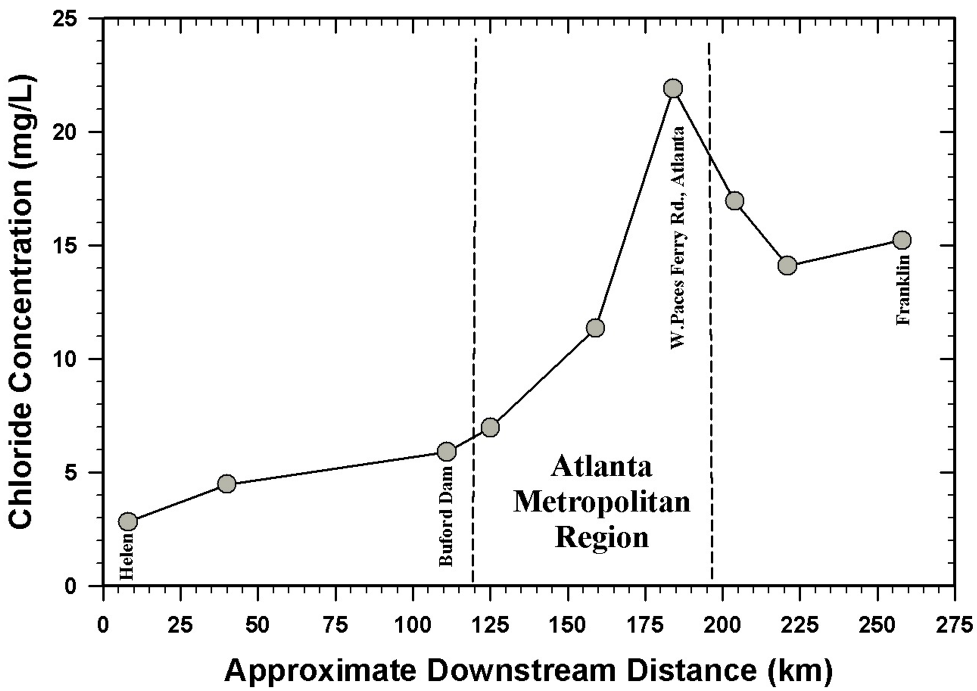

Figure 14. Profile of chloride concentrations within the Chattahoochee River

plagioclase feldspar minerals, biotite, and hornblende which dominate the normal weathering assemblage within Piedmont rocks and soils. The fact that bicarbonate did not appear in the group of highest correlation coefficients is also revealing in that is the dominant ion within Piedmont base flow. These results likely indicate that there is some source in addition to mineral dissolution that serves as a control upon base flow major ion variation.

A probable relationship between sodium, potassium, and chloride is that they are prominent human electrolytes and are therefore concentrated in human wastes (as can be inferred from the major ion chemistry of samples from the sewage effluent (samples WTP-1 and WTP-2) and the South River (Sample SR-1,which receives treated effluent from the Snapfinger Advanced Wastewater Treatment Plant in southeastern Dekalb Co). The potassium concentration in the untreated effluent (WTP-1) was 10.7 mg/L (Appendix 1) which is approximately 10-20 times higher than "background" concentrations in the rural CRB streams. The high degree of correlation between the waste-related ions (Na, K, and Cl) are a basin-wide phenomenon even though there is not a direct input of untreated or treated sewage wastes directly associated with most of the sampling locations. Eliminating data for the two waste treatment plants and the South River lower the regression coefficients somewhat, yet the Na/Cl, Na/K, and K/CL are still high ($r^2 = 0.69$, 0.76 and 0.82, respectively). The relatively high degree of correlation ($r^2 = 0.60$) between sulfate and bicarbonate may be related to their mutual presence in sewage waste; however, the degree of correlation between Ca and SO_4 ($r^2 = 0.69$) is more difficult to explain. The high degree of correlation ($r^2 = 0.73$) between Ca/HCO_3 might be related to mineral weathering.

The correlation coefficient matrix for the major ions in the relatively dilute base flow (see Rose, 2002) for the 32 base flow samples taken from the Flint, Ocmulgee basins is much different than the results for the CRB (Table 7). The regression coefficients were generally lower and the highest values ($0.65 < r^2 < 0.75$) were between Na/Ca, Na/HCO3, Ca/Cl, and Ca/SO4. Potassium (K) is not represented in this group and the regression coefficients for K/Cl, Na/Cl, and Na/K were relatively low ($r^2 < 0.50$) compared to those calculated for the Chattahoochee River Basin ($r^2 > 0.69$). In short, the correlations interpreted as being reflective of waste water (human electrolytes and cleaning solvents concentrated in sewage effluent) were not nearly as strong in the water samples form the relatively rural Flint, Ocmulgee, and Oconee basins. The high Na/Ca and Na/HCO_3 correlations for these rural basins were likely related to normal rock weathering; however, the Ca/Cl and Ca/SO_4 correlations are not as well understood. In short, the regression matrices (Tables 6 and 7) for the two different Piedmont Province base flow data sets are quite different and provide evidence of the human impact upon water quality in the heavily urbanized Chattahoochee Basin.

Table 6
Major Ion Geochemistry of the Chattahoochee River Basin
Regression Coefficient (r^2)Correlation Matrix (n=39)

	Specific Cond.	**Ca**	**Mg**	**Na**	**K**	**HCO_3**	**Cl**	**SO_4**	**H_4SiO_4**	**Sr**	**$^{87}Sr/^{86}Sr$**
Specific Cond.	1.00	0.70	0.45	0.87	0.88	0.88	0.83	0.74	0.18	0.40	0.12
Ca		1.00	0.49	0.43	0.54	0.73	0.45	0.69	0.26	0.63	0.09
Mg			1.00	0.25	0.35	0.39	0.39	0.54	0.43	0.64	0.19
Na				1.00	0.81	0.55	0.87	0.51	0.07	0.18	0.09
K					1.00	0.70	0.90	0.53	0.07	0.21	0.10
HCO_3						1.00	0.55	0.60	0.23	0.43	0.14
Cl							1.00	0.46	0.08	0.17	0.09
SO_4								1.00	0.25	0.64	0.04
H_4SiO_4									1.00	0.63	0.11
Sr										1.00	0.13
$^{87}Sr/^{86}Sr$											1.00

Summary of Strongest Regression Coefficient Values for Ionic Parameters	
$r^2 > 0.80$	Na/K; Na/Cl; K/Cl
$0.60 < r^2 < 0.79$	Ca/HCO_3; Ca/SO_4; Ca/Sr; Mg/Sr; K/HCO_3; HCO_3/SO_4; SO_4/Sr

Table 7
Major Ion Geochemistry of the Oconee, Ocmulgee, and Flint River Basins
Regression Coefficient (r^2)Correlation Matrix (n=32)

	Ca	**Mg**	**Na**	**K**	**HCO_3**	**Cl**	**SO_4**
Ca	1.00	0.51	0.68	0.24	0.32	0.75	0.71
Mg		1.00	0.53	0.23	0.49	0.35	0.19
Na			1.00	0.29	0.70	0.50	0.26
K				1.00	0.19	0.35	0.07
HCO_3					1.00	0.13	0.01
Cl						1.00	0.58
SO_4							1.00
Summary of Strongest Regression Coefficient Values for Ionic Parameters							
$r^2 > 0.65$	Na/Ca, Ca/SO_4, Na/HCO_3, Ca/Cl						

Strontium Ion Concentrations and Strontium Isotope Ratios:

Comparison With Results From the Middle Oconee Basin: Strontium ion concentrations and strontium isotope ratios were measured in base flow and sewage effluent samples in order to determine if these parameters can provide useful information pertaining to the effects of land utilization and sewage waste disposal upon water quality within the study area. A necessary related objective of this analysis was to examine the correlations between Sr isotope ratios and the major ion concentrations. There was a wide range of both strontium concentrations [5.2 μg/L < Sr < 140.8 μg/L] and $^{87}Sr/^{86}Sr$ ratios [0.709460 < $^{87}Sr/^{86}Sr$ < 0.723274] as summarized in Tables 8 and 9. This is consistent with the variation observed with respect to the major ion geochemistry of the Chattahoochee River Basin.

The strontium data are only meaningful when analyzed on a comparative basis. As stated previously, a similar study of strontium isotope variation was undertaken in 2003-2004 within the rural Middle Oconee basin north of Athens, Georgia - approximately 50 miles east of the AMR (Rose, 2004 and Rose, 2005). Sr concentrations within the smaller (860 km^2) Middle Oconee basin varied only between 16.3-26.9 μg/L in base flow while $^{87}Sr/^{86}Sr$ ratios varied between 0.712595 and 0.717572. Recall that these ratios are significant to approximately the 6th decimal place and that the isotopic ratio at a given sampling location was virtually constant throughout the year. Both the Sr ion concentration and isotopic variation within the rural Middle Oconee Basin base flow is far less than the variation observed within the Chattahoochee basin samples acquired for this present study. The Middle Oconee Basin strontium isotope ratios variation was to third decimal place while the Chattahoochee River Basin ratios varied to the second decimal place. The two factors responsible for the relatively high degree variation (shown on Figure 15) within the Chattahoochee River Basin sample set are its far greater watershed area (with its related mineralogical diversity) and population density (with its attendant urban development).

Strontium Ion Variation within the Chattahoochee Basin: The regression matrices shown on Table 6 indicate that strontium ion concentrations correlate fairly well with the alkaline earth ions calcium (r^2 = 0.63) and magnesium (r^2 = 0.64). In comparison the correlations with the alkali ions sodium (r^2 = 0.18) and potassium (r^2 = 0.21) were considerably weaker. Strontium is an alkaline earth that can substitute for calcium and magnesium which are major elements in hornblende. This iron-rich aluminosilicate is one of the most important minerals that weathers in Piedmont watersheds (Burns et al., 2003). However, anthropogenic factors are likely necessary to account for the relatively high Sr ion concentrations (i.e. [Sr] > 30-50 μg/L) observed within base flow for many of the urban watersheds.

Strontium ion concentrations within CRB base flow vary strongly as a function of land use as can be inferred from the tight clustering of data with respect to each of the groups shown on Figure 15. Taking the extremes, the median strontium ion concentrations within the rural base flow and the CSO/effluent-impacted basins were 14 and 138 μg/L respectively (Table 9). Interestingly, median Sr concentrations were significantly higher within the CSO/sewage effluent- impacted basins (Proctor Creek, Clear Creek, and the South River) than within the effluent (75 μg/L) collected from the two waste treatment plants. The higher concentrations in the CSO-impacted stream basins may be the result of the combined input of strontium from mineralogical sources and waste water. Both mean and median Sr ion concentrations increase in the order of $[Sr]_{\text{rural basins}} < [Sr]_{\text{Chattahoochee River}} < [Sr]$

$_{\text{semi-developed basins}} < [Sr]_{\text{developed basins}} < [Sr]_{\text{basins along main sewage lines}} < [Sr]_{\text{basins impacted by CSOs and sewage effluent}}$. This is similar to the order observed for most of the major ions and it is the exact order that would be expected if waste water was a major control over Sr ion concentrations. The t-test results (Table 5) confirmed that these and other similar comparisons are statistically significant.

Strontium ion concentrations within the Chattahoochee River varied approximately between 20-40 µg/L and were generally lower than within the urban tributaries (Table 9). This variation closely (but not exactly) resembles river profiles for most of the major ion parameters including TDS and alkalinity concentrations. Strontium concentrations were lowest (<10-20 µg/L) in the Blue Ridge headwaters and then increased to greater than 40 µg/L in Chattahoochee River base flow within the AMR (Figure 16). Clearly the peak on Figure 16 coinciding with urban Atlanta portion of the Chattahoochee shows that Sr is strongly controlled by urban sources of this trace metal. Other metals such as lead and zinc show a strong *urban gradient* or influence as well within the Chattahoochee basin [Neumann et al. (2005); Rose et al. (2001); and Callendar and Rice (2000)].

The range of $^{87}Sr/^{86}Sr$ ratio variation (between 0.709460 - 0.723274) observed within Chattahoochee River basin base flow (Figure 15) is considered major for a watershed comprised only of metamorphic rock and aluminosilicate minerals. This range of variation which was significant to the second decimal place is far more common to mixed lithology watersheds where both silicate rocks which yeild relatively high $^{87}Sr/^{86}Sr$ ratios and carbonate rocks which yield relatively low ratios are present (McNutt et al., 1990; Bullen and Kendall, 1998; and Palmer and Edmond, 1992). A definitive explanation can not be given for the observed range of variation; however, it is possible that there is a trace volume of carbonate minerals present as vein material within these watersheds.

Strontium isotope ratios were generally greater in rural base flow (particularly upstream of the AMR) than in the other groups (Figure 17). This is apparent when examining Sr isotope ratios along the longitudinal profile of the Chattahoochee River (Figure 18) in which values decline from greater than 0.7160 upstream of the AMR to approximately 0.7120 in Chattahoochee River base flow within the metropolitan region. This may be the result of natural variation and/or may have some poorly understood anthropogenic cause. However, an explanation for these ratios can not be directly attributed to the imposition of waste water.

As shown on Table 9, the median isotopic ratio of the CSO/sewage impacted basins was 0.713958 which was intermediate between the rural streams (0.716989) and the semi-developed basins (0.710295). Median $^{87}Sr/^{86}Sr$ isotope ratios varied by group as follows (Table 9): $^{87/86}Sr_{\text{semi-developed basins}} < {}^{87/86}Sr_{\text{Chattahoochee River}} < {}^{87/86}Sr_{\text{developed basins}} < {}^{87/86}Sr_{\text{basins impacted by CSOs and treated waste water}} < {}^{87/86}Sr_{\text{basins along main sewage line}} < {}^{87/86}Sr_{\text{rural basins}}$. This is not the relationship observed for Sr ion concentrations and the relative magnitude of the isotopic ratios can not be directly associated with waste water input. Results of t-tests (similar to those shown on Table 5) confirm that there are no significant correlations between mean $^{87}Sr/^{86}Sr$ isotope ratios and Sr concentrations or major ion concentrations. The $^{87}Sr/^{86}Sr$ isotope variation can not be explained in terms of simple mixing between waste water and natural water. If this was the case than the base flow samples would fall on or nearly on a straight "mixing line" when $^{87}Sr/^{86}Sr$ ratios are plotted versus Sr ion concentrations or the inverse of Sr concentration. Clearly, there is no "straight line" relationship that can be inferred from Figure 19 (with the possible exception of the subset of Chattahoochee River samples) and therefore there is little isotopic evidence to support the supposition that the strontium isotopic ratios resulted from the mixing of waste water and natural water.

Table 8
Summary of Strontium Ion Concentrations and $^{87}Sr/^{86}Sr$ Isotope Ratios

Sample No.	Stream/Treatment Plant Name	Strontium Concentration (μg/L)	$^{87}Sr/^{86}Sr$ Ratio	Percentage Error[(a)]
WTP-1	RN Clayton Treatment Plant	54.8	0.713090	0.0007
WTP-2	Utoy Creek Treatment Plant	64.8	0.712979	0.0006
SR-1	South River on Klondike Rd.	57.0	0.712079	0.0008
CB-1	Chattahoochee River north of Helen	5.8	0.723274	0.0009
CB-2	Smith Creek at Anna Ruby Falls	5.2	0.719390	0.0009
CB-3	Sweetwater Creek south of Austell	38.4	0.710295	0.0007
CB-4	S. Utoy Creek at Harbin Rd.	79.1	0.714059	0.0007
CB-5	N. Utoy Creek at Peyton Rd.	70.0	0.714626	0.0008
CB-6	Utoy Creek at Fulton Industrial Blvd.	77.4	0.712622	0.0007
CB-7	Proctor Creek at Hightower Rd. (CSO)	140.8	0.713958	0.0007
CB-8	Burnt Fork Creek at Decatur	58.3	0.713813	0.0006
CB-9	South Peachtree Creek at Hahn Woods	57.0	0.714582	0.0007
CB-10	North Peachtree Creek at Druid Hills Rd.	66.0	0.713532	0.0007
CB-11	Clear Creek at Monroe Drive (CSO)	138.4	0.714493	0.0007
CB-12	Nancy Creek at West Wesley Rd.	68.8	0.715748	0.0008
CB-13	Peachtree Creek at Northside Highway	74.9	0.714171	0.0007
CB-14	Chattahoochee River at Franklin	39.8	0.713103	0.0007
CB-15	Acorn Creek at Highway 5	18.8	0.717913	0.0008
CB-16	Snake Creek near Banning	12.5	0.722794	0.0008
CB-17	Chattahoochee River at Whiteseburg	30.5	0.713302	0.0007
CB-18	Dog River at Highway 166	22.8	0.719831	0.0007
CB-19	Chattahoochee River at Capps Ferry Rd.	33.7	0.713288	0.0007
CB-20	Pea Creek at Highway 70	30.7	0.713877	0.0007
CB-21	Big Creek near Roswell	41.3	0.713005	0.0007

Sample No.	Stream/Treatment Plant Name	Strontium Concentration (µg/L)	$^{87}Sr/^{86}Sr$ Ratio	Percentage Error[(a)]
CB-22	Big Creek near Cumming	37.5	0.713305	0.0008
CB-23	Chestatee River south of Dahlonega	15.3	0.716064	0.0008
CB-24	Bear Creek west of Highway 129	43.2	0.714476	0.0007
CB-25	Chattahoochee River at State Rd. 52	20.1	0.716116	0.0006
CB-26	Chattahoochee River at State Rd. 20	21.1	0.714486	0.0008
CB-27	Sewanee Creek at Highway 23	54.7	0.713682	0.0006
CB-28	Chattahoochee River near Duluth	26.3	0.714002	0.0006
CB-29	Crooked Creek near Norcross	65.7	0.712171	0.0007
CB-30	Chattahoochee River at Holcomb Bridge Rd.	24.0	0.714198	0.0008
CB-31	Chattahoochee River at West Paces Ferry Rd.	35.4	0.712612	0.0007
CB-32	Chattahoochee River near College Park	41.1	0.712789	0.0007
CB-33	Camp Creek near Campbellton	55.1	0.713124	0.0008
CB-34	Sweetwater Creek near Villa Rica	35. 5	0.711228	0.0006
CB-35	Lick Log Creek on State Road 92	33.9	0.709460	0.0008
CB-36	Oily Creek north of Austell	56.2	0.712327	0.0007
[(a)] Percentage errors indicate that the $^{87}Sr/^{86}Sr$ ratio is precise to the 6th decimal place				

Table 9
Summary of Strontium Data by Groups

Strontium Concentrations (values in µg/L)							
Group	**Description**	**No**	**Median**	**Mean**	**Std. Dev.**	**Low**	**High**
I	Rural Streams	8	13.9	19.3	12.9	5.2	43.2
II	Chattahoochee River	9	30.5	30.2	7.8	20.1	41.1
III	Semi-Developed Basins	7	38.4	42.5	9.2	33.9	56.2
IV	Developed Basins	5	58.3	60.4	5.1	55.1	66.0
V	AMR Basins with Streams on Main Sewage Line	5	74.9	74.9	4.5	68.8	79.1
VI	Combined Sewage Overflow Basins/ Basins Receiving Treated Effluent	3	138.4	112.1	47.7	57.0	140.8
VII	Sewage Effluent	2	-----	59.8	7.1	54.8	64.8
Strontium Isotope Ratios ($^{87}Sr/^{86}Sr$)							
Group	**Description**	**No**	**Median**	**Mean**	**Std. Dev.**	**Low**	**High**
I	Rural Streams	8	0.716989	0.718452	0.003538	0.713877	0.723274
II	Chattahoochee River	9	0.713392	0.713776	0.001083	0.712612	0.716116
III	Semi-Developed Basins	7	0.710295	0.710295	0.001609	0.709460	0.712327
IV	Developed Basins	5	0.713532	0.713444	0.000889	0.712171	0.714852
V	AMR Basins with Streams on Main Sewage Line	5	0.714059	0.714236	0.001123	0.712622	0.715748
VI	Combined Sewage Overflow Basins/ Basins Receiving Treated Effluent	3	0.713958	0.713510	0.001268	0.712079	0.714493
VII	Sewage Effluent	2	-----	0.713035	0.000078	0.713090	0.712979

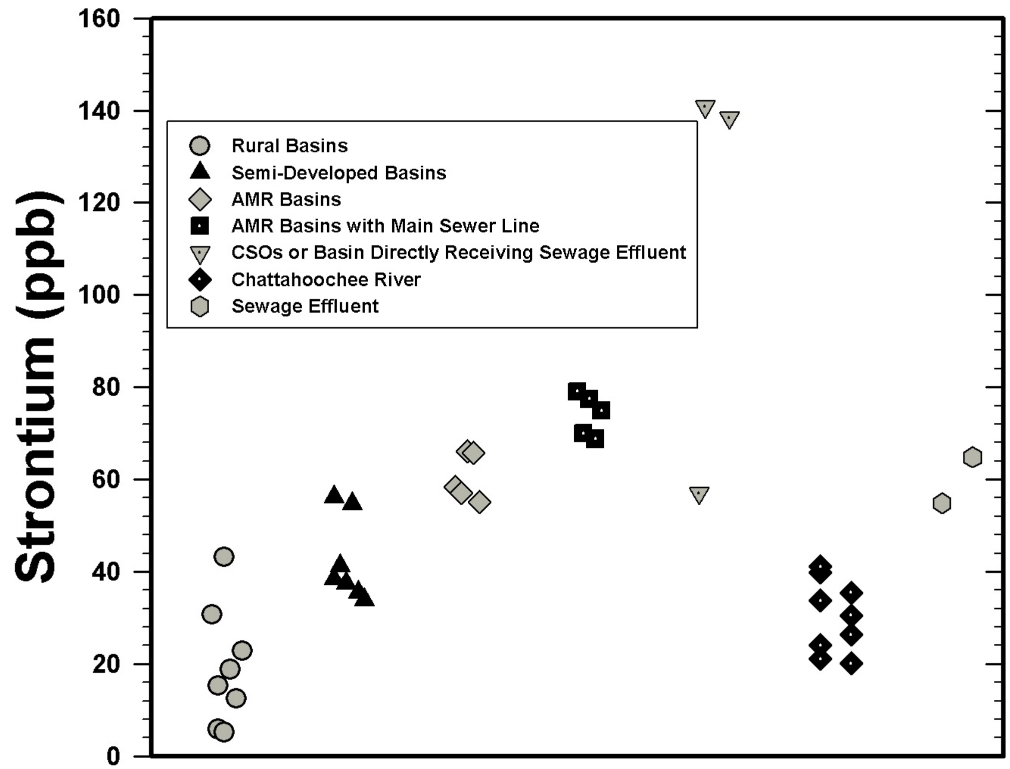

Figure 15: Strontium ion concentrations for the various groups

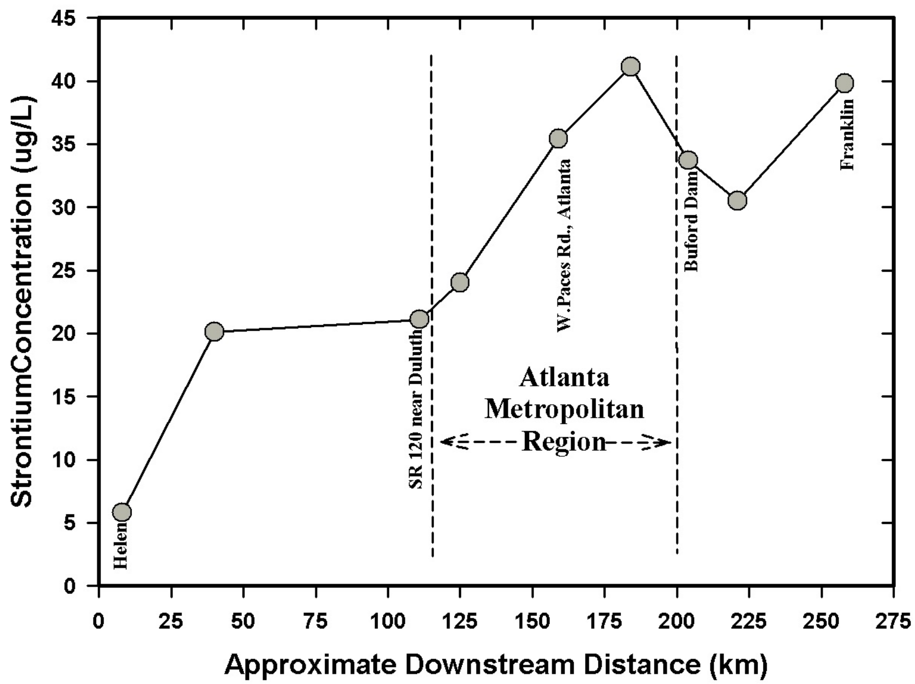

Figure 16. Profile of strontium ion concentrations within the Chattahoochee River

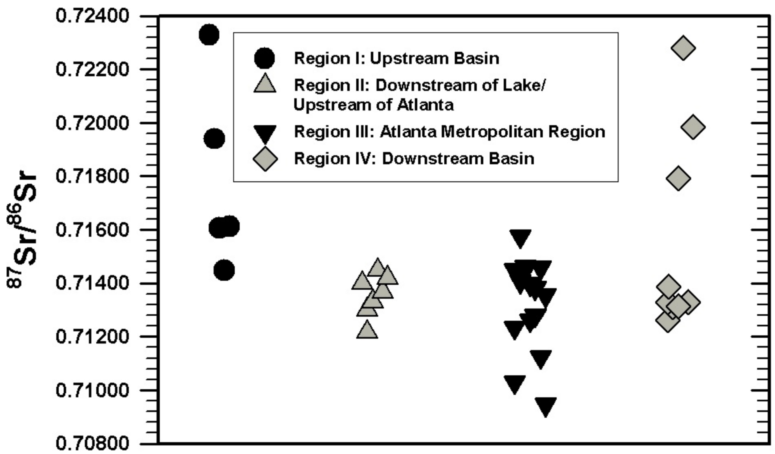

Figure 17: Strontium isotope ratios upstream, downstream, and within the AMR

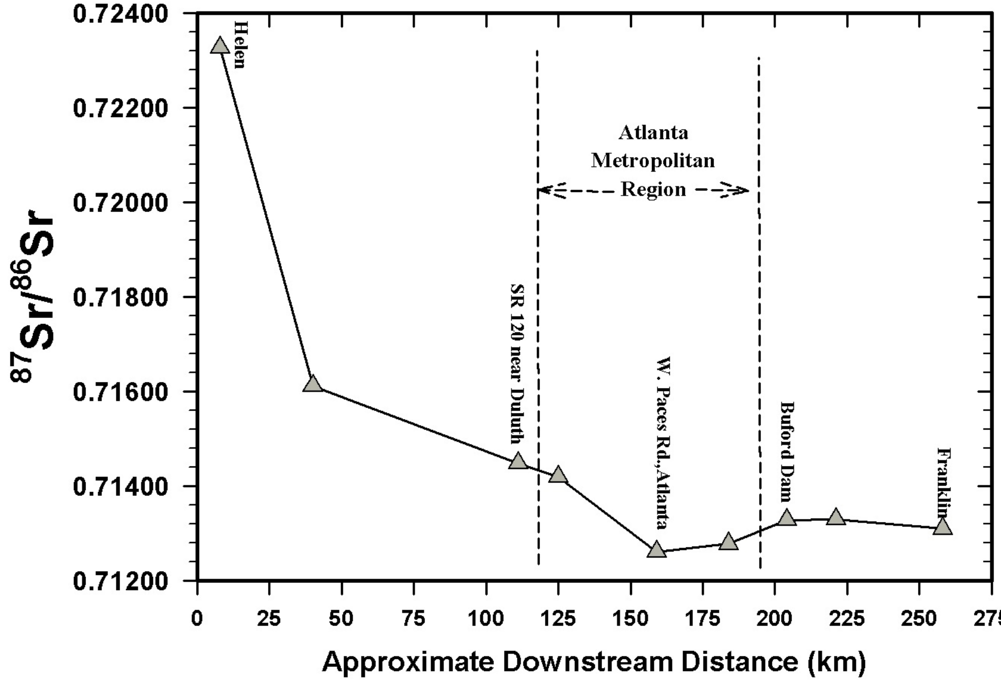

Figure 18: Profile of strontium isotope ratios within the Chattahoochee River

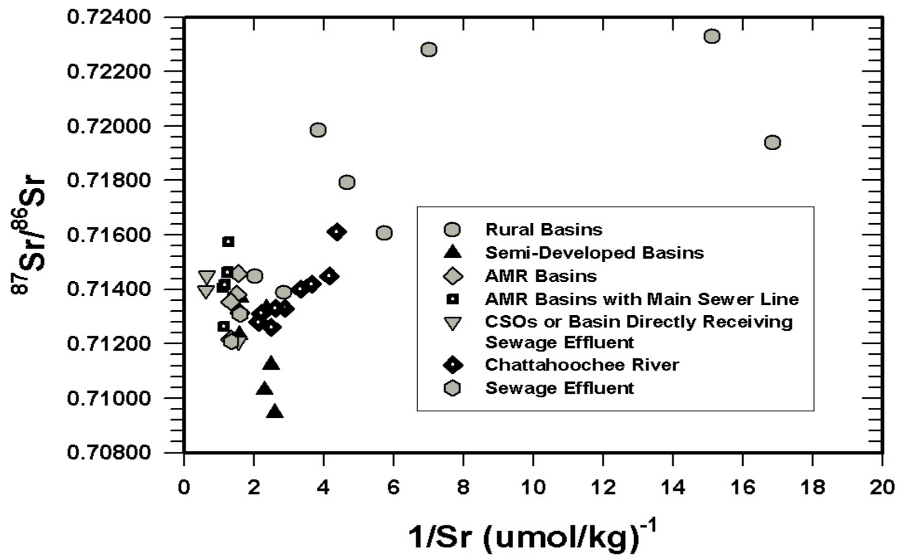

Figure 19: Plot of strontium isotope ratios versus inverse strontium ion concentrations (strontium mixing plot)

DISCUSSION

As previously stated, the major objective of this study was to determine whether strontium isotope ratios can be utilized to determine the effects of urbanization (particularly the effects of the aged sewage conveyance infrastructure of Atlanta) have upon the water quality of stream base flow within the Chattahoochee Basin. In order to accomplish this objective, a detailed comparative analyses of base flow chemistry was undertaken using data collected from approximately 40 sampling locations within the CRB. This may be the most comprehensive synoptic analysis of base flow chemistry within this study area to date and it represents a "pilot" study in this setting with regard to the use of strontium isotope ratios. The Chattahoochee basin with its large urban center and its highly diverse land use within a limited watershed area offers ample opportunities for this type of comparative hydrochemical analysis.

In order to facilitate a comparative analyses the sample set was divided into seven categories shown on Table 1that include: 1) rural basins (both upstream and downstream of the AMR); 2) semi-developed basins (i.e. those basins with a relatively low population basin outside of the highly developed inner core of the AMR); 3) basins in the AMR *not* containing a City of Atlanta main sewage line; 4) basins in the AMR in which the main stream parallels a City of Atlanta main sewage line; 5) basins in which a Combined Sewage Overflow [CSO] facility exists or a basin receiving treated sewage effluent; 6) nine sampling sites along a longitudinal profile of the Chattahoochee River (both upstream and downstream of the AMR); and 7) two sewage effluent samples. Any such subdivision admittedly has some arbitrary elements in that a given stream may not fit into any neat category. For example, Big Creek northwest of the AMR downstream of Cumming, GA (samples CB-21 and CB-22) has been designated as a "semi-developed" basin in that it is well upstream of the AMR; however it likely also receives some sewage effluent from a small upstream treatment plant. Another complication is that is possible that some of the urban basins designated in Group 3 may have a sewage conveyance infrastructure that is as damaged and leaks as much or more sewage into the subsurface than those basins designated on the main sewage line (Group 4). Nonetheless, the results from this analysis were in many ways revealing and are believed to reasonably represent major hydrochemical trends within the CRB.

The clearest finding of this study is that major ion concentrations are often two to four times higher in urbanized basins in the relatively undeveloped basins upstream and downstream of the AMR. The Chattahoochee Basin is underlain by aluminosilicate rocks which has only a limited solubility and when a basin is left within a relatively undisturbed state, total dissolved solid concentrations (TDS) are typically below 50 mg/L. Apparently any degree of basin development results in increased solute concentrations within the base flow component of stream flow. This is akin to saying that basin development results in some form of "ground-water contamination" or "ground-water perturbation"; however, the exact nature of this disturbance is not always clear and its causes and ontology are far more difficult to diagnose than pollution associated with storm water runoff. In most cases this added input of solute to ground water base flow associated with urbanization in the AMR can not be linked with any one point source in ground water nor can it be linked to any one obvious feature present on the earth's surface. The relatively low rate of base flow generation observed in urban basins may also be a contributing factor accounting for the relatively high solute concentrations observed in urban base flow.

The Chattahoochee River receives untreated sewage effluent in surface water runoff from various tributaries following heavy storms. Such occurrences are marked by the often dangerous influx of coliform bacteria within the storm runoff; however, it is not readily apparent what long-term impacts sewage effluent has on water quality within the CRB. It is not known whether this effluent seeps into the subsurface and if these salts are later "flushed" from the riparian zone in stream base flow. The influx of storm runoff into the subsurface (if this does occur) may be accompanied by other sources of sewage wastes including leaky underground pipes. In that the City of Atlanta has an aged infrastructure (which is currently being upgraded at great cost to local and federal tax payers) the influx of subsurface contamination from subsurface conveyance pipes would not be very surprising. Other possible sources of major ion solute contamination are the numerous septic tank systems that exist throughout the basin; however, this report has not addressed this issue. Simple land clearance and the application of fertilizer in the urban environment may also be another "non-point source disturbance" that has some long-term effect upon solute concentrations in base flow.

In addition to the problem of identifying non-point sources for potential subsurface contamination, there is the problem of determining which ions are diagnostic of sewage contamination in stream base flow. The analysis of untreated and treated sewage effluent from the R.N. Clayton and Utoy Creek facilities in metropolitan Atlanta and Snapfinger Creek facility in the South River basin greatly helped to facilitate these analyses. Sewage effluent is concentrated with respect to all the major ions. For example potassium which is the least concentrated of the major elements, is 5-10 times more concentrated in sewage effluent than within base flow from rural streams or the Chattahoochee River.

The most useful of the major ions to focus upon are chloride and sulfate. With the exception of evaporite mineral salts (e.g. halite, anhydrite, and gypsum), chloride and sulfate ions are not readily derived from rock-forming minerals. In that these evaporite salts are not commonly present within the CRB, the sources of chloride and sulfate are not from rock and soil minerals which contribute most of the solute load to non-contaminated base flow. Both chloride and sulfate can be atmospherically derived and then concentrated within the shallow subsurface by evaporation. However, this process does not typically result in inordinately elevated stream water concentrations as evidenced by the relatively low concentrations observed for these ions in rural base flow and within most of the semi-developed basins. Chloride is a major human metabolic electrolyte and therefore is a dominant ion in liquid wastes. Sulfate is likewise an electrolyte and is also derived from the oxidation of reduced sulfur compounds in organic wastes. Mean chloride and sulfate concentrations are approximately 12-14 times greater in sewage effluent than within base flow from rural CRB streams (Table 4). Hence, these two ions are believed to be the most diagnostic of waste influx to stream water. Alkalinity concentrations were also elevated in those waters which were concentrated with respect to sulfate and chloride (Figures 20 and 21). The elevated alkalinity concentrations may have in part resulted from breakdown of reduced sulfur molecules in organic waste which is known to produce high alkalinity concentrations within waste water.

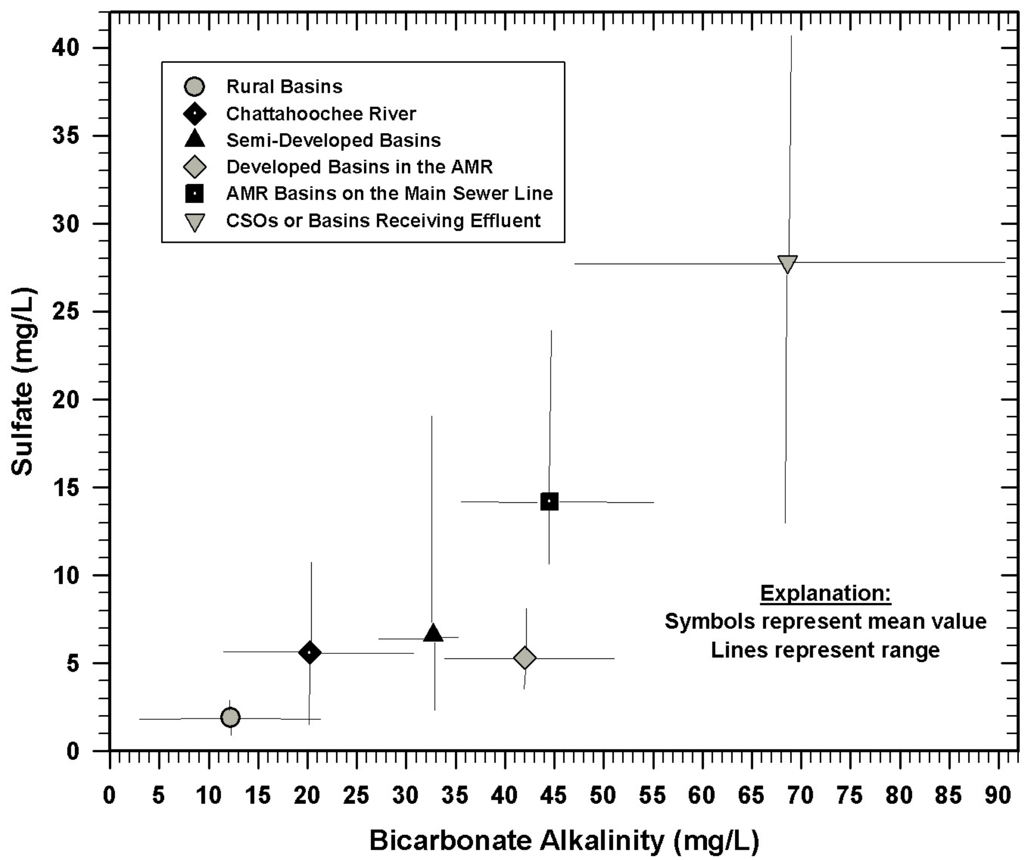

Figure 20: Plot of sulfate versus bicarbonate for various water groups showing ranges

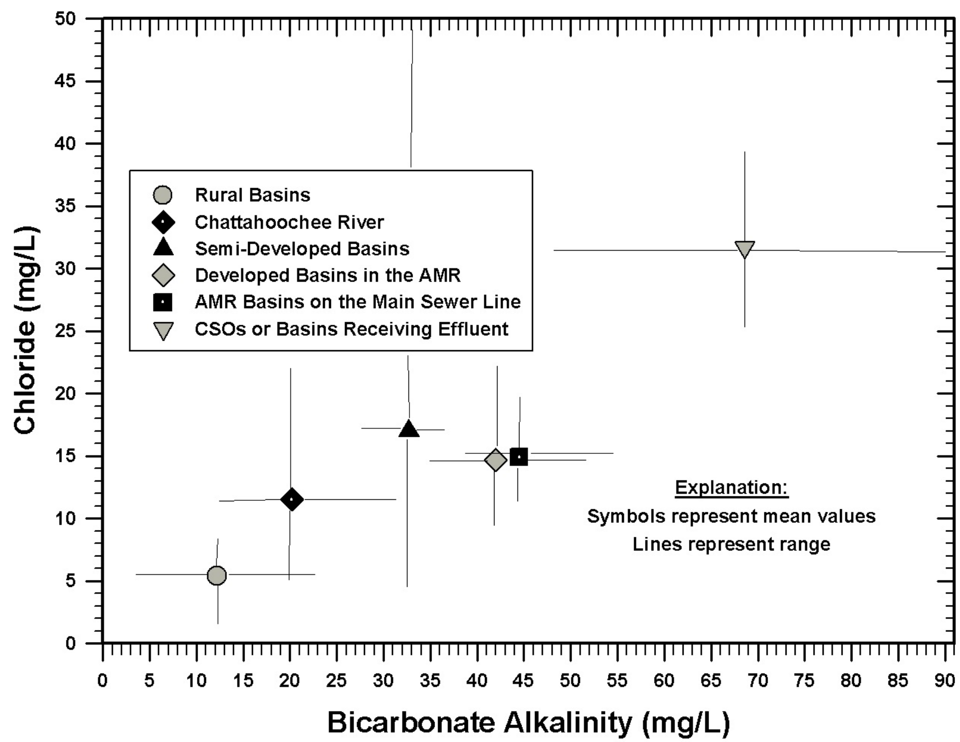

Figure 21: Plot of chloride versus bicarbonate for various water groups showing ranges

Clearly, all of the stream base flow within the AMR were characterized by chloride and sulfate concentrations that were significantly above "background" levels (i.e. concentrations found in rural streams). The high degree of correlation (as evidenced by least-square regression coefficients > 0.80) between potassium, sulfate, and chloride strongly suggests that there is an apparent basin-wide impact of human waste and sewage effluent. However, none of the streams with the possible exception of CSO basins and the South River (which directly receives large quantities of sewage effluent) were as polluted with chloride and sulfate as raw or treated sewage wastes (Figures 20 and 21). Sulfate concentrations within these three basins (samples SR-1, CB-7, and CB-11) equaled or exceeded those concentrations found in raw sewage. Raw sewage runs through these CSOs during periods of heavy storm flow (when sewage treatment facilities can not handle the combined storm and sewer flow) and it is likely that some of this sewage/storm water runoff mixture has seeped below the channels and/or through stream banks (i.e. in the riparian zone). During periods of base flow these salts are assumably "flushed" from the subsurface back into the stream channel, resulting in the extreme concentrations of alkalinity, chloride, and sulfate (Figures 20 through 23 and Table 4). Burns et al. (2003) in a study of a natural Piedmont watershed concluded that the riparian zone near the stream channel provides the most important source of solutes to stream flow within this setting.

This interpretation with respect to the contribution of salts from the near-stream zone around and below CSO facilities is consistent with the findings made by Burns et al. (2003) for the Panola Mountain Research Watershed facility. However, the origin for these relatively high concentrations of sewage-related salts observed in base flow is hypothetical and by no means represents a definitive explanation of the problem. In order to address this problem in a more rigorous manner, a ground water monitoring network (i.e. three-dimensional well "nests") would have to be installed in transects perpendicular to a stream channel in order to study the hydrogeochemistry of ground water flowing into the channel. It would be very difficult (but not impossible) to install such a network in most urban areas.

Definitive assessments of the effects of pollution upon base flow hydrochemistry of the other groups of basins that have been designated in this study are also problematic. One important inference that can be made from this study is that any degree of development within the ever-expanding AMR results in major ion concentrations that are substantially greater than those present within the base flow of rural streams. Sulfate and chloride concentrations are elevated by a factor of factor of approximately 3-4 within the semi-developed basins in the outlying sections of the AMR compared to those basins which have been designated as "rural". The explanation for these elevated salt concentrations is by no means certain; however, I speculate that there may be some low level of input resulting from septic tanks and sewer lines within the outlying regions.

Solute concentrations were generally greater within the urbanized base flow than in the semi-developed basins; however, this was not always the case (Figure 20 and 21). The same is true with respect to the comparison between solute concentrations between those AMR basins in which a main sewage line was present and its urban counterparts not underlain by a main sewage line. However, sulfate concentrations (but not chloride concentrations) were notably higher in base flow for those basins where a main sewage line was present than in the other urban streams (Figure 18 and 19). Therefore, a qualified argument based upon the elevated sulfate concentrations can be made that

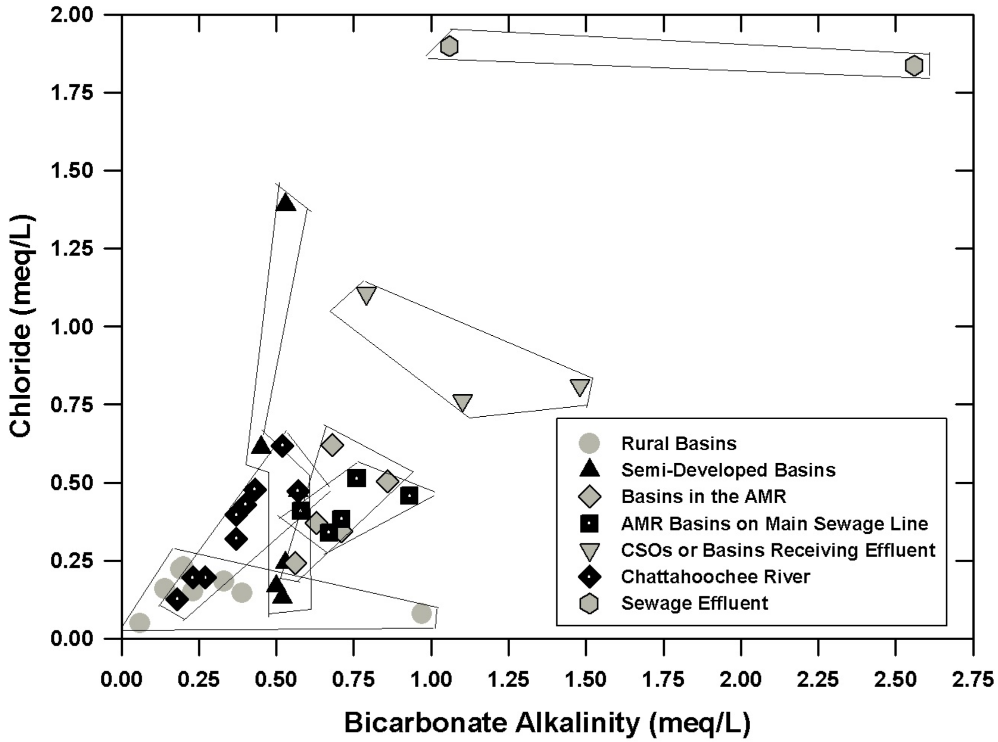

Figure 22. Chloride versus bicarbonate showing differences and similarities between various water groups

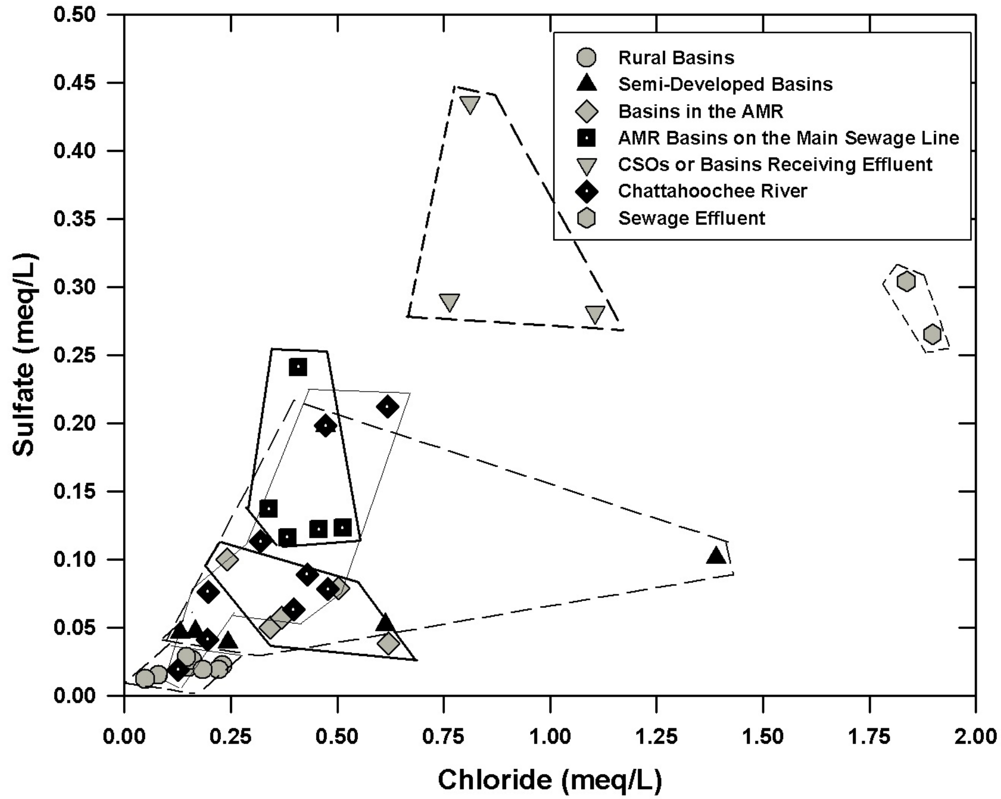

Figure 23. Sulfate versus chloride showing differences and similarities between various water groups

there is an impact from sewage pipes (possibly leaking within the subsurface) upon ground water and base flow hydrochemistry within the AMR. However, the evidence presented in this report is quite limited and the question should still be regarded as open.

There is a high degree of correlation between strontium ion concentrations and other solute concentrations and strontium is highly elevated within those basins that are most clearly impacted by sewage effluent. $^{87}Sr/^{86}Sr$ ratios vary greatly from basin to basin (variation is significant to the 2nd decimal place whereas the ratio can be measured precisely to the 5th or 6th decimal place); however, the variation is not systematic. Much of the variation is likely caused by mineralogical differences in the underlying rocks and soils of these basins; however, this has not been definitively established. The most important mineralogical factor would be the percent of rubidium-bearing minerals in that rubidium-87 produces strontium-87 through beta decay, thereby increasing the $^{87}Sr/^{86}Sr$ in water that has partially dissolved the rubidium-bearing minerals.

Although human wastes and cleaning solvents may have their own range of $^{87}Sr/^{86}Sr$ isotopic variation, there is no apparent strontium isotopic "signature" that can be definitively linked to sewage effluent within CRB base flow. One possible explanation is that the Sr isotopic ratios associated with sewage effluent are "masked" by natural lithological variation. This is suggested by the data associated with the rural basins in which the $^{87}Sr/^{86}Sr$ ratio varies between 0.713877 - 0.723274, encompassing most of the variation observed for the entire data set. In short, this research has clearly demonstrated "negative results" in that strontium isotope ratios can *not* be effectively used to assess the impacts of sewage effluent or other forms of contamination within base flow in urbanized basins. This present research has not, however, addressed the issue of whether these isotopic ratios can be used to assess the presence or wastes in storm runoff.

