Louisiana Water Resources Research Institute
Annual Technical Report
FY 2002

Introduction

This report presents a description of the activities of the Louisiana Water Resources Research Institute for the period of March 1, 2002 to February 28, 2003 under the direction of Drs. Joseph N. Suhayda and 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. 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.

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 2002 were changed to focus on a selected research theme. In the past (i.e., FY 2001) a broader solicitation was utilized emphasizing non-point source pollution and mitigation of those sources, hydrologic modeling and small watershed hydrology. These research areas were identified as being consistent with national and regional priorities, while addressing high priority issues for the State of Louisiana. Because of the small nature of the projects, however, it was apparent that a greater impact would be possible if a thematic area was 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 estuarine issues. In particular, hurricane flooding had become a major issue for state emergency managers and governmental planning agencies. Therefore, because of this emphasis and Dr. Suhaydas expertise in the area, research support was focused on this issue in FY 2002. Projects selected were from a range of faculty with different academic backgrounds including geographers, environmental engineers and water resources. Supporting research in this priority area has increased the visibility of the Institute within the State.

The research projects are designated as Projects LA-1B, LA-3B, LA-4B, and LA-5B, as listed below.

Project LA-1B Barbé, Flooding in a New Orleans Watershed caused by Hurricanes That Do Not Overtop the Levee System

Project LA-3B Colten, Response to Hurricane Induced Flooding in New Orleans

Project LA-4B Singh, Flood Risk Mapping of the New Orleans Area

Project LA-5B Willson, Groundwater Contaminant Transport Following Flooding Events: Impact of Model Size, Resolution, and Complexity

These projects include 4 new projects in the areas of storm surge and groundwater hydrologic modeling. One of the projects (LA-5B) has direct impact on non-point source pollution and mitigation problems associated with the TMDL regulatory issues and the hydrologic modeling efforts.

Flooding in a New Orleans Watershed Caused by Hurricanes That Do Not Overtop the Levee System

Basic Information

Title:	Flooding in a New Orleans Watershed Caused by Hurricanes That Do Not Overtop the Levee System
Project Number:	2002LA1B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	LA 2nd
Research Category:	None
Focus Category:	Floods, Surface Water, Water Quantity
Descriptors:	None
Principal Investigators:	Donald E Barbe, John Alex McCorquodale, Gianna M Cothren

Publication

A geographical information system was used for comparative residential damage analysis between simulations of a lower category slow moving hurricane and a faster high category hurricane. The method involved determining area of impact for the simulated excess storage volume for each event. Cumulative volumes at 1ft contour intervals were calculated to determine the elevation for which storage occurs. All areas at or below this elevation were then delineated for each event and residences lying within impacted areas were counted. Residences were classified according foundation type and elevation to estimate the residential damage costs.

Using ArcView 3.2, a project file for the drainage area of DPS #4 (Area G) was created. The drainage area was delineated using a streets layer and paper map from the Sewerage and Water Board of New Orleans. The USGS 7.5-minute, 1:24000 scale digital elevation model (DEM) files 3009064 (Spanish Fort) and 29090H1 (New Orleans East) were imported as new themes (Figure 1).

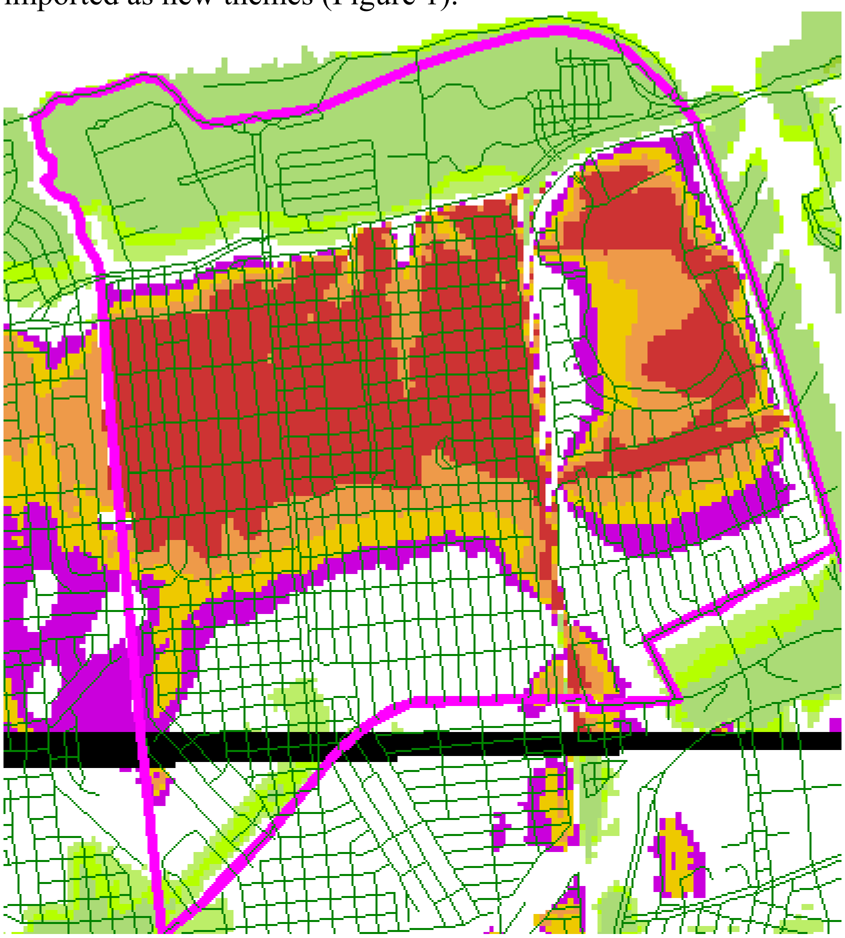

Figure 1: Drainage area for pumping station #4

These DEM elevations are based on 30 meter spacing with Universal Transverse Mercator (UTM) projection. Elevation units are in feet relative to the National Geodetic Vertical Datum 1983. Accuracy of the 15-minute is equal to or better than one-half of a contour interval of the 15-minute topographic quadrangle map. Within ArcView, areas at each elevation are tabulated and exported to an Excel spreadsheet for computing the cumulative volume in acre-ft (Table 1).

Table 1: Cumulative volume spreadsheet

	A	B	C	D	E	F	G	H	I	J
1	Elevations		Mgrid 2	Spanish Fort	(Mgrid2 + Spa.Fort)	(Mgrid2 + Spa.Fort)*ΔElev	Cumulative(Mgrid2 + Spa.Fort)Δ*Elev	Cumulative(Mgrid2 + Spa.Fort)Δ*Elev		
2	Elev (ft)	Elev (m)	G (m²)	G (m²)	(m²)	(m³)	(m³)	(acre*ft)		
3	-4	-1.2192	0	3357000	3357000	1291773.6	1291773.6	1047.253712		
4	-3	-0.9144	4500	1323000	1327500	510822	1802595.6	1461.38219	Hurricane Fran	
5	-2	-0.6096	6300	892800	899100	345973.68	2148569.28	1741.866496		
6	-1	-0.3048	10800	905400	916200	352553.76	2501123.04	2027.685337		
7	0	0	3E+05	2628000	2898000	1115150.4	3616273.44	2931.748863		
8	1	0.3048	88200	296100	384300	147878.64	3764152.08	3051.635548		
9	2	0.6096	82800	155700	238500	91774.8	3855926.88	3126.038292	Hurricane Danny	
10	3	0.9144	12600	439200	451800	173852.64	4029779.52	3266.982357		
11	4	1.2192	0	667800	667800	256969.44	4286748.96	3475.310039		
12	5	1.524	0	890100	890100	342510.48	4629259.44	3752.986693		
13	6	1.8288	0	82800	82800	31861.44	4661120.88	3778.81708		
14	7	2.1336	0	3600	3600	1385.28	4662506.16	3779.94014		
15	8	2.4384	0	0	0	0	4662506.16	3779.94014		
16	9	2.7432	0	0	0	0	4662506.16	3779.94014		
17	10	3.048	0	0	0	0	4662506.16	3779.94014		
18	11	3.3528	0	0	0	0	4662506.16	3779.94014		
19	12	3.6576	0	0	0	0	4662506.16	3779.94014		
20					2994.101776	4662506.16				

