Three Years after Katrina
Restoring and Protecting New Orleans and Coastal Louisiana

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“In our history there is one spot on the globe the possessor of which is our natural and habitual enemy. It is New Orleans through which the produce of three eighths of our territory must pass to market and from its fertility it will ere long yield more than one half of our whole produce and contain more than one half of our whole population.” Thomas Jefferson (1802)

“an inevitable city on an impossible site.”
Geographer Peirce Lewis (1973)

On August 29, 2005, the full force of Hurricane Katrina hit New Orleans and the Louisiana Gulf Coast and inflicted catastrophic damage on people, the built environment, and the natural landscape. For most Americans, the memory of that day has faded and they have logically assumed that, in the more than three years since the disaster, the New Orleans “problem” has been addressed. For many who live and work in the region, Katrina’s memory remains etched in their minds because, in many cases, recovery from the hurricane has been limited and complete salvation is not in sight.

A drive today through the city or to the coast can still demonstrate the devastation that was Katrina. In some areas things are back to normal. In many other areas, the best that can be said is that rebuilding is progressing, albeit slowly. The lower 9th Ward, which was among the areas hardest hit by the flood, became the center of attention for those who saw the economically disadvantaged suffering the most. Today, a drive through that area finds tall grass, a few elevated and energy innovative homes built by charitable groups, but almost no people. Even in the Lakeview area, a considerably more affluent neighborhood than the lower 9th, progress has been spotty and rebuilt or new homes frequently sit next to empty shells. Thirty percent of the residents of New Orleans at the time of Katrina have yet to return to their city.

While Hurricane Katrina created havoc in and around New Orleans, it also attacked the coastal lowlands that sit between the city and the Gulf of Mexico, destroying or badly damaging homes, industries, and over 120 square miles of wetlands. While the oil and gas industry has returned, many other businesses and residents have not.

At the time of Katrina, coastal Louisiana, which also provides the outlet for the drainage of 41 percent of the conterminous U.S., was home for the nation’s largest port, an oil and gas industry that provided access to 35 percent of the nation’s energy supply, a diverse coastal ecosystem that supported a multibillion-dollar fisheries industry, and the largest coastal wetland in the lower 48 states. The New Orleans area was and remains a cultural capital of the South, a major focus of mid-south banking and energy development, and the home for over 700,000 individuals. Lack of long-term plans and accurate knowledge of what the future may bring to the region hinders resettlement and any new development.

Immediately after the hurricane, standing in Jackson Square in the French quarter, President Bush committed the federal government to making “the flood protection system stronger than it has ever been” (Bush 2005). Rhetoric in support of the restoration of the city that was loud and frequent in the months following the hurricane has faded over time. Congressional directives for the immediate preparation of long-term plans have yet to be answered. Support for the restoration of coastal Louisiana wetlands has been pushed into the background by the necessity for funding the rebuilding of the hurricane protection system for
New Orleans to a level that remains below that originally intended for the city. (Would you move back into an area with less protection than you were authorized to have before Katrina?) A growing national economic downturn has exacerbated the funding problem. While many hope that an economic stimulus package will produce public works efforts that include coastal Louisiana, reality says that most national programs do not recognize or appreciate the immensity and complexity of protecting the city of New Orleans and restoring coastal Louisiana.

Many challenges remain to be addressed (Galloway et al. 2009):

1) What level of protection should be provided to New Orleans? The U.S. Army Corps of Engineers (USACE) has been authorized by the Congress to rebuild or improve the originally authorized levee system and its attendant supporting features to protect New Orleans against a 100-year flood (one that has a 1 percent chance of occurrence in any given year and a 26 percent chance of occurring during the lifetime of a 30-year mortgage). This effort, the total cost of which approaches $15 billion, will leave the city with a level of protection that will permit the Federal Emergency Management Agency (FEMA) to exempt those behind the levees from the national requirements to buy flood insurance when you are protected to less than the 100-year level. Given that Katrina was approximately a 400-year surge event and that the Dutch are now seeking to provide protection against a 100,000-year storm, many question the use of the 100-year level of protection for even an interim approach (Battelle 2007).

2) Congress and the state of Louisiana have both indicated that more should be done to protect coastal Louisiana. Immediately after Katrina, the state launched a study of the alternatives for restoration and protection that should be considered and, in May 2007, the state legislature approved “Integrated Ecosystem Restoration and Hurricane Protection: Louisiana’s Comprehensive Master Plan for a Sustainable Coast,” that calls for 200-year or greater protection for the city of New Orleans, 100-year protection for areas south of New Orleans, and restoration of the coastal wetlands, not only for their ecological benefits but also for the benefits they could provide in serving as a buffer against the storms that will attack the region in the future. In 2005, Congress directed USACE to conduct a similar study and to submit its results within two years. However, it now appears that this study will not be completed until mid-2009, if then.

3) In considering how to address the disaster, many pundits suggested that part of the solution should include, in the city of New Orleans, either not resettling the lowest areas or elevating the homes to protect them against the flooding that will inevitably occur. The use of these nonstructural techniques has been demonstrated across the country by the USACE in many communities but found little initial support with those who have been displaced by Katrina. Even though the city sought support for such approaches, little funding was forthcoming to support the effort since many saw that any non-structural effort might divert attention from the restoration of the levees. Many of these non-structural proposals also are seen as socially divisive and not supportive of the needs and wishes of the low income and minority population.

4) Efforts to deal with the continuous loss of wetlands along the Gulf Coast were not new. Calls for such an effort long preceded Katrina. But, it was only when Katrina clearly pointed out the critical nature of these wetlands in the overall protection of the region and the ecological, economic and technological importance of this natural treasure that more senior officials took wetlands restoration seriously. However, as noted, funding for coastal restoration has taken a back seat to funding of the hurricane protection system (now officially called the hurricane damage risk reduction system) and the outlook for long-term funding for wetland restoration is questionable.

5) Flood risk management is replacing flood control and flood damage reduction as a new
paradigm for development of approaches to the challenges being faced by New Orleans. Risk management allows the identification of areas most in need of attention (at risk) and the establishment of priorities to deal with these needs. But managing by level of risk flies in the face of years of providing everyone the same level of protection and is already getting considerable pushback.

6) Any work in coastal Louisiana will involve dealing with problems beyond protection against hurricanes. Restoration of the wetlands will require diversions from the Mississippi River into the wetlands to provide sediment and freshwater, but these diversions will also affect the ability of the river channel to serve as the highway for ocean going vessels that rely on the Mississippi and the port facilities that lie along its banks. Nutrients from throughout the Midwest continue to find their way into the Mississippi and down the river to New Orleans and the Gulf of Mexico creating vast dead zones just off the coast. Water quality in the region remains marginal and also must be addressed.

Unfortunately, the hurricane and flood challenges faced by New Orleans are also being faced in many other parts of the country as attention to Katrina’s destructiveness uncovered levee systems that were no longer capable of protecting those behind them, and riverine and coastal areas where the need for ecological restoration provides strong competition for Louisiana in its quest for funding.

This special issue of the journal is focused on what is happening and what might happen in New Orleans and coastal Louisiana in the years ahead.

• In the first article, Colonel Alvin Lee, the commander of the New Orleans Engineer District, describes USACE’s plan to provide short-and long-term flood risk management for coastal Louisiana.

• Dr. Lewis “Ed” Link, who served as director of the Interagency Performance Evaluation Task Force (IPET) that conducted the post-Katrina forensic examination of the hurricane protection system (IPET 2008), describes the policy and practice issues that were identified by the IPET and the impact this knowledge should have on future actions.

• Dr. Robert B. Gilbert, Brunswick-Abernathy Professor, Department of Civil, Architectural and Environmental Engineering at the University of Texas, Austin, and Robert G. Traver, Department of Civil and Environmental Engineering, Villanova University, describe their experience in evaluating New Orleans’ risk at the time of Katrina and poses questions as to directions that should be taken in moving to a risk-based environment and how this environment might be achieved.

• Dr. Earthea Nance, Director of Disaster Mitigation Planning for the city of New Orleans has been in charge of developing a hazard mitigation strategy for the city and describes New Orleans’ approach to dealing not only the potential for levee failures, but also with catastrophes such as subsidence, coastal erosion sea level rise and more frequent and stronger storm activity.

• Mark Davis, Esquire, Director of the Tulane Institute on Water Resources Law and Policy addresses the lessons that should have been learned from Katrina and how they affect the trade-offs that must be made in moving forward. He also addresses the challenges in trying to deal concurrently with flood and hurricane protection, ecological restoration, navigation, and other water resource issues.

• Dr. Denise Reed, University of New Orleans, reviews the efforts of an interdisciplinary group to sketch out a new approach to river management in coastal Louisiana to produce a sustainable coastal landscape and assesses the progress that has been made since that review towards implementation of the group’s recommendations.

• Dr. Robert Twilley, Associate Vice Chancellor, Louisiana State University and Victor Rivera-Monroy, Louisiana State University, discuss the trade-offs that must be made in developing long-term plans for restoring the Mississippi River Delta to balance the need to move sediment into the wetlands with the need to better control the nutrients that flow in the Mississippi River.
• In the last of the articles on New Orleans-coastal Louisiana, Clive Goodwin, FM Global (Insurance), and Dr. Shirley Laska, University of New Orleans, offer commentary on the above articles and the flood risk management situation in general.

• As school children across the world are taught, the Dutch have become masters of dealing with coastal flooding and must continuously improve their system to protect themselves against the dangers of the North Sea. Dana Woodall and Jay Lund, University of California, Davis, complete the discussion of flooding by examining the approaches and innovations taken by the Netherlands in dealing with their flood challenge and discusses how such policy innovations might be integrated into the flood challenges faced in the state of California.

• The final paper of this issue by Dr. Mary V. Santelmann, Oregon State University, although not directly related to flooding, addresses the challenges faced in providing the intellectual talent necessary to deal with the significant water resource challenges that we face. Dr. Santelmann identifies and discusses the pool of future water resource professionals that exists among women and minorities and urges attention to their recruitment. This discussion is written as a constructive response to issue 139 of the Journal of Contemporary Water Research and Education on “A Creative Critique of U.S. Water Education.”

If I were to seek the commonality among papers in this issue of the journal, I would argue that it is represented in the call for accountability. The authors identify many problems and challenges and offer insights into potential solutions. Common among them is their discussion of responsibility or the lack thereof in making determinations on how to address these difficult challenges and problems. It remains for those in the field of water resources education and research to identify the specifics of this accountability and how the lack thereof might be best addressed. The old adage that ‘when everyone is in charge no one is in charge’ is one of the lessons we should have learned from Katrina.

Author Bio and Contact Information

Gerald E. Galloway is a Glenn L. Martin Institute Professor of Engineering and Affiliate Professor of Public Policy at the University of Maryland. He is also a Visiting Scholar at the U.S. Army Corps of Engineers Institute of Water Resources. Active in water resources research and analysis, he recently chaired an Interagency Levee Policy Review Committee for FEMA. He was a Presidential appointee to the Mississippi River Commission and in 1993-1994, led a White House study of the causes of the 1993 Mississippi River Flood. During a 38-year career in the military, he served in various assignments in the U.S. and overseas, retiring in 1995 as a brigadier general. He can be reached at email: GEGallo@umd.edu.

References


Reducing Risk in New Orleans

Colonel Alvin B. Lee

Commander, US Army Engineer District, New Orleans

When Hurricane Katrina struck the Gulf coast Aug. 29, 2005, it presented the nation and the U.S. Army Corps of Engineers with a unique mission – one of the largest repair and construction jobs in civil works history, with an operational goal to complete the work in only six and a half years. The first priority, however, was to bring the system back to pre-Katrina conditions before the start of the next hurricane season. Therefore, from September 2005 to June 2006, the Corps removed more than 250 billion gallons of water, replaced 2.3 miles of floodwalls and 22.7 miles of levees, repaired 195.3 miles of scour, and built three massive interim gated closure structures.

At the same time, the Corps sought answers to what caused sections of the system to fail. On October 10, 2005, the Corps commissioned the Interagency Performance Evaluation Taskforce to provide scientific and engineering answers to questions about the performance of the Greater New Orleans Hurricane and Storm Damage Risk Reduction System (GNHSDRRS). The taskforce was comprised of some of the nation’s leading engineers and scientists from all levels of government, academia, and private industry. The team included approximately 150 engineers, scientists, and other professionals representing more than 50 organizations.

The Interagency Performance Evaluation Taskforce investigated five elements of the GNHSDRRS and its performance:

1. **The system**: documenting the pre-Katrina characteristics of the GNHSDRRS and comparing them to the original design.

2. **The storm**: understanding the surge and wave environment created by the storm and the forces that hit the levees and floodwalls.

3. **The performance**: understanding the performance of the levees and floodwalls and assessing the residual capability of the reconstituted GNHSDRRS.

4. **The consequences**: understanding the resultant flooding (including the role of the pump stations) and the losses due to flooding from Katrina, and assessing the extent of the flooding and losses if no catastrophic breaching had occurred.

5. **The risk**: determining the risk and reliability of the GNHSDRRS prior to Katrina and after repairs were completed June 2006.

The Taskforce determined that the system was really a system in name only and the Corps gained a new objective – create a system that performs as a system. From 2006 to 2007, a number of improvements were implemented using lessons learned from the Taskforce. Structural deficiencies were corrected, such as replacing I-walls with T-walls (Fig. 1); vulnerable floodwalls were armored; transitions from floodwalls or control structures to levees were armored; levees were restored to previously authorized design heights. All of these efforts made the GNHSDRRS better and stronger than ever before.

In addition, Congress directed the Secretary of the Army to study risk reduction and coastal restoration in south Louisiana and then submit recommendations based on its findings. The Louisiana Coastal Protection and Restoration Preliminary Report was issued in June 2006 and the final report will be forwarded to Congress in 2009.

To develop the best possible plan, the
Corps evaluated economic, geographic, and environmental data, modeled 304 separate storm tracks, met with 325 stakeholder groups, and consulted with our partners in federal agencies and the state of Louisiana’s Coastal Protection and Restoration Authority. The Corps and the National Academy of Sciences both conducted technical reviews of the draft report. Since the reviews, the Corps also incorporated additional stakeholder inputs in addition to the recommendations from the reviews. A second round of agency technical review and external peer review will occur for the final technical report.

The Louisiana Coastal Protection and Restoration Report to Congress will evaluate plans including coastal restoration, structural and non-structural measures for providing risk reduction at 100-year, 400-year, and 1000-year levels across all of south Louisiana. Coastal restoration is a key component of each plan; however, other measures such as the construction of levees and floodwalls and/or elevating, or buying, existing structures are included in alternative plans. However, the Corps did not stop there. Katrina’s aftermath set off a wave of change, not just for the people living in its wake, but also for the whole operational process of the Corps of Engineers. Determination has been the team’s driving force and innovation has been their overriding theme.

The chief of engineers proposed new priorities for the Corps. These “Actions for Change” became the Corps-wide guideposts for modifying the way the Corps conducts business on a daily basis. Four actions represent how the Corps redefined “business as usual.”

1. Comprehensive systems approach
2. Risk-informed decision making
3. Communicating risk to the public
4. Professionalism and technical expertise

The Corps also sought ways to expedite the National Environmental Protection Act (NEPA) requirements while staying within environmental laws and regulations. Typically, the NEPA process can take five to ten years – precious time that Louisiana could not afford to lose. Therefore, the Corps’ environmental team, with concurrence from the White House’s Council on Environmental Quality, Department of the Army, federal and state resource agencies, and Corps stakeholders, are achieving compliance in part with a unique method called alternative arrangements. Through this process, proposed construction projects are identified and evaluated by basins within the system. These alternative NEPA arrangements allow a system-wide environmental study to be completed while still moving segments ahead to construction at a pace feasible to meet our 2011 goal.

