Louisiana Water Resources Research Institute Annual Technical Report FY 2005

Introduction

This report presents a description of the activities of the Louisiana Water Resources Research Institute for the period of March 1, 2005 to February 28, 2006 under the direction of Dr. John Pardue. The Louisiana Water Resources Research Institute (LWRRI) is unique among academic research institutions in the state because it is federally mandated to perform a statewide function of promoting research, education and services in water resources. The federal mandate recognizes the ubiquitous involvement of water in environmental and societal issues, and the need for a focal point for coordination.

As a member of the National Institutes of Water Resources, LWRRI is one of a network of 54 institutes nationwide initially authorized by Congress in 1964 and has been re-authorized through the Water Resources Research Act of 1984, as amended in 1996 by P.L. 104-147. Under the Act, the institutes are to:

"1) plan, conduct, or otherwise arrange for competent research that fosters, (A) the entry of new research scientists into water resources fields, (B) the training and education of future water scientists, engineers, and technicians, (C) the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and (D) the dissemination of research results to water managers and the public.

2) cooperate closely with other colleges and universities in the State that have demonstrated capabilities for research, information dissemination and graduate training in order to develop a statewide program designed to resolve State and regional water and related land problems. Each institute shall also cooperate closely with other institutes and organizations in the region to increase the effectiveness of the institutes and for the purpose of promoting regional coordination."

The National Water Resources Institutes program establishes a broad mandate to pursue a comprehensive approach to water resource issues that are related to state and regional needs. Louisiana is the water state; no other state has so much of its cultural and economic life involved with water resource issues. The oil and gas industry, the chemical industry, port activities, tourism and fisheries are all dependent upon the existence of a deltaic landscape containing major rivers, extensive wetlands, numerous large shallow water bays, and large thick sequences of river sediments all adjacent to the Gulf of Mexico. The Hurricane season of 2005 which included the devastating storms of Katrina and Rita provided further opportunities for the LWRRI to provide leadership and coordination for research activities.

History of the Institute

Louisiana has an abundance of water resources, and while reaping their benefits, also faces complex and crucial water problems. Louisianas present water resources must be effectively managed, and the quality of these resources must be responsibly protected. A fundamental necessity is to assure continued availability and usability of the state’s water supply for future generations. Specifically, Louisiana faces five major issues that threaten the quality of the states water supply, which are also subsets of the southeastern/island region priorities:

Nonpoint sources of pollution are estimated to account for approximately one-half of Louisiana's pollution. Because of the potential impact of this pollution and the need to mitigate its effects while maintaining the state's extensive agricultural base and coastal zones, continued research is needed in the area of nonpoint issues. Louisianas regulatory agencies are addressing non-point source problems through the development of waste load allocation models or total maximum daily load (TMDL) calculations. There are serious technical issues that still require resolution to insure that progress is made in solving the non-point source problem.

Louisiana's vast *wetlands* make up approximately 40% of the nation's wetlands. These areas are composed of very sensitive and often delicately balanced ecosystems which make them particularly vulnerable to contamination or destruction resulting both from human activities and from natural occurrences. Understanding these threats and finding management alternatives for the state's unique wetland resources are priority issues needing attention.

Water resources planning and management are ever-present dilemmas for Louisiana. Severe flooding of urban and residential areas periodically causes economic loss and human suffering, yet solutions to flooding problems can be problems in themselves. Water supply issues have also recently a focus of concern. Despite the abundance of resources, several aquifers have been in perennial overdraft, including the Chicot aquifer. Louisiana passed its first legislation that restricts groundwater use in the past year. Water resources and environmental issues are intricately interconnected; therefore, changes in one aspect produce a corresponding responsive change in another. Further study is needed to understand these relationships.

Water quality protection, particularly of ground water resources, is an area of concern in Louisiana. Researchers are beginning to see contamination in drinking water supplies that was not present in the past. Delineating aquifer recharge areas, understanding the impacts of industrial activities on water resources, evaluating nonpoint sources of pollution, and exploring protection alternatives are issues at the forefront.

Wastewater management has been a long-standing issue in Louisiana. The problem of wastewater management focuses primarily on rural and agricultural wastewater and the high costs for conventional types of wastewater treatment as found in the petrochemical industry.

The Institute is administratively housed in the College of Engineering and maintains working relationships with several research and teaching units at Louisiana State University. Recent cooperative research projects have been conducted with the Wetland Biogeochemistry Institute and the EPAs Hazardous Substance Research Center- South & Southwest.

Research Program

The primary goal of the Institute is to help prepare water professionals and policy makers in the State of Louisiana to meet present and future needs for reliable information concerning national, regional, and state water resources issues. The specific objectives of the Institute are to fund the development of critical water resources technology, to foster the training of students to be water resources scientists and engineers capable of solving present and future water resources problems, to disseminate research results and findings to the general public, and to provide technical assistance to governmental and industrial personnel and the citizens of Louisiana.

The priority research areas for the Institute in FY 2005 focus on selected research themes. Because of the small nature of the projects, it was apparent that a greater impact is possible if a thematic area is chosen to focus several complimentary research groups on a single issue. Several themes were considered. At the State level, greater emphasis was being placed on pollutant transport issues. In particular these issues focused on total maximum daily load (TMDL) calculations in Louisiana water bodies, scale-dependent behavior of hydrologic and water quality parameters, and mercury and methylmercury formation in Louisiana water bodies. Projects selected were from a range of faculty with different academic backgrounds including biological scientists, environmental engineers and water resources. Supporting research in this priority area has increased the visibility of the Institute within the State.

The selected research projects are designated as Projects LA-31B, LA-32B, LA-33B, and LA-34B, as listed below.

Project 2005LA-31B Deng, Modeling Sediment-Controlled TMDLs for the Branched and Braided Networks of Waterways in Louisiana: Model Development and Application to the Amite River Basin

Project 2005LA-32B Devai, Total Mercury and Methylmercury in Louisiana Fresh, Brackish and Salt Marsh

Project 2005LA-33B Singh, Probabilistic Assessment of the Effectiveness of BMPs in Coastal Louisiana

Project 2005LA-34B Abdelghani, A Comprehensive Study Of Mercury/Methylmercury Fate, Transport And Bioavailability In Lake Pontchartrain Sediments

These projects include two projects which focus on water quality issues and solute transport (2005LA31B & 2005LA33B) and one project that focuses on wetlands and sediments (2005LA32B). One of the projects (2005LA34B) was not funded due to the impacts of Hurricane Katrina on the research infrastructure of Tulane University. These funds were rebudgeted to cover the costs of LWRRI research and coordination related to Hurricane Katrina.

Hurricane Katrina went shore near Buras, Louisiana on August 29, 2005. It brought dramatic flooding to the New Orleans area later that day accompanied by massive loss of life and property damage. For LWRRI it presented an opportunity to provide expertise and coordination amongst water researchers. LWRRI made significant contributions during the response to Hurricane Katrina. The Institute led water sampling teams into the New Orleans area as early as September 3rd, 2005 and collected the first water quality data on floodwaters. This culminated in the first peer-reviewed publication on Hurricane Katrina in the ACS journal, Environmental Science & Technology published on the web on October 12th, 2005 (http://pubs.acs.org/cgibin/sample.cgi/esthag/asap/html/es0518631.html). The results described in the paper have been widely disseminated in the media and among federal agencies responding to the cleanup. This has lead to a number of opportunities to speak about the environmental impacts and response to Katrina, the most significant of which is an invitation to the National Academy of Science workshop on Strengthening the Scientific and Technical Response to Hurricane Katrina in November, 2005. In addition to this research effort, LWRRI provided leadership within LSU (http://www.katrina.eng.lsu.edu/index.htm) : facilitating researcher access to New Orleans, organizing research exchanges with the LSU Hurricane Center and documenting media contacts. The attention on LWRRI has been particularly significant since much of the early work on the vulnerability of New Orleans to hurricanes was done within LWRRI by the previous director, Dr. Joseph Suhayda and collaborators. All of these early studies have been posted on our website (http://www.lwrri.lsu.edu/1998_2002WEB.htm) and received thousands of hits immediately following the storms.

In addition to the water sampling, LWRRI researchers have been involved in sediment, air, microbiological and landfill research that will lead to further peer-reviewed publications on the issues raised by the impacts of the storms. We continue to partner with LSU Hurricane Center and others on planning and evacuation work for the upcoming 2006-2007 Hurricane season.

Modeling Sediment-Controlled TMDLs for the Branched and Braided Networks of Waterways in Louisiana: Model Development and Application to the Amite River Basin

Basic Information

Title:	Modeling Sediment-Controlled TMDLs for the Branched and Braided Networks of Waterways in Louisiana: Model Development and Application to the Amite River Basin
Project Number:	2005LA31B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	6
Research Category:	Engineering
Focus Category:	Models, Solute Transport, Water Quality
Descriptors:	None
Principal Investigators:	Zhi-Qiang Deng

Publication

1. Deng, Z., and Mishra, P. Sediment TMDL Calculations for the Upper Amite River. The 2006 AIH annual meeting / international conference on Challenges in Coastal Hydrology and Water Quality. Water Resources Publications, LLC, USA, 2006.
2. Deng, Z-Q., Scaling dispersion model for pollutant transport in natural rivers. The 2005 EWRI World Water and Environmental Resources Congress, Anchorage, Alaska, May 15-19, 2005.
3. Deng, Z., de Lima, João L.M.P., and Singh, V. P. (2005). Transport rate-based model for overland flow and solute transport: Parameter estimation and process simulation. Journal of Hydrology, 315(1-4), 220-235.
4. Mishra, P. K., and Z. Deng (2005). Sediment TMDL development for the Amite River. Submitted to the journal Hydrological Processes.

Modeling Sediment-Controlled TMDLs for the Branched and Braided Networks of Waterways in Louisiana: Model Development and Application to the Amite River Basin

Research

Problem and Research Objectives

An overview of current TMDLs by the EPA shows that over 40% of the United States assessed waters still do not meet the water quality standards which the states, territories, and authorized tribes have set for them. This amounts to over 20,000 individual river segments, lakes, and estuaries. These impaired waters include approximately 300,000 miles of rivers and shorelines and approximately 5 million acres of lakes -- polluted mostly by sediments, excess nutrients, and harmful microorganisms from nonpoint sources. In fact, the largest water pollutants in the United States, by volume, are instream suspended sediment (Fowler and Heady, 1981). In Louisiana, non-coal surface mining activities have been identified as a significant source of increased sediment loadings to rivers and streams, which continue well beyond the period of active industrial operations due to lack of proper restoration at most sites. The Amite River is identified as one of the 59 water bodies impaired by sediments in Louisiana. Fish and wildlife habitat has been directly degraded with significant loss of shoreline and aquatic habitat in approximately 25 miles of the upper reaches of the river above Denham Springs, with potentially many more miles indirectly impacted. This degradation is believed to have been caused by urbanization, sand and gravel mining, erosion, shallower water, faster flow, higher water temperature, increased turbidity, agricultural and forestry practices over the last 50 years. As the habitat deteriorates, wildlife that uses the river and floodplain ecosystem decreases in quantity, quality, and diversity. Another result of the sediment impairment in the river has been higher river stages downstream. The Amite's 1983 flood led to significant property damage, economic loss and disruption of lives in East Baton Rouge, Livingston and Ascension parishes. Therefore, a sediment TMDL calculation is required by EPA for the river. The overall goal of this project was thus to present the sediment TMDL calculation for the Amite River. The objectives of this project were (1) to develop a new sediment transport model for the Amite River, (2) to conduct steady and unsteady flow computation, (3) to estimate sediment loads (sources) produced by watershed erosion, and (4) to determine sediment TMDLs for the Amite River.

Methodology

Using the mass conservation principle and Reynolds transport theorem a new 1-D model has been developed for computation of suspended cohesive sediment transport in the Amite River. To solve the new sediment transport equation, a standard split approach by Sobey (1983) is used. Such an approach requires solving the advection and diffusion parts separately at each time step. The advection-dispersion equation is decomposed into the hyperbolic (pure advection) and the parabolic (pure dispersion with sink and source terms) partial differential equations. The two sub-equations are then solved separately in consecutive fractional steps by the corresponding numerical approaches that best fit the features of each PDE for one time step. Based on the split-operator algorithm it is commonly assumed that the pure advection process and the pure dispersion process alternate with time: the advection process occurs in the first sub-time step, the dispersion takes place in the second sub-time step, and the reaction is considered in the final sub-time step (Holly and Preissmann, 1977). A step size of 375 m is taken for distance and 10 seconds for the time step. The grid size was chosen carefully, so as to meet the stability criterion and also avoid being computationally expensive. The flow computation is performed under steady and unsteady conditions using the HEC-RAS software. The steady flow analysis is intended for calculating water surface profiles for steady gradually varied flow. The basic computational procedure is based on the solution of the energy equation. Effects of various obstructions such as bridges, culverts, weirs, spillways and other structures in the flood plain have been considered in the computations. Sediment erosion in the Amite River Basin is calculated by combining the USLE (Universal Soil Loss Equation) model with ARCVIEW GIS and the digital elevation model of the Amite River Basin. The entire Amite River basin is divided into 15 sub-basins. Digital elevation data was imported into the GIS which generated inputs for USLE. The GIS database provides inputs for land use, soil type, slopes and elevation as shown in Figure 1. Meteorological data from 1987 to 2004 from the USGS stations were used. Surface erosion from land catchments, settling, scouring, and bank erosion were considered.

