Louisiana Water Resources Research Institute Annual Technical Report FY 2001

Introduction

This report presents a description of the activities of the Louisiana Water Resources Research Institute for the period of March 1, 2001 to February 28, 2002 under the direction of Dr. Joseph N. Suhayda. 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. Finally, many of the problems facing the state are derived from changes taking place in or affecting this delta landscape, including coastal erosion, landloss, sea level rise and climate change, hurricane flooding, run-off and riverine flooding, degradation of water quality and hypoxia.

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:Mississippi Water Resources, Barrataria Terrebonne National Estuary Program, LA DNR, LA Board of Regents, NASA, University of Alabama, CEE, New Orleans Army Corps of Engineers, Jefferson Parish Office of Emergency Preparedness, LA Office of Emergency Preparedness, Hazardous Substance Research Center S/SW, USGS, University of Louisiana at Lafayette, LA Governors Office, LSU - Chemistry, University of New Orleans - CEE, LSU Agriculture Center - Biological and Ag Engineering, LSU - Center for Coastal, Energy, and Environmental Resources, LSU - Hurricane Center

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 2001 are non-point source pollution and mitigation of those sources, hydrologic modeling and small watershed hydrology. These areas are the same as in FY 2000. These research areas were identified as being consistent with national and regional priorities, while addressing high priority issues for the Sate of Louisiana. In addition to the traditional focus of the Institute on freshwater issues, greater emphasis is being placed on estuarine issues. In particular, hurricane flooding has become a major issue for state emergency managers and governmental planning agencies, and research support is being focused on this issue. Supporting research in these priority areas has also increased the visibility of the Institute within the State. It is also providing many opportunities for collaboration with the state USGS office which is extensively involved with these same issues.

The research projects are designated as Projects LA2501, LA2541, LA2521, and LA2621, as listed below.

Project LA2501 Aravamuthan, Development of a Two-Dimensional High Spatial Resolution Storm Surge Simulation Model for Single Processors and Distributed Computing Clusters

Project LA2541 Willson, Determining Uncertainty in Capture Zones and Interference from High Volume Wells

Project LA2521 Sansalone et al, Storm Water Transport of Particulate Matter from Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications for Treatment

Project LA2621 Drapcho et al, Fecal Coliform Concentration in Runoff from Fields Applied with Dairy Manure

These projects include 2 projects which continue the non-point source research (Projects LA2521 and LA2621) and 2 new projects in the areas of storm surge and groundwater hydrologic modeling (Project LA2501 and LA2541 respectively). Two of the projects have direct impact on non-point source pollution and mitigation problems associated with the TMDL regulatory issues and the hydrologic modeling effort will be a the focal point of the Institute in 2002-03.

Developement of a Two Dimensional High Spatial Resolution Storm Surge Simulation Model for Single Processors and Distributed Computing Clusters

Basic Information

Title:	Developement of a Two Dimensional High Spatial Resolution Storm Surge Simulation Model for Single Processors and Distributed Computing Clusters
Project Number:	2001LA2501B
Start Date:	3/1/2001
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	06
Research Category:	Not Applicable
Focus Category:	Floods, Hydrology, Models
Descriptors:	Storm Surge Modeling, Hydrodynamic Model, Rainfall, Parallel Computers, Distributed Clusters
Principal Investigators:	Vibhas Aravamuthan

Publication

1.0 Introduction

Human societies have become increasingly vulnerable to natural disasters like hurricanes. Due to increases in population and urbanization, a hurricane of a similar intensity causes more damage to life and property now than it did fifty years ago. A category four or five hurricane has enormous damage potential and can ruin the economic and social fabric of entire states.

This is especially true in south Louisiana, which due to its geographic proximity to the Gulf of Mexico is extremely vulnerable to hurricanes. Much of this area is low lying and consists of bayous and wetlands, which further increase the threat of storm surge inundation. Major metropolitan areas like New Orleans are especially vulnerable as much of the city is below sea level, and is protected by hurricane levees. Preliminary studies conducted at NSEL indicate that it would only take a category three storm to overtop the levees east of New Orleans submerging the city in over 20 feet of water.

The damage caused by hurricane Andrew has prompted a detailed national re-evaluation of several aspects of hurricane preparedness (National Weather Service, 1992) that has significant relevance to Louisiana. The NWS report pointed out that the problem of hurricane disasters is exacerbated by a continued destruction of natural protective features in the coastal zone, such as beaches, dunes and tidal wetlands. Unfortunately, Louisiana has recently experienced an annual loss of about 25,000 acres of wetlands and expectations are that wetland loss will continue. Thus the hurricane threat in Louisiana will be changing in the future. The NWS report also noted that winds caused most of the damage during Andrew and the emergency preparedness officials must considered the hurricane threat as a "wind/flood/storm surge" event that extends many miles inland from the coast. Therefore assessment of the threat in Louisiana must be comprehensive. Finally, in light of this newly defined hurricane threat, the report states that new approaches and standards must be developed to protect the public. Thus the preparedness and evacuation procedures used in the future in Louisiana need to use the best methods currently available.

Although natural hazards are not preventable, adequate precautions can be taken to minimize losses to both life and property if proper vulnerability assessments can be made before designing large infrastructure projects. These projects include flood control structures like levees, wind resistant buildings, and also in the area of urban planning and management.

2.0 Objectives

The overall goal of the project is to develop a high resolution storm surge simulation model for assessing the impact of hurricanes on coastal communities. To accomplish the project the following specific objectives are defined:

- To develop a coastal hydrodynamic model with sub-grid scale features such as, rivers and barriers, for predicting tidal circulation in the wetlands.
- To implement the NWS 38 hurricane wind model which would characterize the wind field from a particular storm.
- Incorporate the influence of rainfall on spatial flooding patterns.
- Use state of the art parallel and distributed computing paradigms in order to achieve fast and timely execution of all the model components.

- Calibrate the model against historical storms.
- Do a sensitivity analysis of the various model parameters.

3. Methods, Procedures and facilities

This research focuses on the development of a storm surge simulation model with very high spatial resolution of the order of 100 to 200 meters. Due to the high spatial resolutions, the model would enable us to do accurate mapping of the flood threat of urban areas. The high spatial resolutions result in grid sizes, which are of the order of 2000 by 2500, which translates to about five million grid points. Problems of this magnitude requires enormous computational power both in terms of CPU and memory, beyond the capabilities of even the most powerful uni-processor workstation. The only alternative to solving problems of such magnitude is to use parallel/distributed supercomputers. Keeping the above factors in mind, the model has been developed using parallel and distributed computing paradigms and is capable of running on both shared memory systems consisting of a number of processors accessing a global shared memory with processors interconnected by a high speed crossbar bus, and distributed memory multiprocessor architectures which can be clusters of workstations connected by a high speed network. This has been achieved by writing the model code using FORTRAN 90 with High Performance FORTRAN (HPF) extensions. A brief description of the various model components is given below.

3.1 Hydrodynamic Model

The important factors affecting coastal dynamics are tides, and winds. In order to resolve this, water level fluctuations due to both tides and winds must be accurately simulated. This would be accomplished by developing a coastal hydrodynamic model capable of simulating water level fluctuations and currents due to tides and winds. Due to the flat coastal topography and shallow water depths a two-dimensional vertically averaged model would be used.

The governing equations of the model consist of the two horizontal components of momentum and an equation for the conservation of mass. The equations of continuity and momentum are shown in Equations (1), (2) and (3)

Continuity

$$\frac{\partial z}{\partial t}+\frac{\partial (uH)}{\partial X}+\frac{\partial (vH)}{\partial Y}=r \qquad (1)$$

X- Momentum

$$\frac{\partial u}{\partial t}+\frac{\partial (uuH)}{\partial X}+\frac{\partial (uvH)}{\partial Y}+gH\frac{\partial z}{\partial X}=\tau_x^w-\tau_x^b+fv-\frac{gH}{2\rho_0}\frac{\partial \rho}{\partial X}+\frac{ru}{H} \qquad (2)$$

Y-Momentum

$$\frac{\partial v}{\partial t}+\frac{\partial (uvH)}{\partial X}+\frac{\partial (vvH)}{\partial Y}+gH\frac{\partial z}{\partial Y}=\tau_y^w-\tau_y^b-fu-\frac{gH}{2\rho_0}\frac{\partial \rho}{\partial Y}+\frac{rv}{H} \qquad (3)$$

Where:
u and v are the horizontal velocity components in the X and Y directions
r is the rainfall
z is the water level elevation measured from the mean sea level
H is the total water depth
f is the coriolis parameter
ρ is the density of water
ρ_0 is the reference density of water
τ^b_x, and τ^b_y are the bottom friction terms
τ^w_x, and τ^w_y are the wind stress terms

These equations are discretized using a semi-implicit finite difference method developed by Casulli and Cheng (1990). This then results in a set of linear algebraic equations, which is solved using a preconditioned bi-conjugate gradient stabilized (BICGSTAB) method. Due to the semi-implicit finite difference scheme used in this model, the overly restrictive gravity wave stability criterion imposed by most explicit schemes is avoided. The semi-implicit scheme in theory is unconditionally stable and the size of time steps need to be restricted purely from an accuracy standpoint.