The Inner Harbor Navigation Canal surge reduction barrier is the largest design and build civil works project in Corps history. After completion of the NEPA process, construction of the 1.4 mile barrier, located at the confluence of the Gulf Intracoastal Waterway and the Mississippi River Gulf Outlet, is expected to be complete in 2011. But given the area’s vulnerability to flooding from storms and the current schedule for completion, the Corps is calling for advanced measures. This requires the contractor to provide a certain level of risk reduction in 2009, an innovation that supports the Corps’ charge to reduce risk continuously as
we work toward delivering a completed system. The Corps is also providing interim measures in some areas to provide a degree of risk reduction until a permanent solution is formulated. On the Company Canal, located on the northern end of Bayou Segnette on the west bank of the Mississippi River, a barge gate has been constructed at the mouth of the canal to impede storm surges until a final solution is determined. When the water level is anticipated to rise in the canal, the barge gate will be closed, filled with water, and sunk to block surge from entering the canal.

Since Hurricane Katrina struck in 2005, Corps employees’ dedication and perseverance has been extraordinary in providing a hurricane and storm damage risk reduction system for the Greater New Orleans area. But just three years after Katrina, and three years prior to the completion of the 100-year system, Hurricane Gustav came along and provided an opportunity to test the system, and the GNHSDRRS did its job. Gustav was not a benign event in New Orleans, as was evident by the 12 ft. surge and wave run up that caused limited overtopping in the Inner Harbor Navigation Canal (Fig. 2). It was a significant test and the work that was done by the Corps was critical in how the floodwalls performed. Hurricane Gustav was the first operational test for the 17th Street Canal and London Avenue Canal structures. The gates and pumps performed well. As water levels in Lake Pontchartrain rose, the Corps positioned the canal teams at each location and closed the gates before water levels rose to each canal’s respective safe water elevation. By closing the gates, the Corps prevented storm surge from entering the outfall canals and jeopardizing the structural integrity of the floodwalls that line the canals. Once the gates were closed, the canal teams operated the pumps in close coordination with local Sewerage and Water Board to ensure we were removing water being pumped into the canals by the local pump stations. The operation was a success and these systems performed precisely as designed.

Our “team of teams” did an amazing job. The New Orleans District’s emergency operations center hosted Chief of Engineers, Lt. Gen. Robert Van Antwerp. The team is also comprised of 13 local government liaisons, who were located in each of the 13 coastal parishes. We also had three employees in Gov. Jindal’s Office of Homeland Security and Emergency Preparedness. At each of the three outfall canals and Harvey Canal, a three-person team stayed on location in the safe rooms throughout the storm. In addition, we deployed our rear emergency operations center to Port Allen, LA and our alternate command post to Vicksburg, MS to ensure smooth operations during the hurricane. Additionally, our lock team and hired labor crew were safe harbored at the Inner Harbor Navigation Canal Lock, as well as personnel at the Algiers Canal and other structures throughout Louisiana. Our Operations Division was truly outstanding in getting our waterways re-opened rapidly following Gustav.

The command and control plan for this storm also placed key Corps leaders at essential locations throughout New Orleans and Louisiana prior to and during the storm. Once the immediate dangers of Hurricane Gustav subsided, the Corps, along with their state and local partners, began a complete assessment of the area’s GNHSDRRS and non-federal storm protection systems. The GNHSDRRS performed as expected during the storm. However, with a tropical storm event of Gustav’s magnitude, some damages were anticipated. Immediately following the storm, the Corps deployed 12 damage assessment teams throughout Jefferson, Lafourche,
Orleans, Plaquemines, St. Bernard, St. Charles, St. Mary and Terrebonne parishes. Corps personnel were accompanied by state representatives and local levee officials in the field.

Assessments were conducted in two phases. During Phase I, two aerial teams, each equipped with Automated Route Reconnaissance Kit (ARRK) technology, began surveying and compiling data of areas prioritized by the local authorities. With the ARRK, these teams were able to compile photographs and voice recordings in a rapid preliminary analysis. This information was then used by the Corps to accurately pinpoint several areas of concern. During Phase II, ten teams blanketed the identified areas for closer ground inspection of the risk reduction system. Once initial assessments were complete, many of the teams returned to conduct follow-up inspections of identified vulnerable areas. During inspections, 30 initial work areas were identified but overall, the system performed very well. Yet, while the Corps took a moment to celebrate the great things we have done over the last three years that led to the more resilient system we have today, we realized that this hurricane clearly demonstrated the critical nature of the work we are doing to reduce risk. Therefore, following the damage assessments to the system, it was important for everyone to immediately focus again on the Corps’ number one domestic priority – providing 100-year level of protection to the Greater New Orleans area.

Success is our only option. Uniting our team of teams like never before is necessary to achieve mission success. All of the districts in the Mississippi Valley Division of the Corps, as well as the Northwest Division and Chicago District will have a hand in completing the GNHSDDRRS, making the entire region responsible for delivering the mission by 2011. Looking back on the last three years not only reinvigorates our determination to do everything within our realm for public safety, but also highlights the sheer magnitude of work that has been accomplished. Everyday that the Corps is working to meet our goal, we are reducing risk for the community and providing a stronger system than ever before.

Author Bio and Contact Information

Colonel Alvin B. “Al” Lee, the New Orleans District’s 60th commander and district engineer, took command on July 20, 2007. As district engineer, Lee is responsible for a district which, in tandem with the Hurricane Protection Office, is working on appropriations exceeding $7 billion for hurricane restoration. He can be reached at alvin.b.lee.col@usace.army.mil.
The Interagency Performance Evaluation Task Force (IPET) was established by the Chief of Engineers of the U. S. Army Corps of Engineers to determine the facts concerning the performance of the New Orleans Hurricane Protection System (HPS) in response to Hurricane Katrina. The Task Force conducted in-depth analyses that: (1) defined the surge and wave levels resulting from the storm, (2) determined the forces experienced by the HPS, (3) characterized the design, as-built, and as-maintained character of the HPS, (4) determined the most likely causes and mechanisms for observed behavior (failure and success), (5) characterized the extent and consequences of flooding (including the influence of the pumping stations), and (6) performed a risk and reliability assessment of both the pre-Katrina and post-Katrina HPS.

Over 300 individuals from more than 50 organizations have contributed to IPET. Those organizations included 25 universities, 23 private sector firms, and 10 government agencies. There were many individuals from the Corps of Engineers embedded in the IPET teams to provide direct two-way exchanges of information and ideas. This was essential to the literally real-time transfer of information and findings to the repair and rebuilding process.

The IPET Web site (https://IPET.wes.army.mil) is the primary venue for documenting and providing the IPET analysis and results. It contains over 4,300 documents dealing with the design and construction of the HPS, as well as the 9 Volume IPET Final Report, Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System. The IPET analysis and results were peer reviewed by the American Society of Civil Engineers External Review Panel and the National Research Council Committee on New Orleans Regional Hurricane Protection Projects.

Policy and Practice Issues

IPET was primarily an engineering-based forensic analysis of what happened and why during Katrina. Yet, this in-depth engineering analysis both exposed and reinforced a number of serious water resources policy and practice issues that contributed to the disaster experienced in New Orleans. The issues identified are summarized below using the five fundamental areas of the IPET investigation.

The System: During the IPET analysis, the basis for the design, construction, and operation of the HPS was examined in detail to understand the character and capability of the structures that comprised the HPS when Katrina struck. One of the most significant issues was the long time frame between inception and completion. The system in place before Katrina was compromised by a long series of decisions driven by competing priorities, incremental decision making and piecemeal funding. Also, within the 50-year tenure of the HPS, changes occurred in the basic hazard that defined the design criteria and errors were discovered in the assumptions made for the basic geodetic and water level data used in the design process. Deliberate decisions were made not to halt construction and change the structures to accommodate these factors. Some sections...
of the HPS, particularly on the West Bank, were not completed when Katrina struck and the many pumping stations that are crucial to keeping New Orleans dry from rainfall and ground water were not part of the HPS and not intended to operate during large hurricanes. The HPS could not and did not perform as a system because of these and other factors. If risk reduction measures are to be put in place they must be designed, constructed, and maintained as systems. The promise or perception of a system when it does not exist is perhaps more dangerous than no system at all.

As a nation we lack clear standards for planning, design, and development of major public infrastructure for water resources. New knowledge is often too slow to be incorporated into engineering guidance, and we too often optimize based on immediate cost and accept short-term gains instead of long-term solutions. This is a national cultural malady that can only be reversed if the public demands a change in policy. Life-cycle solutions are important to our future, and we can only get there through the election cycle.

The Storm: Figure 1 is a NOAA satellite image of Katrina prior to landfall and showing the enormous physical size of the storm. Katrina generated the highest surge ever experienced on the North American Continent. It was a 400-year event based on its surge generation capability and overwhelmed most of the structures on the east side of New Orleans and to the south. High performance computer models using high resolution computational grids were necessary to reproduce the surge and wave conditions experienced by the levees and floodwalls. While a Category 3 (on a 1-5 scale) storm according to the Saffir-Simpson Scale, Katrina demonstrated that intensity alone (based on central pressure) is not an adequate predictor of the severity of a hurricane. Katrina
also demonstrated that central pressure, the typical criteria used, is alone not an appropriate estimator of the frequency of occurrence of hurricanes. It is the joint probability of central pressure, physical size (radius), forward speed, and track that better describe the probability of experiencing different surge levels.

There is much more to learn. If we as a nation hope to manage risk from the most severe hazards, we need to learn how to work with, rather than control, nature. Research is needed to better define the actual role of natural environments in managing surge and waves; rules of thumb are just too inaccurate. Given the challenges of continued sea level rise and subsidence and the potential for more intense storms, the art of building and sustaining the natural environment is especially important. The vulnerability of natural features to large storms is a particular challenge if we are to rely on them for long-term risk reduction.

The Performance: Katrina damaged over 200 of the 350 miles of floodwalls and levees surrounding New Orleans and southeast Louisiana. There were 50 major breaches that resulted in approximately 80 percent of New Orleans being flooded. Four of the breaches occurred at water levels below the design criteria, all involving I-walls (levees with imbedded concrete capped sheet piles that rose above the levee). All of the remaining breaches occurred as the result of overtopping of the structures and subsequent erosion of the constituent or supporting materials. Ironically, the four floodwall failures that did not involve overtopping resulted in up to half of the floodwaters that entered New Orleans. Levees performed well until overtopping and those constructed of clay withstood overtopping without catastrophic breaching. The levees constructed of

![Image](image_url)

**Figure 2.** View of Gulf Inter-coastal Water Way levee being overtopped during Katrina. This levee constructed of quality clay was resilient to overtopping and did not fail. Levees constructed of more erodable sandy materials and capped with clay did not perform nearly as well.
materials less resistant to erosion did not perform well when overtopped (Figure 2.).

Beyond the failure of the four I-wall sections (three on the outfall canals and one within the Inner Harbor Navigation Canal), it was the lack of resilience that stands out as a major factor in the ultimate flooding and losses. If no catastrophic breaching had occurred, the flooding and losses would have been significantly reduced, perhaps by half. Structures must be designed to be resilient to overtopping and to prevent catastrophic breaching. Such capability would not only have dramatically reduced the losses in New Orleans but also dramatically eased the burdens of recovery.

Man-made measures alone cannot sufficiently reduce risk for vulnerable areas such as New Orleans. Natural processes and attributes such as marshes, mangroves, and barrier islands need to be integral to a systems strategy for risk reduction. In combination with traditional structures and aggressive emergency management planning and execution, an enhanced natural environment can be a significant component to a sustainable and effective long-term strategy to deal with the dynamics of climate, systems and demographics.

Consequences: The consequences of Katrina were staggering. Over 1600 fatalities occurred. 75 percent of the fatalities were people over 65 years of age; many of them were not self-mobile and were unable to evacuate. There was over $20 billion in direct property losses, 78 percent of which was associated with residential losses. People were living in the areas most prone to flooding, but then most of New Orleans is prone to flooding. There was another $10 billion in public property losses and indirect economic losses that dwarf property damage. Beyond the fatalities, perhaps the most severe losses with respect to recovery were social and cultural. Most of the neighborhoods that made up New Orleans were decimated, losing their population, social services, and social fabric.

Risk is increasing significantly along the nation’s coastlines, in part because natural hazards such as hurricanes appear to be more severe, but even more so because increasing numbers of people and property are being allowed to reside in harm’s way. There is little that governments or individuals can do about the changing hazard, but there is much that can be done to manage risk by reducing exposure to the hazard. The simplest approach in principle is managing land use to avoid placing more people and property in areas vulnerable to hazards. While simple in principle, the dichotomy of land-use authorities between levels of government, the lack of adequate risk reduction standards, and the dependence on continued development has made this the correct path seldom taken. Many individuals are drawn into this web by ignorance or lack of clear information.

Risk: The risk of loss of life and property in New Orleans prior to Katrina was both high and unknown. There had not been any attempt to quantify risk for hurricanes for any major metropolitan area. Risk had been used for major site-based critical infrastructure such as dams and power plants, but geographically distributed hurricane protection systems such as that in New Orleans, or major expanses of levees such as those that occur along many rivers, were not addressed. The result was a situation where the current hazard was not well understood or quantified and the performance of the structures in place was not tested or quantified. The potential consequences of major flooding were not completely undefined in that a major emergency response exercise was conducted in New Orleans not long before Katrina involving a hypothetical hurricane not unlike Katrina (named Pam). The response exercise in fact estimated much higher loss of life than occurred in Katrina. The risk assessment involved defining a future hazard using joint probability methods that modeled over 150 hypothetical hurricanes with a wide range of characteristics, many having surge generation capabilities equal to and beyond that of Katrina. The surge and wave conditions generated by these storms were used as input to a reliability analysis to estimate the probability of breaching and overtopping of the structures protecting each of 27 drainage areas within New Orleans. This analysis was accomplished for both the pre-Katrina and post-Katrina HPS structures as well as the structures intended for the 100-year risk reduction system under construction. The reliability analysis provided basic information on the probability of flooding of different depths across the city. Combining this information with
the population and property distributions in the city allowed estimates to be made of the risk of loss of life and loss of property. This information forms a new basis for the public and public officials to understand their vulnerability to flooding and associated losses.

While risk continues to be high in New Orleans, some significant improvements have resulted from the work to date. The surge gates and pumps added to the outfall canals along Lake Pontchartrain have demonstrated their value as recently as Hurricanes Gustav and Ike. Similarly, stronger and higher levees along the east side of the city and stronger floodwalls within the city have reduced the potential for catastrophic breaching. The risk maps for the new system under construction, however, demonstrate that much more can be done and needs to be done to reduce the risk for New Orleans.

Understanding risk is a powerful tool in helping both individuals and government agencies to make consistent and conscientious decisions concerning natural hazard risk management. The ability to quantify risk for large geographical areas and complex engineered systems is just emerging through the work in New Orleans and a similar effort is ongoing in central California. Figure 3 is an IPET flood depth-frequency map for New Orleans prior to Katrina. Coupled with estimates of losses from these flood depths, it allows estimation of risk of loss of life and loss of property. Risk provides a much richer body of knowledge to understand and manage vulnerability to hazards as well as providing a clear common picture of the situation to all. Risk methods for regional

Figure 3. Maps showing system-wide vulnerability to flooding such as the one above are critical to understanding risk and making decisions about how to manage risk. Coupled with estimates of potential loss of life and property, they provide a strong scientific basis for decisions to manage both sides of the risk equation, reducing the threat of flooding and reducing the extent of losses.
infrastructure, if fully developed, will not only allow assessment of multiple hazards, but also allow collective consideration of life safety, direct and indirect economics, and social-cultural issues, enabling customization of solutions to situations. But the evolution and application of risk to support decision making must be enabled by policy which currently does not exist.