Principal Findings and Significance

(1) Using mass conservation and Reynolds transport theorem, the following 1-D sediment transport model has been developed for the sediment TMDL calculations. The new model is capable of predicting suspended sediment transport in the Amite River.

$$\frac{\partial S}{\partial t} + U\frac{\partial S}{\partial x} = \frac{1}{A_f}\frac{\partial}{\partial x}\left(A_f K_x \frac{\partial S}{\partial x}\right) + \frac{\alpha(u_* - u_{*c})(S_* - S)}{h} - \frac{\beta\omega_S S}{h} + \frac{q_L}{A_f}(S - S_L) \quad (1)$$

in which U = flow velocity, h = flow depth, S = sediment concentration (M/L^3), S_L = sediment concentration of lateral inflow (M/L^3), S_* = suspended sediment concentration under equilibrium conditions or suspended-load carrying capacity (M/L^3) which is determined using the formula proposed by WIHEE (Chien and Wan 1999), u_* = shear velocity (L/T), u_{*c} = critical shear velocity (L/T), ω_s = settling velocity of sediment particles (L/T) which is calculated using the equation presented by Cheng (1997), α = constant , β = constant, A_f = channel cross-sectional area (L^2), K_x = longitudinal dispersion coefficient (L^2/T) which is calculated using the method presented by Deng et al. (2001), x = longitudinal distance [L], t = time [T].
The main advantage of Eq. (1) over existing 1-D sediment transport models is that sediment erosion (described by the second term on the right hand side of the equation) and sediment settling (represented by the third term on the RHS) are treated as two different processes and thus modeled by two separate terms. The last term on the RHS of Eq. (1) stands for the influence of tributaries on sediment transport in the Amite River.

(2) The combination of USLE model and GIS technology is an efficient and effective approach for estimation of watershed sediment erosion. GIS is very useful compared to traditional methods by breaking up the land surface into many small cells which enables an analysis to be performed on both large regions as well as discrete areas. GIS not only generates inputs for USLE, but also displays outputs such as land use distribution, as shown in Figure 1.

Spatial variation of soil loss correlated with land use can be observed, as shown in Figure 2. Based on USLE and the average intensity rainfall of 1990, erosion rate of the Amite River Basin is found to be 5.41 tons/acre/year. This erosion rate represents the average annual erosion rate for the entire basin. This erosion value can be used for sediment TMDL calculations under steady flow conditions. The MUSLE model which is a single event model can be employed to determine the soil erosion for the TMDL calculations under unsteady flow conditions.

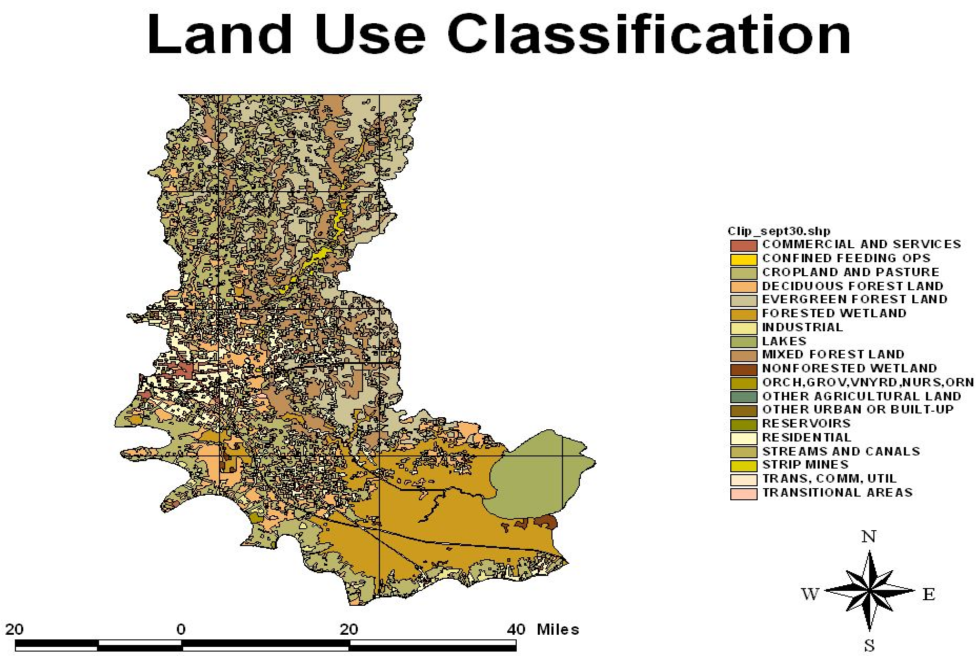

Figure 1: Land Use distribution in the Amite River Basin

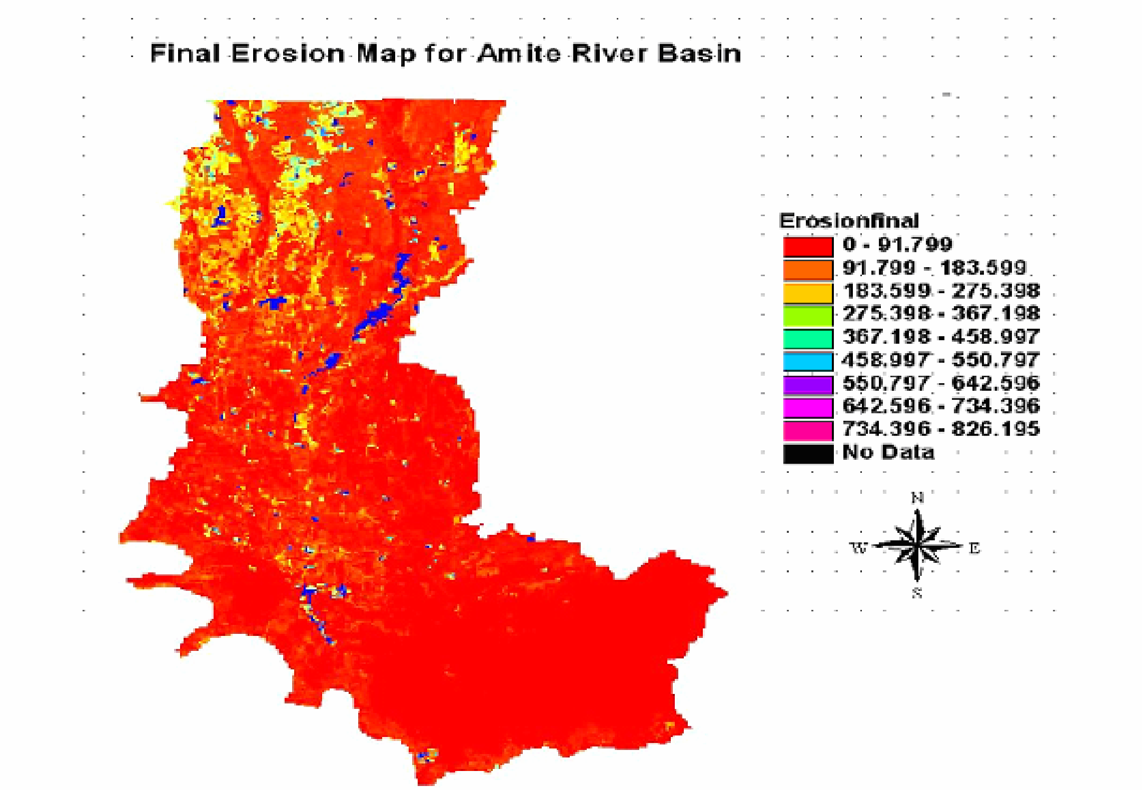

Figure 2. Spatial distribution of computed soil erosion in the Amite River Basin

(3) The flow parameters for both the steady and unsteady flow conditions can be efficiently computed using the HEC-RAS. The calculated discharge and flow velocity of the Amite River vary in the range of 285 – 771 m^3/sec and 0.34 – 2.4 m/s, respectively, as shown in Figures 3 and 4.

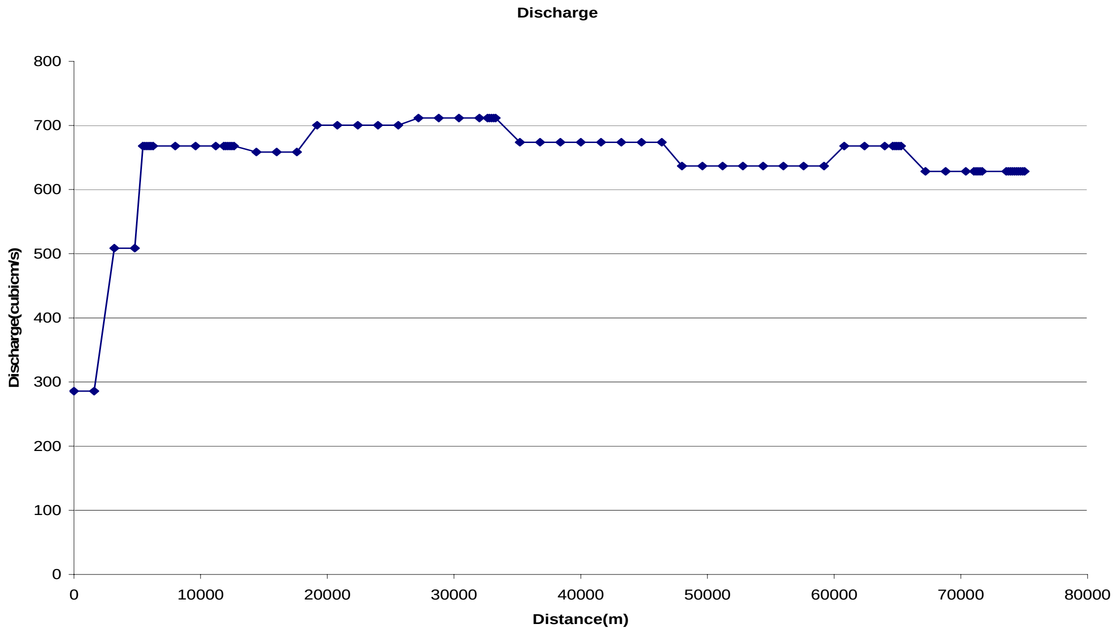

Figure 3: Steady flow discharges with the various inflows and outflows

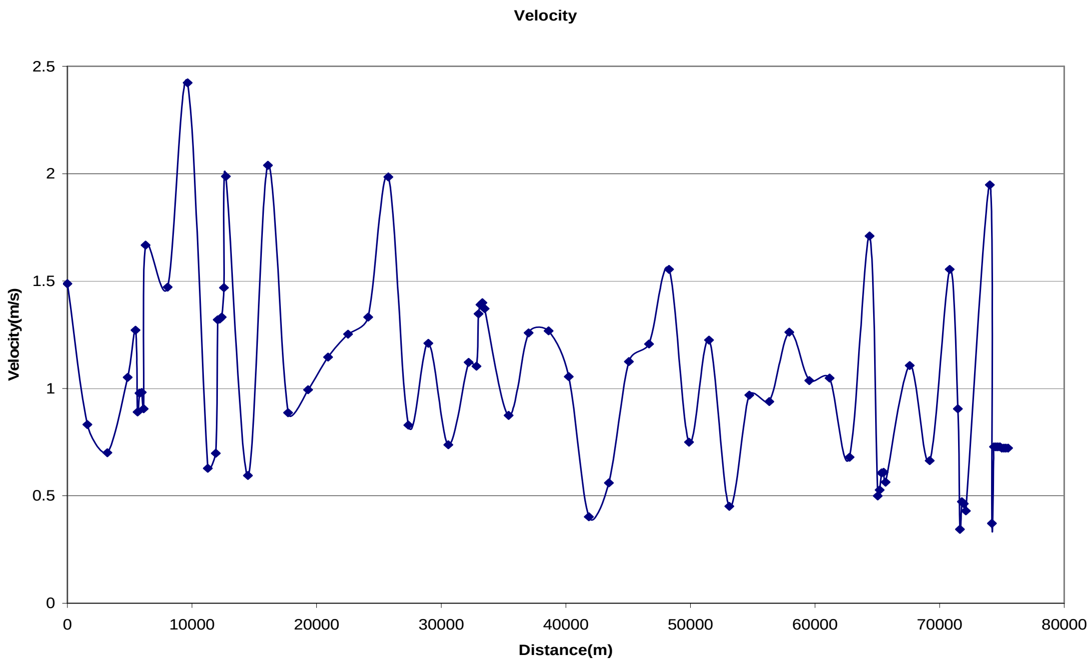

Figure 4: Velocity variations along the Amite River

(4) The 1-D model predicts a maximum sediment concentration of 114 mg/L and the average concentration of 25 mg/L, ranging from 3 mg/l to 114 mg/l in the Amite River, as shown in Figure 5.