SUMMARY AND CONCLUSIONS

This study summarizes the results of a comprehensive synoptic investigation of the hydrochemical and isotopic composition of base flow within the upper 6,940 km^2 of the Chattahoochee River basin. Its most pressing concern was to determine what effects the imposition of sewage wastes and other urban contamination from the Atlanta Metropolitan Region (AMR) have upon the base flow hydrochemistry within the Chattahoochee River and its urbanized tributaries. Strontium ion concentrations, strontium isotope ratios, and the major ion chemistry were analyzed in ~40 diverse steam basins within the study area during the summer of 2005. The study took a comparative approach by subdividing the total sampling set into various sub-categories representing land use, population density and urban infrastructure placed on or near the stream basin (e.g. "CSOs" and "urban stream basins that parallel a main sewage line"). The major findings of this study are summarized as follows:

1) Runoff rates are approximately 520 mm (20 in) per year throughout most of the Piedmont portion of the Chattahoochee River Basin. This rate of runoff is approximately 40% of the annual rainfall (1320 mm or 52 inches) within this region of Georgia. Total runoff rates were slightly higher in Peachtree Creek, one of the of the most urbanized watersheds within the AMR, than elsewhere. Rates of base flow within the five CRB streams vary widely between 164-770 mm/year. This represents between 30-70% of the total yearly runoff. The relatively low rates of base flow

generation within urban basins might be a factor contributing to the increased solute concentrations observed within urban base flow.

2) Base flow in this region is characterized by stable oxygen isotope ($\delta^{18}O$) ratios that range from -6.10 to -3.47 per mil which increase gradually from north to south (i.e. downstream). $\delta^{18}O$ values increase in the Chattahoochee River from -5.8 per mil in the Blue Ridge headwaters to -4.0 per mil in Franklin, Georgia which was the most southern and downstream sampling point of the study area. This trend is congruent with latitudinal variation in weighted annual precipitation and strongly suggests that the base flow sampled as part of this study represents well-mixed annual precipitation averages. This is consistent with the tritium concentrations that average 7.6 T.U. indicating that base flow is comprised of a substantial component of ground water that has a subsurface residence times of several decades.

3) Strontium ion concentrations are highly elevated in those basins which sewage effluent likely affects the major ion chemistry of the streams; however, strontium isotope ($^{87}Sr/^{86}Sr$) ratios do *not* provide an adequate means for assessing the imposition of sewage waste effluent within this setting. This is likely because naturally occurring mineral weathering reactions impart a very wide range of isotopic variation ($0.709460 < {}^{87}Sr/^{86}Sr < 0.723274$) in stream base flow that encompasses and obscures any "waste signature" that might be present.

4) All major ion concentrations in base flow within all semi-urbanized and urbanized streams are greater than within rural basins both upstream and downstream of the Atlanta Metropolitan Region. Major ion concentrations within the Chattahoochee River increase as a result of influx from the AMR and remain elevated well downstream of the AMR. In general, there is a great diversity of water types and solute concentrations within the CRB and this variation is most likely more related to land use, population density, and sewage waste disposal activities than it is to natural lithological variation.

5) Major ion concentrations are most elevated in those stream basins that are most clearly impacted by waste water effluent including CSO facilities (Clear and Proctor Creek) and effluent disposal sites(South River). Solute concentrations are also typically greater within developed basins in the AMR than in the semi-developed basins north and west of Atlanta. There is less clear of a distinction with respect to the major ion chemistry between those AMR basins in which a main sewer line is present and those urbanized basins in which there is no main sewer line. However, sulfate concentrations are significantly greater in those basins such as Peachtree Creek which flow parallel to a main City of Atlanta sewer line.

6) Mean and median Sr ion concentrations in the order of $[Sr]_{\text{rural basins}} < [Sr]_{\text{Chattahoochee River}} < [Sr]_{\text{semi-developed basins}} < [Sr]_{\text{developed basins}} < [Sr]_{\text{basins along main sewage lines}} < [Sr]_{\text{basins impacted by CSOs and sewage effluent}}$. Interestingly, this is similar to the order observed for most of the major ions and it is the exact order that would be expected for an increasing contribution of contamination from sewage waste.

7) Apparently any degree of urbanization results in major ion concentrations that are elevated with respect to "background" (i.e. rural streams within the CRB). However, there is a wide range of variation and "overlap" associated with most of the major ion concentrations for the urbanized and

semi-urbanized subgroups designated in this study. This is the case for alkalinity, sulfate, and chloride concentrations which are associated with sewage waste.

8) Major ion and strontium ion concentrations within the Chattahoochee River are significantly greater downstream of the AMR than they are upstream of Lake Lanier. “Dilution” from the rural basins downstream of the AMR results in lower solute concentrations but is insufficient to negate the effects of pollutant influx from the AMR.

9) Regression analyses indicate that the highest major ion correlations within the CRB are between sodium, potassium, and chloride in the urban basins. This is not a common occurrence for stream water within the Georgia Piedmont Province as indicated by a comparative regression analysis of stream base flow from nearby rural streams within the Flint, Ocmulgee, and Oconee basins. The most likely origin for the elevated concentrations of sodium, potassium, chloride, sulfate, and alkalinity is sewage effluent in that these ions are concentrated in human electrolytes, household cleaning products, and the breakdown of organic molecules. The relatively high regression correlation coefficients (r^2 values $>$ 0.69)for sodium, potassium, and chloride may indicate that waste water effluent has a basin-wide effect (at least downstream of Lake Lanier within the AMR).

10) An unequivocal origin of elevated solute concentrations within CRB base flow is far more difficult to identify than the elevated solute concentrations in surface water or storm water runoff. The most probable source of contamination is within the near-stream or riparian zone as evidenced by the high TDS, sulfate, potassium, chloride, and alkalinity concentrations observed in those river channels that were directly impacted by CSO facilities. One possible origin for these ions is the concentration of sewage-related salts in the subsurface (as a result of CSO discharges and/or leaky sewer lines). This inferred source is only speculative and would require detailed ground water investigations for confirmation. Other possible non-point sources of subsurface contamination are less obvious and can not be ruled out. These include septic tank effluent, fertilizer, and the infiltration of salts that may accumulate on disturbed land. However, these possible sources appear less likely and are far less understood than the input of sewage wastes to the shallow subsurface.

REFERENCES CITED

Alhadeff, S.J., Musser, J.W., Sandercock, A.C., and Dyar T.R., 2001. *Digital Environmental Atlas of Georgia*. CD ROM.

Atlanta Regional Commission, 2000. Population Density, 1999. http://www.atlantaregional.com/movers/about_region.html/

Aubert, D., Probst, A, Stille, P. and Viville, D., 2002. Evidence of hydrological control of Sr behavior in stream water (Strengbach catchment, Vosges mountains, France). *Applied Geochemistry*, v17, p285-300.

Bailey, S.W., Hornbeck, J.W., Driscoll, C.T. and Gaudette, H.E., 1996. Calcium inputs and transport in a base-poor forest ecosystem as interpreted by Sr isotopes. *Water Resources Research*, v32, p707-719.

Banner, J.L., Wasserburg, G.J., Dobson, P.F., Carpenter, A.B., and Moore, C.H., 1989. Isotopic and trace element constraints on the origin and evolution of saline groundwaters from central Missouri. *Geochimica et Cosmochimica Acta*, v53, p383-398.

Berner, E.K. and Berner, R.A. 1987. The Global Water Cycle. Englewood Cliffs, New Jersey, 397pp.

Bishop, P.K., Smalley, P.C., Emery, D. and Dickson, J.A.D., 1994. Strontium isotopes as indicators of dissolving phase in a carbonate aquifer: implications for ^{14}C dating of groundwater. *Journal of Hydrology*, v154, p301-321.

Blum, J.D., Erel, Y. and Brown, K., 1994. $^{87}Sr/^{86}Sr$ ratios of Sierra Nevada stream waters: implications for relative mineral weathering rates. *Geochimica et Cosmochimica Acta*, v56, p2099-2111.

Bullen, T.D. and Kendall, C. 1998. Tracing of weathering reactions and water flowpaths: a multi-isotope approach. In: Kendall, C., McDonnell, J.J. (Eds.), Isotope Tracers in Catchment Hydrology. Elsevier, Amsterdam, pp611-646.

Bullen, T.D. and Kendall,C., 1998. Tracing of weathering reactions and water flowpaths: a multi-isotope approach. In: (Eds.) Kendall, C. and McDonnell, J.J., Isotope Tracers in Catchment Hydrology, Ch. 18, Elsevier, Amsterdam, 611-646.

Burns, D.A., Plummer, L.N., McDonnell, J.J., Busenberg, E., Gasile, G.C., Kendall, C., Hooper, R.C., Freer, J.A., Peters, N.E., Beven, K., Schlosser, P. 2003. The geochemical evolution of riparian ground water in a forested Piedmont catchment. *Ground Water*, v41, p913-925.

Callender, E. and Rice, K. 2000. The urban environmental gradient; anthropogenic influences on the spatial and temporal distributions of lead and zinc in seidments. *Environmental Science and Technology*, v34, p232-238.

Center for Watershed Protection, 1999. Watershed protection techniques. *Microbes and Urban Watersheds*, v3. no 1., p551-596.

Cleaves, E.T., Godfrey. A.E., and Bricker, O.P. 1970. Geochemical balance of a small watershed and its geomorphic components. *Geological Society of America Bulletin*, v81, p3015-3032.

Douglas, T.A., Chamberlain, C.P. and Blum, J.D., 2002. Land use and geologic controls on the major elemental and isotopic (^{15}N and ^{87}Sr/^{86}Sr) geochemistry of the Connecticut River watershed, USA. *Chemical Geology*, v189, p19-34.

Drever, J.I. 1997. The Geochemistry of Natural Waters. Prentice Hall, Upper Saddle, New Jersey, 436pp.

Frick, E.A., Hippe, D.J., Buell, G.R., Couch, C.A., Hopkins, E.H., Wangsness, D.J. and Garrett, J.W. 1998. Water quality in the Apalachicola-Chattahoochee-Flint River Basin, Georgia, Alabama, and Florida, 1992-1995. *U.S. Geological Survey Circular 1164.* 38p.

Gibbs, R.J. 1970. Mechanisms controlling world water chemistry. *Science*, v170, p1088-1090.

Goldstein, S.J. and Jacobsen, S.B., 1987. The Nd and Sr isotopic systematics of river-water dissolved material: implications for the Nd and Sr in seawater. *Chemical Geology*, v66, p 245-272.

Gregory, M.B. and Frick, A. 2000. Fecal-coliform bacteria concentrations in streams of the Chattahoochee River National Recreation Area, Metropolitan Atlanta, Georgia, May-October 1994 and 1995. *U.S. Geological Survey Water-Resources Investigation Report 00-4139*, 8p.

Hogan, J.F., Blum, J.D., Siegel, D.I., and Glaser, P.H., 2000. ^{87}Sr/^{86}Sr as a tracer of groundwater discharge and precipitation recharge in the Glacial Lake Agassiz Peatlands, northern Minnesota. *Water Resources Research.* v36, p3701-3710.

Hogan, J.F. and Blum, J.D. 2003. Tracing hydrologic flow paths in a small forested watershed using variations in ^{87}Sr/^{86}Sr, [Ca]/[Sr], [Ba]/[Sr] and δ^{18}0. *Water Resources Research*, v39, p1282-1293.

Hunt, R.J., Bullen, T.D., Krabbenhoft, D.P. and Kendall, C., 1998. Using stable isotopes of water and strontium to investigate the hydrology of a natural and a constructed wetland. *Ground Water*, v36, p434-443.

Johnson, T.M., and DePaolo, D.J., 1994. Interpretation of isotopic data in groundwater-rock systems: model development and application to Sr isotope data from Yucca Mountain. *Water Resources Research*, v30 p1571-1587

Katz, B.G., Coplen, T.B., Bullen, T.D. and Davis J.H., 1997. Use of chemical and isotopic tracers to characterize the interactions between ground water and surface water in mantled karst. *Ground Water,* v35, p1014-1028.

Krishnaswami, S., Trivedi, J.R., Sarin, M.M., Ramesh, R. and Sharma, K.K., 1992. Strontium isotopes and rubidium in the Ganga-Brahmaputra river system: weathering in the Himalaya, fluxes to the Bay of Bengal and contributions to the evolution of oceanic ^{87}Sr/^{86}Sr. *Earth and Planetary Science Letters*, v109, p243-253.

Land, M., Ingri, J., Andersson, P.S. and Öhlander, B., 2000. Ba/Sr, Ca/Sr, and ^{87}Sr/^{86}Sr ratios in soil water and groundwater: implications for relative contributions to stream water discharge. *Applied Geochemistry*, v15, p311-325.

Lyons, W.B., Tyler, S.W., Gaudette, H.E. and Long, D.T., 1995. The use of strontium isotopes in determining groundwater mixing and brine fingering in a playa spring zone, Lake Tyrell, Australia. *Journal of Hydrology*, v167, p225-239.

McConnell and J.B., Buell, G.R. 1994. Georgia stream water quality. *U.S. Geological Survey Water-Supply Paper 2400*, p231-238.

McDonnell JJ, Freer, J., Hooper, R.P., Kendall, C., Burns, D., Beven, K., and Peters N.E., 1996. New method developed for studying flow on hillslopes. *EOS, Transactions of the American Geophysical Union*, v77, p465-472.

McNutt, R.L., Frape, S.K., Fritz, P., Jones, M.G. and MacDonald, I.M., 1990. The $^{87}Sr/^{86}Sr$ values of Canadian Shield brines and fracture minerals with applications to groundwater mixing, fracture history, and geochronology. *Geochimica et Cosmochimica Acta*, v54, p204-215.

Miller, E.K., Blum, J.D. and Friedland, A.J., 1993. Determination of soil exchangeable-cation loss and weathering rates using Sr isotopes. *Nature*, v362, p438-444.

Musgrove, M.L. and Banner, J.L., 1993. Regional ground-water mixing and the origin of saline fluids: midcontinent, United States. *Science*, v 259, p1877-1882.

Négrel, P., and Lachassagne, P., 2000. Geochemistry of the Maroni River (French Guiana) during the low water stage: implications for water-rock interaction and groundwater characteristics. *Journal of Hydrology*, v237, p212-233.

Nelms, D.L, Harlow, G.E., Hayes, D.C., 1997. Base-flow characteristics of streams in the Valley and Ridge, the Blue Ridge, and the Piedmont physiographic provinces of Virginia. *U.S. Geological Survey Water-Supply Paper 2457.*

Neumann, K. and Dreiss, S., 1995. Strontium 87/strontium 86 ratios as tracers in groundwater and surface waters in Mono Basin, California. *Water Resources Research*, v31, p3183-3193.

Neumann, K, Lyons, W.B., Graham, Y, and Callender, E. 2005. Historical backcasting of metal concentrations in the Chattahoochee River, Georgia: Population growth and environmental policy. *Applied Geochemistry*, v20, p2315-2324.

Palmer, M.R. and Edmond, J.M.., 1992. Controls over the strontium isotope composition of river water. *Geochimica et Cosmochimica Acta*, v56, p2099-2111.

Rose, S., 1993. Environmental tritium systematics of baseflow in Piedmont Province watersheds, Georgia (USA). *Journal of Hydrology*, v143, p191-216.

Rose, S.,1996. Temporal environmental isotopic variation within Falling Creek (Georgia) watershed: implications for contributions to streamflow. *Journal of Hydrology*, v174, 243-261.

Rose, S. and Peters, N.E. 2001. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. *Hydrological Processes*, v15, p1441-1457.

Rose, S., Crean, M.S., Sheheen, D.K. and Ghazi, A.M. 2001. Comparative zinc dynamics in Atlanta metropolitan region stream and street runoff. *Environmental Geology*, v40, p983-992.

Rose, S. 2002. Comparative major ion geochemistry of Piedmont streams in the Atlanta, Georgia region: possible effects of urbanization. *Environmental Geology*, v42, p102-113.

Rose, S. 2003. Comparative solute-discharge hysteresis analysis for an urbanized and a "control basin"in the Georgia (USA) Piedmont. *Journal of Hydrology*, v284, p45-56.

Rose, S. 2004. A combined hydrological, geochemical and isotopic approach to understanding the effects of basin scale on base flow systematics in the Georgia Piedmont Province. Technical Completion Report for the Georgia Water Resources Institute FY 2003.

Rose, S. and Fullagar, P.D. 2005. Strontium isotope systematics of base flow in Piedmont Province watersheds, Georgia (USA). *Applied Geochemistry*, v20, p1571-1586.

Seabrook, C. 1997. River in peril: how Atlanta's sewers threaten the Chattahoochee. *Atlanta Journal Constitution*. 1 July 1997.

Soler, A., Canals, A., Goldstein, S.L., Otero, N., Antich, N., and Spangenberg, J., 2002. Sulfur and strontium isotope composition of the Llobregat river (NE Spain): tracers of natural and anthropogenic chemicals in stream water. *Water, Air, and Soil Pollution*, v136, p207-224.

Stuckless, J.S., Peterman, Z.E. and Muhs, D.R., 1991. U and Sr isotopes in ground water and calcite, Yucca mountain, Nevada: evidence against upwelling water. *Science*, v254, p551-553.

Tricca, A., Stille, P., Steinmann, M., Kiefel, B., Samuel, J. and Eikenberg, J., 1999. Rare earth elements and Sr and Nd isotopic compositions of dissolved and suspended loads from small river systems in the Vosges mountains (France), the river Rhine and groundwater. *Chemical Geology*, v160, p139-158.

University of Georgia, 2005. Georgia Automated Environmental Monitoring Network. http://www.griffin.peachnet.edu/bae/.

USGS, 2005. Water resources of Georgia. http://ga.water.usgs/gov/.

Velbel, M.A. 1992. Geochemical mass balances and weathering rates in forested watersheds of the southern Blue Ridge. III. Cation budgets and weathering rates of amphibole. *American Journal of Science*, v292,

Wadleigh, M.A., Veizer, J. and Brooks, C., 1985. Strontium and its isotopes in Canadian rivers: fluxes and global implications. *Geochimica et Cosmochimica Acta*, v49, p1727-1736.

White, A.F., Bullen, T.D., Schulz, M.S., Blum, A.E., Huntington, T.G., and Peters, N.E., 2001. Differential rates of feldspar weathering in granitic regoliths. *Geochimica et Cosmochimica Acta*, v65, 847-869.

Woods, T.L., Fullagar, P.D., Spruill, R.K. and Sutton, L.C., 2000. Strontium isotopes and major elements as tracers of ground water evolution: example from the Upper Castle Hayne aquifer of North Carolina. *Ground Water,* v38, p762-771.

Appendix 1: Description of Sampling Sites and Sample Inventory

Sample No.	Site	Sample Date	County	Description
WTP-1	RN Clayton Waste Water Treatment Plant	4/14/05	Fulton	Raw Sewage
CB-1	Chattahoochee R. north of Helen	4/21/05	White	Rural Blue Ridge headwater stream:
CB-2	Smith Ck.	4/21/05	White	Rural Blue Ridge headwater stream: 0.2 miles south of Ruby Falls
CB-3	Sweetwater Ck. south of Austell	5/9/05	Douglas	Semi-urbanized stream (AMR)[1]
CB-4	South Utoy Ck. @ Harbin Rd.	5/9/05	Fulton	Urbanized AMR stream on main sewer line
CB-5	North Utoy Ck @ Peyton Rd.	5/9/05	Fulton	Urbanized AMR stream on main sewer line
CB-6	Utoy Ck. @ Fulton Ind. Blvd.	5/9/05	Fulton	Urbanized AMR stream on main sewer line
CB-7	Proctor Ck. @ Hightower Rd.	5/9/05	Fulton	Urbanized AMR stream - downstream of CSO facility
CB-8	Burnt Fork Ck.	5/12/05	Dekalb	Suburban tributary to S. Peachtree Ck. in AMR
CB-9	South Peachtree Ck. @ Hahn Woods	5/12/05	Dekalb	Urbanized/Surburbanized AMR tributary to Peachtree Ck.
CB-10	North Peachtree Ck @ Druid Hills Rd.	5/12/05	Dekalb	Urbanized/Suburbanized AMR tributary to Peachtree Ck.
CB-11	Clear Ck.@Monroe Dr.	5/12/05	Fulton	Urbanized AMR stream - downstream of CSO facility
CB-12	Nancy Ck. @W. Wesley Rd.	5/12/05	Fulton	Urbanized AMR stream on main sewer line
CB-13	Peachtree Ck. @ Northside Highway	5/12/05	Fulton	Urbanized AMR stream on main sewer line
CB-14	Chattahoochee R. @ Franklin	5/13/05	Heard	Chattahoochee River downstream of AMR, terminal downstream site of study
CB-15	Acorn Ck. @ Highway 5	5/13/05	Carroll	Small rural watershed downstream of AMR
CB-16	Snake Ck. near Banning	5/13/05	Carroll	Small rural watershed downstream of AMR
CB-17	Chattahoochee R. @ Whitesburg	5/13/05	Coweta/ Carroll	Chattahoochee River downstream of AMR
CB-18	Dog River @ Highway 166	5/13/05	Douglas	Small rural watershed downstream of AMR

[1] AMR = Atlanta Metropolitan Region

Appendix 1: Description of Sampling Sites and Sample Inventory

Sample No.	Site	Sample Date	County	Description
CB-19	Chattahoochee R. @ Capps Ferry Rd.	5/13/05	Douglas/ Carroll	Chattahoochee River downstream of AMR
CB-20	Pea Ck. @ Highway 70	5/13/05	Fulton	Small rural watershed outside west of AMR
WTP-2	Utoy Ck. Water Treatment Plant	5/13/05	Fulton	Treated Sewage Effluent
CB-21	Big Ck. off S.R. 140 near	5/18/05	Fulton	Suburbanized watershed in northern AMR
CB-22	Big Ck. near Cumming	5/18/05	Forsyth	Rural/newly suburbanized watershed north of AMR
CB-23	Chestatee R. on SR 19 south of Dahlonega	5/18/05	Lumpkin	Rural watershed upstream of Lake Lanier and AMR
CB-24	Bear Ck. west of Highway 129 and east of Highway 283	5/15/05	Hall	Rural watershed upstream of Lake Lanier and AMR
CB-25	Chattahoochee R. @ State Rd. 52	5/18/05	Hall	Small rural watershed upstream of Lake Lanier and AMR
CB-26	Chattahoochee R. @ State Rd. 20	5/18/05	Gwinett/ Forsyth	Chattahoochee River immediately downstream of Lake Lanier and upstream of AMR
CB-27	Sewannee Ck. off Highway 23	5/18/05	Gwinett	Small rural/newly urbanized watershed north of AMR
CB-28	Chattahoochee R. @ State Rd. near Duluth, GA	5/19/05	Fulton/ Gwinett	Chattahoochee River immediately upstream of the AMR
CB-29	Crooked Ck. near Norcross	5/19/05	Gwinnett	Suburbanized stream in the northern AMR
CB-30	Chattahoochee R. @ Holcomb Bridge Rd.	5/19/05	Fulton/ Gwinett	Chattahoochee River in the north portion of the AMR
CB-31	Chattahoochee R. @ West Paces Ferry Rd.	5/23/05	Cobb/ Fulton	Chattahoochee River in the north portion of the AMR
CB-32	Chattahoochee R. @ State Rd. 166 west of College Park	5/23/05	Fulton/ Douglas	Chattahoochee River immediately downstream of the AMR
CB-33	Camp Ck. near Campbellton	5/23/05	Fulton	Urbanized watershed in the southern AMR
SR-1	South River @ Klondike Rd.	5/23/05	Dekalb	Ocmulgee Basin (not within the Chattahoochee River Basin) - receives treated sewage effluent from major sewage treatment plants in the AMR

Appendix 1: Description of Sampling Sites and Sample Inventory

Sample No.	Site	Sample Date	County	Description
CB-34	Sweetwater Ck. near Villa Rica	5/24/05	Douglas/ Paulding	Rural/semi-developed watershed west of the AMR
CB-35	Lick Lock Ck. @ State Rd. 92	5/24/05	Paulding	Rural/semi-developed watershed west of the AMR
CB-36	Olley Ck. north of Austell	5/24/05	Cobb	Rural/semi-developed watershed west of the AMR

Appendix 2: Chemical Analyses (in mg/L)

Sample Number	Sample Designation	Date	Temp oC	Specific Conduct. uS/cm	pH	HCO3 mg/L	Silica mg/L	Mg mg/L	K mg/L	Ca mg/L	Na mg/L	Cl mg/L	SO4 mg/L
WTP-1	RN Clayton WTP	4/14/05	NA	460.0	6.54	156.1	12	2.43	10.74	26.4	40.9	65.11	29.17
CB-1	CR near Helen	4/21/05	13.2	12.0	6.03	4.1	8	0.23	0.61	0.5	1.7	2.82	1.41
CB-2	Smith Creek	4/21/05	14.2	10.2	5.92	3.9	7	0.18	0.51	0.4	1.3	1.73	1.11
CB-3	Sweetwater Ck -1	5/9/05	18.1	70.5	6.26	32.3	15	1.83	1.33	6	6.4	8.61	3.76
CB-4	S. Utoy Creek	5/9/05	21.2	146.5	6.45	35.4	19	3.06	2.75	10.4	10.4	14.51	23.12
CB-5	N. Utoy Creek	5/9/05	19.3	131.1	6.39	46.4	18	2.36	2.47	10.9	10.0	18.19	11.83
CB-6	Utoy Creek	5/9/05	20.1	121.9	6.39	40.7	17	2.35	2.49	9.4	9.1	12.02	13.17
CB-7	Proctor Creek	5/9/05	22.9	306.5	7.10	90.3	16	5.06	4.52	30.5	19.8	28.75	41.81
CB-8	Burnt Fork Creek	5/12/05	18.0	107.9	6.50	43.1	13	2.07	2.54	10.6	7.87	12.17	4.79
CB-9	S. Peachtree Creek	5/12/05	20.0	109.5	6.56	38.2	12	2.06	2.54	10.4	5.86	13.13	5.44
CB-10	N. Peachtree Creek	5/12/05	20.5	143.9	6.52	52.5	13	2.17	2.82	15.9	11.9	17.82	7.59
CB-11	Clear Creek	5/12/05	21.5	224.3	6.66	67.1	26	3.80	4.69	19.1	16.6	27.04	27.89
CB-12	Nancy Creek	5/12/05	20.2	122.0	6.75	43.1	13	2.24	2.66	11.6	9.0	13.58	11.12
CB-13	Peachtree Creek	5/12/05	21.2	160.1	6.47	56.9	14	2.50	3.34	17.5	14.1	16.19	11.72
CB-14	CR near Franklin	5/13/05	20.3	94.2	6.69	24.4	7	1.29	2.81	6.6	10.6	15.22	8.54
CB-15	Acorn Creek	5/13/05	18.1	35.2	6.16	14.0	13	0.74	1.24	1.2	5.1	5.35	2.02
CB-16	Snake Creek	5/13/05	22.9	31.1	5.95	8.5	6	0.63	1.30	1.3	3.4	5.63	2.54
CB-17	CR at Whitesburg	5/13/05	19.5	86.2	6.21	22.8	8	1.21	1.46	5.3	9.7	14.06	6.05
CB-18	Dog River	5/13/05	20.9	46.4	6.17	12.2	11	0.85	1.51	5.1	5.3	8.16	2.11
CB-19	CR at Capps Ferry Rd	5/13/05	22.4	107.2	6.38	26.0	8	1.27	3.34	2.5	11.6	16.94	7.54
CB-20	Pea Creek	5/13/05	19.7	55.8	6.30	23.7	12	0.89	1.47	6.1	6.3	5.19	2.70
WTP-2	Utoy Creek WTP	5/13/05	NA	400.2	6.83	64.7	14	2.77	7.81	14.20	54.3	67.3	25.42
CB-21	Big Creek SR 140	5/18/05	16.6	98.9	6.36	27.7	12	2.39	3.38	6.1	8.6	21.71	4.99
CB-22	Big Creek - Cumming	5/18/05	17.2	167.9	6.15	32.5	12	5.08	5.68	6.9	17.2	49.26	9.66
CB-23	Chestatee River	5/18/05	17.2	25.6	6.00	11.3	9	0.58	0.89	1.2	2.6	7.87	1.79
CB-24	Bear Creek	5/18/05	17.2	56.1	6.09	20.0	11	1.36	2.12	2.5	4.8	6.54	1.82
CB-25	CR near Lula	5/18/05	21.6	37.1	5.77	10.7	8	0.66	1.31	1.4	3.1	4.48	1.78
CB-26	CR near Buford Dam	5/18/05	17.9	39.5	6.26	13.1	7	0.89	1.83	2.2	4.1	5.9	3.21
CB-27	Sewanee Creek	5/18/05	20.1	160.1	6.13	34.6	11	2.11	3.64	10.1	17.6	16.78	19.01
CB-28	CR near Duluth	5/19/05	13.7	46.4	6.25	16.6	5	1.00	1.95	3.2	5.0	6.93	3.95
CB-29	Crooked Creek	5/19/05	20.4	128.9	6.56	41.7	17	1.94	2.59	8.2	13.8	21.99	3.67

Sample Number	Sample Designation	Date Date	Temp oC	Specific Conduct. uS/cm	pH	HCO3 mg/L	Silica mg/L	Mg mg/L	K mg/L	Ca mg/L	Na mg/L	Cl mg/L	SO4 mg/L
CB-30	**CR at Haynes Bridge Rd**	5/19/05	18.9	47.5	6.41	14.0	6	0.95	2.32	2.9	4.7	6.96	3.73
CB-31	**CR at W. Paces Ferry Rd**	5/23/05	19.6	77.4	6.27	22.4	7	1.25	2.71	5.9	7.5	11.35	5.56
CB-32	**CR at S.R. 166**	5/23/05	21.5	136.3	6.73	31.5	9	1.59	3.69	9.1	19.5	21.90	10.35
CB-33	**Camp Creek**	5/23/05	20.3	91.0	6.41	34.3	16	1.87	2.35	6.9	7.2	8.54	4.91
SR-1	**South River - Klondike Rd.**	5/23/05	21.1	206.5	6.21	48.3	13	2.26	5.42	25.4	20.5	39.21	13.78
CB-34	**Sweetwater Ck. - Villa Rica**	5/24/05	21.1	76.7	6.57	35.0	14	2.03	1.09	5.20	5.2	4.65	2.24
CB-35	**Lick Log Ck.**	5/24/05	21.7	71.7	6.72	31.9	13	1.76	0.96	4.4	5.6	5.93	2.29
CB-36	**Olley Ck.**	5/24/05	20.7	95.2	6.48	34.6	15	1.94	2.32	8.1	6.7	12.15	4.07

Chemical Analyses (in mmol/L)													
Sample Number	**Sample Designation**	**Date**	**Temp oC**	**Specific Conduct. uS/cm**	**pH**	**HCO3 mmol/L**	**Silica mmol/L**	**Mg mmol/L**	**K mmol/L**	**Ca mmol/l**	**Na mmol/L**	**Cl mmol/L**	**SO4 mmol/L**
WTP-1	RN Clayton WTP	4/14/05	NA	460.0	6.54	0.07	0.087	0.009	0.016	0.012	0.074	0.080	0.015
CB-1	CR near Helen	4/21/05	13.2	12.0	6.03	0.06	0.076	0.007	0.013	0.012	0.074	0.080	0.015
CB-2	Smith Creek	4/21/05	14.2	10.2	5.92	0.53	0.163	0.075	0.034	0.010	0.057	0.049	0.012
CB-3	Sweetwater Ck -1	5/9/05	18.1	70.5	6.26	0.58	0.206	0.126	0.070	0.150	0.278	0.243	0.039
CB-4	S. Utoy Creek	5/9/05	21.2	146.5	6.45	0.58	0.206	0.126	0.070	0.259	0.452	0.409	0.241
CB-5	N. Utoy Creek	5/9/05	19.3	131.1	6.39	0.76	0.195	0.097	0.063	0.272	0.435	0.513	0.123
CB-6	Utoy Creek	5/9/05	20.1	121.9	6.39	0.67	0.185	0.097	0.064	0.235	0.396	0.339	0.137
CB-7	Proctor Creek	5/9/05	22.9	306.5	7.10	1.48	0.174	0.208	0.116	0.761	0.861	0.811	0.435
CB-8	Burnt Fork Creek	5/12/05	18.0	107.9	6.50	0.71	0.141	0.085	0.065	0.264	0.342	0.343	0.050
CB-9	S. Peachtree Creek	5/12/05	20.0	109.5	6.56	0.63	0.130	0.085	0.065	0.259	0.255	0.370	0.057
CB-10	N. Peachtree Creek	5/12/05	20.5	143.9	6.52	0.86	0.141	0.089	0.072	0.397	0.518	0.503	0.079
CB-11	Clear Creek	5/12/05	21.5	224.3	6.66	1.10	0.282	0.156	0.120	0.477	0.722	0.763	0.290
CB-12	Nancy Creek	5/12/05	20.2	122.0	6.75	0.71	0.141	0.092	0.068	0.289	0.391	0.383	0.116
CB-13	Peachtree Creek	5/12/05	21.2	160.1	6.47	0.93	0.152	0.103	0.085	0.437	0.613	0.457	0.122
CB-14	CR near Franklin	5/13/05	20.3	94.2	6.69	0.40	0.076	0.053	0.072	0.165	0.461	0.429	0.089
CB-15	Acorn Creek	5/13/05	18.1	35.2	6.16	0.23	0.141	0.030	0.032	0.030	0.222	0.151	0.021
CB-16	Snake Creek	5/13/05	22.9	31.1	5.95	0.14	0.065	0.026	0.033	0.032	0.148	0.159	0.026
CB-17	CR at Whitesburg	5/13/05	19.5	86.2	6.21	0.37	0.087	0.050	0.037	0.132	0.422	0.397	0.063
CB-18	Dog River	5/13/05	20.9	46.4	6.17	0.20	0.119	0.035	0.039	0.127	0.231	0.230	0.022
CB-19	CR at Capps Ferry Rd	5/13/05	22.4	107.2	6.38	0.43	0.087	0.052	0.085	0.062	0.505	0.478	0.078
CB-20	Pea Creek	5/13/05	19.7	55.8	6.30	0.39	0.130	0.037	0.038	0.152	0.274	0.146	0.028
WTP-2	Utoy Creek WTP	5/13/05	NA	400.2	6.83	1.06	0.152	0.114	0.200	0.354	2.362	1.898	0.265
CB-21	Big Creek SR 140	5/18/05	16.6	98.9	6.36	0.45	0.130	0.098	0.086	0.152	0.374	0.612	0.052
CB-22	Big Creek - Cumming	5/18/05	17.2	167.9	6.15	0.53	0.130	0.209	0.145	0.172	0.748	1.390	0.101
CB-23	Chestatee River	5/18/05	17.2	25.6	6.00	0.19	0.098	0.024	0.023	0.030	0.113	0.222	0.019
CB-24	Bear Creek	5/18/05	17.2	56.1	6.09	0.33	0.119	0.056	0.054	0.062	0.209	0.184	0.019
CB-25	CR near Lula	5/18/05	21.6	37.1	5.77	0.18	0.087	0.027	0.034	0.035	0.135	0.126	0.019
CB-26	CR near Buford Dam	5/18/05	17.9	39.5	6.26	0.21	0.076	0.037	0.047	0.055	0.178	0.166	0.033
CB-27	Sewanee Creek	5/18/05	20.1	160.1	6.13	0.57	0.119	0.087	0.093	0.252	0.766	0.473	0.198
CB-28	CR near Duluth	5/19/05	13.7	46.4	6.25	0.27	0.054	0.041	0.050	0.080	0.217	0.195	0.041
CB-29	Crooked Creek	5/19/05	20.4	128.9	6.56	0.68	0.185	0.080	0.066	0.205	0.600	0.620	0.038

Sample Number	Sample Designation	Date	Temp oC	Specific Conduct. uS/cm	pH	HCO3 mmol/L	Silica mmol/L	Mg mmol/L	K mmol/L	Ca mmol/L	Na mmol/L	Cl mmol/L	SO4 mmol/L
CB-30	CR at Haynes Bridge RD	5/19/05	18.9	47.5	6.41	0.00	0.000	0.039	0.000	0.000	0.00	0.000	0.000
CB-31	CR at W. Paces Ferry Rd	5/23/05	19.6	77.4	6.27	0.37	0.076	0.052	0.069	0.147	0.33	0.320	0.057
CB-32	CR at S.R. 166	5/23/05	21.5	136.3	6.73	0.52	0.098	0.066	0.094	0.227	0.85	0.618	0.106
CB-33	Camp Creek	5/23/05	20.3	91.0	6.41	0.56	0.174	0.078	0.060	0.172	0.31	0.241	0.050
SR-1	South River - Klondike Rd.	5/23/05	21.1	206.5	6.21	0.79	0.141	0.094	0.139	0.634	0.89	1.106	0.141
CB-34	Sweetwater Ck. - Villa Rica	5/24/05	21.1	76.7	6.57	0.57	0.152	0.084	0.028	0.130	0.23	0.131	0.023
CB-35	Lick Log Ck.	5/24/05	21.7	71.7	6.72	0.52	0.141	0.073	0.025	0.110	0.24	0.167	0.023
CB-36	Olley Ck.	5/24/05	20.7	95.2	6.48	0.57	0.163	0.080	0.059	0.202	0.29	0.343	0.042

Chemical Analyses (in meq/L)

Sample Number	Sample Designation	Date	Mg meq/L	K meq/L	Ca meq/L	Na meq/L	Sum Equiv. Cations meq/L	Cl meq/L	SO4 meq/L	HCO3 meq/L	Sum Equiv. Anions meq/L	Charge Balance %	
WTP-1	RN Clayton WTP	4/14/05	0.200	0.275	1.317	1.779	**3.571**	1.837	0.304	2.56	**4.699**	-13.6	
CB-1	CR near Helen	4/21/05	0.019	0.016	0.025	0.074	**0.133**	0.080	0.015	0.07	**0.161**	-9.5	
CB-2	Smith Creek	4/21/05	0.015	0.013	0.020	0.057	**0.104**	0.049	0.012	0.06	**0.124**	-8.7	
CB-3	Sweetwater Ck -1	5/9/05	0.151	0.034	0.299	0.278	**0.762**	0.243	0.039	0.53	**0.812**	-3.1	
CB-4	S. Utoy Creek	5/9/05	0.252	0.070	0.519	0.452	**1.293**	0.409	0.241	0.58	**1.230**	2.5	
CB-5	N. Utoy Creek	5/9/05	0.194	0.063	0.544	0.435	**1.236**	0.513	0.123	0.76	**1.397**	-6.1	
CB-6	Utoy Creek	5/9/05	0.193	0.064	0.469	0.396	**1.122**	0.339	0.137	0.67	**1.143**	-0.9	
CB-7	Proctor Creek	5/9/05	0.416	0.116	1.522	0.861	**2.915**	0.811	0.435	1.48	**2.727**	3.3	
CB-8	Burnt Fork Creek	5/12/05	0.170	0.065	0.529	0.342	**1.107**	0.343	0.050	0.71	**1.100**	0.3	
CB-9	S. Peachtree Creek	5/12/05	0.169	0.065	0.519	0.255	**1.008**	0.370	0.057	0.63	**1.053**	-2.2	
CB-10	N. Peachtree Creek	5/12/05	0.179	0.072	0.793	0.518	**1.562**	0.503	0.079	0.86	**1.442**	4.0	
CB-11	Clear Creek	5/12/05	0.313	0.120	0.953	0.722	**2.108**	0.763	0.290	1.10	**2.153**	-1.1	
CB-12	Nancy Creek	5/12/05	0.184	0.068	0.579	0.391	**1.223**	0.383	0.116	0.71	**1.205**	0.7	
CB-13	Peachtree Creek	5/12/05	0.206	0.085	0.873	0.613	**1.778**	0.457	0.122	0.93	**1.511**	8.1	
CB-14	CR near Franklin	5/13/05	0.106	0.072	0.329	0.461	**0.968**	0.429	0.089	0.40	**0.918**	2.7	
CB-15	Acorn Creek	5/13/05	0.061	0.032	0.060	0.222	**0.374**	0.151	0.021	0.23	**0.401**	-3.5	
CB-16	Snake Creek	5/13/05	0.052	0.033	0.065	0.148	**0.298**	0.159	0.026	0.14	**0.325**	-4.3	
CB-17	CR at Whitesburg	5/13/05	0.100	0.037	0.264	0.422	**0.823**	0.397	0.063	0.37	**0.833**	-0.6	
CB-18	Dog River	5/13/05	0.070	0.039	0.254	0.231	**0.594**	0.230	0.022	0.20	**0.452**	13.5	
CB-19	CR at Capps Ferry Rd	5/13/05	0.104	0.085	0.125	0.505	**0.819**	0.478	0.078	0.43	**0.983**	-9.1	
CB-20	Pea Creek	5/13/05	0.073	0.038	0.304	0.274	**0.689**	0.146	0.028	0.39	**0.563**	10.1	
WTP-2	Utoy Creek WTP	5/13/05	0.228	0.200	0.709	2.362	**3.498**	1.898	0.265	1.06	**3.224**	4.1	
CB-21	Big Creek SR 140	5/18/05	0.197	0.086	0.304	0.374	**0.962**	0.612	0.052	0.45	**1.118**	-7.5	
CB-22	Big Creek - Cumming	5/18/05	0.418	0.145	0.344	0.748	**1.656**	1.390	0.101	0.53	**2.023**	-10.0	
CB-23	Chestatee River	5/18/05	0.048	0.023	0.060	0.113	**0.243**	0.222	0.019	0.19	**0.426**	-27.3	
CB-24	Bear Creek	5/18/05	0.112	0.054	0.125	0.209	**0.500**	0.184	0.019	0.33	**0.531**	-3.1	
CB-25	CR near Lula	5/18/05	0.054	0.034	0.070	0.135	**0.293**	0.126	0.019	0.18	**0.320**	-4.5	
CB-26	CR near Buford Dam	5/18/05	0.073	0.047	0.110	0.178	**0.408**	0.166	0.033	0.21	**0.415**	-0.8	
CB-27	Sewanee Creek	5/18/05	0.174	0.093	0.504	0.766	**1.536**	0.473	0.198	0.57	**1.238**	10.7	
CB-28	CR near Duluth	5/19/05	0.082	0.050	0.160	0.217	**0.509**	0.195	0.041	0.27	**0.509**	0.1	
CB-29	Crooked Creek	5/19/05	0.160	0.066	0.409	0.600	**1.235**	0.620	0.038	0.68	**1.342**	-4.1	

Sample Number	Sample Designation	Date	Mg meq/L	K meq/L	Ca meq/L	Na meq/L	Sum Equiv. Cations meq/L	Cl meq/L	SO4 meq/L	HCO3 meq/L	Sum Equiv. Cations meq/L	Charge Balance %	
CB-30	CR at Haynes Br.Rd.	5/19/05	0.079	0.059	0.145	0.20	**0.487**	0.196	0.076	0.23	**0.502**	-1.5	
CB-31	CR at W. Paces Ferry Rd	5/23/05	**0.104**	0.069	0.294	0.33	**0.794**	0.320	0.113	0.37	**0.801**	-0.5	
CB-32	CR at S.R.166	5/23/05	0.132	0.094	0.454	0.85	**1.529**	0.618	0.211	0.52	**1.345**	6.4	
CB-33	Camp Creek	5/23/05	0.155	0.060	0.344	0.31	**0.873**	0.241	0.100	0.56	**0.903**	-1.7	
SR-1	South River-Klondike Rd.	5/24/05	0.187	0.139	1.267	0.89	**2.485**	1.106	0.281	0.79	**2.179**	6.6	
CB-34	Sweetwater Ck. -Villa Rica	5/24/05	0.168	0.028	0.259	0.23	**0.682**	0.131	0.046	0.57	**0.751**	-4.8	
CB-35	Lick Log Ck.	5/24/05	0.146	0.025	0.220	0.24	**0.634**	0.167	0.047	0.52	**0.737**	-7.5	
CB-36	Olley Ck.	5/24/05	0.161	0.059	0.404	0.40	**0.916**	0.343	0.083	0.57	**0.993**	-4.0	
											Average	**4.8%**	

Phosphorus Storage and Transport in Headwaters of the Etowah River Watershed

Basic Information

Title:	Phosphorus Storage and Transport in Headwaters of the Etowah River Watershed
Project Number:	2005GA82B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	12th
Research Category:	Water Quality
Focus Category:	Water Quality, Hydrology, Non Point Pollution
Descriptors:	
Principal Investigators:	C. Rhett Jackson

Publication

Annual Program Report

"Phosphorus Storage and Transport in Headwaters of the Etowah River Watershed"

Submitted to: **Dr. Aris Georgakakos**
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Date: **May 12, 2006**

Executive Summary

Our research funded by the U.S. Geological Survey through the Georgia Water Resources Research Institute is investigating phosphorus (P) transport in terms of what forms and quantities move through different hydrologic pathways and how such transport relates to P stored in soils and sediments. Our research is being performed in three headwater catchments—two agricultural and one forested—in the upper Etowah River watershed of north central Georgia. Our approach has been to develop watershed P budgets and characterize the concentrations of different forms of P in soils, sediments, and hydrologic pathways. Emphasis is placed on identification and characterization of critical source areas on hillslopes where soils with high concentrations of P are collocated with hydrologic source areas. Methods are based, in part, on high spatial and temporal resolution of field data collection. At this point, our major accomplishment is finding that P loads in the systems we are monitoring are highly variable and can increase by orders of magnitude over short time intervals. Understanding processes at the hillslope and small watershed scales are crucial to developing effective strategies for mitigating transport of P to downstream waterbodies.

(1) RESEARCH

In most watersheds that have undergone human development, the mass of phosphorus (P) transferred hydrologically over and through the soils and into streams and rivers greatly exceeds what would be transferred naturally. In the southeastern U.S., accelerated loads of P entering lakes and reservoirs used for drinking water and recreation stimulates growth of nuisance phytoplankton algal communities. Seasonal cycles of growth and subsequent decay of the algal communities degrade drinking water supplies, deplete oxygen for aquatic life, and cause imbalances in overall aquatic ecosystem function. The processes that regulate hydrologic transfer of P are complex and highly variable. Effective management of P through best management practices (BMPs) is directly linked to our understanding of how sources, pathways, and mobilization mechanisms that lead to P transfer and delivery are integrated at the watershed scale.

Our research funded by the U.S. Geological Survey (USGS) through the Georgia Water Resources Research Institute (WRRI) is evaluating how amounts and forms of P in storage and in different hydrologic pathways relate to the amounts and forms of P exported. Our research is being performed in three headwater catchments—two agricultural and one forested—in the upper Etowah River watershed of north central Georgia. The approach is to develop watershed P budgets and characterize the concentrations of different forms of P in soils, sediments, and hydrologic pathways. Emphasis will be placed on identification and characterization of critical source areas (CSAs) (i.e. Gburek and Sharpley (1998), Pionke et al. (2000)) which are soils with high concentrations of P are collocated with hydrologic source areas. Methods will be based in part on high spatial and temporal resolution of field data collection. Our research is aimed at answering the following questions:

(1) How is P yield related to the amount of P stored in the watershed?
(2) How is P yield related to present inputs of P?
(3) How do forms and concentrations of P vary among different hydrologic pathways?
(4) What are the primary hydrologic and chemical controls affecting P yield?

Our research augments a separate 2-year study by a UGA research team funded by the U.S. Department of Agriculture. In that study, 12 headwater streams within the upper Etowah River watershed, predominated by either agricultural or forested land use types, are being monitored to generate information to be used to explore options for point/non-point pollution trading of P. Monitoring methods include continuous streamflow measurement using H-flumes and a combination of systematic, biweekly grab samples coupled with storm sample collection using ISCO autosamplers. Water quality samples are analyzed for total P (TP), dissolved (<0.45 µm) reactive P (DRP), total suspended solids, and turbidity. Water quality and flow data are used to estimate both short-term (i.e. storm-specific) and long term (annual) P loads and yields.

Interim results from the UGA Etowah study are illustrated in Figures 1-3 at the end of this report section. Results for grab samples, which are typically collected during baseflow conditions, are differentiated from storm samples, which are typically collected via ISCO autosamplers. Median concentration, median load, and median unit-area load (yield) for TP and DRP are depicted in Figures 1-3, respectively. The three forested streams are represented by Sites 1, 2, and 3. All other sites (4 thru 12) represent agricultural land use conditions. Key results for TP only are discussed here. Median TP concentrations for grab and storm samples from forested watersheds range 3.4 to 7.6 and 3.8 to 10 ug-P/L, respectively. For agricultural watersheds, median TP concentrations for grab and storm samples range 3 to 298 and 30 to 1,970 ug-P/L, respectively. Highest P concentrations, loads, and unit-area loads are associated with agricultural watersheds #5, 6, and #12. These three watersheds are the smallest agricultural watersheds being monitored.

From the UGA Etowah study, forested site #2 plus agricultural sites #5 and #12 were selected for our current USGS/WRRI-funded research. Forested site #2 was chosen because of its ease for access for monitoring of in-stream water quality, hillslope hydrologic conditions, and atmospheric deposition. At sites #5 and #12, phosphorus concentrations, loads, and yields are among the highest of the 9 agricultural streams being monitored under the UGA study. This suggests that they are likely to be among the most critical in terms of support needed to guide future nutrient management. As stated previously, effective management of P through best management practices (BMPs) is directly linked to our understanding of how sources, pathways, and mobilization mechanisms that lead to P transfer and delivery are integrated at the watershed scale.

Our study plan remains largely the same as originally proposed. Development of P budgets will require knowledge of P inputs, outputs, and storage. Attempts will be made to directly monitor all P inputs including manure application and wet and dry forms of atmospheric deposition. Wet-deposition will be monitored using rain-activated deposition samplers. One sampler will be installed at each of the three watersheds. Methods will be adapted from the National Atmospheric Deposition Program (NADP) (Dossett and Bowersox 1999) with the exception that our monitoring equipment will be intentionally sited near confined animal feeding operations. Dry deposition monitoring will be based on sampling of foliage and inert surfaces (i.e Lindberg and Lovett 1985) and/or throughfall (i.e. Argo 1995). Attempts may be made to collect samples of runoff from roofs of poultry houses. Concentrations of P in atmospheric deposition samples are expected to be low, highly variable, and subject to measurement-type errors. Personnel with the NADP laboratory in Illinois have offered analytical support. Samples of different forms of manure will be collected for laboratory analysis. This will require coordination with farmers and landowners. Information on the volume, rate, frequency, and place of application will be gathered from farmers.

Streamflow outputs will be measured through the current UGA Etowah project. However, modifications will be incorporated that include higher frequencies of sample collection and laboratory analyses that encompass the full range of P forms. Characterization of streamflow biologically-available P via anion-exchange resin (AER-P) strips and/or filtration media smaller than 0.45 um are currently being explored.

Estimation of P in storage in each watershed must account for P held by soils, sediments, and vegetation. Accounting for uptake and recycling of P by vegetation will be based on methods used by Harned et al. (2004) and other studies. The quantity of P in storage by soil will be estimated via collection of soil samples at different depths on a grid basis throughout the catchments. At each grid point, samples will be collected at multiple depths. At the soil surface of each gridpoint, the degree of vegetative cover will be characterized. In the soil subsurface at each gridpoint, the depth to the B_t horizon, and soil redoximorphic features at gridpoints will be observed as a means of attempting to elucidate the potential for interflow or induction of variable source area runoff. Geostatistical methods will be used to identify hotspots and overall spatial variability of soil P. Soil sampling along transects at each site has been performed to elucidate variability in soil P concentrations as a function of hillslope position, soil depth, and distance between sample points. This will guide future grid-based soil sampling and subsequent geostatistical analyses. Stream sediment samples will be collected from the upper 2-3 centimeters of depositional zones in each stream. Composite samples will be collected from different depositional zones. Soil and sediment samples will be analyzed for TP, water-soluble P, AER-P, and degree of P saturation.

