CUAHSI HO Prospectus:

Apalachicola–Chattahoochee–Flint Rivers
`www.hydrology.uga.edu/acf`

Principal Investigator:

M. Bruce Beck
Eminent Scholar and Endowed Chair
Water Quality and Environmental Systems
The University of Georgia, Athens, GA
mbbeck@uga.edu

Spatial Extent

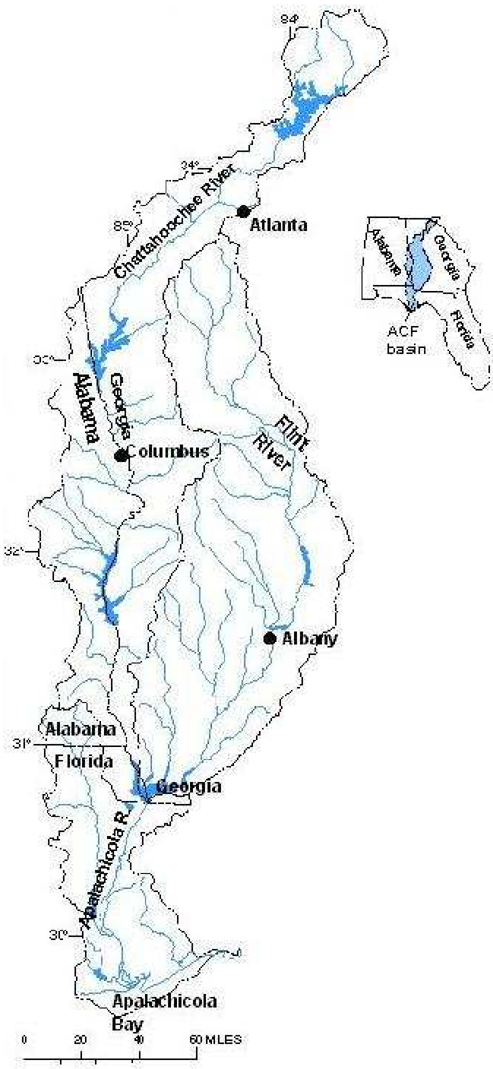
The Apalachicola-Chattahoochee-Flint River system forms a watershed of approximately 20,000 square miles. The Apalachicola River is the lowermost segment of this system, draining 2,600 mi^2, including a shallow estuary that covers 208 mi^2. The discharge of the Apalachicola River, approximately 19,602 cfs, is 21^{st} in magnitude among the rivers of the contiguous United States, and is the largest in Florida. The Apalachicola River is formed by the confluence of two large tributaries, the Chattahoochee and Flint Rivers, near the Alabama-Florida-Georgia border.

This project focuses on five different segments within the ACF:

Headwaters: Draining from the southern reaches of the Appalachian Mountains to (and including) Lake Lanier - the only natural, free-flowing segment of the Chattahoochee River;

Chattahoochee River Corridor: From below Lake Lanier to the confluence with Peachtree Creek - an urbanized section that is heavily utilized for potable water;

Middle Corridor: Includes the Piedmont sections of the Chattahoochee and Flint River systems below the Atlanta metro area - affected by waste discharges and flow alteration;



Coastal Plain: The lower sections of the Chattahoochee and Flint Rivers, and the riverine extent of the Apalachicola River - affected by ground-water use and reservoir operations; and

Apalachicola Bay: The estuarine component of this hydrologic observatory.

The Chattahoochee River is the largest tributary to the Apalachicola, and drains 8,770 mi^2 with a median discharge of 8,250 cfs. The river is the most heavily used water resource in Georgia, supplying 80% of the water for the Atlanta metro area, but is one of the smallest rivers in America serving a major metropolitan area.

One focus of the HO initiative is the Chattahoochee River Corridor, which represents the portion of the river that flows from Lake Lanier - a headwater reservoir operated by the U.S. Army Corps of Engineers - through the northern urban areas of Atlanta with a corridor terminus at Peachtree Creek in the middle of the Atlanta metro area. While the Chattahoochee River Corridor is a National Recreational Area, it also serves as the primary potable-water source and receiving body for stormwater, urban stormwater, and reclaimed wastewater.