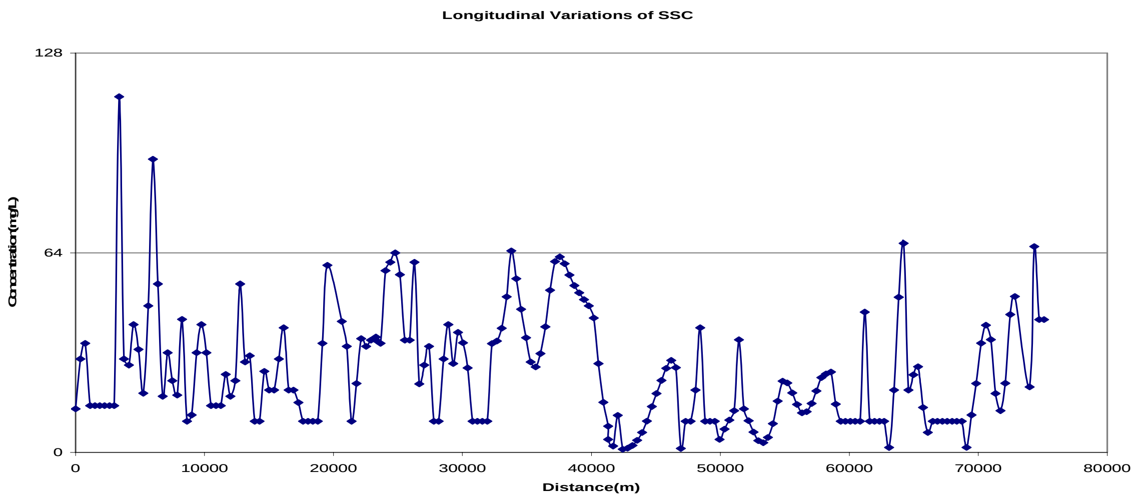

Figure 5: Longitudinal Variations of suspended sediment concentration (SSC) along the Amite River

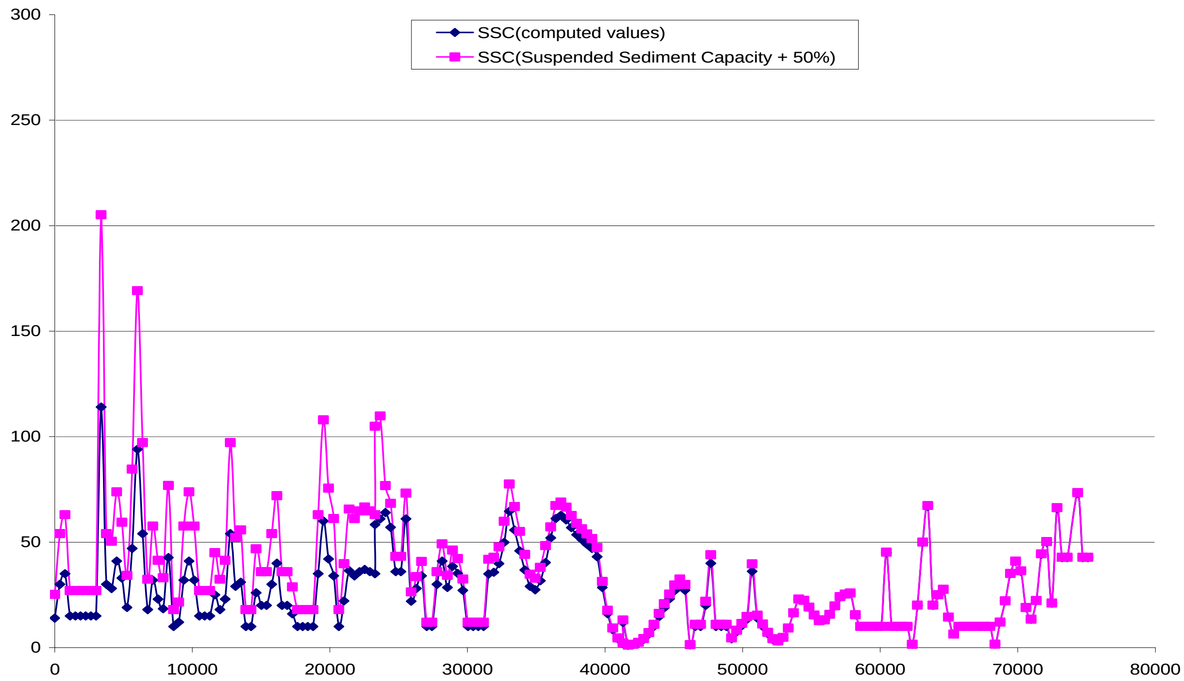

Figure 6: Sensitivity analysis for sediment carrying capacity

(5) Based on the EPA's and LDEQ's water quality standard of 50 NTU, the calculated sediment TMDL for the Amite River is 4665.235 tons/day. The daily reduction in this case

is found to be approximately 220 tons. The TMDL accounted not only for waste load allocation, but also for margin of safety (MOS) and future growth.

(6) Unsteady flow is found to have a significant effect on TMDL calculations. Event based rainfalls produce unsteady flows in the river and a higher erosion rate and thereby sediment concentration in the river, resulting in a higher TMDL for the Amite River. The TMDL value for unsteady flow is found to be 5418.357 tons/day. The median daily reduction is found to be 2653.29 tons/day for the Amite River.

(7) Results of sensitivity analysis show that the most sensitive parameter in the model is the suspended sediment carrying capacity, as shown in Figure 6. Other model parameters such as constant α, settling velocity and dispersion coefficient are also found to have effect on resuspension and on suspended sediment concentration.

(8) Sediment criteria for the Amite River can be met by adopting best management practices such as terraces on the steep slopes, creation of buffer zones along the river. Results indicate that the new model can be an effective tool for sediment TMDL calculations.

This research provided critical insights into the land use, water quality, and sediment TMDLs of the Amite River Basin. The results obtained from this research contribute to developing second phase sediment TMDL development for the Amite River and assessing the feasibility of the Amite River ecosystem restoration. This project produced one Master thesis entitled "SEDIMENT TMDL CALCULATIONS FOR AMITE RIVER" and led to the graduation of one Master's student. Furthermore, the project and its results will be introduced in several civil engineering courses (CE 3200 and CE 7255) at LSU, immediately benefiting both graduate and undergraduate students in learning how science applications solve real world problems related to coastal restoration in Louisiana.

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Total mercury and methylmercury in Louisiana fresh, brackish and salt marsh

Basic Information

Title:	Total mercury and methylmercury in Louisiana fresh, brackish and salt marsh
Project Number:	2005LA32B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	6
Research Category:	Biological Sciences
Focus Category:	Wetlands, Toxic Substances, Sediments
Descriptors:	None
Principal Investigators:	Istvan Devai, Ronald D. DeLaune

Publication

1. Kongchum, M., Devai, I., DeLaune, R.D., and Jugsujinda, A. 2006. Total mercury and methylmercury in freshwater and salt marsh soils of the Mississippi River deltaic plain. Chemosphere. Peer Reviewed (In Press).

TOTAL MERCURY AND METHYLMERCURY IN LOUISIANA FRESH, BRACKISH AND SALT MARSH

Problem and Research Objectives:

Mercury contamination of lakes and streams has taken on new importance worldwide since it was discovered several decades ago that inorganic mercury compounds can undergo methylation in sediments under proper anaerobic conditions with a resulting increase in solubility, mobility and bioaccumulation in the food chain (Jernolov and Lann, 1971). Many waterbodies worldwide have evaluated mercury levels in top predator fish that has prompted the issuance of advisories on fish consumption by various public health agencies. Lakes and waterbodies in the southern U.S. including Louisiana have been impacted by mercury contamination. Recent finding of elevated mercury concentrations in fish and wildlife from fresh water lakes throughout much of the Southern United States including Louisiana has caused great concern for person for whom fish are significant part of their diet and for pregnant women and nursing mothers. Levels of up to 3 ppm have been found in largemouth bass in some lakes, which is considerably above the maximum permissible level (1 ppm) for edible fish tissue. The Louisiana Department of Health and the Department of Environmental Quality have issued mercury advisories for a number of lakes in the state with the results that the desirability of these lakes for fishing has decreased. This proposal describes a study of the conditions in Louisiana marshes that govern the formation and accumulation of methylmercury, the form of mercury that bioaccumulates in the food chain.

Mercury contamination of fish in Louisiana wetlands has become a serious water quality problem with advisories on consumption of fish issued for several areas in the state. The accumulation of unacceptable concentrations of mercury in fish is thought to occur largely as the result of bioaccumulation of methylmercury up the food chain to the top predator fish, which are also the most desired species. Methylmercury is thought to form largely in the anaerobic sediments and then move up through several tropic levels. Information is needed on the historical accumulation of mercury and production of methyl Hg in Louisiana coastal marsh habitats, which serve as nursery ground for aquatic fish species and other organisms.

The over-all research objective was to determine the historical patterns of mercury deposition, rates of accumulation, sources, and distribution of mercury in the Louisiana coastal marsh environment. The study quantifies the amount of methylmercury in Louisiana coastal marsh, which serve as nursery ground for fish and other aquatic species. Due to high organic matter contents of marsh or wetland soil, there likely be greater amount of methylmercury.

Methodology

In this study was determined the accumulation and distribution of mercury and methylmercury in profile of Louisiana Mississippi River deltaic plain fresh water and salt marsh soils and in surface soil of wetland sites surrounding Lke Pontchartrain and Lake Maurepas. Profile distribution of mercury and methylmerucry. Cores (15 cm diameter X 50 cm length) were taken from Louisiana Barataria Basin freshwater marsh, and salt marsh was determined. Salinity level in freshwater marsh was less than 1 ‰. In the salt water marsh salinity was in range of 10 to 14 ‰ (Hatton et al., 1983). The cores were section into 3 cm increments. The sections were air-dry and bulk density determined. Sedimentation or vertical accretion rates were calculated from the peak ^{137}Cs concentration measured in the marsh profile, which corresponded to 1963, the year of ^{137}Cs fallout, and 1954, the first year of significant ^{137}Cs fallout (DeLaune et al., 1978). In addition we collected surface soil from 33 wetland sites surrounding Lake Pontchartrain and Lake Maurepas.

Total mercury was extracted from individual sections using a hydrochloric-nitric acid mixture. Total (organic and inorganic) mercury Hg was measured by cold vapor technique based on EPA Method # 245.1 and 245.5 and 7471A using a Instruments Analytical Technologies LabAnalyzer Model 254. Basis for determination of the mercury concentration is the resonance absorption of the Hg atoms at a wavelength of 253.7 nm. Mercury contained in the sample is reduced to its elementary state by reductant (tin-II-chloride). A stream of air, which is produced by a built-in membrane pump, strips the mercury from the sample and draws it into the optical cell. In this cell the concentration of mercury is determined by measuring light absorption at a wavelength of 253.7 nm. A built-in computer performs the quantitative evaluation of the results. In order to get an extremely stable baseline, the UV-light source is controlled by the reference beam method. In addition to that, the UV-detectors of the LabAnalyzer are thermostatically stabilized. Heating of the optical cell prevents sensitively stabilized. Heating of the optical cell prevents sensitivity for water vapor. Thus the use of a desiccant, which always shows adsorption of mercury vapor, is avoided. Using this method a stable and accurate calibration will be obtained (R=0.998). Continuous calibration check will be maintained over the time of the project and recorded.

MeHg analysis was performed using a GC-AFS system. An integrated gas chromatography-mercury atomic fluorescence spectrometer included a Hewlett-Packard model HP 6890 Series Plus gas chromatograph and coupled to a PSA Merlin Detector via a pyrolysis oven maintained at 810 C. A fused silica analytical column with dimensions of 15 m x 0.53 mm i.d. (Megabore) coated with a 1.5 µm film thickness of DB-1 (J&W Scientific) will be used in the analysis. The column oven temperature will be maintained at 50 C for 1.0 min, programmed at 30 C/min. to 140 C, which will be held for 3.0 min. A split/splitless injector was used in the splitless mode and maintained at 200 C. The carrier gas flow will be 4.0 mL/min. of high purity argon and make-up gas flow was 120 mL/min. of high purity argon. The column eluate will be passed through a pyrolyzer (P.S. Analytical)-positioned inside the oven of the gas chromatograph-via a deactivated fused silica tubing into a Merlin Mercury Fluorescence Detector System (AFS) Model 10.023 (P.S. Analytical) which will be used for mercury detection. For the PSA Merlin Mercury Fluorescence.

Detector system, the sheath gas flow will be 200 mL/min. of argon (Alli et al., 1994; Cai et al. 1996). A real time chromatographic control and data acquisition system (Hewlett-Packard ChemStation) interfaced with the GC and AFS detector system will be used for the analysis. Quantitative MeHg analysis will be obtained using a five-point (between 0.2 ppb and 10.0 ppb) calibration curve forced to zero (R=0.999) generated using standard solutions which were prepared by dissolving appropriate amounts of MeHgCl powder in methanol and then subsequently diluting it with methylene chloride to achieve the required concentrations. Sample preparation will be performed based on the method of Alli and co-workers (1994) and Cai and co-workers (1996,1997a, 1997b). Continuous calibration check will be maintained over the time of the project and will be recorded appropriately.

Principal Findings:

The salt marsh soil had higher bulk density than fresh marsh soil. Average bulk density (0-30 cm) of fresh marsh was 0.07 g cm^{-3} compared to 0.25 g cm^{-3} for salt marsh. The higher bulk density value for salt marsh reflects a greater amount of sediment input onto the vertically accreting marsh soil profile. Due to rapid subsidence Louisiana coastal marshes vertically accrete through organic matter and mineral sediment accumulation to keep pace with water level increases (Hatton et al. 1983). ^{137}Cs activity of fresh and salt marsh showed accretion rates for 0.90 and 0.75 cm yr^{-1}, respectively. The freshwater marsh soil on a dry weight basis contained more methylmercury and total mercury than the salt marsh soil (Table 1). Average total mercury content in the soil profile was 140 μg kg^{-1} dry soil for freshwater marsh and 80 μg kg^{-1} dry soil for the salt marsh (Figure 1). Average methylmercury content was 4.2 μg kg^{-1} dry soil and 1.33 μg kg^{-1} dry soil, respectively for the freshwater and salt marsh (to depth 30 cm) (Figure 2).

Due to greater bulk density the salt marsh soil contained more total mercury per unit area (μg m^{-2}, 30 cm depth) than the fresh marsh (Table 2). On a volume basis average methylmercury content was approximately the same for the fresh marsh and salt marsh. Due to greater sediment input as reflected in the higher bulk density mercury accumulation was greater in salt marsh as compared to the fresh marsh. Along a salinity gradient extending inland from the Louisiana coast, sediment input decreases going from salt to freshwater marsh (Hatton et al., 1983). Methylmercury represented a larger percentage of total mercury content in fresh marsh soils as compared to the salt marsh soils (3 percent versus 1.7 percent). The results show that coastal marshes, which serve as nursery ground for fish species, contained considerable greater amount of methylmercury in the soil profile than reported data for bottom sediment from Louisiana stream and water bodies.

Results when expressed on a dry soil weight basis support greater methylation in freshwater marsh as compared to higher salinity salt marsh soil. However, when expressed on a volume basis the amount of methylmercury in the soil profile is the same. In the salt marsh, sediment input is a greater mercury source than for freshwater marsh soil where mercury input is primary from atmosphere source.