A cumulative volume of 1461 acre-ft is the next volume greater than the simulated 1180 acre-ft of excess storage for the hurricane Fran simulation. At this volume all areas at or below an elevation of -3 ft are impacted. At a cumulative volume of 3126 acre-ft, just above the simulated 3118 acre-ft for hurricane Danny, all areas at or below +2 ft are impacted. The corresponding impacted areas were digitized and added as new themes (Figures 2-3).

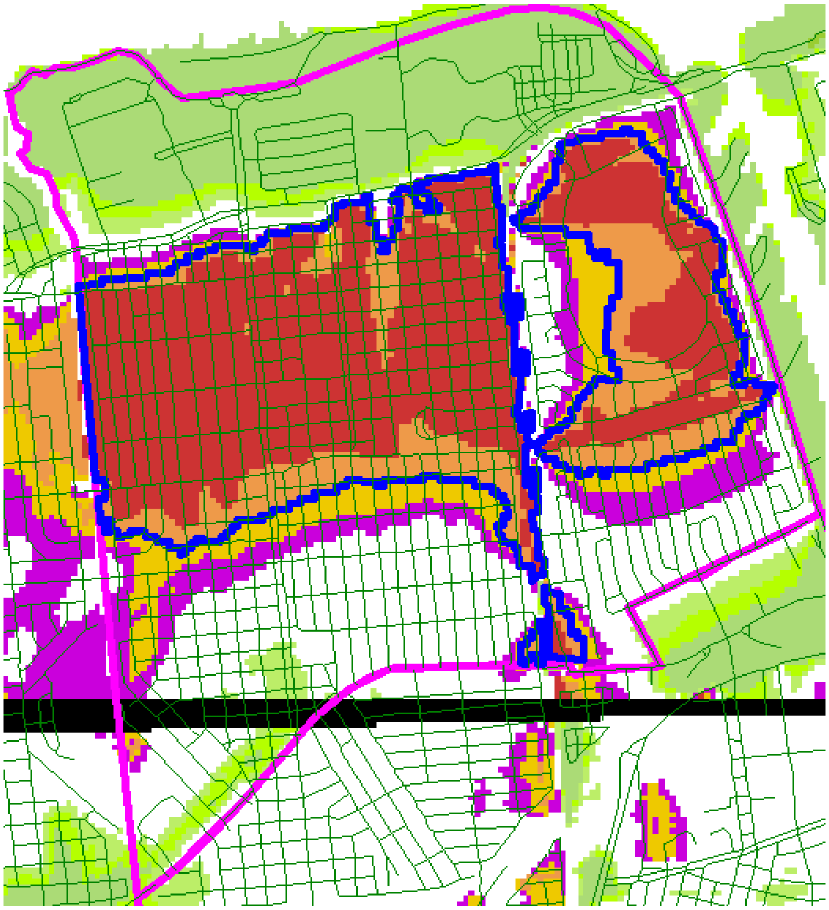

Figure 2: Area impacted by Hurricane Fran simulation

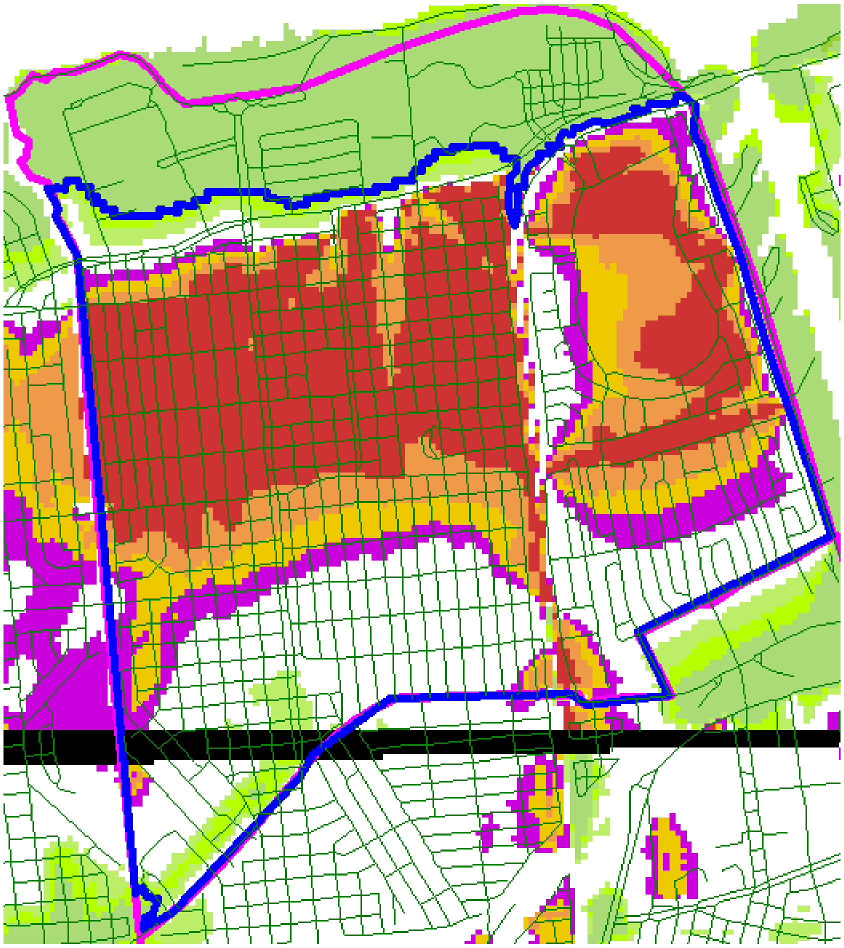

Figure 3: Area impacted by Hurricane Danny simulation

These were then overlain onto the digital color infrared orthophoto for the Spanish Fort quadrangle in Louisiana for counting the residences. There were 4518 houses affected by the hurricane Fran simulation and 8687 affected for the hurricane Danny simulation.