The Atlanta metro region relies on surface water for 98% of its needs because shallow bedrock limits groundwater resources. Alternative water resources are limited because the Atlanta region is located at the headwaters of its rivers and streams. The Atlanta region's rate of growth has eclipsed most other major cities - growing by a million residents during the past ten years.

Above Lake Lanier, the river is dominated by rural regions with major agricultural activities focused on poultry and agricultural crop production. The river corridor is at the point of maximum allocation as a potable-water resource and this maximum allocation has been reached, and occasionally exceeded, each year in the past decade. There are also major concerns as to the sustainable use of the river corridor both as a potable-water source and as a receiving stream for stormwater runoff and wastewater.

Key components of the hydrologic observatory include Lake Lanier and its downstream river corridor, as well as water-use facilities and systems associated with the river. Lake Lanier is a multipurpose reservoir located to the north of Atlanta that is used to augment water supplies during drought periods.

The second major tributary is the Flint River, which is 350 miles in length and drains an area of 8,460 mi^2. The lower sections of the Flint River lie in the Dougherty Plain, where the hydrology is primarily controlled by stream-aquifer interactions. The Floridan aquifer system, one of the most productive aquifers worldwide, underlies this region.

Regional Importance: The 20-county Atlanta Metropolitan Area is the ninth largest - and one of the fastest growing - regions in the nation. The metro area has grown from a half-million inhabitants in the 1950s to more than four million today, plus another million people are expected to move to the area over the next 15 years. Severe droughts in the 1980s and from 1998–2002 caused severe disruptions in water systems throughout the region.

Meeting the needs of a projected 60% increase in water demands by the year 2020 is a major regional challenge. To meet these needs, the State of Georgia has been withdrawing increasingly more water from the Upper Chattahoochee and Etowah rivers and is proposing controversial water transfers between these basins.

Also, environmental litigation related to waste-water and storm-water discharges to the Chattahoochee River has resulted in an initiative to spend upwards of $5 billion on infrastructure improvements within the Atlanta Metropolitan Area. The Chattahoochee Corridor was included within the recent USGS water-quality study of national waters, and is clearly at risk relative to trace levels of anthropogenic contaminants such as pharmaceuticals, which represent an emerging class of persistent and toxic organic compounds.

Finally, the two downstream states, Florida and Alabama, are increasingly concerned about the water allocations and burgeoning waste loads in the headwater state of Georgia. Currently, Alabama, Florida, and Georgia are attempting to form an interstate compact to establish a long-term allocation of river flows. Efforts to establish limits on waste loads are not being considered during these negotiations, but are clearly an essential component of long-term planning.

Ecologic Diversity and Importance: The Apalachicola - Chattahoochee - Flint River system harbors a rich diversity of ecosystems, including the Apalachicola Bay and its flourishing fishing industry. The maintenance of the biological productivity of Apalachicola Bay is of great importance to Florida. The upper sections of the river provides a refuge for a large number of aquatic species, including fish, mussels, and aquatic invertebrates.

The environmental health of this system is threatened by coal-fired power plants that use the river for cooling water disposal. Also, municipal wastewater and stormwater discharges routinely adversely affect river water quality. A series of reservoirs have flooded significant sections of the Chattahoochee River, and current release policies threaten to alter the natural magnitude and variation in flows within the few remaining sections of the river.

In addition, increasing rates of groundwater pumping by agriculture, industries, and municipalities from the Floridan aquifer threaten to reduce instream flows in the lower sections of the river. Reductions in instream flows and the concomitant alteration of stream temperatures and dissolved oxygen concentrations are of great concern to fisheries ecologists.

Need for Comprehensive Water Management: The combination of recent droughts, burgeoning growth, environmental litigation, and interstate water claims have forced Georgia - and the Atlanta Metropolitan Area - to recognize the finite nature of their water resources. The challenge is to utilize the limited water resources for future development, while at the same time protecting the unique Southeastern aquatic environment present in these systems.