Model parallelization is achieved by incorporating HPF extensions into the model code. HPF extensions look like Fortran 90 comments to a sequential program. When the code is run through a HPF compiler a Fortran 90 code with message passing protocols is obtained. Parallelism is mainly achieved by distributing arrays over a number of processors. The parallelism can be described by the following example which describes the parallelisation of the Laplace's equation:

```
Real u(0:imax+1,0:jmax+1)
!HPF$DISTRIBUTE(block,block):: u
!! Setup Gauss Seidel Iterations
tol=1.0e-05
do iter=1,max_iterations
!HPF$ DO INDEPENDENT,  NEW(i)
do j=1,jmax
!HPF$ DO INDEPENDENT, NEW(u1), REDUCTION(duu)
do i=1,imax
u1=u(i,j)
u(i,j)=0.25*(u(i+1,j)+u(i-1,j)+u(i,j+1),u(i,j-1))
duu =  duu + (u(i,j)-u1)**2.0
enddo
enddo
if(duu < tol)
!! Stop iterations
enddo
```

In the above piece of code in line 2 the array u is distributed in rectangular blocks among an abstract rectangular grid of procesors. Line 6 indictaes that the do loop in Line 7 is a parralelisable loop. Line 8 indicates that the Loop in Line 9 is paralleliasable and that the value duu should be summed across all processors indicating a reduction clause. Similar directives were embedded in the hydrodynamic code to parallelize it.

3.2 Boundary Conditions Formulation

Different types of boundary conditions are needed for the model. Boundary conditions need to be prescribed on all four horizontal boundaries. The boundary condition prescribed on the seaward side includes the water level variation due to tides combined with the prescription of the inverted barometric pressure. At the lateral seaward boundaries a radiation boundary condition is used in order to minimize the reflection of outgoing waves. At the land boundaries a moving boundary condition is used so that that the process of covering and uncovering of tidal flats can be taken into account. An advantage of using this numerical procedure is that the moving boundary aspects can be be taken into account automatically without resorting to specialized procedures.

3.3 Modeling Sub-Grid Scale Features

An important subcomponent of the hydrodynamic model is the resolution of sub-grid scale features. Louisiana has a number of small bayous and big rivers. During periods of low flow tides can propagate upstream along these channels. A one dimensional river model, a component of the hydrologic model, would be embedded in the 2-dimensional hydrodynamic model. Another important feature in the Louisiana landscape is the presence of several natural and artificial levees. These features play an important role in the hydrodynamics in the sense that they block the free movement of sediments and water. A subgrid barrier formulation similar to the one used in the Federal Emergency Management Agency (FEMA) Coastal Hurricane Storm Surge model (Greenhorne and O'Mara, 1985) has been incorporated in the present model.

The different sub grid scale features include, submerged barriers, overtopped barriers, and no flow barriers. Opening through barriers in the forms of culverts, and gates are also incorporated. The barriers also can have weirs at their crest and a weir formulation is also incorporated.

3.4 Hurricane Storm Model

The hurricane storm model describes the distribution and magnitude of the wind velocity and atmospheric pressure within the hurricane and provides the wind stress, pressure gradient, and inverted barometer water elevation forcing to the hydrodynamic model. In the hurricane storm model, a hurricane is considered fully described by its barometric pressure field at sea level and the corresponding 10-meter elevation, 10-minute average wind field over the sea surface. The sea level pressure field is parameterized by, the radius of maximum winds, the central pressure depression, and the far field pressure. The wind field is parameterized by, the radius of maximum winds, the central pressure depression and the storm forward speed. The storm track and its translational velocity are used to describe the complete history of the barometric pressure field and wind field everywhere on the hydrodynamic grid. The wind and pressure distributions are based upon data from a large sample of observed hurricanes. The National Weather Service has provided an updated version of the hurricane description known as NWS-23 (1979) for inclusion into the model. The isobars for hurricanes are assumed to be circular about the hurricane eye and are therefore defined in a polar coordinate system. The barometric pressure distribution in NWS-23 is described in terms of the central pressure, and the far-field pressure.

3.5 Rainfall Component

During the course of a hurricane event the areas affected by flooding is much larger than the storm surge impact areas, due to the high rainfall intensities experienced by these areas. Interior areas far away from the coast, experience flooding due to high rainfall intensities. This situation is made worse in Louisiana where large areas are impounded by levees. These levees although afford a measure of protection from storm surge flooding, but are vulnerable to rainfall induced flooding. This is especially true in the City of New Orleans, where a large part of the city is below sea level and is surrounded by hurricane levees river levees. High rainfall intensities have caused significant flooding in the city in the past. An important component of the current model is the inclusion of rainfall as a source. This is accomplished by adding a source term to the continuity equation. Once a cell receives the rainfall, as a source the momentum equation would calculate the appropriate velocities associated with the runoff accompanying the rainfall event.

3.6 Data Requirements

- The data requirements for the model include, topography/bathymetry, storm parameters, rainfall amounts, surface roughness characteristics, levee and roadway heights etc. Sources for this data include the USGS, US Army Corps of Engineers, and Louisiana State Department of Natural Resources, Louisiana State University Southern Regional Climate Center, and the National Weather Service. An attempt was made to include accurate topography information from the LIDAR surveys. Due to the delay in the release of data for the entire state this was not undertaken. Due to the dynamic nature of Louisiana's coast LANDSAT-TM satellite images are used to accurately delineate land-water features.
- The data required for running the model at a 100 m resolution is not available. This is especially true regarding bathymetry data. An attempt was made to use the data released by NOAA which integrates USGS DEM and bathymetry data at a resolution of 30 m. It was found that this data set was of poor quality with a lot of missing data.
- It was finally decided to run the and test the model at a resolution of 1 km for which all data were available.

3.7 Computational Design

Although field data were not available at 100m resolution the model has been developed to run simulations at very high resolutions when data does become available. In order to model the entire Louisiana Coast at a grid resolution of 100m typical grid sizes of 2500 X 2000 have to be used. This translates to several Gigabytes of core memory. The time steps range from about 1 minute to 5 minutes. For a one-week simulation, with a time step of one minute the number of time steps is about 10080. This large number calculation indicates the extremely computation-intensive nature of the model. Typically models of this nature are run on shared memory vector supercomputers like the Cray

C90. These supercomputers are extremely expensive costing several million dollars, financially well beyond the reach of university departments.

In order to take advantages offered by a workstation cluster the model algorithm is parallelized using HPF directives. The problem is distributed across the workstation cluster with each node performing a subset of the total computation. The subsets communicate with each other by exchanging messages which travel across the network. An inherent drawback of such a system is the slow speed of the network increasing the communication costs. The challenge lies in minimizing the communication costs by keeping the message passing overhead at a minimum. Conceptually, the program is executed on all processors simultaneously. Since each processor only has access to a subset of the distributed data, there will be times when a processor needs to access data stored in the memory of another processor. The actual details of the inter-processor communication needed to support this access are determined by the compiler rather than being specified explicitly, they are implicit in the program. A great advantage of writing code using HPF directives is that the code is portable across both uni-processor, shared memory multiprocessor, and distributed memory workstation clusters.

3.8 Visualization of model Results

All model outputs are compatible with GIS based visualization systems. ARC/INFO a commercial GIS system is used for visualizing the model results. Vector features like roads, railway lines, parish and state boundaries, levees, etc. would be overlaid. Point features like shelter locations would also used as overlays.

3.9 Facilities used for the project.

The facilities required to complete this work are available at LWRRI. These include a distributed computing cluster, graphics workstations for display and related equipment like scanners, color printers etc. A brief description of the distributed computing cluster is given below.