References

U.S. Geological Survey, 7.5-minute Digital Elevation Model

Louisiana Oil Spill Coordinator's Office (LOSCO), 19990309, Color Infrared Orthophoto, SW quadrant of Spanish Fort Quadrangle, LA, 50:1 MrSID compressed, LOSCO (1999) [c3009064_sws_50]

Response to Hurricane Induced Flooding in New Orleans

Basic Information

Title:	Response to Hurricane Induced Flooding in New Orleans
Project Number:	2002LA3B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	LA - 6th
Research Category:	None
Focus Category:	Floods, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	Craig Colten

Publication

Hurricane Betsy and Its Effects on the Architectural Integrity of the Bywater Neighborhood: Summary

Craig E. Colten
and
John Welch
May 2003

INTRODUCTION

Very few places face the risk of experiencing the chaos and damage of a hurricane as much as New Orleans. In addition to the risk of physical damage and loss of life, New Orleans faces cultural risks of an extreme nature. New Orleans is a city with a unique architectural legacy that it has utilized as a significant factor in its thriving tourist industry. Many academic works have been penned documenting the existence, age, and unique character of New Orleans' architectural heritage. From the Uptown district along St. Charles Avenue, downriver through the French Quarter, and further downriver into the Bywater and Holy Cross neighborhoods, architecture, and the framework that it creates, defines the New Orleans landscape. From grand mansions along St. Charles Avenue, to the shotgun structures which dominate the Bywater neighborhood (64 percent of architectural stock), the range of architectural styles, and their sheer numbers, is astounding. Additionally, the geographic range of these structures within the city creates a zone, roughly following the river, which encourages tourists to experience structures designed for the wealthiest Louisianans, bourgeois housing contructed for shopkeepers and other middle class residents of the city, to the simple though highly articulated homes of dockworkers and laborers, which cover the Bywater neighborhood.

Despite this widespread appreciation of the city's unique architectural assets and efforts by preservationists, the historic fabric of the city is at risk. One of the most pervasive issues in New Orleans is how the city will respond to a major hurricane, a category four or five storm, following the path east of the city that is projected to cause the most damage. A storm of this type would inundate much of the city and could potentially ruin many historic structures and thereby undermine a central tourist attraction.

How would the city's unique architectural heritage fare following a devastating flood? We sought an analogous situation by which to assess how private property owners responded to hurricane induced flooding in the past. This situation existed within the city limits, downriver from the French Quarter in the Bywater neighborhood. Hurricane Betsy struck the New Orleans area in 1965 and provided the parallel situation which we sought. The storm surge created by the hurricane overtopped the protective levees within the Inner Harbor Navigational Canal (IHNC) and flooded the neighborhoods on either side of the canal. On the western side of the IHNC, floodwaters entered "6,350 homes and 396 businesses [with] water as high as 7.0 feet above first floor level" (USACE 1965, 27). Even though the Bywater is mostly located on higher ground closer to the river, sections of the neighborhood flooded to a depth of roughly five feet, which inundated structures, outbuildings, and automobiles in those areas.

The use of this study area is important when one considers the elevations within the French Quarter and upriver portions of the city. The five-foot elevation contour runs through the center of the Bywater neighborhood, continuing upriver through the French Quarter between Dauphine and Burgundy, and upriver from that point crisscrossing back and forth across St. Charles Avenue. From that perspective, the importance of this study area resonates with relevance and physical similarity to other significant architectural assets and tourism attractions of the city.

The research question relates to most other historic structures and areas within New Orleans – did the historic building fabric of the Bywater remain intact after damage by hurricane induced flooding? Would a similar event sufficiently damage historic architecture to the extent that tourism would be affected? This project will seek to answer those questions by examining a specific area flooded in 1965, classifying those structures based on their existing "integrity," or alternatively, their negative alteration or destruction. This examination will offer insight into the potential recovery and maintenance of integrity following a significant flooding event.

In an area where tourism has become one of the main economic generators, any disruption of that tourism has immediate and devastating effects on the economy and people. Impacts to the French Quarter and Uptown neighborhoods could have far-reaching consequences. As part of the City of New Orleans stock of architecturally significant buildings, the Bywater neighborhood is part New Orleans' economic base. As an area that has experienced significant flooding in the past, it becomes important to study this area and its recovery.

HURRICANE BETSY

Since 1559, 172 hurricanes have affected coastal Louisiana and of these, thirty-eight have reached New Orleans via Lake Pontchartrain (Shallat 2000, 122). Storm surges delivered by hurricane-force winds across Lake Pontchartrain pose the greatest risks. A storm that struck the state of Louisiana and the City of New Orleans in 1965 proved to be the "most destructive hurricane on record to strike the Louisiana coast" (USACE 1965, foreword).

A classic Cape Verde storm, Betsy formed in the tropical Atlantic and wandered across the Atlantic Ocean and the Gulf of Mexico over a period of fourteen days. On September 9, 1965, Betsy was in the southern Gulf of Mexico and gaining northerly momentum as it approached Louisiana's coast. In addition to gaining forward speed, the storm was intensifying as it moved toward land. Mid-afternoon on September ninth, “Navy reconnaissance aircraft indicated the storm was intensifying and had a central pressure of 28.00 inches” (USACE 1965, 4). Weather forecasters estimated the peak winds at 150 m.p.h. Winds in New Orleans “exceeded 100 m.p.h.” shortly after 10 p.m. (USACE 1965, 4).

“Vast areas of Orleans, Plaquemines, and St. Bernard Parishes were inundated by the tidal surge that accompanied the storm. This surge either overtopped or breached the non-Federal levee protecting these areas” (USACE 1965, 8). Rainfall varied from 3 inches to nearly 6 inches, but very little of the serious flooding accompanying the storm could be attributed to rainfall (USACE 1965, 20). New Orleans’ weather office measured 5.10 inches of rainfall.

The storm’s record tidal surge produced by the rapid forward movement of the storm (17-22 m.p.h.), combined with the intensity of the storm caused the most damage. “The fast rising waters exceeded previously established high water records on the Mississippi River from Pointe-a-la-Hache to the mouth of the river” (USACE 1965, 20). The U.S. Army Corps of Engineers inventory of flooding in the Ninth Ward reports that: (See Figure 1)

> Flooding in the New Orleans area west of the Inner Harbor Navigation Canal and south of Gentilly Boulevard resulted from a tidal surge which overtopped the Inner Harbor Navigation Canal west levee, in the vicinity of the intersection of the canal and the Mississippi River-Gulf Outlet. Subsequent levee breaks and/or overtopping southward along the canal caused additional flooding in this portion of New Orleans. After the low-lying areas adjacent to the canal were flooded, this water backed up into the area west of the Inner Harbor Navigation Canal and north of Gentilly Boulevard by way of drainage canals and subsurface drains. In the area west of the Inner Harbor Navigation Canal and south of Gentilly Boulevard, 6,350 homes and 396 businesses had water as high as 7.0 feet above first floor level. Losses in this vicinity were especially severe to homes, businesses, and automobiles. (USACE 1965, 27)

The damage and inundation throughout the state covered “4,800 square miles, killed 81 persons, caused about 250,000 persons to be evacuated, and disrupted transportation, communication, and utilities service throughout the eastern coastal area of Louisiana for weeks" (USACE 1965, foreword).

ANALYSIS

Parts of the Bywater neighborhood flooded during Hurricane Betsy. The Corps of Engineers mapped the area inundated by the storm surge in the Bywater neighborhood. The data derived from a review of structures, (Table 1) show that 37 years after a severe flood event, the neighborhood still maintains a high degree of architectural integrity. Over 76 percent of properties which experienced some degree of inundation still retain architectural integrity. The areas that were not flooded maintain 83 percent architectural integrity. The degree of intrusive properties, (those that do not contribute to integrity), is 24 and 17 percent respectively. This percentage of intrusion is well within the acceptable range for historic districts based on national averages (Louisiana Department of Historic Preservation 1985, 8:10).