The base minimum regulated daily flow for the Chattahoochee River is regulated to assure adequate potable-water resources and dilution of wastewater discharges. This minimal regulated flow has routinely been reached in summer months and represents the maximum water allocation possible for the Atlanta metro area.

There is an ongoing regional debate over the allocation of water represented by the peak power capacity of Lake Lanier to other non-power-generation uses. While this issue is not resolved, it adds to the opportunities for use and implications of this waterway as part of a hydrologic observatory.

A small step has recently been taken to begin the process of Comprehensive Water Management Planning. Georgia has established a process for designing how a water management system should be organized. Basic data and monitoring systems are lacking, however. Only parts of the system are monitored with sufficient density to provide the data needed for water allocation that effectively protects environmental systems.

Scientific Rationale for Design

The Apalachicola - Chattahoochee - Flint River system provides a unique opportunity to address urban impacts on the hydrologic cycle and water quality because of the importance of the system as a drinking water resource within the Atlanta metro area, as well as the effects of waste loading on downstream systems. We have the opportunity to link HO monitoring data and research findings to metropolitan water use, distribution, decision-making processes, and human-health effects (via the Centers for Disease Control and Prevention). We also feel strongly that any proposed monitoring systems and research focus areas must be hydrology-driven.

There are clear research needs that must be addressed before management of the regions natural resources - especially water - can be addressed, including:

- We have limited understanding of the impacts of urban development on the movement of nutrients and contaminants through impounded river systems and into their estuaries.
- We need a better understanding of whether so-called *smart urban development* can mitigate adverse effects of nutrient loading and cycles associated with urban development;
- Our knowledge of the effects of urban heat loading on hydrologic systems is poorly supported by data - our knowledge of stream temperature response is limited to the effects associated with shade removal, but little about the response to runoff from hot paved areas.
- We require a more comprehensive understanding of hillslope water flow dynamics and stream responses to landscape changes.

A hydrologic observing system is proposed that focuses on two fundamental challenges in comprehensive water management. The first challenge is related to urban water, wastewater, and stormwater issues associated with the Atlanta metro area. Lessons learned in this study can serve as the basis for solutions in other rapidly expanding urban areas throughout the country.

The second challenge is the need to protect environmental systems - both within the urban core as well as within the outlying rural fringe that is increasingly subject to development pressure. In addition, downstream areas are becoming increasingly affected by the waste loading and flow reductions caused by rapid metro development.

The following subsections addresses each of these challenges in more detail.

Water, Nutrients, and Pathogen Cycling in Urban Systems: Expanding metropolitan areas require increasing amounts of high-quality water at an affordable price. This escalating demand is a function of both population increases as well as increased per capita water uses. Increasing affluence means that water-intensive amenities (swimming pools, landscape irrigation systems, etc.) are becoming *de rigueur* for suburban living. Conservation practices, in many areas, are not keeping up with these increased expectations - resulting in increased per capita water usage.

Once delivered to metropolitan areas, water is ideal for transporting wastes - both domestic and industrial. While many of these wastes are contained within sanitary sewage systems and onsite waste disposal systems, many fugitive contaminants make it into nearby waterbodies as nonpoint source pollution, combined sewer overflows, or from sewer blockages and overflows. The health effects related to water reclamation and reuse require a better understanding of contaminant fate and transport in urban systems.

A critical need is to provide complete coverage of the urban water cycle, including the abstraction, potable treatment, distribution, discharge to a sewerage system, wastewater treatment, and return to natural systems. This coverage must account for the nutrients and pathogens mobilized and removed during the urban cycle itself. While the global nitrogen cycle related to agriculture (and other nonurban sectors) have received great attention - a glaring gap exists when it comes to the water cycle passing through the city and its water infrastructure. Quantifying sources and amounts of fugitive discharges is also needed within urban waterways.

Wastewater re-use is being considered as a means of increasing available supplies, yet pathogens and trace contaminants (such as endocrine disruptors) within treated wastewater introduce risks that have not yet been quantified nor fully accepted by the public. There is also a critical need for pathogen work from data-collection and modeling-development perspectives, while others of us are interested in pathogens from an aquatic ecology perspective.