3.9.1 Distributed Computing Cluster

The distributed computing cluster consists of 32 Pentium II 350 MHz workstations with 256 MB of RAM and 4.5 GB of disk space. The workstations are interconnected using a 100 Mbit fast ethernet network connected through two 24 port 3 Com Superstack II 3300 switch. This provides an aggregate backplane bandwidth of one Gigabit/sec. The switches are interconnected by a matrix cable so that there is no loss of bandwidth when two switches are stacked. The cluster is monitored through a front-end workstation which consists of a Pentium II 350 MHz motherboard with two 100 Mbit fast ethernet cards, a 8 MB Matrox Millenium G200 video card, two 9 GB IDE hard drives, a 24 X CDROM and a floppy drive. The front end also has a Portland Group optimizing C, C++, F77, F90 and HPF compilers. Various GNU compilers like GCC, G77 etc. are also available. Message passing libraries like MPII, PVM, BSP etc. also available. All the nodes in the cluster run LINUX a public domain UNIX like operating system.

4.0 Results:

The storm surge simulation was paralleized and a summary of its performance on a cluster of workstations is shown in Table 1. In order to evalaute the performance a fine grid channel model was used to gauge the performance metrics. The channel consists of a channel 20 km wide and 100km long. The grid resolution was 100 m in both the X and Y directions for 200 grid cells in the X direction and 1000 grid cells in the Y direction. A sinusoidal wave of 24 hr period was prescribed at the southern boundary. A no flow condition was prescribed at the northern, eastern and western boundaries. The model was run period of 7 days with a time step of one minute. The results are summarized in table 1. The first column indicates the number of processors, the second column indicates the total execution time, the third column indicates the Millions of floating point operations per second (Mflop/s), the fourth column indicates the Mlop/second/processor, and the fifth column indiactes the speedup with respect to a single processor run.

Table 1. Performance of a high resolution hydrodynamic model

#of procs	Time (Secs)	Mflop/s	Mflop/s/proc	Speedup
1	3406.67	47.8	47.8	1
9	426.9	394.2	43.8	7.98
16	257.1	654.4	40.9	13.25
25	149.3	1127.0	45.0	22.81

From Table 1. It is apparent that the model scales well from one to 25 processors, with speedup of 22.81 for a 25 processor run. Due to the unavailability of all data at 100m resolution it was decided to run the model at a one km resolution.

A 1km grid resolution run was made on a historical hurricane (hurricane Camille). The model was run for the eastern part of the state with boundary forcings obtained from a coarse grid FEMA model run. The maximum envelope of flooding which indicates the maximum water level obtained at a grid point during the course of the simulation is shown in Figure 1. The model results compared well with observed maximum elevation data.

5.0 Conclusions

The following conclusions can be regarding the study.

- A high resolution storm surge simulation model was developed.
- The model code was parallelized using High Performance Fortran directives.
- The model implemented sub grid scale features such as barrier, levees, inlets through barriers.
- A hurricane wind model based on NWS 23 was developed.
- The model also includes rainfall as a source term so that high intensity rainfall can be incorporated.
- The parallel model scaled well over 25 processors.

- Calibrations against hurricane Camille indicated good agreements.

6.0 Future Enhancements Planned

The model is still evolving. Some of the work underway include:

- Collect high resolution topography and bathymetry data. Currently such data is being gathered by NOAA and the state of Louisiana using LIDAR surveys. Once these data are obtained and quality checked they would be included into the model.
- Use updated Levee information. This information is being collected by the U.S. Army Corps of Engineers. We have obtained a preliminary data set which is currently undergoing testing.
- Although the model includes rainfall as an input this modules has not been thoroughly tested. This would be tested in a future release of the model.
- Incorporate a pollutant transport model. This is important because often times during a hurricane a lot of toxic chemicals may be released, especially if the hurricane hits certain regions of Louisiana where there is a large concentration of chemical industries.
- Update the model by incorporating MPI (Mwssage Passing Interface) as a parallelization protocol instead of HPF. This is important as for a large number of processors MPI is more scalable than HPF.

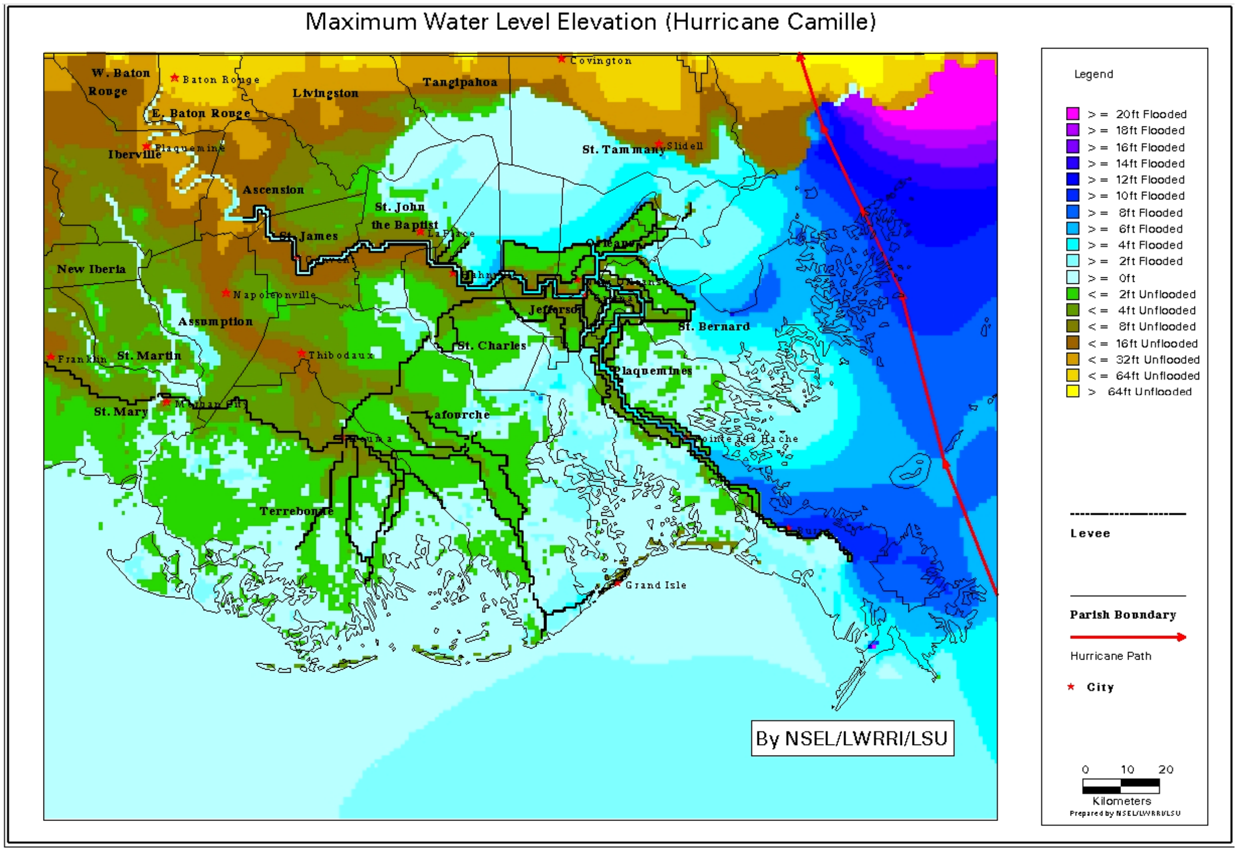

Figure 1. Maximum Water Level Elevation (Hurricane Camille)

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Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment

Basic Information

Title:	Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment
Project Number:	2001LA2521B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	
Congressional District:	6th
Research Category:	
Focus Category:	Non Point Pollution, Treatment, Hydrology
Descriptors:	Urban Hydrology, Granulometry Elevated Infrastructure, Storm water, Mitigation, Unit Operations and Processes, Granulometry, Heavy Metals, Particle Transport, Best Management Practices (BMP)
Principal Investigators:	John Joseph Sansalone, Frank K. Cartledge, Marty Tittlebaum

Publication

1. Cristina, C. and Sansalone, J.J., (2002), An evaluation of the first flush, power law model and process selection diagram for storm water runoff, ASCE J. of Environmental Engineering (accepted).
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gradations and settling column analysis, 9th International Conference on Urban Drainage, Paper and Presentation, ASCE/IWA, Portland, Oregon, September 2002.