As stated earlier, this study will emphasize identification of CSAs. Identification of CSAs will be attempted by utilizing information gained through surface and subsurface soil monitoring (i.e. high soil P concentrations, redoximorphic features, shallow depth to groundwater or B_t layer, and/or poor vegetative cover) described in the previous paragraph combined with topographic surveys. These surveys may either be quantitative or qualitative and may be based on the assumption that a CSA is characterized by variable source area hydrology. Variable source areas typically are located on the lower portion near or along stream channels where steeper hillslopes converge to flat, topographic lows (i.e. $\ln A/\tan \beta$ concept).

Soil monitoring and attempts to identify CSAs will guide placement of instrumentation for monitoring hydrologic pathways. For monitoring purposes, pathways to be sampled will include 1) Horton overland flow, 2) interflow, 3) variable source area runoff, and 4) shallow groundwater. An assortment of surface collectors, drop collectors, piezometers, and suction cup lysimeters will be used to characterize different P forms in these pathways. Piezometers, instrumented with data-recording capacitance probes, will be placed in both near-stream areas and stream channels to determine the hydraulic gradient of shallow groundwater. Streamflow and shallow groundwater will be continuously monitored for temperature, pH, and oxidation-reduction potential (ORP) using thermistors, pH probes, and ORP probes linked to dataloggers.

Attempts will be made to monitor P transfer in different hydrologic pathways during different flow regimes and before and after poultry litter application. A combination of instrumentation and on-the-ground field staff will be used to collect intrastorm data from in-stream and different hydrologic pathways. This monitoring data will be used to describe hydrochemical response as a function of soil P levels and other critical factors including water storage and antecedent moisture conditions. An underlying approach for the hydrologic monitoring component of this study is short-duration (i.e. storm event duration), high frequency observations in line with Kirchner et al. (2004).

Concentrations of P forms in different hydrologic pathways may be compared using end-member mixing (EMMA) or principal component analysis (PCA). Past surface water chemistry studies using these methods (i.e. Burns et al. (2001), Hooper (2003)) have been based on conservative solutes to differentiate between and estimate contributions from different sources of streamflow. Because P can be expected to change form along its course from the hillslope to the stream, it may be necessary to include other solutes in the analytical program. Solutes that may warrant consideration may include chloride, calcium, sulfate, or perhaps iron or silica.

REFERENCES

Argo, B. 1995. Field Technician Procedure Manual for Coweeta LTER. Kloeppel, B.D. (ed).

Burns, D.A. J.J. McDonnell, R.P. Hooper, N.E. Peters, J.E. Freer, C. Kendall and K. Beven. 2001. Quantifying contributions to storm runoff through end-member mixing analysis and hydrologic measurements at the Panola Mountain Research Watershed (Georgia, USA). Hydrologic Processes 15: 1903-1924.

Dossett, S.R. and V.C. Bowersox. 1999. *National Trends Network Site Operation Manual*. National Atmospheric Deposition Program Office at the Illinois State Water Survey. NADP Manual 1999-01. Champaign, IL.

Gburek, W.J. and A.N. Sharpley. 1998. Hydrologic controls on phosphorus loss from upland agricultural catchments. Journal of Environmental Quality 27: 267-277.

Harned, D.A., J.B. Atkins, and J.S. Harvill. 2004. Nutrient mass balance and trends, Mobile River basin, Alabama, Georgia, and Mississippi. Journal of the American Water Resources Association 40(3): 765-793.

Hooper, R.P. 2003. Diagnostic tools for mixing models of stream water chemistry. Water Resources Research 39(3): 1055, doi:10.1029/2002WR001528.

Kirchner, J.W., X. Feng, C. Neal, and A.J. Robson. 2004. Invited Commentary. The fine structure of water-quality dynamics: the (high-frequency) wave of the future. Hydrological Processes 18: 1353-1359.

Lindberg, S.E. and G.M. Lovett. 1985. Field measurements of particle dry deposition rates to foliage and inert surfaces in a forest canopy. Environmental Science and Technology 19: 238-244.

Pionke, H.B., W.J. Gburek, and A.N. Sharpley. 2000. Critical source area controls on water quality in an agricultural watershed located in the Chesapeake Basin. Ecological Engineering 14: 325-335.

FIGURES

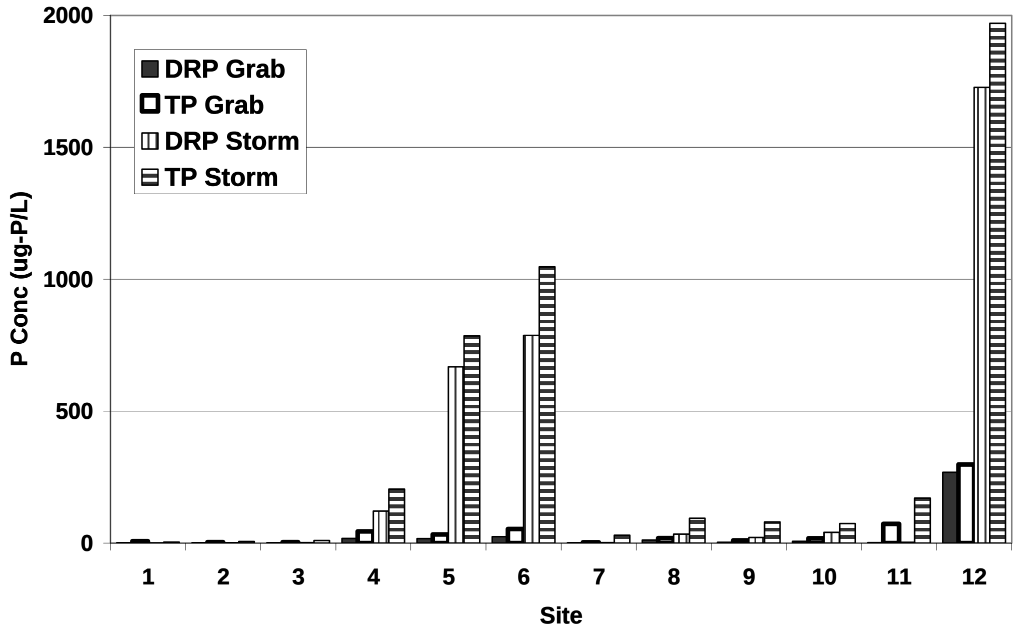


Figure 1. Median total phosphorus concentration by site

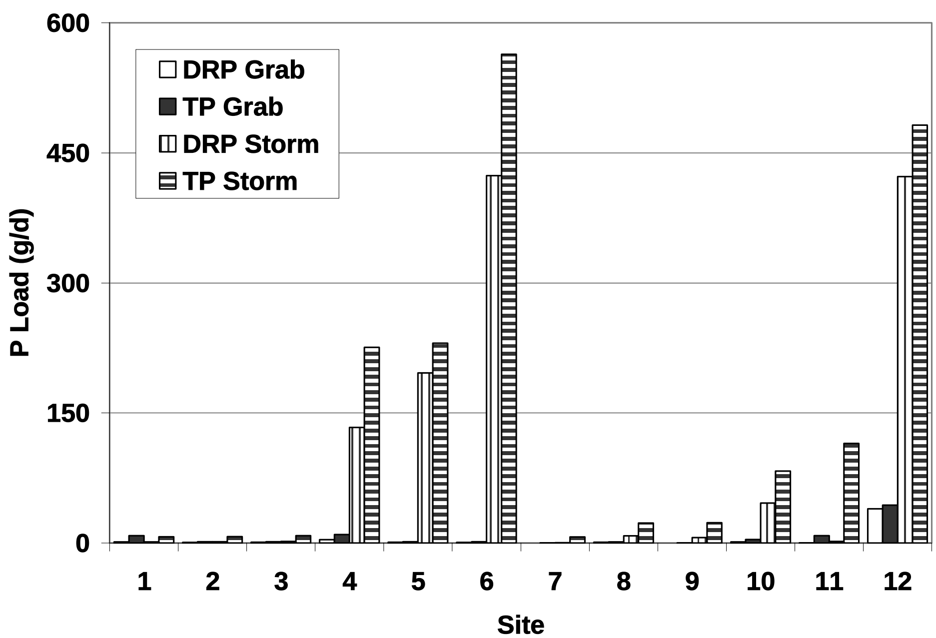


Figure 2. Median instantaneous total phosphorus load by site

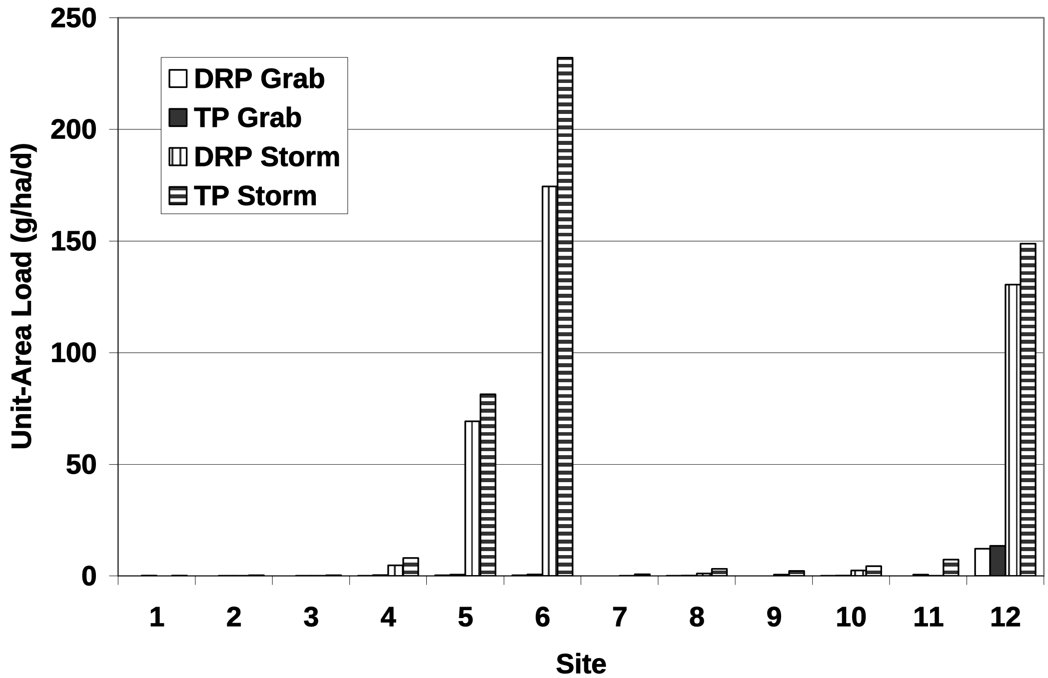


Figure 3. Median unit-area total phosphorus load by site

(2) PUBLICATIONS

Romeis, J. and R. Jackson. 2005. Evaluation of total phosphorus in the Altamaha-Ocmulgee-Oconee River basin. Proceedings of the Georgia Water Resources Conference, April 25-27, Kathy Hatcher, Ed, Institute of Ecology, University of Georgia, Athens, GA.

Romeis, J.J. and C.R. Jackson. 2005. Evaluation of total phosphorus in the Altamaha-Ocmulgee-Oconee (AOO) River Basin, Georgia. Proceedings of the 2005 Annual Conference of the American Water Resources Association, November 7-10, Seattle, WA

(3) INFORMATION TRANSFER PROGRAM

a. Research was presented at the annual conference of the American Water Resources Association conference in November 2006 and at the Georgia Water Resources Conference in April 2006.

b. Meetings were held among poultry and cattle farmers, Etowah River watershed stakeholders, and University of Georgia scientists. Results of monitoring activities have been reported to farmers and landowners.

c. Results of research will be presented in peer-reviewed journal articles.

d. Results will be used to develop a nonpoint nutrient trading program with the goal of reduced phosphorus loading to the Etowah River and Lake Allatoona.

(4) STUDENT SUPPORT

One Ph.D graduate student in the Warnell School of Forestry and Natural Resources at the University of Georgia was supported.

(5) STUDENT INTERNSHIP PROGRAM

Not applicable.

(6) NOTABLE ACHIEVEMENTS AND AWARDS

None.

INFORM: Integrated Forecast and Reservoir Management System for Northern California

Basic Information

Title:	INFORM: Integrated Forecast and Reservoir Management System for Northern California
Project Number:	2005GA131O
Start Date:	4/1/2003
End Date:	8/31/2006
Funding Source:	Other
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Management and Planning, Surface Water
Descriptors:	Integrated Forecast-Decision Systems for River Basin Management
Principal Investigators:	Aris P. Georgakakos, Konstantine P. Georgakakos

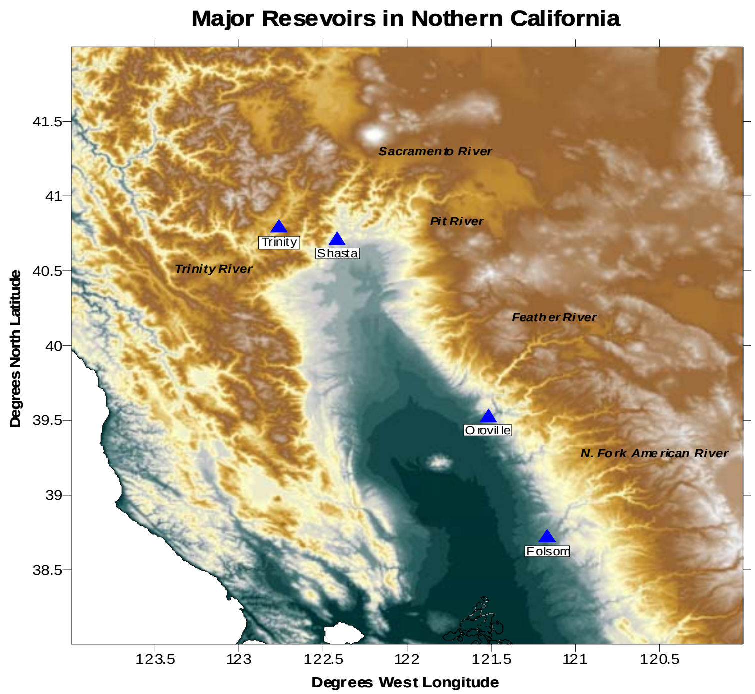
Publication

1. Graham, N., K.P. Georgakakos, A.P. Georgakakos, "Integrated Forecast and Reservoir Management in Northern California, INFORM, A Demonstration project Phase II," Second Annual Climate Change Research Conference and First Scientific Conference, West Coast Governor's Global Warming Initiative, Sacramento, CA, 14-16 September 2005.
2. Georgakakos, A., "Integrated Forecast-Decision Systems for River Basin Management," Invited Paper, American Geophysical Union Metting, San Francisco, CA, December 5, 2005.

INFORM DSS: Validation and Integrated Forecast-Decision Studies

Interim Technical Report

(10/2005-03/2006 Project Period)



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April 2006

1. Introduction

This report describes work performed by GWRI in association with Tasks 9 and 11 (INFORM DSS Validation, Refined INFORM DSS Software, and Workshop with Stakeholder Agencies). This work was performed in the six month period from October 2005 to March 2006.

2. INFORM DSS Validation (Tasks 9 and 11)

To determine the validity of the INFORM DSS long range planning system, and to demonstrate its utility in relation to other existing models, a comprehensive comparison with CALSIM was performed. CALSIM is also a monthly model but includes considerable detail with respect to withdrawals occurring at the various reaches of the Trinity, Sacramento, Feather, American, Yuba, and San Joaquin Rivers. INFORM DSS, on the other hand, includes a more aggregate system representation but has much more elaborate system wide optimization routines. The purpose of the comparison is to investigate whether the two models yield comparable results under the same hydrologic and demand conditions and reservoir release policies.

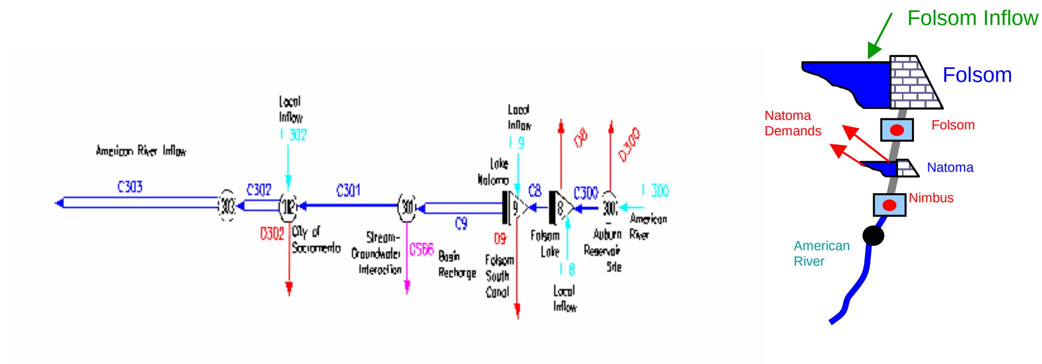
2.1. Comparison Set-up

The comparison effort included the following steps:

- (i) CALSIM and its necessary computational accessories (databases and auxiliary programs) were acquired and rendered operational at GWRI;
- (ii) CALSIM was run using data from the CALSIM 2001 Level-of-Development Benchmark Study;
- (iii) The CALSIM hydrologic (inflows, evaporation coefficients, etc.) and demand sequences were aggregated to the spatial aggregation level used by INFORM DSS;
- (iv) INFORM DSS was run using the previous sequences and the CALSIM reservoir releases;
- (v) CALSIM and INFORM DSS simulation results were finally compared to assess consistency with respect to river node flows, the X2 location, and major reservoir storages.

An example of the spatial aggregation performed on the CALSIM sequences for use by the INFORM DSS is provided in Figure 2.1, depicting a section of the American River. Specifically, the figure shows that INFORM represents inflows to the Folsom reservoir and demands taken out of Natoma, while CALSIM includes a more detailed representation of inflows and demands. The aggregation process is described in the figure. Similar spatial aggregation was performed for all other parts of the northern California reservoir system.

CALSIM Representation *INFORM Representation*



Aggregated INFORM inputs:
Net Folsom Inflow = I300 + I8 –D8 – D300
Net Natoma Demands = I9 – D9 – GS56 + I302 – D302

Figure 2.1: American River Spatial Aggregation

2.2. Model Comparison

CALSIM and INFORM DSS were compared with respect to river node flows, the X2 location (interface of saline and fresh water), and major reservoir storages. These quantities are compared in a series of graphs showing the two model sequences. Figures 2.2.1 through 2.2.3 show results for the delta outflow, X2 location, and reservoir storage comparisons, respectively. With the exception of the Oroville reservoir storage, all CALSIM and INFORM sequences coincide. The discrepancy among the Oroville storages was actually found to be a possible error in CALSIM. During certain months in the sequence (primarily Septembers), CALSIM misrepresents the water balance of Oroville. The end-of-period reservoir storage calculated by the model in these months differs from the value that would be obtained by adding/subtracting the net inflows/outflows from the beginning-of-period storage.

This discrepancy notwithstanding, the comparison results confirm that the INFORM simulation model adequately represents the northern California system water balance and is compatible with CALSIM.

In view of the above model consistency, CALISM and INFORM DSS can be used in a manner that re-enforces their individual utility. Namely, the planning process can benefit as follows: First, the INFORM DSS can be employed to generate long range planning tradeoffs and associated reservoir release policies based on seasonal hydro-climatology forecasts. Second, the INFORM DSS policies and forecasts can be used by CALSIM to develop a more detailed spatial representation of the system processes (inflows, withdrawals, returns) that are more meaningful to individual stakeholders.

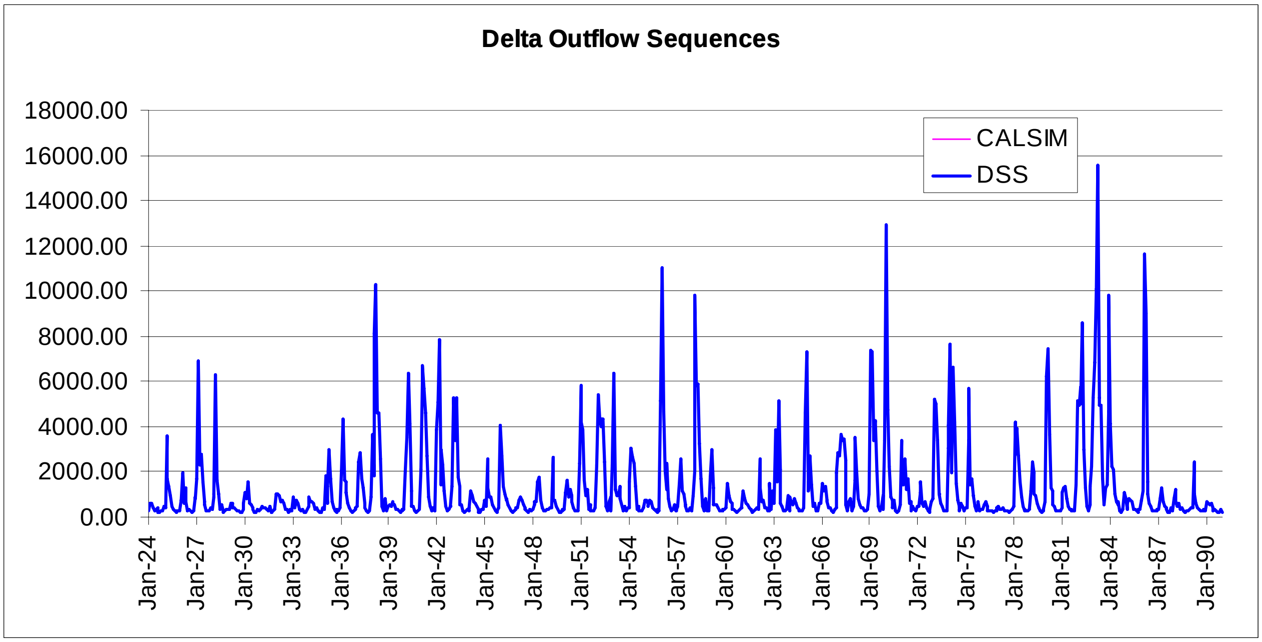


Figure 2.2.1: Delta Outflow

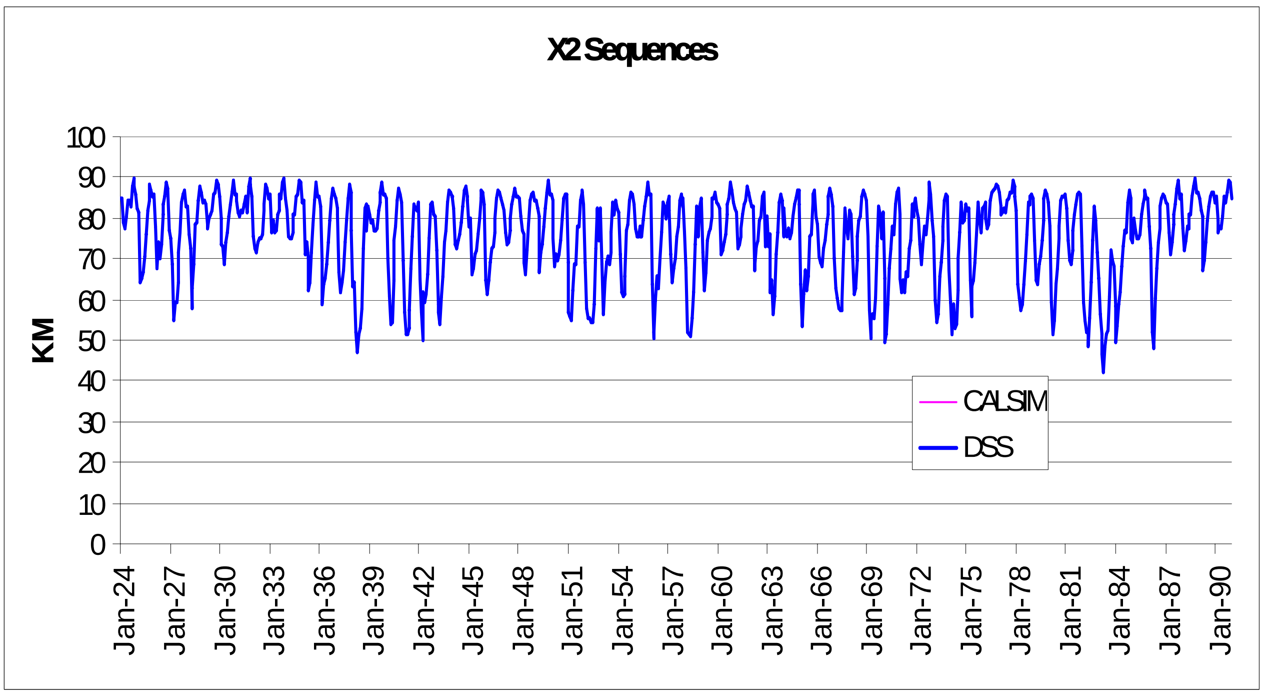
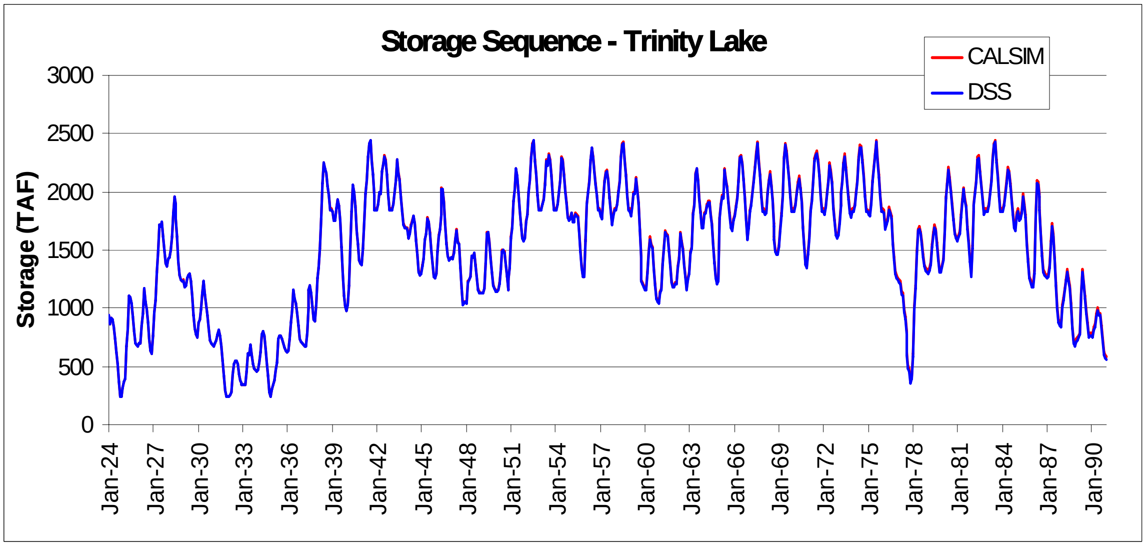
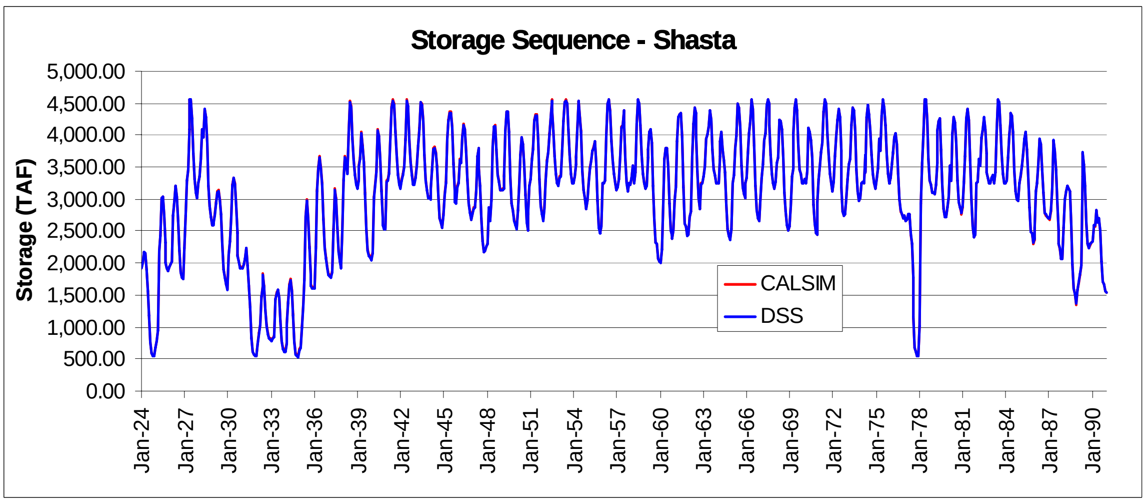


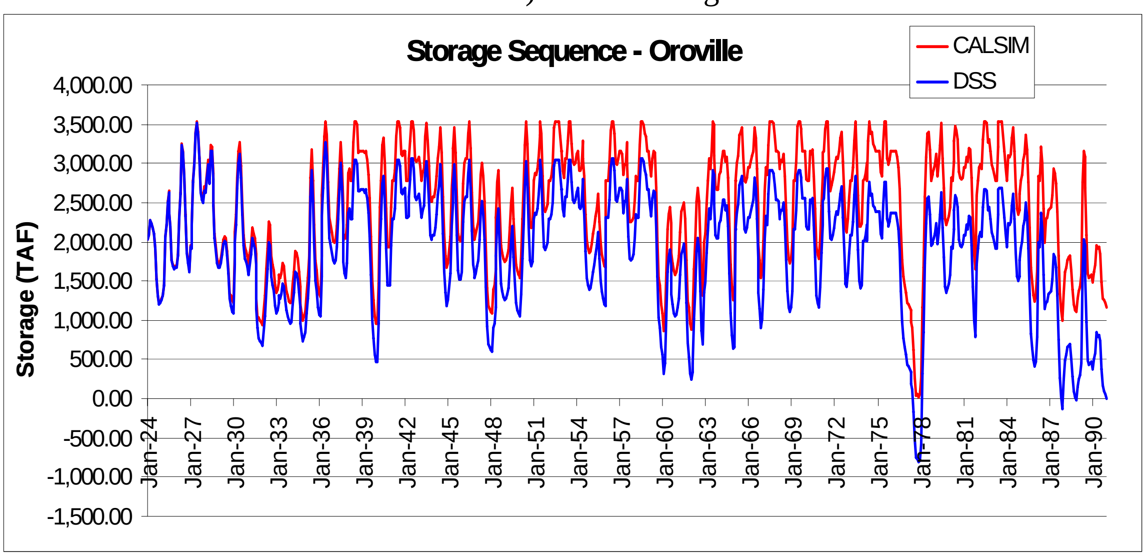
Figure 2.2.2: X2 Location



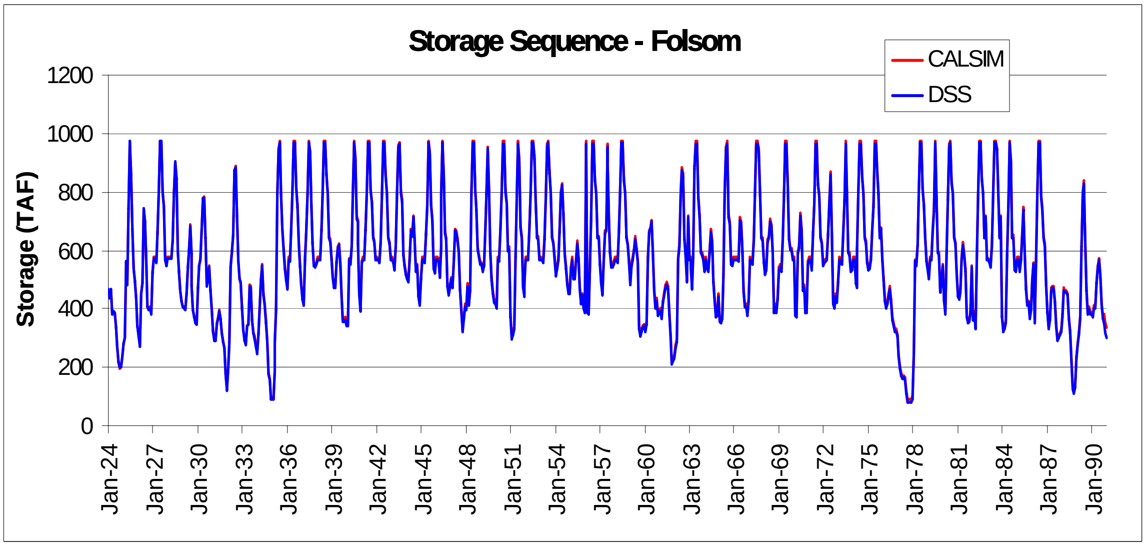
a) Trinity Storage



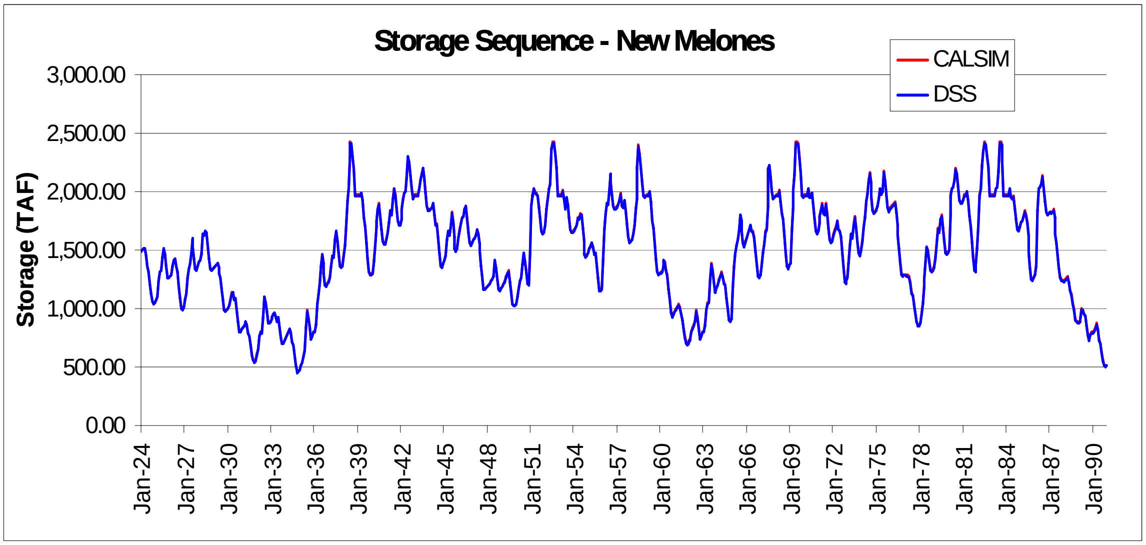
b) Shasta Storage



c) Oroville Storage



d) Folsom Storage



e) New Melones Storage

Figure 2.2.3: Reservoir Storage Comparisons

3. Refined Integrated Forecast-Decision INFORM Software

The development of the INFORM forecast-decision software has been finalized and will be the subject of the upcoming overview and training workshop (discussed below).

To test the integrated INFORM DSS system, and facilitate its assessment for this first experimental year of INFORM operations in Northern California, a forecast-decision model run was performed. For this run, the Hydrologic Research Center (HRC) produced ensembles of GFS-based reservoir inflow with climate-based long-term ensemble streamflow predictions for the 1 March forecast preparation date. These combined forecasts are then used by the Georgia Tech decision team to derive reservoir management assessments for the remainder of the wet season. In what follows, we provide a brief overview of the INFORM DSS model structure and then discuss the results of the integrated forecast-decision experiment.

3.1 INFORM DSS Model Structure

The INFORM DSS includes three modeling layers designed to support decisions pertaining to various temporal scales and objectives. The three modeling layers include (1) turbine load dispatching (representing each turbine and hydraulic outlet and having hourly resolution over a horizon of one day), (2) short/mid range reservoir control (having a daily resolution and a horizon of one month), and (3) long range reservoir control (having a monthly resolution and a horizon of up to one year).

Both the long range and the mid/short range models use inflow forecasts as inputs. The integration of the decision models and inflow forecasting models are done through data exchange. The forecasted inflows are saved in a pre-formatted Excel file. The DSS provides easy tools to read the data in the Excel file and save it into the database. The DSS also provides tools to plot and validate the forecast ensembles.

The long range control model is designed to consider long range issues such as whether water conservation strategies are appropriate for the upcoming year using the provided hydrologic forecasts. As part of these considerations, the DSS would quantify several tradeoffs of possible interest to the management agencies and system stakeholders. These include, among others, relative water allocations to water users throughout the system (including ecosystem demands), reservoir coordination strategies and target levels, water quality constraints, and energy generation targets. This information would be provided to the forum of management agencies (the planning departments) to use it as part of their decision process together with other information. After completing these deliberations, key decisions would be made on monthly water supply contracts, reservoir releases, energy generation, and reservoir coordination strategies.

The short/mid range control model is then activated to consider system operation at finer time scales. The objectives addressed here are more operational than planning and include flood management, water supply, and power plant scheduling. This model uses hydrologic forecasts with a daily resolution and can also quantify the relative importance of, say, upstream versus downstream flood risks, energy generation versus flood control, and other applicable tradeoffs. Such information is again provided to the forum of management agencies (the operational departments) to use it within their decision processes to select the most preferable operational policy. Such policies are revised as new information on reservoir levels and flow forecasts comes in. The model is constrained by the long range decisions, unless current conditions indicate that a departure is warranted.

3.2. Integrated Forecast-Decision Experiment

This experiment uses the following data:

- Forecasted inflows start from March 1st, 2006 (112 traces, 9 month horizon, and five locations: Clair Engle Lake, Shasta, Oroville, Folsom, and Yuba);
- Historical monthly average values are used for locations where forecasted inflows are not available (Table 3.2.1);
- Monthly reservoir parameters and constraints (max, min, and target storage, evaporation rates; Table 3.2.2);
- Minimum river flow requirements (Table 3.2.3); and
- Base monthly demands at all locations (Table 3.2.4).

The long range and the mid range forecasted inflow sequences are shown in Figures 3.2.1 and 3.2.2. Figures 3.2.3 through 3.2.6 show the comparisons between the forecasted inflow means and the corresponding historical means for four major reservoirs. As depicted, the forecasted means during the flood months are much higher than the historical means for all locations. Using the forecasted inflows, tradeoffs are generated by changing the base demands for all locations within a range of 80% to 120%. The tradeoff between the reservoir carry over storages versus the demand level are depicted in Figure 3.2.7. As shown, reservoir carryover storage decreases with higher demands. Figure 3.2.8 quantifies the tradeoff between system energy generation versus required demand. Initially, energy generation increases with downstream demand. However, as releases increase, reservoir levels decrease, generation efficiency decreases, and energy generation eventually decreases. These results imply that the system can meet the demand up to some base level which is approximately 10% more than the base demands. Demands beyond the base levels result in reservoir drawdowns, water supply deficits, and energy generation decreases.

The reservoir and other system sequences corresponding to all tradeoff points are saved in the DSS database. Selected reservoir elevation, release, and energy generation sequences are shown in Figures 3.2.9 through 3.2.11. Figure 3.2.12 shows the X2 location sequences. Due to the wetter than normal forecasts, the X2 location is below 80km in all cases. The Delta outflow sequences are plotted in Figure 3.2.13.

The first month releases determined in the long range planning model are passed on to the mid range model. The daily reservoir elevation, release, and energy generation sequences of four major reservoirs Trinity, Shasta, Oroville, and Folsom are generated and plotted in Figures 3.2.14 to 3.2.16.

Table 3.2.1: Monthly Average Inflows for Selected Locations (TAF)

Month	Whisktown	Keswick-Wilkens	Sacrament Misc	Eastside Streams	Delta Misc Creeks	New Melones	SJR
Jan	8.	-211.27	-100.	80.67	25.5	76.	133.
Feb	4.	-299.69	-220.	60.44	25.5	43.	31.
Mar	2.	-370.28	-330.	20.72	29.	34.	33.
Apr	1.	-267.47	-175.	21.89	19.	33.	28.
May	1.	-117.56	45.	28.71	11.1	31.	33.
Jun	2.	-125.	-15.	33.2	0.8	30.	71.
Jul	2.	-31.24	121.	30.74	0.9	30.	62.
Aug	4.	564.46	981.	21.52	1.2	30.	63.
Sep	8.	841.7	1465.	21.52	1.8	30.	78.
Oct	12.	1767.58	2482.	40.03	32.3	40.	94.
Nov	45.	1021.	1763.	67.33	17.4	70.	103.
Dec	16.	74.65	328.	146.34	15.4	110.	126.

Table 3.2.2: Reservoir Monthly Parameters

Name	Month	Smax (TAF)	Smin (TAF)	Starget (TAF)	Evap Rate (feet)
Clair Engle	Jan	2287.00	312.63	2287.00	0.17
Clair Engle	Feb	2287.00	312.63	2287.00	0.13
Clair Engle	Mar	2287.00	312.63	2287.00	0.20
Clair Engle	Apr	2287.00	312.63	2287.00	0.39
Clair Engle	May	2287.00	312.63	2287.00	0.51
Clair Engle	Jun	2287.00	312.63	2287.00	0.58
Clair Engle	Jul	2287.00	312.63	2287.00	0.76
Clair Engle	Aug	2287.00	312.63	2287.00	0.71
Clair Engle	Sep	2287.00	312.63	2287.00	0.60
Clair Engle	Oct	2287.00	312.63	2287.00	0.30
Clair Engle	Nov	2287.00	312.63	2287.00	0.15
Clair Engle	Dec	2287.00	312.63	2287.00	0.09
WhiskeyTown	Jan	237.90	200.00	205.70	0.17
WhiskeyTown	Feb	237.90	200.00	205.70	0.13
WhiskeyTown	Mar	237.90	200.00	205.70	0.20
WhiskeyTown	Apr	237.90	200.00	237.90	0.39
WhiskeyTown	May	237.90	200.00	237.90	0.51
WhiskeyTown	Jun	237.90	200.00	237.90	0.58
WhiskeyTown	Jul	237.90	200.00	237.90	0.76
WhiskeyTown	Aug	237.90	200.00	237.90	0.71
WhiskeyTown	Sep	237.90	200.00	238.00	0.60
WhiskeyTown	Oct	237.90	200.00	230.00	0.30
WhiskeyTown	Nov	237.90	200.00	205.70	0.15
WhiskeyTown	Dec	237.90	200.00	205.70	0.09
Shasta	Jan	4552	1168	4552	0.17
Shasta	Feb	4552	1168	4552	0.13

Shasta	Mar	4552	1168	4552	0.20
Shasta	Apr	4552	1168	4552	0.39
Shasta	May	4552	1168	4552	0.51
Shasta	Jun	4552	1168	4552	0.58
Shasta	Jul	4552	1168	3882	0.76
Shasta	Aug	4552	1168	3252	0.71
Shasta	Sep	4552	1168	3252	0.60
Shasta	Oct	4552	1168	3872	0.30
Shasta	Nov	4552	1168	4252	0.15
Shasta	Dec	4552	1168	4552	0.09
Oroville	Jan	3538	855	3458	0.17
Oroville	Feb	3538	855	3538	0.13
Oroville	Mar	3538	855	3538	0.20
Oroville	Apr	3538	855	3538	0.39
Oroville	May	3538	855	3538	0.51
Oroville	Jun	3538	855	3343	0.58
Oroville	Jul	3538	855	3163	0.76
Oroville	Aug	3538	855	3163	0.71
Oroville	Sep	3538	855	3163	0.60
Oroville	Oct	3538	855	3163	0.30
Oroville	Nov	3538	855	3163	0.15
Oroville	Dec	3538	855	3163	0.09
Folsom	Jan	975	83	805	0.17
Folsom	Feb	975	83	975	0.13
Folsom	Mar	975	83	975	0.20
Folsom	Apr	975	83	975	0.39
Folsom	May	975	83	975	0.51
Folsom	Jun	975	83	975	0.58
Folsom	Jul	975	83	700	0.76
Folsom	Aug	975	83	575	0.71
Folsom	Sep	975	83	575	0.60
Folsom	Oct	975	83	575	0.30
Folsom	Nov	975	83	575	0.15
Folsom	Dec	975	83	675	0.09
New Melones	Jan	2420	273	2230	0.17
New Melones	Feb	2420	273	2420	0.13
New Melones	Mar	2420	273	2420	0.20
New Melones	Apr	2420	273	2420	0.39
New Melones	May	2420	273	2420	0.51
New Melones	Jun	2420	273	2270	0.58
New Melones	Jul	2420	273	1970	0.76
New Melones	Aug	2420	273	1970	0.71
New Melones	Sep	2420	273	1970	0.60
New Melones	Oct	2420	273	1970	0.30
New Melones	Nov	2420	273	1970	0.15

New Melones	Dec	2420	273	2040	0.09
Tulloch	Jan	67	57	57	0.00
Tulloch	Feb	67	57	57	0.00
Tulloch	Mar	67	57	58	0.00
Tulloch	Apr	67	57	60	0.00
Tulloch	May	67	57	67	0.00
Tulloch	Jun	67	57	67	0.00
Tulloch	Jul	67	57	67	0.00
Tulloch	Aug	67	57	67	0.00
Tulloch	Sep	67	57	62	0.00
Tulloch	Oct	67	57	57	0.00
Tulloch	Nov	67	57	57	0.00
Tulloch	Dec	67	57	57	0.00
San Luis	Jan	2027	450.00	1000.00	0.17
San Luis	Feb	2027	631.60	1464.02	0.13
San Luis	Mar	2027	748.10	1806.84	0.20
San Luis	Apr	2027	835.60	1975.02	0.39
San Luis	May	2027	879.92	1976.43	0.51
San Luis	Jun	2027	694.72	1546.00	0.58
San Luis	Jul	2027	442.12	1062.95	0.76
San Luis	Aug	2027	181.12	642.62	0.71
San Luis	Sep	2027	9.72	352.64	0.60
San Luis	Oct	2027	8.32	312.90	0.30
San Luis	Nov	2027	115.02	354.13	0.15
San Luis	Dec	2027	286.72	514.21	0.09

Table 3.2.3: Monthly Minimum and Target River Flows

Name	Month	Rmin (cfs)	Rtarget (cfs)
Lewiston	Jan	300	300
Lewiston	Feb	300	300
Lewiston	Mar	300	300
Lewiston	Apr	300	300
Lewiston	May	3939	300
Lewiston	Jun	2507	783
Lewiston	Jul	1102	450
Lewiston	Aug	450	450
Lewiston	Sep	450	450
Lewiston	Oct	373	0
Lewiston	Nov	300	300
Lewiston	Dec	300	300
Clear Creek	Jan	150	150
Clear Creek	Feb	200	200

Clear Creek	Mar	200	200
Clear Creek	Apr	200	200
Clear Creek	May	200	200
Clear Creek	Jun	200	200
Clear Creek	Jul	200	200
Clear Creek	Aug	200	200
Clear Creek	Sep	200	200
Clear Creek	Oct	200	200
Clear Creek	Nov	90	90
Clear Creek	Dec	90	90
Spring Creek	Jan	325	325
Spring Creek	Feb	306	306
Spring Creek	Mar	2749	2749
Spring Creek	Apr	252	252
Spring Creek	May	813	813
Spring Creek	Jun	1681	1681
Spring Creek	Jul	2602	2602
Spring Creek	Aug	2114	2114
Spring Creek	Sep	2017	2017
Spring Creek	Oct	1138	1138
Spring Creek	Nov	504	504
Spring Creek	Dec	244	244
Keswick	Jan	3250	3250
Keswick	Feb	3250	3250
Keswick	Mar	3250	3250
Keswick	Apr	8000	8000
Keswick	May	9600	9600
Keswick	Jun	11000	11000
Keswick	Jul	14500	14500
Keswick	Aug	12000	12000
Keswick	Sep	5500	5500
Keswick	Oct	7200	7200
Keswick	Nov	5700	5700
Keswick	Dec	3250	3250
Wilkins	Jan	0	0
Wilkins	Feb	0	0
Wilkins	Mar	0	0
Wilkins	Apr	5000	5000
Wilkins	May	5000	5000
Wilkins	Jun	5000	5000
Wilkins	Jul	5000	5000
Wilkins	Aug	5000	5000
Wilkins	Sep	5000	5000
Wilkins	Oct	5000	5000
Wilkins	Nov	0	0

Wilkins	Dec	0	0
FeatherBelowThermalito	Jan	1250	0
FeatherBelowThermalito	Feb	1250	0
FeatherBelowThermalito	Mar	1250	0
FeatherBelowThermalito	Apr	1250	0
FeatherBelowThermalito	May	2030	0
FeatherBelowThermalito	Jun	0	2706
FeatherBelowThermalito	Jul	0	5692
FeatherBelowThermalito	Aug	5040	5156
FeatherBelowThermalito	Sep	0	4386
FeatherBelowThermalito	Oct	1980	2683
FeatherBelowThermalito	Nov	1750	1815
FeatherBelowThermalito	Dec	1250	0
AmericanRiverbelowNimbus	Jan	800	0
AmericanRiverbelowNimbus	Feb	800	0
AmericanRiverbelowNimbus	Mar	1000	0
AmericanRiverbelowNimbus	Apr	1500	0
AmericanRiverbelowNimbus	May	2300	0
AmericanRiverbelowNimbus	Jun	1800	0
AmericanRiverbelowNimbus	Jul	0	0
AmericanRiverbelowNimbus	Aug	0	0
AmericanRiverbelowNimbus	Sep	0	0
AmericanRiverbelowNimbus	Oct	0	0
AmericanRiverbelowNimbus	Nov	1000	0
AmericanRiverbelowNimbus	Dec	800	0
Goodwin	Jan	175	175
Goodwin	Feb	150	150
Goodwin	Mar	268	268
Goodwin	Apr	760	760
Goodwin	May	800	800
Goodwin	Jun	561	561
Goodwin	Jul	396	396
Goodwin	Aug	352	352
Goodwin	Sep	240	240
Goodwin	Oct	200	200
Goodwin	Nov	200	200
Goodwin	Dec	200	200
DeltaExit	Jan	6001	6001
DeltaExit	Feb	11398	11398
DeltaExit	Mar	11401	11401
DeltaExit	Apr	7848	7848
DeltaExit	May	9319	9319
DeltaExit	Jun	7092	7092
DeltaExit	Jul	6505	6505
DeltaExit	Aug	4261	4261

DeltaExit	Sep	3008	3008
DeltaExit	Oct	4001	4001
DeltaExit	Nov	4655	4655
DeltaExit	Dec	4505	4505