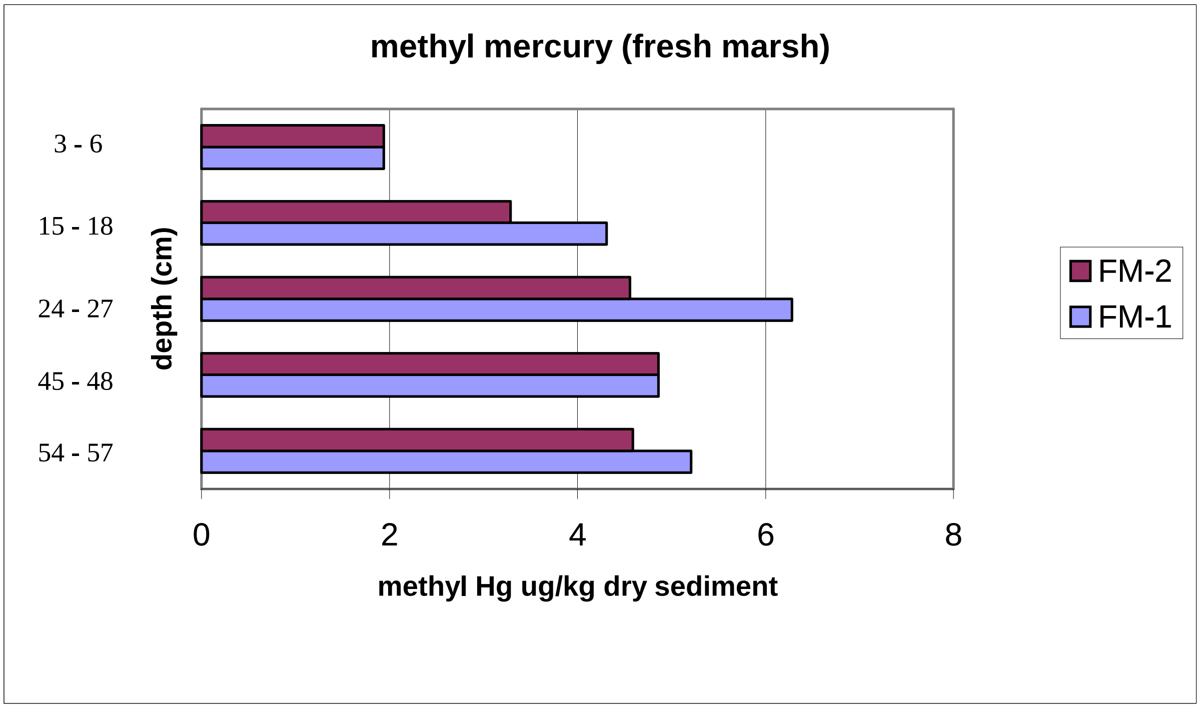
This profile study of Barataria Basin salt and freshwater marsh clearly shows that the amount of mercury present in Louisiana marsh soil differ when results are expressed on a dry weight basis as compared to the amount of mercury/methylmercury on a per unit volume basis. For determining potential source and availability to the aquatic environment additional studies should include diffusion flux studies of mercury release to the overlying water.

Table:1 Total and methylmercury content of fresh marsh and salt marsh at 30 cm depth (data based on soil bulk density)

Site	Bulk Density (g cm^{-3})	Total Hg (µg)	Methyl Hg (µg)
Fresh Marsh	0.07	2,929	87
Salt Marsh	0.25	5,340	91

Table:2 Total and methylmercury content of fresh marsh and salt marsh at 30 cm depth.

Site	Total Hg (µg kg^{-1})	Methyl Hg (µg kg^{-1})	% Methyl Hg
Fresh Marsh	140	4.19	3.0
Salt Marsh	80	1.34	1.7



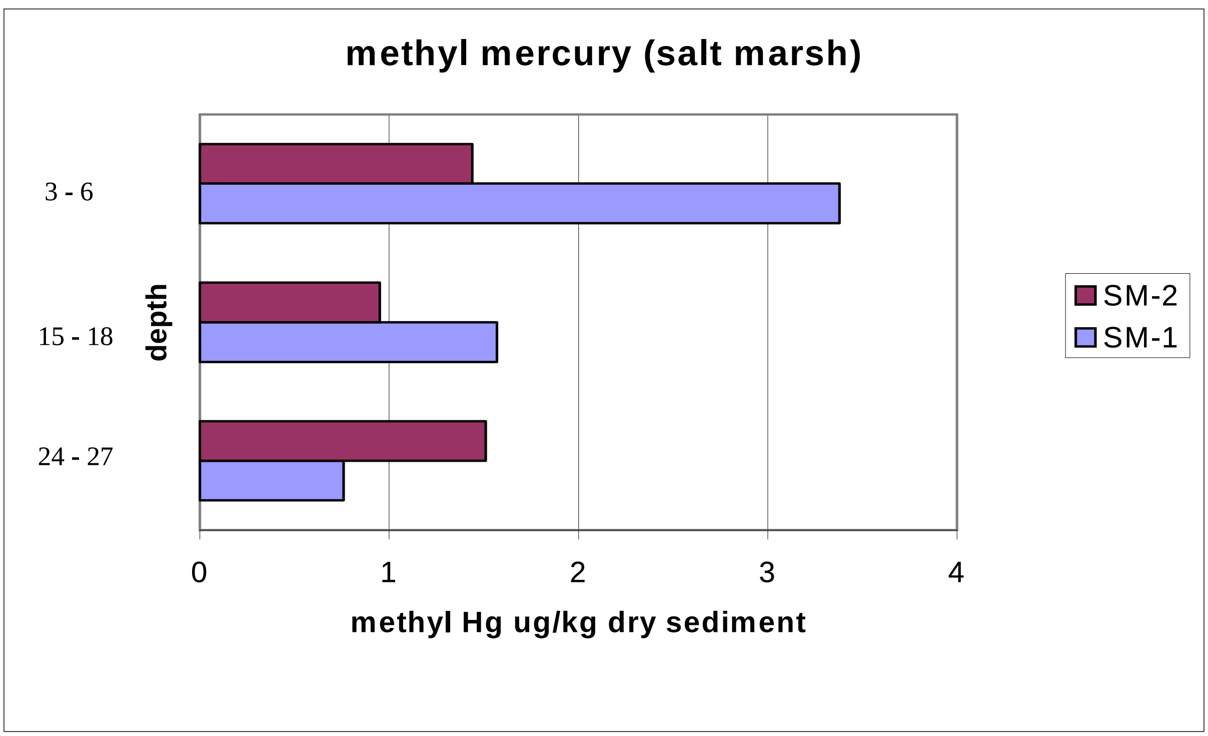
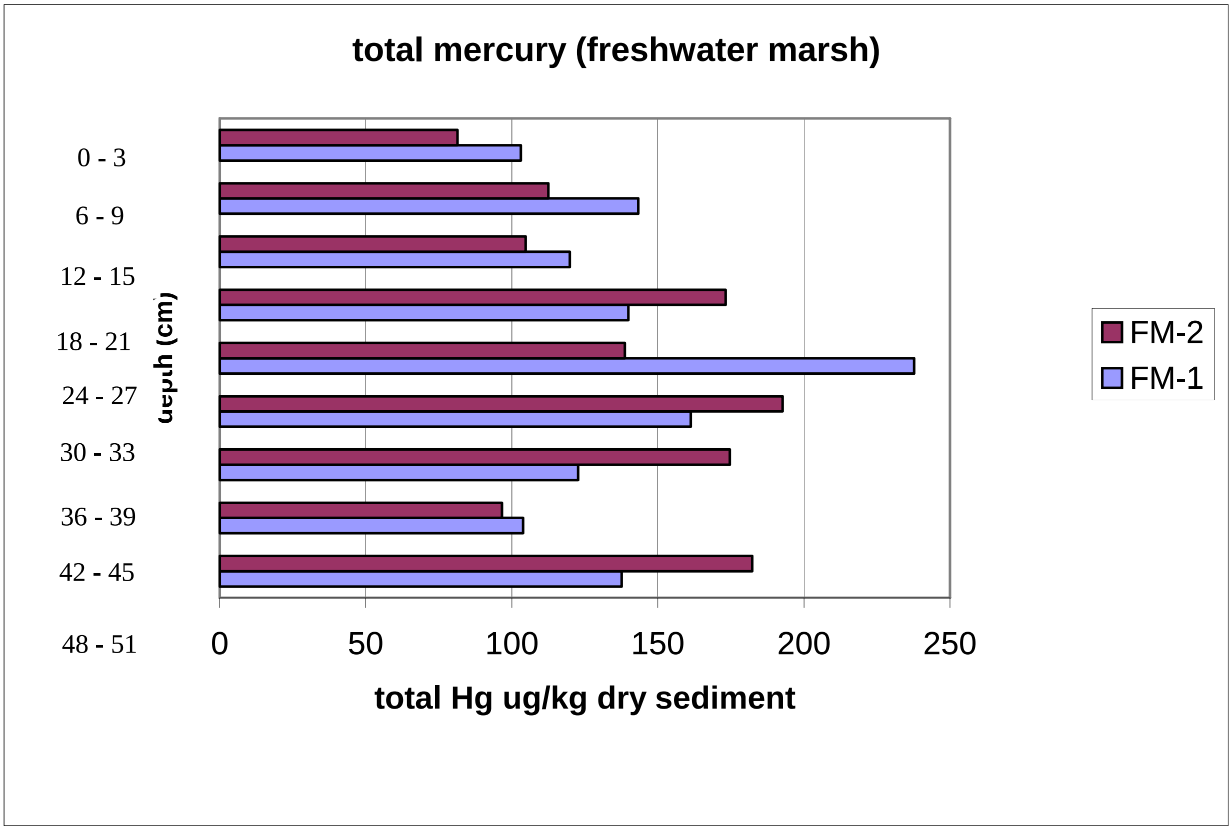


Figure 1. Profile distribution of methylmercury in freshwater and salt marsh soil.



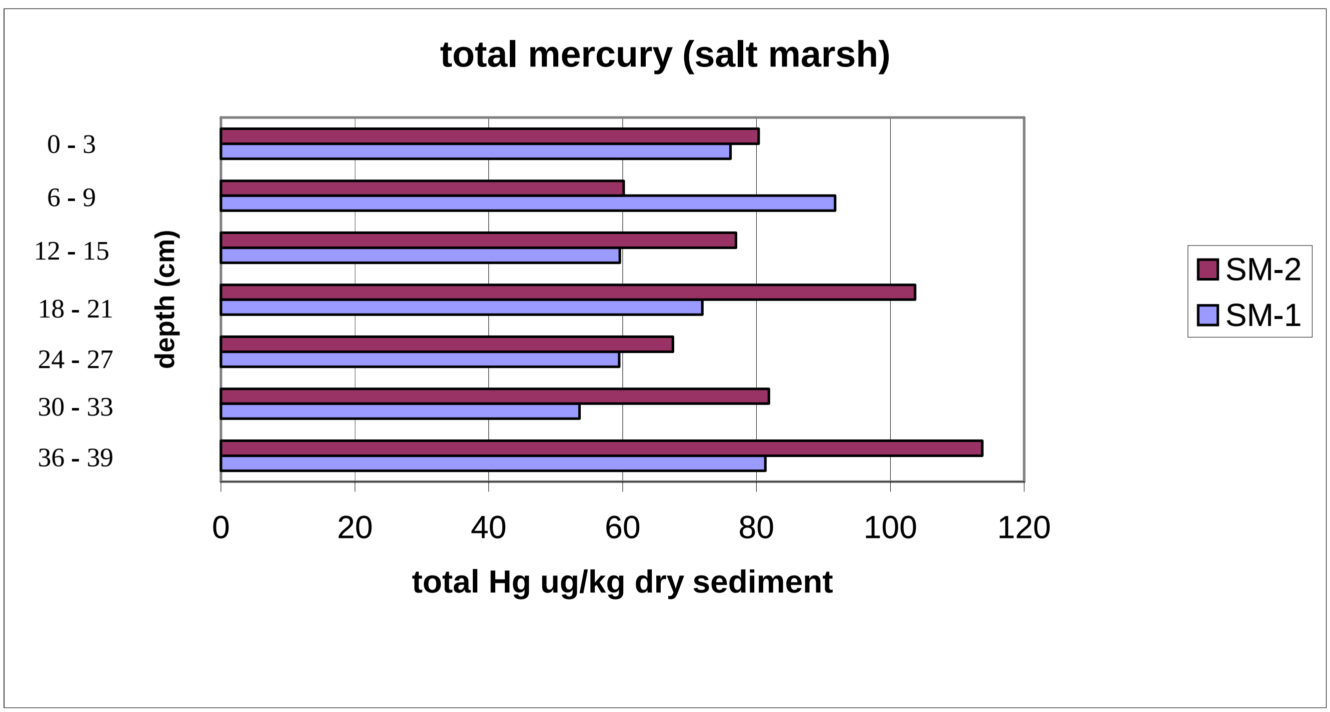


Figure 2. Profile distribution of total mercury in freshwater marsh and salt marsh soil.

Pontchartrain Basin Wetland Soil Mercury Data

In addition to the detailed profile study, we measured mercury and methymercury in surface soil of wetland in the Pontchartrain Basin (33 sites bordering Lake Pontchartrain and Lake Maurepas). The locations and mercury levels in the soil are shown in Table 3. Total mercury level ranged from 8.72 to 138.63 ug/Kg soil methyl mercury ranged from 0.09 to 11.37 ug/Kg soil. Average total mercury and methymercury values for all sites were 63.15(± 26.83) and 1.59 (± 2.48) respectively.

Measured total mercury and methymercury in Lake Maurepas and Lake Pontchartrain bottom sediment, (project funded by Lake Pontchartrain Basin Foundation), water bodies which the wetland sites from which soil samples border were:

Lake Maurepas:

Total mercury	-	96.8 ug/Kg
Methylmercury	-	1.09 ug/Kg

Lake Pontchartrain

Total mercury	-	67.4 ug/Kg
Methylmercury	-	.49 ug/Kg

This study of mercury level in wetland surrounding the lakes shows that average methylmercury level in the wetland soil were higher in methylmercury than in bottom sediment in the 2 lakes.