Water Reclamation and Re-Use: There are six water reclamation facilities on the Chattahoochee River Corridor (between Lake Lanier and Peachtree Creek) with direct discharges to the river and three facilities with discharges to tributaries of the corridor. In addition, over 60 water-reclamation facilities in the Atlanta metro area provide opportunities for research because the majority of these discharge into the Chattahoochee River.

A unique facility at the head of the corridor represents an exceptional research opportunity. Gwinnett County is eliminating its interbasin transfer of waters and will begin placing reclaimed waters back at the headwaters of the corridor, allowing for advanced and unique investigations of water recycling on a metropolitan river. This action would place the observatory in the position of providing long-term research opportunities related to increased re-use and recycling of waters.

An additional facility in this regard is a private system, coupled to a county sewerage system, which is producing re-use water for PGA and other golf courses in the upper reaches of the corridor. This innovative membrane-based facility provides enhanced opportunity for research of the coupled re-use of wastewater in human-contact environments and interconnections between surface and groundwater systems.

Finally, the Atlanta metro area has a county water system that is recycling 80% of its wastewater into its potable-water reservoirs using an advanced nutrient-removal system with an extensive wetlands-based system. This expands upon a land-application system used for the past 25 years to reclaim waters at the 20% level.

Stormwater Management: Stormwater is a critical national concern of the future. The Atlanta metro area provides an opportunity for advanced examination of this issue. The City of Atlanta has initiated a $3 billion initiative to address the effective reclamation of storm waters which will be a major opportunity regarding impacts on stream ecology and water-resource enhancement. Georgia Tech is a partner in this initiative and is expanding its research programs to include the water infrastructure systems of the City of Atlanta.

Growing Urban-Rural Interface: Because the basin is situated in an area with unparalleled biological diversity, the maintenance of critical biogeochemical cycling and biotic evolution and response is a clear challenge to comprehensive water management. We are faced with a tradeoff between urban development and environmental stewardship, with special attention to the need for critical flow regimes and reservoir management issues related to minimum low-flows.

Existing Data Infrastructure

Links to these documents can be found at our main website `www.hydrology.uga.edu/acf`.

USGS Studies: The U.S. Geological Survey has conducted a wide array of technical investigations within the study area. Of specific interest are studies related to fecal coliform, as well as dissolved oxygen. Additional projects can be found at `georgia.usgs.gov/projects/`.

NAWQA Studies: Fortunately, another strong basis for data collection was started as part of the NAWQA program. The basin was extensively monitored during the initial period of NAWQA activities. Recent and current research activities can be found at: `wwwga.usgs.gov/nawqa/`.

Other Studies: Additional data sources include the state of Georgia Environmental Protection Division's Chattahoochee River Corridor study, along with the Upper Chattahoochee Basin Group's Lake Lanier investigations. A wide range of U.S. Fish and Wildlife, NOAA, and other regional studies are ongoing, focusing on the effects of urbanization on environmental systems.

Proposed Core Data

Data Characteristics

Key criteria for data collection are that they:

- Provide continuous (real-time) monitoring of key water quantity and water quality variables;
- Provide uninterrupted time series over very long periods - decadal and beyond;
- Take advantage of existing monitoring networks, in particular, the real-time water quality networks described in a previous section;
- Supplement other specialized observing platforms, such as those described below.

Data Collection and Analysis

Data collection will focus on the following studies. Concurrent and subsequent analysis will be used to refine these studies, with the intent of providing high-quality information for promoting regional development without degrading the environment.

Regional Studies: This component focuses on acquiring data for large-scale hydrologic and eco-hydrologic simulations. Extrapolating existing USGS discharge data to smaller (and larger) systems is needed to account for other data sources, such as unmanned aerial vehicles (UAVs, discussed below) and satellite data. Ensemble forecasts of rainfall and discharge can be generated at a variety of spatial and temporal scales. Forecasts will be used - in conjunction with historical data relating measured discharge to stream species concentration - to predict stream chemistry response to predicted rainfall events.