Summary

First and foremost, the United States lacks a coherent and comprehensive strategy for water resources. Levels of protection are marginal with respect to levels of risk. Investments too often are local in scope, short-term in nature, cost-benefit based, and focused on taming, rather than working with, natural processes. Integrating risk reduction with other critical functions such as water quality, sustainability and commerce remain an idealistic goal. It is time for a new national emphasis on holistic water policy where public safety is a mandatory component.

Second, our current policy and practice do not deal well with change. We must be more anticipatory and adaptive as changes occur in the hazard, the system, or the potential consequences. All of these factors changed dramatically over the life of the hurricane protection projects in New Orleans with little capability for appropriate response. This is another symptom of short-term rather than long-term sustainable strategies, policies, and practices for addressing a major life safety need. Change is inevitable, whether it is climate-induced changes in storm character and frequency, the evolution of structures and systems intended to deal with hazards, or population and property growth in vulnerable areas. Change must be a routine part of any analysis. Equally important, we must have the political will to anticipate and manage change to include continuous monitoring and updating structures and emergency response capabilities.

Third, the 100-year de facto standard is far too risky for the continued vitality of our economy that is highly dependent on the viability of public infrastructure and the continuity of the economy. In fact, it has effectively generated a large volume of infrastructure that resides just outside this boundary that we all know has considerable uncertainty associated with it. The structure or people sitting within the 100-year floodplain are about as vulnerable to flooding and losses as those sitting within the 100-year zone. The nation must go to more comprehensive risk-based standards that provide longer term solutions that combine benefits of both built and natural measures. Risk measures also will allow consideration of life safety, environmental, and social/cultural goals along with economics in making critical infrastructure investment decisions.

Author Bio and Contact Information

Dr. Lewis E. (Ed) Link is a Senior Research Engineer and member of the faculty of the Department of Civil and Environmental Engineering, University of Maryland. In that position he has been serving as the Director, Interagency Performance Evaluation Task Force, leading the forensic analysis of hurricane Katrina in New Orleans. He spent 34 years as a member of the U.S. Army Corps of Engineers culminating as the Director of Research and Development and Principal Scientific Advisor to the Chief of Engineers. He can be reached at elink@umd.edu.
Flooding risks when levee systems fail or are overwhelmed are significant: more than 1,500 people died and tens of billions of dollars in property damage occurred in the New Orleans area from Hurricane Katrina. In the wake of this storm, a substantial effort was undertaken to quantitatively assess the risk of major flooding from future hurricane storm surges in New Orleans. The objective of this paper is to prompt and frame planning for the next steps in managing risk. What level of risk are we trying to achieve? How best can we achieve it?

Evaluating Risk

The value of quantifying risk is in being able to evaluate it. Is the risk acceptable or tolerable? Is the risk too high, meaning that we need to spend resources to reduce it? Is the risk too low, meaning that we are not spending our resources efficiently?

These questions can only be answered if there is a context for evaluating risk. Major dams are evaluated using guidelines relating the tolerable probability of a failure to the estimated number of fatalities caused by that failure (Figure 1). A tolerable risk is one that is needed to secure benefits such as power from a dam, is monitored and is reduced further when practicable; it is not a negligible risk. While there are several different forms of and variations on these types of guidelines for dams (e.g., USBR 2003 and Bowles 2007), the differences are relatively small and the threshold of tolerability in Figure 1 is representative of the state of practice for dams throughout the world. Furthermore, the threshold line in Figure 1 is representative (i.e., within an order of magnitude) of similar guidelines used for nuclear power plants (e.g., U.S. Nuclear Regulatory Commission 2005) and oil, gas and chemical facilities (e.g., Goodwin et al. 2000).

At present, there are no such guidelines to evaluate risks for levees, including flood protection or coastal protection systems. Levees have historically been designed to be overtopped at a much lower risk level than dams. In some areas, levees originally designed to protect farmland now protect housing as the land use behind them changes. Results from a recently completed risk assessment for the coastal protection system in New Orleans are compared with the risk guideline for dams in Figure 1. The risk to human life associated with this system is about 10,000 times greater than what we would consider tolerable for a major dam. The comparison in Figure 1 prompts the following questions:

- Is the risk associated with both of these levee systems too high?
- Is the risk that we are targeting for dams too low?
- Should we invest more money to reduce risks for levee systems than for dams?
- How does the risk associated with the coastal protection system in New Orleans compare to that associated with other levee systems?

Without guidelines on what we are trying to accomplish with levee systems, it is impossible to answer these questions. An important lesson from Katrina is that we, as a society with input...
and leadership from engineers and scientists, need to establish guidelines in order to evaluate and subsequently manage the risks associated with levee systems.

Reducing Risk

Reducing risk to as low as practicable is about making decisions between possible alternatives that mitigate the risk. These decisions need to consider the cost of the possible alternatives and how effective they may be. For the Hurricane Protection System, there are two broad classes of mitigation alternatives. The first alternative is to reduce the probability of flooding (i.e., move the “New Orleans Hurricane Protection System” curve down in Figure 1) by improving the systems of levees, walls, gates and pumps. The second alternative is to reduce the consequences of flooding (i.e., move the “New Orleans Hurricane Protection System” curve to the left in Figure 1) by improving the system for preparing, warning and evacuating people and protecting property, primarily through public education and communication (Mileti 2007) as well as through public policy and innovative engineering solutions to evacuation and property protection and recovery.

A simplified decision tree for comparing these two alternatives is shown in Figure 2. The alternatives can be compared quantitatively on the basis of their expected cost:

\[
\text{Expected Cost} = \text{Cost of Implementation} + \text{Cost of Major Flooding} \times \text{Probability of Major Flooding}
\]  

Figure 1. Risk guideline for evaluating existing dams, published by the Australian National Committee on Large Dams (2003). The annual probability of failure corresponds to an event of failure for which it is estimated that at least that number of fatalities will occur. The threshold line between what is and is not tolerable for dams is dashed for annual probability values less than \(1 \times 10^{-5}\) per year because ANCOLD considers that smaller probability values cannot be assessed credibly. The assessed risk for the New Orleans Hurricane Protection System is based on Interagency Performance Evaluation Task Force (2008) and corresponds to the system as of 2007 assuming that the pumps are 50-percent effective.
where major flooding is defined here as a hurricane with hundreds of estimated fatalities due to flooding and the cost of major flooding includes property damage as well as fatalities. The product of the cost and probability of major flooding in Equation (1) constitutes the expected loss or risk due to flooding:

\[
\text{Risk} = \text{Cost of Major Flooding} \times \text{Probability of Major Flooding}
\]

The information in Figure 1 and Interagency Performance Evaluation Task Force Report (2008) provides a baseline for assessing the current risk in New Orleans. As shown in Figure 1, the annual probability of major flooding is approximately 0.02, while the expected number of fatalities in the event of a major flood is 2,500 (obtained by integrating the possible numbers of fatalities over their respective probabilities of occurrence, which are proportional to the absolute magnitude of the slope of the “New Orleans Hurricane Protection System” curve). The cost associated with 2,500 fatalities is debatable; however, it is an important consideration if we are to define risk reduction in terms of what is practicable. An order of magnitude approximation is about $10 million per life (The Economist 2004), giving an expected cost due to fatalities of about $25 billion per major flood event. Taken together with the estimated property damage from hurricane flooding (Interagency Performance Evaluation Task Force 2008), an approximate total cost in the event of major flooding is on the order of $100 billion. Therefore, the risk of major flooding at present is approximately $100 billion multiplied by 0.02 per year, or $2 billion per year.

For the risk mitigation alternative of improving the levee system, plans have been developed and the construction cost is estimated to be about $15 billion (U.S. Army Corps of Engineers 2008). With a discount rate of 5 percent and an assumed annual cost of $0.25 billion to maintain the improved system, the total cost for this alternative on an annualized basis is about $1 billion. We will assume that this alternative reduces the probability of major flooding but does not impact the cost of major flooding if it were to occur. The expected annual cost associated with this alternative is then

\[
(\text{Expected Cost})_{\text{levees}} = $1 \text{ billion} + $100 \text{ billion} \times (\text{Probability of Major Flooding})_{\text{levees}}
\]

If the probability of major flooding is reduced from 0.02 to 0.01 per year, then the expected cost for this alternative is the same that for the status quo, $2 billion per year. For probabilities of major flooding smaller than 0.01 per year, this alternative is preferred to the status quo on the basis of expected cost.

For the risk mitigation alternative of improving the preparation, warning and evacuation system, the probability of major flooding is unchanged.

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**Figure 2.** Simple decision tree comparing alternatives to reduce risk.
from the status quo: 0.02 per year. Therefore, the expected annual cost for this alternative is

\[
(\text{Expected Cost})_{\text{preparation}} = (\text{Cost of Implementation})_{\text{preparation}} + (\text{Cost of Major Flooding})_{\text{preparation}} \times 0.02 \text{ per year}
\]  

(4)

Figure 3 provides a comparison of the expected costs for these two alternatives. Each line corresponds to a particular probability of major flooding obtained if the levee system is improved. For example, consider that the probability of major flooding can be reduced with the improved levee system by a factor of 50 to a value of 0.001 per year. Alternatively, consider that the total expected cost in the event of a major flood can be reduced from $100 billion to $25 billion with the improved preparation, warning and evacuation system. If we could achieve this reduction in flooding damage with the improved preparation, warning and evacuation system for less than $0.6 billion, then we would prefer this alternative over improving the levees (Figure 3).

The information in Figure 3 motivates the following questions:

- How much could we achieve in risk reduction with an improved system of preparation, warning and evacuation and how much would it cost?
- How much should we invest in reducing the probability of major flooding versus mitigating the consequences of major
flooding?
- Is it worthwhile to spend $15 billion in the next few years to improve the system of levees, wall, gates and pumps?

An approach that balances the cost and benefits of various alternatives for risk mitigation, such as spending $0.75 billion per year on improving the levees system and $0.25 billion per year on improving the preparation, warning and evacuation system, would likely be optimal. Similarly, investing entirely in the hard system (levees) without considering the soft system (public preparation) would not likely be the optimal approach. An important lesson from Hurricane Katrina is that the people and property at risk are as much a part of the Hurricane Protection System as the levees and walls.

Summary

Managing risks requires a context within which to evaluate the risk and a practical means for reducing the risk. The context for evaluating risk needs to consider not only the New Orleans Hurricane Protection System, but levee systems and ultimately infrastructure systems throughout the country. We need to make sure that we are investing our limited resources in an efficient and rational manner. The means for reducing risk need to include both measures to reduce the probability of flooding and measures to reduce the consequences of flooding. Projections for the possible effects on climate change generally increase the flood hazard: more frequent and more intense flood events. Measures that do not rely entirely on our ability to prevent floods and instead reduce the consequences of flooding will take on even greater significance in this environment.

Our role as civil engineers in moving forward to better manage flooding risks is challenging. It will require that we collaborate with scientists, sociologists, economists, policy makers, and communication specialists. It will require that we interact with the owners and operators, including public agencies and governmental bodies, and that we interact with the users, the public we are trying to protect. It will require that we participate in difficult decisions that directly affect the safety, health and welfare of the public and are constrained by limited resources.

Author Bios and Contact Information

Dr. Gilbert is the Brunswick-Abernathy Professor in Civil, Architectural and Environmental Engineering at The University of Texas at Austin. His expertise is the assessment, evaluation and management of risk in civil engineering. Applications include building foundations, slopes, pipelines, dams and levees, landfills, and groundwater and soil remediation systems. Recent activities include analyzing the performance of offshore platforms and pipelines in hurricanes; managing earthquake and flooding risks for the Sacramento-San Joaquin Delta in California; and performing a forensic analysis of the New Orleans levee failures. He can be reached at bob_gilbert@mail.utexas.edu.

Dr. Traver has been a member of the Water Resources and Environmental Engineering Program at Villanova since 1988. He is a registered professional engineer, and a Diplomat of the American Academy of Water Resource Engineers. Dr. Traver has conducted research on topics that include modeling of stream hydraulics, urban hydrology, water quality, and measures to mitigate adverse stormwater effects. He constructed the Stormwater Best Management Practice Demonstration and Research Park on the Villanova Campus, and founded the Villanova Urban Stormwater Partnership to enable continuing long term stormwater research. Immediately after the tragic failure of the New Orleans Hurricane Protection System, Dr Traver was asked to serve on ASCE’s External Review Panel (ERP) of the Corps investigation of Hurricane Katrina. Most recently he was honored by his appointment to a National Academies Project Entitled Reducing Stormwater Discharge Contributions to Water Pollution. He can be reached at robert.traver@villanova.edu.

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New Orleans faces unique types of catastrophic risk resulting from a combination of factors that include potential levee failure, land subsidence, coastal erosion, rising sea level, and stronger and more frequent storm activity. A comprehensive hazard mitigation strategy would address these unique types of catastrophic risks in addition to addressing the standard types of repetitive risk already covered by conventional approaches. Diverse actors are engaged in the making of this new strategy. This paper introduces New Orleans’ response to its emerging risk profile, with emphasis on the risk of flooding.

Background

The premise underlying the Federal Emergency Management Agency’s (FEMA) Hazard Mitigation Grant Program is that future claims covered by the National Flood Insurance Program (NFIP) must be reduced. Such claims arise as a result of flood damage to homes insured under NFIP. Flood insurance for homeowners is federally subsidized and shared across the U.S. In the case of Louisiana, most claims are covered by payments from outside the Southeast region (FEMA 2008). Naturally, the federal government has an interest in reducing overall program costs, and for this reason it operates a national hazard mitigation program comprised of several types of grants to mitigate against flood risk and to reduce the cost of claims. Only those homes that have already filed numerous flood damage claims are eligible for these grants. FEMA keeps track of these repetitively damaged homes by identifying them as Repetitive Loss and Severe Repetitive Loss properties.

To meet the goal of reducing the overall cost of claims paid, the primary objective of the Hazard Mitigation Grant Program is to provide grants for mitigating Repetitive Loss and Severe Repetitive Loss properties (e.g., by elevation, reconstruction, acquisition, etc.) when the cost of the mitigation is less than the cumulative cost of NFIP claims. Only NFIP-insured property owners are eligible, and only those property owners that filed enough past claims to warrant inclusion on the Repetitive Loss and Severe Repetitive Loss lists can receive mitigation grant money. Therefore, these criteria prioritize properties with a documented history of flood damage, and they direct hazard mitigation funds to properties that were the subject of past flood risk. While necessary in its own right, this hazard mitigation strategy is insufficient on several grounds. Most fundamental of these is that the strategy manages risk as if it were a static phenomenon. In truth, risk is a changing phenomenon. The risks of the past are not the same as the risks of the future. Moreover, our understanding of risk continues to change over time. As a result, the conventional hazard mitigation strategy as performed under FEMA’s Hazard Mitigation Grant Program contains gaps that preclude a focus on the elimination of future flood risk, which is considerable.

How Mitigation Funds are Prioritized

What does this mean in New Orleans? Figure 1 is a map of the properties on FEMA’s 2008 Severe Repetitive Loss list for New Orleans. The most severely damaged properties are concentrated in the lowest lying area of the city, known as the bottom...
of the New Orleans bowl, which happens to be in a neighborhood called Broadmoor. Broadmoor is a low and middle income area with a pre-Katrina average household income of $36,399 (compared to a parishwide average of $43,176 and a statewide average of $44,833). Benefit-cost ratios for mitigating the kinds of homes in Broadmoor range anywhere from 2 to 20, making mitigation quite a sound investment theoretically.