A significant percentage of the Bywater neighborhood structures maintain integrity. Hurricane Betsy predates the advent of the National Flood Insurance Program, the placement of the neighborhood on the National Register, and the establishment of the HDLC as an oversight body for the neighborhood. Without significant resources with which to renovate and rehabilitate, and without rigorous building codes for reconstruction efforts, the neighborhood still maintains its architectural significance as a unique and contributing inventory of historic structures in New Orleans, the South, and the country.

Why does this neighborhood still retain its architectural integrity in spite of little attention from federal agencies and historic preservation organizations? The degree of flooding was not as great in the Bywater as in the lower Ninth Ward. Also, the conversion during the 1960s and 1970s of many properties to rental units, with absentee landlords, might have prevented extensive renovation from occurring following the storm. Absentee landlords often perform minimal repairs, in order to make a structure habitable, but no more.

What this research suggests is that historically significant areas of the city, the Bywater, the French Quarter, and the upriver neighborhoods of the Garden District and Uptown, would probably continue to retain their architectural integrity following a major hurricane event, with its accompanying storm surge.

CONCLUSION AND DISCUSSION

Despite serious hurricane-induced flooding, important architectural fabric within the Bywater neighborhood still retains its historical integrity. Original, mostly nineteenth-century designs have persisted through past hurricane flooding and damage. Even in a low-income area, with large absentee landlord ownership, original fabric is largely intact. This degree of integrity has now become a focus for renovation and rehabilitation, with an upsurge in property values and population density increasing.

In terms of risk from hurricane-induced flooding to historic architecture in New Orleans, this study suggests that historic structure restoration and maintenance would persist if damage were not too extreme. If the city responded in a fashion similar to Charleston after Hurricane Hugo, negative affects on tourism would be minimized and the economy would recover within an acceptable time frame.

At a time when there would have been a tendency to remove housing stock and replace it with new, non-flooded dwellings, the neighborhood was going through a period of economic decline. Instead of replacing damaged buildings, owners instead repaired what remained, sold out at reduced rates to investors who then converted the property to rental units, which were then rented to less-affluent tenants. Absentee landlords took advantage of the situation by buying properties from those who found themselves living in damaged homes with inadequate insurance. This social factor caused huge out migration within the neighborhood and then in migration of those less fortunate individuals who could not afford adequate housing in other areas. Daniel McElmurray, current president (2002-2003) of the Bywater Neighborhood Association (BNA), states that this trend did not begin to reverse itself until the late 1980s. The reversal accelerated after the successful nomination of the neighborhood to National Register status.

Hurricane Betsy occurred before the advent of the National Flood Insurance Program. Instead of having insurance money and federal dollars flowing into a historic neighborhood, the Bywater made do with what was left, thereby preserving the integrity of the district through neglect and acceptance of less than desirable circumstances.

In studying historic districts, this phenomenon is not unique. Two very relevant examples exist in Charleston and New Orleans. In Charleston, the city entered a period of decline following the Civil War and that decline was not reversed until midway through the twentieth century. In 1933, preservations formed the Historic Charleston Foundation and began saving properties that had been neglected for over 70 years. These properties maintained significant architectural integrity because many in Charleston, during the lean years, stated the typical Southern upper-class credo: "Too poor to paint, too proud to whitewash." So with a lack of resources, those who had been members of the property owning class simply maintained what they had, thereby preserving architectural integrity for future generations.

In New Orleans, the French Quarter had become a ghetto and an abandoned area. Preservationists realized the potential loss that was occurring and formed the Vieux Carré Commission in 1935, to rescue some of the oldest and most unique architecture in the city. The result is one of the most widely recognized and successful historic districts in the country.

During a period of great affluence and modernization, the 1920s, these two areas in Charleston and New Orleans were basically untouched by progress and left to be rescued by future generations. I contend that this same sort of cultural phenomenon occurred in the Bywater: that by attrition, neglect, and abandonment, the architectural stock of the neighborhood was left alone, mothballed so to speak, until the current gentrification of the neighborhood began to occur in the mid 1980s.

This research did not demonstrate a distinct difference between the flooded and non-flooded areas. I contend that what this shows is the absolute importance of examining the cultural influences, the human agency -- whether negative or positive -- to determine why things occur. Only by looking at historical events in context can we begin to understand why results are not what we expect. Additionally, this research also underscores the importance of particularity in looking at a hazard event. If this event had occurred in an affluent, well-insured area, the results might have been completely different and modern ranch houses might have replaced damaged structures.

Just as Charleston founded the Charleston Heritage Foundation, civic leaders and preservation organizations within New Orleans should consider forming a general oversight organization which would oversee protection of architectural properties following a natural disaster. A foundation, acting as a conduit between federal disaster relief and all of the preservation organizations, would prevent confusion and duplication of services at a time when there would be few resources available, thereby protecting as many structures as possible.

The kind of structure created in Charleston to deal with the damage from Hurricane Hugo must be duplicated in New Orleans in the event of a major flooding event. The same issues that historic preservationists dealt with in Charleston would exist in New Orleans. The involvement of the various agencies dealing with disaster relief need to be coordinated through local agencies familiar with the vernacular building materials and forms in order to preserve the integrity of the historic architecture of the city. Federal aid is a critical component of disaster recovery in today's economy and world. The coordination of that aid through local agencies would ensure that property owners had a central point of contact by which they could file claims, receive permits for restoration and return the city to normal as soon as possible.

Flood Risk Mapping of the New Orleans Area

Basic Information

Title:	Flood Risk Mapping of the New Orleans Area
Project Number:	2002LA4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	LA - 6th
Research Category:	None
Focus Category:	Floods, Hydrology, Surface Water
Descriptors:	None
Principal Investigators:	Vijay P Singh, Donald Dean Adrian

Publication

1. Lan, Z. and Singh, V. P., Bivariate flood frequency analysis using the copula method. ASCE Journal of Hydrologic Engineering, under review, 2003.
2. Singh, V.P., Wang, S.X. and Lan, Z., Frequency analysis of non-identically distributed flood data. Journal of Hydrology, under review, 2003.

Flood Risk Mapping of the New Orleans Area

Abstract: The conventional methods of incorporating risk in floodplain delineation, and design of drainage systems and surface impoundments are the safety factor and return period. These methods are, however, inadequate and do not directly consider the damage distribution. This project argues for incorporation of a more comprehensive definition of risk based on three aspects: (1) scenario or cause identification, (2) probability of that scenario, and (3) the consequence of that scenario. Using this risk definition, a risk methodology is proposed for determining flood risk and then constructing a flood risk map. This methodology is illustrated by applying to the New Orleans area, one of the most flood prone areas in the United States, and can be easily extended to other areas of the country. The risk map can be employed as a tool for making real-life decisions.

1. Introduction

The Gulf Coast region (GCR) is perhaps one of the most flood prone areas in the United States. This is even more true in Louisiana where flooding is a regular annual occurrence in one part or the other. For example, the 1995 related floods of southeast Louisiana and Mississippi claimed seven lives and resulted in property damage estimated at over 3 billion dollars. Landfalling hurricanes occur frequently during the hurricane season and cause extensive flooding and property damage. In 1992 hurricane Andrew made a landfall in Florida and Louisiana resulting in 58 deaths and caused over 30 billion dollars of property damage. These damages were attributed in part to the heavy rainfall which caused extensive flooding. The flooding patterns are greatly influenced by climatic factors. Climatic anomalies such as El Nino also affect the spatial distribution of the amount and intensity of rainfall and its intensity.

