Georgia Water Resources Institute
Annual Technical Report
FY 2006

Introduction

The Georgia Water Resources Institute GWRI mission is to help improve water resources management in Georgia, the US, and the world through innovative new research, education, technology transfer, and information dissemination. GWRI is housed at the Georgia Institute of Technology (www.gatech.edu) but involves all Georgia universities including, among others, the University of Georgia (www.uga.edu) and Georgia State University (www.gsu.edu). Thus, GWRI brings to bear a very broad faculty resource base in all aspects of science, engineering, and policy. In keeping with the above-stated mission, during Fiscal Year 2006, 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) Restoration of flood pulses to the lower Savannah River: responses of Floodplain, Darold Batzer PI, University of Georgia, sponsored by GWRI under grant #1260014005 (Fund #R7113-G3).

(2) Characterizing Nutrient Releases from Southeastern Piedmont Lake Sediments, Todd Rasmussen PI, University of Georgia, sponsored by GWRI under grant #12600014006 (Fund #R7113-G2).

(3) Investigating the use of compost for sediment and erosion control in concentrated flow conditions, Lawrence Mark Risse PI, University of Georgia, sponsored by GWRI under grant #1260014007 (Fund #R7113-G1).

(4) Water Resources Planning Tool for Georgia, Aris Georgakakos PI, Georgia Tech, sponsored by the Georgia Environmental Protection Division under grant #2006L93

(5) A Decision Support System for Water Resources Planning in the Huaihe River, Aris Georgakakos PI, Georgia Tech, sponsored by the Chinese Ministry of Water Resources under grant #2006L23.

(6) INFORM: Integrated Forecast and Reservoir Management System for Northern California, Aris Georgakakos PI, Georgia Tech, sponsored by NOAA, the California Energy Commission, and CalFed under grants #2006J04, #2006J39, and #2006J76 respectively.

EDUCATION AND TECHNOLOGY TRANSFER:

(1) Nile Decision Support Tool Technology Transfer Program, Aris Georgakakos PI, Georgia Tech, sponsored by the Food and Agriculture Organization of the UN under grant #2206205W6.

(2) Kindsvater Symposium--Water Resources: Planning for Georgia's Future , co-sponsored by GWRI, Ga EPD, ASCE, USGS.

(3) Mega City Water Forum: Innovative Water Supply Strategies for the 21st Century, co-sponsored by GWRI, Georgia Tech, CIFAL Atlanta, and the City of Atlanta.

PROFESSIONAL AND POLICY IMPACT:

GEORGIA: In collaboration with the Georgia Environmental Protection Division, GWRI is developing information and modeling tools aiming to provide stakeholder organizations and groups with objective facts and information useful in developing a sound and sustainable water resources planning and management framework for Georgia. The GWRI planning tools are used to (i) determine flow regime requirements for environmental management and aquatic life protection in individual sub-basins as well as basinwide; (ii) assess the water amounts available in each sub-basin to meet current and future water supply demands; and (iii) quantify the benefits and impacts of basin storage, inter-basin transfers, drainage/sewer infrastructure, and conservation practices. In addition to research activities, GWRI sponsors and organizes major water resources conferences and workshops in Georgia including the Georgia Water Resources Conference, the Mega-City Water Forum, and the Kindsvater Symposium.

CALIFORNIA: With funding from National Oceanic and Atmospheric Administration, CALFED, and the California Energy Commission, GWRI is collaborating with the Hydrologic Research Center (HRC) in San Diego, the California Department of Water Resources, the US Bureau of Reclamation (USBR), the US Army Corps of Engineers (USCOE), and the Sacramento Flood Control Authority (SAFCA) to develop and operationalize a comprehensive forecast-decision system for all major river basins in Northern California. This prototype decision support system is intended to assist the State of California in securing water supplies for urban, industrial, and agricultural use, provide adequate flood protection along the Sacramento River, generate energy, and sustain the environmental and ecological integrity of the Bay Delta.

INTERNATIONAL: Under the aegis of United Nations Agencies, International Aid Agencies, and the World Bank, GWRI has developed a state-of-the-science decision support system to support the information and decision making needs of the Nile Basin nations. With 250 million people spread into ten different countries (Egypt, Ethiopia, Sudan, Eritrea, Uganda, Tanzania, Kenya, Rwanda, Burundi, and Congo) and rapidly rising populations and economic pressures, The Nile Basin nations are in urgent need to set forth equitable and lasting water development and utilization agreements. The purpose of the GWRI decision support system (Nile DST) is to evaluate the merits of various water development and management strategies and support the integrated and efficient utilization of the regional water, energy, and environmental resources. As part of this effort, GWRI conducts extensive training and technology transfer programs for water scientists and engineers in the Nile Basin. Similar activities are undertaken in other world regions including China, Europe, Middle East, and South Africa.

Research Program

Restoration of flood pulses to the lower Savannah River: responses of floodplain invertebrates and fish

Basic Information

Title:	Restoration of flood pulses to the lower Savannah River: responses of floodplain invertebrates and fish
Project Number:	2006GA106B
Start Date:	7/1/2006
End Date:	6/30/2007
Funding Source:	104B
Congressional District:	11
Research Category:	Biological Sciences
Focus Category:	Wetlands, Ecology, Hydrology
Descriptors:	None
Principal Investigators:	Darold Paul Batzer

Publication

TECHNICAL REPORT: Restoration of flood pulses to the lower Savannah River: responses of invertebrates and fish

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PERFORMAMCE PERIOD: March 1, 2006 to February 28, 2007

Statement of Water Problem

River regulation is now recognized as a serious ecological problem. Dams restrict the downstream flow of water and of sediments and dissolved and suspended nutrients (Richter et al. 1997, Shannon et al. 2001). They also restrict the upstream as well as downstream movement of aquatic organisms that use the river corridors for migration (Gehrke et al. 1995). But perhaps most important to large floodplain rivers, dams alter the natural flood pulses to which organisms that occupy or use river floodplains are adapted, thus disrupting patterns of plant dispersal, establishment and growth, and of animal breeding and foraging (Junk et al. 1989, Poff et al. 1997, Ward et al. 1999, Jansson et al. 2000). These natural functions of large floodplain rivers are important to our society, not just because of their support of biodiversity but because humans derive substantial ecosystem service benefits from healthy, properly-functioning rivers (food, building material, water purification, flood mitigation, wildlife, soil maintenance, nutrient processing, coastal marsh maintenance, recreation, tourism, provision of beauty and life-fulfilling values)(Postel and Richter 2003, Dyson et al. 2003).

As such, efforts have been initiated to restore flood pulses to some regulated rivers (e.g., Shannon et al. 2001, Postel and Richter 2003, The Nature Conservancy 2004). However, projects to restore functions to river-floodplain systems by returning flood pulses are based largely on speculation because many (most) hypotheses on the ecological effects of flood pulses remain untested and responses of river ecosystems to flooding go largely unmonitored. This is highly undesirable, because being wrong about environmental flow needs has two potentially large societal consequences. Either the ecosystem will not get what it needs and degrade – with associated loss of socially valued ecosystem services – or other potential human uses of the water will be unnecessarily curtailed or limited, with attendant social and economic disruption. Water managers struggle to balance a broad spectrum of human needs or desires, and their decisions should be informed by well-documented evidence. Restoration attempts, especially the initial ones, should be based upon solid science and their success should be rigorously documented (Molles et al. 1998, Shannon et al. 2001, Middleton 2002; Poff et al. 2003). Only in this manner will water managers be able to evaluate the benefits of various water management options or scenarios.

The US Army Corps of Engineers (Corps) owns and operates three large multi-purpose dams on the Savannah River. It is difficult to exaggerate the degree to which the hydrology of the Savannah River has been modified. Under the flood management regime of the last 50 years, the 100-year flow is approximately the same size as the pre-dam 2-year flow. The current two-year flow (approximately 35,000 cfs) is one-third the size of the pre-dam 2-year flow (approximately 90,000 cfs). River-floodplain interactions probably have decreased commensurately. The altered flows and hydrographs undoubtedly have ramifications for the ecology of the Savannah River floodplain and estuary.

Nature, scope, and objectives of the project

The Nature Conservancy (TNC) and the Corps have entered into a national partnership to explore the potential for modifying Corps dam operations for ecological benefits while continuing to meet other human uses of water. This "Sustainable Rivers Project" includes 10 regulated rivers in 11 states. The Savannah River is a major project focus, with both agencies working towards returning flood pulses to the lower river, at least on an experimental basis, as part of the Savannah Basin Comprehensive Plan (which assessed authorized uses of the river to determine if existing water management adequately addresses all stakeholder needs).

In 2002, TNC and the Corps began a process to develop flow recommendations for the Savannah (Richter et al., in press). Over a series of workshops, almost 50 leading river, wetland, and estuary scientists from across the southeastern United States were convened and asked to develop expert-opinion recommendations on how to restore more natural-like river flow conditions to the Savannah River in order to rehabilitate floodplain and estuarine biotic communities. The resulting recommendations were, by intention, meant to support ecological values, with the understanding that the Corps would be assessing other interests through the comprehensive plan. Recommendations were developed for normal, wet, and dry years.

The Corps is fully supportive of working to integrate the ecosystem flow recommendations into the existing set of water management priorities. A small pulse was released in March 2004 to facilitate sturgeon migration through a small lock and dam facility below Augusta. In October 2004, a large pulse (30,000 cfs) of tropical storm induced run-off was released through Thurmond Dam to inundate floodplains as recommended for wet years, and a second pulse was released in March 2005 in conjunction with heavy regional rains. In 2006, a single pulse was released in March. In 2007, no water was released form the dam to create a flood pulse, however, a small natural pulse developed from heavy rainfall in early March. The Corps has expressed interest in making this type of adaptive, ecosystem-sustaining water management part of their standard practice. It is, however, critically important for all stakeholders that this is done in a scientifically credible manner.

Invertebrates and fish are logical organisms to use in assessing biological responses of flood restoration in Savannah floodplains. Both groups are crucial ecologically, and both groups have been successfully used in bioassessment programs elsewhere. The objective of this project is to empirically assess whether flow restoration is achieving the goal of restoring a more natural invertebrate and fish fauna on Savannah River floodplains.

Study sites

The headwaters of 27,000 km^2 Savannah River watershed are located in the Southern Appalachians. The upper Savannah flows though the Piedmont ecoregion and the lower Savannah through the Atlantic Coastal Plain, with the city of Augusta, GA located at the Fall Line that divides the two regions and Savannah, GA near the mouth of the river at the ocean terminus. On the upper Savannah River, the Corps maintains three large dams that form Hartwell, Russell, and Thurmond reservoirs. Thurmond Dam was the first built, in 1954, and is located the furthest downstream, just above Augusta. All three dams are multi-purpose, being authorized for hydropower generation, flood control, recreation, water supply, and fish and wildlife habitat.