Table 3.2.4: Monthly Demands (cfs)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Thermolito	35	0	11	67	189	178	200	178	78	95	104	71
Folsom Pumping	4	4	4	7	8	12	13	12	10	7	5	4
Folsom South Canal	1	1	1	1	2	3	4	4	3	2	1	1
OID/SSJID	0	0	14	60	90	90	95	95	74	14	0	0
CVP Contractors	0	0	0	0	0	0	0	0	0	0	0	0
CCWD	14	17	18	18	14	14	13	13	13	10	11	13
Barker Slough	2	2	1	2	4	5	7	7	6	5	3	3
Federal Tracy PP	258	233	258	250	135	169	270	268	260	258	250	258
Federal Banks On-Peak	0	0	0	0	0	0	28	28	28	0	0	0
State Banks PP	390	355	241	68	108	125	271	278	238	175	193	390
State Tracy PP	0	0	0	0	0	0	0	0	0	0	0	0
Delta Mendota Canal	30	60	100	120	190	220	270	240	180	110	40	30
Federal Dos Amigos	40	50	60	70	110	180	238	178	68	30	30	30
Federal O'Neil to Dos Amigos	0	1	1	1	1	2	2	1	0	0	0	0
San Felipe	6	6	10	15	19	20	21	20	13	11	8	8
South Bay/San Jose	2	2	2	5	5	7	7	8	7	12	8	6
State Dos Amigos	105	127	158	105	348	348	423	388	269	229	196	61
Delta Consumptive Use	-56	-37	-10	63	121	191	268	252	174	118	55	2
Freeport Treatment Plant	14	13	14	12	12	12	12	13	12	12	12	13

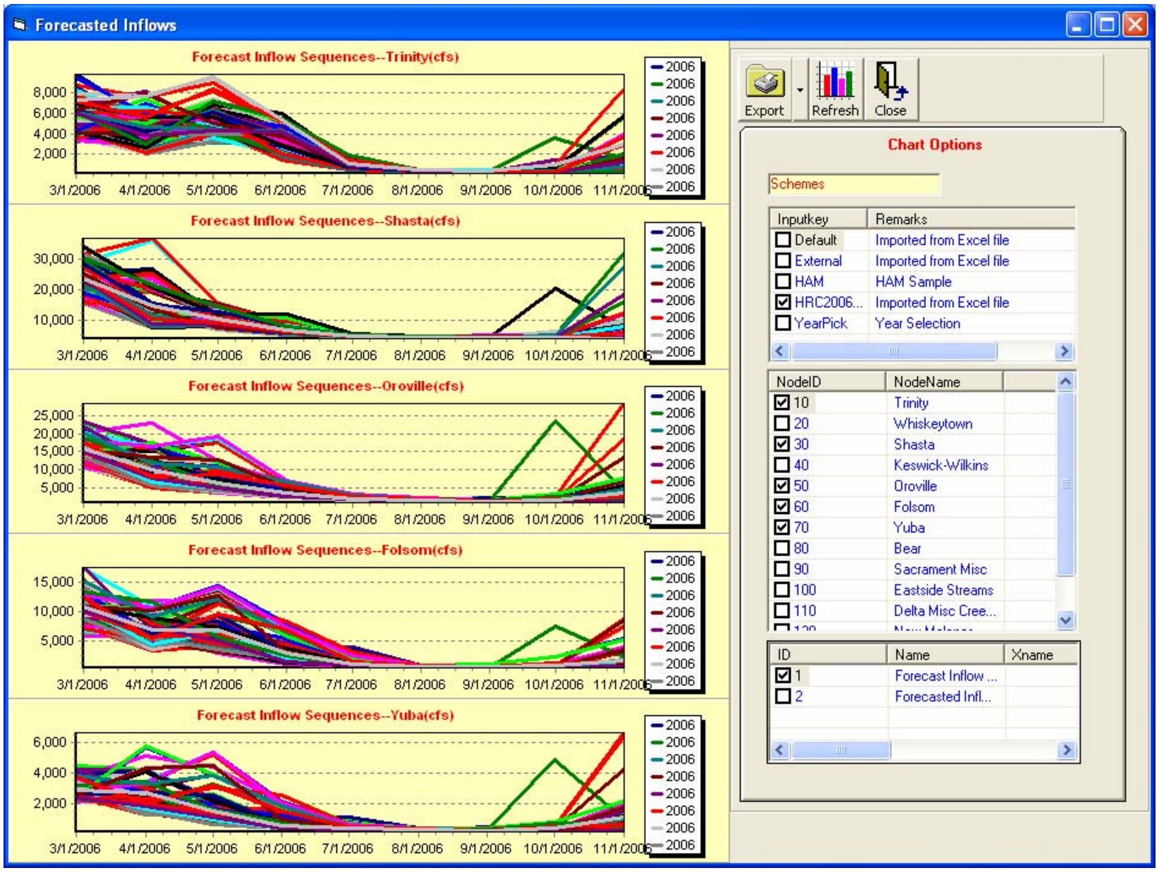


Figure 3.2.1: Long Range Inflow Forecasts

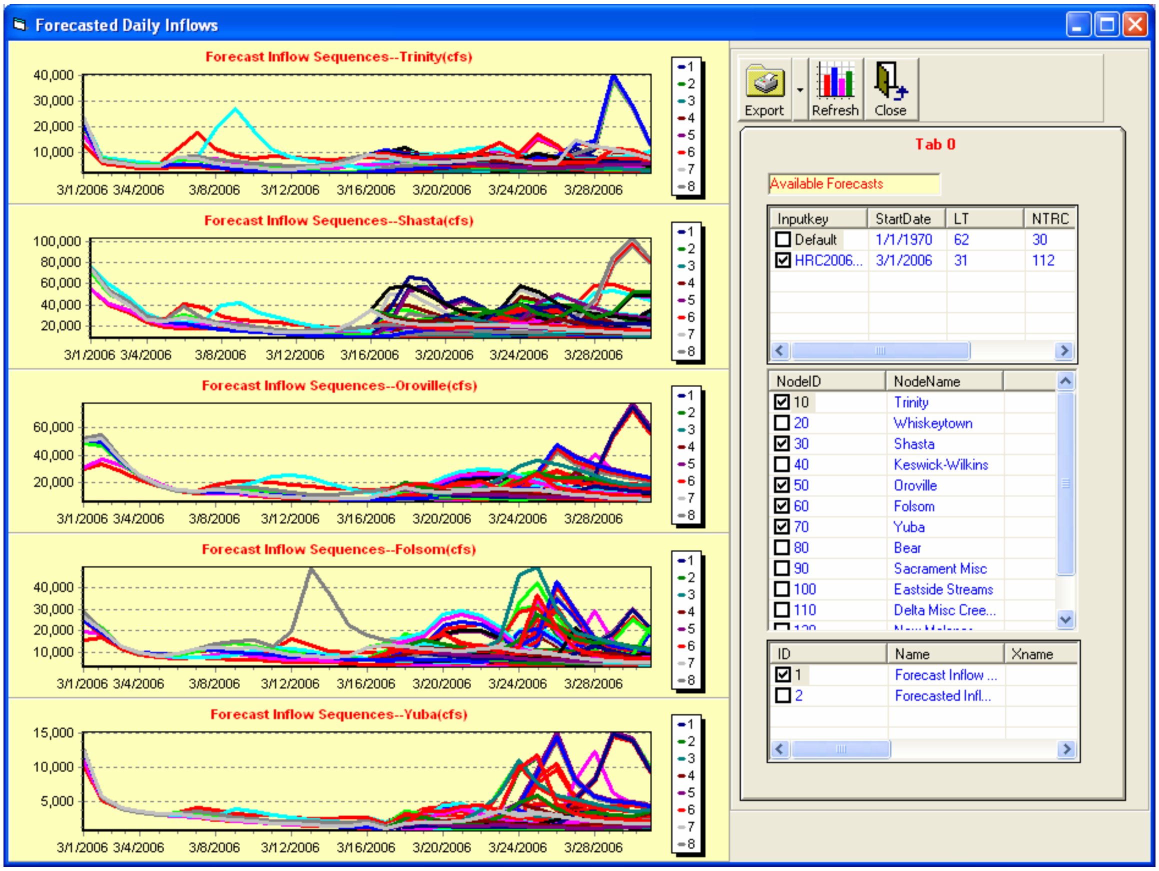


Figure 3.2.2: Mid Range Inflow Forecasts

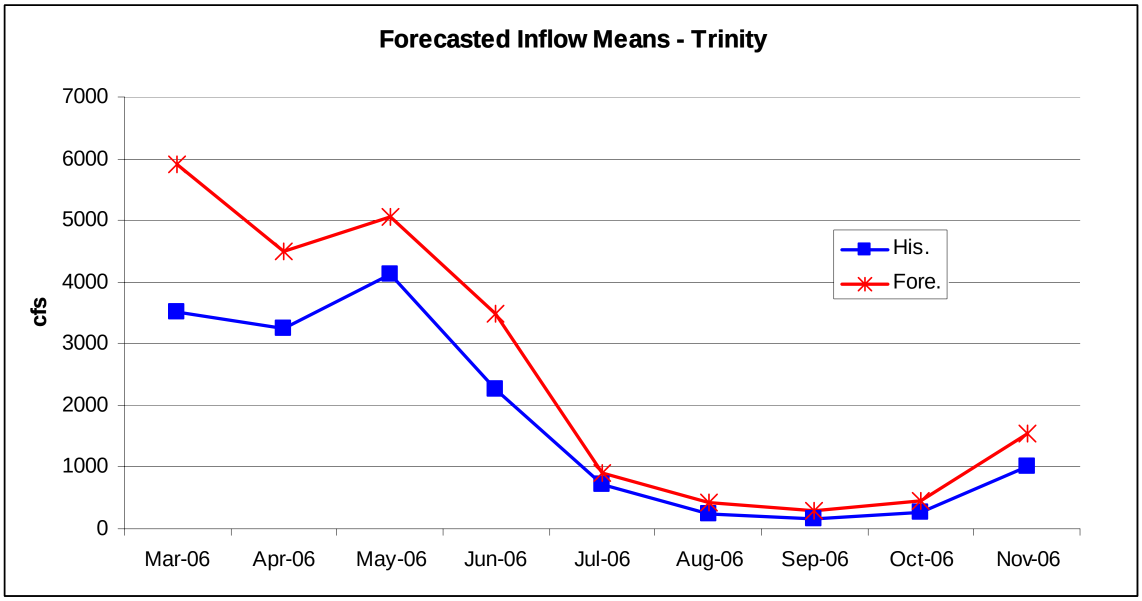


Figure 3.2.3: Forecasted Inflow Mean Comparison; Trinity

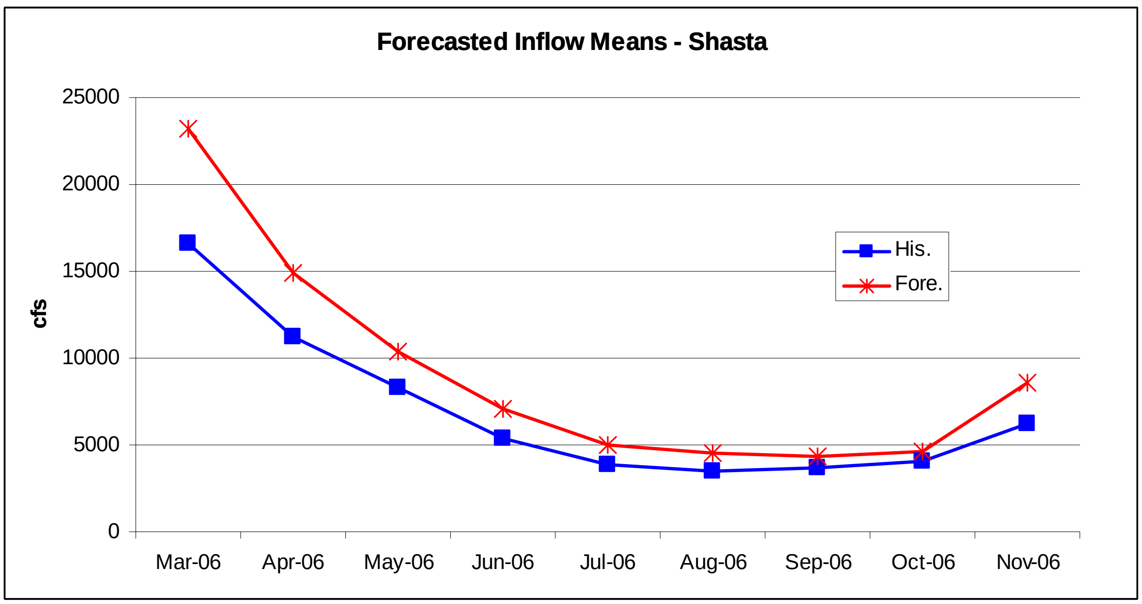


Figure 3.2.4: Forecasted Inflow Mean Comparison; Shasta

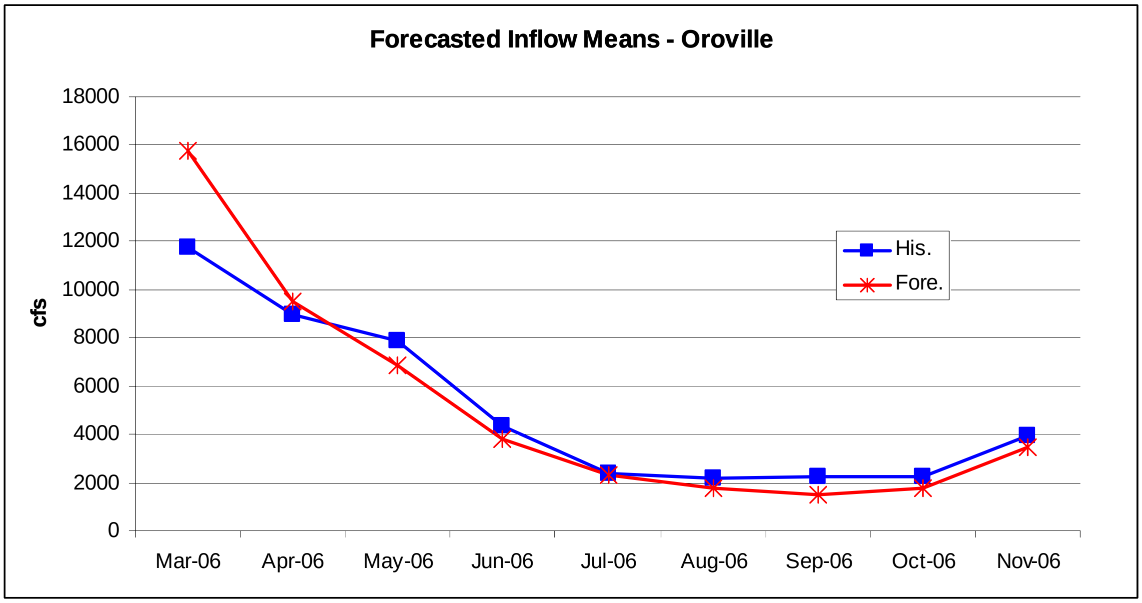


Figure 3.2.5: Forecasted Inflow Mean Comparison; Oroville

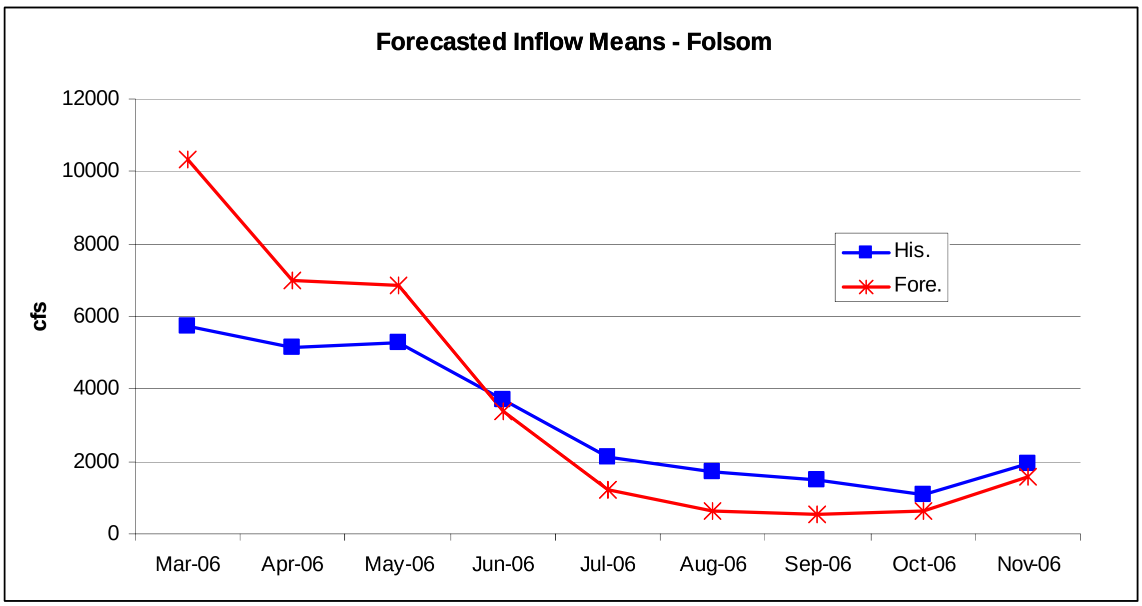


Figure 3.2.6: Forecasted Inflow Mean Comparison; Folsom

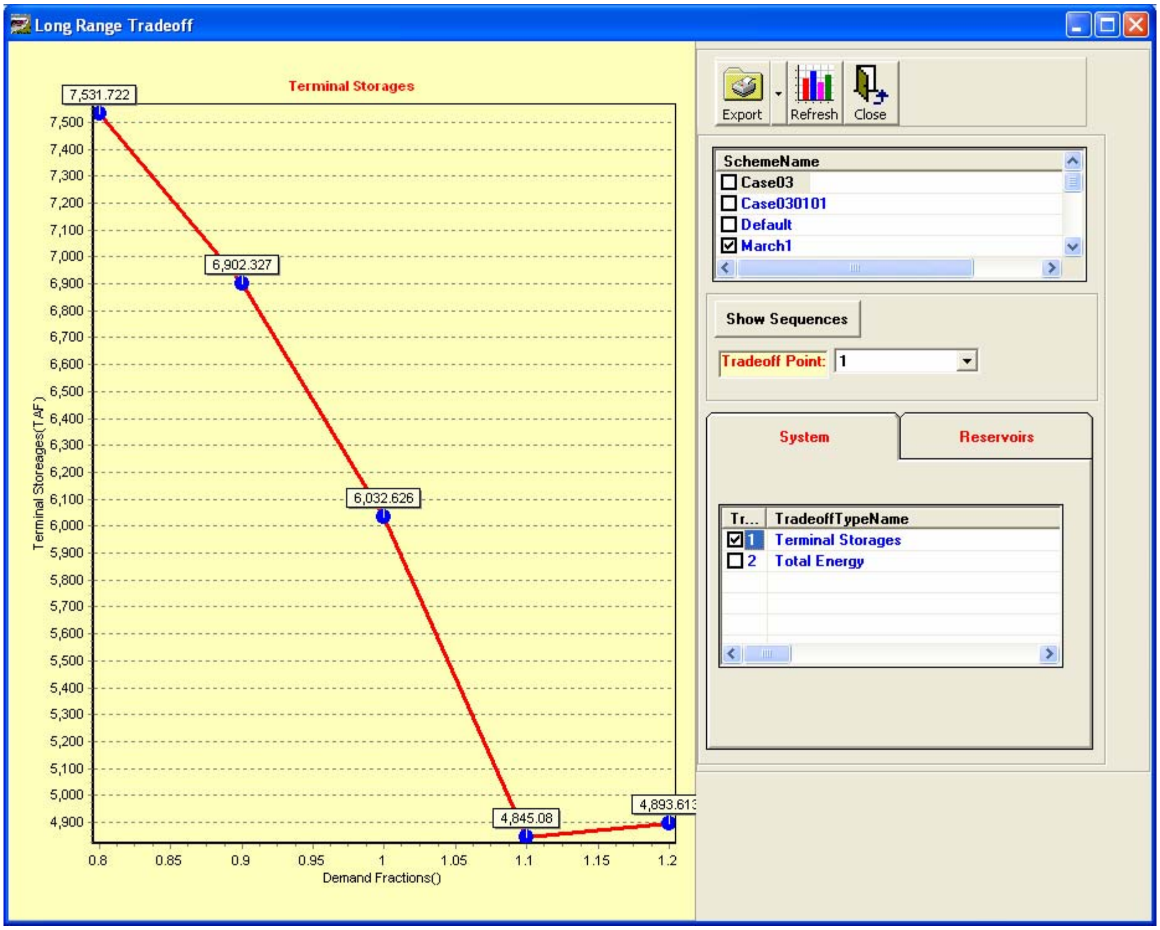


Figure 3.2.7: Sample Tradeoff (Total Carryover Storage vs. Demand)

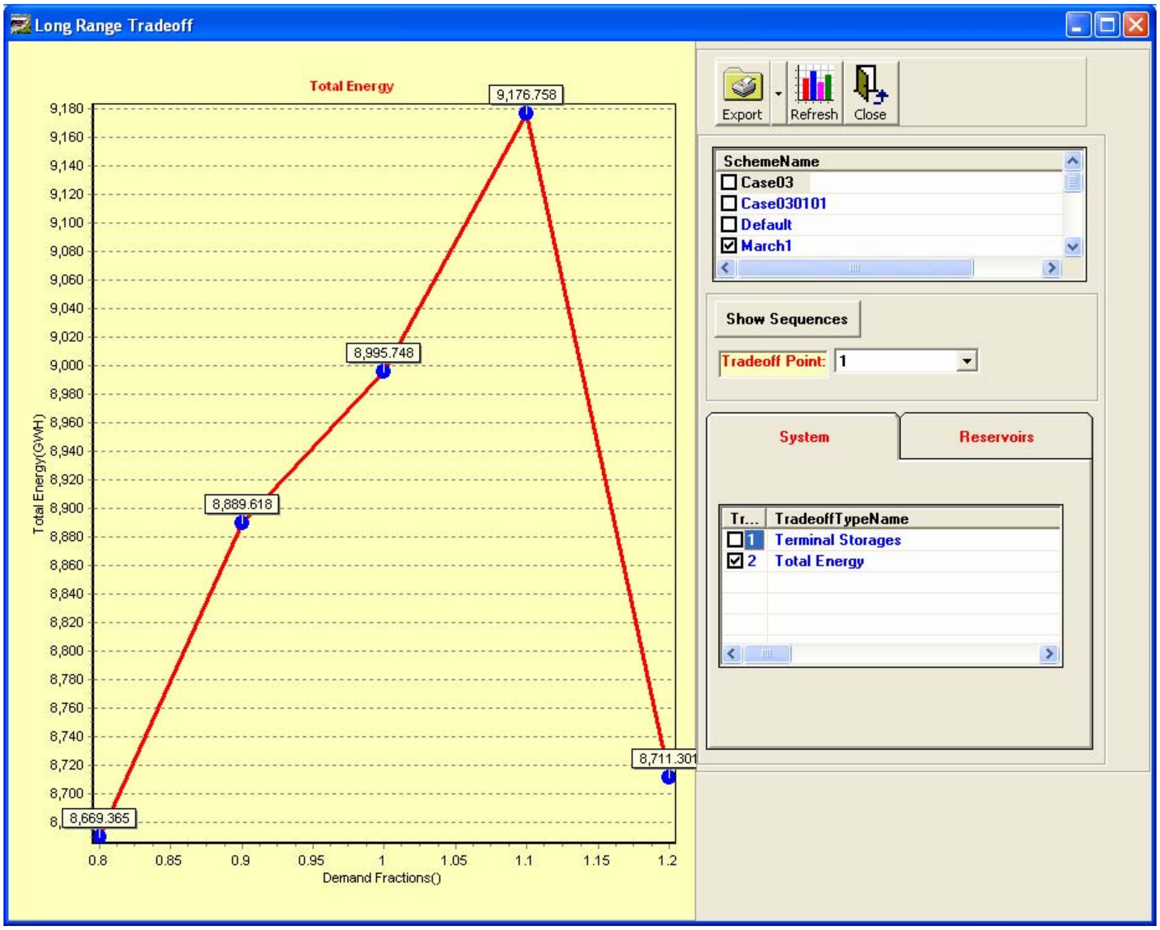


Figure 3.2.8: Sample Tradeoff (Total Energy vs. Demand)

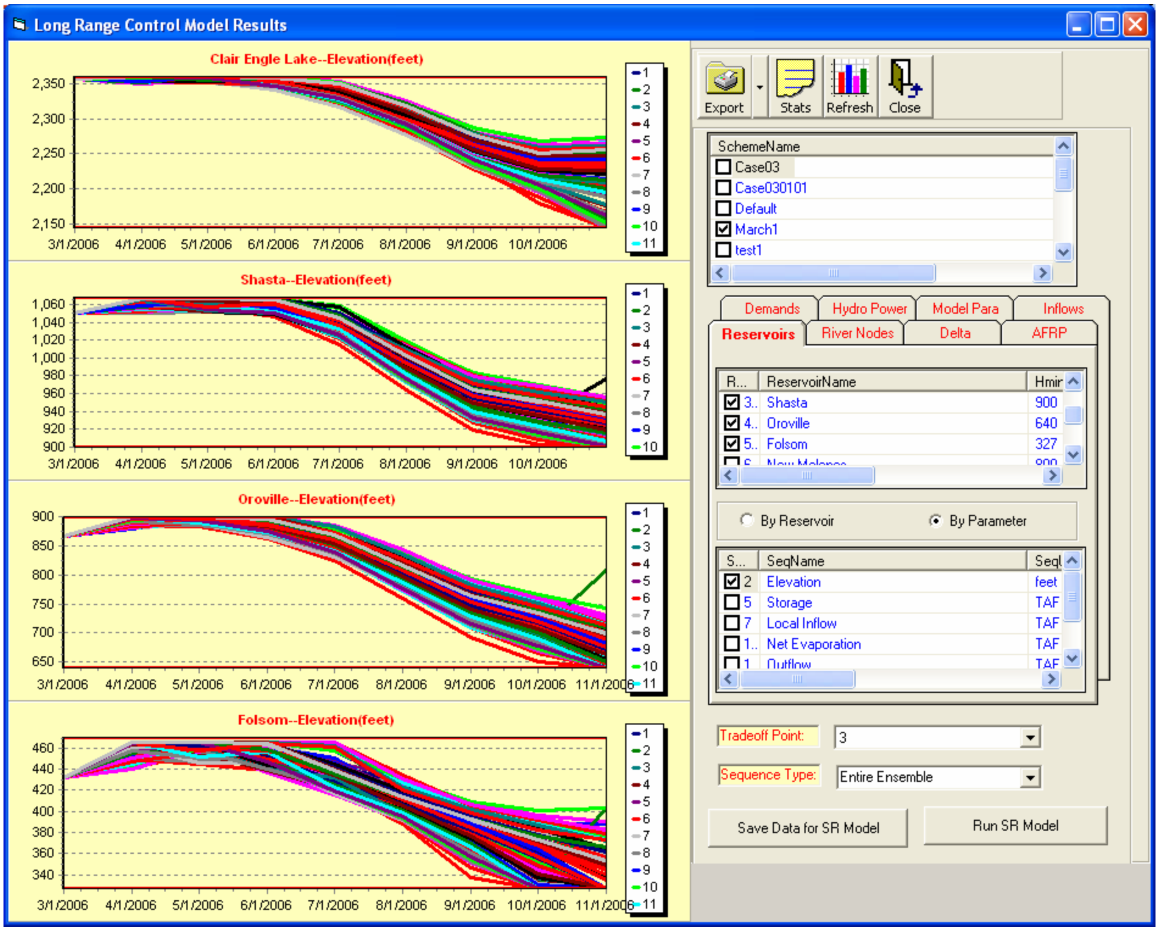


Figure 3.2.9: Reservoir Elevation Sequences (Tradeoff Point 3)

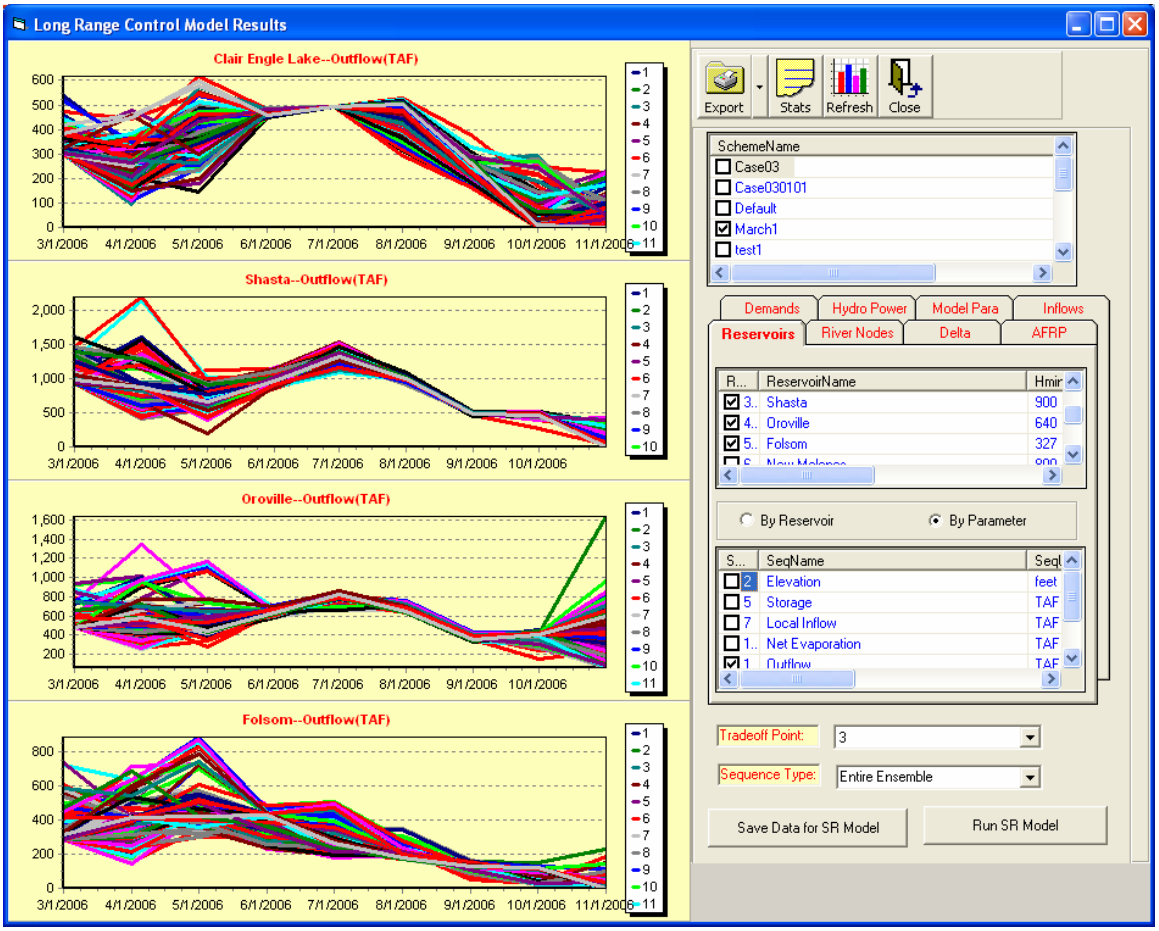


Figure 3.2.10: Reservoir Release Sequences (Tradeoff Point 3)

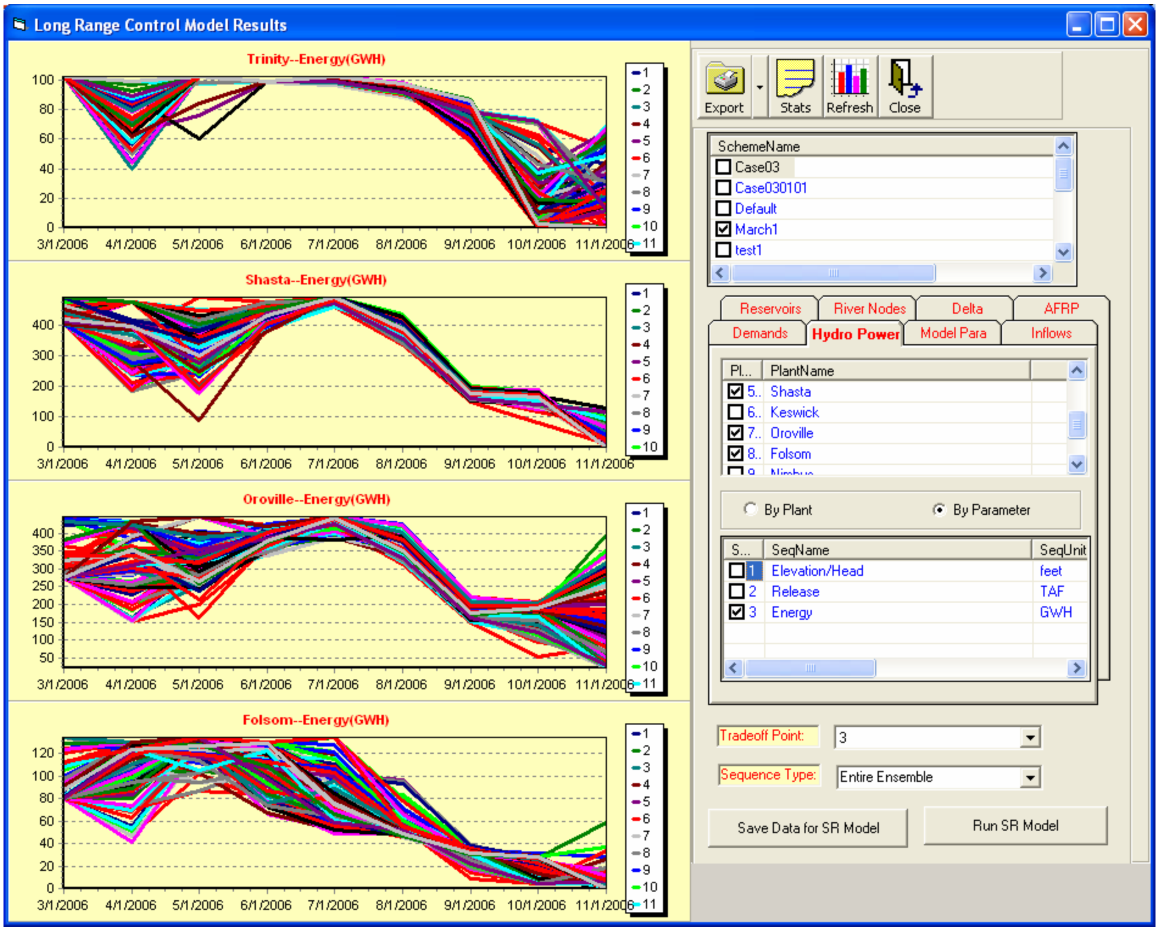


Figure3.2.11: Reservoir Energy Generation Sequences (Tradeoff Point 3)

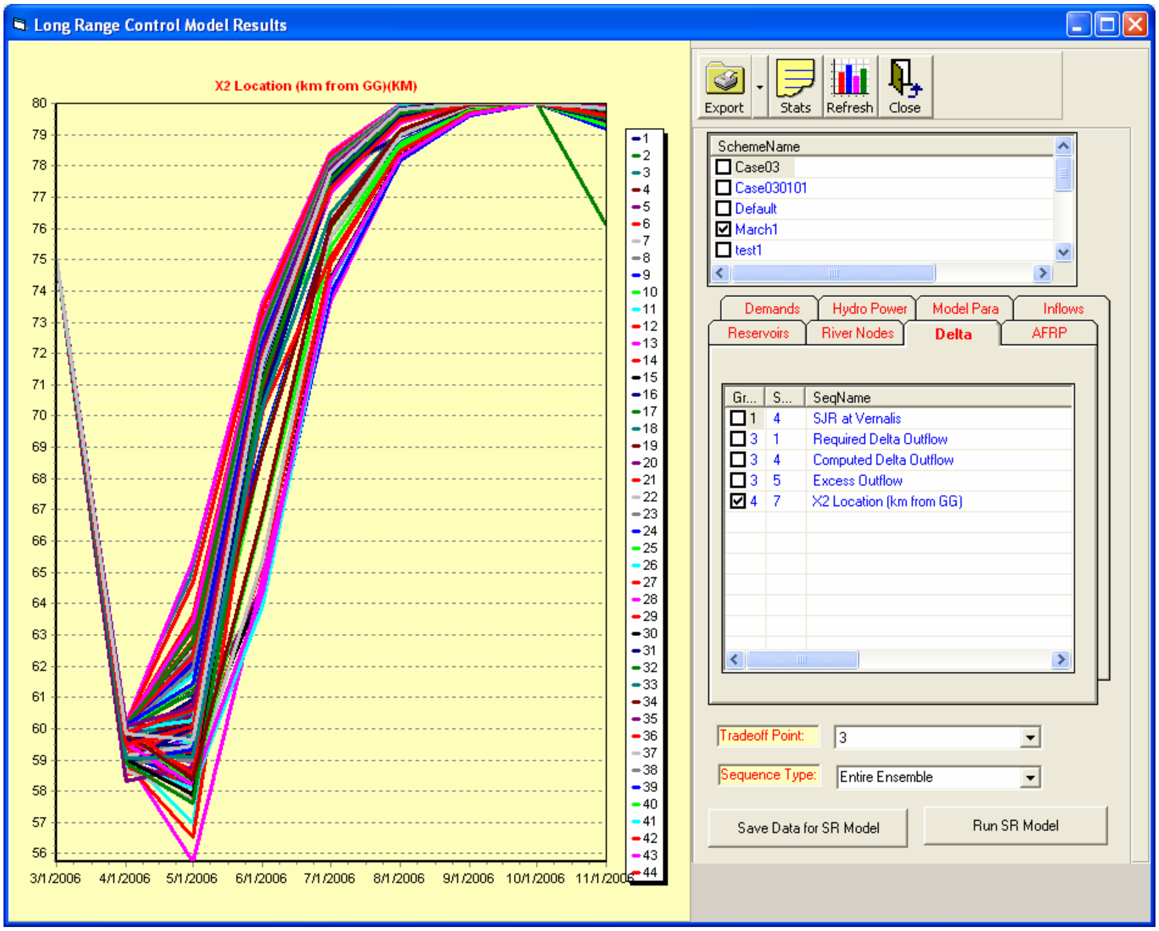


Figure 3.2.12: X2 Location Sequences (Tradeoff Point 3)

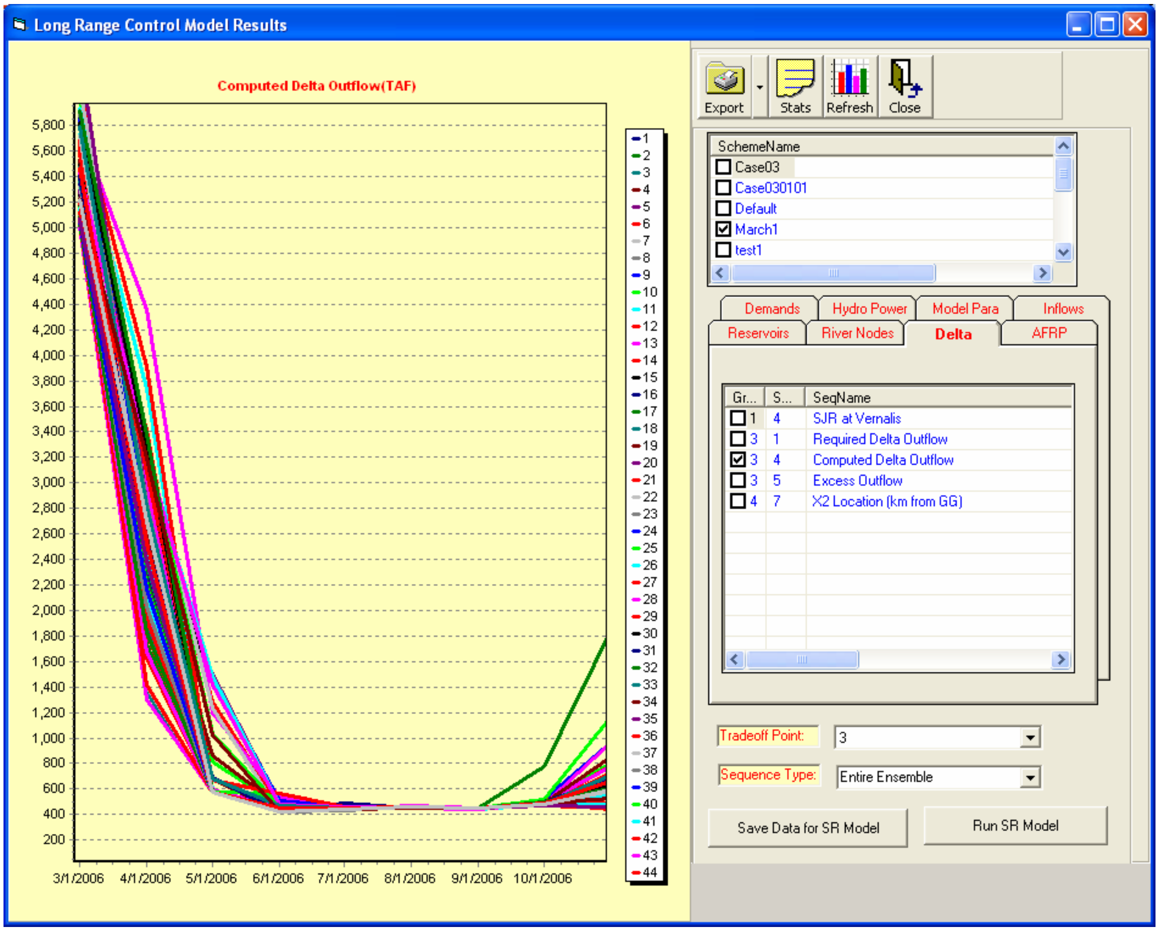


Figure 3.2.13: Delta Outflow Sequences (Tradeoff Point 3)

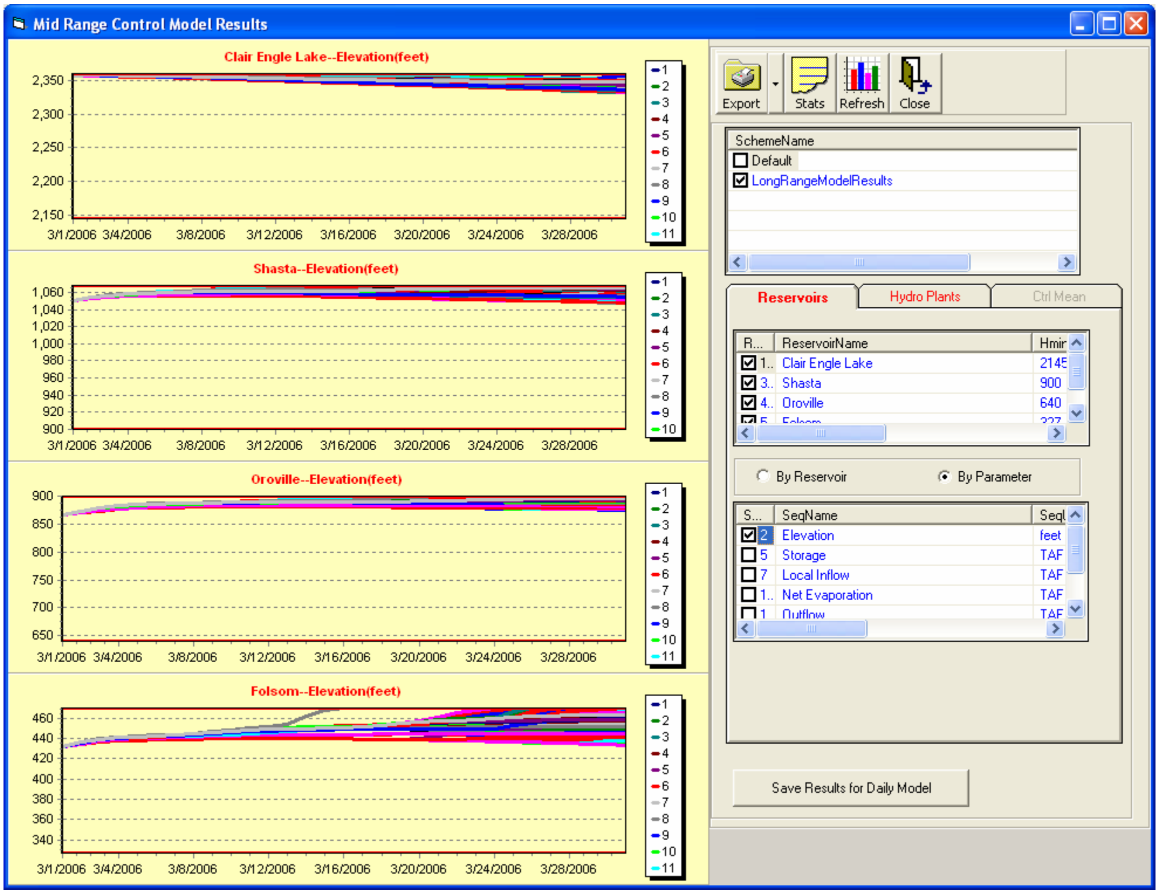


Figure 3.2.14: Mid Range Reservoir Elevation Sequences

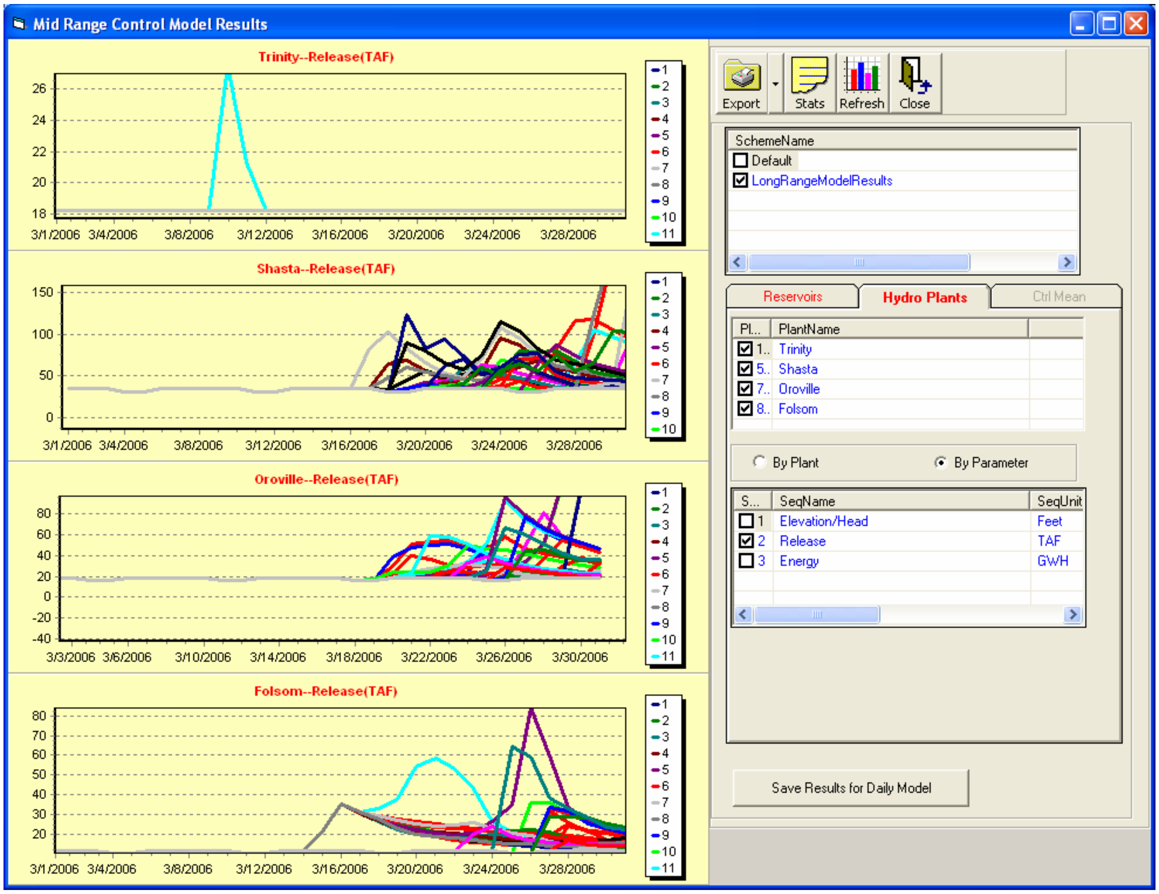


Figure 3.2.15: Mid Range Reservoir Release Sequences

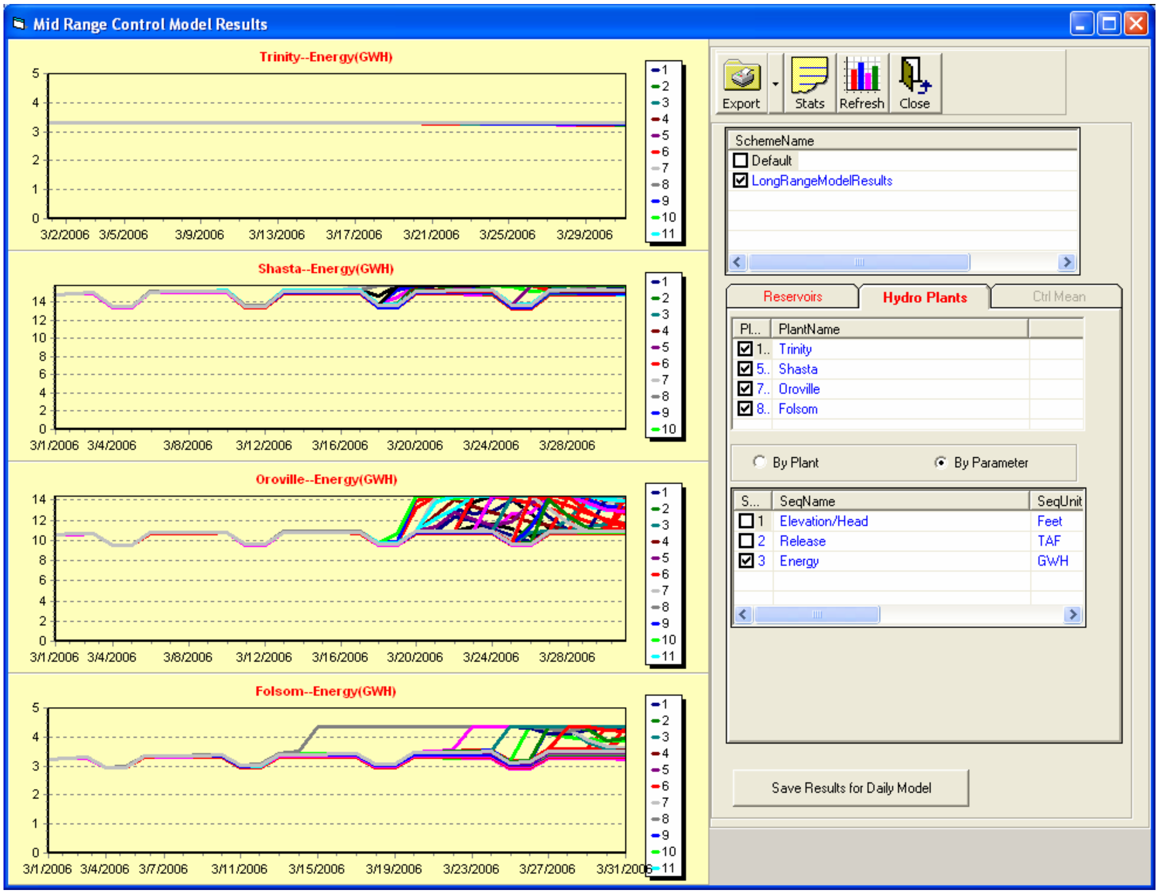


Figure 3.2.16: Mid Range Energy Generation Sequences

4. Workshop with Stakeholder Agencies

An overview and training workshop with stakeholder agencies is scheduled to occur on April 19 and 20, 2006. The purpose of the workshop will be twofold: (1) Provide an overview of the INFORM validation process, and (2) perform software installations and agency staff hands-on training with Spring 2006 hydro-climatic forecasts. The workshop agenda is included below. It is envisioned that in the follow-up phase of the project, similar workshops will be repeated as needed to facilitate the integration of the new forecast-decision technology within the agency planning and management processes.