Louisiana has as much if not more risk from hurricanes and other types of flooding than any other state. Over the past century, south central Louisiana has experienced what appears to be the highest number (6) of landfalls of major hurricanes (Category 3-5 storms). Louisiana and Texas typically rank number one and two in annual flood insurance claims. New Orleans is the most vulnerable major city on the Gulf Coast and perhaps in the entire United States. Had Hurricane Georges not taken a last minute turn to the east in 1998, major portions of New Orleans would have flooded. It would likely have been one of the worst disasters of the century in terms of loss of life and damage. Additionally, Louisiana has extensive infrastructure of oil and gas facilities, chemical plants, and hazardous, industrial and residential landfills. Most of these facilities are in flood prone areas and within the confines of levee systems protecting housing and other structures from flooding. Even in areas where mitigation strategies have been engineered (i.e., levee, drainage, and pumping systems), such designs are unable to capture and control all storm water runoff from occasional extreme rain events.

Louisiana's outer buffer or defense to hurricane winds and storm surges are its coastal wetlands and barrier islands. Since 1930 approximately 1 million acres of buffer have been lost. Even with the present coastal restoration activities (i.e., Coastal Wetlands Planning, Protection and Restoration Act), future wetland loss will range from 28,000-32,000 acres a year. The corridor from Morgan City through Houma to New Orleans loses about 20,000 acres of buffer annually. Thus, potential impacts are far more severe now than in the past and the picture worsens every day. A major flood in Louisiana would have greater impacts compared to a similar sized flood in North Carolina, posing more severe health risks.

The New Orleans area possesses an unusual topography in that some of the area is below the mean sea level and some barely above it. It is close to the Gulf of Mexico and is subject to intense hurricane activity almost on an annual basis. It has the distinction of having the Lake Ponchartrain and the Mississippi River flows through the city of New Orleans. It has an annual rainfall of more than 1700 mm. Flooding in the New Orleans area is caused either by high rainfall, hurricanes, storm surge, high tides or a combination thereof.

Flooding of the New Orleans metropolitan area is of highest priority for the state of Louisiana. Recent studies and evaluations indicate that the city is at risk during an extreme flood event. What is that risk? What will be the consequences if an extreme flood event occurred? What can be done to minimize the risk? These questions require serious thought. A careful consideration would show that to answer these and other related questions would involve a risk analysis and assessment. This is especially true of the design of urban drainage facilities as well as other civil works. Therefore, it is reasoned that drainage works, flood control projects, and other civil works must be designed, based on risk analysis. This issue is addressed in the proposed study.

2. Current Practice of Incorporating Risk

Flood plain mapping, land use zoning, design of drainage facilities, design of surface impoundments, and water diversion systems are based on an appropriate (or acceptable) level of risk. There are two conventional criteria to account for the acceptable risk. The first is the safety factor criterion. However, this risk criterion is unacceptable for two main reasons. First, the cost of increasing the safety factor is too high in most cases. Second, even with increased safety factor, there will usually be some risk, for risk cannot be eliminated entirely.

The second criterion which is more popular in water resources planning, design and management is the selection of an appropriate return period. This concept is simple but has serious drawbacks. First, in practice neither the form of the most appropriate stochastic model of flood frequencies nor the values of the parameters of the model are known and therefore assumptions and estimates must be made. As a result, because of statistical and epistemological uncertainties, the best estimate of the flood of a given probability (p) and return period (T) will probably be exceeded in the future more frequently than once in T years. In other words, if risk is defined as the probability that the design flood will be exceeded in any one year, then the expected risk of having a flood event greater than its estimated magnitude in future is greater than the exceedance probability p. Thus, what is needed is not the best estimate of the magnitude of the flood of probability p but instead the flood with the expected risk of occurrence (Stedinger, 1991). It is, therefore, necessary to estimate the flood with an expected risk (Beard, 1960; Hardison and Jennings, 1972). This flood magnitude will be higher than the conventional best unbiased estimate of the p-probability flood, and the difference will depend on the uncertainties in parameter estimation. The difference between the two magnitudes can be seen as an adjustment factor.

The other difficulty with the return period criterion, which is more serious, is that it provides no information on damage resulting from the T-year flood. Damage is one of the most important considerations in the risk evaluation and analysis (Borgman, 1963). This difficulty is because of the very narrow interpretation of the concept of risk implied in the return period criterion.

3. Related Research

There is vast literature on flood frequency analysis (Rao and Ahmad, 2000). By comparison, flood risk has received limited attention. Kaplan and Garrick (1981) provided perhaps the best quantitative definition of risk. However, this definition has been employed only in a few hydrologic studies and to our knowledge it has never been applied to flood risk in the New Orleans area. Borgman (1963) was one of the first to consider risk criteria for wave heights in coastal areas. His analysis, however, did not consider flood risk in a comprehensive manner. Murota and Etoh (1984) applied the equi-risk line theory to the design of a detention reservoir. Arnell (1988) obtained unbiased estimation of flood risk with the generalized extreme value distribution. His methodology was based on the return period criterion and did not consider the damage issue. Young and Walker (1990) developed a risk-cost design of pavement drainage systems. Like other studies, they did not consider risk as a set of triplets. Haimes et al. (1992) developed a partitioned multiobjective risk method for analyzing extreme events. Their study is probably the most comprehensive of above-cited risk studies. But it may not be entirely appropriate for the New Orleans area, because it arbitrarily divides the extreme events into three categories which may not be appropriate. Thus, there is a gap in our knowledge of flood risk, especially in the New Orleans area. The objective of this project was to fill this gap.

4. Objectives

This research project employed a more versatile definition of risk and the resulting methodology which remedies the aforementioned drawbacks and omissions. Thus, the overall goal of this proposal was to develop a flood risk methodology and a flood risk map of the New Orleans area. To that end, the specific objectives were: (1) to develop a flood damage model, (2) to develop a flood frequency model, (3) to develop a flood risk model, and (4) to develop the flood risk map.

5. Risk Methodology

Before presenting the risk methodology, it is deemed important to clarify the definitions and develop the context. The term risk is used in many different senses and defined differently. Intuitively, the notion of risk involves both uncertainty and some kind of loss or damage. Risk is the possibility of loss or injury and the degree of probability of such loss. The loss or injury stems from a source of danger; this source is called hazard. Thus, risk includes the likelihood of conversion of that source into actual delivery of loss, injury or some form of damage. This points to the concept of reducing risk by employing safeguards. In other words, risk also involves hazards and safeguards. It may be noted that risk can be reduced but as a matter of principle it cannot be completely eliminated.

Thus, risk has three elements: (1) cause, scenario, or source (s), probability of that scenario or source (p), and (3) consequence of that scenario or source. Now, following Kaplan and Garrick (1981) risk (R), as used in the proposed research, is defined as a set of triplets:

$$R=\{(s_i, p_i, x_i)\}, \qquad i=1,2,3,............,N \tag{1}$$

where s_i is the i-th source or scenario, p_i is the probability of s_i, and x_i is the i-th consequence. In our case, for example, s_1 may be flooding due to extreme rainfall, s_2 may be flooding due to storm surge, and so on. Likewise, the consequences of flooding may be denoted as: x_1 is the damage to dwellings, x_2 is the damage to roads, x_3 is the damage to water supply, and so on.