The Corps will continue to seek to implement the flow recommendations for the Savannah River. Because weather patterns will change yearly, and the recommendations differ depending on precipitation patterns, this will result in numerous pulses of various magnitudes being released over the coming years. This variation will permit testing hypotheses addressing how biota respond to different kinds of flood pulses. A key challenge will be to gain an understanding of the necessary magnitude (size), timing, duration, frequency, and rates of rise and fall of the flood pulses that will generate a targeted ecological response. I will assess responses of invertebrates and fish to individual pulses. Over the longer term, I will assess responses on an annual or seasonal basis. Finally, over multiple years, I will measure overall community and functional recovery of the system, assessing whether invertebrate and fish communities are approaching reference standards.

To field test hypotheses, I have selected a set of habitats spaced systematically along the length of the lower Savannah River (Figure 1). My first study station is located on the reach of the Savannah just below Augusta and the Thurmond Dam, adjacent to the Savannah River Site. The second site is along the mid-reaches of the lower Savannah in Georgia's Tuckahoe Wildlife Area. The third site is along the lower portions of the river (above tidal influence) in South Carolina's Webb Wildlife Area. When hypothesis tests require contrasts with a reference standard, I am using habitats in the nearby Altamaha River that are spatially paired to those in the Savannah (Figure 1).

The Altamaha River is a useful reference because it shares many features with the Savannah in terms of size and geomorphology. Additionally, while no large river in the southeastern United States is free of human impacts, the Altamaha is perhaps the least regulated, most pristine large river system in the region. Importantly to this project is the fact that near-natural flood pulses still exist in the Altamaha. There are no dams along the 290 km length of the Altamaha. The Oconee and Ocmulgee River are the major tributaries of the Altamaha. The Ocmulgee also has no major dams along its length. Although two large dams occur on the Oconee River, they are managed using a pump-back system, where reservoirs remain near capacity. This practice reduces downstream baseflows but does not limit the magnitude of high water flood pulses through downstream habitats (what goes into these reservoirs must come out).

Figure 1. Locations of study floodplains on the Savannah and Altamaha Rivers

Hypothesis testing

The timing, duration, and magnitude of floods play an integral role in the establishment and survival of animals on river floodplains. For fish, most of the biological activity in floodplains occurs during the winter and spring flood pulses. There is a pattern of high-flows that, if provided to the river-floodplain section of the Savannah River, would increase fish production and potentially biodiversity via mechanisms associated with access to floodplain habitats and the "flood-pulse advantage". These mechanisms involve a subsidy to aquatic foodwebs by nutrients derived from the floodplain, and availability of floodplain habitats favorable to fish reproduction and growth. Floodplain habitat availability to riverine fishes depends on the physical extent and duration of floodplain inundation. Additionally, the size of the "flood-pulse advantage" - the pulse-induced increase in fish production per unit of water surface area - is hypothesized to depend on the rate of rise and fall of the flood-pulse, and pulse seasonality. Rapidly rising and falling pulses, which also tend to be short in duration, are unlikely to provide significant benefit to fishes. Pulses that occur when water temperatures are low also are less likely to benefit fishes than pulses that coincide with spawning and juvenile growth periods. Invertebrates in floodplains are influenced both by flood characteristics and fish. Wellborn et al. (1996) hypothesize that relative water permanence and fish presence or absence are the major factors structuring aquatic animal communities in lentic habitats.

I expect fish and invertebrate community changes that reflect the increase in frequency and duration of high flow events, and these changes should affect trophic dynamics of the animal community. Fish response to pulses are being assessed by sampling communities during flood events at the 3 Savannah and 3 Altamaha floodplains using electrofishing.. Community composition, individual size, and diet of fish are all useful measures for testing hypotheses. Invertebrate community composition are being assessed at each of the 6 floodplains using core sampling. Because aquatic invertebrate communities develop in precipitation-filled backswamp habitats, even in the absence of flood pulses, invertebrate sampling is being conducted in both wet and dry years, and not only during pulses. Invertebrates samples are collected soon after floodplains begin to hold water (December-February) to ensure rapid developing, aestivating forms are collected, and again in April to collect later colonizers and forms that develop slowly.

Impacts of flood pulses

Hypothesis 1. The small size and short duration of post-dam flood pulses has limited fish access to floodplains. A major question concerning the benefits of restoring pulses to the Savannah River is whether prescribed pulses will be of sufficient size and duration, and appropriately timed, to provide significant benefit to fishes. The area of floodplain inundated, as well as the rise, fall and duration of any particular pulse event likely varies geographically depending on floodplain morphology and drainage conditions. An individual flood pulse of sufficient magnitude and timed when fish are positioned to move into floodplains (spawning periods) has the potential to distribute fish across a greater portion of the floodplain.

Preliminary findings: From 2005-2007, I have collected 29 species of fish on the floodplains. Fish communities occurring on both Savannah and Altamaha floodplains comprise only a relatively small portion of the species present in the river. Collections have been dominated by various centrarchid species, mosquitofish, and assorted other typical wetland fish. I have observed minimal movements of fish onto floodplains that were not already adapted to wetlands.

Dominant fish species (of 29)

- Mosquitofish (*Gambusia* spp.)
- Warmouth (*Lepomis gulosus*)
- Chain and Grass pickerel (*Esox niger, E. americanum*)
- Pirate perch (*Aphredoderus sayanus*)
- Bullhead (*Ameiurus* spp.)
- Coastal shiner (*Notropis petersoni*)
- Flier (*Centrarchus macropterus*)
- Bluegill (*Lepomis macrochirus*)

Table. Fish collected

Fish communities have not differed markedly between the Savannah and Altamaha Rivers (Figure 2), with annual variation between the 2005 and 2006 study years exceeding the spatial difference between rivers. However, the most up-stream floodplain in the Savannah supported an aberrant fish fauna (Figure 3). In 2007, only a small early season pulse developed, and fish collections in both rivers were meager, suggesting that fish remained restricted to the rivers or deep water areas on the floodplains.

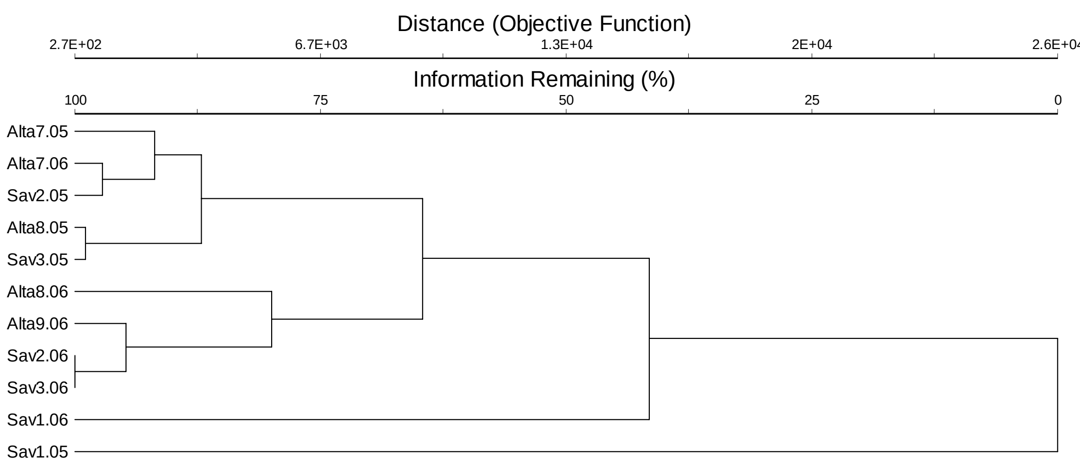

Figure 2. Fish community comparisons among 6 study floodplains over 2 years.

Hypothesis 2. An individual flood pulse of sufficient magnitude could enable predatory fish to exploit invertebrate resources on the floodplain (both aquatics and stranded terrestrials). *Preliminary findings*: Mostly aquatic invertebrates have been found in fish guts thus far, with microcrustaceans (Cladocera and Ostracoda), asselid Isopoda, Chironomidae midge larvae, and Dytiscidae beetle larvae and adults occurring most commonly and in the greatest numbers. I do not yet have sufficient information to assess whether foraging patterns on the Savannah and Altamaha differ.

Hypothesis 3. Fish reproduction will only be successful if water remains ponded on floodplains for periods sufficient for development, and that floodplain connections are maintained at least periodically to permit fish larvae to return to the river. Flood pulses must provide dual service to fish of providing access to the floodplain and an escape route, so one pulse is required when fish are ready to spawn and at least one more when fish larvae are ready to return to the river.

Preliminary findings: Because the fish fauna is dominated by wetland taxa (see above), it is unclear whether successful reproduction requires annual egress from the floodplain. I have detected most of the fish commonly caught during floods persisting in shallow backwaters long after floods have subsided (e.g., October 2006). I am developing a hypothesis that fish success in floodplains is not only dependent on the connectivity between the floodplain and the main channel, but also by connectivity with semi-permanent backwater habitats. If this is true, then the impacts of past flow regulation on the fish community on Savannah floodplains may have been buffered by the persistence of backwater habitats.

Hypothesis 4. The small size and short duration of post-dam flood pulses has probably affected invertebrate communities because species unable to complete development rapidly were inhibited. Conversely, small and short duration flood pulses have probably benefited some invertebrates because some predatory fish have been excluded. Pulse restoration should allow more invertebrates to successfully reproduce and complete development before the floodplains dry, although populations tolerant of short duration hydroperiods but susceptible to fish predation may decline.

Hypothesis 5. Low nutrient and mineral inputs from a lack of over-bank flooding may be limiting invertebrate productivity on Savannah floodplains, and water-borne chemicals associated with flood waters may affect invertebrate productivity.

Preliminary findings: Data thus far indicate that invertebrate communities in the Savannah and Altamaha River differ (Figure 2). The most aberrant invertebrate faunas on the Savannah occurred in 2 sites that were virtually fishless at the time.