Thermal imaging systems deployed on UAVs will be used to characterize the location, intensity, and region directly influenced by major point-sources of wastewater entering the river. This approach will provide regular, instantaneous overviews of the major inputs and their local impact. We will explore the feasibility of using this technique to characterize and validate local productivity through via remotely sensing products.

Natural Tracer Studies: Tracer studies that use the natural abundance of ^{15}N are proposed to characterize the spread of nutrients from local sources. We will measure the $\delta^{15}N$ of dissolved species (nitrate and ammonium) in groundwater, at the outfalls of point-sources, and in the river itself when concentrations are high enough. We will follow the movement of nitrogen through the river ecosystem, by measuring the $\delta^{15}N$ of suspended particles, benthic vegetation, and selected consumers (invertebrates and fish) at a network of sampling sites.

In the simplest scenario, A simple two-endmember mixing model will be used to assess the local impact of isotopically distinct inputs to the river ecosystem. In practice, inputs may not be isotopically distinct from the mean isotopic composition of dissolved nutrients. We will rely on the isotopic fractionation that accompanies uptake of nutrients to generate a spatial pattern of variation in $\delta^{15}N$ in these areas.

We will investigate the nutrient enrichment history of the system by measuring the $\delta^{15}N$ and $\delta^{13}C$ of organic matter in combination with other geochemical parameters in sediment cores collected in the major reservoirs in the system. Radioisotope dating techniques will be used to provide temporal context for our data. We will also explore the utility of other isotopic parameters (e.g., $\delta^{13}C$ and $\delta^{18}O$) in assessing the impact of human activities on the river ecosystem. We anticipate that the $\delta^{13}C$ of suspended organic matter may provide insight into the degree of recycling and heterotrophy within the river, while the $\delta^{18}O$ of river water may vary in response to large and/or locally focused diffuse inputs of groundwater to the system.

Contaminant Studies: This component will focus on processes governing the transport, transformation, retention, and removal in natural and engineered wetlands, treated effluent and sludge land application systems, and small catchments and feeder streams of inorganics (e.g., metals), organics (e.g., antibiotics, endocrine disruptors, MTBE, chlorinated solvents), and pathogens (e.g., virus, cryptosporidium).

We will monitor and study sediment and colloid-facilitated transport of sorbed-phase contaminants in surface runoff as well as rivers and streams. Trace organic and pathogen monitoring could potentially involve collaboration with CDC scientists and faculty in the Emory School of Public Healt. These studies will investigate the fate and effects of water-borne contaminants on natural water-column and sediment systems and natural and engineered processes that attenuate contaminant and their impacts. Efforts will address stream and stormwater monitoring, impacts and control, as well as water reclamation and re-use in urban systems.

Hillslope Hydrology Studies: This component focuses on the design of subsurface observation units for monitoring the vadose zone. Additionally, we will design and implement an integrated investigation of ground water and surface water interactions within the near-stream zone (where main sewage lines are located) that incorporates the following components: 1) naturally occurring isotopic tracers (Sr isotope ratios, environmental tritium, tritium-helium system, and stable oxygen isotopes of water); 2) major ion chemistry of ground water and surface water; 3) the natural hydraulic system including flow monitoring and ground-water level monitoring; 4) characterization and quantification of bacteria in both ground water and surface water; and 5) characterization and quantification of *urban chemicals* (i.e. estrogens and other pharmaceuticals) in both ground water and surface water.

The end result will be the development of a modeling system to simulate the transport water and soil constituents down the hillslope and from the hillslope to the streams at both local and regional scales. Both empirical and mechanistic models will be developed to capture the relationships between discharge and stream chemistry-nutrient-sediment concentrations given seasonality and the variability in antecedent conditions, geomorphology, storm intensity, etc. Soil core release curves from extracted soil cores will be used to better model the infiltration of precipitation and the ensuing hydrologic activity.

Sediment Studies: It is proposed that an existing sediment monitoring station on the North Fork of Peachtree Creek be operated to obtain both short-term and long-term sediment discharge and channel geomorphic data for an unstable reach that has been studied in previous research. Both turbidity monitoring and collection of discrete samples during storms with an automatic sampler are proposed along with continuous monitoring of bank erosion.