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Title: Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana – The Role of Partitioning and Implications For Treatment

Project Number:

Start Date: March 2001

End Date: March 2002

Research Category: NPP, TRT, HYDROL, TS

Descriptors: Urban Hydrology, Granulometry Elevated Infrastructure, Storm water, Mitigation, Heavy Metals, Particle Transport, Best Management Practices (BMP)

Lead Institution: Louisiana State University (Civil Engineering, Chemistry Departments)

Investigators: John J. Sansalone, P.E. (LSU), Frank K. Cartledge (LSU),
Marty E. Tittlebaum (University of New Orleans)

Students Supported: Two Master of Science students (Civil and Environmental Engineering)

Problem Statement:

Since passage of the 1972 Clean Water Act, storm water nonpoint pollution has advanced from being a problem that was understood only well enough to realize the difficulties associated with application of conventional unit operation and process design, to now becoming the wastewater of the next several decades and our most important water treatment challenge. From urban interstate highway pavement alone, annual heavy metal, total suspended solids (TSS), chemical oxygen demand (COD) loadings and storm water flows have been shown to equal or exceed annual loadings and flows from untreated domestic wastewater for a given urban area (Sansalone et al., 1998). Storm water runoff, impacted by both urban transportation activities and associated urban transportation infrastructure, transports significant loads of dissolved, colloidal and suspended solids in a complex heterogeneous mixture that includes heavy metals, inorganic and organic compounds. Urban storm water levels of Zn, Cu, Cd, Pb, Cr, and Ni are significantly above ambient background levels, and for many urban and transportation land uses often exceed surface water discharge criteria on an event basis for both dissolved and particulate-bound fractions (Sansalone et al, 1997). Storm water transports a wide gradation of particulate matter ranging in size from smaller than 1-μm to greater than 10,000-μm (Sansalone et al, 1998). From water quality and potential treatment perspectives, entrained or engineered solids having reactive sites and large surface-to-volume ratios are capable of mediating transport of heavy metals.

With very few exceptions, runoff from elevated urban and transportation infrastructure in the United States is discharged directly to the surrounding environment. This is particularly true for challenging conditions typical of Louisiana. In Louisiana transportation infrastructure of urban areas, industrial corridors and inter-urban corridors is commonly elevated, and discharge storm water directly to waterways, estuaries, marshes and coastal areas. In fact, Louisiana has more elevated transportation infrastructure than any other state except California and over 80% of Louisiana's transportation infrastructure is over water. The Causeway and a section of I-10 over Lake Pontchartrain and elevated I-10 over the Atchafalaya Basin are well known examples. Since authorization of the NPDES Phase II Storm Water Final Rule in February of 2000, these discharges to receiving water will first require permitting and eventually control. Since NPDES Storm Water Phase I regulations in the 1980s there has been a proliferation of "best management practices" (BMPs). However, experience has demonstrated a significant gap in knowledge exists between BMP design/analysis and a fundamental understanding of unit operations and processes that can demonstrate treatment viability. Much of this gap in knowledge stems from a lack of fundamental understanding of the complex heterogeneous nature of storm water and the interactions that occur in storm water such as heavy metal partitioning to and from particulate matter. Such knowledge is critical to the success of a new generation of storm water treatment systems that will develop in response to the new February 2000 NPDES Phase II Final Rule. This rule requires characterization and permitting of storm water discharges and development of BMPs to control storm water discharges for communities down to populations of 10,000.

Research Objectives:

The fundamental goals of this research study were fourfold. The first objective was to examine the water quality characteristics and the runoff hydrograph from an elevated stretch of an urban interstate site in Baton Rouge. More specifically, the second objective involved the assessment of the partitioning between the dissolved and particulate phases of the respective constituents as they are flushed directly off the bridge surface, as the relative phase distributions have significant implications with regards to treatment design. The third objective quantified the extent to which a disproportionate delivery or "first-flush" type phenomena propagated throughout the duration of the events characterized, as the terminology of this phenomenon implies that this is an ephemeral occurrence phenomena that occurs only during the preliminary stages of an event. Finally, the fourth objective was to evaluate the correlation between the measured conductivity readings and the concentration of total dissolved solids (TDS).

Methodology

Storm water runoff from the I-10 City Park Lake over-pass was sampled for 9 discrete events throughout the course of this study, from which hydrologic and water quality data were collected. Traffic flow characteristics are primary variables that significantly influence pollutant loadings. Consequently, total vehicular counts were performed for all eastbound lanes from which the runoff being sampled drained.

Discrete fully-labeled 1-liter samples were collected from the time of the start of observable rainfall at the site (defined as time = 0) to the cessation of runoff for each particular event. Samples were collected every 2.0 to 5.0-minutes until peak flow was reached and then every 5.0 to 15.0-minutes thereafter, with increased sample spacing to accommodate longer duration events, while at the same time keeping the sample base manageable.

Flow rate measurements are essential to calculate mass loading contributions and were recorded throughout the duration of the storm, from the time of first runoff until the completion of the particular rainfall runoff event. Volumetric flow rates were taken every 2.0-minutes, until the peak of the storm had been measured and then in 5.0-minute increments thereafter, until the end of the rainfall runoff event.

Stormwater Runoff Sample Analysis

Because many water quality parameters are time dependant, time critical data measurements and laboratory analyses were performed immediately or at most within 12-hours of collection with the samples refrigerated at 5^{o}C for the interim. The following water quality parameters were measured immediately in the field: temperature (^{o}C), pH (s.u.) (APHA Standard Method 4500- B), redox potential (+ mv) (APHA Standard Method 2580-proposed), conductivity (µs/cm) (APHA Standard Methods 2510), dissolved oxygen concentration (mg/L) (APHA Standard Method 4500-O- membrane electrode method)

Upon the determination of the end of the event, all samples were returned to the laboratory for further analysis. These analyses (where appropriate) were performed on both the unfractionated sample and the fractionated dissolved phase. The dissolved fraction is that material that passes through a 0.45-µm GFC membrane filter. The time critical laboratory procedures that were performed were: Total alkalinity (mg/L-$CaCO_3$) (APHA Standard Method

2320 B), Phase fractionation between the dissolved and particulate phases (APHA Standard Method 3030 B)

Samples were also fractionated between the total and dissolved phases immediately upon return to the laboratory, for Chemical Oxygen Demand (COD) analysis on the respective phases. That fraction which passed through the 0.45-μm GFC filter constitutes the dissolved phase COD. The particulate fraction was directly inferred from the product of the result of these analyses.

Stormwater runoff samples were fractionated into total suspended solids (TSS) volatile suspended solids (VSS), total dissolved solids (TDS) and volatile dissolved solids (VDS). TSS, VSS and TDS were determined in accordance with the APHA Standard Methods 2540-D, 2540-E, and 2540-C respectively. The methodology to determine VDS is not officially documented in APHA Standard Methods and was determined by igniting the residue from the TDS analysis (APHA Standard Method 2540-C) in a similar fashion to the determination of VSS in Standard Method 2540-E.

All samples were homogenized immediately prior to analysis and between replicate measurements and then placed on a magnetic stir plate to maintain homogeneity while readings were being taken. All analyses, with exception of suspended solids and total turbidity analyses were performed in replicate. TSS, VSS and turbidity were performed in triplicate.

Principal Findings and Significance

One of the key design constraints when considering treatment alternatives for storm water treatment, is the stochastic nature of rainfall-runoff events. This study has revealed that the hydrologic characteristics for storm events for a particular site are highly variable both between events and within the same event. The frequency of occurrence of storm events is not only controlled by prevalent regional climatic conditions, the occurrence of such events also exhibits significant temporal variation within seasonal variations. These temporal variations manifest themselves in the large variability in previous dry hours recorded. This local temporal variability within regional climatic controls is evidenced by the fact, that even though the site is located in sub-tropical climate, on two occasions, within the study occurred two events with previous dry hours in excess of 700 hours.

These temporal variations in both absolute occurrence of an event and variations in intensity within the same event, have fundamental implications for treatment strategy selection and treatment alternative design. Naturally, the stochastic nature of these events precludes the selection of a treatment strategy that involves biological unit processes. The majority of treatment alternatives are linked to biological processes would fail as the microbial populations would soon die when exposed to the extended periods of non-operation. What is also important in rainfall runoff dynamics is the fluctuations in flow rate that can not only varies by orders of magnitude between events, in response to rainfall intensity, but also that the flow rate can also vary by an order of magnitude within the same event.

Another of the principal variables of rainfall-runoff event hydrology is runoff volume. The volume of rainfall runoff, although essentially linked to rainfall amount, duration and intensity, is also affected by previous dry hours and traffic volume. Traffic flow volume will govern the amount of re-entrainment of the rainfall as vehicular spray and as a consequence has a significant impact on not only time of concentration for the runoff, but also the co-efficient of concentration. Traffic flow prior to an event is also a fundamental contributory factor in pollutant accumulation during the previous dry hours leading up to the event. Mass loading rates are obviously fundamentally controlled by rainfall runoff hydrology dynamics, whereas the relative contributions from the dissolved, particulate and particulate-bound phases is a complex relationship between, metal element solubility, partitioning coefficients, the amount of particulate matter in the runoff and the relative concentrations of organic material within this particulate fraction, the pH, ORP and the total alkalinity of the runoff. This complex relationship is shown by the differing f_d values for the same element between storm events.