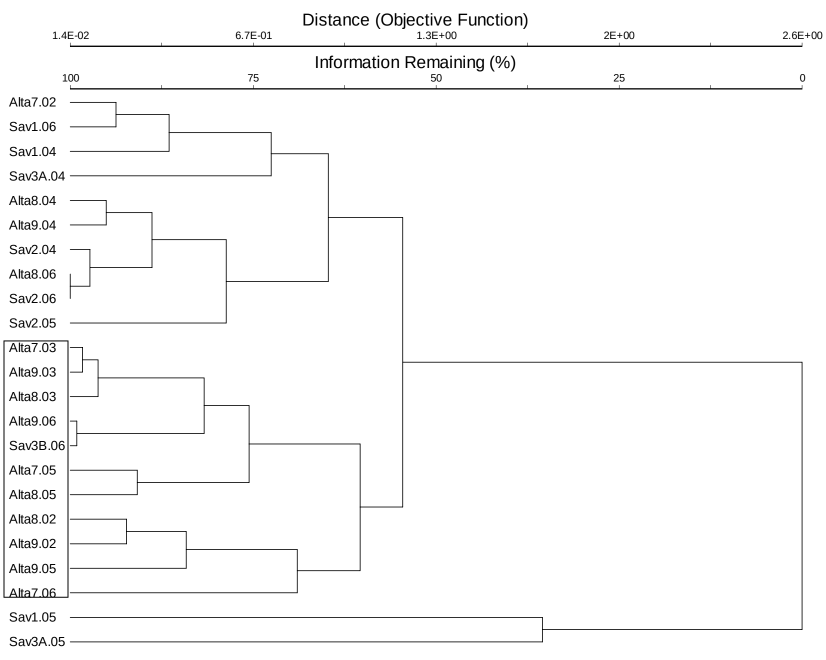

Figure 2. Invertebrate community compositions in Altmamah (Alta) and Savannah (Sav) floodplains. The first numbers indicate the floodplain number (Figure1) and the second the year.

Hypothesis 6. Fish and invertebrate communities on the Savannah should shift over the years to become more similar to those communities occurring in non-regulated systems. Animal

communities will be affected by both flooding and structural and compositional changes in the vegetative community brought about by changing hydrology.
Preliminary findings: It is too early to assess responses over longer terms, but this is a goal of the project.

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Characterizing Nutrient Releases from Southeastern Piedmont Lake Sediments

Basic Information

Title:	Characterizing Nutrient Releases from Southeastern Piedmont Lake Sediments
Project Number:	2006GA110B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	GA 12
Research Category:	Water Quality
Focus Category:	Nutrients, Water Quality, Non Point Pollution
Descriptors:	None
Principal Investigators:	Todd Rasmussen, Bruce Beck, William Miller

Publication

Final Technical Report – GA2006110B

Internal Loading of Phosphorus in Lake Allatoona

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Acknowledgements

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Elena L. Ceballos developed and completed most of the laboratory research tasks for this project under my direction. Several people generously contributed their time, ideas, laboratory space and equipment to this project. For this I am indebted to Professor William Miller of Crop and Soil Sciences, Professor Marshall Darley of Plant Biology, Professor Brian Binder and PhD-candidate Christopher Burbage of Marine Sciences, Professor Jeffrey Dean, researchers Paul Montello and Gisele Dean, and Professor Scott Merkle of the Warnell School of Forestry and Natural Resources at the University of Georgia.

Project Type

Deposition of sediments in lakes is an ongoing, storm- and disturbance-driven process, which is exacerbated by increasing watershed urbanization. The internal loading, or recycling, of nutrients in lake sediments is known to be significant, and increases as the lake matures. (Lake maturity refers to the length of time since the lake was constructed or formed by natural processes.) In many cases, internal loading is initially low and there is net accumulation of nutrients in benthic sediment. Over time, however, the deposition of nutrients reaches equilibrium with releases, and continued sequestration of lake sediments is not seen. In addition, if external loading of nutrients is reduced, then releases from lake sediments continues, and thus can cause long-term eutrophication in the absence of external loading.

Current state regulatory programs focus on reducing and minimizing watershed loading to reduce or prevent lake eutrophication in Georgia. While it is clearly important to reduce external nutrient loading to lakes, it is equally important to understand and characterize the release and recycling of sediments within lakes. This project is a pilot laboratory study designed to quantify the effects of internal loading, such as algal blooms, anoxic conditions and alkaline pH, in response in a southeastern Piedmont impoundment.

Background

Cultural eutrophication (CE) of lakes is the accelerated nutrient enrichment resulting in detrimental ecological effects such as algal blooms, lake anoxia and toxic metal release from sediments (Fang et al., 2005). CE is a common occurrence in Piedmont impoundments in Georgia, as well as lakes and impoundments throughout the world. It often results in water unsafe for agricultural use, recreation and drinking.

To reduce CE of local Piedmont impoundments, recent regulatory controls for nutrients were established as part of the Clean Lakes program and court-ordered total maximum daily loads (TMDLs). These regulatory efforts focus on the reduction and minimization of point-source watershed nutrient inputs, primarily phosphorus, into lake systems, as P is the limiting nutrient in Piedmont impoundments. Thus, reductions in phosphorus loading are expected to improve lake water quality.

However, in the Piedmont, as well as worldwide, many lakes continue to experience algal blooms and lake anoxia after sources of external loading are discontinued. The process of nutrient desorption from sediments, known as internal loading, has been identified to be a source of algal-available P, as well as other nutrients. The conditions under which internal loading takes place are region-specific as they vary based on local physical, chemical and biological conditions.

The purpose of our research is to quantify changes in algal biomass in response to internal loading in Southeast Piedmont impoundments. We propose a series of mesocosm experiments and batch tests to quantify internal loading of P and increases in algal biomass due to two mechanisms of internal loading (mixing, alkaline pH) in SE Piedmont impoundments. We will use these findings, along with estimates of external loading, field physico-chemical data and sediment characterization data, to evaluate potential appropriate remediation strategies to minimize detrimental algal blooms in SE Piedmont impoundments.

Project Scope and Introduction

Regional reservoirs within the Piedmont region of the southeastern U.S. are used to meet municipal and industrial water supply, wastewater dilution, recreation, and hydroelectric power generation needs of nearby communities. Poor water quality conditions caused by lake eutrophication adversely affect the use of reservoir waters to meet these needs. In addition, poor water quality also adversely affects native and introduced aquatic species by reducing their ability to forage, reproduce, and respire.

Lake Allatoona is a U.S. Army Corps of Engineers reservoir located in northwest Georgia. The impoundment was constructed in January 1950 for uses including flood control, hydropower generation, water supply, recreation, fish and wildlife management, water quality, and navigation. The surface area of the reservoir, when full, covers approximately 12,010 acres, the maximum depth at the dam is 145 feet, and the storage volume is approximately 367,500 acre-feet. The watershed area upstream of the dam is 1110 mi^2 and contains one large tributary (the Etowah River), and several smaller tributaries (the Little River, Noonday Creek, and Allatoona Creek).

Lake Allatoona, like many of Georgia's reservoirs, experience seasonal algal blooms. These blooms are typically during the warm season (June through September) and are attributed to increased eutrophication from nutrient enrichment, primarily phosphorus (P), as P is the limiting nutrient in Southeastern Piedmont impoundments (Raschke, 1994). Causes of eutrophication for Lake Allatoona include phosphorus loads from watershed sources, including point and nonpoint sources. Point loads generally consist of soluble nutrients, while nonpoint loads consist of both soluble and particulate sources. Soluble loads are likely to become sorbed to suspended and bed sediments, as well as lost via biological uptake, while in transit to the lake.

In response to concerns about lake eutrophication, nutrient limits have been established for Lake Allatoona tributaries. Total maximum daily loads (TMDLs) are required by a federally mandated program, which sets pollution limits for degraded waters. For Lake Allatoona, TMDLs have been established for chlorophyll *a* within the Little River Embayment. Waste load allocations (WLAs) have also been established for total phosphorus for the embayment.

Suspended and bed sediments from influent tributaries accumulate in the upper reaches of the reservoir, primarily in the upper northeastern part of the lake near the Etowah and Little River inlets, forming depositional features including deltas and levees. These areas receive substantial inputs of sediments and nutrients from point and nonpoint sources. In addition, legacy sediments from historic sources have accumulated, providing long-term sources of sediment-related nutrients. These sediments may contribute to lake eutrophication by release of sediment nutrients.

Dredging of nutrient-rich lake sediments has been proposed as a management tool for reducing within-lake nutrients. Small-scale dredging in Lake Allatoona has been conducted primarily for increasing navigability of the lake. Blankenship Sand operates dredges to remove sediment (primarily sand) from North Georgia lakes and rivers, including Lake Allatoona and its tributaries. Sediment dredging involves a mobile, floating, diesel-powered suction dredge with a cutting head. Dredged materials are transported either to the shore or to a waiting clamshell barge that carries the sediments to an in-lake holding area that is re-dredged to the shoreline.

Dredged materials are separated into four parts, i) a rubble fraction containing trash, large woody materials and stones, ii) a sand fraction that is accumulated in sand piles, and then loaded into road transport vehicles using front-end loaders, iii) a tailings material composed of settleable solids (fine sands, silts and clays) that accumulate in holding (sedimentation) ponds, and iv) a tailwater containing some of the clay fraction that is returned to the lake.

An important question is whether this dredging affects lake water quality. The dredging of sediments may reduce internal loading by removing internal sources of lake nutrients. While dredging may remove sand-sized particles from sediments, it may also result in the resuspension of clay and silt-sized particles during initial dredging, with subsequent return of suspended solids to the lake. If desorption of P from these finer materials occurs, then this action may degrade water quality. Yet, it is also possible that these finer materials may remove P from the water column by sorption and subsequent sedimentation. Removing within-lake sediments may benefit lake water quality by reducing the potential release of nutrients and toxic metals from these sediments.

Stakeholders would like to develop a program that would provide financial incentives for removal of lake phosphorus. Therefore, data documenting sediment phosphorus content is needed. Yet, not all phosphorus in sediments contributes to eutrophication and its resulting negative affects. If a phosphorus trading policy is to be implemented to improve lake water quality, a method of determining algal-available benthic sediment phosphorus is needed.

Research Objectives

This project examines the possible benefits of removing benthic lake sediments on lake water quality. The key concerns are the total amount of P and the potentially algal-available P in lake sediments. There were several goals for this study:

(1) The first goal was to assess Lake Allatoona sediment composition and water quality. This was achieved by field data collection and sediment and water analyses.

(2) The second goal was to evaluate whether sediment removal by dredging would reduce algal biomass. This was achieved by a laboratory mesocosm study of sediment resuspension.

(3) The final goal was to assess the amount of algal-available P in lake sediments. A laboratory algal assay in which algae were grown in flasks with sediment as the sole source of P is currently being conducted to meet this goal.

Field data collection and laboratory experiments were conducted to achieve the following specific objectives:

(4) Gain a general understanding of Lake Allatoona sediment composition, especially with regards to differences based on sediment particle size

(5) Assess changes in water quality and algal biomass that may be caused by current dredging methods, including sediment resuspension and sediment removal

(6) Determine if there is a correlation between the results of chemical extraction of P in sediments and algal-available P as determined by algal assay

(7) Make recommendations for future studies to assess potentially algal available phosphorus in sediments of Lake Allatoona

This study focuses on quantifying phosphorus in Lake Allatoona nutrient cycling. Of specific concern is how the cycling of nutrients is affected by lake dredging. Laboratory mesocosm and batch experiments were performed to quantify changes in water quality and algal biomass in response to current dredging methods.