Table 3: Mercury and Methylmercury in wetland soil of Pontchartrain Basin					
Lab#	Sample #	Methyl Mercury	Total Mercury	Latitude	Longitude
		Concentration	Concentration		
		ug/kg dry soil (Avg.)	ug/kg dry soil (Avg.)		
PW1		9.36	138.63	N30.31473	W90.41686
PW2		3.62	63.99	N30.28833	W90.39570
PW3		2.92	53.57	N30.28435	W90.36783
PW4		4.26	59.1	N30.29673	W90.33965
PW5		0.34	47.61	N30.29212	W90.31012
PW6		0.76	57.56	N30.30024	W90.34131
PW7		0.21	49.28	N30.30868	W90.35997
PW8		0.17	41.08	N30.31705	W90.39400
PW9		1.67	86.97	N30.32033	W90.41124
PW10		1.06	74.77	N30.26127	W90.69801
PW11		0.35	50.92	N30.29499	W90.61769
PW12		11.37	68.45	N30.13232	W90.71968
PW13		1.25	110.72	N30.10162	W90.42351
PW14		0.09	71.6	N30.07257	W90.39888
PW15		1.06	99.75	N30.06175	W90.41294
PW16		1.35	49.21	N30.02862	W90.39872
PW17		2.04	119.66	N30.05758	W90.37202
PW18		0.08	82.71	N29.98110	W89.94591
PW19		0.13	58.78	N29.97367	W89.94879
PW20		0.65	71.37	N30.11148	W89.89828
PW21		0.91	35.49	N30.12396	W89.86537
PW22		0.49	54.94	N30.15306	W89.85902
PW23		1.09	55.19	N30.22644	W89.82135
PW24		0.11	54.35	N30.1945	W89.75497
PW25		0.36	18.99	N30.17612	W89.72909
PW26		1.15	41.59	N30.14642	W89.7444
PW27		1.21	53.97	N30.27568	W89.91184
PW28		1.36	57.81	N30.26254	W89.9563
PW29		0.29	40.79	N30.27462	W89.95499
PW30		0.49	8.72	N30.34643	W90.05631
PW31		1.23	90.87	N30.35317	W90.06215
PW32		0.22	51.43	N30.40146	W90.15191
PW33		0.69	64.1	N30.44339	W90.33902
Average		1.59 (± 2.48)	63.15(± 26.83)		

The wetland soil on dry weight basis sediment contained approximately 1.5 times more methylmercury as found in Lake Maurepas and 3 times the amount found in Lake Pontchartrain sediment.

These results suggest that there is greater potential for methlymerucry formation in wetland soils as compared to bottom sediment. This could be attributed to higher organic matter content in wetland soil, which would support more reducing condition conducive to mercury methylation. The ratio of totalmercury to methymercury (40:1) for the wetland sites was considerably lower than the ratio for Lake Maurepas (89:1) and Lake Pontchartrain (138:1). These ratios suggest a greater percentage of the mercury in the wetland soil is being methylated as compared to mercury in bottom sediment of the two lakes.

Probabilistic Assessment of the Effectiveness of BMPs in Coastal Louisiana

Basic Information

Title:	Probabilistic Assessment of the Effectiveness of BMPs in Coastal Louisiana
Project Number:	2005LA33B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	6
Research Category:	Engineering
Focus Category:	Non Point Pollution, Solute Transport, Water Quality
Descriptors:	None
Principal Investigators:	Vijay P. Singh

Publication

1. Zhang, L. and V.P. Singh, 2006, Bivariate Rainfall Frequency Distribution Using Archimedean Copulas. Journal of Hydrology, in press.
2. Zhang, L. and V.P. Singh, 2006, Trivariate Rainfall Frequency Analysis Using the Copula Method. Journal of Hydrologic Engineering, ASCE, in press.
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4. Singh, V.P. and L. Zhang, 2005, Multivariate Stochastic Hydrologic Analysis. Proceedings, International Workshop on Watershed Management in Dry Areas: Challenges and Opportunities, Djerba, Tunisia, 2005.
5. Singh, V.P. and Zhang, L., 2005, Stochastic Air Quality. in Environmental Exposure and Health, edited by M.M. Aral, Brebbia, C.A., Maslia, M.L. and Sinks, T., pp. 3-12, WIT Press, Southampton, U.K.

Probabilistic Assessment of the Effectiveness of BMPs in Coastal Louisiana

Problem and Research Objectives

Louisiana is naturally blessed with an abundance of aquatic systems, including bayous, brooks, streams, rivers, lakes, and aquifers, which provide Louisiana's citizens with fishing, hunting, boating, and recreational opportunities and contribute to the state's wealth and economic growth in agriculture, fisheries, recreation, energy, tourism, and transportation. While the state has more surface water available for its current use (84%) than any other state in the U.S., rapid urbanization and intensive agricultural and forest practices have increased the potential for reduction in the quality of the state's surface waters. Studies on hypoxia in the northern Gulf of Mexico have shown that an average midsummer hypoxic zone of 8,000-9,000 km^2 during 1985-1992 increased to 16,000-20,700 km^2 during 1993-2001 on the Louisiana/Texas continental shelf (Rabalais & Turner, 2001). This 3-fold increase of hypoxic zone over a relatively short period of time has been attributed to the increase of river-borne nutrients that can exacerbate coastal water eutrophication, favor harmful algal blooms, aggravate oxygen depletion, and alter marine food webs (Rabalais et al., 2002).

The northern Gulf of Mexico is found to be the second largest zone of coastal hypoxia in the world (Rabalasis et al., 2002). This oxygen-depleted phenomenon is attributed to nutrient enrichment in the waters of the northern Gulf of Mexico, and it is especially profound from spring through late summer. Agriculture is considered as a major source of nutrient enrichment from the Mississippi River basin (Burkart and James, 1999; Ferber, 2001; Howarth, 2001; Winstanley, 2001; Snyder, 2001). Atmospheric deposition of nitrogen is seen as another significant source to nitrogen limited estuaries and coastal waters (Paerl et al., 2002).

In January 2001, an action plan with the major goal of reducing nitrogen discharge through Best Management Practices from the inland water into the Gulf was endorsed by the state, tribal, and federal agencies and delivered to Congress (U.S. EPA, 2001). The action plan envisages a 30% nitrogen load reduction that is required to ensure a reduction of 5-year running average of the Gulf hypoxia zone to less than 5,000 km^2 by 2015. While this action plan called for an implementation of BMPs based on voluntary, incentive-based sub-basin strategies, several key questions that will influence the success of this plan need to be unanswered: (1) How effective are the current BMP guidelines in protecting stream water quality from agricultural and forest activities? (2) How can one quantitatively assess the effectiveness of BMPs? (3) What is the relationship between BMPs and hydrologic and water quality parameters? (4) To what extent do hydrological and hydrometeorological conditions, such as rainfall and temperature, affect the variability of coastal inland stream water quality? (5) What are the sources and locations of pollution? These questions need to be addressed using the data from the Atchafalaya, Barataria, Calcasieu, Mermentau, Terrebonne, and Vermillion-Teche River basins.

A recent study by Thomson et al. (2002) reported that rainfall deficits accumulated since 1998 in Louisiana have culminated in a twofold increase in the mean annual salinity in the Lake Pontchartrain estuary. Using monthly measurements selected from 25 subbasins in Louisiana over a period of 1978–2001, Xu (2003) showed that the nutrient loads, total suspended solids, and dissolved oxygen concentrations all varied widely in the monitored streams and across seasons. However, monthly routine monitoring seems to work well for characterizing base flow conditions, but may not be adequate to characterize rapidly changing conditions in response to storm events. An understanding of hydrologic influences on water quality indicators at the watershed scale is apparently needed, and such an understanding is especially critical for the coastal regions of Louisiana where storm weather occurs throughout the year.

Thus the objective of the proposed project was to probabilistically assess the effectiveness of BMPs and their relationship with stream water quality changes with hydrological and hydrometeorological conditions in Louisiana's six major basins close to the Gulf of Mexico. The project utilized existing long-term water quality data, hydrometeorological data, and stream discharge data maintained by Louisiana Department of Environmental Quality, Southern Regional Climate Center, U.S. Geological Survey, and U.S. Army Corps of Engineers. Specifically, the project had the following objectives:

1. To probabilistically assess the effectiveness of BMPs in reducing the deterioration of water quality in the major stream/rivers on Louisiana's lower coastal plain, including Atchafalaya, Barataria, Calcasieu, Mermentau, Terrebonne, and Vermillion-Teche rivers;

2. To determine the relationship between BMPs and water quality variability and hydrometeorological regime, such as storm weather conditions, rainfall intensity, and temperature fluctuation;

3. To identify the linkage between the probability distributions of water quality parameters and the source, location and extent of pollution

4. To assess the impacts of land use activities on water quality of the coastal streams, wetlands, and estuaries in Louisiana under various hydrologic conditions.

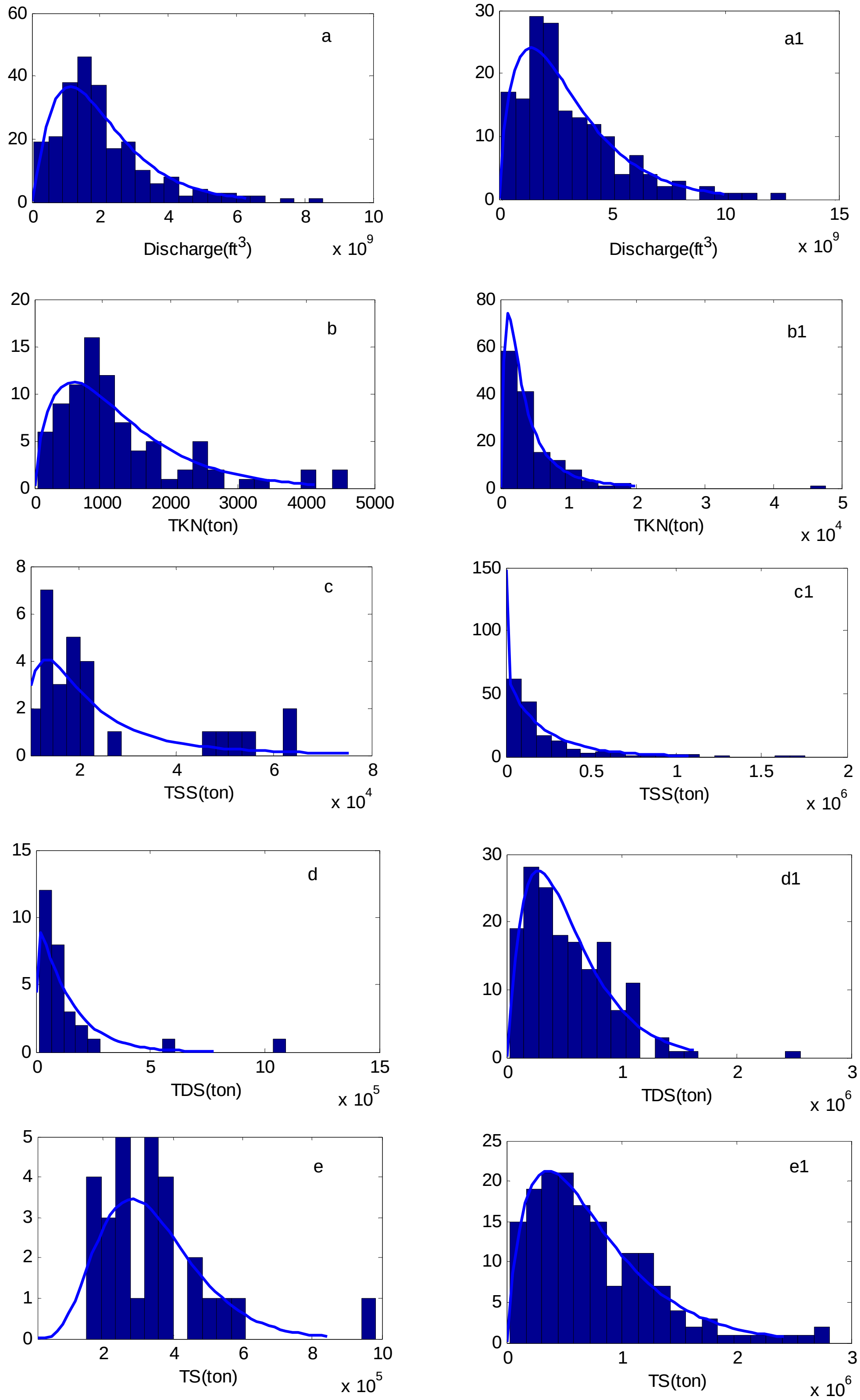

Figure 1. Probability density plots of Vermilion River (a, b, c, d, e: upstream; a1, b1, c1, d1, e1: downstream).

Information on land use activities and timber harvesting from the watersheds would also be gathered to investigate the magnitude of hydrological influences on water quality under various land use activities and BMPs.

Methodology

This project utilized existing long-term datasets collected from six coastal basins in Louisiana. Despite a large number of studies conducted on water quality in Louisiana's shore of the Gulf of Mexico during the past 2 to 3 decades, little knowledge has been actually gained about the impact of land use change and BMPs on the dynamics of water quality indicators. Many studies have been conducted, and many are being conducted on various aspects ranging from restoration of bottomland forests to microbiology of the coastal estuaries, inland streams and bayous. As a result, there exists a large amount of data that has not yet been fully analyzed, whereas fortunately USGS and LDEQ continue collecting water quality and streamflow data in real time across the state's rivers and bayous.