Most of the homes in Broadmoor are on the Severe Repetitive Loss list because their low elevation, and historically poor local drainage puts the area at high risk of flooding. In general, rainfall events above 0.5 inches per hour exceed the capacity of the city’s drainage pumps (Roberts 2008) and result in localized flooding in the lowest lying areas. New Orleans receives an average of 62 inches of rain each year, often in torrential downpours typical of humid sub-tropical climates. A history of poor drainage and low ground levels have resulted in repeated flooding and NFIP claims, as documented by Broadmoor’s prevalence on the Severe Repetitive Loss list. Housing developments were allowed to proliferate even in the lowest lying areas after the 1950s, when the city was under great pressure to expand. FEMA’s Hazard Mitigation Grant Program is perfectly designed for tackling the high frequency flooding that Broadmoor faces, and applying Program resources to Severe Repetitive Loss properties first achieves the Program’s fundamental objective. The City of New Orleans is in fact doing this. The great majority of its post-Katrina hazard mitigation funds are being used to elevate and reconstruct homes in the Broadmoor area.

The City is subject to riverine, coastal, and rainfall-induced flooding. This flood risk was last codified by FEMA in 1980s-era flood insurance rate maps for New Orleans. In those maps, the entire neighborhood of Broadmoor is designated an “A” Zone, indicating that the whole neighborhood is within the 1 percent (i.e., 100-year) flood zone and that NFIP flood insurance is required. So, despite its apparently undesirable location in the bottom of the bowl, the Broadmoor neighborhood is nicely covered by the NFIP and Hazard Mitigation Grant.
In addition to these programs, the Broadmoor neighborhood has recently received local flood control infrastructure improvements as part of the Southeast Louisiana Urban Flood Control Project. These improvements, which include a pump station expansion and box culvert to transport rainfall-induced flood waters away from the area, were completed in 2004 by the Army Corps and Orleans Parish. The project has successfully reduced flood risk to the point where past risk no longer provides an accurate picture of future risk. Properties on the Repetitive Loss and Severe Repetitive Loss lists are no longer subject to the same flood risk that put them on these lists to begin with, as documented thoroughly by a neighborhood area analysis conducted by the University of New Orleans (Laska et al. 2007). This is a case study of success, where the conventional strategies of flood plain management, flood control, and mitigation have combined to reduce overall risk in one of the most flood-prone areas of the city.

But despite this success, much more of New Orleans is at risk of flooding outside of the low-lying bowl. Figure 2 shows the properties on FEMA’s 2008 Repetitive Loss list for New Orleans, and Figure 3 shows the properties that were substantially damaged as a result of Hurricanes Katrina and Rita. It is evident from Figure 2 that there are thousands (i.e., over 6000) of repetitively damaged properties in New Orleans primarily due to moderate rainfall events, and that these properties are quite evenly distributed throughout the city. On the other end of the scale are the catastrophically damaged properties that resulted from Hurricanes Katrina and Rita, which are also well distributed across the city. Figures 2 and 3 reveal that flood risk in New Orleans is widespread; however,
neither of these maps gives the policymaker any leverage in terms of prioritizing mitigation.

The question is whether the widespread risk shown in Figures 2 and 3 can be mitigated effectively using the conventional Hazard Mitigation Grant Program mitigation approach that is so well suited for mitigating the risk shown in Figure 1. There clearly is not enough Program funding to mitigate every home on the Repetitive Loss list or to mitigate every substantially damaged property in New Orleans, and it does not make sense to simply elevate random individual homes throughout the city (https://ipet.wes.army.mil). What is needed is a strategy for prioritizing mitigation beyond using the Severe Repetitive Loss list. Fortunately, more information about risk is now becoming available that will guide future mitigation efforts in a comprehensive way.

**The Emerging Picture of Flood Risk**

No city in the world understands its future flood risk better than New Orleans. Because of the severity of Hurricanes Katrina and Rita in 2005, New Orleans now has the best available surge and flood risk models in the world, including the complex storm surge model produced in collaboration with the Army Corps by the Interagency Performance Evaluation Task Force. New Orleans now has a better idea of which sections of the levee system are weaker than others, and we now know exactly what areas are most at risk of flooding. Figure 4 is one of the Interagency Performance Evaluation Task Force risk maps recently made available to the public on the Army Corps’ website (as of March 2008). It highlights the areas of the city most at risk of surge-induced flooding during a 1 percent (i.e., 100-year) storm with 50 percent

![Figure 3](https://example.com/figure3.png)  
**Figure 3.** Properties in New Orleans substantially damaged by Hurricanes Katrina and Rita in 2005 (Source: Office of New Orleans, Mayor’s Office of Technology, GIS Department).
Figure 4 includes levee repairs and improvements completed as of June 2007 (IPET 2008). Like many of the maps released with the Interagency Performance Evaluation Task Force Report, it reveals that the eastern half of the city is more at risk of flooding than the western half. These high risk areas include the neighborhoods of Gentilly, New Orleans East, and the Lower 9th Ward. These areas do not have the historical and well-documented drainage problems of Broadmoor; in fact they rarely flooded at all.

It is important to point out the striking contrast between the areas of past risk that were mostly contained inside the New Orleans “bowl” (Figure 1) and the areas of future risk that are primarily located in the eastern half of the City (Figure 4). It is also important to recognize several key distinctions when viewing the various maps. Figures 1 and 2 were developed from actual cumulative damages caused by intense rainfall and hurricane-induced flooding, while Figure 3 was developed from actual damages caused by two catastrophic hurricane-induced flood events. Figure 4, on the other hand, was derived from probability calculations of the risk of surge-induced flooding caused by a wide range of hypothetical events. The conventional mitigation approach has been developed on the basis of an accumulation of actual damages, not on the basis of catastrophic events or hypothetical risk. As a result, the areas of New Orleans that are at highest future risk (i.e., the eastern half of the city), are not currently prioritized for Hazard Mitigation Grant Program mitigation funding because of their low prevalence on the Severe Repetitive Loss list.

What is so different about the risk in these two areas that the outcomes can be so disparate? Broadmoor’s risk is largely due to frequent intense rainfall events and occasional hurricane
events, while risk in the eastern neighborhoods (i.e., Gentilly, New Orleans East, and the Lower 9th Ward) is mostly due to catastrophic hurricane-induced flooding. This difference in risk – high frequency risk versus high consequence risk – is significant because the conventional mitigation approach is designed to handle high frequency type risk quite well, but not high consequence risk. Most of New Orleans’ high consequence risk is mitigated by the levee system and flood zone management, but, despite this system, local differences in high consequence risk remain.

While the differences in high frequency risk were widely known because they were visible every year, the differences in high consequence risk were not widely apparent before Hurricane Katrina. As a result, residents had no way to know what they were getting into (in terms of high consequence flood risk) when they made decisions about where to live. It is critical for all New Orleans residents to understand not just risk, but the type of risk and how it is geographically distributed.

Developing a Hazard Mitigation Program for New Orleans

What can New Orleans do to reduce residual high consequence risk across the city if the funding available through the Hazard Mitigation Grant Program cannot be readily targeted to the areas of the city most at risk? Prior to Hurricane Katrina, mitigation had not been deeply incorporated into urban development decisions in New Orleans. Rather, New Orleans had relied historically on a federal system of levees, floodwalls, and pumps to provide the primary protection from flooding. Despite the fact that much of the city was below sea level and that land subsidence was a continuing reality, large swaths of the city were allowed to be constructed with slab-on-grade construction and many residents in elevated homes were allowed to inhabit the first floor, thus placing people and property in direct risk of flooding. An exaggerated sense of reliance on the levee system (now known as the hurricane protection system) probably fueled these settlement patterns, which in hindsight now seem foolish. Furthermore, after Hurricanes Katrina and Rita the City was unable to strictly enforce elevation requirements on substantially damaged properties (USA Today, Sept. 2008). Urban planning decisions, enforcement of building standards, flood plain management, and emergency preparedness all have enormous impacts on risk exposure and on actual damages to life and property, and these are the kinds of decisions to which municipal officials can directly contribute. One of the positive outcomes of the catastrophic levee failure in New Orleans is that the stage was set for strengthening these areas and for incorporating mitigation into the city’s rebuilding and recovery process.

A hazard mitigation unit was launched in February 2007 as part of the city’s recovery management office (see Table 1). In August 2008, the hazard mitigation unit transitioned into its permanent organizational home in city government, the Office of Homeland Security and Emergency Preparedness. The hazard mitigation unit is developing mitigation policy along two major lines: 1) maximize the city’s participation in FEMA’s conventional hazard mitigation grant programs to provide protection in areas of the city at highest historic risk based on past NFIP claims

Table 1. Objectives of the New Orleans hazard mitigation unit.

- Communicate hazards and risks to New Orleans residents in coordination with the Office of Emergency Preparedness, the Office of Communications, the Office of Recovery, the LRA, GOHSEP, FEMA, and the Army Corps of Engineers.
- Develop comprehensive solutions, policies, and programs to manage hazards and risks in coordination with the Department of Safety and Permits, the Office of Emergency Preparedness, and the City Planning Commission.
- Build long-term City capacity in hazard mitigation and risk reduction, including acquiring funds for hazard mitigation projects.
- Include knowledge about hazards and risks into city planning and project development processes.
- Incorporate hazard mitigation and risk reduction principles and requirements into the City’s Master Plan and Municipal Code.
(i.e. high frequency risk mitigation), and 2) seek Hazard Mitigation Grant Program and other funds to develop a non-structural program that provides mitigation in areas of the city at highest future risk (i.e., high consequence risk mitigation). These two policy components are a direct response to the two broad types of risk that were described previously. Since Hurricane Katrina, the hazard mitigation unit has sought over $100 million in FEMA mitigation grants for activities including (1) elevating and reconstructing homes on the Repetitive Loss and Severe Repetitive Loss lists; (2) hardening drainage pump stations, the emergency operations center, and other critical facilities; (3) implementing flood control projects in several neighborhoods; (4) conducting a citywide all-hazards risk assessment; (5) updating the city’s mitigation plan; and (6) scoping new mitigation projects. FEMA has also expanded the amount of hazard mitigation funds directly available to homeowners.

The City’s hazard mitigation unit is developing a non-structural program to protect the most at-risk areas of the city using Hazard Mitigation Grant Program grants to incentivize mitigated development on higher ground. A non-structural strategy will be incorporated into the City’s long-term urban development policy via a number of steps. First, the policy will be articulated in the update to the City’s Hazard Mitigation Plan. This plan will be linked to the City’s master plan, zoning ordinance, and municipal code, and projects will be scoped and implemented.

In selecting pilot and demonstration projects, the City will prioritize projects located in Target Recovery Areas identified in the City’s recovery plan, projects located in areas with a high or medium residual risk of flooding to maximize the benefit of investing in mitigation, and projects that facilitate the creation of clustered communities and that keep neighborhoods intact. There is widespread agreement that the target recovery areas are critical to the City’s economic and neighborhood development, and for this reason these are the City’s priority areas for investment. It is also widely understood that returns on investment in mitigation are higher when the avoided cost of damage is high, resulting in higher benefits at higher risk levels and lower benefits at lower risk levels. Furthermore, building clustered development around strong economic and commercial centers and maintaining existing neighborhoods to the degree possible are aspirations that were widely cited by New Orleans residents in the 2007 Unified New Orleans Plan. These principles will be carried forward as part of a non-structural policy. Five types of non-structural protection will be demonstrated:

- **Property Buyouts and Relocation to New Elevated Structures.** This option involves buying out homeowners located in low-lying, high risk areas and offering them new elevated homes elsewhere in the same or an adjacent neighborhood. The cost of the buyout and the cost of providing mitigated housing would be covered by the project. For an existing urban area like New Orleans, the bought out property must be able to be redeveloped appropriately.

- **Elevation of Structures in Place.** Existing homes or commercial structures would be elevated on their existing site. To qualify for this option the site can be at more than medium risk, where relocation is not required, but mitigation is still achieved. Higher risk sites will require relocation because structures cannot be elevated above the maximum 12-15 feet. For most structures, elevations of this height would be undesirable for functional reasons.

- **Secondary Levees/Floodwalls.** This option involves the construction of small secondary levees or floodwalls, up to 6 feet around critical public facilities or commercial facilities.

- **Dry Flood Proofing of Commercial Facilities.** In this option waterproof walls up to 4 feet in height would be installed on the surface of the existing external walls of a commercial structure. To qualify for this mitigation method the structure must be located in an area that has not received more than 2-3 feet of flooding.

- **Hardening of Critical Facilities.** Critical facilities would be retrofitted to increase their operability during a typical flood event. Changes would include: elevating pumps, generators, electrical wiring, and
other critical equipment above a structure’s flood zone; moving operations above the first floor.

Developing a clustered residential elevation program (i.e., the first example listed above) is particularly difficult to implement in existing neighborhoods for several reasons. The first challenge is the extensive information needed at the address level about risk, cost, and the desire of existing property owners to make appropriate siting decisions. Also, large scale property acquisition is problematic in most cities because removing property from commerce in perpetuity (as required under FEMA’s traditional mitigation rules) is undesirable from a local economic development and recovery perspective (FEMA 1999). Voluntary buyout programs (such as the buyout option associated with FEMA’s Road Home Program) typically yield only scattered sites rather than contiguous land, so this approach only goes so far in terms of risk reduction. A demonstration of clustered, elevated residential development will most likely be associated with new construction and will probably have to target specific homeowners from a medium-to-high risk location. Most of the arrangements for this kind of demonstration project will have to be worked out with individual homeowners on a case-by-case basis.

Less than half of the households have returned in 16 of the 50 New Orleans neighborhoods that flooded in Hurricane Katrina (Greater New Orleans Community Data Center 2008). And with each additional significant storm, the public increasingly wonders about the level of risk and the recurring cost of rebuilding. FEMA’s ongoing project to update the country’s flood insurance rate maps, including the New Orleans maps, will incorporate much of the now-public risk information provided in the Interagency Performance Evaluation Task Force maps. This could result in the re-zoning of some at-risk areas and possibly an increase in flood insurance rates in those areas, which would further incentivize existing residents to mitigate their properties or move to higher ground. To avoid the potential dampening effects on the City’s recovery and on the rate of population return, it is important to have non-structural options available to affected residents so they can make decisions based on full knowledge of risk and cost. Such options should be widely available, but prioritized for known areas of risk such as the eastern half of the city and the bowl. In order to succeed in doing this, conventional hazard mitigation criteria must be adjusted to the new conditions of existence in New Orleans. If these criteria are not updated, then much of the city will not be eligible for mitigation in spite of their risk level and the degree of flood damage caused by Katrina and Rita.

Several tensions and challenges have emerged thus far in developing these parallel policy approaches. First of all, funding is readily available for the first policy area through a range of hazard mitigation grants provided by FEMA; however, there is no direct funding for a city-driven non-structural program per se. The funding that is available is very short on administrative support, leaving most cities, including New Orleans, without an ongoing source of funds to establish permanent hazard mitigation divisions with adequate levels of capacity and authority. New Orleans has been fortunate to receive supplemental support by outside organizations, especially the Orleans Recovery Foundation, which has provided the City with a mitigation director. A more sustainable solution would be for FEMA to enhance the administrative funds available to local jurisdictions and municipalities to cover the actual administrative costs of running a hazard mitigation division, particularly in cities like New Orleans that must manage both frequent and catastrophic risk.

With regard to the second policy area, City officials have been discussing a non-structural strategy with officials from the Army Corps’ non-structural division, and the outcome of these discussions appears in the Draft Louisiana Coastal Protection and Restoration (LACPR) Report as a set of recommended pilot projects (US Army Corps of Engineers 2008); however, funding for these projects is currently unidentified. The non-structural policy directive remains on the city’s policy agenda; however, the city is attempting to use the Hazard Mitigation Grant Program to fund similar pilot projects that are designed to address the residual risk that will remain after the Army Corps has the 100-year hurricane protection system in place by 2011. The projects will target substantially damaged homes in target recovery
areas and housing opportunity zones most at risk of flooding (structures subject to 3-13 feet of flooding) in order to provide more uniform levels of protection against future flood hazards. At an average reconstruction cost of $93.50 per square foot, a typical 1800 square foot home would cost $168,300 to reconstruct and elevate. The city plans to use a $3 million non-competitive Hazard Mitigation Grant Program allocation associated with Hurricane Katrina to develop an elevated cluster of about 15 reconstructed homes. Because these funds have been made available on a non-competitive basis, the City has more discretion in establishing criteria for the use of these funds. The exact location of the project will be determined using information on damage estimates, flood depths, residual risk, and repetitive loss history.