Materials and Methods

This study focuses on how internal loading is affected by lake dredging.

Mesocosm Experiment

Six clear acrylic columns were used to investigate the interaction between sediment and lake productivity. The columns were 122 cm high by 26.7 cm in diameter. The bottom ends were sealed using a PVC cap with an embedded o-ring to prevent leakage.

Sediment collected from Noonday Creek embayment was used for these column experiments. A slurry of approximately 20 L of sediment and 40 L of water was created using a blunger (mixing tool) in a 75 L container. Equal amounts of the slurry were transferred to four of the six columns. All columns were filled to a total height of 111 cm with water collected from Lake Herrick, a local impoundment on the University of Georgia campus. A single control column was filled with lake water to a total height of 111 cm. The columns were allowed to reach equilibrium over a period of eight weeks. After settling, the sediment depth was approximately 21 cm in experimental columns.

The columns were maintained in a 12:12 light:dark cycle illuminated by GE wide-spectrum plant and aquarium fluorescent grow lamps. After four weeks the fluorescent lamps were replaced with three GE R400 Multi-vapor lamps such that two columns shared a single light source. A small water pump was placed approximately 25 cm below the surface in each column to circulate water at a rate of approximately 1.5 L per minute. Lake water was added as needed to compensate for evaporative loss.

Three columns were mixed with a blunger: two containing sediment and the control without sediment. The two experimental columns containing sediment were mixed until they held 20-22 g/L suspended solids as read by an ASTM soil hydrometer. Two columns containing sediments were left undisturbed. Temperature, specific conductance (SC), pH, and dissolved oxygen (DO) were measured using a Hydrolab Quanta. Soluble reactive phosphorus (SRP) was measured on

0.22 um filtered water by a colorimeter, turbidity by a turbidimeter, and chlorophyll a (Chl *a*) using a fluorometer. All were measured daily between 5 and 8pm for 14 days.

Batch Experiments

The purpose of batch experiments is to quantify potentially algal-available phosphorus (PAAP) in Lake Allatoona sediment, and to compare these results with the results of chemical extractions in effort to find a correlation between chemical extraction and algal assay. Also of interest is whether greater turbidities support higher algal biomass than lower turbidities.

Collection of sediments

Sediments used for particle-size distribution, sorption isotherm, desorption studies and algal assay were collected from approximately 0.5-m below the sediment surface in the Noonday Creek Embayment. Sediments were air-dried at room temperature and sieved through a 2mm (10 mesh). Particle size distribution was determined by micropipette method (Miller and Miller 1987).

PO_4^{3-} Sorption Isotherm

To quantify the maximum sorption capacity of sediments used for algal assay, a sorption isotherm was performed by adding 50mL 0, 2.5, 5, 10, 15, 20, 30, 40 50 and 60 mg/L PO_4^{3-} solution to 0.5 g sediment. Samples were incubated at 21°C in a 40rpm end-over-end shaker for 12 hours and centrifuged at 3700rpm for 10 minutes. 20mL of supernatant was filtered through 0.22µm filters, and the samples diluted to approximately 0.01-0.5 mg/L concentration. The SRP concentrations of the diluted samples were measured using the ascorbic acid method (Eaton et al., 2005) and read by spectrophotometer.

Sediment desorption with iron-impregnated filter papers

Plant available phosphorus was measured by extraction with iron-impregnated filter papers (Sparks, 1996).

Sediment desorption into 1-mM $CaCl_2$

Three replicates each of 2, 4, 8 and 16 g air-dried sediment in 45 mL 1-mM $CaCl_2$ solution and three replicates of 24g air-dried sediment in 40 mL 1-mM $CaCl_2$ solution in 50-mL centrifuge tubes were mixed by end-over-end shaker for 24 hours. Samples were centrifuged for 15 minutes at 1500rpm and filtered through 0.45µm syringe filters. The orthophosphate concentrations in the supernatant were measured using the ascorbic acid method (Eaton et al., 2005).

Algal Assays

Media

Two media were evaluated for the P:biomass curve and sediment algal assay. They differ mainly in the concentration of macronutrients. Both media, Bold's Basal Medium (BBM) and Synthetic Algal Nutrient Medium (SANM a.k.a. NAAM) (Miller, 1978) are broad range growth media for algae. When tested in initial P:biomass curves, SANM severely limited biomass of the *S. capricornutum.* BBM was chosen for algal assays because it supports rapid growth of *S. capricornutum*.

When grown in P-free BBM, this alga was determined to be P-limited. To establish that nitrogen was not limiting in P-free BBM, 6 replicates were grown in P-free BBM with the standard concentration of $NaNO_3$ in BBM (2.94mM) and 6 replicates were grown in twice the standard of $NaNO_3$ in BBM (5.88 mM).

P – biomass curve

A biomass curve was made to compare algal densities with varying concentrations of PO_4^{3-}. 77µL P-starved *S. capricornutum* (3,872,000 +/- 5% cells/mL as measured by improved Neubauer hemacytometer; 11.0 raw units fluorescence to make an initial concentration of approximately 3000 cells/mL) was used to inoculate four replicates each of modified BBM with 0, 10, 25, 50 and 100 µmol P. Autoclaved #6 foam stoppers were used to limit contamination while allowing gas exchange.

Samples were incubated on an orbital shaker at 100rpm under continuous illumination by six Philips F40T12/DX Alto 40 W fluorescent lamps until cells reached a stationary growth phase (<10% increase in density over 24 hours).

Fluorescence/ cell concentration curve

A standard curve of cell concentration to fluorescence was made by serial dilution and enumeration of samples by improved Neubauer hemacytometer. These results were used to estimate the concentration of *S. capricornutum* in algal assays.

On-going Research: Sediment P Algal Assay

Much of the P in sediments is not algal-available, and therefore does not contribute to algal blooms or lake anoxia. For this reason an experimental assay used to measure potentially algal available phosphorus (PAAP) of whole sediments was developed. By establishing a standard protocol PAAP from northeastern Lake Allatoona sediments could be compared to PAAP within and among lakes.

The initial assay was developed to test for PAAP under conditions of neutral pH and high redox potential. Our goal is to refine the assay to quantify PAAP under conditions of varying pH and redox potentials, as both conditions affect internal loading of P and are seen in Lake Allatoona from late summer to early Fall.

The algal assay method developed is loosely based on the Algal Assay Bottle Test (AABT), which was developed by the U.S. Environmental Protection Agency (Miller, 1978). Our method deviates from the AABT in the following:

(1) The AABT suggests an initial inoculum of 1000 cells/mL. Our method will use an initial inoculum of 3000 cells/mL as recommended by Schultz et al. (1994). The higher initial concentration results in more rapid increases in biomass, hence more rapid results.

(2) The standard AABT method counted cells using an electronic particle counter, and converted these data to maximum standing crop as dry weight. Our method includes Chl *a* extraction to quantify biomass.

Sand, silt and floating organic matter will be removed from sediment used in this assay because, in lentic systems, these portions of the sediment would settle out of the photic zone quickly, and therefore contribute little P to algal biomass.

Sediments used in this algal assay will not be sterilized because (1) sterilization would change sediment physical and chemical properties, and (2) microbes play a key role in altering non-algal available forms of nutrients to algal-available forms, and (3) lysing of cells would result in the release of cell content nutrients.

Procedure

Sediment clay-sized particles (<2µm) were extracted by mixing of 25g air-dried sediment from Lake Allatoona with 1 liter deionized water for 24 hours in an end-over-end shaker, and removal of supernatant after 24 hours settling time. One liter each of approximately 0, 50, 175 and 350 NTU was made from dilutions of the sediment supernatant. Enough silicate was added to each liter to raise the turbidity of each to approximately 400 NTU. Concentrated phosphorus-free BBM was then added to each liter to reach standard nutrient concentrations. Because light-limited algae contain more Chl *a* per cell than non-limited algae, silicate was added in order to minimize the effect of varying turbidities.

Triplicates of 100-mL each turbidity in P-free BBM will be placed in 250-mL Erlenmeyer flasks. Each flask will be inoculated with enough *S. capricornutum* to create a starting cell concentration of 3000 cells/mL. Samples will be incubated on an orbital shaker at 100 rpm under constant illumination by Philips F40T12/DX Alto 40-W fluorescent lamps. When cell density reaches a stationary growth phase (<10% increase in density over 24 hours), Chl *a* will be measured using standard methods from Eaton (2005).

To measure Chl *a* in sediments, control triplicates of each turbidity will be incubated without algal inoculum. The mean of these results will be subtracted from measurements of Chl *a* in experimental samples in effort to isolate biomass increase due to internal loading.

Facilities Used

Mesocosm studies were conducted in the Hydrology laboratory in Warnell School of Forestry and Natural Resources. Samples were analyzed in the Hydrology Lab, in the Analytical Chemistry Laboratory in the Institute of Ecology at UGA, the Soil Chemistry Laboratory in the department of Crop and Soil Sciences at UGA.

Algal assays were performed in Dr. William Miller's laboratory in the department of Crop and Soil Sciences at UGA and in Dr. Marshall Darley's laboratory in the department of Plant Biology at UGA. Some preliminary experiments not reported here were conducted in Dr. Brian Binder's laboratory in the department of Marine Sciences at UGA.

Results

Mesocosm experiment

SR in experimental columns resulted in an immediate drop in pH and dissolved oxygen (DO), followed by a rise in both.

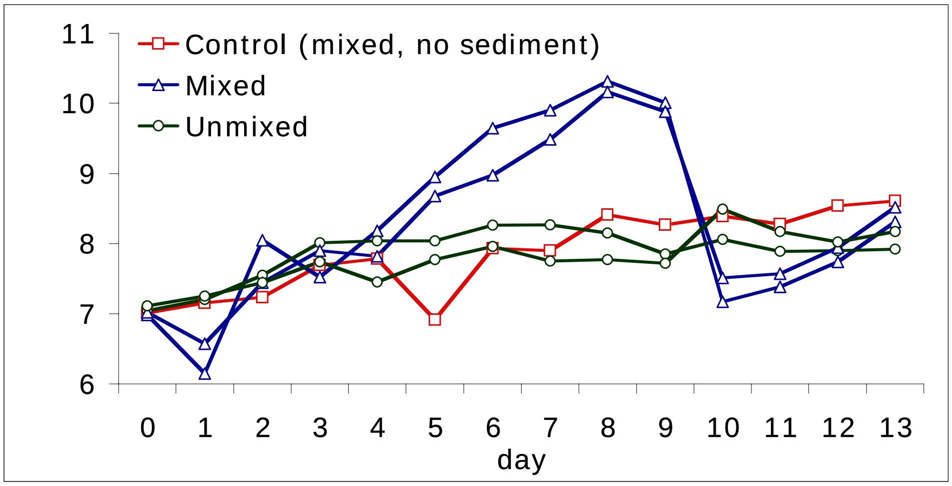

Figure 1. pH as measured at the surface of mesocosms after sediment resuspension.