The stochastic nature of storm events and the highly variable runoff dictates that the proposed treatment alternative must be able to operate over a wide range of loading rates, withstand extended periods of non-operation, and be unaffected by the high heavy metal concentrations without any compromise in pollutant removal efficiencies. This suggests physico-chemical unit operations and processes capable of removing both heavy metals and suspended solids. The toxicity associated with high heavy metal concentrations and also extended downtime would lead to a rapid failure in the biological-type treatments.

The linear site constraints combined with the issues of accessibility associated with elevated structures over water necessitates the collection of the non-point source pollution before treatment. Because of the inaccessibility of elevated structures over water, a treatment system that is passive in application with minimum operational requirements and maintenance is required.

The majority of conventional technologies applied to the treatment of wastewater, although often applicable to the mitigation of urban storm water runoff are not suitable treatment strategies for elevated highways. More often than not, this preclusion is based on simple space availability. Elevated structures do not have hard shoulders or vegetative strips to the side, which could be utilized for the implementation of various treatment strategies.

Table 1. Hydrological indices of the rainfall-runoff events characterized at the City Park Lake bridge

Rainfall Runoff Event	PDH[1] (hrs)	Rainfall duration (min.)	Runoff duration (min.)	Specific Drainage Area IPRT[2] (min.)	t_p[3] (min.)	Q_p[4] (L/min.)	V[5] (L)	Entire Bridge Q_{pT}[6] (L/min.)	V_T[7] (L)	vds[8]
18 Mar-2000	70	42.0	45.0	10.0	23.0	226.0	1728.0	2806.9	21461.8	5595
5 Jun-2000	720	66.0	76.0	27.0	10.0	10.0	976.5	124.2	12121.9	6705
9 Jun-2000	110	21.0	25.0	3.0	8.0	40.0	326.6	496.8	4056.4	6728
7 Aug-2000	106	48.0	18.0	42.0	32.0	0.9	9.0	11.4	111.8	4350
10 Aug-2000	70	41.0	37.0	8.0	16.0	240.0	3175.5	2980.8	39439.7	4860
21 Sep-2000	238	234.0	210.0	15.0	30.0	150.0	4795.4	1863.0	59558.9	3943
4 Nov-2000	704	75.0	57.0	23.0	50.0	27.0	826.3	335.3	10262.6	2815
13 Dec-2000	170	83.0	92.0	8.0	35.0	240.0	8142.6	2980.8	101131.1	6033
29 Jan-2001	236	181.0	165.0	25.0	164.0	150.0	3184.2	1863.0	39547.8	4114
All events median	170.0	66.0	57	15.0	30.0	150.0	1728.0	1863.0	21461.8	4860.0
All events mean	269.3	87.9	91.222	17.9	40.9	120.4	2493.3	1495.8	30966.4	6132.6
All events SD	258.7	71.6	72.519	12.4	48.0	102.0	2678.9	1266.3	33272.0	4155.7
All events RPD%	164.6	167.1	168.42	173.3	181.4	198.5	199.6	198.5	199.6	142.5

1) PDH = previous dry hours
2) IPRT = initial pavement residence time (measured from time 0 to first runoff)
3) t_p = time to Qp (measured from start of rainfall)
4) Q_p = peak flow from specific drainage area =532-m^2
5) V = Runoff volume from specific drainage area during event
6) Q_{pT} = peak flow from entire bridge deck = 6607-m^2
7) V_T = Total runoff volume from entire bridge deck during event
8) vds = vehicles during storm (I-10: east-bound)
Average Daily vehicles (I-10: eastbound) = 70,400

Table 2. Event based water quality characteristics of the storm water from City Park Lake

Rainfall Runoff Event	Event mean concentrations (EMC)[1]						
	T (°C)	pH (s.u.)	total alkalinity [mg/L]	Conductivity (µs/cm)	Redox (+mV)	Dissolved Oxygen [mg/L]	Turbidity (NTU)
18 Mar-2000		6.9 (6.4-7.0)	23.10 (18-36.0)		394.7 (386.9-418.1)		50.1 (32.6-263.0)
5 Jun-2000	21.9 (21.5-22.0)	6.7 (6.3-6.9)	107.4 (62.0-182.0)	2314.2 (776.0- 11240.0)	469.0 (439.8-476.1)	0.5 (0.1-1.9)	1883.6 (55.3-1049.5)
9 Jun-2000	25.6 (25.8-25.4)	7.3 (6.8-8.4)	30.2 (22.0-208.0)	145.6 (92.6-1050.5)	398.6 (386.1-476.4)	1.8 (0.1-3.1)	121.9 (52.8-1277.0)
7 Aug-2000	27.9 (29.1-29.7)	6.5 (6.8-7.1)	58.1 (56.5-71.0)	1503.7 (479.0-1777.0)	288.3 (274.0-331.0)	4.2 (4.0-4.9)	12.2 (5.3-36.9)
10 Aug-2000	22.0 (22.0-22.3)	6.6 (6.3-6.8)	12.8 (5.0-65.0)	5889.3 1160.5-10073.4)	473.3 (466.0-487.0)	0.3 (0.1-1.9)	101.3 (38.2-1610.0)
21 Sep-2000	25.9 (25.0-26.5)	7.6 (6.7-7.9)	35.2 (25.0-94.5)	158.0 (85.1-1175.1)	511.1 (493.0-624.0)	4.3 (0.2-6.2)	228.2 (43.0-1143.5)
4 Nov-2000	20.1 (19.8-21.5)	7.0 (6.6-7.1)	40.9 (29.5-136.3)	426.1 (266.1-1704.5)	500.9 (487.0-535.0)	1.4 (1.9-9.1)	434.9 (99.7 6290.0)
13 Dec-2000	20.4 (16.8-21.3)	8.1 (7.0-8.5)	16.9 (11.5-90.5)	83.0 (34.0-1180.0)	374.8 (34.0-1180.0)	6.9 (6.0-8.2)	136.3 (55.4-1113.8)
29 Jan-2001	19.3 (17.8-22.7)	8.0 (7.4-8.3)	26.2 (18.6-86.5)	154.3 (46.0-1401.0)	403.8 (387.0-458.0)	7.0 (4.9-7.6)	408.5 (114.3-2221.8)
All events median	22.0	7.0	30.2	292.1	436.4	3.0	136.3
All events mean	22.9	7.2	39.0	1334.3	427.5	3.3	375.2
All events SD	3.2	0.6	29.0	2011.3	75.4	2.7	584.7
All events RPD%	36.4	21.9	157.4	194.4	55.7	183.6	197.4

1) maximum and minimum values in parenthesis

Table 3. Water quality summary data for the rainfall-runoff events characterized

Rainfall Runoff Event	Event Mean Concentrations (EMCs)[1]					
	TSS [mg/L]	VSS [mg/L]	TDS [mg/L]	VDS [mg/L]	COD_p [mg/L]	COD_d [mg/L]
18-Mar-2000	138.0 (57.0-1444.0)	32.5 (16.7-626.0)			142.0 (86.0-7449.0)	57.1 (29.1-419.6)
5 Jun-2000	560.5 (89.3-1302.7)	214.5 (44.7-404.7)	2241.3 (630.4-7204.3)	351.6 (467.0-6470)	585.0 (169.4-887.0)	854.5 (224.4-2524.9)
9 Jun-2000	206.1 (67.7-1809.3)	62.2 (22.3-634.7)	106.0 (67.2-803.1)	49.5 (37.0-648.4)	248.1 (8.1-540.2)	45.9 (14.0-418.9)
7 Aug-2000	32.3 (18.0-703.0)	20.6 (11.0-38.3)	1206.1 (1095.3-1482.4)	430.1 (386.1-512.1)	54.1 (13.1-87.9)	429.6 (289.0-635.0)
10 Aug-2000	225.0 (40.1-1269.3)	99.9 (21.3-213.0)	103.0 (32.3-983.3)	88.0 (30.3-925.9)	71.7 (32.54-804.9)	55.9 (19.5-293.6)
21 Sep-2000	159.7 (50.0-1027.0)	47.8 (26.0-495.0)	154.6 (85.0-1159.3)	75.5 (13.1-916.9)	94.1 (40.0-491.0)	55.3 (16.1-390.0)
4 Nov-2000	442.4 (58.3-8734.7)	148.2 (28-7-2416.0)	274.4 (152.5-882.3)		343.2 (58.4-7185.4)	162.0 (80.5-568.2)
13 Dec-2000	334.4 (40.0-1910.0)	53.0 (9. 0-531.3)	274.4 (55.4-1113.8)		343.2 (10.9-901.4)	162.0 (28.7-379.1)
29 Jan-2001	518.6 (86.7-1837.3)	82.5 (20.7-402.7)	117.8 (38.4-477.5)		151.7 (25.2-839.8)	60.7 (30.5-390.5)
All events median	225.0	62.2	214.5	88.0	151.7	60.7
All events mean	271.9	78.6	515.0	187.3	211.0	186.5
All events SD	159.0	49.2	664.5	167.0	141.4	212.8
All events RPD%	176.5	154.5	179.3	158.7	157.2	173.6