Other than program and administrative funding, the second major challenge that has developed in establishing and implementing non-structural hazard mitigation policy in New Orleans has been a lack of access to technical information and modeling results. Such information is typically kept confidential by the Corps and FEMA until it is ready for public release. However, cities should be seen as real partners in hazard mitigation rather than consumers who are the last to know. If non-structural approaches are to succeed, local jurisdictions will need access to technical information in real time in order to engage our communities in discussions of risk as people are making decisions about where to rebuild and where to invest scarce resources. We need technical information to back up the advice and recommendations we make to elected officials who are the final decision makers when it comes to budget priorities. Cities must be involved not only as stakeholders, but as decision makers in responding to risk if we are to remake New Orleans.

Conclusion

The City of New Orleans is developing a comprehensive mitigation program that embraces non-structural approaches for managing both high frequency risk and high consequence risk. According to the Interagency Performance Evaluation Task Force results, over half of the city is at risk of significant flooding, and some areas will continue to live with residual risk after repairs and improvements to the hurricane protection system are complete. FEMA’s conventional Hazard Mitigation Grant Programs are well-suited for dealing with high frequency risk at scattered individual sites; however, in cases where selection criteria are less restrictive, the City is using Program funds to initiate non-structural pilot and demonstration projects that include clustered elevated housing developments. As more and more details emerge about the flood risk in New Orleans, the City’s response has been to embrace non-structural approaches that increase overall risk reduction beyond that provided by the hurricane protection system.

Author Bio and Contact Information

Earthea Nance, Ph.D., P.E., is currently the Director of Disaster Mitigation Planning for the Mayor’s Office of Homeland Security and Emergency Preparedness in the City of New Orleans. Prior to that, she served in the City’s Office of Recovery as the Director of Infrastructure and Environmental Planning. Dr. Nance has held faculty positions in urban environmental studies at Virginia Tech and Massachusetts Institute of Technology. She formerly served as an environmental engineer for Lawrence Livermore National Laboratory, and as a principal environmental engineer for two consulting firms in California. She can be reached at eanance@cityofno.com.

End Notes

1. The 1968 National Flood Insurance Act (Section 1361A) and the 2004 Flood Insurance Reform Act (Section 102, 42 U.S.C. 4102a) define Repetitive Loss properties as having at least four damage claims of over $1000 each or two separate claims within a 10-year period that when combined equal or exceed the market value of the property or at least three claims that equal or exceed the market value of the building. Severe Repetitive Loss properties must have at least four building and content claim payments over $5000 each or two separate building claim payments within a 10-year period that when combined exceed the market value of the building. In both cases, the designation applies only to residential property.

2. These data are available at <www.gnocdc.org/index.html>.

3. The FEMA flood maps that were in effect for New Orleans as of September 2008 are available at <http://www.cityofno.com/portal.aspx?portal=1&tabid=56>. 
4. Because of storm-induced power outages and flooding, the city had only 15 percent pumping capacity during Hurricane Katrina (Interagency Performance Evaluation Task Force Report 2007).

5. The term “non-structural” differentiates secondary flood protection from primary “structural” protection provided by the federal system of levees, floodwalls, pumps, and gates that allows the greater New Orleans area to exist. A non-structural flood protection strategy would further reduce the risk of property damage from future disasters in New Orleans beyond the structural protection provided around the perimeter of the city by the U. S. Army Corps of Engineers’ hurricane protection system.

6. A map showing the location of target recovery areas (and the surrounding Housing Opportunity Zones) is viewable on the City of New Orleans website at [www.cityofno.com](http://www.cityofno.com).

References


To What End: Resilience, Tradeoffs, and the Lessons of Katrina

Mark S. Davis

Senior Research Fellow and Director, Tulane Institute on Water Resources Law and Policy, Tulane Law School

Modern industries are handling the forces of nature on a stupendous scale….Woe to the people who trust these powers to the hands of fools! Then wealth is destroyed, homes are overwhelmed, and loved ones killed. John Wesley Powell, “The Lesson of Conemaugh” (North American Review, August 1889: 156)

The storm was not a surprise. We could see it coming. In August 2005 Hurricane Katrina was strong and massive as it approached the Gulf Coast and New Orleans. We knew that rising seas, sinking lands, and the loss of the wetlands and barrier islands that historically had buffered our cities and towns made us increasingly vulnerable to storms. We even knew, if we were paying attention, that it would overwhelm some of our levees and pumps leaving some of our neighborhoods flooded and our outlying areas devastated. We knew that. But we also believed some things.

We believed that, bad as it might be, the levels of flooding, in New Orleans at least, would be limited to a few feet and most likely a few days. We believed that the levees and flood walls would hold and that the City would clean up, mop up, and move ahead with life as it always had. After all it had happened before – at least 38 times hurricanes have reached New Orleans – and besides, this is America and we do not let our engineering and public rhetoric get bested by nature. We believed that. We were wrong.

The aftermath of Katrina, and its sister storm Rita, left us, the nation, and even much of the world stunned. How could such a thing have happened? What lessons did it teach? More importantly, have any lessons been learned? There will probably never be final answers to those questions but a few important things are already clear.

Hurricane Katrina happened because it was inevitable. Storms are a natural part of this landscape the same way fires are to prairies and forests. We could not have prevented Katrina and will not be able to prevent the next storm. The death, destruction and dislocation that resulted from the storms are a different matter. They were not so inevitable. It was not a hurricane that wrecked New Orleans but rather a combination of trade-offs, compromises and decisions that turned powerful natural events into human tragedy. This is the central lesson, the central tragedy of Katrina.

New Orleans, like most major port cities, was a hard bargain with nature from the get-go, but a bargain that had to be made. Its vulnerabilities to storms, flooding and disease were appreciated by its founders but more than offset by its strategic and commercial value. The city grew and prospered as a result of its proximity to the Gulf of Mexico and the Mississippi River and the attendant risks were managed through its infrastructure, architecture, and grit. Without the benefit of federal flood protection or flood insurance the city grew to greatness, its population reaching its zenith of nearly 650,000 in the early 1960s.

Ironically, the seeds of Katrina’s destruction of New Orleans were sown in large part by federal and local programs and public works projects intended to spur economic development and provide flood protection. Concerns about how navigation channels, oil and gas activity, drainage projects, and levees might degrade wetlands or increase flood risk were trumped by the prospect of growth and economic gain. Public funds were used to build levees around wetlands to induce development instead of increasing the protection
for existing neighborhoods. State and federal involvement in the flood and property and casualty insurance business induced people to build and live in places and in ways that would have been unthinkably risky before.

In short, people were in harm’s way because it was, in effect, policy to put them there – the unintended but very real result of compartmentalized planning and decision making married to a pronounced practice of overestimating benefits and undervaluing risks and costs. Nowhere is this clearer than in the case of the hurricane protection system surrounding New Orleans.

Hurricane protection for New Orleans, and as a responsibility of the U.S. Army Corps of Engineers, is a fairly recent development. New Orleans has had levees on the Mississippi Rivers since the time of French settlement. For most of its history, New Orleans was open to periodic hurricane flooding. By concentrating its development on higher ground and by elevating structures the city not only survived but thrived. Storms still came, but flood waters would drain, buildings would dry out, losses would be mourned and life would go on.

Growth pressures fueled land reclamation projects in the 1930’s along the shores of Lake Pontchartrain that drew residential development to the lake front and effectively created a levee, but it was one with houses on top of it, not one to protect what was behind it.

Things changed dramatically in 1965 when Hurricane Betsy hit, the storm against which all others would be measured until Katrina. The flooding in some neighborhoods was much like that in Katrina. The response was anything but. In those days the nation’s appetite for public works was much greater than it is today and President Lyndon Johnson spurred Congress to authorize a massive federal hurricane protection system for the entire New Orleans area that would guard it against the worst storm that might reasonably be expected. That was thought to be what we would now call a once in 200-300 year storm event. It turned out that something very different was built.

The system that was built – the system that failed – was the product of political and budgeting compromises, the failure to adapt to changing conditions and knowledge, and human error. That system, combined with the shifting of risk made available by the flood insurance program, led to changes in expectations and behavior. Low-lying areas were drained and developed, homes were built on slabs instead of being elevated, and less water resistant building materials were employed. The importance of natural defenses and individual and local responsibility were largely lost. After all, the federal government was providing protection and shouldering most of the burden. The perverse result of this was a city that gained protection but lost resilience. The net effect was a city at higher risk.

The notion that decades of work and billions of dollars actually exacerbated risk is not an easy thing to accept. Harder still is the fact that the tens of billions of dollars that have been committed to patching the failed system and rebuilding the devastated communities since Katrina could have the same effect if important changes don’t occur in the way protection, resilience, and community vitality are approached. First and foremost, before embarking on any flood or storm protection effort it is crucial to ask two questions: How safe do we want to be? What values do we want to enhance or secure in the process? The failure to ask these questions or to slough the answers, as happened in New Orleans, can be the difference between vitality and calamity.

Admittedly, these are very subjective questions, but life is a subjective undertaking. The suggestion, often made, that we can or should leave these matters to objective scientists and engineers is a dodge. The best of our objective knowledge can inform our judgments and define our tradeoffs but they cannot set our purposes or make our decisions for us. This is particularly so when the key decisions are not technical in nature, but rather are legal or policy matters. This is what makes New Orleans’s Katrina experience so instructive. But to understand the lesson, one first needs a little history.

The vulnerability of New Orleans to hurricanes was well known. The Army Corps of Engineers had begun studying protection options pursuant to a Congressional study authorization in 1955. Those plans, still under development, took on a level of importance and urgency when Hurricane Betsy struck in 1965. Shortly thereafter, Congress directed the Army Corps of Engineers to develop
a hurricane protection plan for the New Orleans region to combat a “hurricane that may be expected from the most severe meteorological conditions reasonably characteristic in the region”

Roughly speaking, that meant a storm equivalent to a Category 3 storm on the Saffir-Simpson Scale or, as noted earlier, a once in 200-300 year event. Hurricane Katrina, a Category 3 storm at landfall in Louisiana, was in the range of storms that New Orleans was supposed to be protected against. Leaving aside the very real possibility of negligence and human error, the fact that those constructed protections not only were overwhelmed but failed is less a matter of having the know-how to have built a more robust and resilient system than it was of not having the will and wisdom to build that system.

Such a system is more than a network of levees, gates and pumps. It is a purposeful and methodical approach to living with water that includes wetland conservation and restoration, land use controls, evacuation plans, adaptation to changing conditions (e.g., sea level changes and improved knowledge), and finally levees, gates, and pumps. There is nothing really new here. The importance of wetland and barrier buffers, flood-proofing, and land use planning and regulation were clearly recognized in the 1966 report of the Task Force on Federal Flood Control Policy and President Lyndon Johnson’s message transmitting the report to Congress. While urging greater federal involvement in flood protection, President Johnson wrote, “I cannot overemphasize that very great responsibility for success of the program rests upon State and local governments and upon private property owners in hazard areas. The key to resolving the problem lies, above all else, in the intelligent plan for and State and local regulation of use of lands exposed to flood hazard.” (Emphasis added)

Despite that clear awareness, the prospect of levees spurred more development in low, wet areas and the construction of unelevated structures and the use of unresilient building materials. The over reliance on structural flood protection actually created new vulnerability and each year that passed without a major storm fed a growing belief, a complacency, that all was well and life inside the levees could go on without worry. Indeed, prior to Hurricane Georges (1998) New Orleans was not a place to evacuate from but a place to evacuate to.

In and around New Orleans the appearance of protection had become confused with the fact of protection. That was never an intentional deception, it was one arrived at gradually through a series of compromises, tradeoffs, and mistakes. Rainwater flooding concerns trumped storm flooding risks. The need for land use controls and hurricane building codes were trumped by the desire for low-cost, quick housing and the assumption that the levees had eliminated the risk. Wetland conservation and restoration were trumped by economic development and private property rights pressures. And the need to adapt to improved knowledge about hurricanes, sea level rise, and coastal land loss was trumped by the pressure to build what had been planned and politically promised. The idea that just building something was better than nothing was irresistible. The foolishness of those tradeoffs is as apparent now as were the lessons of the Johnstown flood (Conemaugh) to John Wesley Powell. But the pressures that led to them were predictable, just as it is predictable they will recur.

Indeed if there is one common theme in humankind’s reaction to great disasters it is the tendency to try to become ignorant of their lessons as quickly as possible. That instinct may have had utility in a distant past when human society had a more passive relationship with nature, but it is dangerous folly today. New Orleans is a portent of the challenges that face many places. We can muddle along, content to be victims of change, or we can use the best of our abilities – our science, our engineering, our laws, arts, ethics, and our policies – to be purposeful managers or stewards of change. There is scant middle ground. The central lesson of this tale is that the tradeoffs we make matter and there is hell to pay when we get it wrong. It is lesson well taught. Whether it is a lesson well learned remains to be seen.

There is at least some evidence it is being learned. Wetlands restoration and accommodating sea level rise are now broadly recognized as essential components of flood protection and the sustainability of the region. The state has recognized the need for smarter land use choices and has adopted a state-wide building code.
The Mississippi River-Gulf Outlet has been deauthorized. The Army Corps of Engineers has shifted from providing a levee system with a high protection target (against 1-in-300 year events) with a low confidence level to a lower level of protection (1-in-100 year events) with a higher confidence factor.

Much more will be needed however. The real proof will come when the hard choices are made about which communities will get higher levels of protection – and when. It will come when the decisions are made whether to fully commit to conserving and enhancing Louisiana’s coastal wetland landscape. It will come when land use planning is made a priority with the force of law. And it will come when the state and the nation decide to develop and implement effective strategies for contending with climate change and rising seas.

None of this will be easy, but neither will it be easy to live with the consequences of standing pat. At stake in Louisiana and elsewhere is the fundamental tradeoff question: Are we as a people willing to make the laws, polices, investments, and commitments necessary to give ourselves a shot at a vibrant and sustainable future? The stakes are high and time is shorter than many think.

End Notes

5. Id.

Author Bio and Contact Information

Mark Davis is a Senior Research Fellow at Tulane University Law School and Director of the Institute on Water Resources Law and Policy at the Law School. He can be reached at msdavis@tulane.edu or 504-865-5982.
A New Approach to River Management: Action for a Sustainable Coastal Landscape

Denise J. Reed

Pontchartrain Institute for Environmental Sciences, University of New Orleans
Department of Earth and Environmental Sciences, University of New Orleans

“Sustainable restoration of Louisiana’s coast and all it supports can be achieved only by redirecting the freshwater and sediments of the Mississippi River onto the nearshore, stemming the direct loss of these valuable resources to the deep waters of the Gulf of Mexico.”

On June 1, 2006 at the beginning of the first hurricane season after Hurricanes Katrina and Rita, a group of 35 experts in geology, ecology, coastal geomorphology, oceanography, engineering, and economics from across the United States and from as far away as Italy, the Netherlands, the United Kingdom, Egypt, Russia, and Australia delivered this message to the Governor of the State of Louisiana (http://www.futureofthegulfcoast.org/files/finalreport.pdf). Brought together to consider the future of the Louisiana coast after the hurricanes of 2005, for a week in April 2006 the Technical Group of the Envisioning the Future of the Gulf Coast (TGEFGC) conference toured the coast, heard about its problems, shared their perspectives, and then developed their recommendations. This paper considers those recommendations and the progress, or lack thereof, toward their implementation in the post-Katrina management of the Louisiana coast.