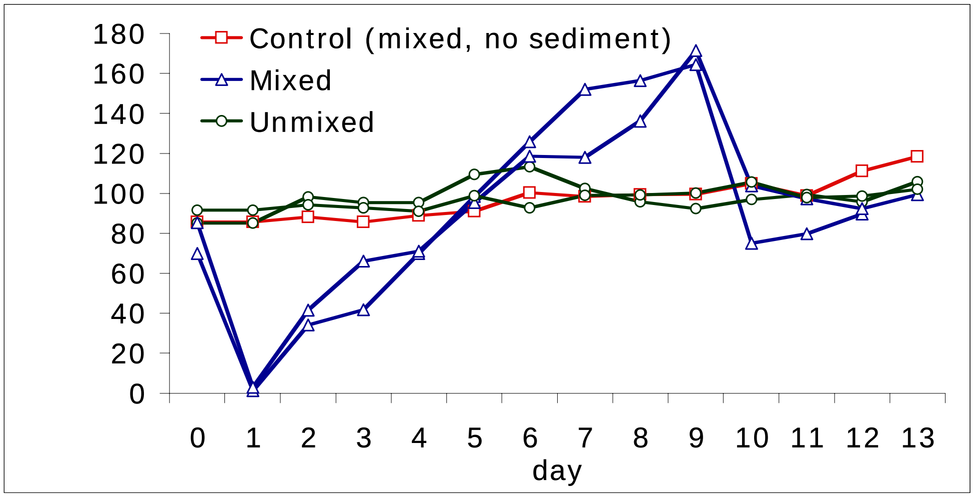

Figure 2. Dissolved O_2 as measured at the surface of mesocosms after sediment resuspension.

pH remained between 8.7 and 10.3, and DO remained between 120% and 170% saturation from 5 to 10 days after mixing (Figs. 1-2). Planktonic Chl *a* increased to peak concentration 7-9 days after mixing (Fig. 3), while periphyton biomass increased throughout the experiment.

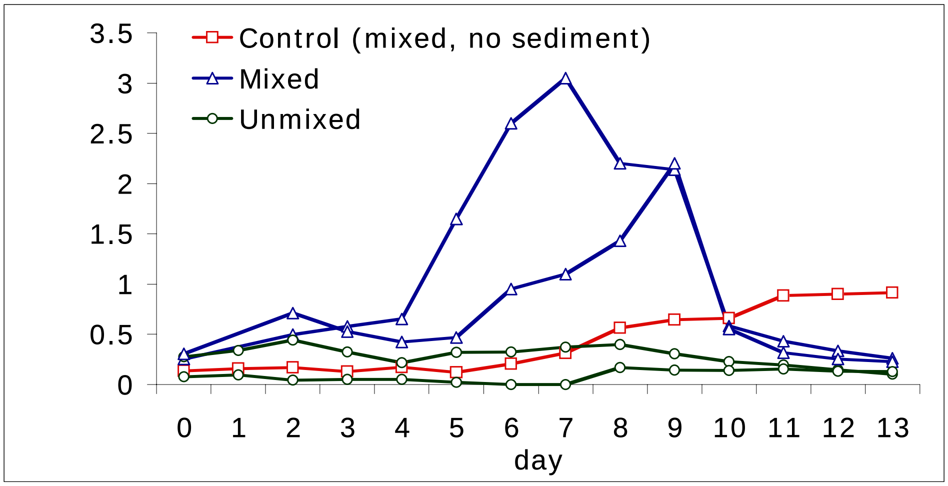

Figure 3. Chlorophyll *a* as measured at the surface of mesocosms after sediment resuspension.

Control columns showed no similar rise or fall in Chl *a*, pH or DO.

The filamentous green alga *Oedogonium* (Chlorophyta) dominated the algal community in all columns. Long filaments of this alga attached to the walls of all columns. By the end of the experiment (day 13) the filaments were shortest, approximately 2 cm, in the column without sediment. The filaments in the unmixed columns containing sediment were approximately 6 cm. The filaments in the mixed column were long enough so that they stretched from the walls of the columns into the center where they wrapped around filaments attached at the opposite wall (>13 cm). The predominance of *Oedogonium* was likely due to the high surface area:volume ratio in the columns giving the alga much more area for attachment than would exist in a lake.

The fluorometric measurement of Chl *a* in the mixed mesocosms was affected by high concentrations of suspended sediment blocking both excitation and emission wavelengths. Therefore, Chl *a* concentration from the mixed columns were likely higher than recorded.

Batch Experiments

Sediment desorption into 1-mM $CaCl_2$

All concentrations were below detection limits (read "0" absorbance).

PO_4^{3-} Sorption isotherm

Maximum orthophosphate sorption capacity was approximately 1200mg PO_4^{3-}-P/kg sediment (Figure 4).

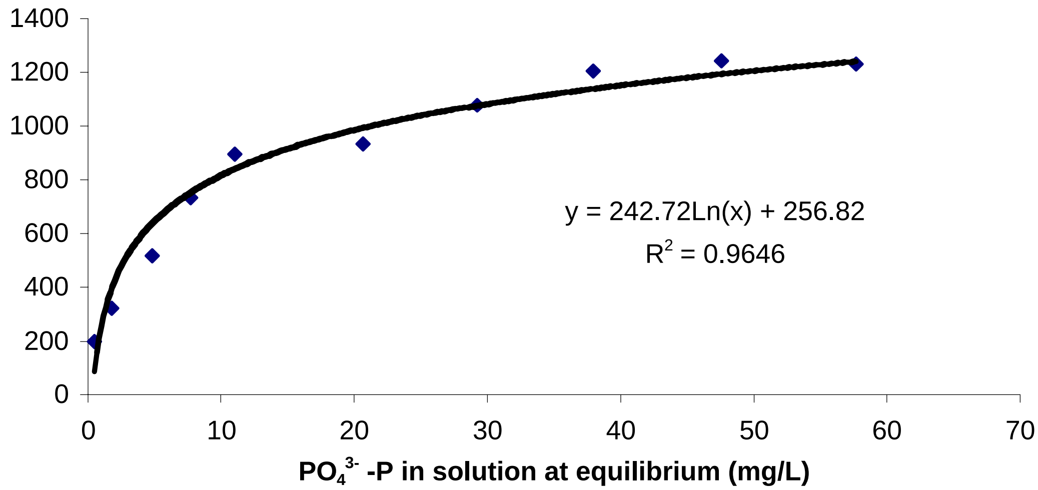

Figure 4. Results of sorption isotherm conducted at 22ºC.

Table 1. Results of particle size distribution analysis.

	% sand	% silt	% clay
sediment	38.5	59.0	2.5
silica	10.8	88.2	1.0

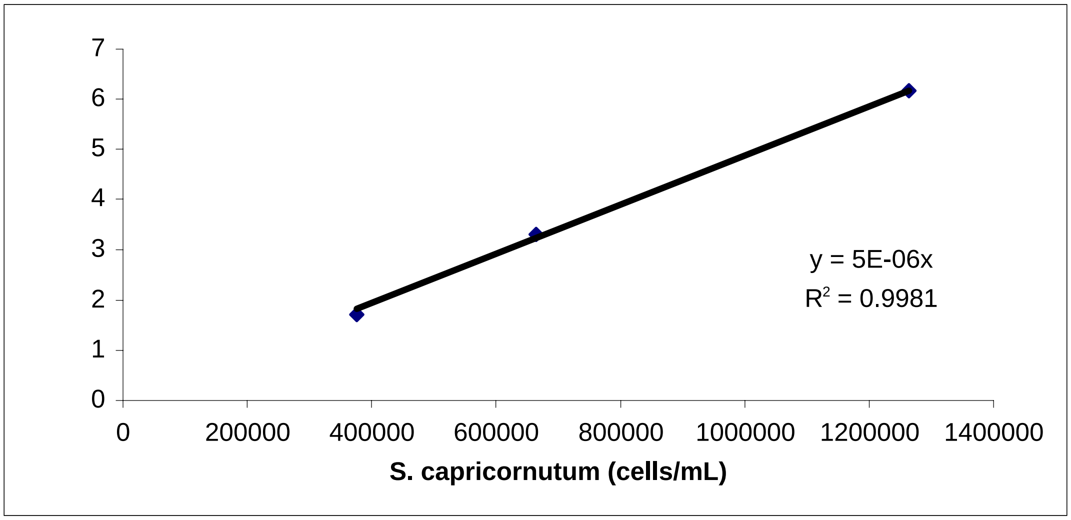

Figure 5. Fluorescence/ cell concentration curve used to estimate cell concentration.

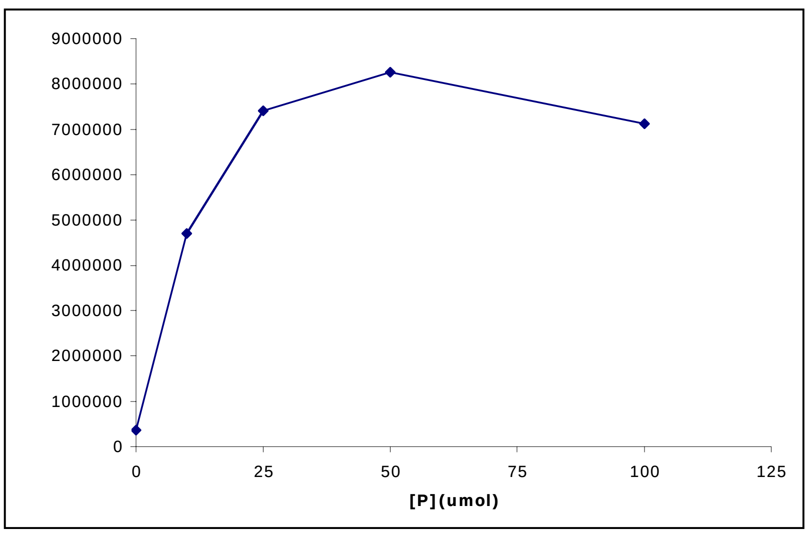

Figure 6. PO_4^{3-} / *S. capricornutum* biomass curve.

Discussion and Conclusions

Mesocosms

In this experiment, dredged and non-dredged conditions were compared using mesocosms placed in ambient conditions that simulate the natural setting. Changes in environmental conditions, including DO, pH, and Chl *a* were used to evaluate the effects of benthic sediment removal on the overlying water quality.