Scientific issues include a) the contribution of fine vs. coarse sediment to surrogates such as turbidity and its temporal variability during storm events, b) the relationship between point measurements of suspended sediment concentration and cross-sectional averages, c) the contribution of bed load to the total sediment discharge and its measurement, and d) the erodibility of bank sediments using laboratory erosion measurements.

Engineering issues to be studied with the monitoring data include a) a methodology for identification of unstable stream reaches, b) recommendations of stream restoration techniques that address both stream form and process in a rational manner, and c) modeling of the consequences and effectiveness of restoration techniques both in terms of stability and biological effects.

Data Platforms

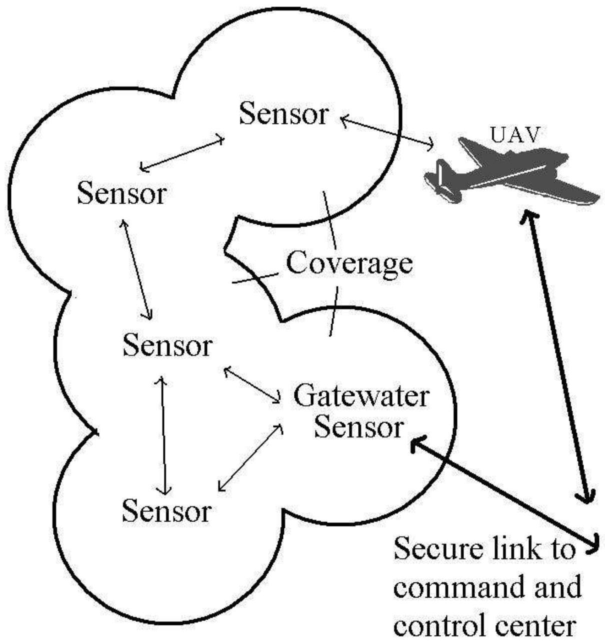
The emphasis will be on hydrologic monitoring and subsequent modeling at a range of watershed scales. We propose to develop specialized platforms on which individual sensor systems can be installed in a modular fashion. Data will be analyzed to improve platform performance, and to identify optimal platform location. Feedback between data and models is required to guide acquisition strategies because finding the right time and place to monitor requires an understanding of hydrologic systems.

UAV: A small unmanned aerial vehicle (UAV) will be used to measure river skin surface temperature using an infrared pyrometer. The UAV selected for this project is the Aerosonde, which weighs thirty pounds and has a nine-foot wing span. Georgia Tech has extensive experience using this platform in a variety of field observations.

EPCL: The Environmental Process Control Laboratory (EPCL), located at the University of Georgia, is a mobile platform that provides real-time sensor capability for monitoring a wide range of water quality parameters, including nutrients (nitrates plus nitrites, ammonia), respiration, turbidity, specific conductance, temperature, dissolved oxygen, among others.

Panola Mountain: The USGS WEBB Panola Mountain Research Watershed - located 20 miles from downtown Atlanta - can be used as a data acquisition platform for studying water cycling in Piedmont systems. Experiments will focus on the controls over hillslope flushing of soil water, chemicals, nutrients, and sediments. New ISCO's will be installed on the hillslope. One small catchment, 36% covered by a large granitic outcrop, will be used to understand stormflow in urbanized areas. A neighboring catchment, with similar geomorphology, but not outcrop will be brought online and serve as a control catchment. The site can be used to focus on the flushing of storm water, nutrients, and sediments at various locations along the stream reach.

Wireless Sensor Network: An interesting approach to data collection in the study area is the deployment of an autonomous wireless sensor network capable of monitoring critical river attributes such as turbidity, temperature and dissolved oxygen with



Wireless sensor network concept

sufficient spatial and temporal resolution to provide important information regarding the perturbations of the river ecosystem. In the short term this system will provide data for the assessment of environmental impact before, during and after storm events. In the long term the wireless sensor network can be incorporated into a control system that can be used to take appropriate water management actions.