The Future with Current River Management

Their message was clear – without aggressive action, the future is bleak for Louisiana. Even if populated areas can be protected from hurricanes with levees and floodgates, the continued loss of the coastal landscape will pose an increasing threat to the regional economy and environment. Despite all of the previous restoration efforts, including the investment of over $50 million per year since 1990 under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) – a wide range of analyses still shows that land loss exceeds land gain (Barras et al. 2003, Bernier et al. 2006). The processes that contribute to ongoing land loss (Day et al. 2007) will be compounded in the 21st century as sea-level rise accelerates (Intergovernmental Panel on Climate Change 2007, Rahmstorf 2007) and by the likelihood of increased frequency or intensity of major hurricanes (Webster et al. 2005, Emanuel 2005). Higher and wider levees will be required just to retain the current levels of storm flood protection for the communities fortunate to be within a protection system. The haphazard retreat of people from the unprotected communities along the coast that occurs after every storm impact will continue. Despite these projected calamities, more than 120 million tons of river sediment that could be used to rebuild and sustain the coast will be lost to the Gulf of Mexico each year (Galler and Allison 2008).

The Call for Action

Small-scale management efforts such as sediment mining to construct marshes and stabilize barrier islands or the diversion of flow and sediments from the Mississippi River through controlled breaches may slow land loss locally. However, from the system perspective, the collateral impacts of some of these approaches must be weighed against their benefit. Many past restoration
projects have mined the bottom of shallow open bays to rebuild marsh substrates in adjacent areas. The volumes of the material excavated are not trivial. For example, two CWPPRA projects, the Dedicated Dredging near Round Lake, and Bayou LaBranche Wetland Creation each dredged approximately two million m$^3$ of sediment from adjacent water bottoms for marsh creation. Cannibalizing adjacent habitats to replace lost marsh is not a sustainable approach to system level restoration in coastal Louisiana. Such measures will never achieve a sustainable coastal landscape for future generations. Allowing relatively small amounts of the riverine sediment supply to reach coastal wetlands through ‘diversions’ gives the false impression that the coastal landscape can be restored while maintaining ‘business as usual’ on the river. Rather, all the available resources of the Mississippi and Atchafalaya Rivers will be required to sustain the coastal system, as was typical over past millennia before engineered channels and levees began forcing sediment directly to the deep Gulf, reducing coastal sediment deposition.

According to the TGEFGC, aggressive action is needed to redirect all of the available renewable resources within the Mississippi River system to rebuild, replenish, and sustain coastal Louisiana. Harnessing the resources of the Mississippi River is the only way to move towards a sustainable landscape in the face of continued subsidence, rising sea levels, and more frequent and intense tropical storms and hurricanes. It is important to recognize that under the best of circumstances, the sustainable coast will likely be smaller than the present, and its character, in terms of the distribution of habitat types and the configuration of landforms, will be different from both the present and the recent past. However, it could still support the culture and economy unique to the region by allowing many threatened coastal communities to safely persist as well as maintain the array of recreational and commercial activities currently enjoyed that are dependent on healthy wildlife habitat and ecosystems.

An Opportunity for Action

Such a new approach to management of the Mississippi River and its resources can be compatible with the needs of riverine navigation and the provision of freshwater for industries and residents. Our current approach to river management began in the 1800’s with the taming of the river for navigation. Control and management of the river system was reinforced with the 1927 Mississippi River and Tributaries Act. Since that time, navigation and flood control have been the paramount concerns in managing the Mississippi River system, not the sustainability of the coastal ecosystem. However, in the 2007 Water Resources Development Act, Congress identified coastal restoration as an important national priority comparable to that for River navigation and flood control. Section 7002 of the Act integrated the traditional concerns under the Mississippi River and Tributaries program into a long-term framework for the coast that provides for “the comprehensive protection, conservation and restoration of the…coastal Louisiana ecosystem”.

Further, the 2007 Water Resources Development Act calls for an investigation of strategies to take maximum advantage of the water and sediments of the Mississippi River system for coastal restoration.

Since the passage of the 2007 Water Resources Development Act, there has been little obvious action toward a new approach to using the resources of the Mississippi River. Rather, agencies involved in restoration are wrangling over who should pay for shoaling in the river apparently induced by a Coastal Wetlands Planning, Protection, and Restoration Act project that moves water and sediment into West Bay. The potential for shoaling has long been recognized, ‘The diversion may induce shoaling in the main navigation channel of the Mississippi River and the adjacent Pilot town anchorage area. Dredging of the main channel is accomplished under the U.S. Army Corps of Engineers’ ongoing Operations and Maintenance Program for the river, but additional dredging of the anchorage area would be an added feature and cost of the project.’ (MR-03 Project Fact Sheet - http://lacoast.gov/reports/gpfs/MR-03.pdf). The discussion about who pays for shoaling the river channel resulting from the removal of water and sediment for restoration purposes illustrates the disconnect that still exists amongst those seeking to use the river for navigation and trade and those seeking a sustainable coast. Despite the
recent legislation, navigation is still seen as the primary use of the river – currently any alterations or modifications to that use associated with reconnecting the river with the delta plain must be compensated.

The Future of the Coast

The TGEFGC acknowledged that the future would not be like the past, that a sustainable coastal landscape was possible, even in the face of subsidence and sea-level rise, if bold action is taken and the sediment resources of the river are directed to restoring the coast. Achieving a sustainable coast will bring change for all aspects of the environment and the river-dependent economy. The sediments supplied by the Mississippi River are insufficient to rebuild and maintain the entire coast as it looks now. The future coastal landscape will likely be less extensive than at present, and retreat from some areas must be expected and planned for. Such changes occur now as communities react to storms, coastal land loss, and as global trade and changing societal preferences influence commodity prices for seafood.

Change is also on the horizon for others who use the river. As issues such as biofuel production and climate variations influence global commodity prices, the types of materials imported and exported from the U.S. via the Lower River will also change. Just as the nature of vessels entering and leaving the mouth of the river have changed since the mid-19th century, so will they likely change in the 21st century as vessel drafts increase, the new expanded Panama Canal facilities are completed, and fuel prices alter the economics of global trade.

The idea of fully utilizing the resources of the Mississippi River to restore the coast is not new. Many recent coastal restoration plans (e.g., the 1998 COAST 2050 report (LCWCRTF 1998) and the Louisiana Coastal Area (LCA) Study (USACE 2004)) document the importance of major realignment of the lower Mississippi River as essential to addressing coastal sedimentation issues and comprehensive restoration. Managing the river as a whole is a daunting task – and all previous restoration plans include an array of seemingly more tractable, if less effective, approaches. It requires the engagement of an array of stakeholders, addressing technical challenges, and the direct involvement of many state and federal agencies. There are three essential steps to moving this concept forward:

- establishment of a committed high-level leadership group (including State and Federal officials with decision-making authority, senior experts in engineering and natural sciences, and conservation leaders),
- outreach to and involvement of key stakeholders for the affected economies, environments, and societies, and
- an invitation for the world’s experts on large river management and public works to contribute the newest and best ideas.

Most importantly, a new approach to river management requires forward thinking. Thinking more about the possibilities for the future than the problems of the past; thinking about economy, environment, and society together as a system. The group of 35 scientists and engineers convened as the Technical Group for Envisioning the Future of the Gulf Coast started that thinking anew. For post-Katrina coastal Louisiana, turning those thoughts into plans and actions is essential.

Acknowledgements

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Author Bio and Contact Information

Denise Reed is a Professor of Earth and Environmental Sciences at the University of New Orleans and Interim Director of Pontchartrain Institute for Environmental Sciences. He can be reached at: Department of Earth and Environmental Sciences, University of New Orleans, 2000 Lakefront Dr., New Orleans LA 70148. e-mail djreed@uno.edu.
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Environmental problems (e.g., eutrophication, unsustainable fisheries, wetland loss, climate change, etc.) are inherently complex, with increasingly dominant effects of human systems on natural system dynamics (Vitousek et al. 1997). The 21st century will be critical as we face the transition from the past era of technology to a new era, which has been referred to as the anthropocene, of adaptation in both natural and social systems. The vulnerability of environmental systems to human effects depends on the ability of the natural system to adapt to land use changes within highly engineered landscapes (Odum 1974). Riverine environments of all kinds have the additional complexity that they are linked over large scales by the river network, so that problems in downstream locations may be affected by decisions made thousands of kilometers upstream. Coastal landscapes, particularly deltaic systems, represent some of the most impacted and altered ecosystems worldwide and they integrate the effects of processes over their entire catchment, making them prime examples of environmental teleconnections that require systemic solutions to water resource problems.

Hurricane Katrina, along with the river floods in the upper river basin, brought international attention to the major environmental changes in the nearly 1.3 million square mile watershed of the Mississippi River over the past century, including conversion of more than 80 percent of forested wetlands to agriculture and urban areas, channelization, and construction of dams and levees (Goosby et al. 2000). The lower Mississippi deltaic plain has also been engineered by construction of a massive structure that maintains the relative flow of the Mississippi and Red Rivers down two specific channels, Mississippi and Atchafalaya Rivers, along with continuous levees that restrict sediment and freshwater supply to river flood plains (Kesel 1988). These changes have been especially damaging to the more than 12,000 square miles of coastal wetlands associated with the Mississippi River delta including 40 percent of the total coastal salt marsh in the conterminous U.S. (Baumann et al. 1984). These wetlands are disappearing at an average rate of 17 square miles per year or about 50 acres per day, and more than 1,000 square miles of freshwater wetlands in Louisiana have already been converted to other habitats (Gooselink 1998, Conner and Day 1988, Barras et al. 2003). Wetland loss rates over the next 20 years in coastal Louisiana, due to the combination of sea-level rise and disruption of coastal processes, will continue to convert land to open water, threatening the region’s enormously valuable fisheries, aquaculture, and coastal agriculture, as well as navigation and other industries located near the coast (Barras et al. 2003, Day et al. 2007). As a result of the water management system, the Mississippi River delta is a threatened wetland landscape whose sustainability is critically at risk, particularly given scenarios of sea level rise and hurricane intensity and frequency projected for the Gulf Coast Region (Day et al. 1994, Twilley et al. 2001, Day et al. 2007).

Extensive engineering of water management systems in the Mississippi River basin constrain how economic and ecological systems can adapt to proposed features of integrated protection and restoration planning objectives. Deltaic environments, such as wetlands of the Mississippi
River floodplain, receive sediments during floods that were delivered historically in pulsed events (Day et al. 1994). In these river-dominated deltaic coasts, wetland soil formation is dependent on mineral inputs that also produce large amounts of organic matter from plant production contributing to increased surface elevation. River management systems, such as levees and flow diversions, have reduced river-pulsed events and the delivery of sediment to floodplain wetlands, decreasing the ability to form soil and increase elevation (Baumann 1984). Public works projects, largely constructed to reduce risks of communities and economic assets to river flooding, interfered with regional hydrology and coastal processes important to sustaining natural structure, function and extent of wetland ecosystems (Boesch et al. 1994).

Consequently, the goal of reducing risks to society from events such as the 1927 flood and other events over the last 50 years have caused increased risks to ecosystems and natural resource capital in the Mississippi River deltaic plain. Hurricanes Katrina and Rita brought attention to the irony that these public works projects have also reduced the capacity of nature to protect human settlements. Extensive wetland ecosystems, particularly coastal forests, are a buffer against storm damage and a nursery area for fish and crustaceans. Louisiana ranks first among all states in the commercial harvest of menhaden, oysters, and crabs and is a major producer of shrimp. The delta region is also a working coast; approximately 17 percent of the nation’s oil and 25 percent of its natural gas come from Gulf coast waters. The ports of New Orleans, South Louisiana, Baton Rouge, and Lake Charles together handle more than 20 percent of the nation’s foreign waterborne commerce. Now a more integrated system of structural and non-structural approaches to protecting this built infrastructure and populated communities is challenged to consider the restoration of ‘green’ infrastructure that must parallel efforts to increase protection from hurricane flooding events.

Delta restoration – system design toward a resilient, self-sustaining delta – is a generic environmental problem worldwide in which human and natural dynamics are strongly and inherently coupled. The urgent need for wetland restoration and rehabilitation at large spatial scales have been addressed through the diversion of riverine water from the Mississippi River (Day et al. 2003, Mitsch et al. 2005, Mitsch and Day 2006). This management strategy aims to deliver sediment-laden water to declining wetlands areas and promote wetland productivity (Delaune et al. 2008) using human water control structures in major basin areas undergoing wetland loss (e.g., Barataria Bay, Breton Sound) (Day et al. 2005, Lane et al. 2006, Keddy et al. 2007). The conflict to resolve ecosystem needs of river and coastal processes to sustain the delta with demand for structural features from levees and floodgates to protect people and infrastructure has always historically favored investments in resiliency of the social system at the expense of the natural system (Barry 1997). However, reductions in sediment loading to the deltaic region and restricted distribution of river flow across wetland landscapes constrain resources needed to have any chance of stabilizing some wetland footprint in this area (Reed 2009).

The challenge to develop bold new ideas of river management to reintroduce sediment to the coast are further complicated by how the chemistry of the river has changed over the last four decades. The Louisiana coastal region is at the receiving end of a large input of nitrate from upstream agricultural activities (Coleman et al. 1998, Turner 2001, Rabalais et al. 2002a). Because of large nitrogen loading through the Mississippi River basin, there is increasing coastal eutrophication and the development of a large hypoxia zone (up to 21,000 km$^2$) (Rabalais et al. 2002b, Scavia et al. 2004, Hyfield et al. 2008, Turner et al. 2008). As nitrogen is delivered to coastal waters, there is a risk of exacerbating eutrophic conditions through seasonal algae blooms, some of which are toxic, excess organic matter production, low oxygen concentrations in water and sediments, and long term nitrogen and phosphorous accumulation (Brown et al. 2006). As more freshwater diversion projects are planned along major waterways throughout the state of Louisiana, there is concern that this new constituent of nitrate will contribute to reduced water quality conditions of shallow bays and estuaries of the delta. Concerns about creating large human health risks as a result of toxic algal blooms induced by increasing nitrogen inputs, underscore the difficulty of implementing
large-scale restoration plans in coastal regions (e.g., Sklar et al. 2005).

Denitrification is a major pathway for the removal of inorganic nitrogen in lakes, rivers, and coastal estuaries. This reduction is biologically mediated through a series of intermediate gaseous products to $\text{N}_2$, representing a direct loss of nitrate to the atmosphere (Seitzinger 1988, Burgin and Hamilton 2007). This conversion of nitrate to nitrogen gas is currently considered a critical ecological function for the removal of highly enriched N from anthropogenic sources (Galloway et al. 2004, Howarth and Marino 2006, Seitzinger et al. 2006). Since nitrate is generally the dominant form of excessive nitrogen entering coastal regions, it is potentially viable to ameliorate water quality problems through the reduction of nitrate via direct denitrification (Mitsch et al. 2001, Galloway et al. 2003, Mulholland et al. 2008). As nitrate-enriched water masses flow through the landscape, the presence of riparian, headwater streams, and coastal wetlands can efficiently remove reactive nitrogen. Comparative studies of wetland and riparian ecosystems along the Mississippi River basin suggest that those habitats can retain up to 70 percent of nitrate inflow (Mitsch et al. 2005). However, large-scale managed input of nutrient-enriched Mississippi waters into wetlands and open waters has been controversial since its implementation in coastal Louisiana (Turner 2001, Lane et al. 2003, Turner et al. 2006a, Day et al. 2007, Turner et al. 2007). Presently there is no clear consensus on whether restoring wetlands with sediment from the river will also enhance the capacity of nitrate removal, thus reducing risks of eutrophication.