The immediate fall in pH and dissolved oxygen (DO) of the experimental sediment-mixed mesocosms after mixing was likely due to the integration of reduced anoxic, acidic sediments with the overlying water. The subsequent rise of pH and DO observed would then be due to gradual resettling of suspended particles and associated microbial biomass. The rise in *Chl a*, pH and DO could be due to the release of P from suspended particles promoting algal growth.

A second hypothesis that could account for the increase in *Chl a*, DO and pH in the mixed columns is the reseeding of the euphotic zone with algal spores released from sediments. In this scenario any P release from resuspended sediments may or may not contribute to the increase in photosynthetic biomass.

A hypothesis that could account for the increase in *Chl a* is that light-limited algae produce more *Chl a* per cell than non-light limited algae. While this effect may account for increase in *Chl a*, it would not contribute to the rise in pH or DO. Again, the rise and pH and DO were most likely due to increase in primary productivity. pH has been successfully used to estimate algal biomass (Miller et al., 1978; Lopez-Archilla et al., 2003) due to the rise in pH under high rates of photosynthesis removing carbonates.

While it has already been established that P limits algal biomass in Lake Allatoona, the fact that a non-diazotrophic (not able to fix N) alga dominated all mesocosms supports the theory that P was also the limiting nutrient in the mesocosms. Theoretically, if N were the limiting nutrient in this system, one would expect N-fixing algae to dominate the algal community. The fact that a non-diazotrophic alga dominated suggests that N was not limiting. The diatom *Synedra* was abundant as well. This suggests that silica was not limiting.

It is likely that measurements made by fluorometer were confounded by increased turbidity shielding algae from excitation light. The overall effect would be a decrease in *Chl a* measurements. Similar future studies would benefit from a more accurate measurement of algal biomass. A method to quantify *Chl a* of periphyton on column walls is also needed.

Sediment was collected by shovel, and collected sediments were mixed with lake water before being placed in mesocosms. This method could be improved dramatically. Anoxic sediments were mixed with oxic water, thus altering the established microbial community. A more efficient method of collection would be to use a sediment corer. Sediments could then be transferred directly to mesocosms. This would (1) reduce the amount of time necessary for sediment settling and microbial recovery, and (2) result in a microbial community more similar to natural conditions.

Mixing of benthic lake sediments with the overlying pelagic water column is a proposed mechanism for increasing the biological availability of nutrients contained within the sediments. Results from the mesocosm study support the theory that nutrient releases from benthic sediments cause increased lake productivity.

While these experiments are preliminary, results suggest that the removal of lake sediments would decrease the occurrence and severity of algal blooms in Lake Allatoona. However, if the dredging process in Lake Allatoona results in sediment resuspension, then dredging would exacerbate the problem by releasing sediment-sorbed nutrients into the water column, thus making them algal-available.

Batch Experiments

The algal assays performed used sediment from one area of Lake Allatoona solely. Sediment algal assays using sediment from other parts of the lake are needed.

This assay could be modified to more closely represent the natural algal community and lake environment. While the natural algal community is not recommended for this assay, the assay could include other algae found in the lake if they were cultured from a reputable supplier. Using algae from a supplier ensures the repeatability of the assay. Use of several algae in a sediment assay may be especially desirable if pH and/or redox potential is to be manipulated as not all algae can tolerate such changes in their environment.

The assay could also be easily modified to quantify algal biomass in response to mixing regime. For example, one treatment could be sediment and algae left undisturbed, a second treatment would be lightly shaken, and a third treatment total sediment resuspension.

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Meetings and Publications

Ceballos, EL and TC Rasmussen. 2007. Internal Loading in Southeastern Piedmont Impoundments. *Proceedings of the 2007 Georgia Water Resources Conference*, March 27-29, Athens, GA

Research was presented at the American Geophysical Union's 2006 Fall Meeting at the Moscone Center in San Francisco in December 2006, and will be presented at the Georgia Water Resources Conference in March 2007.

Using compost to control soil erosion and manage stormwater under concentrated flow conditions

Basic Information

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Descriptors:	
Principal Investigators:	Lawrence Mark Risse, xianben zhu

Publication

Investigating the Use of Compost for Sediment and Erosion Control under Concentrated flow Conditions

Final report

Mark Risse and Xianben Zhu

Mark Risse: Professor, Department of Biological and Agricultural Engineering, University Of Georgia, **Xianben Zhu**: Master student, Department of Biological and Agricultural Engineering, University Of Georgia

Abstract: To investigate the process of rill erosion on compost blankets, yard waste compost, commercial erosion control compost and a Cecil soil were tested under laboratory conditions. Four slope levels and four sequential inflows were tested. Erosion rate and shear stress of the flow were calculated and the shear stress model was fit for each material. The results indicated that rill erosion on both Cecil soil and yard waste compost conform to the shear stress model. There was not significant difference between Cecil soil and yard waste compost for critical shear stress, however erodibility values appeared to be higher for the yard waste compost under our experimental conditions. The commercial erosion control compost produced very little erosion under steady-state conditions and did not fit the shear stress model. Because of the larger particle size and greater porosity, this compost dispersed and filtered the water flow, effectively reducing the shear stress and erosion under steady flows.

KEYWORDS: Compost blankets, critical shear stress, rill erodibility

BACKGROUND

Soil erosion is considered the biggest contributor to nonpoint source pollution in the United States according to the federally mandated National Pollution discharge Elimination System (NPDES). The U.S. Environmental Protection Agency recently released major new regulations to control erosion and runoff from farms, construction sites, and roads in an effort to make over 20,000 rivers, lakes, and estuaries safe for swimming and fishing. Georgia enacted some of the nation's toughest regulations on erosion and runoff from construction sites in an effort to improve water quality in the state's surface waters.The new regulations label development as "point sources" requiring better erosion control practices and new permitting programs.

Compost is the product resulting from the controlled biological decomposition of organic material, occurring under aerobic conditions, which has been sanitized through the generation of heat and stabilized to the point that it is appropriate for particular application. Compost has been widely used as a soil conditioner to improve the properties of soils and support the growth of vegetation. Compost is recognized as being beneficial in erosion control and is commonly used as blankets in many sites, some of which were exposed to concentrated flow(Ghomas and Bruce, 2006). While previous studies have shown that compost blankets are effective in reducing interrill erosion, little knowledge is available on how effective of this practice is and the limits of using compost blanket under concentrated flow conditions.

OBJECTIVES

The overall objective of this study was to investigate the process of rill erosion on compost blankets and improve our understanding of the effectiveness and limitations of using compost blankets under concentrated flow conditions. The specific objectives included:

1. To determine the hydraulic shear stress and erosion rate of compost materials caused by concentrated flows.
2. To evaluate the applicability of shear stress model to compost blankets.
3. To determine the critical shear stress and erodibility of compost material.

LITERATURE REVIEW

Currently, most research regarding compost application as erosion control practices focused on its effectiveness of reducing interrill erosion. Bresson et al. (2001) tested the impact of compost application on soil surface structure degradation, the resulting runoff and erosion process. They concluded that utilization of MSW compost stabilized the aggregates and delayed crust formation and runoff generation, sediment concentration in runoff was decreased. Risse et al. (2004) investigated the amounts of runoff, erosion, and nutrient losses under simulated rainfall using a variety of composts and mulch materials. The results indicated that the loss of total solids was reduced from soil plots treated by compost blankets. Glanville (2004) compared the concentration and total mass of nutrients and metals contained in runoff from compost-treated and conventionally treated highway embankments with typical 3:1 side slope. Results indicated that the total mass of most pollutants measured in runoff produced from compost treated plots was significantly less than that from conventionally treated soils.

Persyn et al. (2005) tested rill erosion from 3 types of compost blanket at a 33% slope, using both simulated rainfall and inflow. They attempted to fit their data to the shear stress model and the results suggested that the shear stress model was not valid for the rill erosion on compost. They cited considerable uncertainty in that paper due to floatation of compost particles on the flow; the narrow width of the test plots (0.2m) which resulted in preferential flow along the plot boundaries, and "movement of compost down the slope in bulk rather than as individual particles."

Rill erosion on soil can be represent using shear stress model (Foster et al., 1982; Nearing, 1994) which can be expressed as

$$Dr = Kr \times (\tau - \tau_c)^n \qquad (1)$$

Where

Dr = rill detachment rate (g s^{-1} m^{-2})

Kr = rill erodibility (g N^{-1} s^{-1})

τ= hydraulic shear stress (N m^{-2})

τ_c = critical shear (N m^{-2}).

n = exponent assumed to be equal to unity 1(Foster et al., 1984; King et al., 1995).

Both the Kr and τ_c can be obtained by fitting the shear stress model, the slope is erodibility Kr and X-intercept is critical shear stress value τ_c.

The hydraulic shear stress can be calculated using equation 2(Forster et al., 1984;

King et al., 1995)

$\tau = \gamma R S$ ………………………………………………………… (2)

Where γ = the weight density of the flowing fluid (N m^{-3}), R = hydraulic radius (m), and S = slope of the channel (m/m).

Although erodibility is defined as a soil property and is quantified in terms of sediment loss, composts should display a similar property relative to the solids loss from a surface cover(Risse et al., 2004). Due to the soil like texture of most compost materials, it was hypothesized that the erosion mechanism of blanket-applied compost would be similar to the mechanism of soil erosion.

METHODS AND MATERIALS

Experimental design

The experiment was conducted in the Fluid Mechanics Laboratory at the Department of Biological and Agricultural Engineering at University of Georgia. A 3 m, 1 m and 0.7 m (length × width × height) aluminum hydraulic flume was built (fig 1). A 0.8 m × 0.2 m × 0.2 m aluminum box with a reversed vaulted face was built and set on the head of the flume as flow distributor to direct the water flow on the tested material.The slope of the flume was changed by tilting the upstream end. Concentrated flow was generated by pumping clean water from a water tank.

Materials

Two types of composts and a Cecil soil as a control were tested. Yard Waste Compost (YWC) was collected from the University compost facility; Commercial Erosion Control Compost (CECC) that met standards of the Seal of Testing Assurance as outlined by the United State Composting Council was obtained from a commercial composting facility; and a Cecil Soil was collected from the USDA Agricultural Research Service site at Watkinsville, Georgia, the same location where WEPP erodibility experiments were conducted for Cecil Soil sample.

Basic physical properties and organic matter content were analyzed for the three materials based on methods outlined in Test Methods for Examination of Compost and Composting (TMECC). The results are shown in Table 1 and 2.