Keeping the above considerations in mind, the proposed risk methodology entails the following elements as illustrated in Fig. 1.

(1) Flood Model: There is a large number of flood models available in the hydrologic literature (Cunnane, 1973; Singh, 1998). We tested the log-Pearson type III and the generalized extreme value and select the best, depending on the nature of the hydrologic series. Both univariate and bivariate models were developed. The bivariate models were developed using the copula method.
A brief discussion of the flood models is in order.

Univariate flood frequency analysis: Empirical methods of flood frequency analysis (FFA) were used for analysis of a single flood variable, such as flood peak, flood volume or flood duration, as a function of return period, T. If there are n-year daily flow data available, then an n-year annual flood series can be constructed by extracting the maximum daily value for each year. Assuming that annual floods are independent and identically distributed, the probability distribution function can be derived by conventional frequency analysis. Here, F(Q) is the cumulative frequency (probability) distribution (CDF), $P(Q \leq q)$ is the probability of Q being less than or equal to a given value q. In frequency analysis, T-year event, q_T, is interested, where T is the average time interval (or return period) between two exceedances of q_T ($Q \geq q_T$) and is given by $T=1/(1-F)$. Univariate flood frequency analysis is the first step in the whole study in order to perform the multivariate analysis according to stationary and nonstationary assumptions.

Multivariate flood frequency analysis using copulas: Several multivariate (bivariate) flood frequency analysis methods have been developed by many researchers. However, these models have the following drawbacks:
(1) Each bivariate model must have the same marginal distributions. This requirement is too restrictive, since in practice, the two hydrologic variables may not have the same distribution type.
(2) The measure of association or correlation is sensitive to the marginal distributions for the correlation structure of these bivariate distributions is constructed directly or indirectly from Pearson's product moment correlation coefficient.

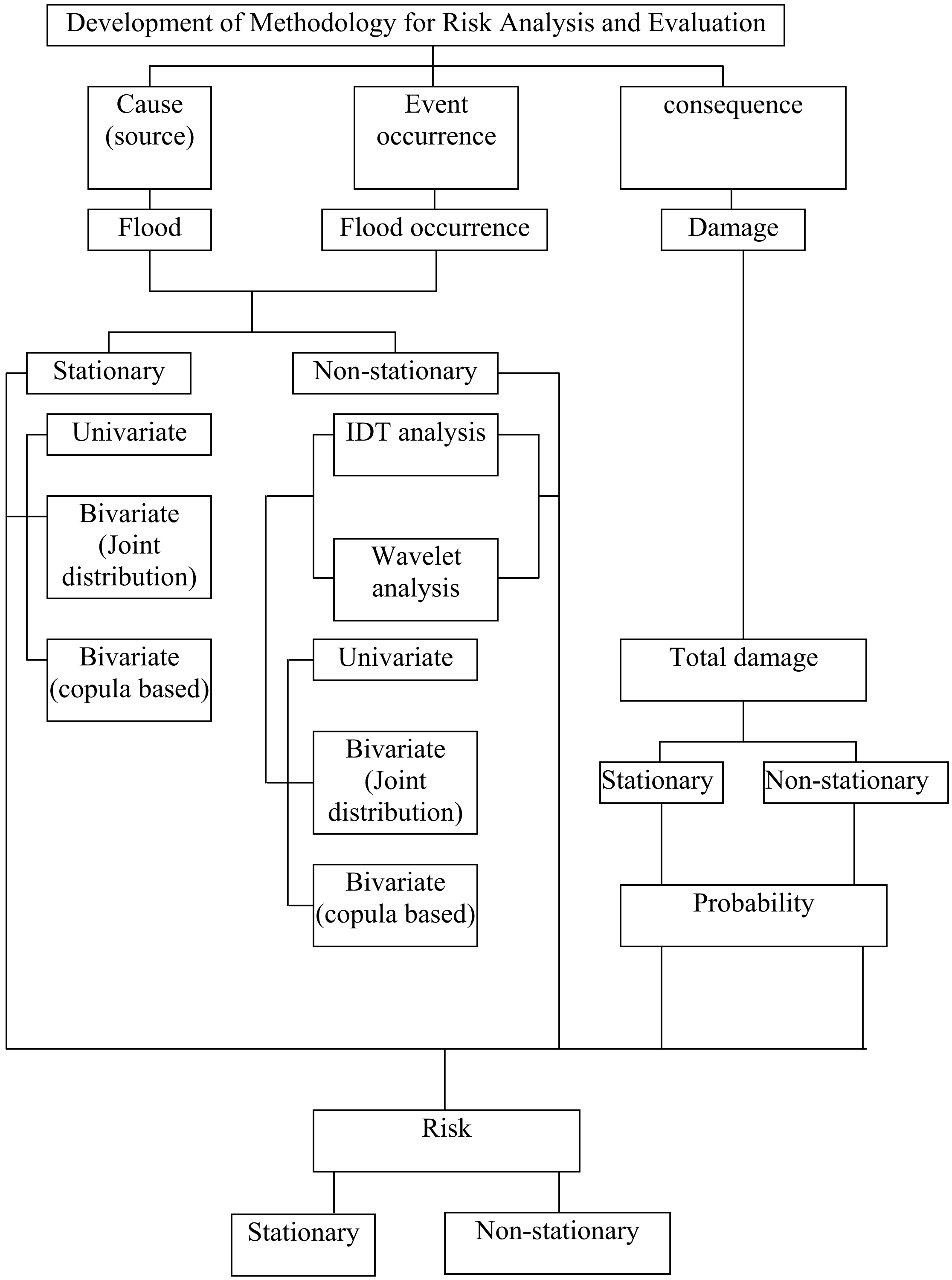

Figure 1. Outline of Risk Methodology.

(3) Except for the bivariate normal distribution, other bivariate distributions can hardly be extended to more than two dimensions as their correlation structure among variables is not known.

In order to overcome those drawbacks, the copula method was introduced and applied for the multivariate (bivariate) flood frequency analysis. The theory of copulas has not yet been applied to represent joint statistical properties of hydrologic events. Although a number of copulas have been proposed in the statistical literature, it is not clear which may be directly applicable for modeling multivariate hydrologic events.

Determination of copulas: The following was pursued in this study:

(1) Investigation of the existing copulas for modeling bivariate events with the same marginal distributions, such as bivariate normal, lognormal, exponential and Pearson (gamma) and Log-Pearson III distributions. Since these bivariate distributions have been applied to model two correlated hydrologic variables, it was instructive to compare the copula models with conventional models. Such a comparison sheds light on the advantages and shortcomings of the copula models in comparison with conventional models.

(2) Investigation of the existing copulas for modeling bivariate events with a mixture of marginal distributions. More frequently, two correlated hydrologic variables may have different distribution types. It is important to model a joint event with a mixture of marginals than to model it with the same marginals. Therefore, the suitability of the existing copulas for modeling bivariate events with a mixture of marginals was examined.

(3) Investigation of the existing multi-dimensional copulas for modeling multivariate (more than two dimensions) events with a mixture of marginal distributions. In hydrologic practice, more than two correlated hydrologic variables may be correlated and have different distribution types. In such cases, it is necessary to model a joint multivariate event with a mixture of marginals using a multivariate distribution model. The suitability of the existing multidimensional copulas for modeling multivariate events with a mixture of marginals was examined.