Delta restoration involves one or more carefully sited, partial river diversions (controlled avulsions, in a sense) that set in motion the natural processes that created the delta, but in a controlled manner that either builds new land area or nourishes existing wetlands preventing them from drowning. With increased nitrate concentrations over the last four decades, the reintroduction of river water into coastal areas may potentially contribute to harmful algal blooms and increased incidence of hypoxia. Social benefits will depend on how these increments of river input will alter existing physical, biological, and chemical characteristics to degrees of river flow (Laska et al. 2005). These natural science processes are coupled to human dynamics through tradeoffs such as displacing marine fisheries with freshwater species, or hard versus soft forms of coastal protection, or threats of hypoxia versus new wetland formation. In the end, these tradeoffs will determine the level of delta restoration (magnitude of river input) that will take place under various incremental scenarios of river management.

In summary, the Mississippi River delta faces another round of human control through expanded public work projects following the catastrophic realities of hurricanes in 2005 and 2008. The challenge is even greater with complex interactions of land use change throughout the catchment to the coast that must be resolved to accommodate bold new river management plans in concert with structural protection. First, expansion of engineered landscapes to reduce risks to hurricane flooding may further reduce the opportunities provided by systems-level approaches to river management using diversion structures to replenish sediment to the deltaic plain. Second, agricultural practices of land use and fertilization in the Mississippi River basin further complicate the opportunities provided by changing river management, since nitrogen enrichment contributes to expanding eutrophication problems in the region. Thus, urgent solutions to post-Katrina issues in the Mississippi River involve providing increased protection to communities while expanding river processes to restore wetland landscapes, which will also require changing approaches to agricultural land use to reduce nitrogen load and risks of eutrophication. This juxtaposition of protection, wetland restoration, and eutrophication, all linked to bold new approaches to river basin management, has all been highlighted by the post-Katrina challenges for a sustainable coast. Managing all these competing tradeoffs to sustain the economic and natural resources of this region are representative of how we must consider new approaches to coastal catchments throughout the world. Water resource quantity and quality are largely determined by highly engineered landscapes of public work projects and agricultural land use interacting with a changing global hydrologic cycle. Thus water resource planning is arguably
one of the most important features of national security, public health, economic development, and natural resource management in the next century. Ecosystem services derived from healthy natural resources will support our national wealth depending on how well we manage the finite water resources to satisfy our social needs.

Author Bios and Contact Information

Robert R. Twilley is professor in the Department of Oceanography and Coastal Sciences at Louisiana State University. Most of Dr. Twilley’s research has focused on coastal wetlands in the Gulf of Mexico, throughout Latin America, and in the Pacific Islands. Dr. Twilley received his PhD in 1982 in plant and systems ecology from the University of Florida, and performed his post-doc studies at University of Maryland on the Chesapeake Bay. Presently his current focus is coupling natural and social system science with engineering to forecast the rehabilitation of coastal landscapes as Associate Vice Chancellor in charge of the ‘Coastal Sustainability Agenda’ at LSU (http://www.research.lsu.edu/csa ). He can be contacted at tel. (225) 578-8810, fax (225) 578-6423 or rtwilley@lsu.edu.

Victor Rivera-Monroy is Assistant professor-Research in the Department of Oceanography and Coastal Sciences at Louisiana State University. Dr Rivera-Monroy received his PhD in 1995 in Marine Sciences from Louisiana State University and his current research focus on biogeochemistry of wetlands, landscape and ecosystem modeling, rehabilitation/ restoration of mangrove dominated ecosystems, and coastal management issues particularly the impact of aquaculture on the water quality of estuarine and coastal ecosystems in tropical regions (http://www.sce.lsu.edu/faculty/rivera-monroy.htm ). He can be reached at tel. (225) 578-2745, Fax (225) 578-6423 or vhrivera@lsu.edu.

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Sediment and Nutrient Tradeoffs in Restoring Mississippi River Delta


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Flood risk management is an important part of life in the Netherlands. The Netherlands is formed by the deltas of three rivers—the Scheldt (rain-fed, originating in southern Belgium), the Meuse (rain-fed, originating in northern France), and the Rhine (glacier and rain-fed, originating in Switzerland). The country also borders the North Sea, with the Scheldt River connecting the sea to Antwerp Harbor. The Rhine is the largest of the three rivers, splitting into three branches (the Ijssel, the Lek, and the Waal) as it crosses the border into the Netherlands (Tol et al. 2003). Two-thirds of the country lies below mean sea level (Voortman 2003).

The Dutch have a long history of attempting to control floods. As early as the ninth century, the Dutch started building dikes to protect reclaimed bog land (Kaijser 2002). These dikes started as local, individually-owned structures, but communities soon realized that closed dike rings were necessary to protect all sides of the region. These dike rings eventually became waterschaps or “waterships,” regional districts charged with water management including drainage and dike building. These districts are still the administrative body for flood defense (Linsten 2002, Voortman 2003). The 14th century saw the first major recorded floods in 1313 and 1315, leading to the famine from 1314-1317 that killed 5-10 percent of the population. Periodic flooding continued through much of the Netherlands’ history. As sediment settled between the dikes, dikes grew taller. During the 19th century, reorganization of the water districts occurred and a national body was formed. Military engineers took over the construction and maintenance of the dike system (Tol and Langen 2000).

During the 20th century, as trained engineers and the central government took over flood control efforts, the analysis of appropriate techniques and construction increased (Disco and van dev Ende 2003). Prior to 1953 dikes were built to the height of the previously known high-water level plus a margin of safety (Jonkman et al. 2004). Following the catastrophic flood of 1953, the Delta Committee was formed to advise the government regarding flood control (Voortman 2003). One recommendation of the Committee was to establish an optimal exceedance frequency of the design water level based on risk of flooding and cost of protection. Van Dantzig’s 1956 paper described this risk-based calculation. He proposed that flood management required integration of three areas with noted problems: statistics, hydrology, and economics. In the past 50 years, significant effort has been devoted to expanding on van Dantzig’s work and working on solutions to the problems he noted and the assumptions he made. Increased computing power, additional rainfall and hydrologic data, and watershed models have all added to the understanding of flooding while increased emergency preparedness and response have enhanced protection of land, homes, farms, businesses, and lives.

Northern California also has a history of devastating floods, although the history of floods and water management is much shorter than in the Netherlands. Throughout the past century and a half, winter rains and snowmelt have resulted in flood events that have caused billions of dollars in damage and multiple deaths. One of the largest floods in California history occurred in January, 1862 following four weeks of rain. No quantitative flows are known, but the banks of the Sacramento were breached and the water was, at minimum, three feet deep from Sutter’s Fort to Davis (Harding 1960).
This flood also brought significant mining debris, covering the land near Marysville with one to six feet of sediment. During the second half of the 19th century, mining techniques had developed from ditch and flume operations to high powered hydraulic techniques that discharged up to a million gallons an hour from a single nozzle (Kelley 1989, Larson 1996). Over 1.5 billion cubic yards of sediment was discharged into the Feather, Yuba, Bear and American River basins from hydraulic mines (Larson 1996). However, the litigation between Woodruff and North Bloomfield Gravel Mining Company (1884) effectively stopped hydraulic mining by requiring complete containment of debris.

Early in the settlement of California, flood control was typically very local, with levees built by individuals or local governments. Following this major flood in 1862 and the resulting litigation, hydraulic mining ended and levee management moved to larger regional agencies and the state government.

The largest recorded flows in the Sacramento River were reached during the flood of March 1907. Although some tributaries have since exceeded their 1907 flows, the Sacramento River has not exceeded its peak flow of about 600,000 cubic feet per second (16,990 m³/s) (Harding 1960). Thirty to forty inches of precipitation across Northern California during the week before Christmas in 1955 led to severe damages and levee failures. Seventy-four lives were lost and over $200 million in economic losses were attributed to the flood (Harding 1960). Record rainfalls led to major flooding in 1986. Levee breaks in the Sacramento River Basin led to 13 deaths and over $400 million in damages. Two of the most expensive floods in California’s history (1995 and 1997) occurred within two years of each other and together caused nearly $4 billion in damages (Department of Water Resources website).

Early in California’s history, no state or federal agencies managed flood control; flood control projects were managed locally. As settlement increased, however, state and federal funding and regional management became necessary. First, state and county agencies began acting to prevent flooding and then in 1917, federal authority for flood management was granted by Congress. Since then, there has been a fluctuating balance of power between regional and district, state, and federal flood control planning, funding, and management (Kelley 1989).

Six types of actions can be considered for flood management (Hooijer et al. 2004):

- Actions to prevent flood generation: land use management in the upstream basin,
- Actions to modify flood flows and elevations: flood storage, levees, bypasses, and channel improvements,
- Flood damage reduction actions: floodplain zoning, building codes, awareness raising,
- Preparatory actions: flood forecasting, warning and emergency plans,
- Flood event actions: crisis management, evacuation, and
- Post-flooding actions: aftercare, financial compensation, insurance.

The Dutch concentrated mostly on preventive flood control measures, and many of the measures implemented in California were first tested by the Dutch in their attempt to control flood waters. Some more recent Dutch innovations might increase California’s ability to reduce flood damage. This paper is organized into three subjects. First is a review of Dutch flood control innovations. Next, implementation of each measure is discussed in California’s context. The final section wraps up the discussion with a summary of key points and conclusions.

**Dutch Flood Management**

**Flood Control Structures**

Dutch flood defenses have three components: dunes, dikes, and special structures. Natural sea dunes protect coastal areas from tides and storm surges. The dunes are planted with helm grasses to hinder erosion. Where there are no dunes, the Dutch built dikes. The dikes, initially constructed along the river, have become dike rings to provide protection on all sides. The 1500 mile dike system in the Netherlands includes some massive engineering and construction accomplishments. The Afsluitdijk dike, for example, prevents North Sea intrusion into the Zuiderzee and has created the IJsselmeer freshwater lake. The dike is over
90 m wide and 32 km long. Cross dikes are used to protect against upstream dike bursts. An early example was constructed between the Lek and Linge rivers in 1284. Although this crossdike offered protection to those downstream, it increased the damage upstream (Tol and Langen 2000).

Special structures include the Maeslankering storm surge barrier that closes to protect Rotterdam and surrounding towns from flooding from abnormally large storm surges. Each of the two barrier “arms” is as tall as the Eiffel Tower if placed upright (Sayler 2006). Other special structures include cofferdams, gates, and retaining walls. In general, these special structures are in place as temporary solutions in response to a flood event or storm surge.

**Risk-based versus Reliability-based Design**

Flood management policies and system designs are established to reduce flood damages. Engineers today use two strategies to evaluate flood management solutions: risk-based and reliability-based design. These design strategies are described below (Hoes and Schuurmans 2006, Vrijling et al. 1997, 2005, Yanmaz 2000).

Risk-based design focuses on minimizing the future costs of flooding by taking preventative measures today. Risk has two components - the chance an event will occur and the consequences of that event (Sayers et al. 2002). A subset of cost-benefit analysis, the optimal risk-based design results in the minimum total cost, from summing all costs multiplied by their probabilities for each alternative, and choosing the least expensive alternative. Risk-based design requires having a pre-established flood probability distribution, as well as reliable estimation of the damages from different flood levels. A discount rate is applied to future costs to give a net present value for evaluating different protection levels. A benefit of the risk-based approach is that it allows choices based on comparison of expected outcomes and costs of solution alternatives (Sayers et al. 2002, Hall et al. 2003, Vis et al. 2003).

Reliability-based design is based on a pre-established “acceptable” failure probability target. Legislation, insurance policies, or other parties may determine an acceptable failure probability based on different preferences regarding loss of life, infrastructure investment, or economic loss. Acceptable failure levels may be based on the previously discussed risk-based design using the failure rate with the best net present value for the flood protection system and probable damage during flood events. Reliability-based design allows engineers and planners to develop a solution set of alternatives that provide the target level of protection and then choose the lowest-cost alternative.

Flood protection systems can incorporate both methods. For example, risk-based design requires substantial data for a given floodplain. By evaluating just one section of that region with risk-based design, a target failure probability can be established and applied in a reliability-based approach to the entire region, provided other parts of the region have similar flood hydrologies, costs, flood damages, and benefits.

Currently the Dutch use a minimum acceptable flooding probability for flood protection. The reliability-based design standard is based on an economic optimal value, or risk-based evaluation. The safety standard for a dike ring protecting a heavily populated city and its suburbs is higher than the standard for a dike ring protecting agricultural land. This integrated method results in the reliability design standards summarized in Figure 1.

**Resistance versus Resilience Strategies**

Evaluation of risk- and reliability-based designs considers the two factors of flood risk: the frequency of flooding and the consequences of flooding. Resistance strategies are designed to reduce flood risk by reducing the frequency and magnitude of flood events. Historically, these are the most common and include dike or levee systems, and reservoirs and dams. Vis et al. 2003, list the following disadvantages to resistance strategies:

- design discharge is constant, resulting in the assumption that all areas and land use types have equal probability of flooding,
- inaccurate projections of economic development occur when a resistance strategy was designed decades ago, and
- continual maintenance and improvements
reduce environmental habitat and spoil landscape qualities.

Resilience strategies focus on minimizing the consequences of a flood. These strategies include allocating land as floodplains, developing better emergency response systems, and expediting flood clean-up and recovery. Often resilience strategies are described as ways of “living with the flood” instead of “fighting floods” (Vis et al. 2003). One disadvantage of resilience strategies is de-valuation of land due to rezoning for uses compatible with flooding.

### Van Dantzig

In the 1950s, van Dantzig (1956) and the Delta Committee focused on three areas of flood management: statistics, hydrology and hydraulics, and economics. Van Dantzig’s approach involved risk-based design for a (mostly) resistance strategy. He was the first to approach flood defense design using probability-based quantitative cost-benefit analysis (Voortman 2003). In evaluating the economic decision, van Dantzig made several assumptions:

- Critical dike height refers to the height at which the dike may break, but only describes the relationship between this height ($H$) and crown height ($H_c$) as $H \leq H_c$,
- Dikes only fail by overtopping,
- Dike breaks are repaired immediately,
- Value of goods is stable in time relative to estimated national growth,
- Probability distribution of reaching critical dike height is stable in time once corrected for sinking dikes (no climate change),
- Value of ecological habitat (and other non-economic entities) is neglected, and
- Emergency response and evacuation capabilities are perfect with regards to human life.

Figure 2 illustrates van Dantzig’s basic approach.
The horizontal axis is the project size, or level of protection, and the vertical axis is the annualized cost of the project. The dotted line is the annualized installation cost which is the sum of annualized construction and maintenance costs; as the level of protection increases, so do these costs. The dashed line is the annual expected damage cost – as the level of protection increases, these costs decrease. The solid line is the total cost line and which is the sum of the two types of costs. The optimal risk-based design is the level of protection corresponding to the least total cost, or the lowest point on the curve.

Valuing Natural and Cultural Preservation

Within the Dutch river districts, the importance of preserving natural and cultural lands has historically received varying attention. In 1993, however, landscape, natural, and cultural-historical values were incorporated into national Dutch policy on dike improvements (Walker et al. 1994, Lenders et al. 1999). Since then, each river district has varyingly integrated these values into their dike reinforcement plans. Environmental Impact Assessments are compulsory for projects that are not classified as immediate and urgent (Lenders et al. 1999). Participation by local citizens and environmental groups is also encouraged.

Extended Life Quality Index (ELQI): Combining Economics and Life Expectancy

Van Dantzig ignored the value of human life in his calculations for economic optimization. Nathwani et al. (1997) developed the Life Quality Index as a measure of the economic benefits of life expectancy. Voortman et al. (2002) used this to create the Extended Life Quality Index for evaluating flood protection decisions and for allowing human life to be included in mathematical and economic calculations for flood defense systems. However, the Extended Life Quality Index may be less important to total flood damage estimates when emergency alert and evacuation systems are included in flood defense measures. Currently, flood forecasting along the Rhine allows 2 to 3 days for evacuation and along the Muese forecasting is between 12 to 36 hours ahead of flooding (Hooijer et al. 2004).