Data collection

Materials were placed on the flume as 5 cm blankets. A trapezoidal channel was manually created along the center of blankets. Materials were pre-wetted by ponding water on it for 10 minutes. Four slope levels (1%, 3%, 5% and 7%) were used and four sequential inflow rates were applied for each slope level. The lowest flow rate was determined based on previous trials on which rilling was initiated. The subsequent flow rates on soil were increased between 5 and 10 L/min and between 8 and 15 L/min for yard waste compost depending on the slope level. Flow was controlled using a rotameter and manual gate valve. The duration for each inflow rate was 30 minutes. Steady state flow conditions were assumed to occur after 3 minutes of constant flow. This was considered first flush and no sample was taken. The last 27 minutes were used to collect discharge samples which were used to determine erosion rate. Discharge samples were taken at 3 minute intervals using 500mL bottles. A total of 10 samples were collected for each flow rate and 40 total samples were taken for each slope and treatment combination.

Sediment samples were weighed and oven dried at 104 till constant weight was reached. The erosion rates were calculated as the dried sediment weight divided by the test duration and the rill area.

Discharge was determined by recording the time required to fill a 2 liter bucket. Surface velocity of flow was measured using a dye tracer. The dye was injected into the flow and the time required for the leading edge to travel one meteralong the central part of the channel was recorded. The travel time for the leading edge was multiplied by 0.7 to calculate average velocity from the surface velocity(Elliot et al., 1989; Persyn et al., 2005). Width measurements within the rill were taken at 10 testing points which were evenly assigned along the channel. The measurements of discharge, velocity and width of rill were conducted every 3 minutes.

Shear stress values were calculated using equation 2 ($\tau = \gamma R S$), Where specific weight of water γ was assumed 9800 N m^{-3}, and the average channel slope equated to the flume slope; hydraulic radius were calculated using equation 3 and assuming a rectangular cross-section:

$$R = \frac{A}{Wp} \tag{3}$$

Where

R = hydraulic radius (m)

A = cross-sectional area of flow (m^2)

W_P = wetted perimeter (m) = width + 2 × depth.

Cross section area was calculated using the continuity equation:

$$Q = \frac{V}{A} \tag{4}$$

Where

Q = flow discharge ($m^3\ s^{-1}$)

V = average flow velocity ($m\ s^{-1}$)

A = cross-section area of flow (m^2) = width × depth

RESULTS

Observations

Rills were quickly formed for both the CS and YWC. However, the progression of rill formation was different for the two materials (figure 2). The head cut on CS channel began at downstream end and moved up the slope. Both the walls and bottom of the channel were eroded resulting in both widening and deepening of the rill for CS. Once rilling initiated on YWC, the flow kept scouring the bottom till reaching the flume bed. Side scour seldom occurred before the floor of flume was exposed, resulting in a relatively small rill of uniform width for the YWC. This phenomenon may due to the higher content of organic matter and coarse materials in the YWC which stabilized the sides of the rills. The YWC also had a higher infiltration capacity than the CS may have resulted in flow occurring between the compost blanket and channel floor creating upward pressure on the blanket material and less shear stress being required

to initiate transport of materials down the rill.

Erosion on CECC only occurred when inflow rate was increased. When this occurred, there was considerable erosion and particle movement, however, it appeared that eroded particles were deposited quicklyand dams were formed along the channel resulting in a new equilibrium condition with little erosion (figure 3). Flow was divided and ponded by dams, resulting in more flow into the walls and sides of the channel and lower flow velocities and shear stresses. These dams would fail when the flow rate was increased, however, the particles deposited again quickly and new dams were formed at this new equilibrium condition. Only under the extreme conditions of 60 L/min at 7% slope were these micro-dams wash out completely. Under the steady state conditions, it was very rare that any measurable solids could be detected in the flow coming off the flume. Only small portion of discharge measured at the flume outlet ran over the blanket surface because most of the water flowed beneath or through the blanket layer, resulting in high uncertainty when equation 2 was used to calculate the shear stress. Both interlocking of the coarser materials and high infiltration capacity contributed to the formation of dams and low erosion on the CECC blanket.

Statistical Analysis

Because of the uncertainty in calculating shear stress and extremely low amounts of eroded solids detected under our experimental method, most of our analysis did not included the CECC blanket material. Essentially, very little of the flow on this material actually occurred in the rills, so the cross section area and shear stresses could not be calculated using the assumptions inherent to the shear stress model.

Table 3 shows the mean values of discharge, shear stress and erosion rate for the three tested materials. The lower value of discharge for CECC represented considerable uncertainty which might due to the severe leakage of flume bed at the later test period. The highest inflow rate of 60 L/min for the CECC generated almost all the erosion on it. The erosion rate for CECC was obtained by collecting the first flush because after that no sediment was detected.

Shear stress model was fit to every replication for each slope level, the correlation coefficients, critical shear stresses and erodibility values are summarized in table 4. Only replications having a positive slope and x-intercept (without bold) were used to determine the average values for the critical shear stress and rill erodibility parameters. Student t-test was conducted ($p<0.05$) for the mean values of critical shear stress and eordibility for YWC and CS. No significant difference was found between YWC and CS for either the critical shear stress or erodibility values. The R^2 value for both CS and YWC suggested the shear stress model was likely valid both on CS and YWC.

Figure 4 shows the overall fit of shear stress model for YWC and CS. Data from the 4 different slope levels were included together in this regression. Even thought the difference of critical shear stress was not significant, the discrepancy of slopes presented in this figure suggests a slightly higher potential rill erodibility for the CS compared to YWC.

CONCLUSIONS

This study shows that the erosion rates for compost under concentrated flow conditions may vary by compost material and are probably different than those for standard soils. While the shear stress model appeared valid for the Cecil soil and the yard waste compost, the inclusion of coarser materials and the higher infiltration capacity of the CECC compost resulted in a failure to apply the shear stress model. The erosion rates were much lower for the CECC compost, however, since the flow was not constrained to the rill and tended to flow through the material rather than over it, the shear stress model could not be applied. The comparison of critical shear stress and erodibility parameters concluded that there were no statistically significant differences between yard waste compost and Cecil soil under our experimental conditions, however, the rill erodibility for the YWC did appear higher. The shear stress model is likely valid for rill erosion both on Cecil soil and yard waste compost. Since there was no difference in the critical shear stress required to initiate erosion, the yard waste compost may not be suitable to apply on sites where concentrated flow is expected. The commercial erosion control compost had higher infiltration capacity and was capable of transmitting larger volumes of flowing water down the surface, and may be able to withstand some level of concentrated flow. Further work is needed to define the limits of flow that could be allowed.

FUTURE WORK

1. Conduct field test to validate the applicability of shear stress model for erosion on yard waste compost and commercial erosion control compost by including the first flush samples.
2. Determine the critical shear stress and erodibility parameters for yard waste compost and commercial erosion control compost under field conditions.
3. Determine the critical inflow rate under a various slope levels for these two types of compost materials.

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TABLES AND FIGURES

Table 1. Particle size distribution for YWC and CECC

Sieve size, mm	YWC, % passing	CECC, % passing
19.00	100.00	98.15
8.00	92.93	89.01
4.00	79.85	69.97
2.00	58.28	47.23
1.00	35.76	23.74

Note: All the materials were dried at 75 for 1.5 hours before being tested

Table 2. Bulk density, organic matter content and water holding capacity

Material	Bulk Density, g/cm3	Organic matter content,%	Water holding capacity, g/g
CS	1.24	0.71	0.102
YWC	0.44	9.85	0.112
CECC	0.17	10.12	0.123

Note: All the materials were dried at 75 for 1.5 hours before being tested

Table 3. Discharge, shear stress and erosion rate

Materials	Discharge L/min		Shear stress, Pa		Erosion rate, g/s/m^2	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
CS	18.23	7.79	3.16	2.23	10.71	13.53
YWC	26.77	20.71	3.47	1.98	4.23	3.79
CECC	21.9	9.7	4.33	4.1	0.34	0.51

Table 4. Rill erodibility, critical shear stress, and R^2 values for CS and CECC for each replication

	1%			3%			5%			7%				
	1	2	3	1	2	3	1	2	3	1	2	3	Mean	Std.Dev
Kr.(Kg $s^{-1}N^{-1}$)														
CS	0.0031	0.0097	0.0340	0.0002	0.0028	0.0032	**-0.0001**	0.0049	0.0261	0.0022	0.0003	0.0082	0.0140	0.0130
YWC	0.0003	0.0005	0.0016	**-0.0029**	0.0012	0.0004	0.0023	0.0004	0.0013	**-0.0042**	0.0055	0.0021	0.0012	0.00067
τc (Pa)														
CS	1.4625	0.1211	0.6937	**-3.8000**	0.6196	2.4534	18.8333	**-1.1296**	1.4611	3.0833	**-1.6786**	1.3675	0.9517	0.5574
YWC	0.5326	0.3369	0.6969	5.2551	0.7840	**-13.4000**	1.9596	**-2.4900**	1.5530	6.9788	4.1172	2.7981	1.1167	0.9226
R^2														
CS	0.94	0.94	0.99	0.85	0.85	0.67	0.04	0.63	0.978	0.854	0.965	0.86	0.8065	0.2644
YWC	0.89	0.9	0.96	0.95	0.43	0.18	0.31	0.52	0.99	0.69	0.71	0.079	0.6332	0.2856