INFORM DSS Workshop Agenda

Time and Place: Wednesday and Thursday, April 19 and 20, 2006; California Nevada River Forecast Center Conference Room in Sacramento, California. 3310 El Camino Ave., Sacramento.

Workshop Agenda

Wednesday, April 19:

2:00 – 3:30 PM: **INFORM DSS Overview**
INFORM-CALCIM Model Comparison
Integrated Forecast-Decision Model Runs

3:30 – 4:00 PM: **Discussion and Agency Input**

Thursday, April 20:

9:00 – 12:00 AM: **Installation of INFORM DSS at Agency Facilities**

12:00 – 1:00 PM: *Lunch*

1:00 – 4:00 PM: **Training of Agency Staff in the use of the INFORM DSS**

A Decision Support System for Water Resources Planning in the Huaihe River

Basic Information

Title:	A Decision Support System for Water Resources Planning in the Huaihe River
Project Number:	2005GA132O
Start Date:	10/20/2005
End Date:	4/20/2007
Funding Source:	Other
Congressional District:	5
Research Category:	Not Applicable
Focus Category:	Management and Planning, None, None
Descriptors:	Decision Support Systems; Water Resources Systems
Principal Investigators:	Aris P. Georgakakos, Huaming Yao

Publication

A DECISION SUPPORT SYSTEM FOR WATER RESOURCES PLANNING IN THE HUAIHE RIVER BASIN

Project Huaihe DSS

Technical Progress Report
for the 03/2005 –02/2006 Funding Period

Aris Georgakakos and Huaming Yao
Georgia Water Resources Institute
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
(404) 894-2240; ageorgak@ce.gatech.edu

June 2006

A Decision Support System for the Water Resources Planing in Huaihe River Basin

GWRI Progress Report

The goal of this project is to develop a prototype decision support system for the planning and management of the water resources in the upper portion of the Huaihe river basin. This system later will be extended to the entire basin once tested. The Huaihe DSS consists of databases, interfaces, and various application programs interlinked to provide meaningful and comprehensive information to decision makers. During the last funding period, GWRI efforts focused on the following project tasks:

- Data collection
- Communication for detailed project scoping
- Data processing and Database design
- Inflow forecasting model development
- Interface development

A brief descrition of the above-mentioned DSS elements is provided below.

1. Data collection

The development of Huaihe DSS is based on hydrologic, reservoir, hydroelectric facility, and operational data. Most of data have been collected and compiled. However, there are still important missing data which include:

- Hydro turbine characteristic curves for the some plants;
- Historical local inflows between the dams and the downstream flood control points; and
- Operational target/constraints related to flood control, water supply, and energy generation for all plants.

2. Communications and Project Scoping

GWRI staff visited Huahe River Commision in January 2006, and met with their engineers and technicians. Agreement on the detailed project scope was reached.

3. Data Processing

The data processsing include digitazation and data preparation for DSS models. Reservoir data and hydro turbine characteristic curves are originally received in the format of hard copies. They have to be digitized and uploaded to the DSS database system. The data preparation is to convert the data in the form which various DSS models can take. This process mainly involves nonlinear regression for reservoir curves. An embedded regression tool in DSS is developed and used to perform this task. Some screen shots of database and data process related functions of the DSS software are are included in Appendix.

3. Historical Analog Inflow Forecasting Model

The Historical Analog (HA) reservoir inflow forecasting model (Yao and Georgakakos, 2001). This model generates an inflow forecast ensemble which is used by the control model. Some screen shots of inflow model are included in Appendix.

4. DSS Interface Development

The interface developement for the database and inflow model have been finished. Some of the screen shots are included in the Appendix.

References

Yao, H, and A. Georgakakos, 2001. "Assessment of Folsom Lake Response to Historical and Potential Future Climate Scenarios," *Journal of Hydrology.* 249, 176-196.

Georgakakos, A., and H. Yao, 2002, "Implications of Climate Variability and Change for Water Resources Management," *The Climate Report*, 3(4), 9-13.

Georgakakos, A. P., and H. Yao, "Evaluation of Water Use Scenarios for the Nile Basin," World Bank, ICCON Series Monographs, October 1999, 116p.

Georgakakos, A. P., "Water Resources Planning and Management for the Lake Victoria Basin," Monograph, FAO Monograph Series, August 2000, 44p.

Georgakakos, A. P., H. Yao, and Y. Yu, "A Control Model for Hydroelectric Energy Value Optimization," *ASCE J. for Wat. Res. Plan. and Mgt,* 123(1), 30-38, 1997.

Georgakakos, A. P., H. Yao, and Y. Yu, "Control Models for Hydroelectric Energy Optimization," *Water Resources Research*, 33(10), 2367-2379, 1997.

Georgakakos, A. P., Yao, H., and Y. Yu, "A Control Model for Dependable Hydropower Capacity Optimization," *Water Resources Research*, 33(10), 2349-2365, 1997.

Georgakakos, A. P., C. Barrett, and B. Attia, "A Decision Support System for the High Aswan Dam," Proceedings of the Fifth International Workshop on Water Resources Operations Management, sponsored by ASCE, Georgakakos, A.P., and Q.W. Martin Eds., pg. 34-66, Arlington, VA, March 4-6, 1996.

Georgakakos, A. P., "Operational Tradeoffs in Reservoir Control," *Water Resources Research*, 29(11), 3801-3819, 1993.

Yao, H., and A. P. Georgakakos, "New Control Concepts for Uncertain Water Resources Systems: 2, Reservoir Management," *Water Resources Research*, 29(6), 1517-1526, 1993.

Georgakakos, A. P. and H. Yao, "New Control Concepts for Uncertain Water Resources Systems: 1, Theory," *Water Resources Research*, 29(6), 1505-1516, 1993.

Hooper, E. R., A. P. Georgakakos, and D. P. Lettenmaier, "Optimal Stochastic Operation of the Salt River Project, Arizona," *ASCE Journal of the Water Resources Planning and Management*, Vol. 117, No. 5, pg. 566-587, 1991.

Georgakakos, A. P., "Computer-Aided Management of the Southeastern U.S. Reservoir System," in "Decision Support Systems," D. P. Loucks, ed., NATO ASI Series, Vol. G 26, pg. 407-428, 1991.

Georgakakos, A. P., "Extended Linear Quadratic Gaussian Control for the Real-Time Operation of Reservoir Systems," pg. 329─360 in the book entitled "Dynamic Programming for Optimal Water Resources Systems Analysis," A. Esogbue, ed., Prentice Hall Publishing Company, New Jersey, 1989.

Georgakakos, A. P., "Extended Linear Quadratic Gaussian (ELQG) Control: Further Extensions", Water Resources Research, Vol. 25, No. 2, pg. 191 - 201, 1989.

Georgakakos, A. P., "The Value of Streamflow Forecasting in Reservoir Control", Water Resources Bulletin, Vol. 25 No. 4, pg. 789─800, 1989.

Appendix A: Selected Huaihe DSS Interface Screen Shots

Figure A.1: DSS Main gateway window

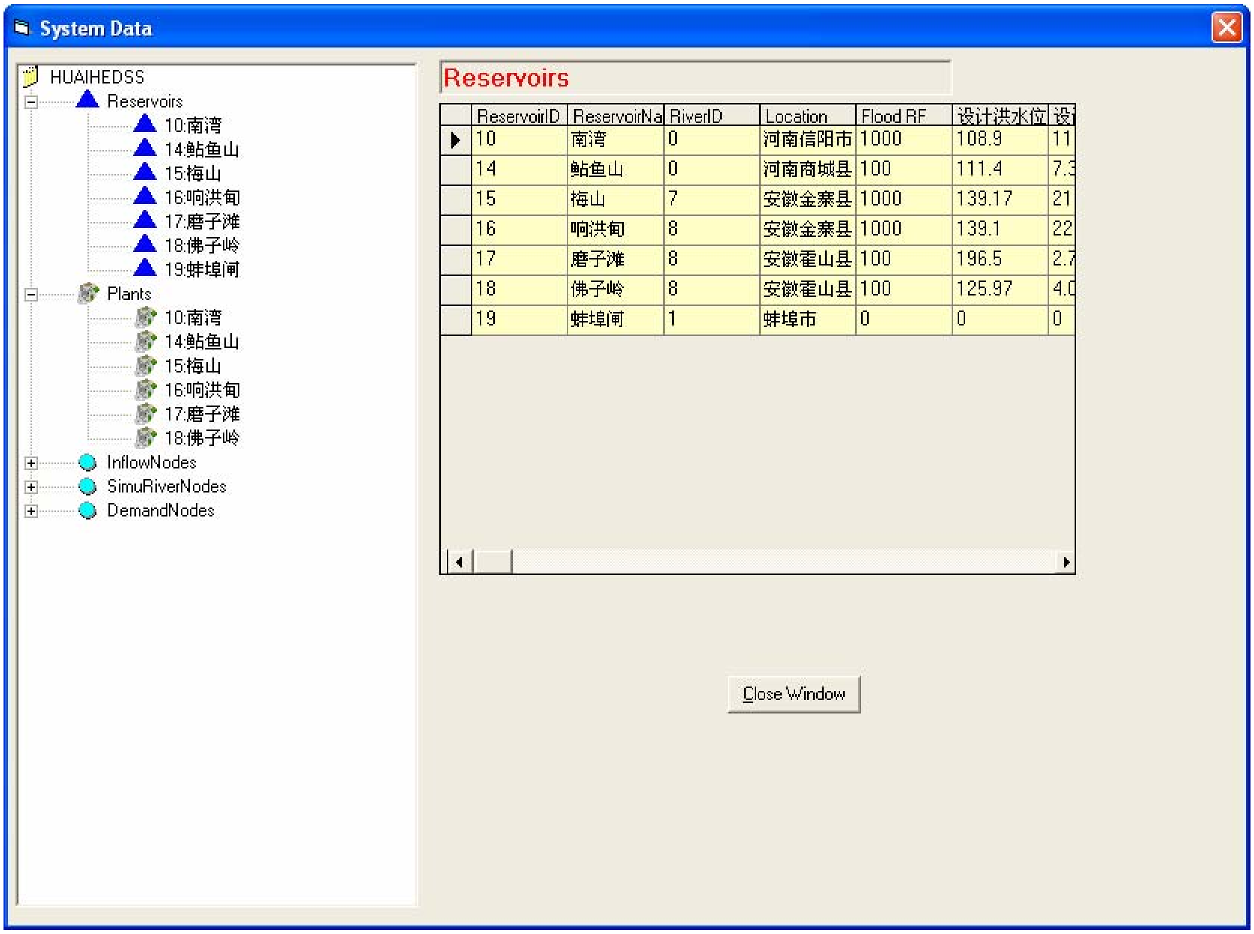


Figure A.2: Database and System Components

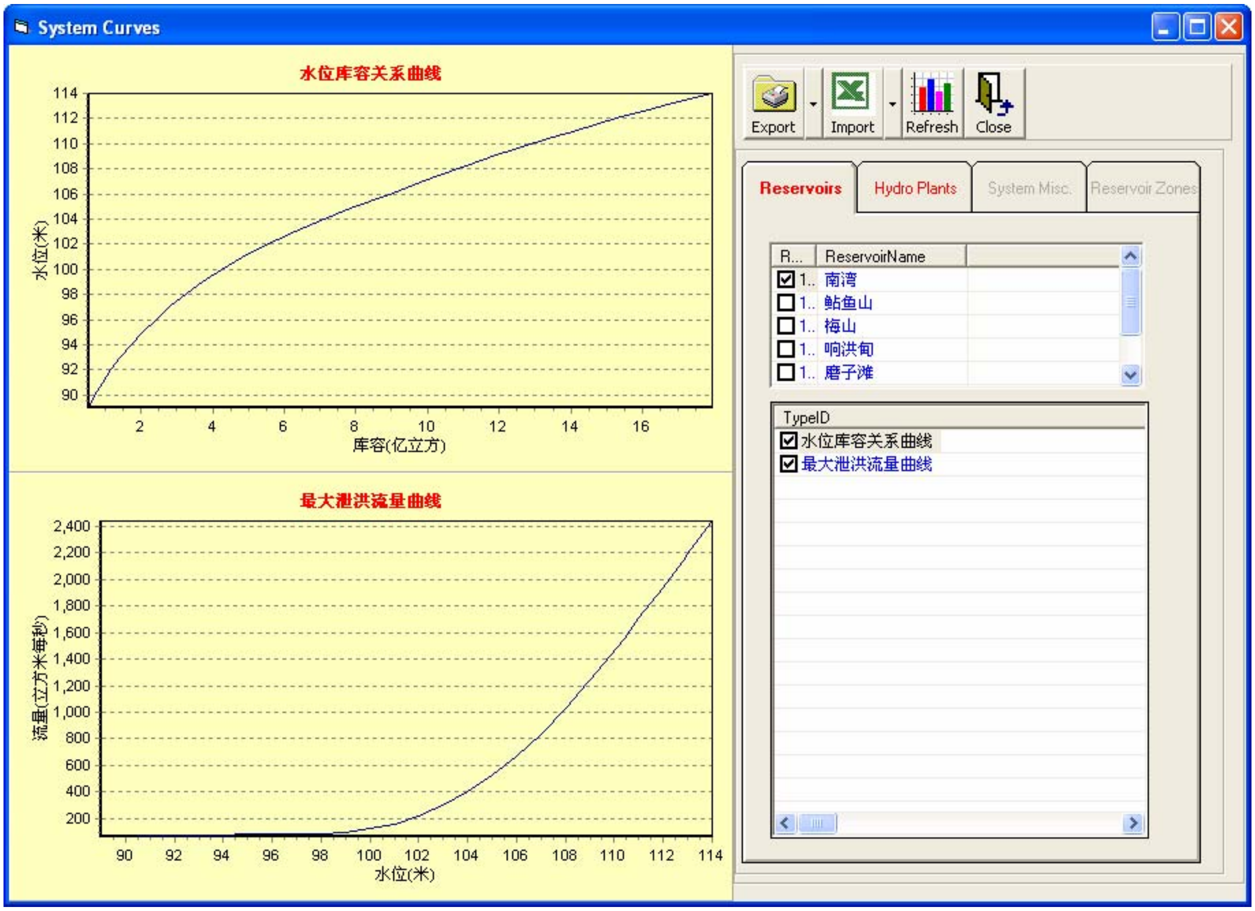


Figure A.3: Reservoir Curves

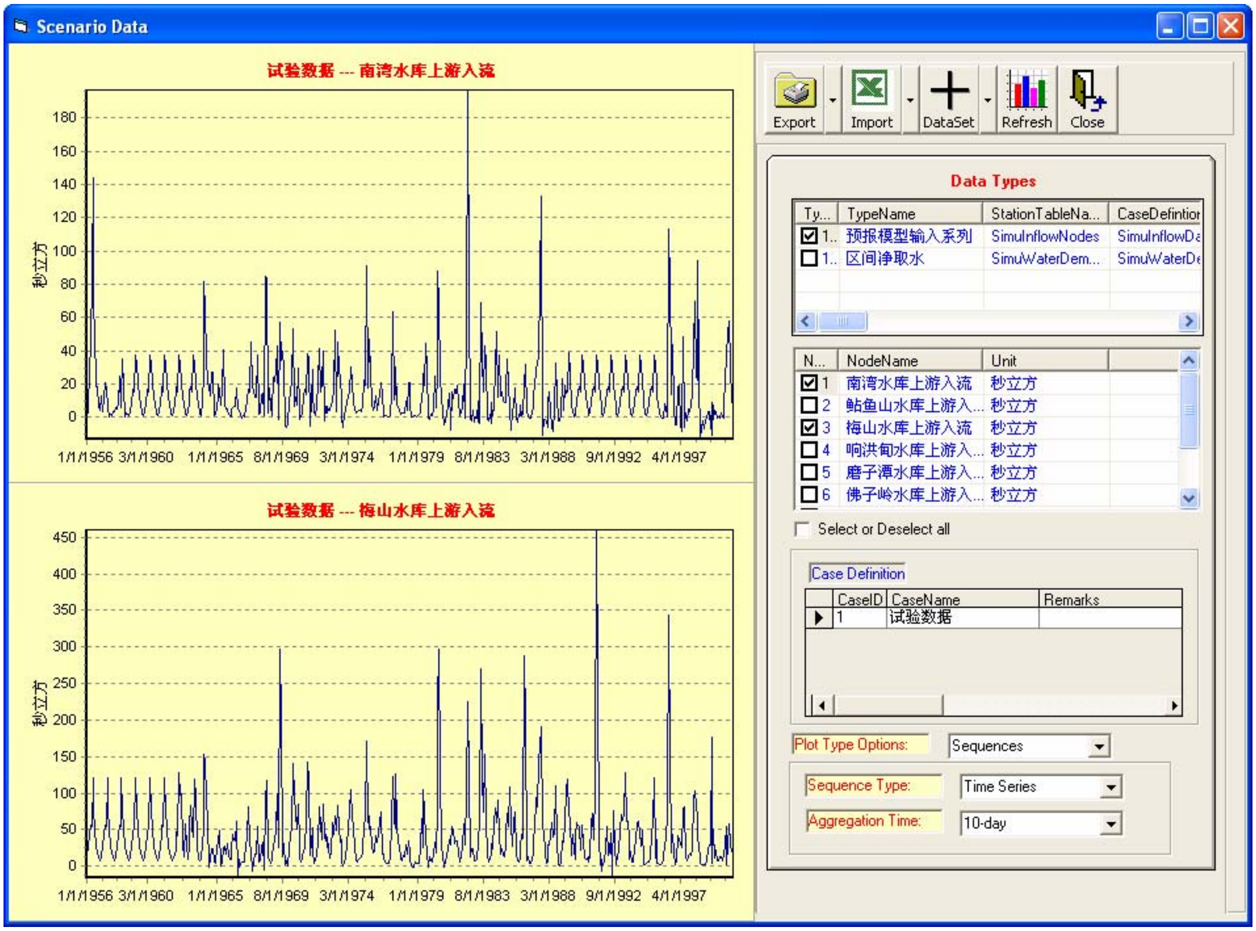


Figure A.4: Inflow data

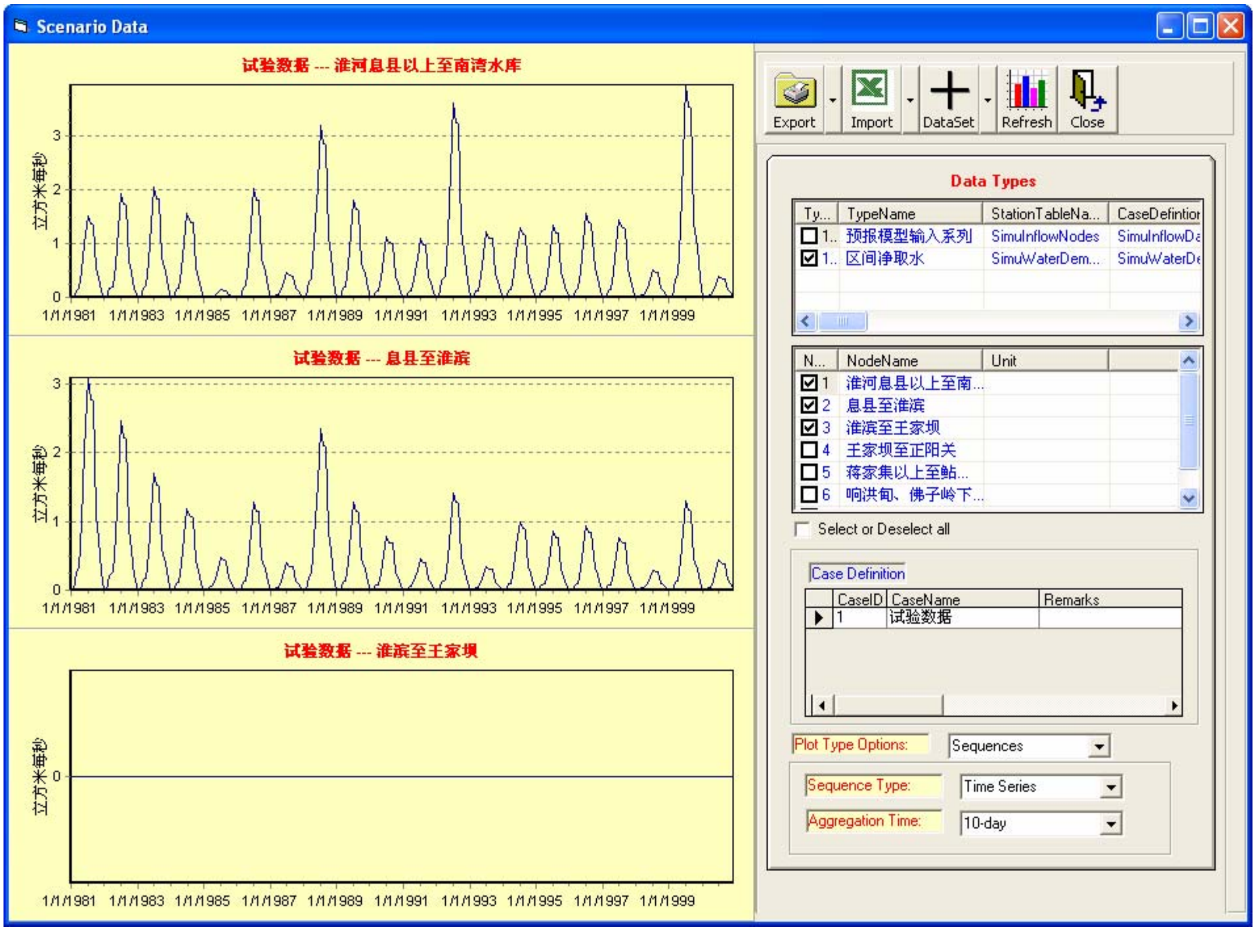


Figure A.5: Water demand data

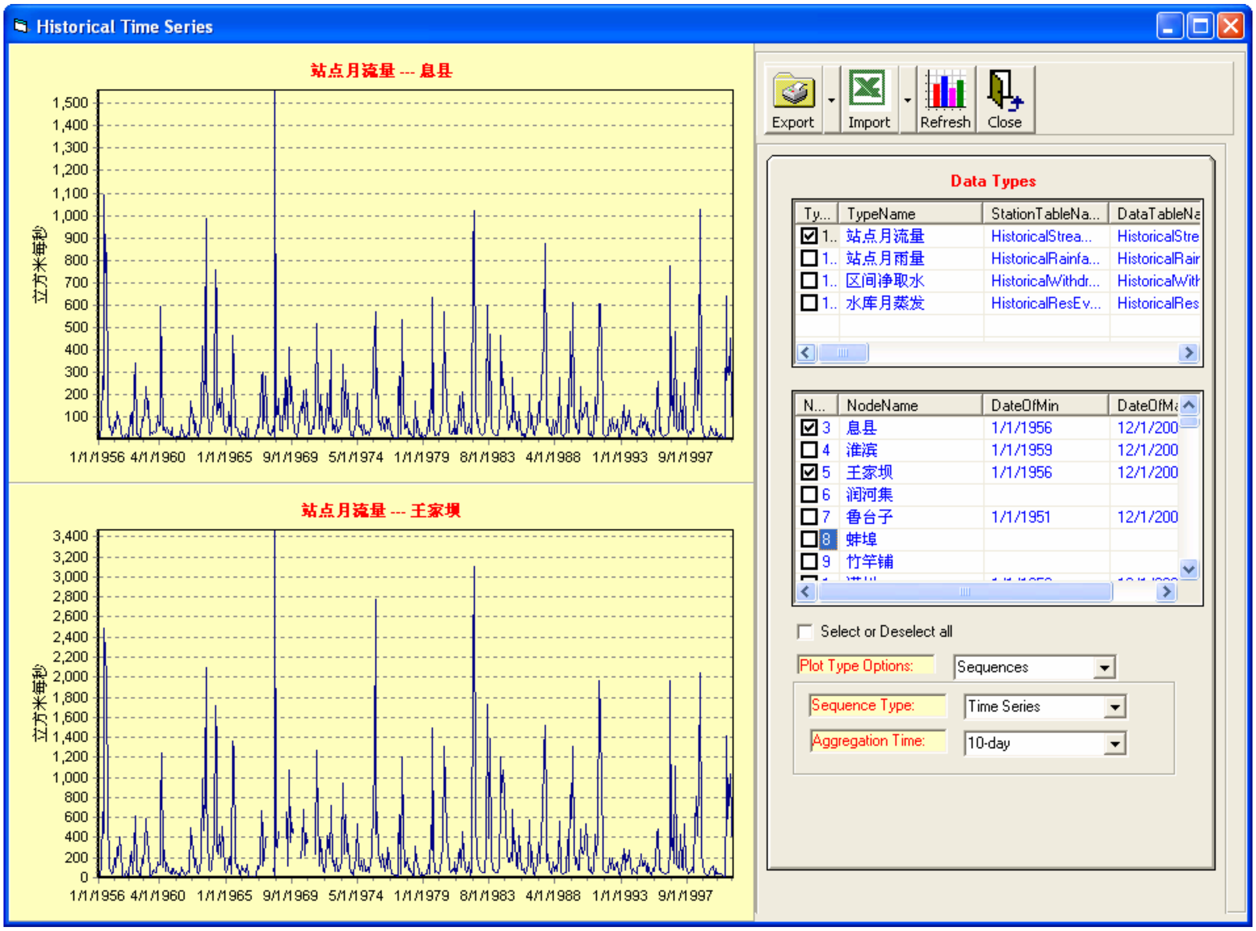


Figure A.6: Histotrical river flow record

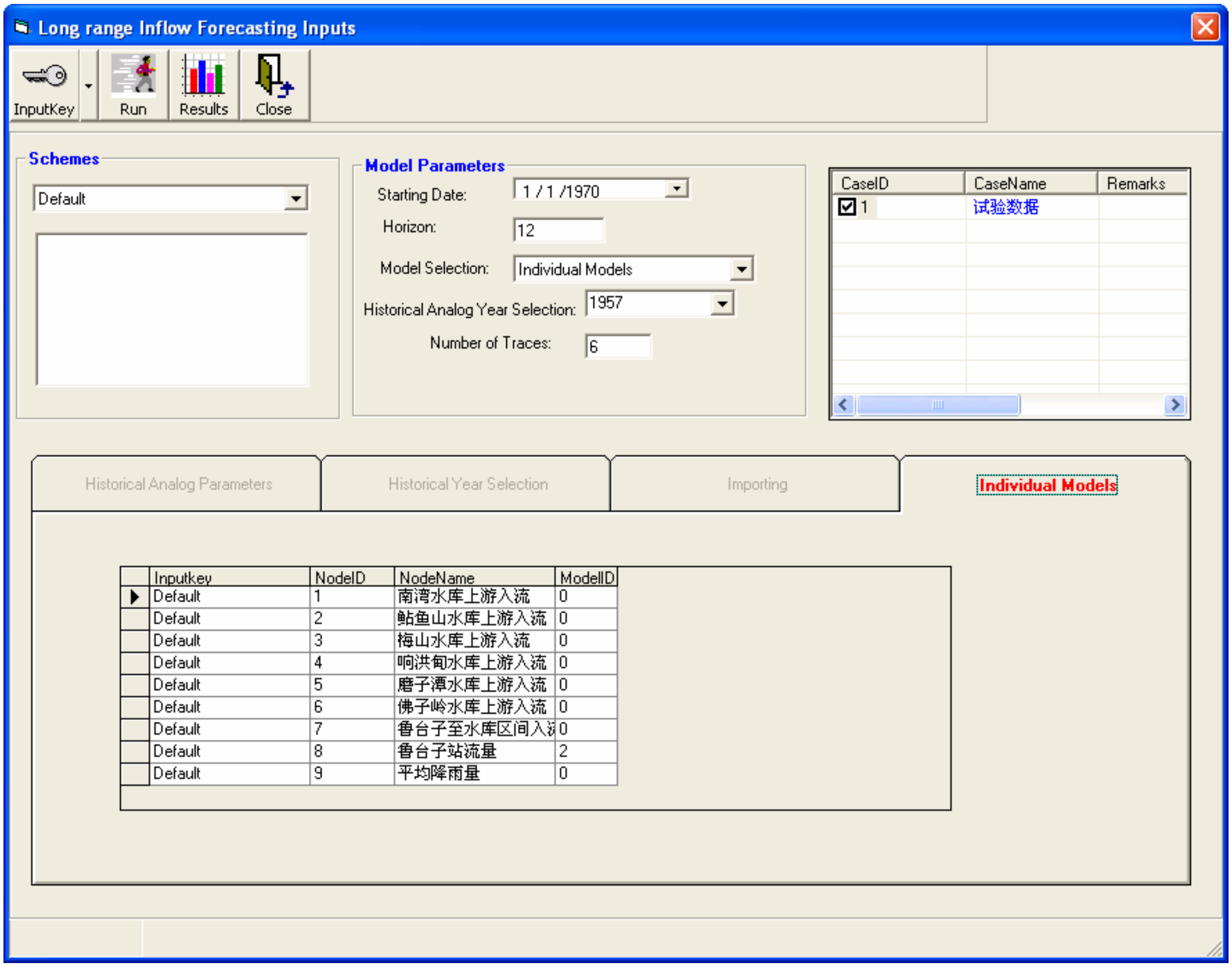


Figure A.7: Inflow model inputs

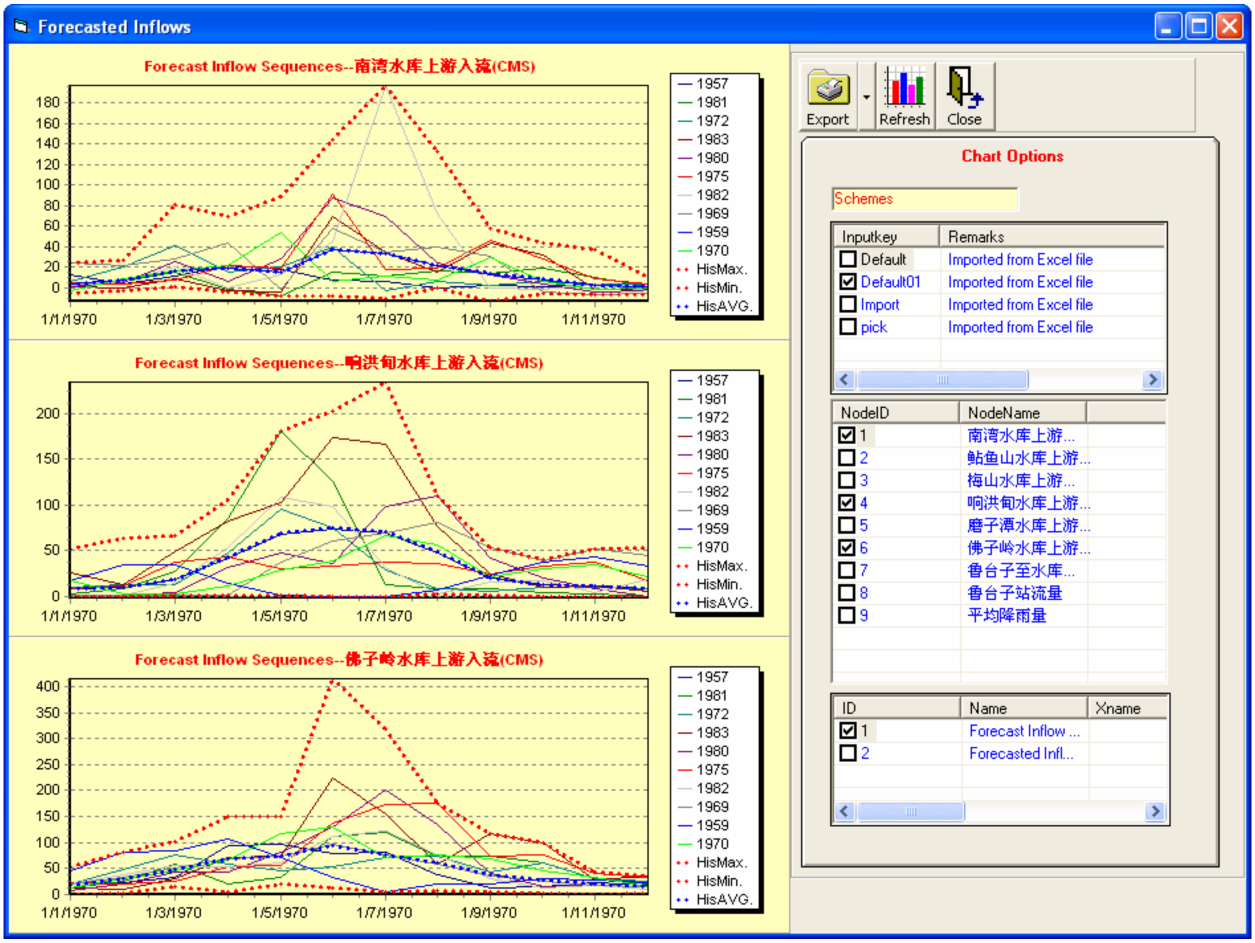


Figure A.8: Inflow model output

ACF-ACT River Basin Assessments

Basic Information

Title:	ACF-ACT River Basin Assessments
Project Number:	2005GA133O
Start Date:	10/14/2005
End Date:	6/30/2006
Funding Source:	Other
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Category:	Management and Planning, Hydrology, Surface Water
Descriptors:	
Principal Investigators:	Aris P. Georgakakos

Publication

Decision Support System for the ACF River Basin

Interim Project Meeting

Aris Georgakakos, Huaming Yao, Martin Kistenmacher, Sopan Patil, Amy Tidwell, Fred Kimaite, Dongha Kim

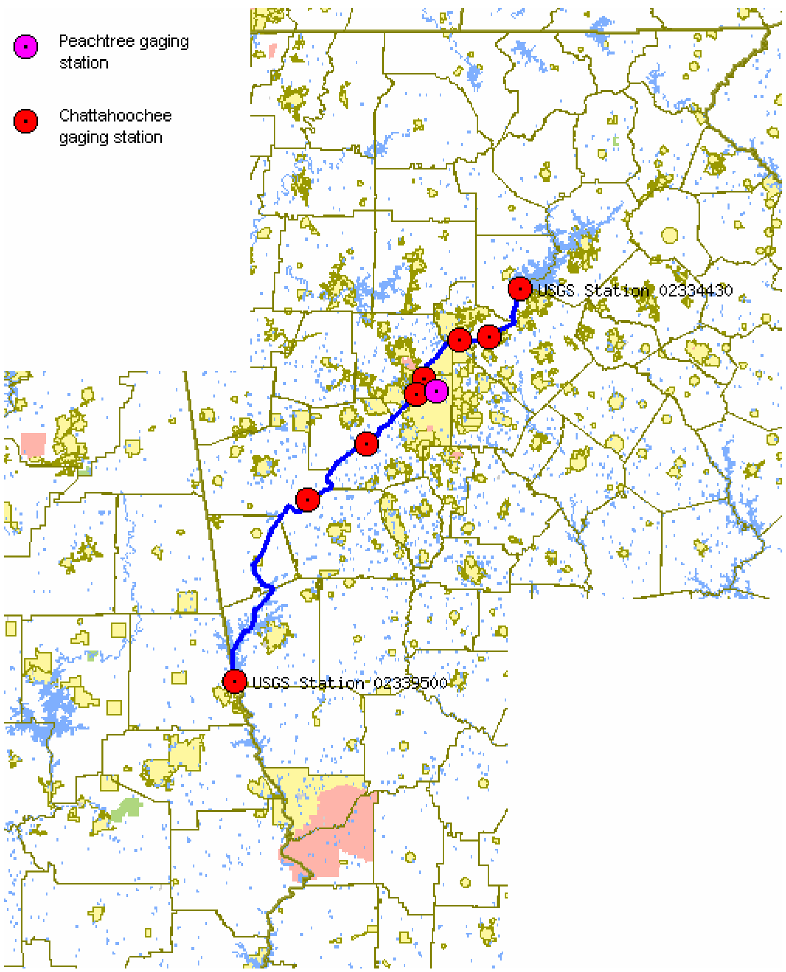
Georgia Water Resources Institute (GWRI)
Georgia Institute of Technology (Georgia Tech)

(26 April 2006)

- **Upper Chattahoochee Withdrawals-Returns Study**
- **ACF DSS Features and Capabilities**
- **Comparison of ACF DSS and HEC-5 Models**
- **Typical Scenario Assessments**
- **Way Forward: DSS Additions/Scenario Analysis**

Upper Chattahoochee Withdrawals-Returns Study
Data

Data Sources:
USGS Gage Flow; Ga EPD Withdrawals and Returns

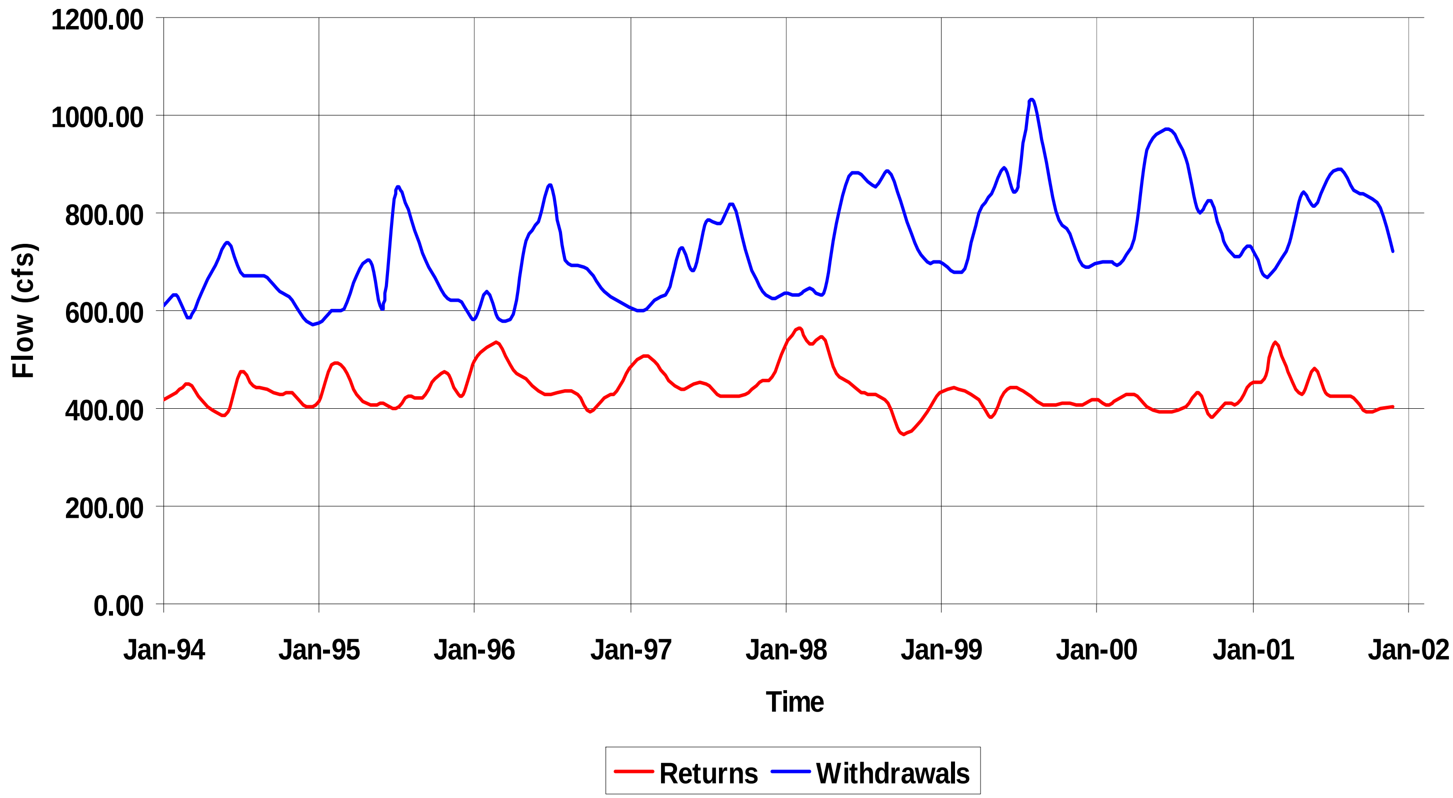


Record Length: Jan 1994 to Dec 2001

	Withdrawals (Facility#)	Returns (Permit#)
	069-1290-06	
	069-1290-06	
Buford	============	
	060-1209-02	GA0023167
		GA0023175
		GA0026433
		GA0046019
Norcross	============	
	060-1207-02	
	060-1209-03	
	060-1209-04	
	060-1290-08	
Roswell	============	
	033-1290-01	GA0024333
	060-1207-04	GA0030684
	060-1209-01	
	060-1290-09	
Atlanta	============	
	044-1290-03	GA0026140
	060-1291-01	GA0026158
GA 280	============	
	033-1214-01	GA0024040
	033-1214-02	GA0021458
	048-1214-03	GA0021482
	048-1216-01	GA0025381
	048-1216-03	GA0030341
	048-1217-03	GA0030350
		GA0031402
		GA0047104
		GA0047201
		GA0049786
Fairburn	============	
	060-1218-01	GA0025542
		GA0027171
Whitesburg	============	
	038-1221-01	GA0021423
	038-1291-02	GA0000311
	072-1293-03	GA0021148
	074-1220-02	GA0031721
	074-1291-06	GA0039951
	074-1291-07	GA Power (Yates)
	141-1222-01	GA Power (Wansley)
	141-1292-01	
	141-1292-02	
West Point	============	
Allatoona	008-1491-05	

Upper Chattahoochee Withdrawals-Returns Study

Return / Withdrawal Relationship



Observations: Returns and withdrawals are spuriously correlated;

Returns are not following withdrawal trend;

Outdoor water use in dry periods does not contribute to returns.

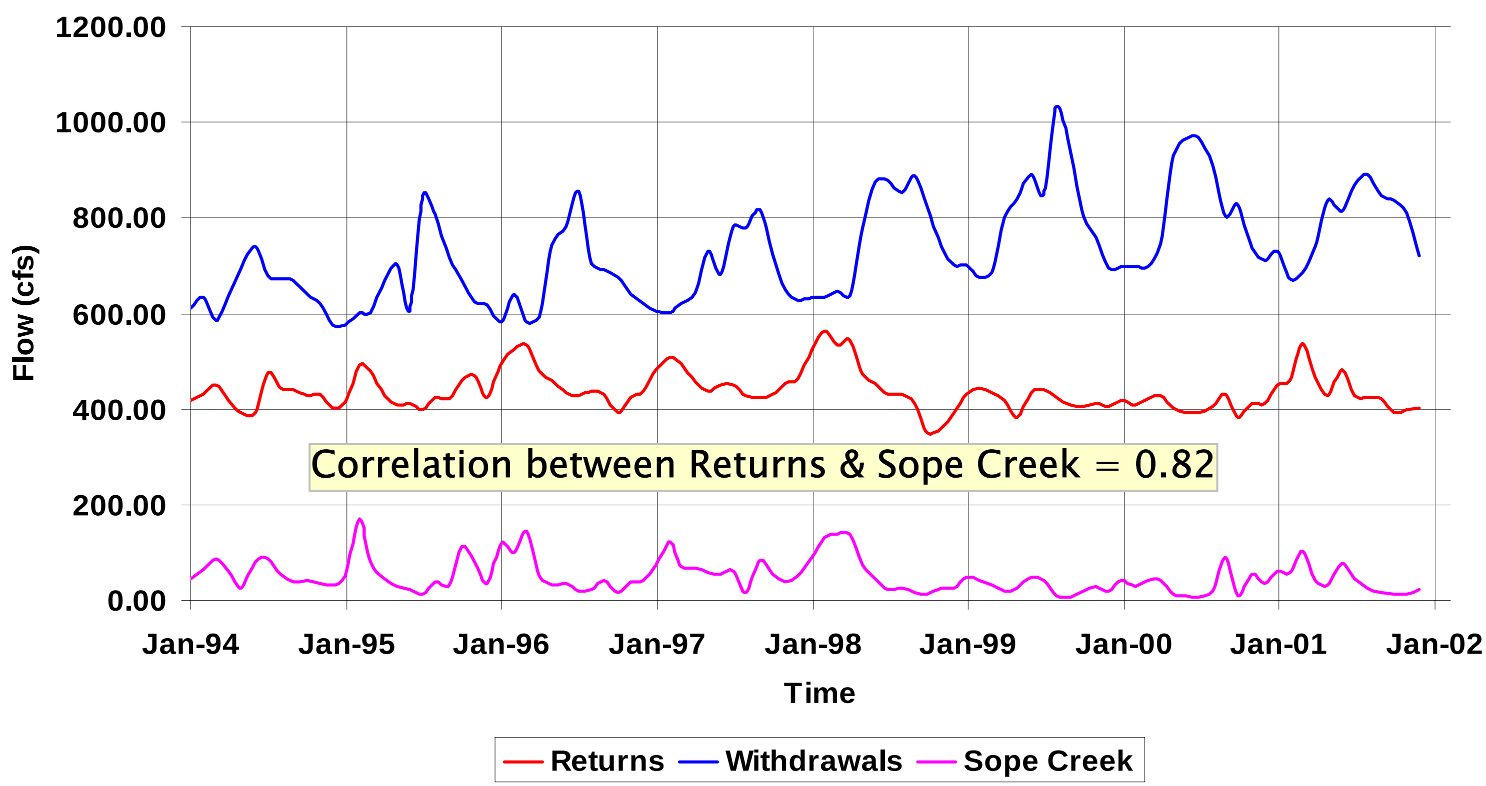
Upper Chattahoochee Withdrawals-Returns Study
Streamflow/Return Relationship

Are returns related to other hydrologic variables?

Due to the combined sewer system (CSS), the return data most likely include actual returns (from indoor water use) plus storm water runoff.

Assess the influence of storm water runoff in returns:

If storm water runoff is significant, it should be correlated with Creek flow.

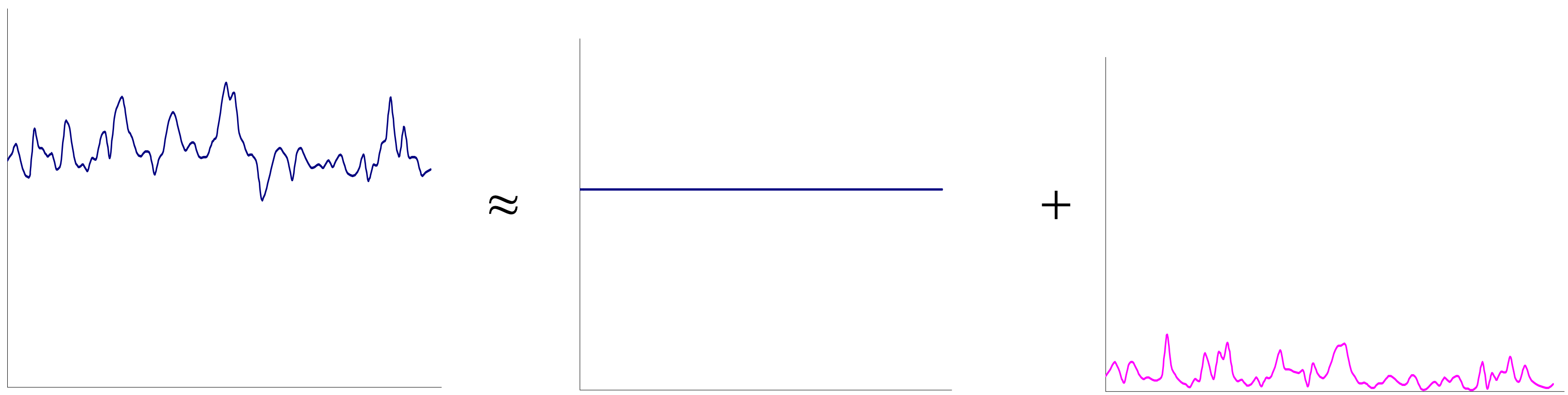


Upper Chattahoochee Withdrawals-Returns Study

CSS Return Model

Total CSS Returns = Indoor Water Use Returns + Storm Water + Basin Transfers

The contribution of Out-of-Basin-Transfers to CSS Returns are most likely part of the Indoor Water Use Returns.



CSS Returns **Indoor Water Use Returns** **Storm Water in CSS**

Can we quantify and separate Storm Water Runoff from Indoor Water Use Returns?