Such a system would be required to cover large areas unserviceable by existing wireless or wired networks. An appropriate communication protocol will be selected for the network from the IEEE standards which are being generated in this field. Ideally, the sensors could detect various river attributes and relay this information through a wireless ad hoc network, as depicted in the above figure. Such networks have long been discussed in the literature due to their inherent robustness, random deployment, and relatively low probability of detection.

Sensors currently exist for the monitoring of turbidity, temperature, and dissolved oxygen. The large number of sensor-pods envisioned adds a level of complexity to the design and deployment of a sensor network. Therefore, the enabling technology element for these wireless sensor networks would be an integrated radio transceiver and embedded controller that could be deployed and operated in various weather conditions. A further aspect of the wireless sensor network is the automated generation of reporting. We will write software codes to collect sensor data and generate distillation of critical components of the data set, such as inputs for GIS mapping.

Sensors: Initially, commercially-available sensors for turbidity, dissolved oxygen and temperature will be deployed and a compact module will be designed and fabricated which combines these sensors with microprocessor-based digital sensor control and data collection. In addition, modules will contain a radio for wireless transmission and reception in a protocol suitable for the ad hoc network. Modules will also contain a GPS sub-system for localization and future integration for GIS mapping of sensor system responses.

The next phase in sensor development will involve miniaturization of sensor modules so that the stationary sensor network can achieve greater resolution within the river basin. Once this has been accomplished, a floating version of the ad hoc sensor modules will be developed so that they may be deployed in the watershed (i.e., during storm events) to monitor the system responses under dynamic and extreme flow conditions in real-time.

In addition to employing a state of the art system during low flow seasonal conditions and storm events, this sensor system complements proposed traditional and non-traditional aspects of monitoring. For much of this project this suite of monitoring methods will be used in concert for calibration and cross checking observations. Sensor calibration will be especially valuable during phase one deployment. For example, turbidity can be related to phosphate export so that traditional monitoring methods can be used to estimate nutrient loads.

Biological sensors will be developed with the goal of monitoring emerging water quality parameters, including pathogens (e.g. E. coli), halogenated organic acids, and antibiotics in the river basin. This initiative will leverage ongoing research in which liquid and vapor phase detection of small molecules and microbes has been demonstrated. For this effort, it will be necessary to detect target contaminants (i.e., halogenated organic acids and antibiotics) at the parts per billion level. As part of this effort MEMS (Micro-ElectroMechanical Systems) approaches will be utilized where appropriate for microfluidic sample collection and sample transport.

Example Science Questions

The proposed environmental monitoring system will provide us with the hydrologic and ecologic models that will allow us to better answer the following questions:

- What quasi-pristine hydrologic and nutrient-sediment regimes (variabilities), ranging in frequency from hourly to decadal (and beyond), have contributed to the presence of such an impressively unique aquatic biodiversity in Piedmont rivers?
- How do urbanizing watersheds and other structural developments play a part in distorting global biogeochemical material cycles and the foregoing frequency spectra?
- What interventions, in terms of urban water infrastructure re-design and operational adaptation, might allow the watershed components of the foregoing global biogeochemical material cycles, as well as the frequency spectra, to be restored to something approaching a quasi-pristine condition?
- Can any hydrologically driven cycle of pathogen propagation, equivalent loosely to the notion of a material cycle, be identified?
- What is the role of episodic flushing in delivering water and nutrients from the terrestrial landscape to the stream?
- What are the roles of the various drivers in controlling the downslope flow of water and nutrients?
- What are the roles of disturbances (increased climatic forcing, increased nutrient availability, etc.) in propagating change across the landscape?

Additional Resources:

A full list of investigators, along with selected documents and links, can be found at: `www.hydrology.uga.edu/acf`.

It is important to note that the list of collaborators includes researchers from a broad range of disciplines, including Ecology, Civil and Environmental Engineering, Forest Resources, Earth and Atmospheric Sciences, Electrical and Computer Engineering, as well as others.

These investigators have been assembled from a number of universities, including the University of Georgia, Georgia Institute of Technology, Georgia State University, Emory University, Morehouse University, and others.