Figure 1: Experimental setup

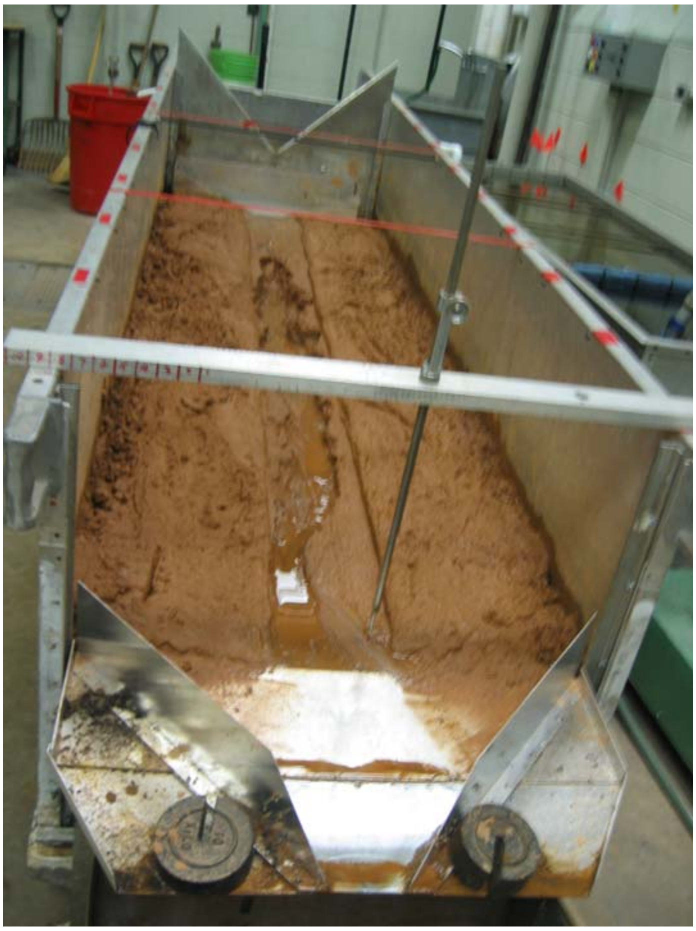
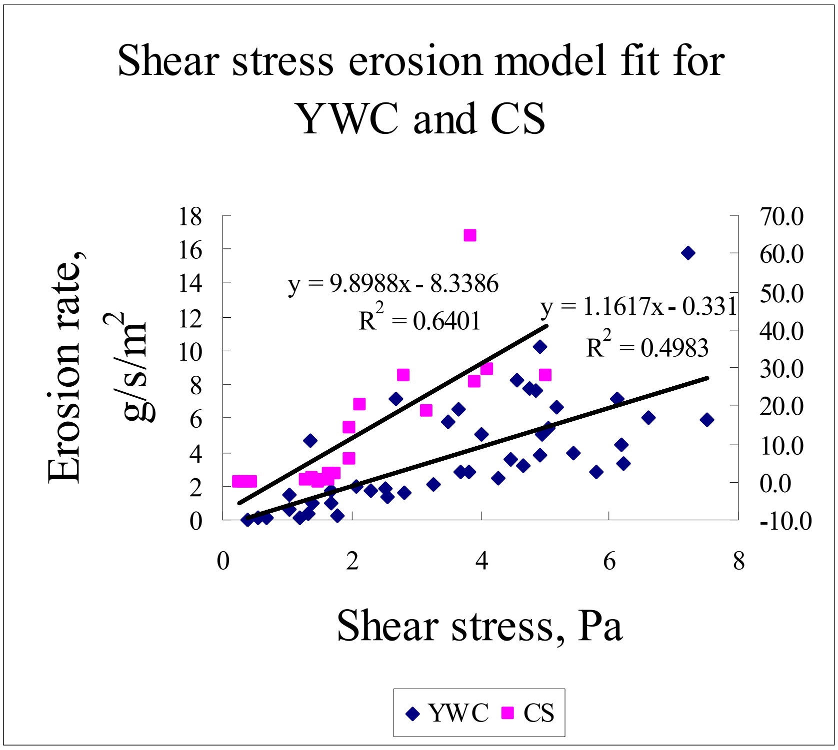


Figure 2: Rill process of on Yard waste compost and Cecil soil

Figure 3: Erosion process on commercial erosion control compost

Figure 4: overall fit of shear stress model for erosion on YWC and CS



Information Transfer Program

1st Annual Mega-City Water Forum: Innovative Water Supply Strategies for the 21st Century

Basic Information

Title:	1st Annual Mega-City Water Forum: Innovative Water Supply Strategies for the 21st Century
Project Number:	2006GA127B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	5
Research Category:	Not Applicable
Focus Category:	Water Supply, Management and Planning, Law, Institutions, and Policy
Descriptors:	
Principal Investigators:	Aris P. Georgakakos, Sebastian Mathews

Publication

Mega-City Water Forum at Georgia Tech

The Georgia Water Resources Institute and the School of Civil and Environmental Engineering in cooperation with the City of Atlanta and CIFAL Atlanta co-hosted the first Mega-City Water Forum "An integrated approach to Water Resource Management: Strategies for the 21st Century" at the Georgia Tech Learning Center on May 1-3, 2006. This event was also co-sponsored by several professional associations, foundations, and corporations including the International Water Association, the American Water Works Association and Research Foundation, the World Bank Institute, the Global Environment and Technology Foundation, the Alliance to Save Energy, Veolia Water, Coca Cola, Bank of America, Western Summit, Goldman Sachs, King and Spaulding, Rockdale Pipeline, and Delta. The Mega-City Water Forum was attended by more than 85 city officials, executives, and utility managers from some of the world's largest cities in 17 countries.

The Forum was officially opened by President Wayne Clough, Commissioner Rob Hunter (Atlanta Department of Watershed Management), and Atlanta's Major Shirley Franklin who welcomed the participants and emphasized the urgency to secure clean and safe urban water supply and to develop innovative strategies for water supply as well as sanitation management. The Key Note Address was delivered by Paul Reiter, Executive Director of the International Water Association.

Mega-City Water Forum Inaugural Luncheon showing (from left to right) Commissioner Robert Hunter, Atlanta Dept. of Watershed Management; Axel Leblois, Executive Director, CIFAL Atlanta; President Wayne Clough, Georgia Tech; Mayor Shirley Franklin, City of Atlanta; and Paul Reiter, Executive Director, International Water Association.

The forum deliberated Mega-City water challenges from an integrated perspective. Parallel breakout sessions focused on water supply and sanitation using the United Nation's interactive and participatory knowledge management approach. The findings of these discussions were evaluated within the context of watershed management and ecological sustainability and distilled into a summary of best practices. This summary document will be available through the websites of the Georgia Water Resources Institute (gwri.org) and CIFAL Atlanta (cifalatlanta.org).

In their closing remarks, forum organizers, including Professor Aris Georgakakos, Director of the Georgia Water Resources Institute, declared the forum a success and re-affirmed their commitment to continue the dialogue on sustainable water supply and sanitation strategies for US and international mega cities.

Carl E. Kindsvater Symposium: Water Resources, Planning for Georgia's Future

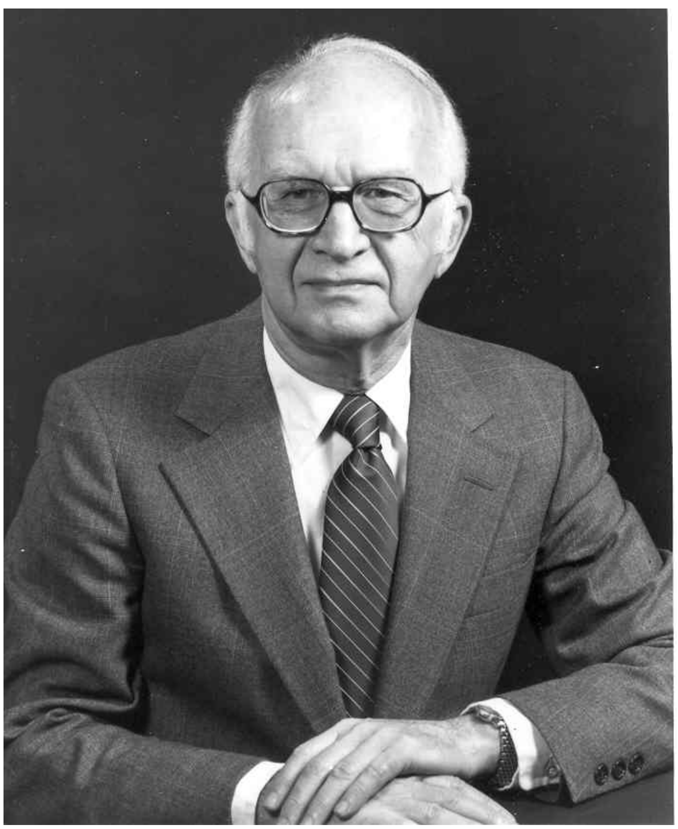
Basic Information

Title:	Carl E. Kindsvater Symposium: Water Resources, Planning for Georgia's Future
Project Number:	2006GA174B
Start Date:	4/24/2006
End Date:	4/24/2006
Funding Source:	104B
Congressional District:	5
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Aris P. Georgakakos, Terry W. Sturm

Publication

Kindsvater Symposium

On April 24, over 100 participants gathered at Georgia Tech for the first annual Carl E. Kindsvater Environmental and Water Resources Symposium and Distinguished Lecture. The event was organized by the Environmental Technical Group (ETG) of the Georgia section of ASCE, the Georgia Water Reources Institute (GWRI), the School of Civil and Environmental Engineering, and the U. S. Geological Survey. The symposium is named in honor of Professor Carl E. Kindsvater (1913-2002) who had a distinguished career at Georgia Tech from 1945-1972. Professor Kindsvater began his career in the area of hydraulic engineering and then moved into the field of water-resources engineering and planning in a multidisciplinary academic setting. Professor Kindsvater built the hydraulics laboratory in the old CE Building and created the graduate program in hydraulics and water resources at Georgia Tech. In addition, he initiated and led the Georgia Water Resources Institute from its infancy into a viable research entity that continues today according to the principles that he established. He was the winner of numerous ASCE awards including the Collingwood Prize, the Norman Medal (twice), the Rickey Medal, and the Julian Hinds Award. Professor Kindsvater also served as President of the Georgia section of ASCE, and Director of the District 10 ASCE Board.



Professor Carl E. Kindsvater (1913-2002)

The symposium was opened by welcoming remarks from Dean Don Giddens, Dr. Aris Georgakakos, Director of GWRI, and Dr. Jim Wallace, who served as symposium moderator representing the ETG of ASCE. In the afternoon session, participants enjoyed the rare treat of listening to speakers whose careers spanned more than three decades as directors of environmental and water resources planning and regulation in the State of Georgia. Leonard Ledbetter, former Commissioner of Natural Resources, Harold Reheis, former Director of the Environmental Protection Division (EPD), and Dr. Carol Couch, current Director of EPD, discussed Georgia environmental and water resources issues from the early days of environmental regulation through the Georgia-Florida-Alabama “water wars” to the present-day efforts to develop a policy and planning framework for the State Water Plan that is currently under development. A panel discussion led by Dr. Jim Kundell of the University of Georgia highlighted regional water issues in Georgia. At the banquet, a brief synopsis of Professor Kindsvater’s career was given by Dr. Terry Sturm of the School of CEE. In the evening session following the banquet, Dr. L. Douglas James, Program Officer of Hydrologic Sciences at the National Science Foundation (NSF), delivered the Kindsvater Distinguished Lecture. Dr. James gave his views on the future of resolving water resources and environmental issues from the perspective of NSF. Dr. James challenged the audience to follow in the footsteps of Professor Kindsvater to use objective analysis and new remote sensing and computational modeling tools to overcome water shortages, extreme hydrologic events, and pervasive environmental contamination to ensure adequate supplies of clean water for future generations.

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	5	0	0	0	5
Ph.D.	4	0	0	0	4
Post-Doc.	1	0	0	0	1
Total	10	0	0	0	10

Notable Awards and Achievements

Publications from Prior Projects

None