To achieve the project objectives, the following tasks were accomplished:

1. Water quality, stream discharge, and climatic data from all monitoring stations within the Atchafalaya, Barataria, Calcasieu, Mermentau, Terrebonne, and Vermillion-Teche river basins were gathered;

2. Spatial and temporal characteristics in water quality and hydrological and hydrometeorological conditions in the drainage basins were identified;

3. The variability of monthly water quality loadings and sediment runoff in relation to the variability of hydrological and hydrometeorological conditions was assessed;

4. Probabilistic analyses were performed for water quality parameters; and

5. Probabilistic analyses for assessing the effectiveness of the BMPs and the effect of land use change were developed.

Because of the lack of land use data the following tasks could not be accomplished:

1. Development of probabilistic analyses for assessing the effectiveness of the BMPs and the effect of land use change;

2. Development of the relationship between BMPs and hydrologic and water quality parameters;

3. Determination of locations, extent and sources of pollution from probability distributions;

4. Recommendations on the adequacy of water quality monitoring networks;

5. Recommendations on changes in BMPs if needed; and

6. Determination of land use impacts on water quality changes under hydrometeorological conditions across landscapes.

Thus, the project could not determine critical areas of water quality deterioration and the causes-land use and anthropogenic, and industrial. This information is considered pivotal to defining BMPs and assessing their effectiveness.

Principal Findings and Significance

The principal findings from the study on spatio-temporal characterization of water quality in coastal watersheds of the Atchafalaya, Barataria, Calcasieu, Mermentau, Terrebonne, and Vermillion-Teche rivers were: (1) The probability distributions of monthly discharge (cubic feet), total suspended solids (TSS), total solids (TS), total K nitrogen (TKN), and total dissolved sediment (TDS), all in tons, are different from one another. (2) These distributions significantly change from an upstream location to a downstream one on the same river, as shown for Vermilion River as an example in Figure 1. (3) For the same water quality parameter, as the probability distribution changes from exponential to gamma or lognormal from an upstream location to a downstream location, meaning that pollution is derived from several places and is not concentrated in one part of the watershed and many tributary watersheds are contributing to it. (3) The probability distributions are significantly affected by hydrologic and hydrometeorologic conditions. (4) All 6 rivers exhibit different hydrologic and water quality responses. (5) For the same frequency, water quality loadings for a river are much higher at a downstream location than would be the case after accounting for increased drainage area. A closer look at the probability distributions reveals that either the BMPs are not being as effective or else land use change is introducing far greater pollution. By comparing the probability distributions in space and time and correlating them with land use as well as BMPs, one can quantify the effectiveness of BMPs.

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A comprehensive study of mercury/methylmercury fate, transport and bioavailability in lake Pontchartrain sediments

Basic Information

Title:	A comprehensive study of mercury/methylmercury fate, transport and bioavailability in lake Pontchartrain sediments
Project Number:	2005LA34B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2
Research Category:	Water Quality
Focus Category:	Water Quality, Sediments, Methods
Descriptors:	None
Principal Investigators:	Aassaf Abdelghani, Maury Howard, Robert S. Reimers, Khalid L. Saleh

Publication

One of the projects (2005LA34B) was not funded due to the impacts of Hurricane Katrina on the research infrastructure of Tulane University. These funds were rebudgeted to cover the costs of LWRRI research and coordination related to Hurricane Katrina.

Saltwater Intrusion Management with Conjunctive Use of Surface Water and Ground Water

Basic Information

Title:	Saltwater Intrusion Management with Conjunctive Use of Surface Water and Ground Water
Project Number:	2005LA38G
Start Date:	9/1/2005
End Date:	8/31/2008
Funding Source:	104G
Congressional District:	Louisiana
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Management and Planning, Solute Transport
Descriptors:	None
Principal Investigators:	Frank Tsai, Vijay P. Singh

Publication

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3. Tsai, F. T-C. and X. Li. 2006. A Genetic Algorithm on Conditional Estimation of Distributed Hydraulic Conductivity in Groundwater Inverse Modeling: Indicator Generalized Parameterization and Natural Neighbors, in Abrahart, See, Solomatine eds. Hydroinformatics in practice: computational intelligence and technological developments in water applications. Springer. (In press)
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Saltwater Intrusion Management with Conjunctive Use of Surface Water and Ground Water

Problem and Research Objectives

Problem Statement

Saltwater intrusion in coastal aquifers is a nationwide problem, which has caused ground water supply shortage, decrease in water availability, drinking water contamination, land subsidence, and estuary ecosystem destruction along the coastal perimeter of the United States. Saltwater intrusion into the drinking water aquifers due to excessive withdrawals has been reported in the southern California, southern Florida, and Gulf of Mexico coastal areas. Many coastal metropolitan cities have been experiencing severe saltwater intrusion and consequent economic impacts due to lack of an appropriate ground water management plan. The East Baton Rouge Parish in Louisiana is one of them, which is located on the Southeastern Louisiana aquifer system. Although the project will be focusing on the saltwater intrusion management in the Southeastern Louisiana aquifer system, other saltwater intruded areas across the country with the similar problem would benefit from the project.

The Southeastern Louisiana aquifer system (known as Southern Hills aquifer system) is approximately bounded by the Mississippi River, Pearl River, and Lake Pontchartrain in Louisiana, and extends into Mississippi as far north as Vicksburg. Recharge to the aquifer system, primarily occurs in the outcrop areas in Mississippi and the northern parts of East and West Feliciana, St. Helena, Tangipahoa, and Washington Parishes. The aquifer ranges in thickness from 50 to 1,100 feet with thickness increasing toward the south. In the Baton Rouge area, the aquifer system is comprised of 10 aquifers that range to a depth of about 3,000 feet. Southward flow in the system is restricted by the Baton Rouge fault (see Figure 1), which extends from Baton Rouge eastward across the northern part of Lake Pontchartrain.

As shown in Figure 1, south of the Baton Rouge fault, little freshwater is present in the aquifer system, and the individual aquifers mostly contain saltwater. On the contrary, north of the Baton Rouge fault, the aquifers store excellent quality and quantity of water for drinking water purposes. Historically, the fault has prevented this saltwater from moving northward.

Due to its long-term dependability, ground water has been the essential, reliable water supply sources for the economic development in the Baton Rouge area (referred to as East and West Baton Rouge, East and West Feliciana, and Pointe Coupee Parishes). Although Louisiana has abundant surface water, ground water is a major water source to the public and industry due to its high water quality. In the Baton Rouge area, the river water (surface water) is used for the power generation purpose in the Pointe Coupee parish. Otherwise, surface water is rarely used. Ground water provides almost all domestic water (81 Mgal/day, million gallons per day) and the industry receives an equivalent amount of domestic water from the aquifers. The major uses of water by industrial groups are for food products, paper products, chemicals, and petroleum refining. The main ground water withdrawal (135 Mgal/day) is taking place in the East Baton Rouge Parish.

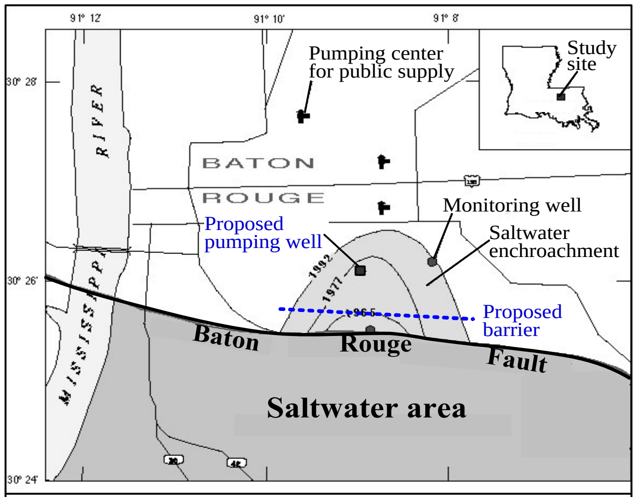


Figure 1. The study site: saltwater encroachment toward pumping centers in the 1,500-foot sand aquifer, the proposed saltwater intrusion barrier, and the pump-and-treat remediation design (Modified from USGS website: water.usgs.gov/wid/html/la.html)

However, population growth and economic development in southeastern Louisiana have led to increased ground water demand. The largest ground water withdrawals have occurred in the Baton Rouge area without an appropriate ground water management plan. Heavy pumping for public-supply and industrial uses in the Baton Rouge area has induced the movement of saltwater across the fault; and saltwater has been detected north of the fault in most of the freshwater aquifers (see Figure 1). Some production wells have experienced undesirable chloride concentration. According to a joint study conducted by USGS and the Louisiana Department of Transportation and Development, ground water levels in the East Baton Rouge Parish have declined by as much as 300 feet since the 1940s. Within the past 10 years, water levels in many wells have declined at a rate of 1 to 3 feet per year due to drought and large withdrawals. Pumping in the Baton Rouge area has also had regional impacts, lowering water levels in many adjacent parishes. Although the saltwater currently affects only very small areas (less than 4 square miles) adjacent to the fault, the saltwater could invade Baton Rouge's public production wells and industrial area in the near future if pumping continues at the current higher rate.

Continuous decline in ground water levels and the projected increases in ground water need a scientific, systematic management plan to protect ground water from saltwater intrusion without causing environmental detriment. To achieve this goal, the project proposes the development of a multi-objective saltwater intrusion management model with the optimized conjunctive use of surface water and ground water using computer simulation. The proposed management model and activity would benefit water availability, ground water conservation, and saltwater intrusion mitigation, and achieve the goal declared in the Louisiana legislature Act 446 (2001): ground water resource is a matter of public interest. Ground water must be managed, protected, and regulated in the best interests of all the citizens of the state. Act 49 (2003) requires the ground water resource management program to meet the goal of long-term sustainability of the state's ground water aquifers and to sustain the economic welfare of the state's citizens.

This project aims at developing a multi-objective saltwater intrusion management model such that the ground water resource can be sustained in the Southeastern Louisiana Aquifer system via the optimal conjunctive use of surface water and ground water. The scope of the project includes saltwater intrusion modeling, saltwater intrusion barrier (SIB) system development and management, and the optimal pump-and-treat (P&T) remediation design.

<u>Objectives</u>

To achieve the project goal, we propose the following specific objectives:

<u>Objective 1 Saltwater intrusion modeling</u>

The project will adopt SEAWAT, a USGS saltwater simulation model, to develop a three-dimensional density-dependent saltwater intrusion model in the study area (see Figure 1). The model will help understand the ground water flow and saltwater encroachment within the proximity of the designated barrier alignment. Also, the model will help understand the Baton Rouge fault effect on the salinity transport and consequent remediation schemes.

<u>Objective 2 Saltwater intrusion barrier (SIB) system development and management</u>

The project will develop an SIB system using a series of injection wells with surface water to prevent further saltwater intrusion as well as enhance water conservation. The SIB system management will evaluate minimum quantity of surface water and minimum cost needed to prevent further saltwater intrusion.

<u>Objective 3 Pump-and-treat (P&T) remediation design development and management</u>

In conjunction with the SIB system, the project will develop an optimal P&T remediation design to cost-effectively clean up the brackish water residing in the aquifers north of the barrier. The project will evaluate the treated water availability to supply additional water to the SIB system to increase water availability and conservation.

Methodology

(1) Saltwater intrusion simulation model development

Modeling of ground water flow and saltwater transport in the aquifers is complex due to water density variation with salinity concentration. The density-dependent Darcy equation is

$$\mathbf{V} = -\frac{K_f}{n}\left(\nabla h_f + \frac{\rho-\rho_f}{\rho_f}\nabla z\right) \tag{1}$$

where $\mathbf{V} = [V_i]$ is the linear average ground water flow velocity in the pore space in vector form; K_f is the hydraulic conductivity in terms of freshwater; h_f is the fresh water head; ρ is the fluid density; ρ_f is the freshwater density; and n is the porosity. Therefore, the density-dependent ground water flow equation is

$$\rho S_f \frac{\partial h_f}{\partial t} + n\frac{\partial \rho}{\partial C}\frac{\partial C}{\partial t} = \nabla \cdot \left[\rho K_f \left(\nabla h_f + \frac{\rho-\rho_f}{\rho_f}\nabla z\right)\right] + \rho_s q_s \tag{2}$$

where S_f is the storage coefficient in terms of freshwater; C is the concentration of the dissolved constituent; ρ_s is the fluid density at sinks or sources; and q_s is the flow rate at the sinks or sources. The density-dependent saltwater transport equation is

$$\frac{\partial C}{\partial t} = \nabla \cdot \left(\mathbf{D} \nabla C \right) - \nabla \cdot \left(\mathbf{V} C \right) - \frac{q_s}{n} C_s \tag{3}$$

where $\mathbf{D} = \left[D_{ij} \right] = \left[\alpha_T \left| \mathbf{V} \right| \delta_{ij} + \left(\alpha_L - \alpha_T \right) V_i V_j / \left| \mathbf{V} \right| + D^* \delta_{ij} \right]$ is the hydrodynamic dispersion coefficient in tensor form; α_L is the longitudinal dispersivity; α_T is the transverse dispersivity; $\left| \mathbf{V} \right| = \sqrt{\sum_j V_j^2}$ is the norm of the ground water velocity; D^* is the molecular diffusion; δ_{ij} the is Dirac delta function; and C_s is the dissolved solid concentration at sinks or sources. The constitutive equation relating fluid density to saltwater concentration with the first order Taylor series of the freshwater density is

$$\rho\left(C \right) \approx \rho_f + \frac{\partial C}{\partial \rho} \left(C - C_f \right) \tag{4}$$

The first-order gradient $\partial C / \partial \rho$ is usually estimated with the seawater which has maximum concentration $C_{sea} = \left[35000\, mg/L \right]$ and the maximum fluid density $\rho_{sea} = \left[1025\, kg/m^3 \right]$. That is

$$\partial C / \partial \rho \approx \left(\rho_{sea} - \rho_f \right) / \left(C_{sea} - C_f \right) \tag{5}$$

In this project, we will adopt SEAWAT, a USGS saltwater simulation model, to solve the governing equations (Eqs.(2) and (3)). SEAWAT is capable of handling density-dependent coupled flow and transport problems. SEAWAT has been tested and verified by several benchmark problems, e.g. Henry problem, and showed good agreement with the results from SUTRA. A three-dimensional ground water flow and salinity transport model will be developed based on SEAWAT for the study area (see Figure 1).