Determining Uncertainty in Capture Zones and Interference from High Volume Wells

Basic Information

Title:	Determining Uncertainty in Capture Zones and Interference from High Volume Wells
Project Number:	2001LA2541B
Start Date:	3/1/2001
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	06
Research Category:	Not Applicable
Focus Category:	Groundwater, Water Supply, Management and Planning
Descriptors:	Groundwater Management, Statistical Analysis,Groundwater Modeling
Principal Investigators:	Clinton Stuart Willson

Publication

SYNOPSIS

Title: **Determining Uncertainty in Capture Zones and Interference from High Volume Wells**

Project Number **2001LA2541B**

Start Date: **3/01/01**

End Date: **2/28/03 (extension approved)**

Research Category

Focus Categories: **GW, WS, M&P**

Descriptors: **Groundwater Modeling, Uncertainty, Water Supply**

Lead Institution: **Louisiana State University**

Investigators: **Clinton S. Willson, PhD**

Number of Students supported: **1 PhD student**

Problem and Research Objectives

Louisiana has a tremendous amount of fresh water in aquifers---an average of over 1 billion gallons per day (GPD) of ground water was removed from various aquifers in 1995 (Lovelace and Johnson, 1995). Industry is becoming increasingly aware of Louisiana's tremendous ground water supply and its advantages; high quality water is becoming a dominant factor in the decision to locate new plants throughout Louisiana. In addition to the groundwater resource, Louisiana is also centrally located between two large consumer bases; northeastern U.S. and rapidly growing Mexico and Central America.

While the amount of freshwater in Louisiana aquifers is enormous, the supply is not infinite, particularly in a local sense. Water levels have been dropping in many aquifers and some regions have experienced an increase in salinity levels. The Sparta Aquifer in north Louisiana provides water to almost 800,000 citizens in 15 parishes. The rate of consumption has outpaced the rate of aquifer recharge for the past two decades which has resulted in dropping water levels at a rate of 1 to 4 feet per year with a simultaneous degradation in water quality. Similar problems with long-term water level decline have begun to appear for portions of the Florida parishes, a region characterized by multiple fresh water aquifers and tremendous fresh water reserves. Water levels are dropping in the Florida Parishes Aquifer System also, in some instances to the point of causing individual water wells to run dry. In East Baton Rouge Parish, salt water is moving across a regional fault boundary and into primary drinking water aquifers. In addition to dropping water levels and interference problems, saltwater pockets have also been discovered in parts of the Chicot aquifer in the Lake Charles area. Corrective measures have been taken, but aquifer recovery takes time.

The purpose of this project is to provide a scientifically-based framework with which to guide groundwater policy and management decisions. The results from this project will lead to a methodology demonstrating the significance of uncertainty associated with hydrogeological parameters on determining the groundwater hydraulics of high-volume point source withdrawals. In particular, the modeling framework will provide information and data, in a probabilistic framework, concerning the location and capture zone of production wells for water supply and the potential interference with existing water supply wells.

This project is focused on the Chicot aquifer system in southwestern Louisiana and complements a joint project with the Louisiana Geological Survey (LGS) being funded by the LA Department of Transportation and Development (LA DOTD). The objective of the LA DOTD project is to evaluate the aquifer capacity to sustain long-term ground water withdrawal from point sources.

The results will be useful in the planning and management of groundwater systems in the state and across the nation. The methodology will also be useful for scientists and engineers who are trying to convey to policy makers or regulators a better description of the uncertainty associated with groundwater systems. This project is forming the basis for a PhD dissertation.

Methodology

Our approach is to use a low-resolution groundwater model to study the regional flow in the Chicot aquifer and to provide boundary conditions for higher-resolution inset models created using telescopic mesh refinement (TMR). These high-resolution models allow us to incorporate more data and information into the study region, including aquifer heterogeneities, recharge rates, and pumping locations and rates. Despite increasingly sophisticated techniques for quantifying this data and information, there are still spatial and temporal uncertainties. At the current time, we are focusing on the heterogeneities in the hydraulic conductivity field and their impact on the groundwater flow dynamics (e.g., drawdowns, capture zones, etc…). Geostatistical methods and conditional simulations are used to model spatial uncertainty of the hydraulic conductivity. Spatial maps of hydraulic conductivity are created using two sequential simulation techniques, Sequential Gaussian Simulation (SGS) and Simulated Annealing (SA) and are compared. GIS techniques will be used to construct probability maps for the exceedance of critical hydraulic conductivity values and for typical scnarios associated with water supply and management problems such as capture zones. The information from this study will improve our ability to manage groundwater supplies.

The hydrogeological conditions in the study area that are relevant to the design of the model are obtained from the existing geologic literature, geologic data from the files of the U.S. Geological Survey, Water Resources Division, and data acquired during a project the P.I. currently has with the Louisiana Geological Survey. There is an extensive set of U.S.G.S. publications concerning the Chicot aquifer that are being utilized for this project Hydraulic conductivity data is obtained from both the literature and from analysis of pump tests and specific capacity tests obtained from the LA DOTD water well database. The locations and pumpages of existing water supply wells is obtained from publications of the U.S.G.S. and records of the LA DOTD.

Reports

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- Rahman, A, Hartano, S. and C.S. Willson, 2003, Incorporating Uncertainty into High-resolution Groundwater Supply Models, accepted abstract for the World Water and Environmental Resources Congress, sponsored by the ASCE Environmental and Water Resources Institute, to be held June 20-23, 2003, Philadelphia, PA
- Rahman, A., R. Milner, B. Hanson, and C.S. Willson, 2001, Linking Local- and Aquifer-scale Groundwater Models Using Telescopic Mesh Refinement, presented at the 2001 American Geophysical Union Fall Meeting, December 10-14, 2001.

Local Presentations

- Willson, C.S., 2001, Groundwater Issues in Louisiana, presented to the Baton Rouge Leadership Program, November 13, 2001.
- Willson, C.S., 2001, Groundwater Modeling of the Chicot Aquifer Underlying Acadia Parish, presented to the Baton Rouge Geological Society, November 8, 2001.

Fecal Coliform Concentrations in Runoff from Fields with Applied Dairy Manure

Basic Information

Title:	Fecal Coliform Concentrations in Runoff from Fields with Applied Dairy Manure
Project Number:	2001LA2621B
Start Date:	3/1/2001
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	6th
Research Category:	Not Applicable
Focus Category:	Non Point Pollution, Agriculture, Surface Water
Descriptors:	fecal coliforms, nonpoint source pollution, dairy
Principal Investigators:	Caye M. Drapcho, Alyson Kristine Bertges Hubbs

Publication

Title: Fecal Coliform Concentration in Runoff from Fields with Applied Dairy Manure

Project Number:

Start Date: 3/01/02

End Date: 3/01/03 (extension approved)

Research Category: NPP, WQL, AG

Descriptors: fecal coliform bacteria, *E. coli*, non-point source pollution, water quality, dairy manure

Lead Institution: Louisiana State University Agricultural Center (BAE Department)

Investigators C. M. Drapcho, A. K. B. Hubbs

Number of Students supported: 2 undergraduate students; 1 M.S. student

Problem and Research Objectives

Wastes produced in livestock production and processing facilities are increasingly applied to agricultural soils for either disposal and/or nutrient recycling (Coyne et al, 1995). Once manure is land applied, it becomes a potential agricultural non-point source of pollution. Pasturing operations also contribute to this type of pollution (Moore et al., 1989). One of the main concerns with land application of animal manure is that bacterial pathogens will reach groundwater and surface water via runoff during or after a storm event (Stoddard et al, 1998). Infectious diseases of microbiological etiology, originating in man and other animals, can be transmitted through waters that receive animal wastes. Thus, human and livestock exposure to surface or groundwater contaminated with fecal bacteria is an important water quality concern (Stoddard et al, 1998).