Upper Chattahoochee Withdrawals-Returns Study

CSS Return Model: Regression Analysis

Regression of CSS returns on streamflow:

CSS Returns = alpha * Streamflow + beta

Sope Creek:

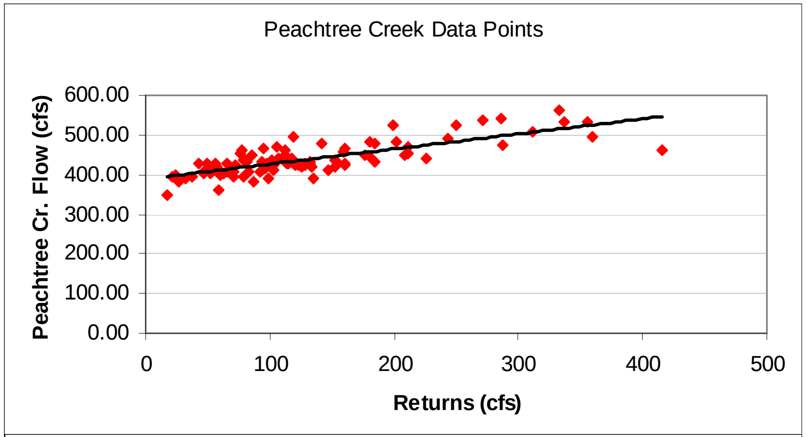
CSS Returns = 0.95 * (Sope Creek) + 390.47

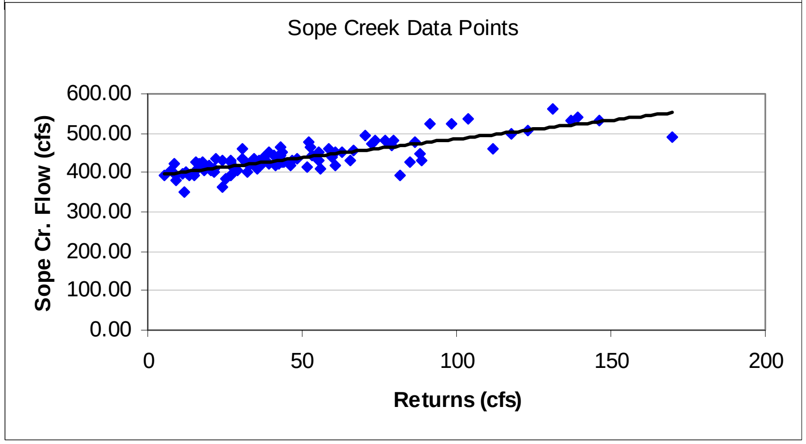
R^2 value = 0.67, SD of residuals = 23.1

Peachtree Creek:

CSS Returns = 0.38 * (Peachtree Creek) + 388.55

R^2 value = 0.62, SD of residuals = 24.9





Significance of beta: beta is statistically the same for regressions performed on different streams, and represents the indoor water use returns (deterministic component) in the CSS returns. More precisely,

Indoor Water Use + Mean Stormwater Runoff = alpha x (Mean Creek Flow) + beta

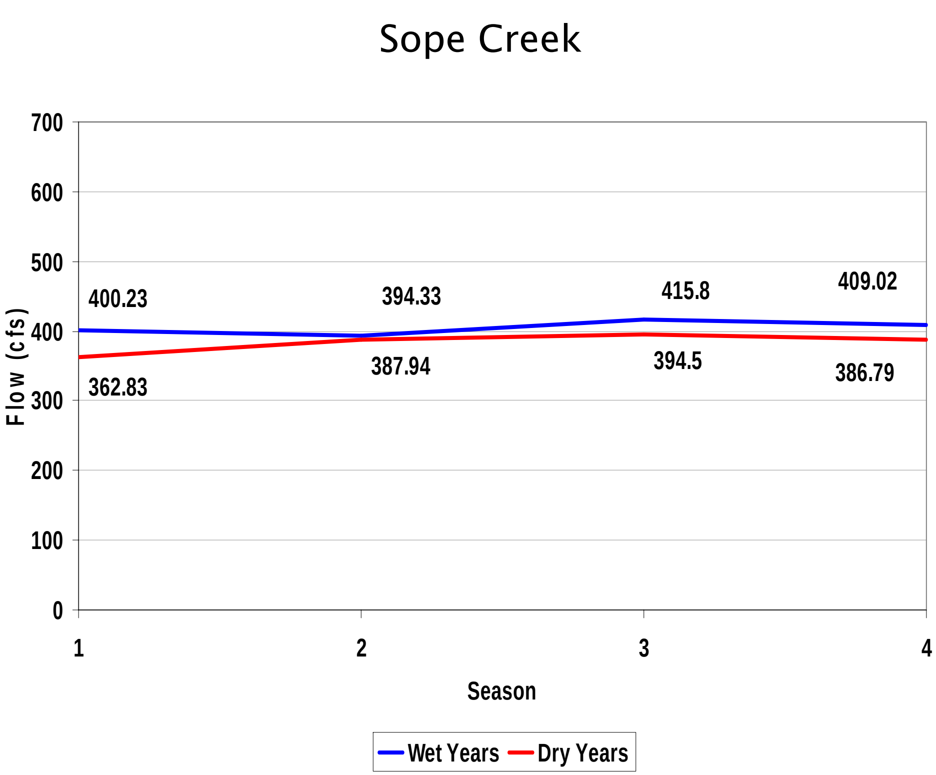
Significance of alpha * Streamflow: Represents the fluctuation of the CSS return data.

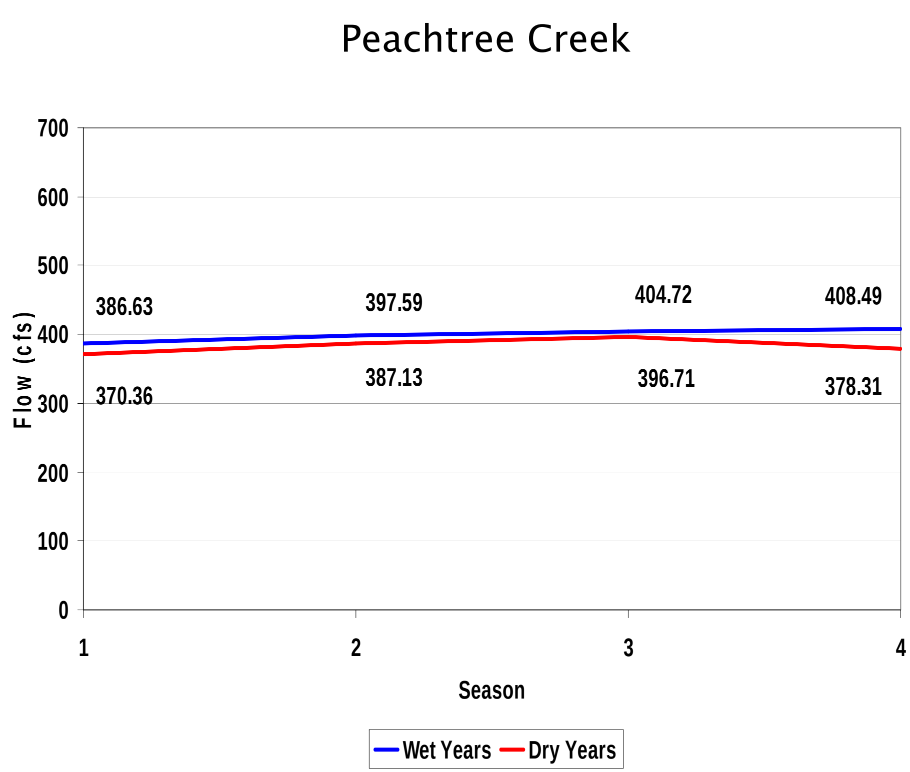
Upper Chattahoochee Withdrawals-Returns Study

Seasonal Variability of Indoor Water Use

Does indoor water use vary seasonally?

Regression analysis for different seasons (DJF, MAM, JJA, SND) and wet-dry hydrologic conditions indicates:





Upper Chattahoochee Withdrawals-Returns Study

Reason for Wet versus Dry Year Difference

Peachtree Creek versus Sope Creek:

Wet Years:

Peachtree Cr. = 1.98 * Sope Cr. + 39.1

R^2 value = 0.64

Dry Years:

Peachtree Cr. = 2.08 * Sope Cr. + 18.64

R^2 value = 0.87

What do these results signify?

Hydrologic variability differences of wet and dry years introduces a small bias, of approximately 20 cfs, in the estimation of Indoor Water Use. Dry years provide a more accurate estimate of Indoor Water Use.

Upper Chattahoochee Withdrawals-Returns Study

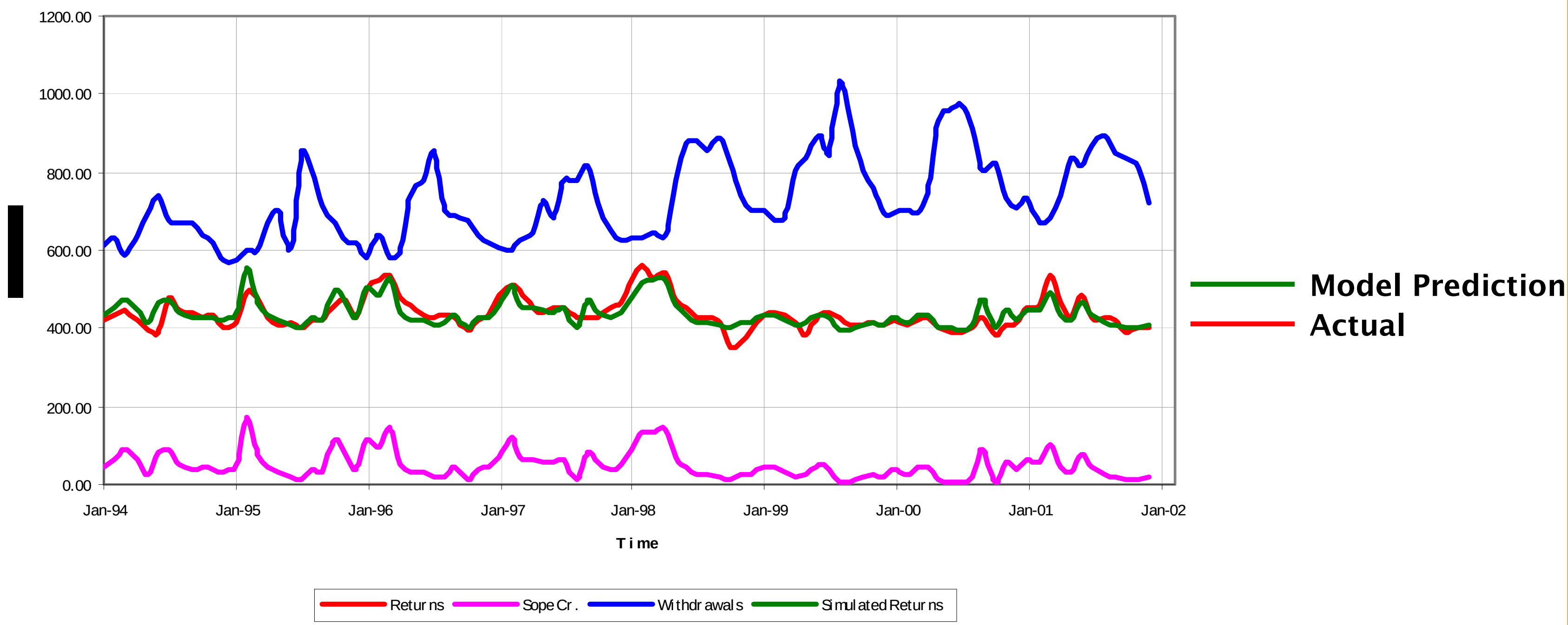
Consistency with National Averages and CSS Return Model

<u>Comparisons with national average per capita consumption:</u>

- Indoor water use ~ 70 gallons/day/capita
- The estimate of 400 cfs would roughly correspond to a population of 3,700,000
- Is this consistent with the actual population served in the Upper Chattahoochee?

<u>CSS Return Model:</u>

CSS Return = Indoor water use return [population x (per capita return ~ consumption)]
+ storm water runoff (function of SC or PC)
+ zero for outdoor watering returns



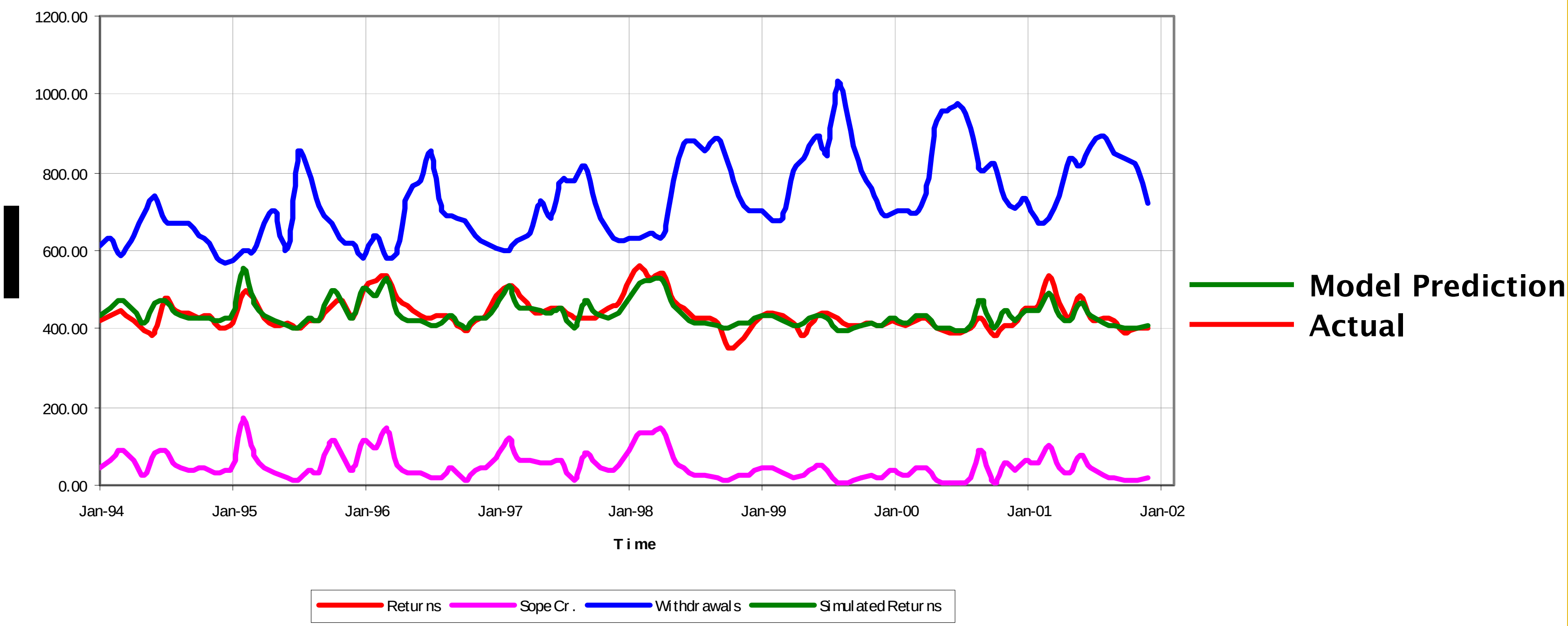
Upper Chattahoochee Withdrawals-Returns Study

Potential Uses of CSS Return Model

Model Uses:

- Estimation/prediction of seasonal municipal returns under variable hydrologic conditions; (Seasonal Management of Lanier-Upper Chattahoochee);
- Assessment of the water benefit of different conservation measures/strategies;
- Estimation/prediction of future municipal returns under population and climate changes (System Planning-Assessments).

Data Needs: Current population served by CSS; Future population projections.



Upper Chattahoochee Withdrawals-Returns Study

Withdrawals

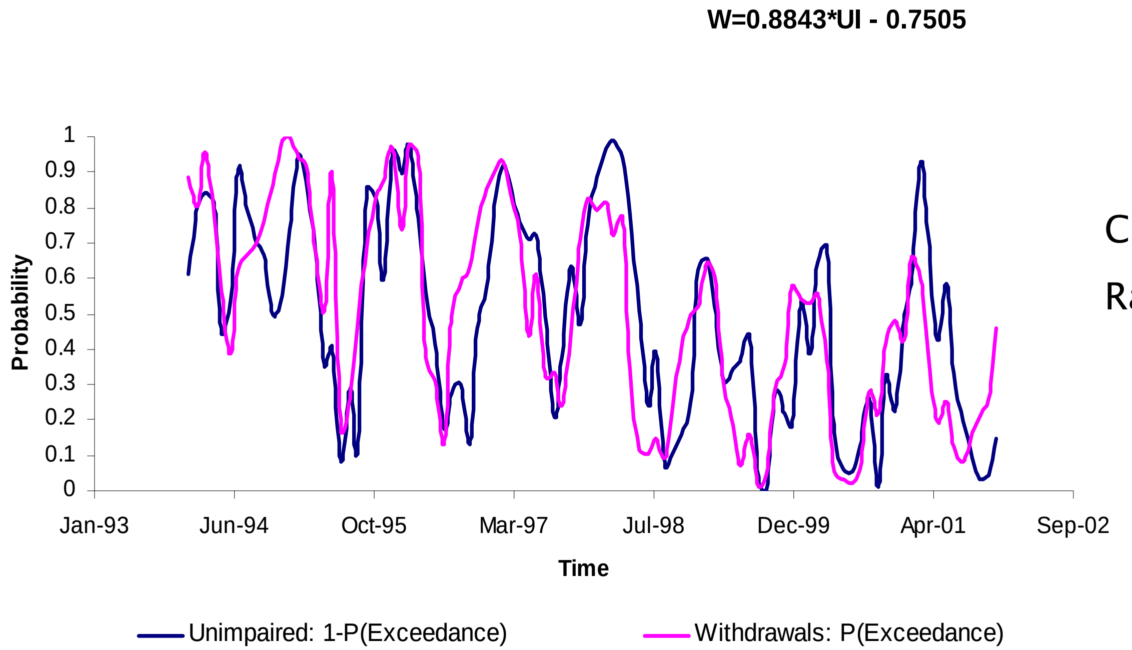
General Approach:

Withdrawals = Indoor Water Use + Outdoor Water Use ± Basin Transfers

Indoor Water Use: Function of the population served;

Outdoor Water Use: Function of Hydrologic Conditions.

Relationship of Outdoor Water Use Withdrawals and Unimpaired Streamflows:



Correlation ~ - 0.65;

Rank Correlation ~ - 0.75

Other hydrologic indicators (temperature, precipitation, soil moisture) may be better correlated with Withdrawals and need to be evaluated.

Upper Chattahoochee Withdrawals-Returns Study
Withdrawal Model Uses

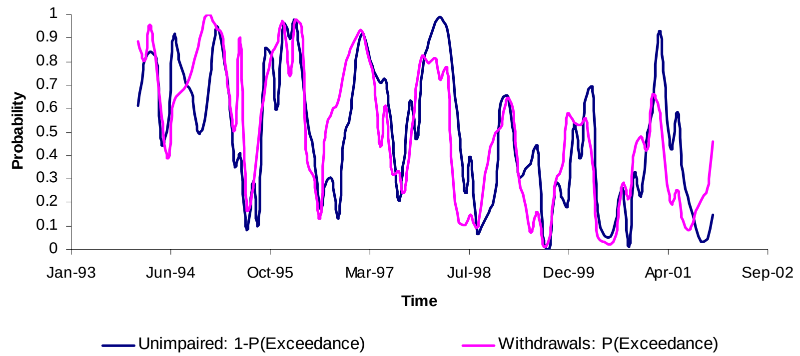
Withdrawal Model:

Withdrawals = Indoor Water Use (population) + Outdoor Water Use (Hydrology) ± BTs

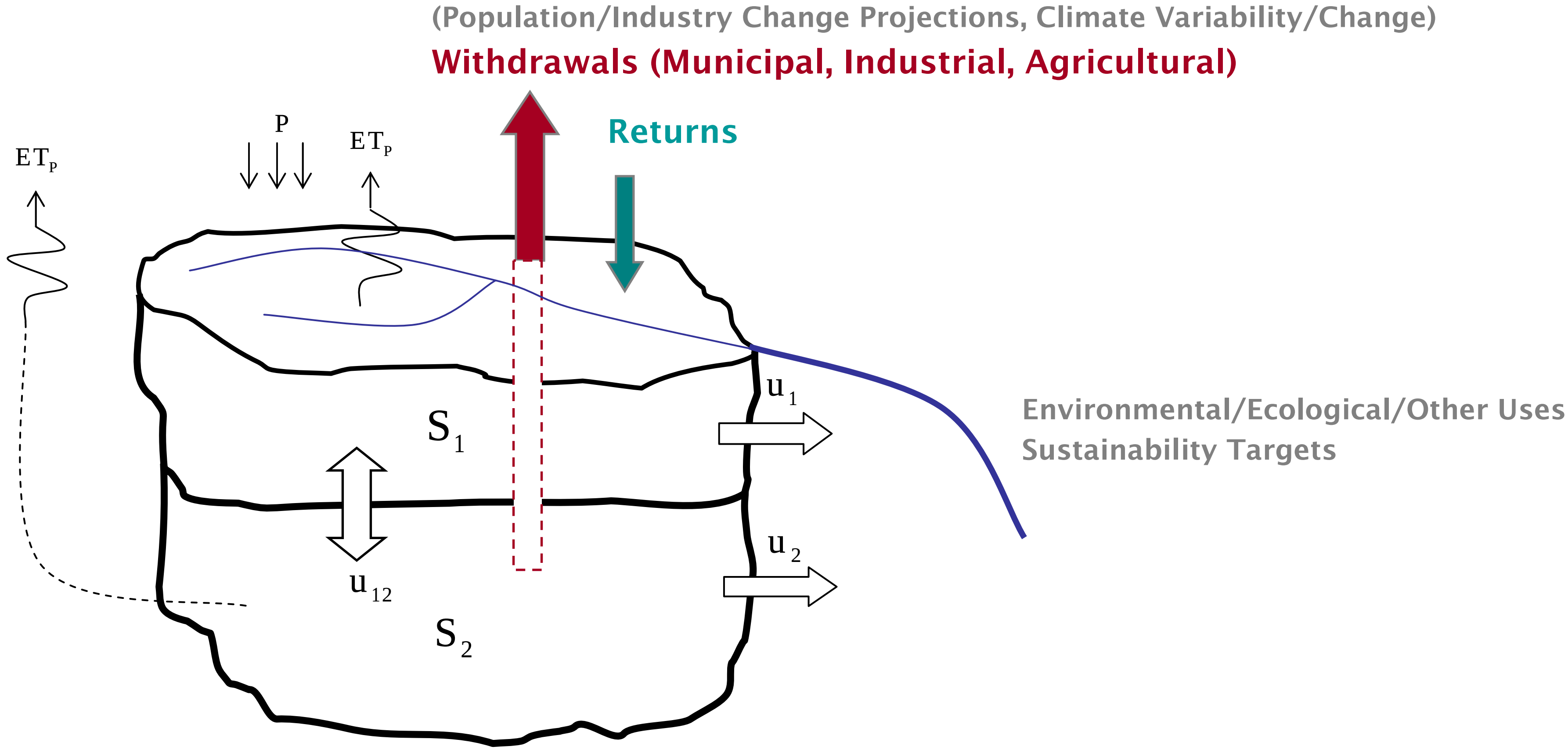
Model Uses:

- Estimation/prediction of seasonal municipal withdrawals under variable hydrologic conditions; (Seasonal Management of Lanier-Upper Chattahoochee);
- Assessment of the water benefit of different conservation measures/strategies;
- Estimation/prediction of future municipal withdrawals under population and climate changes (System Planning-Assessments);
- Holistic assessment of human water use on hydrologic regime, the environment, and the ecosystem.

Data Needs: Basin Transfers by month over the 1994 to 2002 time period, or longer.



Integrated River Basin Assessments, Planning, & Management

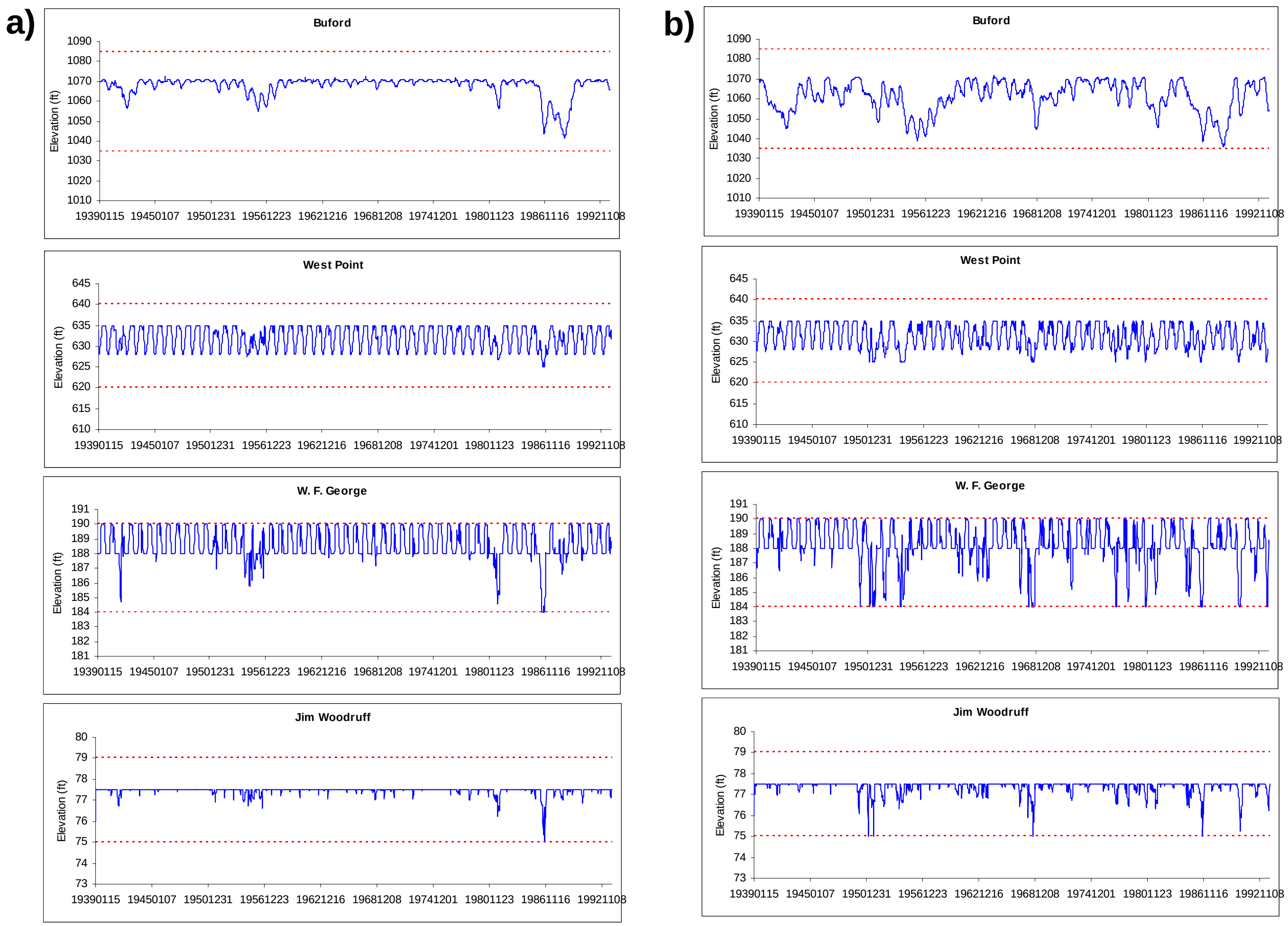


Assessment Goals:

- What is the basin capacity to support human water uses under certain sustainability targets?
- Can this capacity be enhanced by management and conservation strategies?
- Does potential climate change impair/enhance capacity?

Data/Models Needed for Assessments: hydrologic (surface/groundwater), withdrawal/return (munical/industrial/agricultural), climate variability and change, river/reservoir simulation and management, ecological flows, water quality.

Potential Impact of Biological Integrity Requirements



Agricultural Planning

- Data
  Hydro-meteorological; Soils; Land use; Crop; GIS integrated
- Models
  Crop growth models for 11 crops; Irrigation optimization
- Applications
  Crop water production functions;
  Irrigation requirements and scheduling;
  Vulnerability to droughts (climate variability)

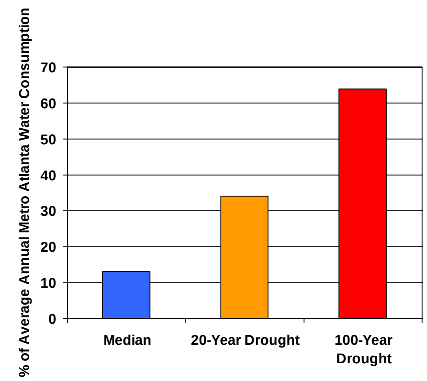
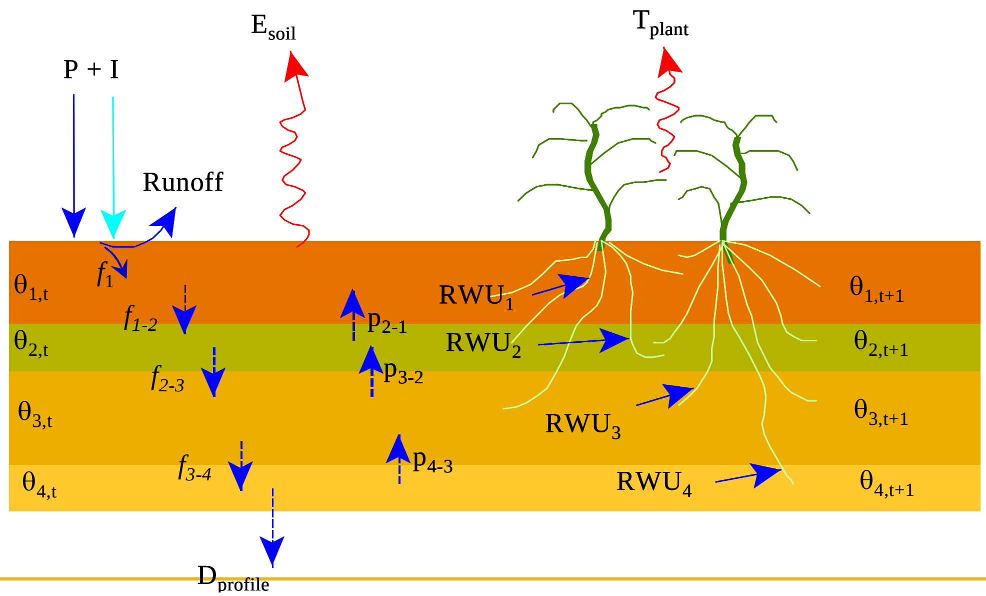
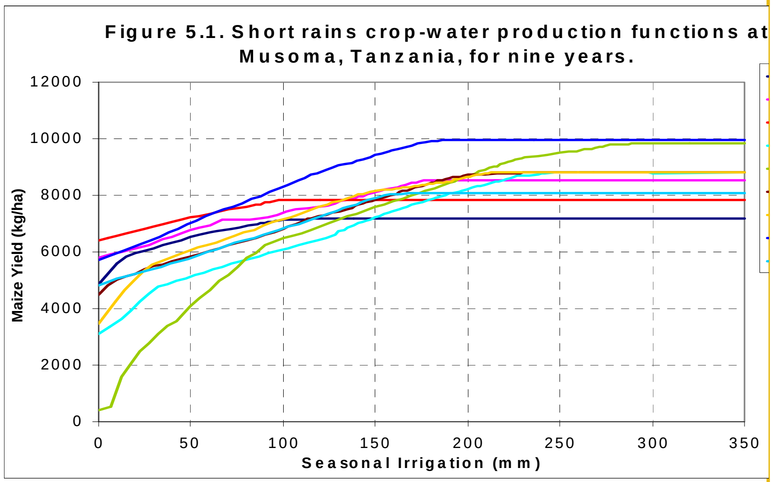


Figure 6: Comparison of Georgia Irrigation Requirements for Peanuts, Corn, and Wheat* (~36% of total acreage) versus Metro Atlanta Water Consumption

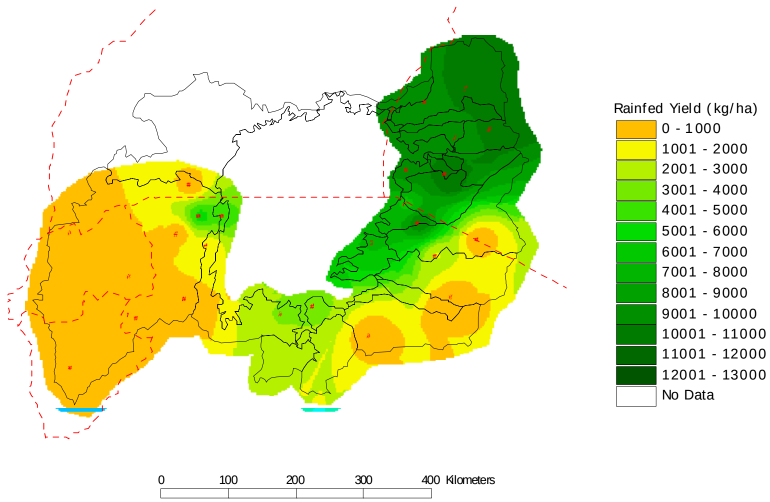




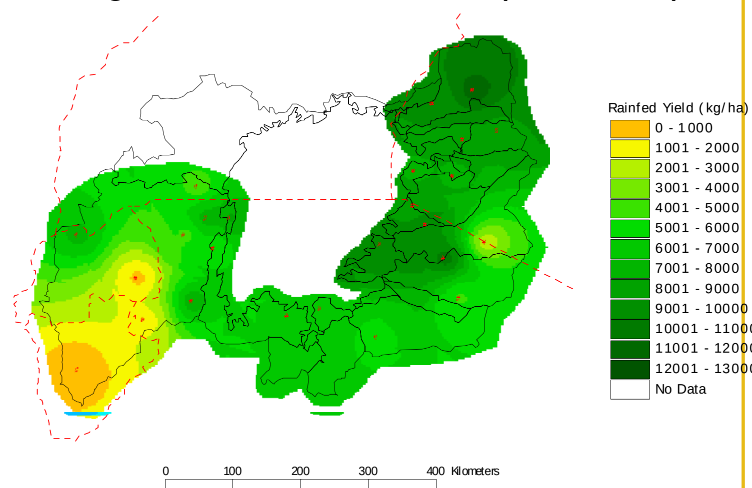
Agricultural Planning

Southern Nile Tradeoffs: Food Production & Water Sharing

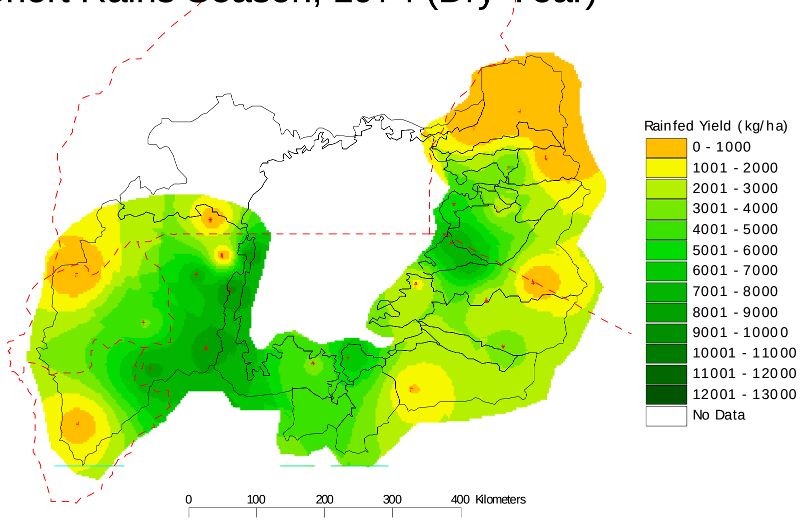
Long Rains Season; 1984 (Dry Year)



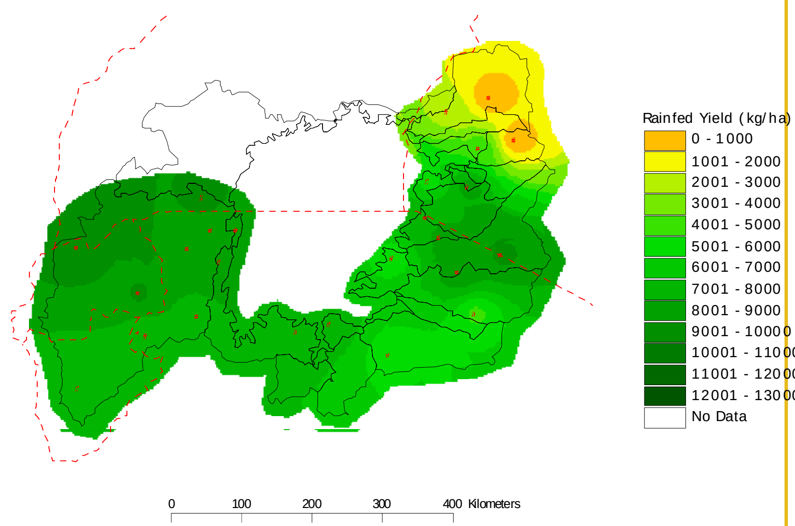
Long Rains Season; 1985 (Wet Year)



Short Rains Season; 1974 (Dry Year)



Short Rains Season; 1972 (Wet Year)



Climate Change Assessments

Statistical Significance Tests ⇐ Historical Climate Data / GCM Data

⇓ Identified "predictor" pixels from the set of significant pixels

Bias and Variance Adjustment

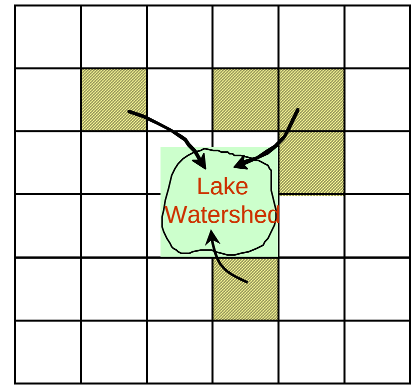
⇓ Adjusted Lake Temperature and Precipitation Scenarios

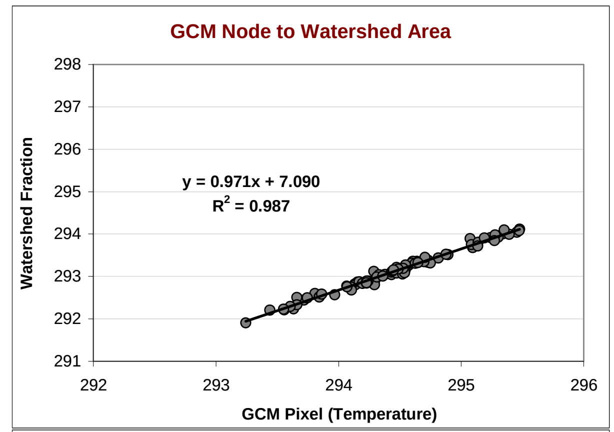
Downscaling

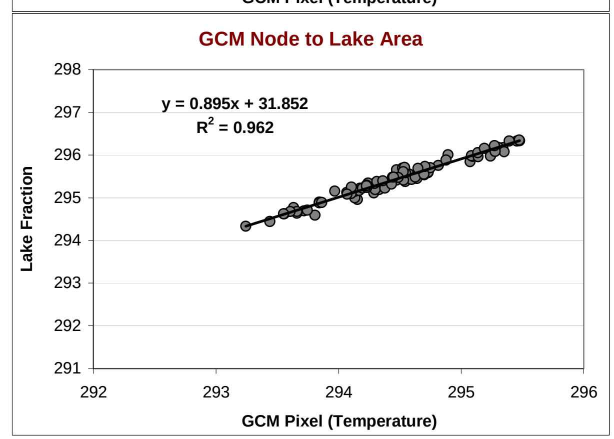
⇓ Statistically downscaled lake series at sub-basin scales

Water Resources Assessments

⇓ **Climate Change Impacts**

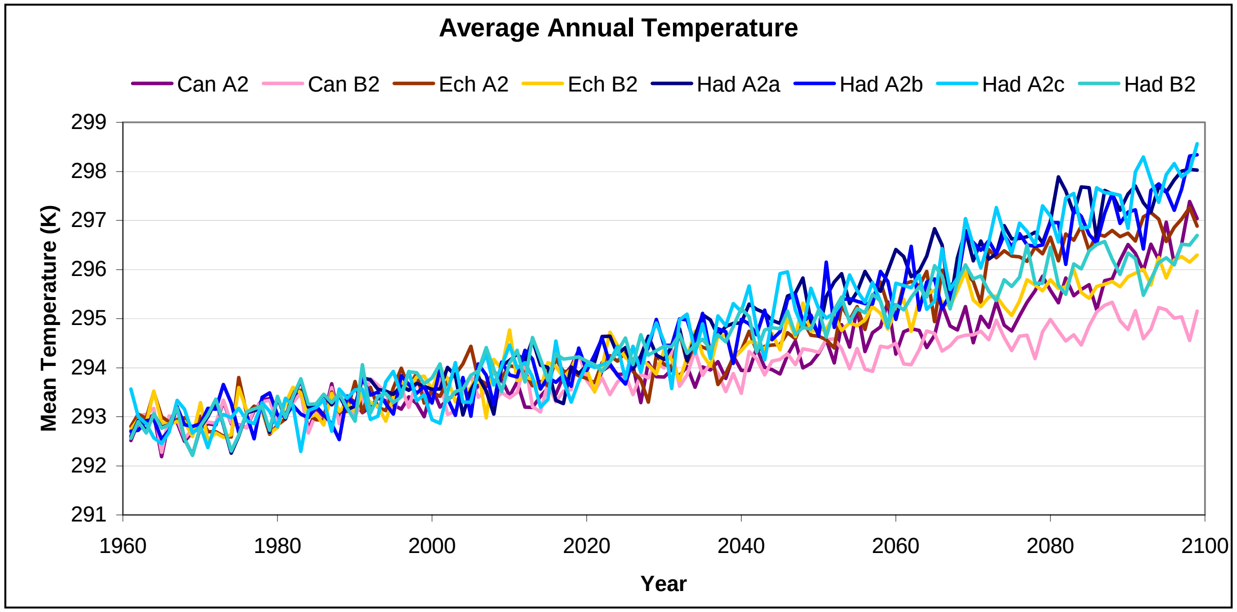




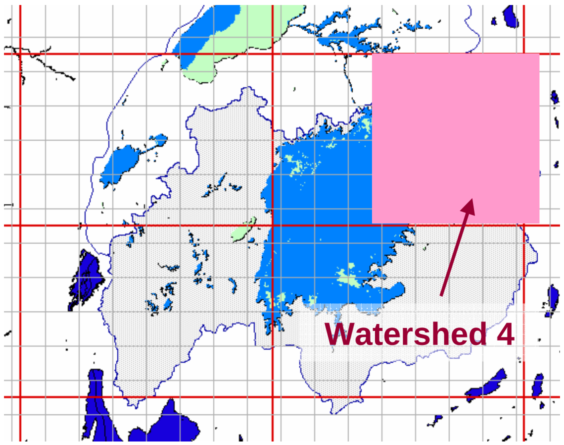


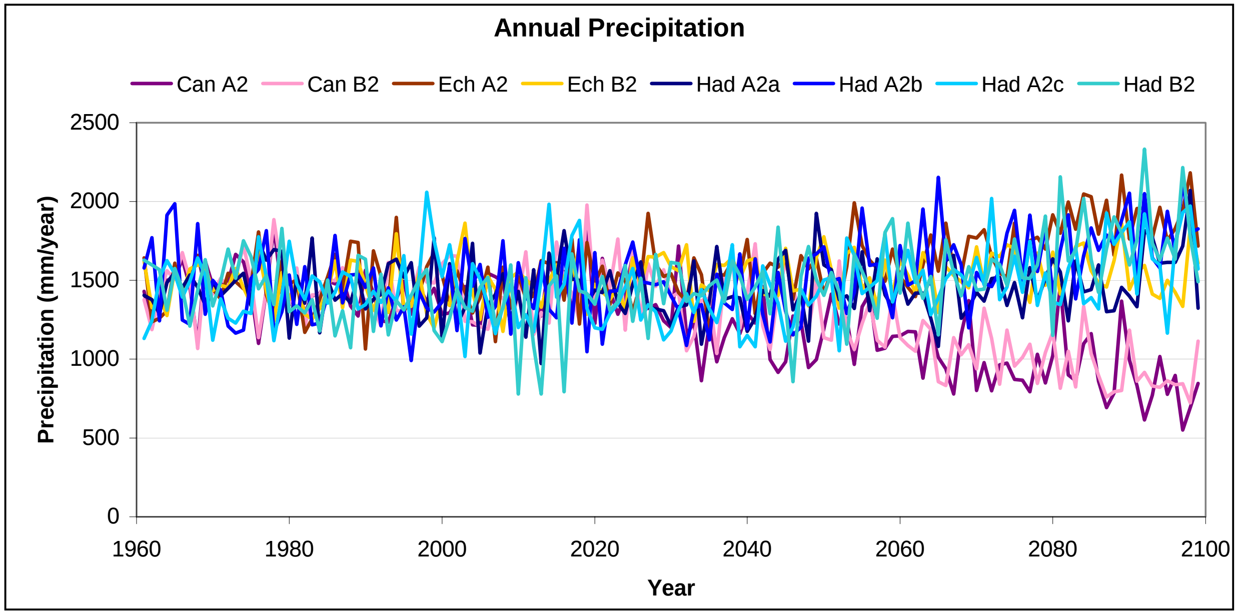
Climate Change Assessments: Lake Victoria

Average annual Temperature

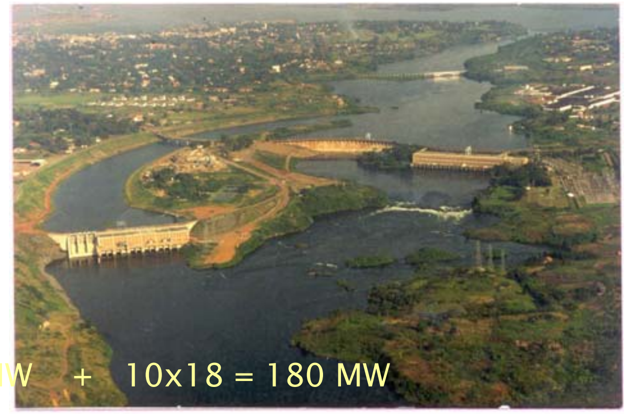


Annual Mean Areal Precipitation



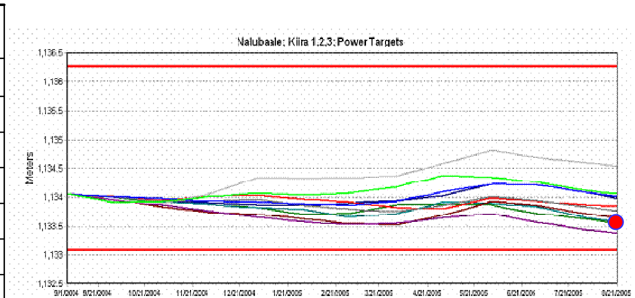


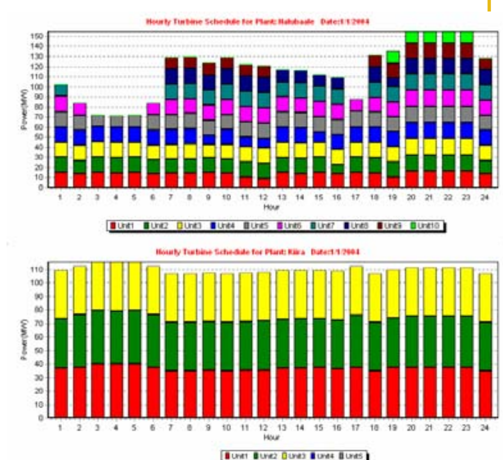
Lake Victoria Water and Energy Management Models



- Energy/Water System Planning
- Energy/Water Management
- Load Dispatching

	Agreed Curve Releases	Energy Demand Driven Releases
Nalubaale/Kiira (390 MW)	Commissioning Year	Commissioning Year
Bujagali (292.5 MW)	0	0
Karuma Falls (220 MW)	2	5
Kalagala (450 MW)	12	15
Ayago North (304 MW)	22	22
Ayago South (234 MW)	26	32
Murchison Falls (420 MW)	32	40

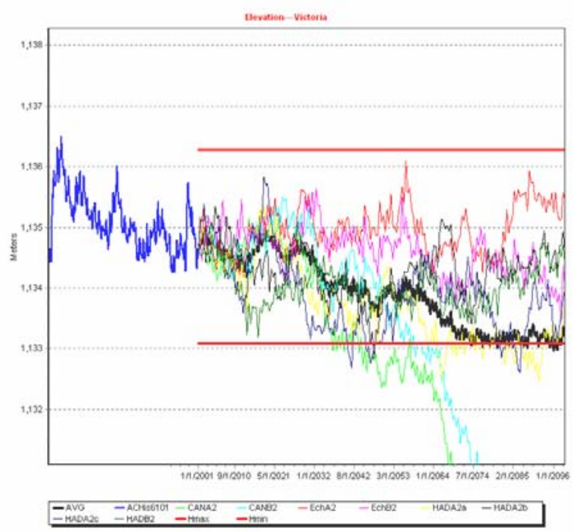




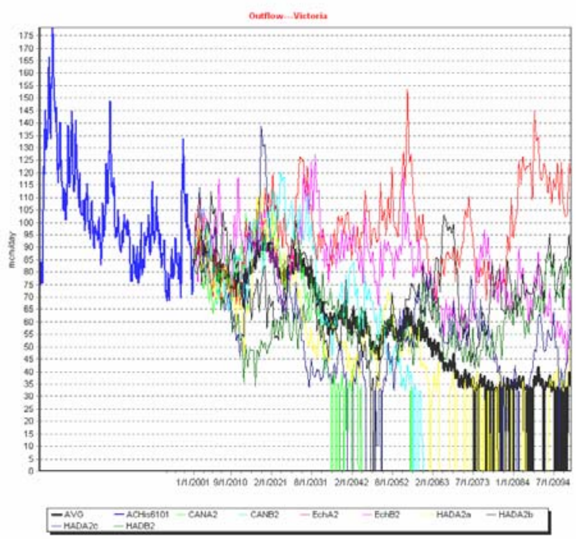
- Hydro economics;
- Assessments: Environmental, Ecological, Agricultural, Public Health, Legal, Climate Change

Climate Change Assessments (2000 – 2099)