(2) Model calibration and parameter estimation

The governing equations, Eqs.(2) and (3), have several model parameters which are not directly measurable and must be estimated by an inverse procedure using historical ground water head and salinity concentration observations. We will use hydrogeological observation data collected by the U.S. Geological Survey (USGS) to calibrate either the parameter values themselves or to estimate the upper and lower bounds of the parameter values. The influence of each parameter will be quantified through a sensitivity analysis. The parameters with high degree of sensitivities with respect to ground water head and salinity observations will be further identified using a formal inverse procedure.

In the project, we propose a generalized parameterization (GP) method to characterize the parameter heterogeneity due to its high flexibility. The GP method is defined as follows

$$p_{GP} = \sum_{j=1, j \neq k} \beta_j \phi_j p_j + \left(1 - \sum_{j=1, j \neq k} \beta_j \phi_j p_j \right) p_k \tag{6}$$

where p_{GP} is the parameter heterogeneity estimated by the GP method along with a set of sample data $\{p_j\}$, a set of weighting coefficients $\{\beta_j\}$, and a set of basis functions $\{\phi_j\}$. The values of weighting coefficients β_j are bounded between 0 and 1. The GP method is able to integrate a zonation structure and an interpolation method (including geostatistics) to better heterogeneity estimation.

We will formulate a norm estimation criterion to estimate the parameter heterogeneity by minimizing the discrepancy between the observed and modeled ground water head and salinity concentrations. The inverse problem is conducted by searching optimal values of the weighting coefficients $\boldsymbol{\beta}$ in the following norm minimization problem,

$$\min_{0\le\boldsymbol{\beta}\le 1} \left\|\mathbf{h}^{cal}(\boldsymbol{\beta})-\mathbf{h}^{obs}\right\|+\eta_1\left\|\mathbf{C}^{cal}(\boldsymbol{\beta})-\mathbf{C}^{obs}\right\|+\eta_2\left\|\mathbf{p}^{cal}\left(\boldsymbol{\beta}\right)-\overline{\mathbf{p}}^{0}\right\| \quad (7)$$

where $\|\cdot\|$ is the norm; $\mathbf{h}^{obs}$ and $\mathbf{C}^{obs}$ are observed heads and concentrations, respectively; $\mathbf{h}^{cal}$ and $\mathbf{C}^{cal}$ are calculated heads and concentrations, respectively; $\mathbf{p}^{cal}$ and $\overline{\mathbf{p}}^{0}$ are calculated and prior estimates of parameter values at computation nodes, respectively; and η_1 and η_2 are weight factors.

The inverse solution in Eq. (7) usually suffers severely from the dependence of initial estimates. In order to increase the likelihood of reaching the global optimum, we propose a global-local optimization approach. We will first use a genetic algorithm (GA) to solve Eq. (7) to obtain a good initial solution estimate. Next, we will use a gradient-based algorithm (e.g., Gauss-Newton method) and local search to revisit Eq.(7).

(3) The SIB system management model

One of the major efforts will be devoted to the development of an SIB system management model to optimize the injection strategy using a set of injection wells. The decision variables are the selection of active injective wells over space and time and the corresponding injection rates at each of the active injection wells during each stress/management period. It is assumed that the injection rate is constant during a stress period, but can be dynamically changed from period to period. The management objective function is to minimize the total cost incurred in installation cost, operation cost, energy cost, etc. due to the injection activity as follows:

$$\min_{z_{i,t}^r,\mathbf{q}_{i,t}^r} \sum_i\sum_t \mathrm{Cost}\left(z_{i,t}^r\mathbf{q}_{i,t}^r\right) \quad (8)$$

where $\mathbf{q}_{i,t}^r$ is a vector of injection rates at an injection site *i* and a time period *t*. The valid range of injection rates is bounded by zero and the maximum injection rates:

$$0\le\mathbf{q}_i^r\le\mathbf{q}_{i,\max}^r \quad (9)$$

$z_{i,t}^r=\{0,1\}$ is a binary variable which controls the injection activity of well *i* during the period *t*. For example, if $z_{i,t}^r=1$, the injection well *i* is active and the injection rate is $\mathbf{q}_{i,t}^r$ in the period *t*. If $z_{i,t}^r=0$, the injection well *i* is not selected in the period *t*. The selection of optimal number of active injection wells for period *t* is also a decision variable and is presented in the following constraint

$$\sum_i z_{i,t}^r\le Z_t^r \quad ,Z_t^r\in\{1,2,\cdots,\mathrm{IW}\},\ \text{and } \forall t \quad (10)$$

where $Z_{i,t}^r$ is the maximum number of active injection wells during period *t*; and IW is the total number of available injection wells for the SIB system. If one considers to attain desired ground water heads and salinity levels as close as possible at some locations, the following constraints are suggested,

$$\left\|\mathbf{h}^{pre}\left(z_{i,t}^r\mathbf{q}_{i,t}^r\right)-\mathbf{h}^{tar}\right\|\le\Delta\mathbf{h} \quad (11)$$

$$\left\|\mathbf{C}^{pre}\left(z_{i,t}^r\mathbf{q}_{i,t}^r\right)-\mathbf{C}^{tar}\right\|\le\Delta\mathbf{C} \quad (12)$$

where $\mathbf{h}^{tar}$ = a vector of targeted ground water heads; $\mathbf{h}^{pre}$ = a vector of the predicted ground water heads using the simulation model (Eq.(2)); $\Delta\mathbf{h}$ = a vector of head tolerance; $\mathbf{C}^{tar}$ = a vector of targeted salinity levels; $\mathbf{C}^{pre}$ = a vector of the predicted salinity levels using the simulation model (Eq.(3)); and $\Delta\mathbf{C}$ = a vector of salinity tolerance. The total required surface water for the SIB system is calculated as

$$Q^r = \sum_i \sum_t z^r_{i,t}\mathbf{q}^r_{i,t} \tag{13}$$

The total cost in Eq.(8) associated with the total required surface water in Eq.(13) is a nonlinear function. Also, the SIB system involves optimization of injection well selection, injection rate scheduling, and injection rate optimization. As a consequence, the SIB system management model is formulated as a mixed integer nonlinear programming (MINLP) problem. To solve this MINLP problem, we will explore the classical combinatorial optimization algorithms as well as the global search methods (e.g. genetic algorithm).

(4) P&T remediation design

The P&T saltwater remediation design is not only to remove the brackish water from the aquifers, but also to prevent the brackish water from moving northward. The P&T remediation design considers the optimal pumping locations, number of active pumping wells, pumping rate, and pumping schedule simultaneously among a set of pumping wells residing in the salinity plume. The P&T design objective is to minimize the total cost including the cost of pumping activities and treatment cost which are relating to the amount of pumped water:

$$\min_{z^p_{j,n},\mathbf{q}^p_{j,n}} \quad \sum_j \sum_n \mathrm{Cost}\left(z^p_{j,n}\mathbf{q}^p_{j,n}\right) \tag{14}$$

where $\mathbf{q}^p_{j,n}$ is a vector of pumping rates at a pumping site *j* and during time period *n*. The valid range of pumping rates is bounded by zero and maximum pumping capacity:

$$0 \le \mathbf{q}^p_j \le \mathbf{q}^p_{j,\max} \tag{15}$$

Again, $z^p_{j,n} = \{0,1\}$ is a binary variable which controls the pumping activity of well *j* during time period *n*. Similarly, if $z^p_{j,n} = 1$, the pumping well *j* is active and the pumping rate is $\mathbf{q}^p_{j,n}$ in the period n. If $z^p_{j,n} = 0$, the pumping well *j* is not selected in the period *n*. The optimal number of total active pumping wells is a decision variable which is presented in the following constraint

$$\sum_j z^p_{j,n} \le Z^p_n \quad , Z^p_n \in \{1, 2, \cdots, \mathrm{PW}\}, \text{ and } \forall j \tag{16}$$

where Z^p_n is the maximum number of active pumping wells during period *n*; and PW is the total number of available pumping wells for the P&T design. If the goal of the P&T remediation design is to meet the targeted salinity level in the brackish water as much as possible, one can formulate the goal as the following constraint:

$$\left\| \mathbf{C}^{pre}\left(z^p_{j,n}\mathbf{q}^p_{j,n}\right) - \mathbf{C}^{tar} \right\| \le \Delta\mathbf{C} \tag{17}$$

As a consequence, the P&T scheme reclaims $\sum_j \sum_n z^p_{j,n}\mathbf{q}^p_{j,n}$ amount of water. Water availability will be increased if the treated water will be blended with surface water in the SIB system. In this case, the total amount of water that is supplied to the SIB system will be

$$Q^r = \sum_i \sum_t z^r_{i,t}\mathbf{q}^r_{i,t} + \sum_j \sum_n z^p_{j,n}\mathbf{q}^p_{j,n} \tag{18}$$

Again, the P&T remediation design (Eqs. (14) to (17)) involves a nonlinear cost function, the selection of pumping wells, and the schedule and rates of pumping activity, which results in an MINLP problem. We will use the proposed optimization methods in the SIB system management to cope with this MINLP problem.

Principal Findings and Significance
Progress in Task 1: Saltwater intrusion modeling development and calibration

The saltwater intrusion models in the Alamitos Gap area, California and the East Baton Rouge Parish, Louisiana are under the development. The Alamitos Gap area has an existing hydraulic barrier formed via a series of freshwater injection wells. The barrier has been operated for more than 40 years. Working on the Alamitos Gap area will provide Louisiana invaluable experience for the saltwater intrusion barrier design and will help understand the continuation of saltwater intrusion in the Southern California.

<u>Saltwater Intrusion Modeling in Alamitos Gap area, California</u>

The Alamitos Barrier Project (ABP) at Southern California is a human-built saltwater intrusion barrier, which uses a series of freshwater injection well (around 42 injection wells) to develop the local hydraulic ridge to prevent the saltwater intrusion through the Alamitos Gap area and protect the groundwater supplies of the Central Basin for Los Angeles County and the southwest portion of the Coastal Plain are in Orange County. The Alamitos Gap area contains 5 major aquifers (R, C, B, A, and I aquifers from the top to the bottom). The injection wells form a V shape alignment and inject freshwater into the five aquifers shown in Figure 2.

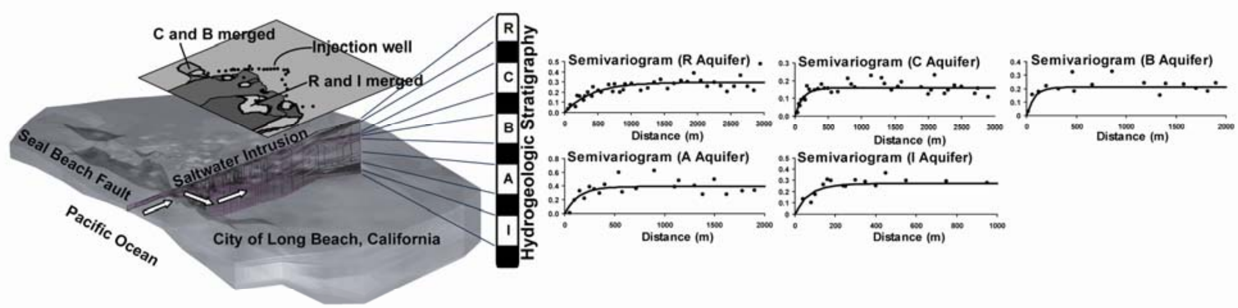
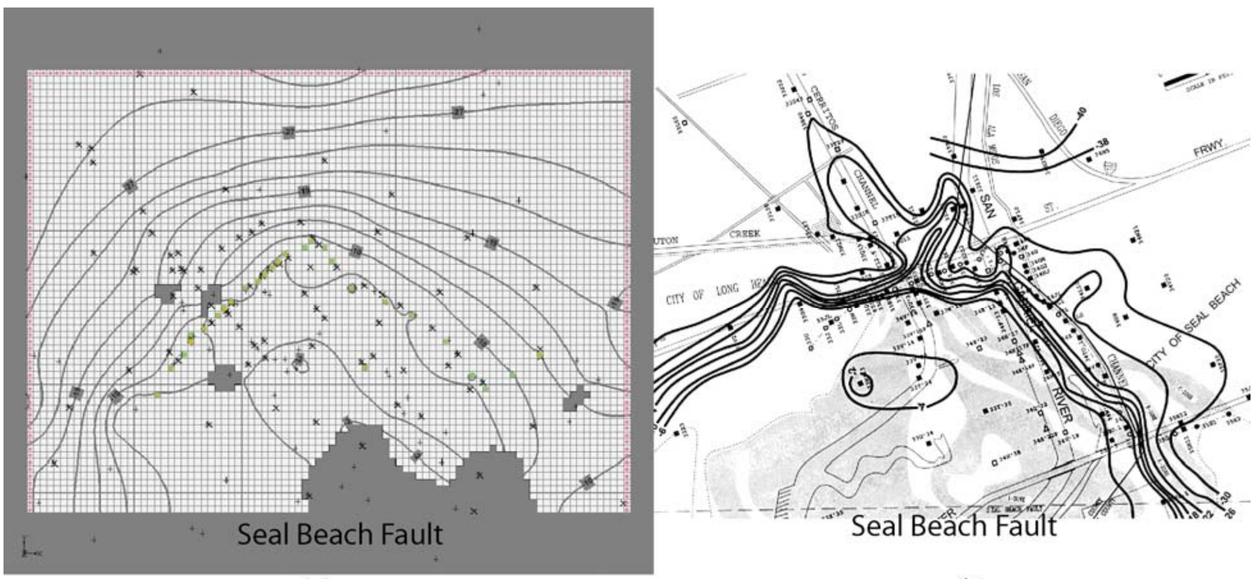


Figure 2. The Alamitos Gap aquifer system including 5 major aquifers. Saltwater intrusion is from the Pacific Ocean through the R aquifer (top aquifer) into all aquifers.