Cattle grazing on rangelands and pastures may account for a significant amount of non-point source water pollution. Further research is needed to determine the extent to which dairy manure on pasture impacts water quality. Studies comparing methods of waste application indicate that the effect of grazing cattle on water quality may differ from that of land applied manure.

Viable fecal coliform (FC) bacteria have been cultured from fecal deposits after extended periods of time, even as long as one year if conditions are favorable (Thelin and Gifford, 1983). Buckhouse and Gifford (1976) in Kress and Gifford (1984) found that fecal coliforms persist in cow feces at least seven weeks under hot, dry summer range conditions. Thus, fecal deposits are capable of providing a long-term source of potential pollution to surface water (Thelin and Gifford, 1983). The fecal deposit appears to act as a protective medium for the bacteria within by forming a crust, thus decreasing interaction of the bacteria with the soil and atmosphere (Stoddard et al, 1998). Thelin and Gifford (1983) have found that a large population of fecal coliforms still exists in a fecal deposit long after the deposit has been thoroughly dried.

Not only have coliform bacteria been found to survive outside of the intestinal tract, but they also have been found to have exhibit initial regrowth in certain conditions. Moist conditions, mild temperatures, and manure crusting are believed to contribute to regrowth (Stoddard et al, 1998). Organic nutrients present within the feces may also provide a favorable environment for growth (Van Donsel et al., 1967). Additionally, fecal bacteria are able to obtain nutrients associated with the sediment particles (Davies et al, 1995). An initial rise in coliform bacteria was noticed in many studies both in soil and in water (Dewedar and Baghat, 1995). Van Donsel et al. (1967) noted evidence of soil coliform growth following rainfall. Although bacteria have been noted to remain viable for an extended period of time when protected within a fecal deposit, the hydrophobic properties of the dried outer crust may prevent bacterial interaction of with rain (Stoddard et al, 1998).

Bacteriological water quality is determined by examining water samples for the presence of indicator organisms. Measurement of the quantity of fecal coliform bacteria is one of the most commonly used methods to establish the quality of natural waters (Valiela et al, 1991). The fecal coliform group is indicative of organisms originating in the intestinal tract of humans and other animals (Thomann and Mueller, 1987) although other sources may exist (Auer and Niehaus, 1993). Fecal coliforms are a thermotolerant group that decline in natural environments. Procedures for routine measurements have been standardized (Valiela et al, 1991), however, the test methods are both labor and materials intensive, and require precise control of laboratory conditions and a high degree of technical skill to perform and interpret results. Such methods include the Membrane Filter (MF) and Multiple Tube Fermentation tests.

A relatively new method, the QuantiTray-Colilert system (developed by IDEXX Laboratories, Inc.), was designed to measure *E. coli* and total coliforms (TC) in drinking water simultaneously (Elmund et al, 1999). This method is much simpler requiring less manipulation, and thus has less chance for human error. The QuantiTray system is very easy to inoculate. Time studies indicate that the QuantiTray system requires significantly less time per sample for setup, reading, and recording of results (Budnick et al., 1996).

The Colilert reagent is a defined substrate MUG-based media for detecting total coliforms and *E. coli*. Per the IDEXX method, 100-ml water samples (diluted with sterile water, if necessary) are mixed with pre-measured packets of Colilert reagent in polystyrene bottles and mixed via rigorous shaking. The mixture is then poured into a QuantiTray, a sterile plastic disposable panel consisting of 96 discrete "wells." The QuantiTray is then mechanically sealed to distribute the sample mixture into all of the wells.

This system provides a Most Probable Numbers (MPN) result based on the presence or absence of yellow color and fluorescence in the individual wells after incubation at 35°C (Fricker et al., 1997). Quantitative results are available within 24 hours. The presence of yellow pigmentation in a well is considered a positive reaction indicating the presence of total coliforms. QuantiTray wells showing no color are considered negative for total coliforms. Wells that fluoresce under UV light are considered positive for the presence of *E. coli*. The positive wells on each tray are counted and compared to a reference table that gives corresponding MPN count of TC or *E. coli* per 100 mL.

One drawback of the QuantiTray method is that there is currently no available procedure for quantifying fecal coliforms. To determine whether or not the QuantiTray system can accurately quantify fecal coliforms using Colilert reagent, the incubation temperature will be raised to the 44.5 ?C to discourage growth on non-fecal coliforms. Subsequently, the recovery of fecal coliforms from the QuantiTray method at this higher temperature will be directly compared to the recovery of fecal coliforms from the MF technique.

Therefore, the purpose of the study was to quantify microbial pollutant transport in surface runoff over manure-amended dairy pastures following rainfall. The specific objectives are as follows:

1. To determine the fecal coliform (FC) concentrations in surface runoff after simulated rainfall from field pasture plots as affected by different methods of manure application and recurrent rainfall and compared to control plots; and
2. To determine whether the IDEXX QuantiTray method is an accurate and reliable method for enumerating fecal coliforms as compared to an approved standard method (Membrane Filtration).

Methodology

The experiment took place at Southeast Research Station in Franklinton, Louisiana. Cattle did not graze at the study site during the experiment or for the prior six years.. Nine field plots were constructed in a 3-row by 3-column layout. Manure application as deposited by cattle (Treatment A) was compared to land application of manure as fertilizer (Treatment B). Application of inorganic fertilizer was used as the control treatment (Treatment C). Each treatment was replicated on three plots in a randomized design. Fresh manure was collected from the feed stall prior to field plot application. Simulated rainfalls were conducted on plots within several hours after initial manure application and runoff samples were collected. Subsequent rainfall simulations were conducted approximately 2, 7 and 14 days after the initial manure application. This sequence was repeated a total of three times. Fecal coliform analyses were performed using Membrane Filtration (APHA, 1995), and the QuantiTray method by IDEXX at incubation temperatures of 35 and 44.5 ?C.

Principal Findings and Significance

The FC concentrations in the surface runoff from the field plots after simulated rainfall Series I are shown in Figure 1. FC counts increased slightly from Day 0 to Day 2 for both the manure treatments (A and B), indicating initial regrowth of the bacteria, and then decreased with time. In Series I, the mean FC concentration for Day 0 runoff from the control plots was 285 cfu/100 mL, near the standard for primary contact recreation of a mean of 200 and a maximum of 400 cfu/100 mL. The mean FC counts for Day 0 runoff from Treatment A and Treatment B were approximately 8,000 and 120,000 cfu/100 mL, 20 and 300 times the primary standard. After 5 rainfall simulations over 30 days, the mean FC concentrations in runoff decreased to approximately 2,000 and 4,000 cfu/100 mL for Treatments A and B, respectively. Similar results were obtained for Series II and III rainfalls.

To compare the impact of the manure treatments, the FC loading was calculated as the FC concentration in the surface runoff multiplied by the volume of runoff produced. Mean FC loading values are shown for Series I in Figure 2. Using data over the three rainfall series, the natural log of the FC loading for Treatment B (m = 15.9, sd = 1.9) was significantly greater than Treatment A (m = 13.7, sd = 1.9), and both manure treatments were significantly greater than the control, Treatment C (m = 9.8, sd = 1.8). Similar results were obtained when data for individual series were tested. These results indicate that distributed manure application releases a greater FC loading to surface water than simulated natural fecal deposition, for the small field plots used in this study.

Fecal coliform enumeration using the QuantiTray method was significantly correlated with that of membrane filtration for both manure treatments, but not for the control. A strong correlation was found for Treatment B (rho = 0.747, $p < 0.001$) and a mild correlation was found for Treatment A (rho = 0.497, $p < 0.001$).

DISCUSSION

The first rainfall event of each Series was representative of a worst-case scenario in which waste application was followed after only a brief interval by a moderate intensity rain. The results of this experiment indicated that at a loading of 1.5 cows/ha, the potential exists for fecal coliform concentration in runoff to exceed the standard for primary contact recreation. However, these concentrations were obtained from runoff that had traversed a very small distance with no buffer or filter zone.

The results of this study indicate that fecal coliform concentrations in runoff from pasture representative of cattle grazing were significantly lower than those obtained from land applied manure. Fecal coliform concentrations and loadings in runoff from plots with Treatment B (scattered manure) were significantly higher than from those plots with Treatment A (manure deposits) in all three Series. These findings indicate that the manure crusting effect may play a role in reducing the potential number of fecal coliforms transported in runoff to surface waters. While the external crust of the manure deposit may provide a shelter for bacteria from environmental factors, its hydrophobic properties also prevent bacterial contact with runoff water. Another rationale for this occurrence is that the available surface area of manure is greater in Treatment B than in Treatment A, thus increasing the potential contact between raindrops and manure.