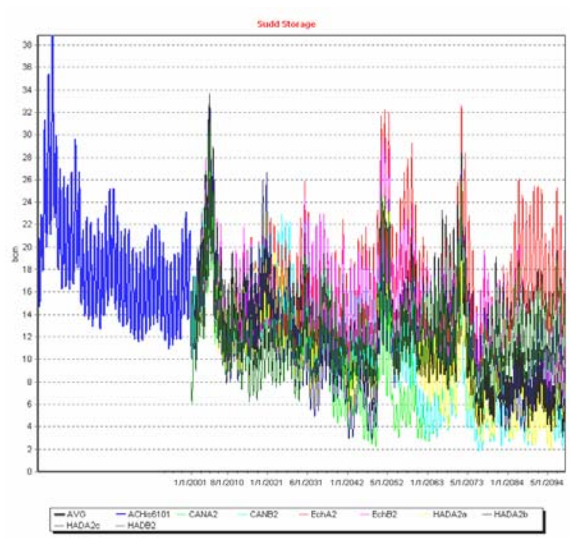
Lake V. Levels



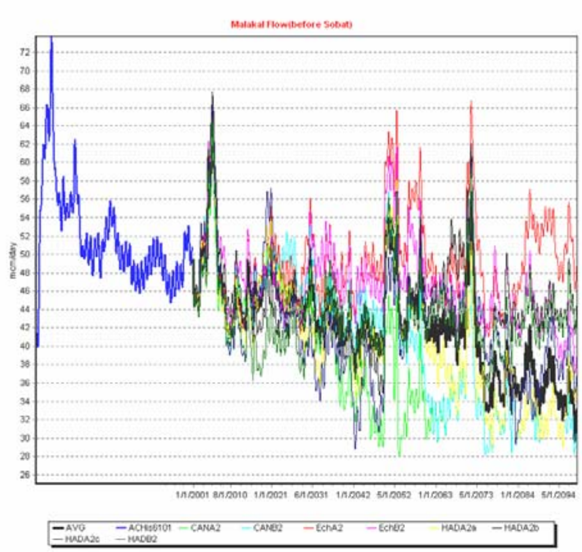
Lake V. Outflow



Sudd Wetland Area



Flow at Malakal



Critically important Implications for Lake Victoria…

… as well as …

..the entire Nile Basin

Integrated Assessments, Planning, and Management for Georgia Basins

(Georgia Tech, Princeton, EPD, NWSRFC, USGS, CORPS)

Climate Models

Predict
rainfall, temperature …

Down-scaling

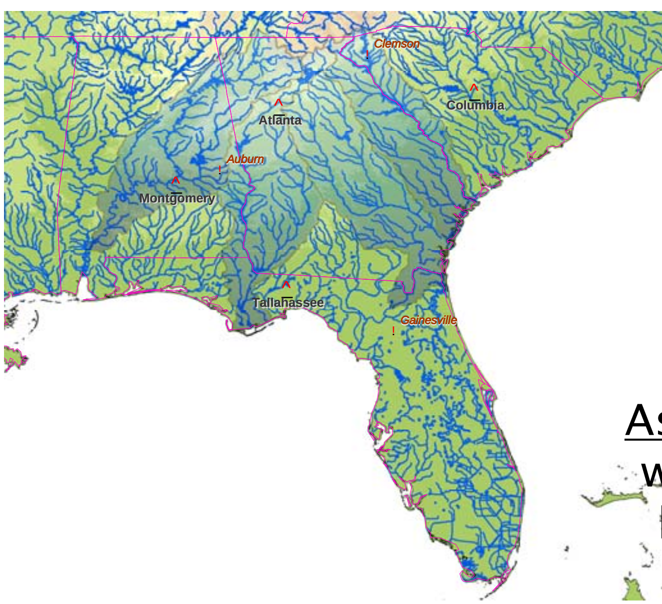
Downscale
rainfall, temperature …
to watershed scales

Watershed Hydrology

Predict
floods, droughts, demands
river flow, soil moisture, …

River/Lake Simulation & Management

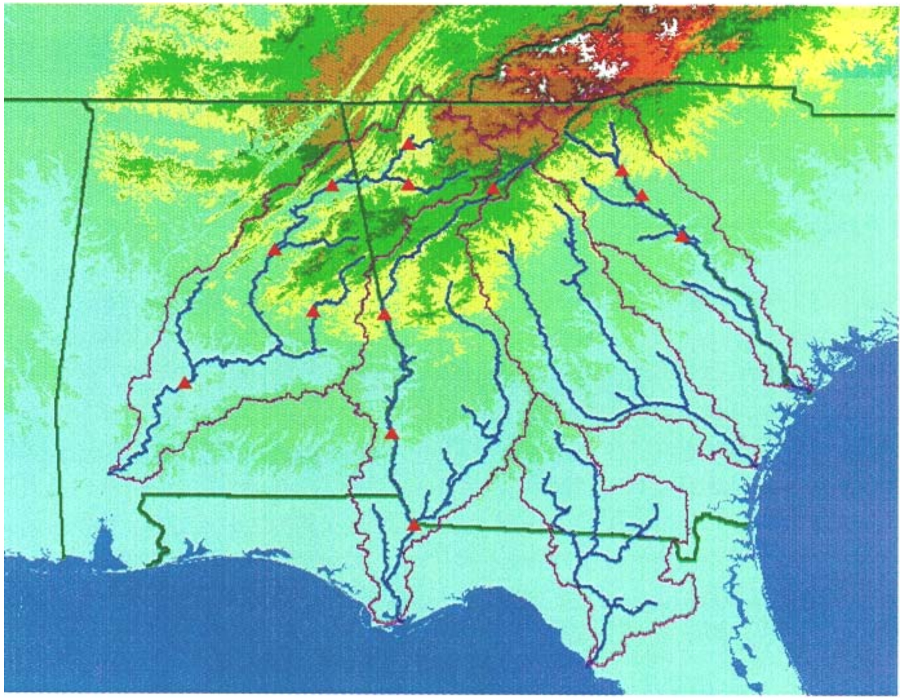
Southeast US

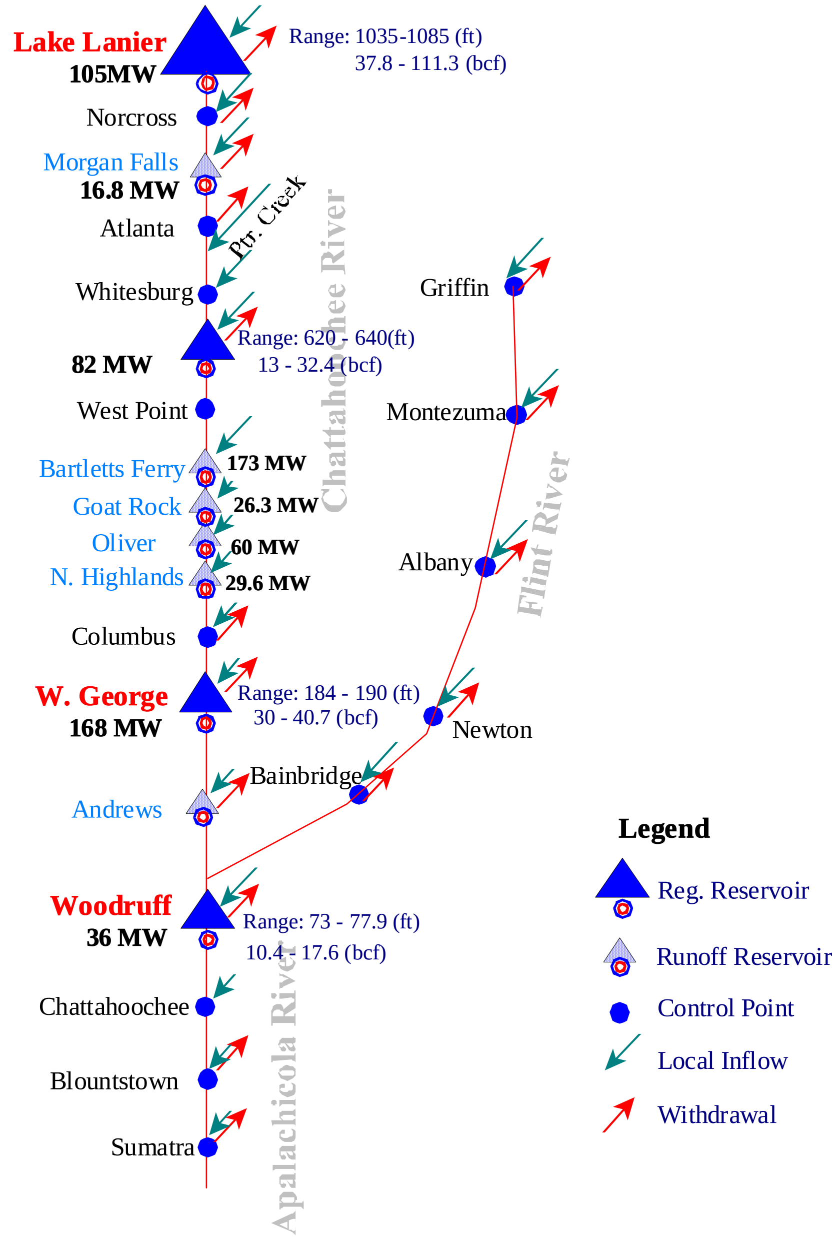


Assess Impacts/Tradeoffs
water supply, lake levels,
hydropower, navigation,
ecology,….

Revise Planning &
Management Policies

ACF DSS System





ACF DSS: Reservoirs/Hydro Plants

ID	Reservoir/Plant	Hmin (ft)	Hmax (ft)	Smin(bcf)	Smax (bcf)	Power Cap (MW)
1	Lake Lanier	1035	1072	37.77	86.86	5+50*2=105
2	Morgan Falls	867	868	0	0.6	16.8
3	West Point	621	635	13	26.33	4+39.35X2=82.7
4	Barletts Ferry	510	540	5	14.5	173
5	Goat Rock	404	415	0	1	26.3
6	Oliver	337	338	1.3	1.5	60
7	North Highlands	268	280	0	0.15	29.6
8	W George	184.5	190	30	40.7	36.25X4=145
9	Woodruff	76	79	14.4	19.5	12X3=36

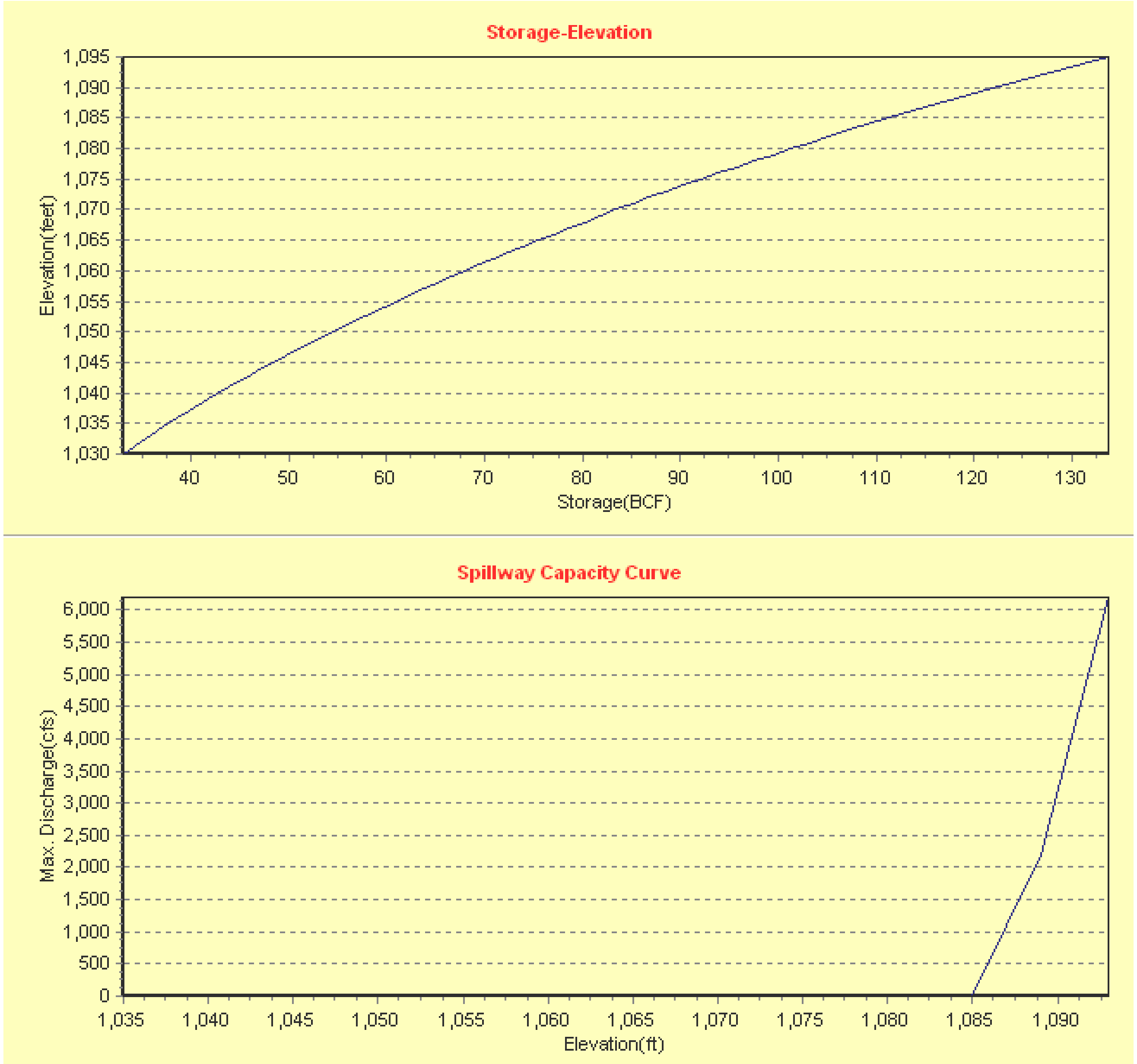
ACF DSS: River Nodes

NodeID	NodeName
1	Norcross
2	Atlanta
3	Whitesburg
4	West Point
5	Columbus
6	Andrews
7	Griffin
8	Montezuma
9	Albany
10	Newton
11	Bainbridge
12	Chattahoochee
13	Blounstown
14	Sumatra

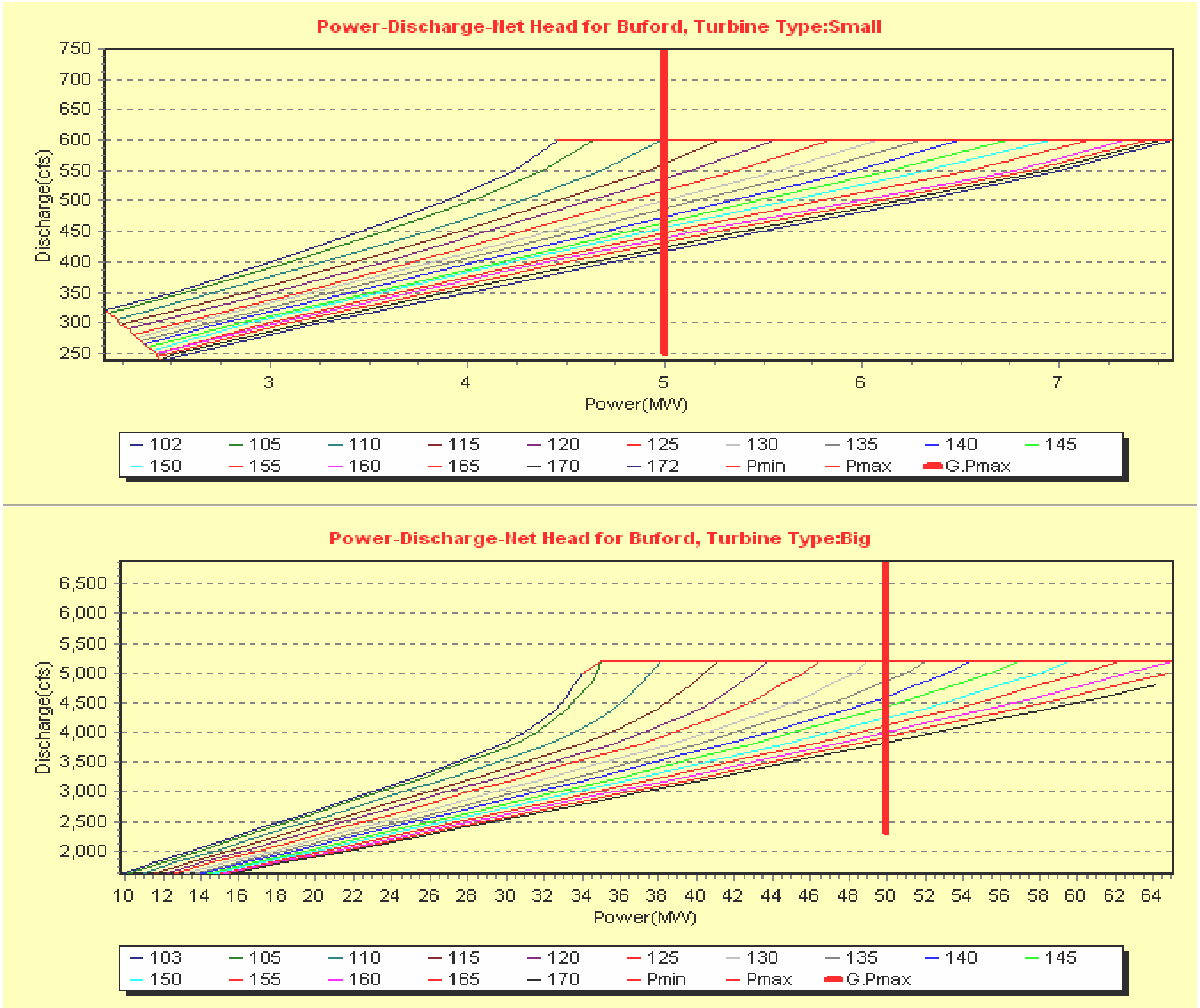
ACF DSS: Inflow/Withdrawal Nodes

NodeID	NodeName
1	Lake Lanier
2	Norcross
3	Morgan Falls
4	Atlanta
5	Whitesburg
6	West Point Lake
7	West Point
8	Bartletts Ferry
9	Goat Rock
10	Oliver
11	North Highlands
12	Columbus
13	W George
14	Andrews
15	Griffin
16	Montezuma
17	Albany
18	Newton
19	Bainbridge
20	Woodruff
21	Chattahoochee
22	Blounstown
23	Sumatra

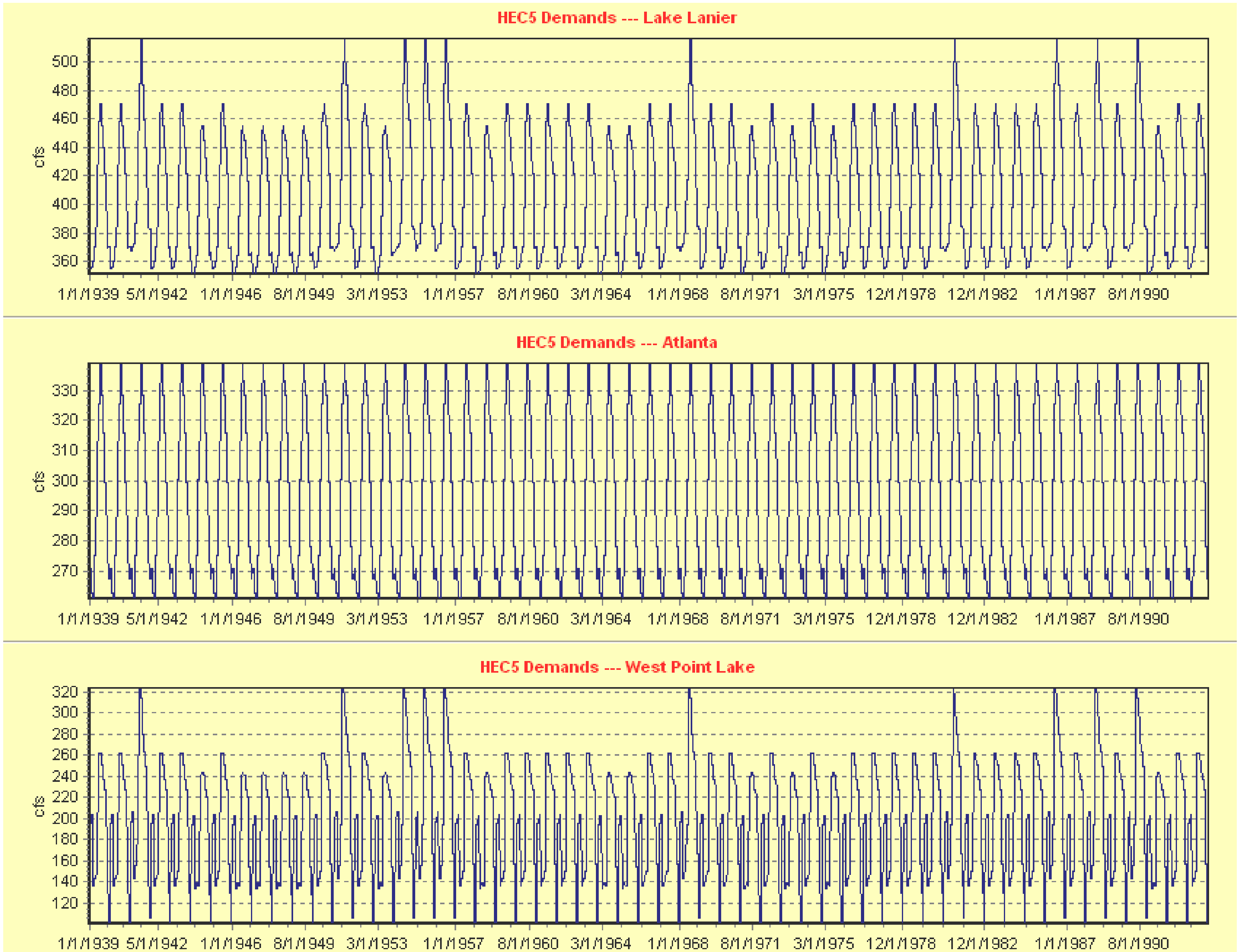
ACF DSS: Reservoir Curves--Lanier



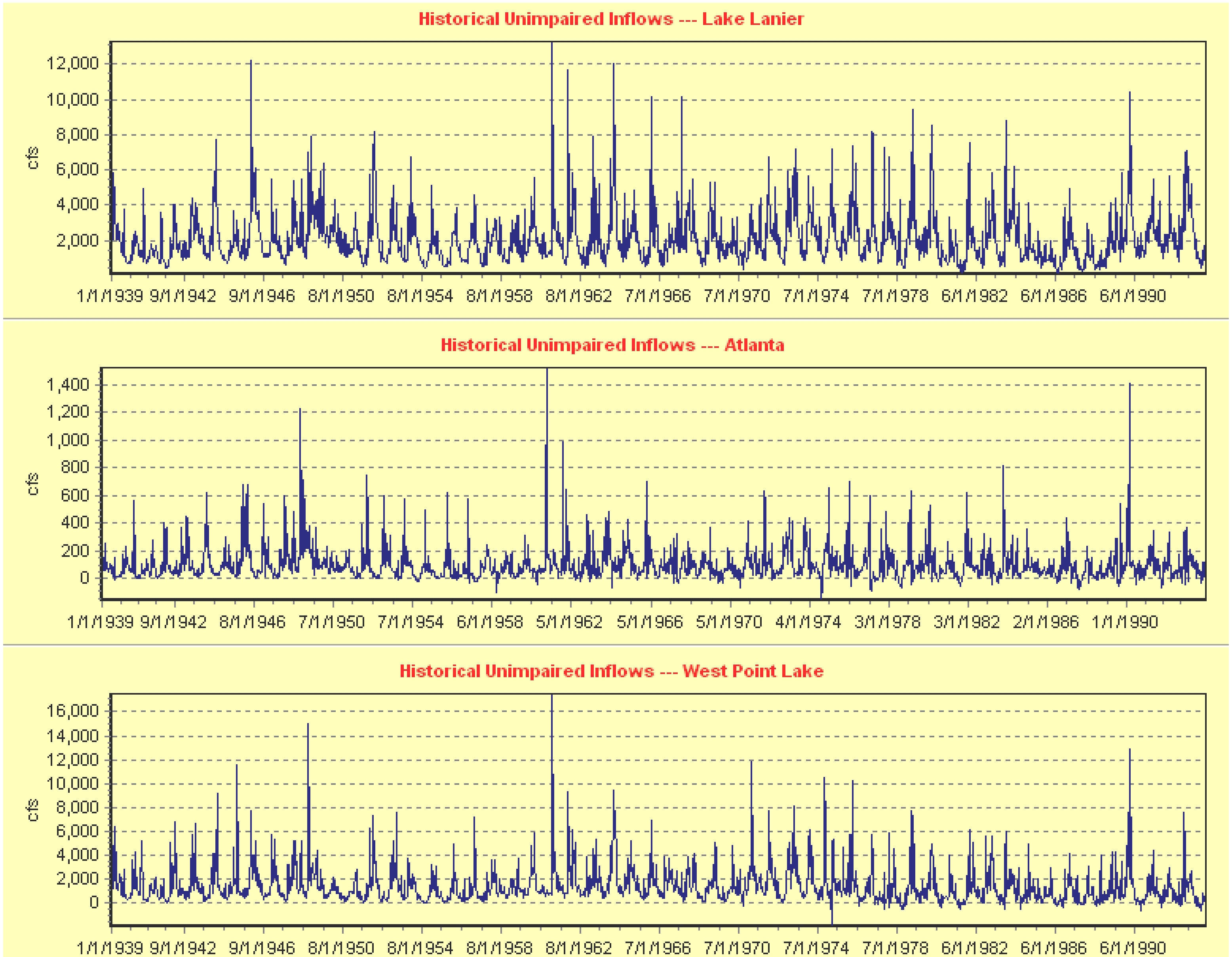
ACF DSS: Hydro Power Data--Buford



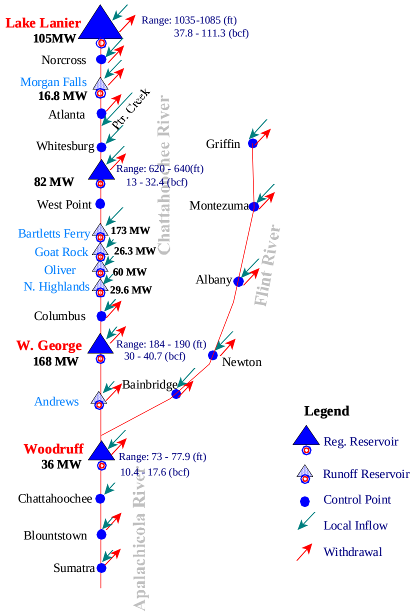
ACF DSS: Withdrawals



ACF DSS: Unimpaired Inflows



ACF DSS: Model Design /Assessment Process



1-Year Forecast-Decision Horizon

Inflow Forecasting

River/Reservoir Simulation

Reservoir Mgt. Basin wide

Management Policy

One Step System Simulation

(Weekly time steps)

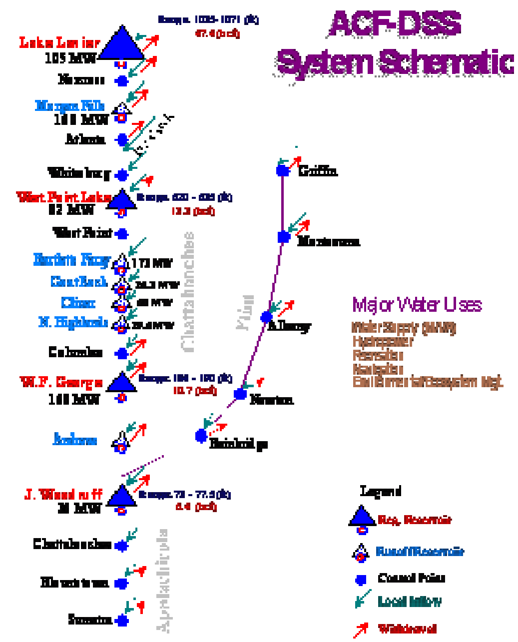
Assessment Criteria
- Lake Levels
- Water Supply Reliability
- Energy Generation
- Instream Flow Reliability
- Navigation, etc.

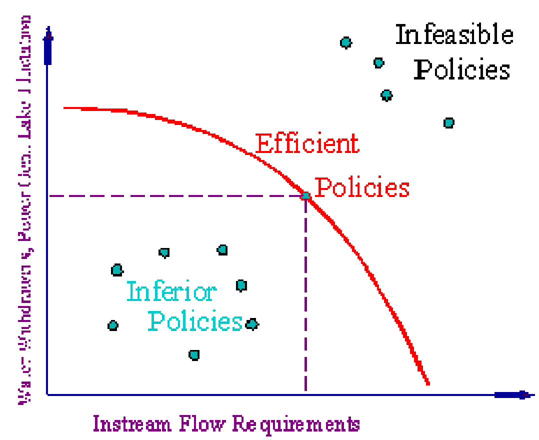
- Demand Scenario
- Inflow Scenario
- Compact Terms
- Instream Flow Trgts.
- Regulation Policy

Simulation Horizon (e.g., 1939 to 2001; 63 yrs)

ACF DSS: Assessment Capabilities

- Basin Response to Minimum Flow Targets
  (e.g., Atlanta; Columbus; Blountstown)
- Basin Response to Peak Generation Hours
- Basin Response to Water Withdrawal Levels
  (e.g., Georgia/Alabama/Florida Demand Proposals)
- Basin Response to Navigation Requirements
  (Channel Depth; Navigation Windows)
- Basin Response to Instream Flow Protection Levels
  (e.g., 7Q10 or Biological Integrity Requirements)
- Basin-wide Drought Assessment & Management
- Management Sensitivity to Inflow Forecast Skill





ACF DSS: Software Demonstration

ACF-DSS and HEC-5 Model Comparison

- Run ACF-DSS and HEC-5 with same input sequences;
- Identify differences, if any
- Document model limitations and evaluate significance

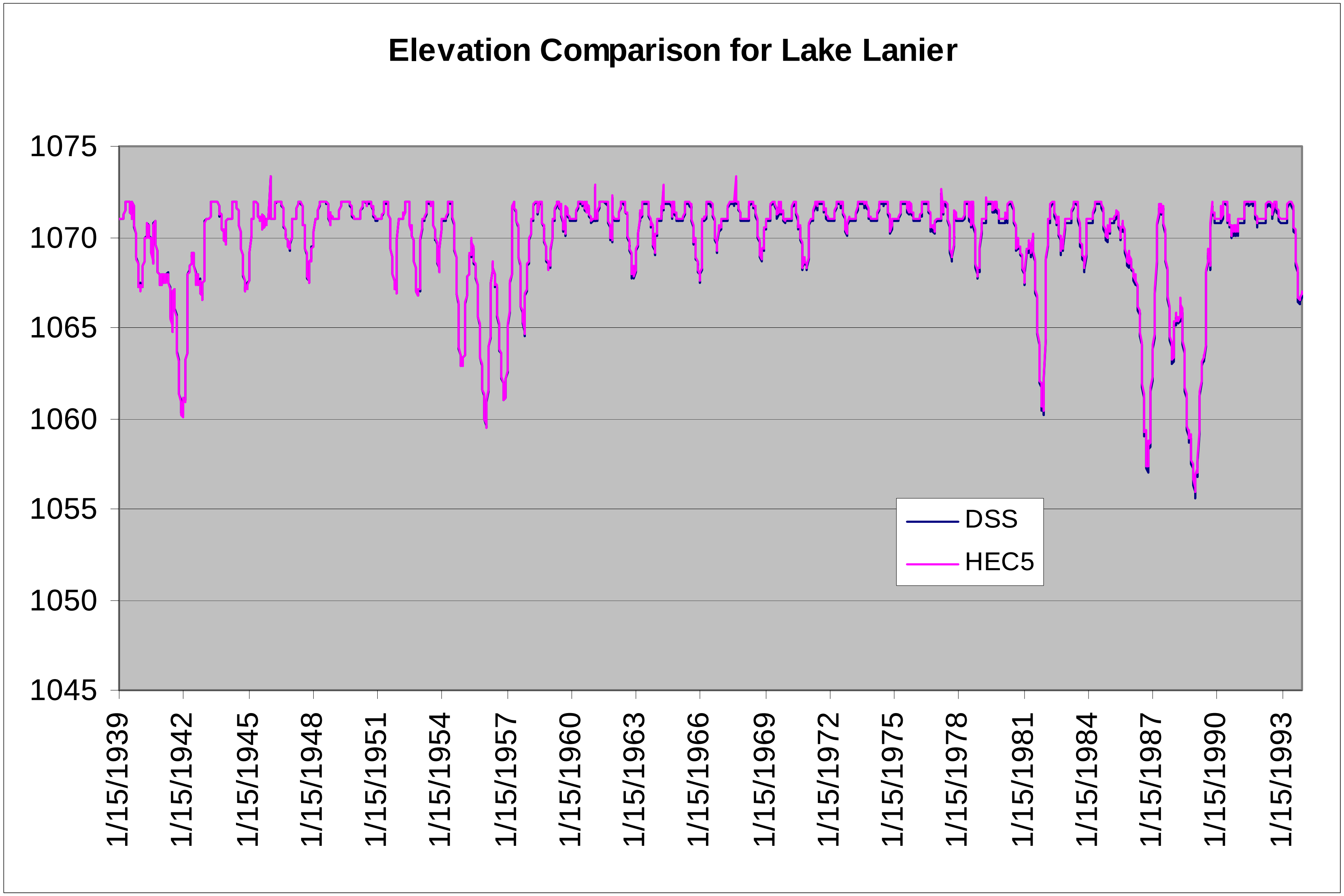
Test Set-up:

HEC-5 Run:
Inflows (1939 to 1993), 2050 Demands, HEC-5 Releases

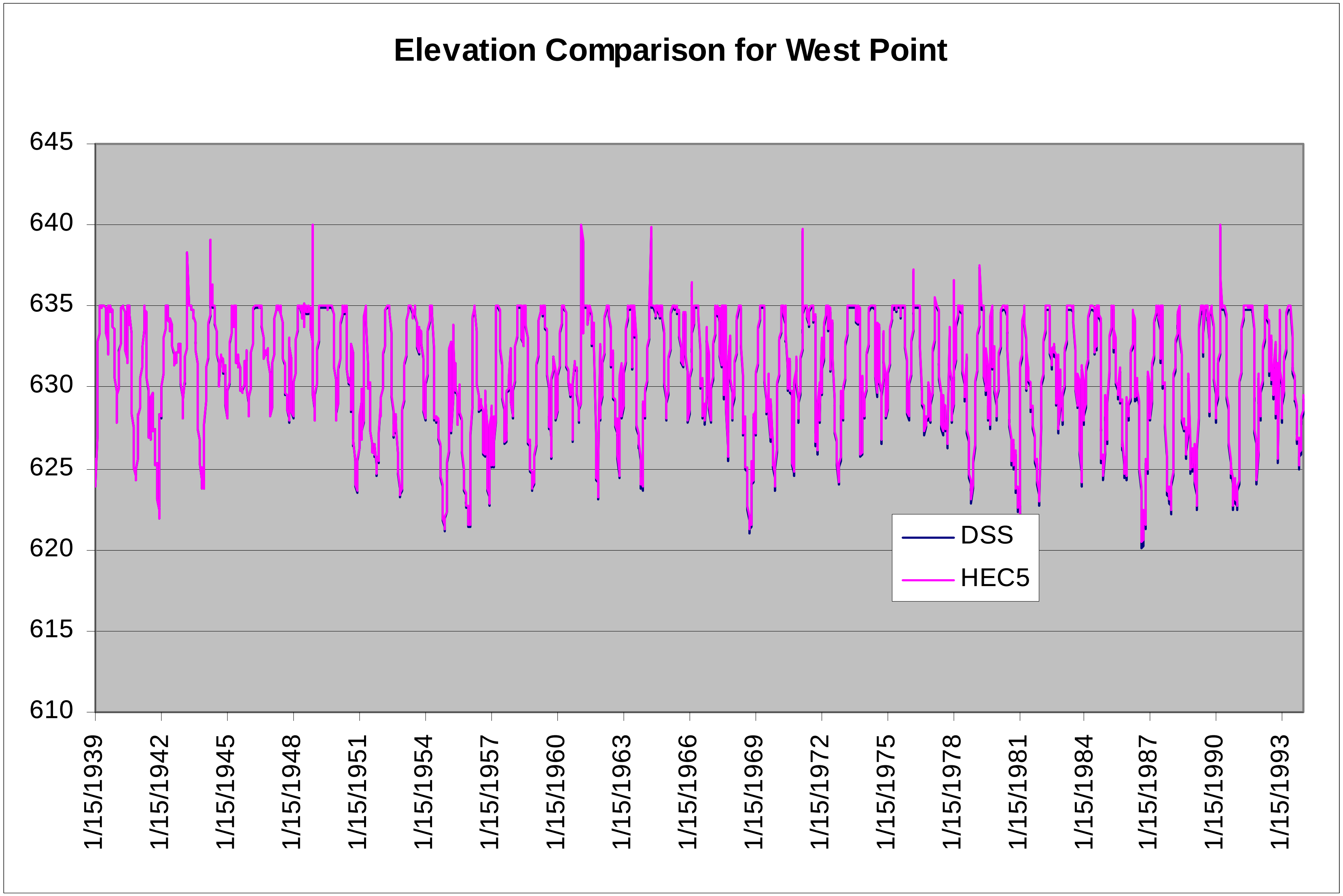
ACF-DSS Run:
Inflows (1939 to 1993) ,2050 Demands, HEC-5 Releases

Comparison Criteria:
Lake levels; Hydro power; Streamflows

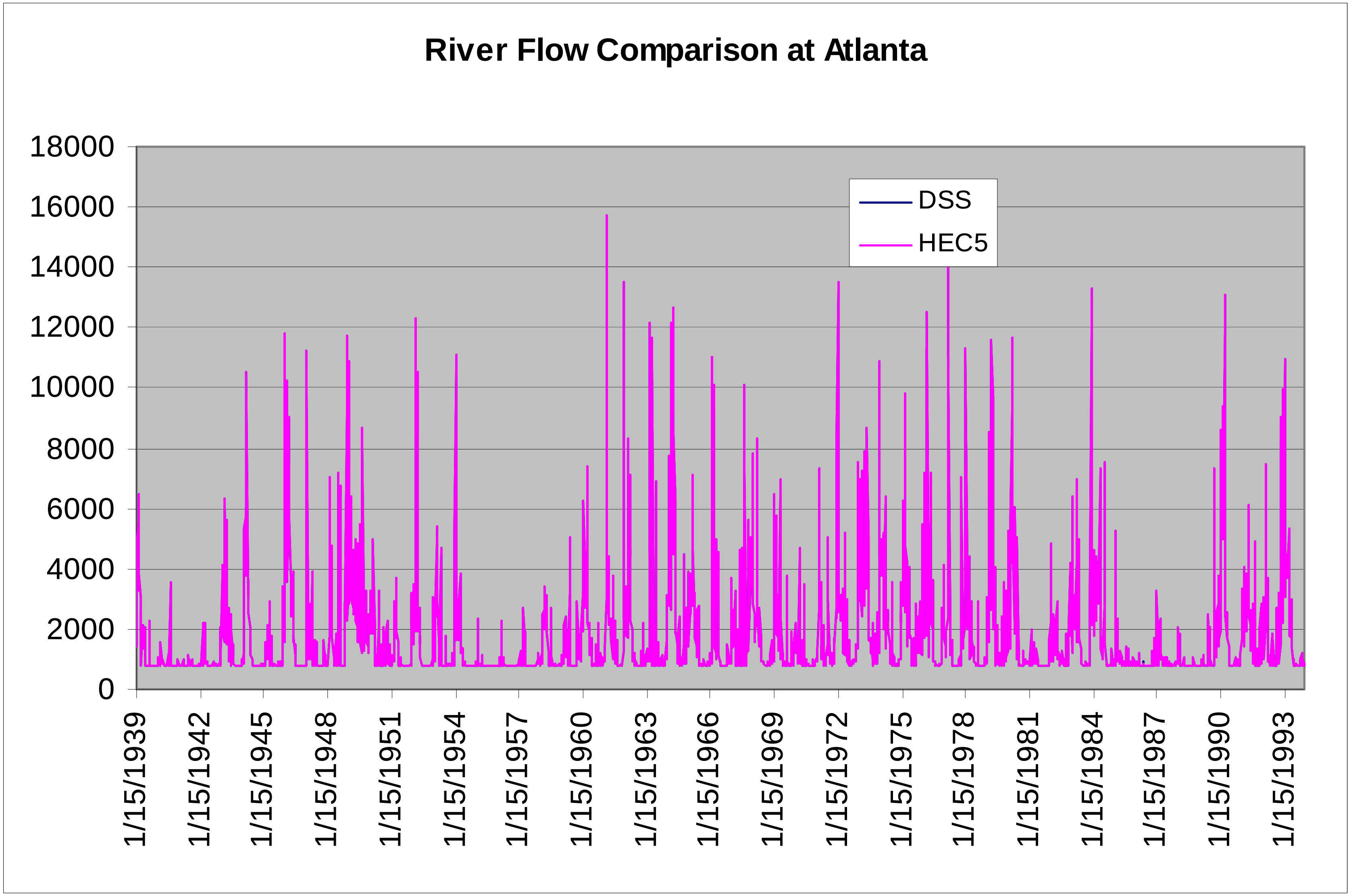
Model Comparison: Lake Levels--Lanier



Model Comparison: Lake Levels—West Point



Model Comparison: Streamflow—Atlanta Gage



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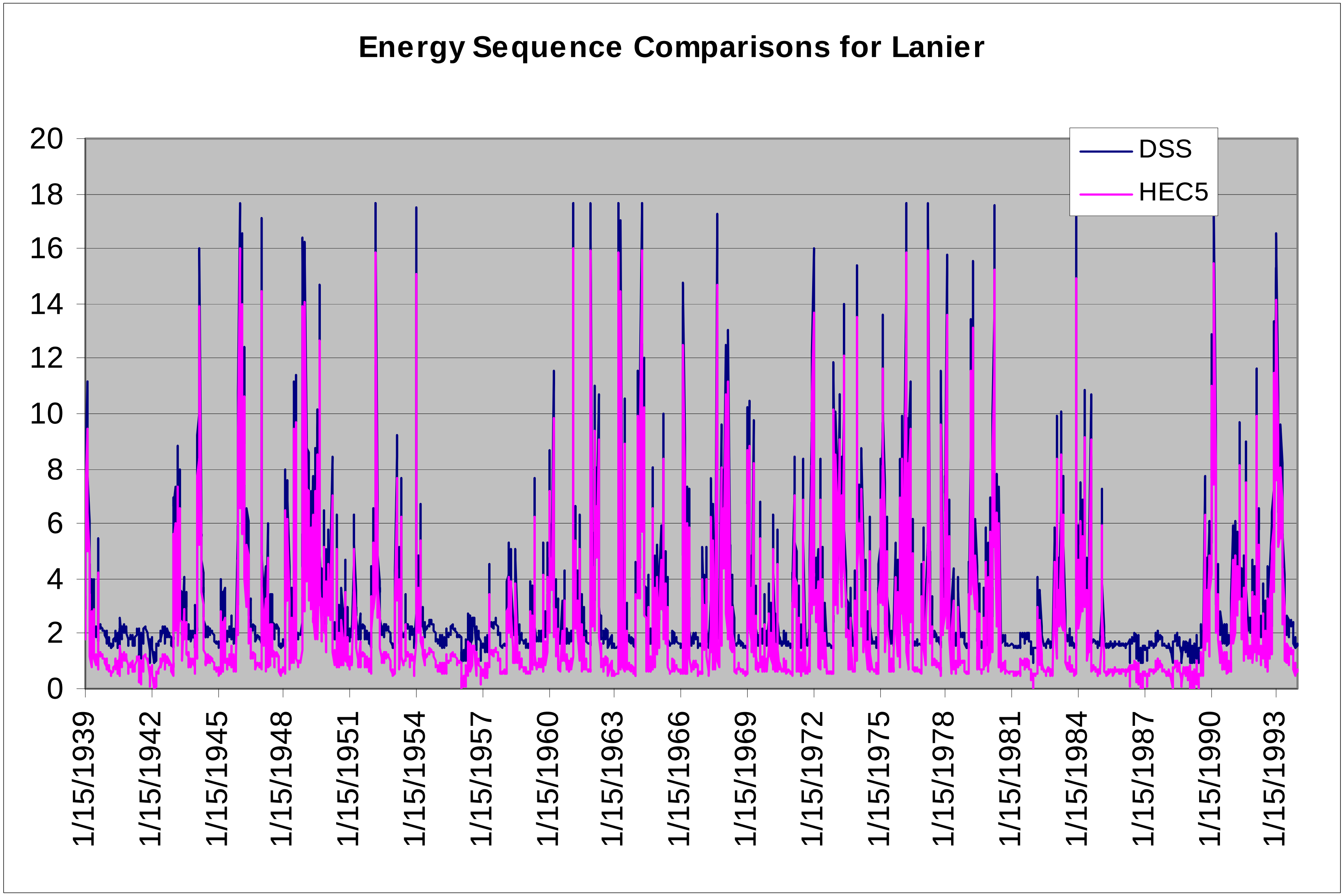
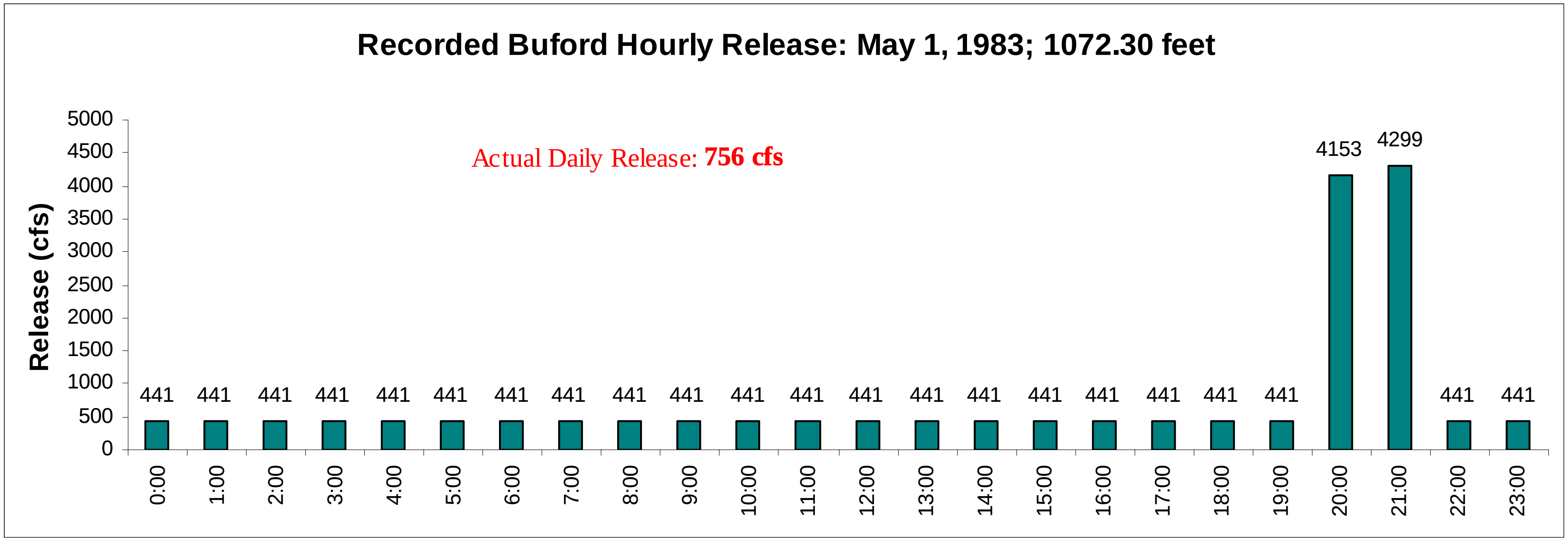
Model Comparison: Hydropower

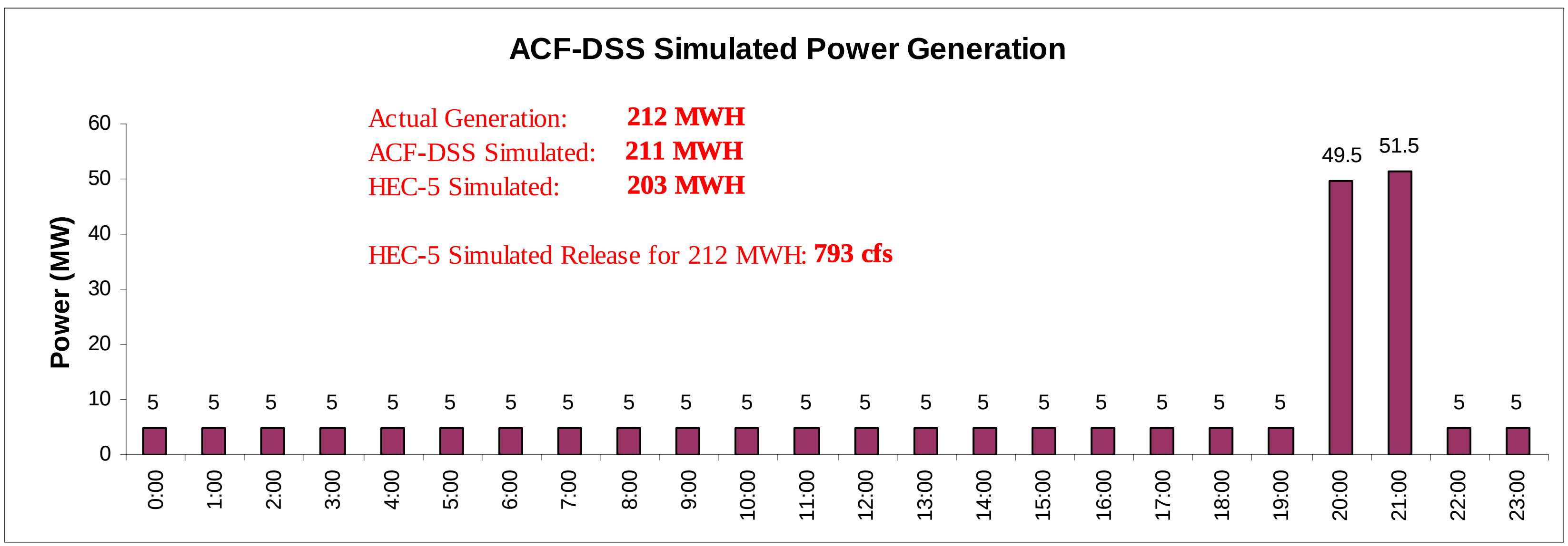


Model Comparison: Energy Generation

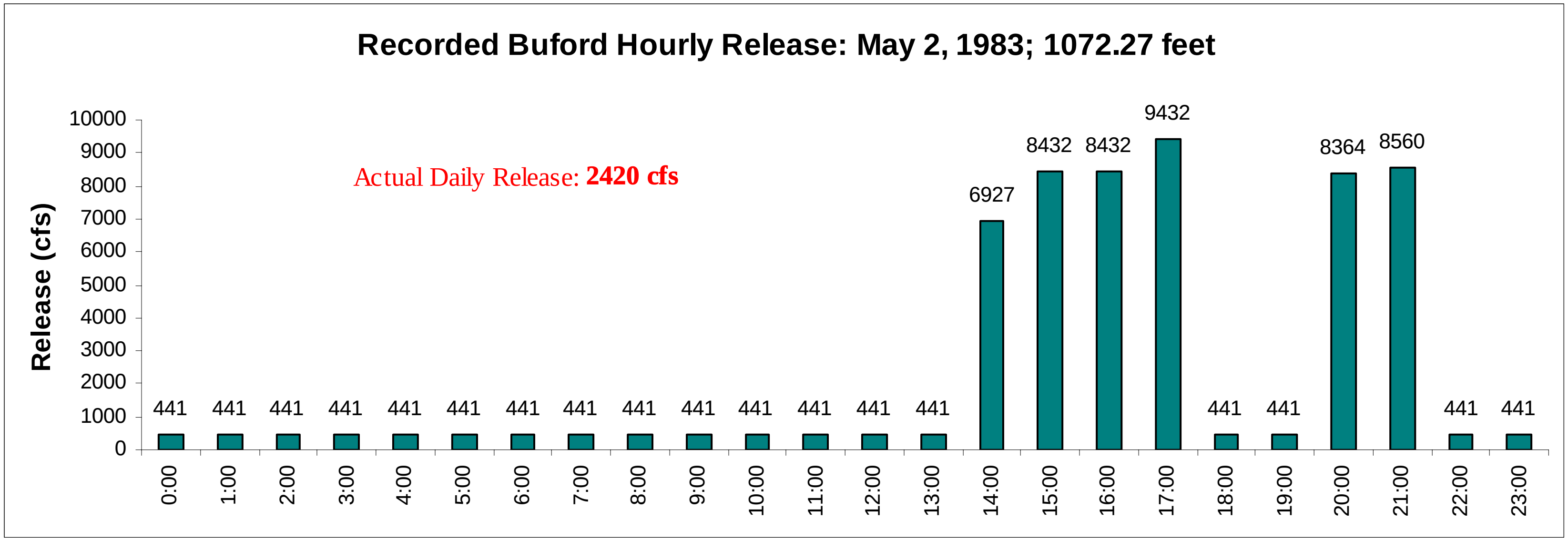
	Buford	West Point	George	Woodruff
DSS (GWH)	163.62	200.09	418.75	201.73
HEC5 (GWH)	151.32	192.76	392.16	217.90
Diff (GWH)	12.30	7.33	26.59	-16.17
Diff %	7.52	3.66	6.35	-8.02