(4) Development of new copulas. The copulas reported in the literature may not be suitable for modeling correlated hydrologic variables. When necessary, new copulas were developed.

Identification of parameters based on multi-dimensional copulas: In practice, when a number of random variables are of interest, given their observed sample data, such as flood peak, flood volume, and flood duration, the following questions must be answered. (1) What distribution do they follow? What is an appropriate copula for constructing the dependence structure between these variables? The two-step way of constructing multivariate models via multi-dimensional copulas permits to identify univariate marginals and a copula function separately. That is, parameters of marginal distributions and the parameters of copula function can be estimated independently.

Identification of marginal distributions: Appropriate marginal distributions were determined first, based on univariate data. Both the conventional stationary and nonstationary statistical approaches were used for deriving the distribution of a single variable.

Identification of an appropriate copula: The basic idea for identifying a copula should be identical to the selection of a goodness-fit of the distribution type for univariate frequency analysis, i.e., determine a theoretical model that fits the observed data best. The procedure is based on nonparametric estimates of $K(u) = P(U_i \le u_i)$, the distribution function of pseudo-observations U=H(x_1,x_2,…,x_N). By comparing the parametric estimates from copulas K(z), the best-fit copula to the observations can be selected. The general equation for the two-dimensional copula is generated by:

$$1+(1-\theta)\frac{1-H(x,y)}{H(x,y)} = \left[1+(1-\theta)\frac{1-F(x)}{F(x)}\right]\left[1+(1-\theta)\frac{1-G(y)}{G(y)}\right] \qquad (2)$$

$$\mathrm{C(u,v)} = \frac{[1-(\theta-1)(\mathrm{u}+\mathrm{v})] \pm \sqrt{[1+(\theta-1)(\mathrm{u}+\mathrm{v})]^2 - 4\mathrm{uv}\theta(\theta-1)}}{2(\theta-1)} \qquad (3)$$

or

$$C(u,v) = \varphi^{-1}(\varphi(u)+\varphi(v)) \qquad (4)$$

The parametric $K_\phi(z)$ with an Archimedean copula is:

$$K_\phi(u) = \Pr[C(U_1,U_2,...,U_N)] = u + \sum_{n=1}^{N}(-1)^n \frac{\varphi^n(u)}{n!}M_{n-1}(u) \qquad (5)$$

with

$$M_n(u) = \frac{\partial_u M_{n-1}(u)}{\partial_u \varphi(u)}, M_0(u) = \frac{1}{\partial_u \varphi(u)} \qquad (6)$$

In the bivariate case, this formula simplifies to

$$K_\phi(u) = u - \frac{\varphi(u)}{\varphi'(u)} \qquad (7)$$

Multivariate stationary flood frequency analysis: There is a large number of flood models in hydrologic literature, (Singh,1998; Rao and Hamed, 2000) for stationary flood frequency analysis. The best fitted statistical model were selected and the proper parameter estimation method were used to determine model parameters. The following joint statistics obtained from the copulas important for a multivariate (bivariate) flood model, can be derived:

(1) The joint distribution of an event with X≤x, and Y≤y;

H(x,y)=Pr(X≤x, Y≤y) and with the probability density function h(x,y), the joint return period of an event with X>x, Y>y or both X>x and Y>y

T(x,y)=1/[1-H(x,y)],
and the joint return period of an event with both X>x and Y>y:
T'(x,y)=1/[1-F(x)-G(y)+H(x,y)].

(2) Conditional distribution of X given Y=y, $F(x \mid Y = y) = \int_{-\infty}^{\infty} \frac{h(x, y)}{f(y)} dy$ and return period T(x|Y=y)=1/[1-F(x|Y=y)].

(3) Conditional distribution of X given Y≤y, F(x|Y≤y)=H(x,y)/F(Y≤y), and the corresponding return period T(x|Y≤y)=1/[1-F(x|Y≤y)].

From joint return periods, one can obtain, for given a return period, various combinations of flood peak and volume and vice versa. Or for a given flood peak and volume, the joint return period can be derived. The scenarios corresponding to different combinations of peaks and volumes are useful for planning, management and design. For example, for a spillway and flood control reservoir, a design flood hydrograph (DFH) is needed. The various pairs of flood peak and volume values associated with a given return period provide a more complete picture of a flood event, and more possible choices on which DFH should be selected. This information permits a better selection of the most crucial scenario according to a specific water resources planning, management, or design problem, which cannot be achieved by single-variable frequency analysis.

(2) Parameter Estimation Model: The most popular parameter estimation methods are the method of moments, maximum likelihood estimation, linear moments, probability weighted moments, and entropy (Singh, 1998). No one method is the best method for every flood model. Thus, depending on the choice of the flood model, the best parameter estimation method selected were the methods of moments and maximum likelihood estimation

(3) Flood Damage Model: This is the trickiest part in the risk methodology and the least investigated in hydrologic literature. From a theoretical point of view, the stochastic flood damage model consists of two parts: (1) the no-damage part and (2) the distribution of damage due to floods exceeding the threshold no-damage flood. Two submodels are needed. The first submodel is for the distribution of damage due to a flood event exceeding a threshold value. The second submodel is for the distribution of the total damage which embeds the first submodel. These two distributions have been derived from the empirical data collected for the New Orleans area. At this stage it seems that the two-parameter gamma distribution is a good candidate for a damage model. The literature, however, provides little guidance in this regard. The model is under testing.

(4) Risk Model: Based on the calculations done using the above models, the value of risk, R, as defined above is computed. Then, for each damage level, the cumulative probability is computed. To that end, the scenarios are first arranged in order of increasing order of severity of flood damage. Then, the cumulative probability, adding from bottom, is obtained for each damage. Then, the risk curve against each damage and flood exceedance is plotted. This part is still under investigation.

Kaplan & Garrick (1980) developed the triplet concept to analyze risk. They stated that risk involves both uncertainty and some kind of loss or damage, which can be written as: Risk=uncertainty+damage. Risk is the possibility of loss or injury and the degree of probability of such loss, which includes the likelihood of conversion of that source into actual delivery of loss, injury, or some form of damage. It is obvious that risk can be reduced but cannot be completely eliminated.

Fundamentally, in the triplet concept, there are 3 elements: (1) s_i: scenario (source) identification (2) p_i: the probability of that scenario; (3) x_i: is the consequence or evaluation measure of that scenario (source). Then, risk can be denoted as a set of triplets: $R=\{s_i, p_i, x_i\}$. The risk can be obtained from the outline of the following table:

Table 1. Scenario list with cumulative probability.

scenario	likelihood	consequence	cumulative probability
S_1	p_1	x_1	$P_1=P_2+p_1$
S_2	p_2	x_2	$P_2=P_3+p_2$
.	.	.	.
.	.	.	.
.	.	.	.
s_i	p_i	x_i	$P_i=P_{i+1}+p_i$
.	.	.	.
.	.	.	.
.	.	.	.
s_{N-1}	p_{N-1}	x_{N-1}	$P_{N-1}=P_N+p_{N-1}$
s_N	p_N	x_N	$P_N=p_N$

In Table 1, scenarios have been arranged in increasing order. By adding a fourth column in which we write the cumulative probability, and adding from the bottom, the risk curve can be obtained from the triplets.