The presence of fecal coliforms in the runoff from plots with Treatment C could be due attributed to contamination by wildlife and/or the presence of thermotolerant soil coliforms such as Klebsiella (Moore et al., 1989). In many studies, little difference is seen between areas used as pastures and control areas where manure has not been spread (Kunkle, 1970; Robbins et al., 1972; Doran and Linn, 1979;).

The results of this study indicate that IDEXX may be an acceptable alternative to the standard method of Membrane Filtration for enumerating fecal coliforms. Although the IDEXX medium was formulated for total coliform enumeration at 35°C, the results of this study indicate that when incubated at 44.5°C, counts are significantly correlated with those of Membrane Filtration for both manure Treatments. The false positives obtained during both membrane filtration and the QuantiTray method may explain why a correlation was not established for the control.

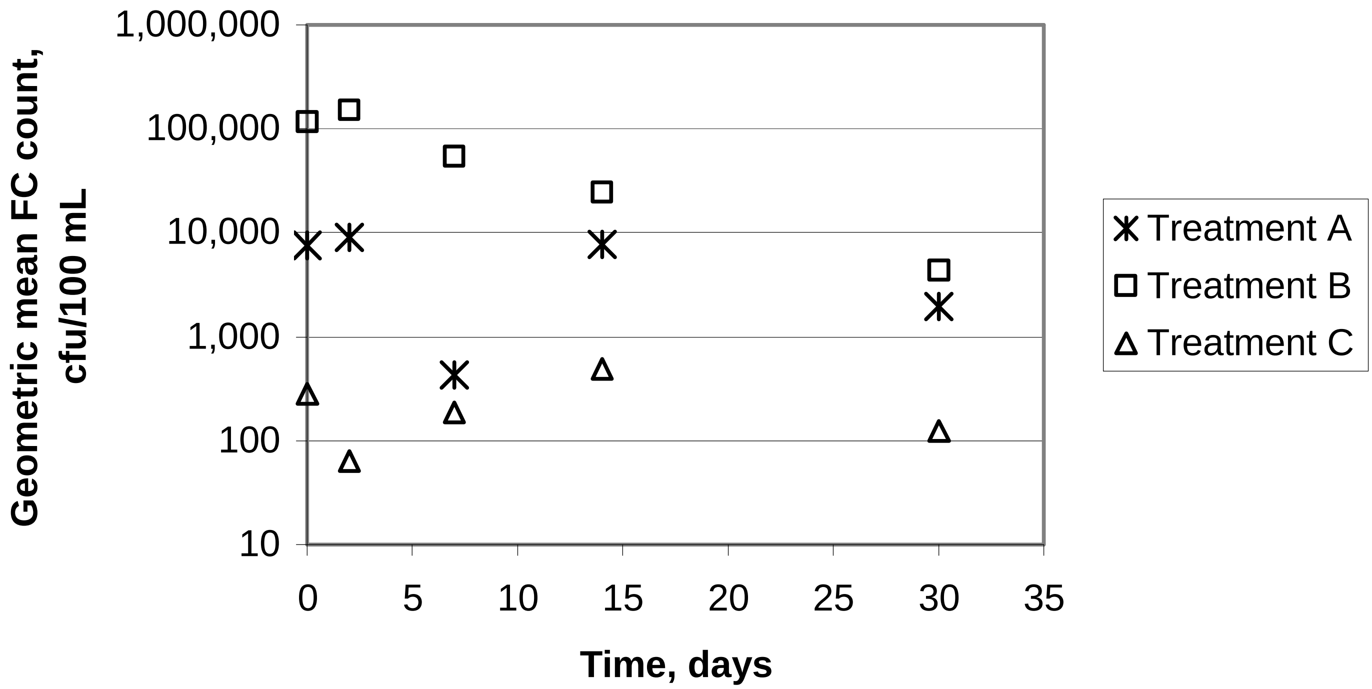

Figure 1: Mean FC counts in surface water from field plots after simulated rainfall Series I.

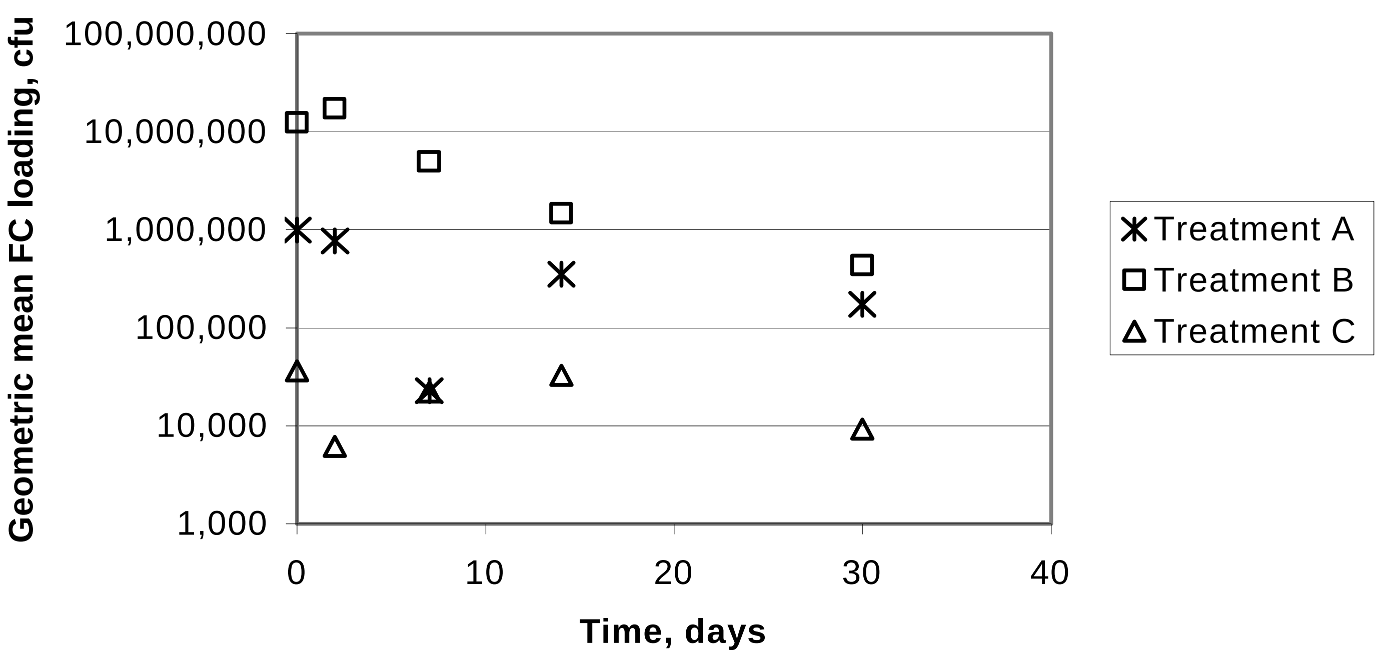

Figure 2: Mean FC loading in surface water from field plots after simulated rainfall Series I.

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Information Transfer Program

In the Information Transfer area, LWRRI has utilized email and web resources to disseminate RFPs for various organizations like the Mississippi Water Resources, in addition to our own RFP. Our distribution list within the state is approximately 120 email addresses and 125 regular mailing addresses. We send out notifications of meetings and events for the American Water Resources Association, The Capital Area Ground Water Conservation Commission, and the Louisiana Rural Water Association. In addition, our organization is contacted regularly with various questions from 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. Our annual report is housed at the Louisiana State Archives, Hill Memorial Library at LSU, and is available online at the Institutes web site.

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	5	0	0	0	0
Masters	5	0	0	0	0
Ph.D.	1	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	11	0	0	0	0

Notable Awards and Achievements

The City of New Orleans lies below sea level and is at extreme risk from Hurricanes and other major storm events. LWRRI under the direction of Joe Suhayda has led and effort to model the magnitude of the storm surge inundating New Orleans and ways of mitigating the effect. This research has been sponsored by many organizations and agencies including the New Orleans Army Corps of Engineers, Jefferson Parish Office of Emergency Preparedness, and the LA Office of Emergency Preparedness. It has been featured in Scientific American, the New York Times, on National Public Radio, CNN, and elsewhere.

Publications from Prior Projects

1. Suhayda, J.N. (2001) LA Water Resources Research Institute Annual Program Report, Louisiana Water Resources Research Institute, Louisiana State University, Baton Rouge, LA, 16 pages.