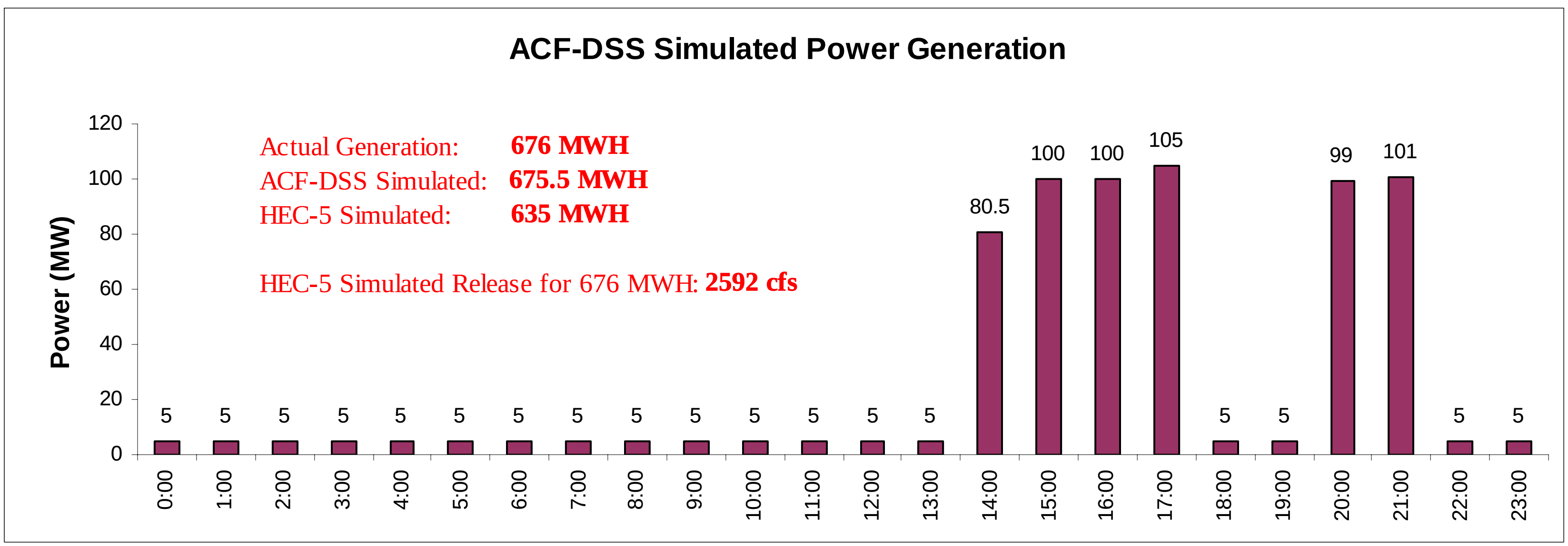
Model Comparison: Power Generation Verification--Buford



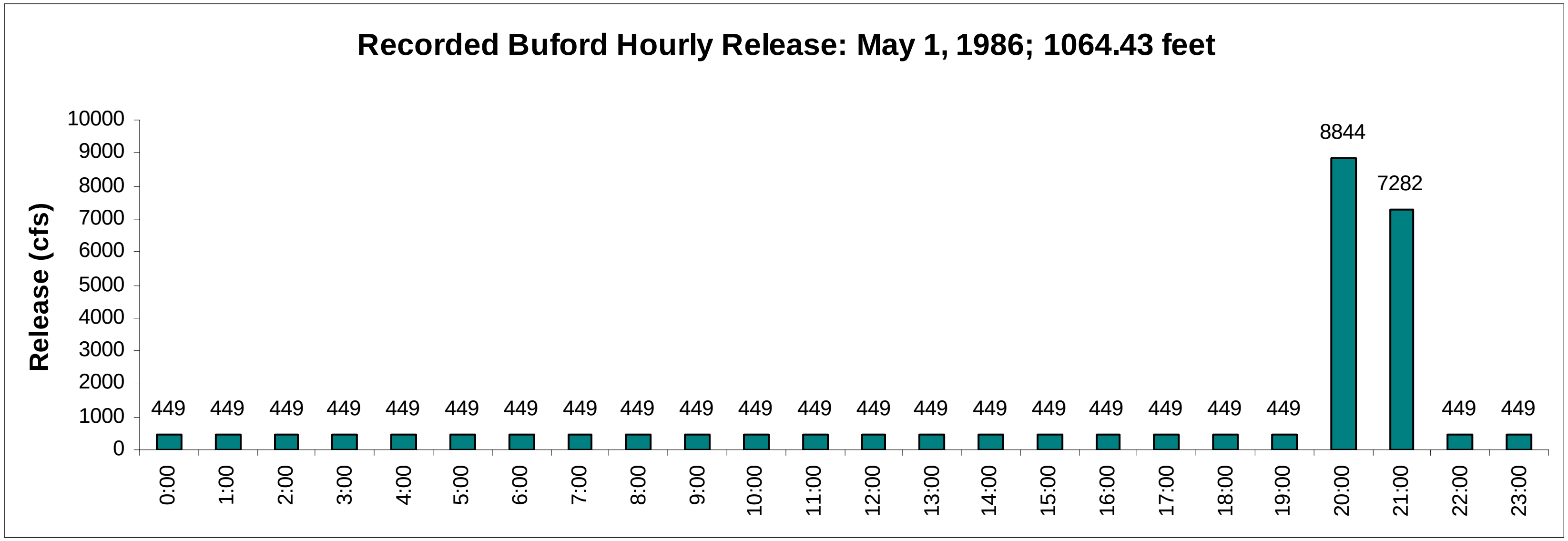


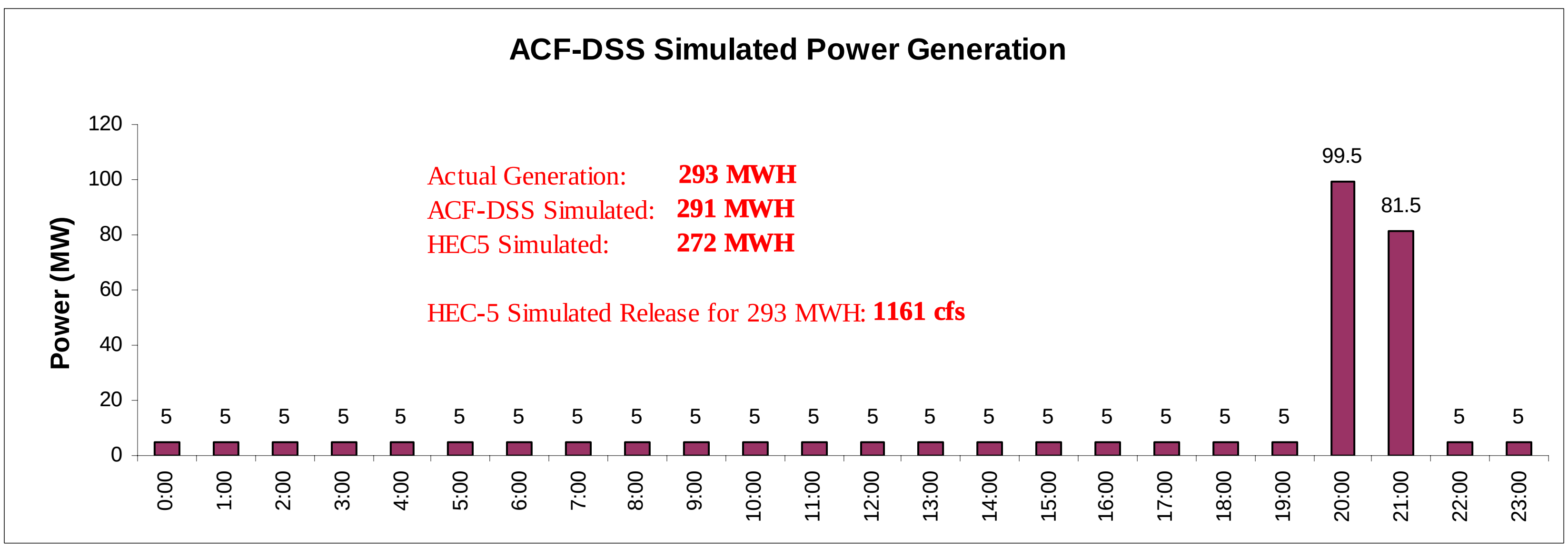
Model Comparison: Power Generation Verification--Buford





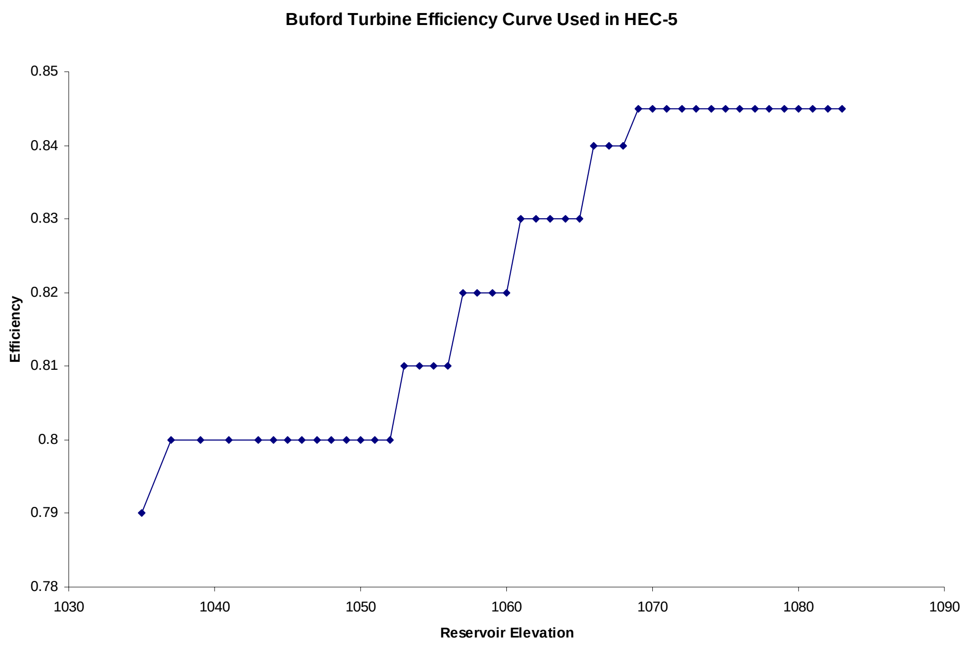
Model Comparison: Power Generation Verification--Buford



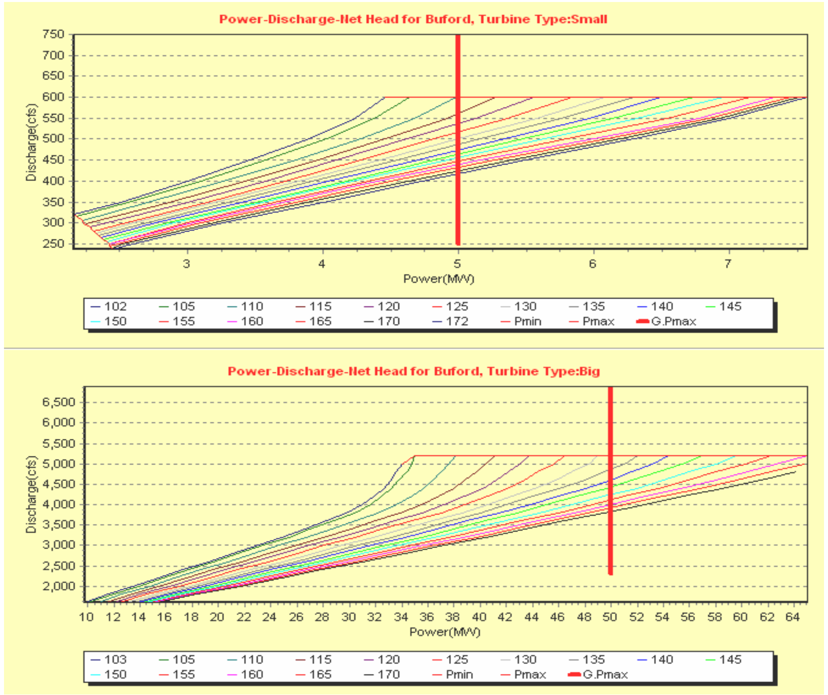


Model Comparison: Cause of Hydropower Discrepancy

HEC-5



ACF DSS



Scenario Investigations

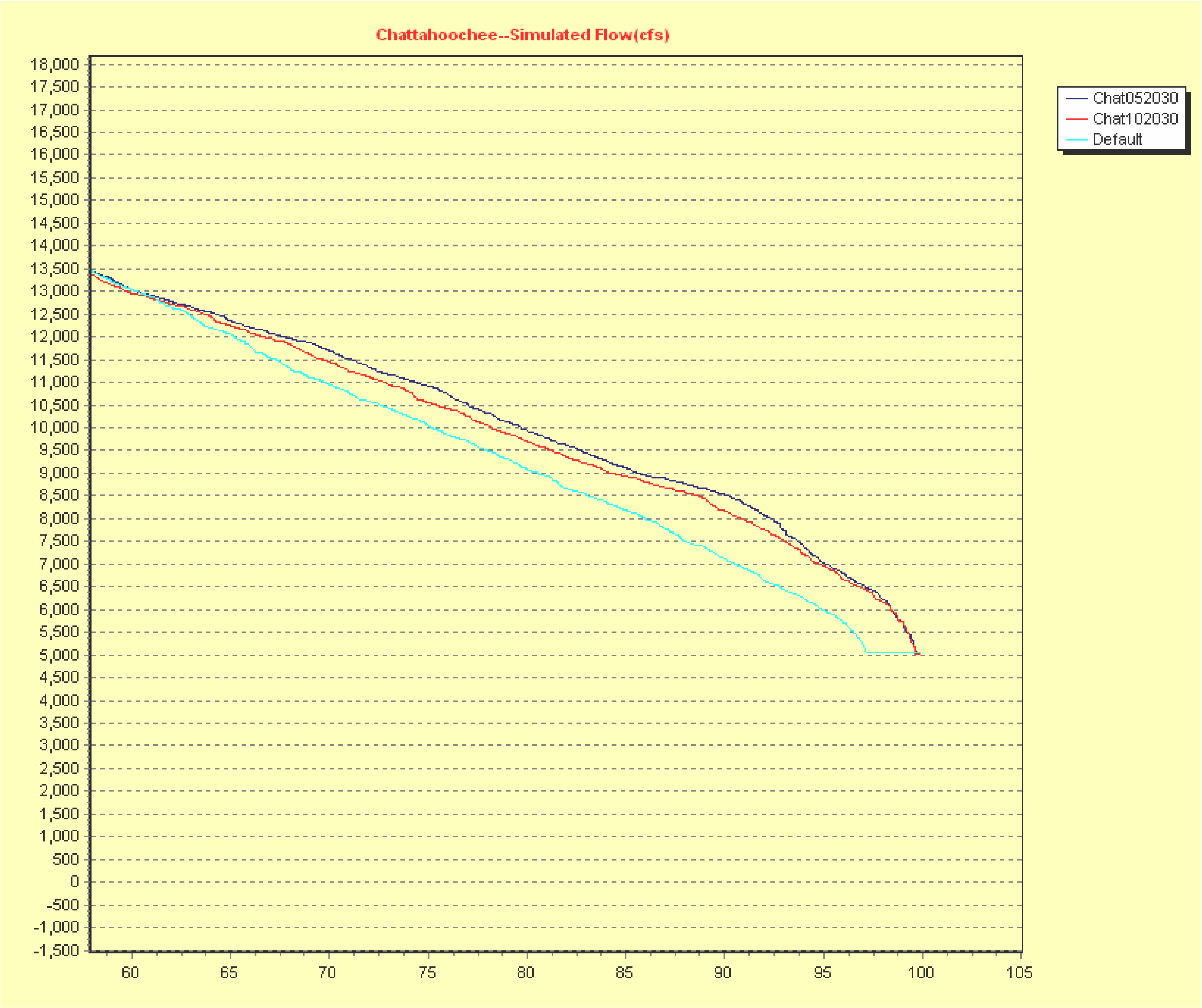
Scenarios:

- ACF Basin Sensitivity to Minimum Flow Targets
  (Atlanta, Columbus, Chattahoochee)
- ACF Basin Sensitivity to Peak Generation Hours
- ACF Basin Sensitivity to Water Withdrawals
- ACF Basin Sensitivity to Navigation Requirements
- ACF Basin Sensitivity to Ecologically Sustainable Flows
  (7Q10, etc.)

Criteria:

- Lake Level Fluctuations
- Energy Generation
- Minimum Flow Constraint Violations
- Water Demand Deficits

Scenario Investigations: Florida Streamflow Target (2030 Dmnds; 750 cfs Atl; 1850 cfs Col; 5000 cfs Chat)



Scenario Investigations: Florida Streamflow Target (2030 Dmnds; 750 cfs Atl; 1850 cfs Col; 5000 cfs Chat)

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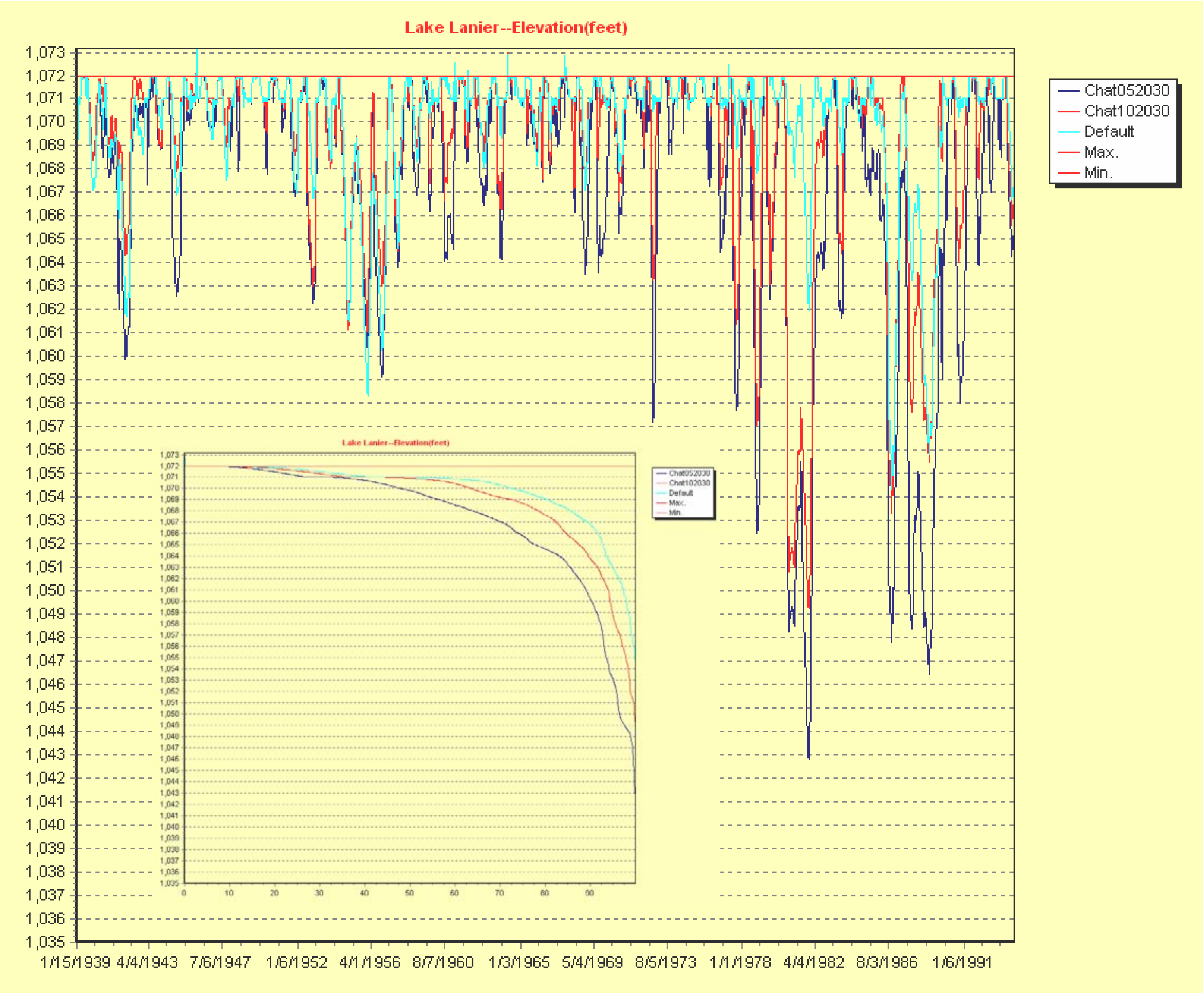
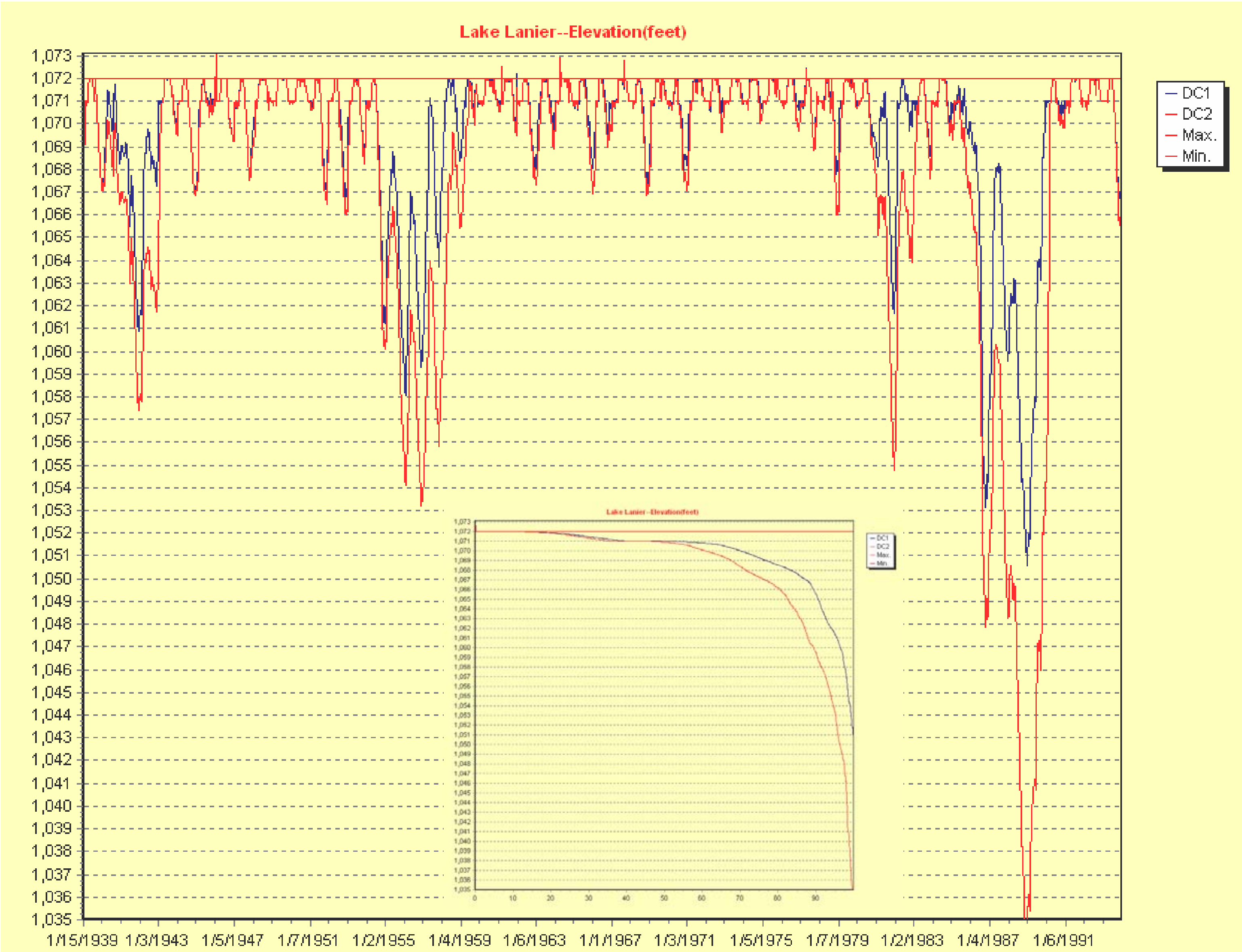
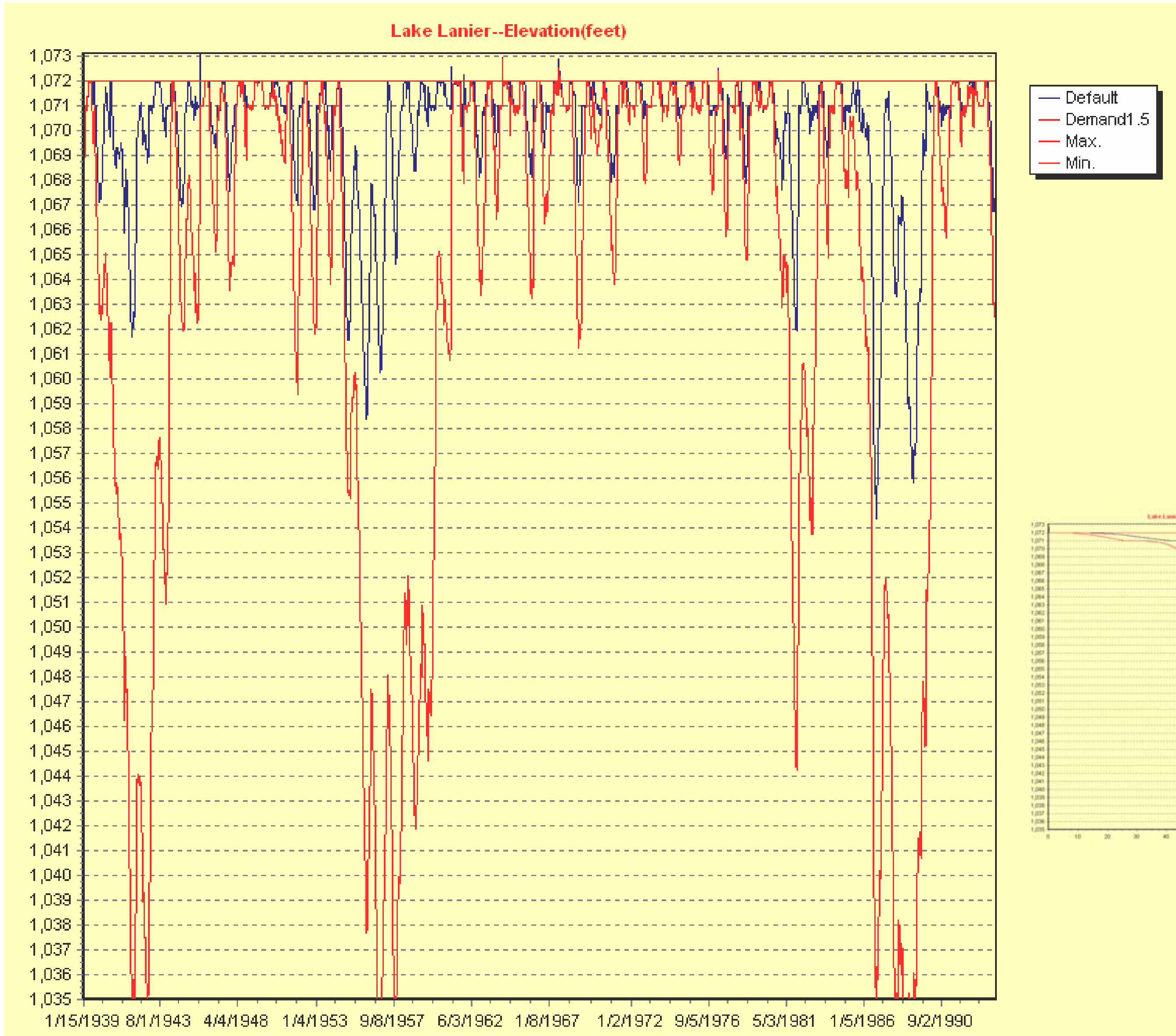
Scenario Investigations: Florida Streamflow Target (2030 Dmnds; 750 cfs Atl; 1850 cfs Col; 5000 cfs Chat)

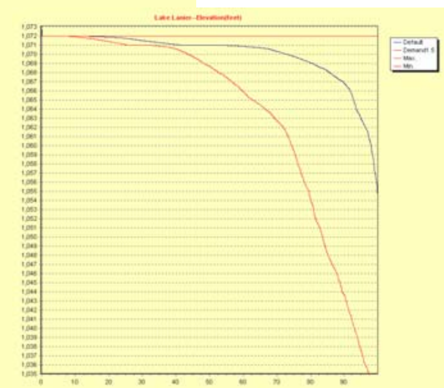


Scenario Investigations: Dependable Capacity Hours (2050)



Scenario Investigations: Demands (2050 vs. 1.5x2050)





Way Forward: DSS Modifications/Scenario Analysis

DSS Modifications ?

- Agricultural Withdrawals/Returns?
- Other?

Assessments/Scenarios to be performed ?

- Potential Compact Terms?
- Critical Basins
- ...

The Impact of Precipitation Measurement Missions on Hydrologic and Water Resources Predictions

Basic Information

Title:	The Impact of Precipitation Measurement Missions on Hydrologic and Water Resources Predictions
Project Number:	2005GA134O
Start Date:	6/1/2004
End Date:	5/31/2007
Funding Source:	Other
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Models, None
Descriptors:	Remote Sensing; Rainfall Estimation
Principal Investigators:	Aris P. Georgakakos, Carlo De Marchi, Christa D. Peters-Lidard

Publication

1. DeMarchi, C., and A. Georgakakos (2006). "A Satellite based rainfall estimation method using Geostationary and TRMM data." Poster Paper, NASA meeting, San Francisco, December 12-13, 2006.

Probabilistic Remote Sensing of Precipitation Combining Geostationary and TRMM Satellite Data

Carlo De Marchi*, Aris Georgakakos*, and Christa D.Peters-Lidard**

*School of Civil and Environmental Engineering, Georgia Institute of Technology
** Hydrological Sciences Branch, NASA-GSFC

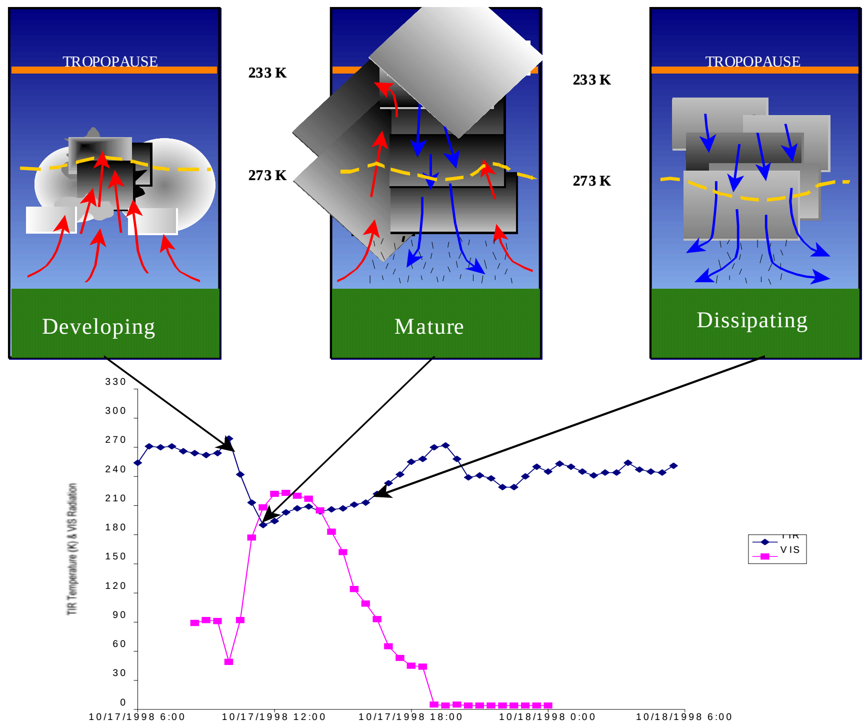
Precipitation Measurement Missions (PMM) Science Team Meeting, Monterey, CA, 12-15 December 2005

Overview

This procedure combines TRMM PR rain-rate measurements (precise, but infrequent) with geostationary satellite infrared (IR), visible (VIS), and water vapor (WV) images (continuously produced) to provide reliable precipitation estimates over a range of temporal and spatial scales. A distinctive feature of the methodology is the use of a neural network for identifying the presence and temporal evolution of convective storms at the pixel level. This operation improves the association of TRMM rain-rates and IR/VIS/WV data by discriminating major storms from smaller events and noise, and by separating the distinct precipitation regimes of the different stages of a storm. Further, the methodology explicitly quantifies the uncertainty of the estimates by providing their error probability distributions instead of single "optimal" values. This is necessary in assessing flood and drought risks.

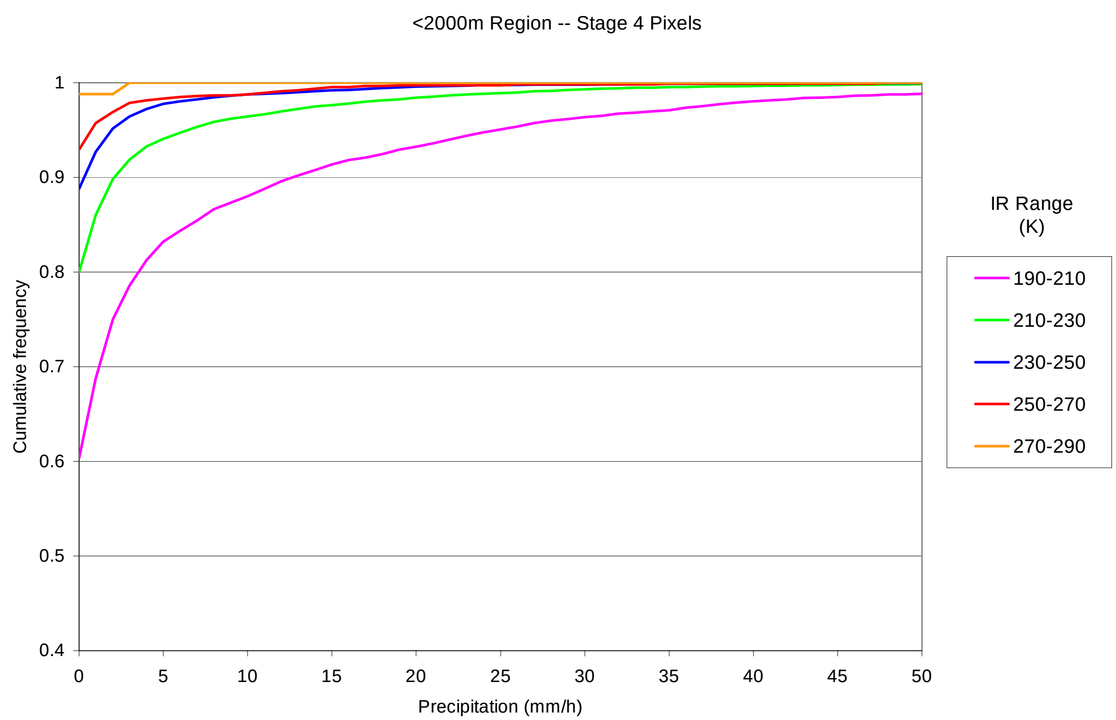
The technique is applied to the Lake Victoria basin over the period 1996-1998. Precipitation estimation accuracy and reliability is tested against data from more than one hundred rain gages.

Convective Cells Evolution



Developing phase: The rapid rise and thickening of clouds result in a steep decrease of the IR temperature and increase of VIS albedo. **Mature phase**: Clouds reach their higher thickness (maximum VIS) while the cloud top approaches the tropopause (minimum IR temperature). **Dissipating phase**: As the convective cell dissipates, the VIS decreases and the IR temperature increases.

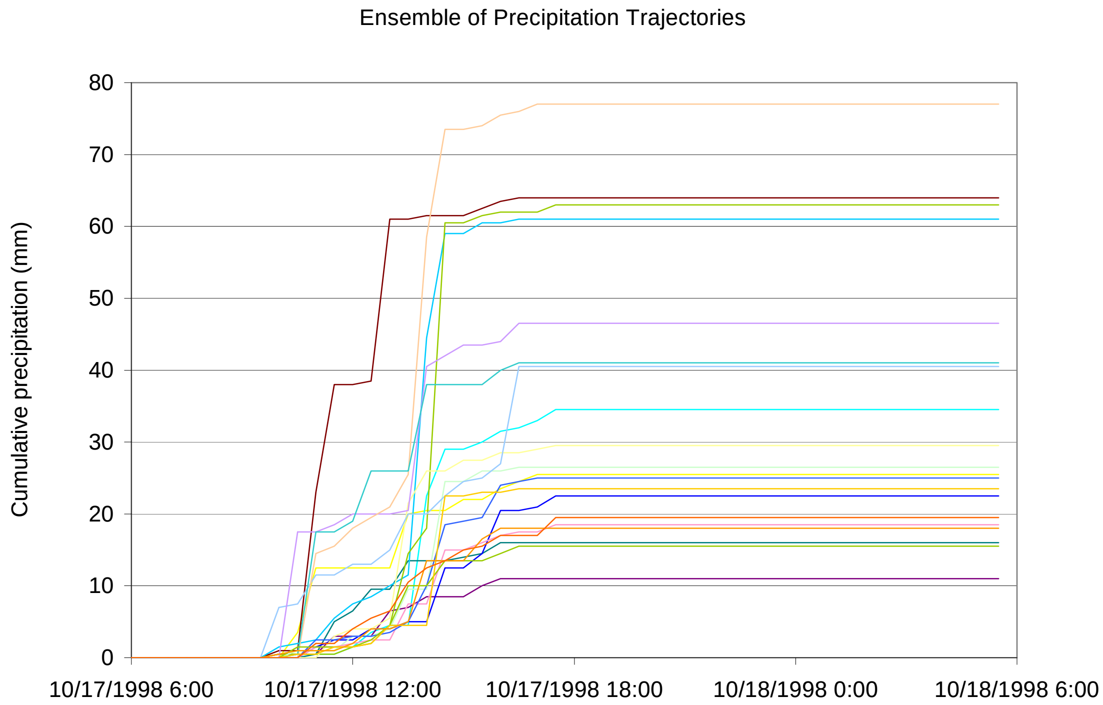
Combining Geostationary and TRMM Satellite Information



IR patterns corresponding to pixels qualified by TRMM PR as convective are used to train a neural network to recognize the IR pattern typical of developing and mature phases, thus providing the basis for identifying the storm stages.

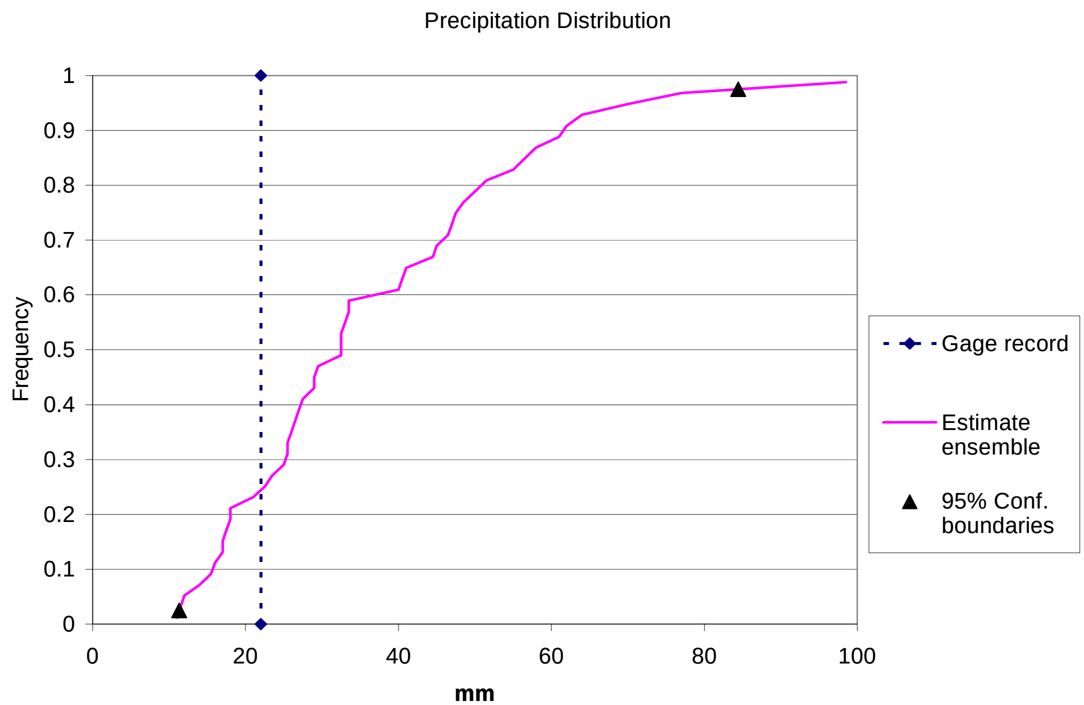
Coincident TRMM PR and geostationary IR/VIS/WV data from 1998-1999 are used to derive pixel-level rain-rate distributions for each combination of IR, VIS/WV, Stage, Orography, and Month.

Generation of Precipitation Ensemble



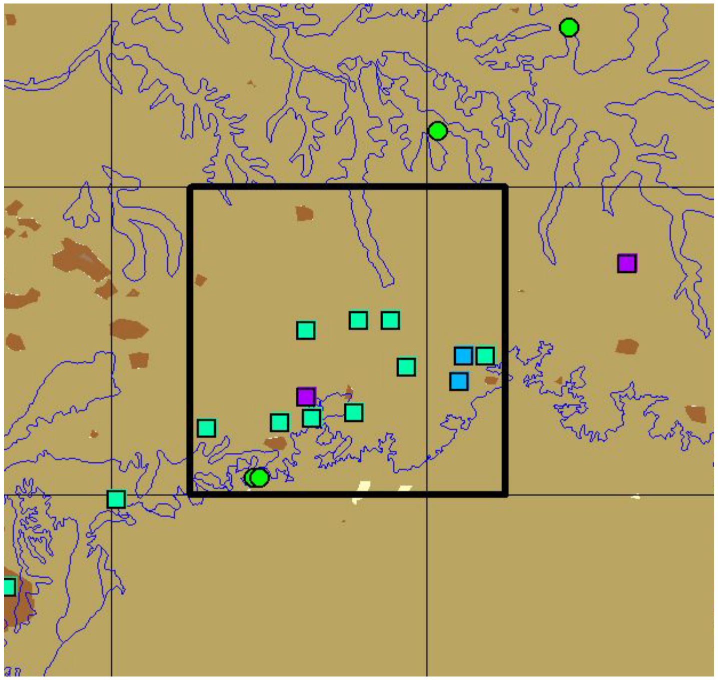
An ensemble of N precipitation values is generated for each half-hour of the estimation period by sampling the entire frequency distribution of available PR rain-rates associated to the observed combination (IR, VIS/WV, Stage, Orography, Month). The half-hour precipitations are accumulated over the desired period and area, providing the range of possible precipitation.

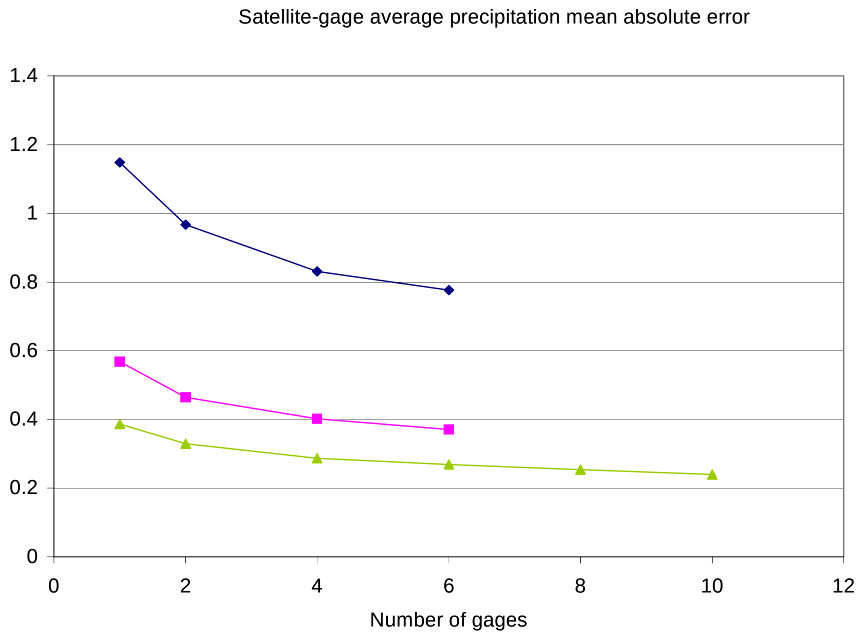
Evaluation of Precipitation Variability



The ability of the estimation procedure to track precipitation variation in space and time can be measured by the correlation and error between average precipitation and gage data. Its capability to represent the precipitation variability can be evaluated by statistics such as the fraction of gage records falling within the estimated 95% confidence interval.

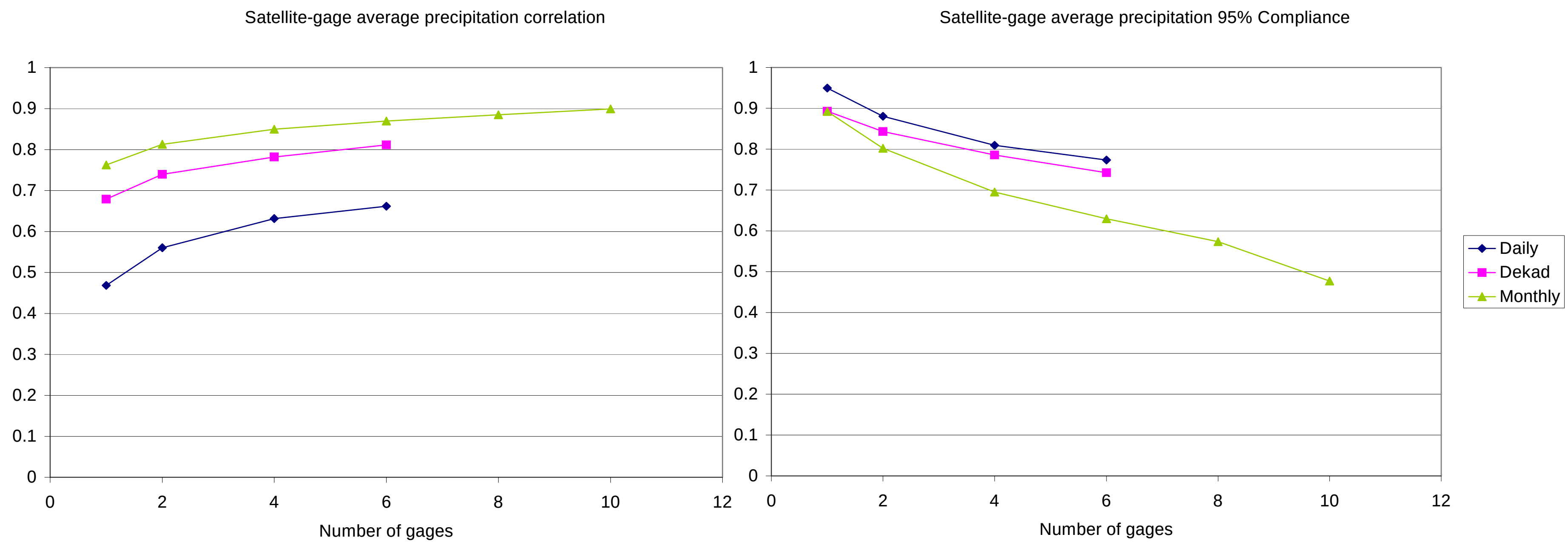
Evaluation of Spatial Performances





Comparison between satellite precipitation estimates and gage records at different temporal (daily, dekad, and monthly) and spatial (1 to 10 gages) scales in the Entebbe-Kampala-Jinjia area in 1996-1997. Good quality monthly data are available for a higher number of stations.

Evaluation of Spatial Performances, Cont.



Decrease in fraction of gage records falling in the estimated 95% confidence interval is caused by the fact that spatial correlation is not modeled. Ongoing work aims to address this issue.

Information Transfer Program

Hydrologic Engineering for Dam Design

Basic Information

Title:	Hydrologic Engineering for Dam Design
Project Number:	2005GA135O
Start Date:	10/11/2005
End Date:	10/12/2005
Funding Source:	Other
Congressional District:	5
Research Category:	Engineering
Focus Category:	Hydrology, Floods, Water Supply
Descriptors:	Continuing Education Course
Principal Investigators:	Bert Holler

Publication

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	1	0	0	0	1
Ph.D.	8	0	0	0	8
Post-Doc.	1	0	0	0	1
Total	10	0	0	0	10

Notable Awards and Achievements

Publications from Prior Projects