(5) Risk Map: For each streamflow gaging station and each raingage station in the New Orleans area, the risk curve is under construction. Then, iso-risk lines will be plotted on the area map. This will be the risk map of the area.

6. Results: This research has led to the development of a systematic methodology for estimating flood risk, which can be used for flood plain delineation, design of drainage facilities, evaluation of the existing drainage facilities, land use zoning, design of detention ponds, and the like. Second, it will provide a flood risk map, with an application to the New Orleans area. The methodology can, with little effort, be extended to other areas. Thus, the results obtained in the research will be of great practical value to planners, designers, and decision makers.

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Groundwater Contaminant Transport Following Flooding Events: Impacts of Model Size, Resolution, and Complexity

Basic Information

Title:	Groundwater Contaminant Transport Following Flooding Events: Impacts of Model Size, Resolution, and Complexity
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Principal Investigators:	Clinton S. Willson

Publication

SYNOPSIS

Problem and Research Objectives

In spite of numerous safeguards and precautions, there exists a potential for accidental release of contaminants during and following flood events. Sources for contamination include ruptured or damaged pipelines, storage tanks and water/wastewater treatment facilities. While some of the contaminant is expected to be transported by the surface water during the event, a portion of the release may enter the subsurface through infiltration, or if the chemical is denser than water, it may sink directly into the ground. This contaminated groundwater can potentially impact the natural habitat, water wells, or surface water bodies.

Numerical modeling of groundwater flow and solute transport is constrained by the required computational time and available data. In addition, risk or dose assessments require the simulation of many contaminants under multiple scenarios. Thus, choices must be made concerning the model domain, mesh resolution, and model complexity. The overall objective of this research is to develop a better understanding of these issues in scenarios where a release has occurred following a flooding event that results in subsurface contamination.

This project is continuing work by the PI's research group toward incorporating uncertainties into groundwater flow and transport models and the use of telescopic mesh refinement (TMR) for constructing localized, high resolution models within regional models. Contaminant transport scenarios are typically localized and require fine mesh spacing---TMR allows investigators to develop these high-resolution models within large site-wide or regional models. This allows for the larger scale processes and dynamics to be incorporated into the fate and transport models without having a high-resolution, and computationally-expensive, regional model. In addition, smaller-scale modeling domains are amenable to techniques that allow for the quantification of uncertainty. While able to incorporate more of the processes that control fate and transport, complex models can be computationally expensive and require the identification and quantification of multiple parameters. Simple models are computationally efficient, require fewer parameters, and are much easier for decision-makers to understand.

Regardless of the source, once in the subsurface, contaminant fate and transport will be effected by complex physical, chemical, and biological processes. A proper risk assessment (before any release) or site assessment (after a release) requires an understanding of the spatial and temporal variabilities inherent in the natural systems and their impact on the fate and transport. The results from this project will guide us towards the development of better modeling techniques and strategies for assessing the impacts of contaminant releases following flooding events.

Methodology

When dealing with contaminant flow and transport modeling, there are a variety of approaches available. The model used depends on the amount and quality of the information/data available and the type of contamination event. For multiphase scenarios (e.g., leaking underground storage tanks, DNAPLs, etc…), complex multiphase, multicomponent models are available to simulate the release, flow of free phase product, and subsequent groundwater transport. However, these models require a large investment in user training and a significant amount of data. Simpler models (e.g., Hydrocarbon Spill Screening Model) are available to provide order-of-magnitude estimates of groundwater contamination. A variety of models are also available for scenarios where only the contaminant transport is to be modeled.

There are complex models that are capable of incorporating multiple chemical and biological reactions (e.g., RT3D) and simple models that can be run using a spreadsheet (e.g., BIOSCREEN).

The first step is to identify the various sources of contamination within the study area. This includes information on the location, volume, and chemical/contaminant composition. The next step is to obtain, organize, and analyze information concerning the hydrogeology within the study area. This includes both geological and hydrological data. All of this data and information will be combined into a Geographical Information System (GIS), which will allow for the development of the various "conceptual" models that will be used to investigate groundwater contamination.

Project Status

The data and information on the location, volume, and chemical/contaminant composition of the all the underground storage tanks in the New Orleans Area has just been compiled and put into a GIS format. We are currently compiling the hydrogeological data from the region. As mentioned above, this project has been granted an extension. Work will continue on this project over the next year.

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), one research associate (half-time LWRRI support), and the associate director, Dr. John J. Sansalone. 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 Remote Sensing and Image Processing (RSIP) Program 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 (125+ email addresses and 125 regular mail addresses) to Louisiana college 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. 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. 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 New Orleans focused RFP for the 2002-2003 solicitations, we received only 5 proposals and funded 4 of those after advisory board review. The institute has had a Director retire during this reporting period and the new Director has maintained the thematic approach to research solicitation. The next theme, selected in consultation with faculty and advisory board members, is focused on characterizing particulates for heavy metals in aquatic systems using non-invasive spectroscopy and tomography. In addition, a continuing interest in total maximum daily load (TMDL) calculations in Louisiana water bodies is being maintained.

Student Support

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

Notable Awards and Achievements

LWRRI under the direction of Dr. Joe Suhayda led an effort to model the magnitude of the storm surge inundating New Orleans and ways of mitigating the effect. This research effort 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. In the current reporting year, Dr. Suhayda reorganized the LWRRI research program around the New Orleans flooding theme, effectively leveraging LWRRI funds to create a larger impact. The New Orleans storm surge research has been featured in Scientific American, the New York Times, on National Public Radio, CNN, and elsewhere. Dr. Joe Suhayda received a LSU award commemorating 30 years of service at LSU upon retirement, and a LWRRI plaque thanking him for his water resources service at the Institute since 1994.

Publications from Prior Projects

1. 2001LA2521B ("Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment") - Articles in Refereed Scientific Journals - Liu, D., Sansalone, J.J. and Cartledge, F.K., Bench scale comparison of storm water filter media for heavy metal capacity ASCE J. of Environmental Engineering, (accepted)
2. 2001LA2521B ("Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment") - Articles in Refereed Scientific Journals - Cristina, C. and Sansalone, J.J., An evaluation of the first flush, power law model and process selection diagram for storm water runoff, ASCE J. of Environmental Engineering, April 2003.
3. 2001LA2521B ("Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment") - Articles in Refereed Scientific Journals - Sansalone, J.J., and Z. Teng, In-situ storm water eco-treatment and recharge through infiltration: Quality and Quantity Attenuation, ASCE J. of Environmental Engineering, (accepted) 2003.
4. 2001LA2521B ("Storm Water Transport of Particulate Matter From Elevated Urban Transportation

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5. 2001LA2521B ("Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment") - Articles in Refereed Scientific Journals - Cristina, C. and Sansalone, J.J., Kinematic wave model of urban pavement runoff quantity subject to traffic loadings, ASCE J. of Environmental Engineering, (in press) 2003.
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8. 2001LA2521B ("Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana The Role of Partitioning and Implications For Treatment") - Conference Proceedings - Tramonte, J.C., Cartledge, F.K., Tittlebaum, M.E., and Sansalone, J.J., Transport and treatment of entrained particulate matter from elevated transportation infrastructure, 9th International Conference on Urban Drainage, Paper and Presentation, ASCE/IWA, Portland, Oregon, September 2002.
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