Los Angeles County, Department of Public Works (LACDPW) spends more than 2 million dollars every year injecting freshwater into the aquifer system to maintain the hydraulic barrier. During the Fiscal Year July 1, 2001 to June 30, 2002, a total of 6,062 acre-feet of fresh water was injected at an average rate of 8.4 cfs with a total water cost of $2,758,005. Although the ABP has been implemented for more than 40 years, the saltwater intrusion is still detected behind the barrier. Re-evaluating the barrier operation is necessary in order to better the barrier performance.

Collaborating with the Los Angeles County Department of Public Works (LACDPW), we have collected 179 borehole data in the Alamitos Gap area to develop a three dimensional aquifer system as shown in Figure 2. The hydrogeological stratigraphy is very complex at the sea side due to the aquifers/aquitards merging and missing. The semivariograms of log-hydraulic conductivity for all aquifers are calculated and shown in Figure 2. We also collected historical ground water head data, salinity concentration data, and freshwater injection data at the existing ABP injection wells, and pumping data from 1990 to 2002 for saltwater intrusion simulation model development and calibration.

Before conducting the model calibration, we first targeted the I aquifer for groundwater flow simulation in the study area shown in Figure 3. The I aquifer has high freshwater extraction rates and has been detected with high salinity level due to saltwater intrusion. The geostatistical method was adopted to obtain the hydraulic conductivity distribution. We adopted MODFOLW to develop a groundwater simulation model. The same MODFLOW model setting will be used in the SEAWAT model in the future. Figure 3 shows the preliminary ground water head simulation at the I aquifer on July 2002. The ground water distribution is close to the reported groundwater head distribution by LACDPW.



(a) (b)

Figure 3. (a) Simulated ground water head distribution in the I aquifer on July 2002. (b) Ground water head in the I aquifer on July 2002 plotted in the LACDPW "Annual report on the control of seawater intrusion 2001-2002" by S.S. Hamad.

Saltwater Intrusion Modeling in East Baton Rouge Parish, Louisiana

Working with the USGS staff in the EBR Parish office, Louisiana Capital Area Ground Water Conservation Commission (CAGWCC), and Louisiana Geological Survey (LGS), we have collected more than 50 electrical resistivity log data to construct the Southern Hills aquifer system in EBR including 10 major aquifers shown in Figure 4. Moreover, the historical groundwater withdrawal data, groundwater head observations, salinity level measurements are also collected. The saltwater intrusion mainly occurs in the “1,500-Foot” sand and “2000-Foot” sand aquifers. This project focuses on the saltwater intrusion problem in the “1,500-Foot” sand aquifer. With the collected pumping test data, the semivariogram of hydraulic conductivity for the “1,500-Foot” sand was obtained. The saltwater intrusion model for EBR is under the development.

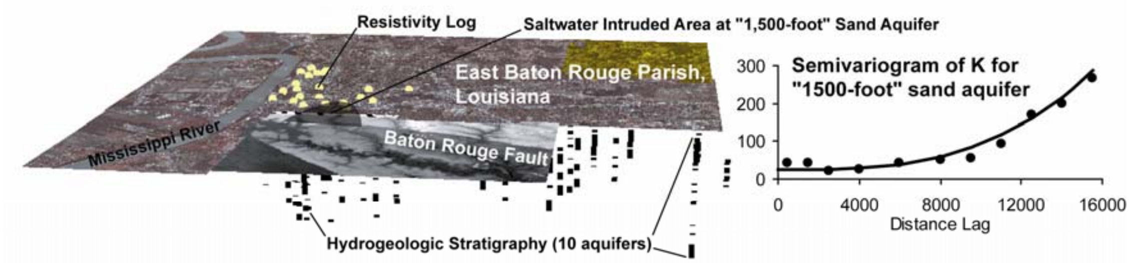


Figure 4. The illustration of hydrogeological stratigraphy demonstrated in GIS where DEM and LIDAR data are presented. LIDAR data is used to delineate the Baton Rouge Fault. The saltwater intrusion area in the “1,500-foot” sand aquifer is around 4 mi^2.

Model Calibration and Parameter Estimation

We have developed a generalized parameterization (GP) method to identify the hydraulic conductivity distribution. The GP method is able to honor the pointwise hydraulic conductivity measurements obtained by the pumping tests and electrical resistivity logs to obtain a conditional estimation of hydraulic conductivity. The estimation uncertainty is evaluated with the norm of the conditional covariance obtained by GP. The GP method can be applied to the stationary and non-stationary random fields. Several publications have demonstrated the GP applicability in the groundwater inverse modeling.

Information Transfer Program

One of the Institute's objectives is to make research results available to the general public and to interested researchers and institutions through publications and other information transfer activities. Although the information transfer component of the budget of Section 104 funds is relatively small (10%), LWRRI attempts to meet this goal in many ways which include actively participating in conferences and workshops, distributing summaries and other Institute information to the public and governmental agencies, maintaining internet access and web sites, and maintaining a library of water research materials. The Institute requests that its investigators participate in reporting and information transfer activities such as publications in professional journals, workshops, and seminars.

The Institute's information transfer program is a subset of its administration program. Assisting with LWRRI's information transfer activities are two undergraduate student workers, a program coordinator (part-time LWRRI support), and one research associate (half-time LWRRI support). Two research associates are also available to assist in information transfer activities of the Institute. The Director, Dr. John Pardue, attends the annual National Institutes of Water Resources meetings in Washington, D.C., to discuss Institute and Program activities.

Further assisting in information transfer, the Engineering Incubation Research Center (EIRC) has given LWRRI access to image processing, GIS, and computing systems. This access provides the Institute with the necessary tools to transfer information in visual graphic format, utilize Internet resources, and develop state-of-the-art presentations. Because of the Institute's expanding development, more emphasis is being placed on updating the public and other organizations about activities and objectives using electronic media and presentation tools.

The Institutes staff continues to maintain emphasis on acquainting Louisianas research community with the research-funding opportunities through the U.S. Geological Survey Section 104 research program. 104 G program announcements, Mississippi SE-TAC RFPs, and Section 104 RFPs were widely distributed (241+ email addresses and 252 regular mail addresses, totaling 493) to Louisiana colleges and universities and to research organizations throughout the state. In addition, public announcements were made at professional and faculty meetings to encourage wide participation in the program. We send out notifications of meeting and events for the American Water Resources Association, The Capital Area Ground Water Conservation Committee, and the Louisiana Rural Water Association.

Performance during Hurricane Katrina. Our information transfer program was widely used during Hurricane Katrina. The Institute fielded hundreds of calls from reporters, government officials and interested citizens about the floodwater work performed and the environmental safety of the city, itself. We shared data with EPA contractors and Louisiana Department of Environmental Quality officials. In addition, LWRRI staff provided important coordination of the research effort immediately after the storm hit. This included assisting with credentialing of LSU and off campus researchers, coordinating weekly on campus research meeting in the months following the storm and providing access advice for out-of-state researchers and New Orleans scientists and engineers trying to reach their data and research labs. Our current and past research products dealing with storm surge received hundreds of hits and our past director, Dr. Joseph Suhayda was widely consulted by both the media and government officials on the future of New Orleans. These events have provided unprecedented visibility for LWRRI that we plan to build on in the upcoming years.

Collaboration with major university research initiatives. LWRRI have collaborated extensively with other campus research centers during this cycle. These have led to other funded centers and center proposals. Through these activities we have continued to leverage our resources by collaborating with other faculty. These collaborations include a Biotechnology Center (funding from Governors Biotechnology initiative) within HSRC (use of molecular techniques for microbial community structure analysis), and the Heath Excellence Fund Public Heath Effects of Hurricanes center (chemical transport following a major hurricane), LWRRI also collaborated on the Department of Homeland Security CENTEX proposal which received a site visit in summer 2005. Unfortunately, that center funding went elsewhere.

In addition, our organization is contacted regularly with various questions for the public and/or private sector concerning water issues; we try to connect these people with the proper experts within our organization and the broader academic community. We have built a comprehensive web portal LAWATER.com in conjunction with the LWRRI web site to help facilitate this effort.

LAWATER and electronic publication project. Two outreach projects that we would particularly like to highlight is the development of the LAWATER web portal for Louisiana water issues (www.lawater.lsu.edu) and the digital document library within LWRRI. The web portal LAWATER was designed as a comprehensive collection of web-based information on water issues within Louisiana. It captures information not only from the Institute but collects the rich content developed by USGS, EPA, DEQ, FEMA and others into one location. The portal is divided into several sections emphasizing 4 major issues: water quality, water supply, hazards and flooding and coastal restoration. While only in existence a little over a year, the web portal is being utilized in Louisianas water community. In addition to LAWATER, we have been active archiving our past research products. LWRRI is one of the oldest research institutes on campus (founded in 1964). The collection of research products funded by the Institute date is in paper versions that are vulnerable to age and not accessible to the public. We have been scanning all of the documents produced by the institute into electronic archived versions for preservation and for any interested researchers to access (http://www.lwrri.lsu.edu/dwaterlibrary.htm).

Under the direction of our director, the Institute has developed a new branding symbol for all of the information transfer activities and publications and is reconstituting the newsletter. Our annual report is housed at the Louisiana State Archives, Hill Memorial Library at LSU, and is available online at the Institutes web site.

In response to the focused RFP for the 2005-2006 solicitations, we received 4 new proposals and funded 3 of those after advisory board review. The theme, selected in consultation with faculty and advisory board members, is focused on total maximum daily load (TMDL) calculations in Louisiana water bodies, scale-dependent behavior of hydrologic and water quality parameters, and mercury and methylmercury formation in Louisiana water bodies.

NIWR-USGS Student Internship Program

The Louisiana Water Resources Research Institute did not have any students in the formal NIWR-USGS Intern Program during this reporting period. The Institute maintains both formal and informal relationships with the Baton Rouge office through part time employment of students not in the intern program, and the USGS District Chief serves on the Institute Advisory Board. During this reporting period we have undergone a series of discussions with the state USGS office on rapidly expanding our participation in the student intern program. At the time of this report, those discussions have not been finalized.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	2	0	0	0	2
Ph.D.	1	3	0	0	4
Post-Doc.	2	0	0	0	2
Total	7	3	0	0	10

Notable Awards and Achievements

LWRRI performance during Hurricane Katrina. LWRRI made significant contributions during the response to Hurricane Katrina. The Institute led water sampling teams into the New Orleans area as early as September 3rd, 2005 and collected the first water quality data on floodwaters. This culminated in the first peer-reviewed publication on Hurricane Katrina in the ACS journal, *Environmental Science & Technology* published on the web on October 12th, 2005 (http://pubs.acs.org/cgibin/sample.cgi/esthag/asap/html/es0518631.html). The research efforts and information transfer are details previously in the report.

External Activities. LWRRI has been involved in several external activities directed at improving the Institutes presence in Washington, D.C. During this review cycle, LWRRI paid enrollment fees ($2,000) for LSU to become a full member of CUAHSI (Consortium for the Advancement of Hydrologic Sciences; www.cuahsi.org), a multi-institute consortium for hydrologic research. CUAHSI is working with NSF to develop a hydrologic observatories program and LWRRI researchers are involved with planning activities at several of the proposed observatories. LWRRI has also been active with NIWR in the yearly efforts to maintain the 104 funding within USGSs budget. Under the current administration, the Presidents budget has allocated no funding for the water institutes program. Every year, however, the Institutes have been able to restore funding by working with their congressional delegations. We have been active informing the Louisiana delegation about the benefits of the program and we have obtained legislative support for our efforts. This culminated in the passage of the Water Resources Research Act Amendments of 2004 (S. 1017) in the Senate in Fall, 2005. The bill was cosponsored by Senator Vitter and it continues the states institutes program for the next 5 years and plans to double the funds allocated to each institute.

Publications from Prior Projects

1. 2004LA21B ("Quantifying Hydrologic Impacts on Spatio-Temporal Variability of Stream Water Quality in Coastal Louisiana") - Conference Proceedings - Singh, V.P., Flow Routing in Open Channels: Some Recent Advances. Proceedings, River Flow 2004, held June 23-25, 2004, in Naples, Italy, 2004.

2. 2004LA21B ("Quantifying Hydrologic Impacts on Spatio-Temporal Variability of Stream Water Quality in Coastal Louisiana") - Conference Proceedings - Singh, V.P., Applications of Fluid Mechanics in Hydrology and Environmental Engineering. Recent Advances in Fluid Mechanics, Proceedings of the 4th International Conference on Fluid Mechanics, held July 20-23, 2004, in Dalian, China, edited by F. Zhuang and J.C. Li, pp. 29-40, 2004.
3. 2004LA21B ("Quantifying Hydrologic Impacts on Spatio-Temporal Variability of Stream Water Quality in Coastal Louisiana") - Conference Proceedings - Singh, V.P. and L. Zhang, Stochastic Dependence Modeling in Environmental Hydrology. Proceedings, International Conference on Hydraulic Engineering: Research and Practice, October 26-28, 2004, Indian Institute of Technology, Roorkee, India, pp. 46-59.
4. 2004LA21B ("Quantifying Hydrologic Impacts on Spatio-Temporal Variability of Stream Water Quality in Coastal Louisiana") - Conference Proceedings - Singh, V.P. and Zhang, L., Multivariate Stochastic Hydrologic Analysis. Proceedings, International Workshop on Watershed Management in Dry Areas: Challenges and Opportunities, January 4-6, 2005, Djerba, Tunisia, 2005.
5. 2003LA18B ("Metal Speciation in Particulates in the Mississippi River in Louisiana") - Articles in Refereed Scientific Journals - Roy, Amitava and J. Sansalone (2006) Manganese Oxide-Coated and Uncoated Cementitious Media for Rainfall-Runoff and Snowmelt Adsorptive-Filtration, submitted to Canadian Mineralogist.
6. 2003LA18B ("Metal Speciation in Particulates in the Mississippi River in Louisiana") - Conference Proceedings - Roy, Amitava (2006) Speciation of Heavy Metals in Katrina Sediments from New Orleans, Louisiana, XAFS13 International Conference, Stanford University, Palo Alto, California, July 9-14, 2006.