Measuring and Managing Uncertainty

Uncertainty can contribute to flood management calculations in two ways – estimation of flood probability and estimating flood damages. Flood frequency estimates require knowing the probability and associated uncertainty of 1) hydraulic and hydrologic conditions, 2) failure modes of flood defense infrastructure, and 3) infrastructure failure and flood wave propagation (Kortenhaus and Oumeraci 2001). Expected damage is a function of economic development and hazard warning and preparedness (Sayers et al. 2002).

Hydrologic uncertainty is often due to lack of sufficient data for estimating flood frequency curves (Yue et al. 2002, Van Noortwijk 2004).

Figure 2. Example of Risk-Based Design.
Five statistical distributions are commonly used for flood frequency analysis: Generalized Extreme Value, Gumbel, Lognormal, Weibull, and the Pearson-III (Singh and Strupczewski 2002, Apel et al. 2004). Using 35 years of data from the Rhine and Cologne Rivers, Apel et al. showed that the selection of distribution led to large variability (25 percent of maximum flood flow) in the estimate of the 150-year flood.

Failure of the dike system can be estimated based on failure mode. Voortman et al. (2002) list failure modes as internal erosion, breaching through inner slope via wave overtopping, overflowing, or uplifting inner revetment, and breaching through outer slope via failure of pitched block revetment. Each failure mode can be assigned a probability of failure. The combination of all failure modes can be used to estimate the overall probability of failure (Voortman 2003).

Once the defense system fails, flood wave propagation is important for estimating the extent of flood damage. Flood wave propagation can be a factor of the failure mechanism, the extent or length of original dike failure, and the characteristics of the flood hydrograph (Kortenhaus and Oumeraci 2001). Uncertainty can be reduced as better models for flood wave propagation are developed and the interactions of these factors are better understood.

As these different types of uncertainty are reduced through better models, more data, or further study, flood risk and damage calculations will improve. This will enable engineers and planners to more precisely evaluate flood protection systems and design alternatives.

Perception of Risk

Cost-benefit analysis requires economic quantification of all costs and consequences for a flood defense design (Schmandt et al. 1988, USWRC 1962). Because not all costs are easily defined in monetary terms, the bias of the decision-maker can be reflected in the analysis. Risk-prone decision making results in reported costs being lower than actual costs and benefits being valued more in the analysis. Risk-averse decision makers report higher costs and lower benefits than the flood defense system actually provides (Voortman 2003). Such bias is often unintentional.

An interesting aspect of flood management and risk assessment is how the public perceives risk and the importance of flood protection. Public perception of flood risk can affect budget, construction and maintenance of flood defense systems, and other aspects of flood risk management policy. There are three bases for public risk perception: dormant flood risk, immediate flood threat, and accidental/uncontrolled flooding (Baan and Klijn 2004). Dormant flood risk has two components - crisis effect and levee effect. Crisis effect occurs immediately after a disaster and causes people to overestimate future flood risk. Levee effect starts once protection measures have been taken and causes people to rely too heavily on the protection of the system and then grossly underestimate future flood risk (White 1945).

Immediate flood threat occurs during a flood event. As water height increases and comes close to the top of the dike, people feel emotions ranging from fear to inconvenience to solidarity (Baan and Klijn 2004). The degree of fear typically is inversely correlated to experience with flood events. People that live with frequent flooding typically experience less fear than those new to an area or living in an area that has not experienced flooding in several years. Past experience may be the single most important factor affecting people during high water levels. Those who have experienced minor flooding with little or no damage will underestimate the risk of damage. Those who have experienced loss of life or extensive property damage in the past are most likely to experience helplessness and fear (Burn 1999).

Evacuation is often perceived as more troublesome and threatening than the high water level (Baan and Klijn 2004). Those that require assistance from others to evacuate (elderly, children, disabled) are the most susceptible to negative feelings during high water events. Interestingly, even the forecast of a high water event may be enough to trigger these feelings. Not all feelings are negative. Feelings of solidarity or togetherness can occur among people who band together during a high water event.

The third base for risk perception is uncontrolled flooding. A flood event is linked to several negative effects ranging from premature death to feelings of ill-health and mental distress. These feelings typically fade as time passes after the flood event.
Public risk perception has been integrated into the Netherlands’ flood strategy with specific regard to incorporating public involvement in decision-making. When the public is more involved and more educated in actual flood risk, negative feelings are reduced (Baan and Klijn 2004). Recent research indicates that people in the Netherlands no longer perceive flooding as a natural disaster, but instead as a failure of the flood management system (Baan and Klijn 2004). This has increased the likelihood that people overestimate the level of protection and place disproportionate trust in the man-made systems.

Financing Water and Flood Management

In the earliest days of dike building, landowners were responsible for protecting their property and making dike repairs. As cities formed, coordination among landowners was necessary, regional water authorities started to form. Maintenance costs were still distributed among land owners protected by the dikes and cities were mostly exempt from regular maintenance costs, but the waterschappen had authority to manage the construction, maintenance, and operation of dams, sluices, dikes and drainage canals (Tol and Langen 2000, Kaijser 2002). “Dike counts,” dijkgraaf, were executives assigned to inspect dikes three times a year (spring, summer, and fall). The spring inspection identified repairs to be made; the summer inspection made sure that the work had been completed; the fall inspection was a final opportunity to identify problems before the winter. If a land owner was unable to fund repair costs, the dike count would loan the money at interest rates in excess of 100 - 200 percent (Tol and Langen 2000). For extensive repairs or following flood damage, the dike count could raise money by imposing a tax on cities. However, most of the financial burden fell on landowners and frequently these repair costs led to bankruptcy. Often dike counts abused this privilege and were able to amass large amounts of land (Tol and Langen 2000).

In 1798, a new constitution and more stable central government led to reorganization of a national budget and the formation of a national water authority (Tol and Langen 2000). The funding for flood protection comes from a combination of inhabitant and property taxes at state, provincial, and municipal levels of government. Provincial governments are responsible for implementing state water policies. Costs for flood protection may be covered by the national general budget, as long as they fit within the following activities:

- “Formulation of the national, strategic policy on flood protection and water management, supervision of its realization and enforcement,
- The realization of the operational tasks concerning the infrastructure,
- The flood protection works lacking hinterland or financial capacity; the Main Dike separating the Wadden Sea from the Lake IJssel, dams and barriers in the estuaries, dunes and dikes on the Wadden islands,
- The preservation of the coast by fighting the structural erosion,
- The operational management of the state waters. These waters concern the Rhine with its branches, the Meuse, the Scheldt, the Lake Ijssel, the estuaries, the principal canals and the territorial and international sea, and
- The promotion of the (inter)national shipping routes.” (Huisman 2002: 4).

In 1998 (the most recent year with published information), The Netherlands spent 1 percent of its national income (US $ 3.14 billion) on water management - 15 percent of which was for flood protection (US $ 444 million). In the next ten years, the Dutch anticipate spending $2.9 billion on flood protection (Woorden 2006).

The Water Board Bank (Nederlandse Waterschapsbank) was formed in 1954 when funding for the substantial repair work caused by the 1953 floods was difficult. The local water boards were too small on their own and formed the collaborative to allow long-term borrowing at favorable rates (Huisman 2002). The Water Board Bank is the fifth largest Dutch bank and is owned by public authorities (81 percent is held by the water boards with state and provincial government holding the remaining 19 percent) (Huisman 2002).

Flood damages place a large financial burden
on the government as a result of requests for compensation. Previously, insurance policies excluded coverage for flood damages, and the government was responsible for all claims. In 2000, a special committee convened by the Netherlands’ government provided recommendations on flood insurance policy (Kok et al. 2002). The committee recommended that the government work with insurance companies to designate flooding as a result of high rains (and no failure of flood defense systems) as part of property insurance. This reduced the governments’ exposure to flood damage claims (Kok et al. 2002).

Public-private enterprises can help finance flood system improvements. Two recent partnerships include gravel and sand production and urban planning. The Grensmaas project combined private gravel and sand extraction with floodplain lowering (van Stokkom et al. 2005). Private enterprises have also presented plans for floating villages, which allow for river dikes to be moved further inland and maximize the public’s willingness to pay for riverfront property. Although these partnerships have potential, so far implementation has been difficult and inefficient (van Stokkom et al. 2005).

**Recent Developments in Dutch Flood Management: Room for the Rivers**

The Dutch are increasingly incorporating resilience strategies in their flood management policies (Olsthoorn and Tol 2001, Van Steen and Pellenbarg 2004). This is increasingly important as the economic value protected by the flood management system increases faster than dike heightening can occur. The economic value protected has increased nationally by a factor of six in the past 40 years, and more in many local areas. Two strategies are receiving the most attention as potential resilience methods to minimize economic consequences of flooding: storing flood waters and increasing maximum flow capacity of channels (Vis et al. 2003, Hooijer et al. 2004, Silva et al. 2004). Upstream compartments are filled first to reduce the flood peak’s height and duration further downstream. Typically, the compartments designated to receive flood waters first should be designated as natural or agricultural lands to minimize economic damage (Vis et al. 2003). These detention compartments also can be managed to help recharge groundwater supplies, reduce river bed erosion, and improve biodiversity (van Stokkom and Smits 2002).

Silva et al. (2004) evaluated the potential for compartmental detention for Rhine flood waters. Because upstream storage is most desired, the Netherlands would have to focus on areas near the German border. To reduce flood water flow from an “average” flood hyetograph by 1000 m$^3$/s, 150 million m$^3$ of storage is required. This is equivalent to 3000 hectares (30 km$^2$) flooded to 5 meters (Silva et al. 2004). An increase of 1000 m$^3$/s from 15,000 m$^3$/s (current maximum flow capacity) to 16,000 m$^3$/s results in the probability of the detention area being used in a given year being approximately 1 in 500 (Silva et al. 2004). Such a low probability may lead to people forgetting the purpose of the detention area and begin development in ways...
that diminish its effectiveness at lessening flood damages.

Green rivers or flood bypasses are one method to increase the maximum flow capacity of part of a channel. Green rivers are designated areas where water flows only during flood periods and may be used for agriculture or ecological habitat at other times (Vis et al. 2003, Silva et al. 2004). These are similar to the flood bypasses in California’s Central Valley, but with greater environmental emphasis. In the Netherlands, green rivers typically flood during the off-season for agriculture, providing an economic benefit.

Two final strategies for creating room for the rivers are relocating existing levees or lowering flood plain levels. These strategies require having enough undeveloped or minimally developed land available to adequately set back the levee or lower the floodplain. In the Netherlands, this is often difficult because of flow capacity restrictions, or bottlenecks, most often in urban areas with little undeveloped land (Hooijer et al. 2004, Silva et al. 2004).

Implications for California Flood Mitigation

Flood Control Structures

The history of flood control structures in California is similar to that of the Netherlands, although on a different time scale. Initially, flood-control efforts were undertaken by local interests – typically nineteenth century settlers building their own rudimentary defense system with a lack of knowledge about flood periods and water heights (Harding 1960, Kelley 1989). In the twentieth century, local, state and federal agencies began to cooperate to build flood control systems. One of the earliest cooperative governmental projects was in 1916 to construct flood by-passes that are still in operation today (Harding 1960).

The U.S. Army Corps of Engineers, in cooperation with state and local agencies, constructed 1600 miles of federal levees in the Sacramento and San Joaquin River basins, also known as the Central Valley. Following construction, the federal government turned over maintenance of the levee system to the state. An additional 700 miles of non-federal levees have been constructed by landowners and local reclamation districts. These levees mostly protect agricultural land with the exception of Sacramento and its growing suburbs. Today, California’s levees are regulated by the state Reclamation Board. Approximately 1300 miles of floodways have been designated by the Reclamation Board for flood discharge. The state, along with local reclamation and water districts, operates and maintains the extensive system of dams, levees, weirs, channels and bypasses along the Sacramento and San Joaquin Rivers.

Much like the Netherlands, the flood protection system is under increased pressure as development and demand for housing and land increase. Today, these levees protect over $47 billion in Central Valley infrastructure (www.water.ca.gov/levees). One example of this increased pressure is the Natomas neighborhood of Sacramento. The 53,000 acre Natomas area and its 70,000 residents contribute upwards of $4 billion to the local economy each year (Lamb 2008). A recent reclassification of the 43 miles of levees that protect Natomas from flooding on all four sides has resulted in a construction permit moratorium and a tripling in required flood insurance (Lamb 2008). According to FEMA and the Army Corps of Engineers, the levee system would not meet the safety standards during a storm that has a 3 percent chance of occurring, which equals a 60 percent chance of occurring during a 30-year mortgage (Lamb 2008). The construction moratorium has halted growth in an area that accounts for 47 percent of new development in the greater Sacramento area. The Sacramento Area Flood Control Agency has pushed the levee improvements in Natomas to its top priority, and has a plan to allow the area to meet FEMA standards (described below) by 2010. This work is funded in part with $49 million from a state bond measure passed in 2006.

Reliability-based Design

The Flood Insurance Administration of the Federal Emergency Management Agency (FEMA) uses the 100-year flood as a “base flood” to determine floodplains and flood insurance requirements and premiums under the National Flood Insurance Program (Federal Emergency Management Agency 2002). These floodplain maps often lead citizens to believe that they are more protected and “safer” from flood damage
than they actually are (Moser 1997, White 1945).

The state of California has used a standard project flood to evaluate flood protection systems. This standard project flood is meteorologically based and is a derived discharge from a storm with a set return period. The Central Valley level of protection standard is a rain event with a return period ranging from a 200 to 500 years (Galloway et al. 2007).

Much like engineers in the Netherlands, the USACE historically used a design flood plus a freeboard when constructing flood defense systems (typically called flood reduction measures by the Corps). Often the design flood was the 100-year flood, or 1 percent exceedance flood (Commission on Geosciences, Environment and Resources 2000) in accordance with the FEMA National Flood Insurance Program standards. The freeboard is included to account for uncertainties in the discharge, stage, and damage of a flood (Moser 1997). Recently the USACE has shifted to a risk-based approach, discussed next.

Risk-based Design

When the U.S. Congress passed the Flood Control Act of 1936, it required consideration of the consequences following flood control structure failure. However, it was not until after van Dantzig’s work that the economic costs were explicitly considered. H.D. Pritchett in 1964 provided an early U.S. risk-based design for the hydraulic design of highway drainage culverts (Tung 2005).

Although early USACE flood design was reliability-based, in the 1990’s, there was a push within the USACE to transition to a risk-based analysis (Figure 3). First, the discharge associated with a standard set of exceedance probabilities (p = 0.5, 0.2, 0.1, 0.04, 0.02, 0.01, 0.004, and 0.002) (upper right-hand of figure) is determined. Then the discharge-stage relationship is determined (upper left-hand of figure). The stage (H) is then related to a damage function (lower left-hand of figure), which is then related back to the exceedance probabilities originally input in the first step (lower right-hand of figure) (Commission on Geosciences, Environment and Resources 2000).

Following this analysis, the USACE makes evaluations based on national economic development. This decision rule requires the USACE to invest funds in projects that have a risk-reward tradeoff at a national level (Yoe 1993). This may mean that local interests would increase the level of protection based on the economic trade-offs, but at the federal level, the additional spending can achieve greater reward elsewhere (Yoe 1993). This does not exclude local governments from providing additional funding to reach the increased level of protection (Moser 1997). Some academics have applied related risk-based analysis to evaluating levees and flood protection for islands in the Sacramento San Joaquin Delta (Suddeth et al. 2008, Al-Futaisi and Stedinger 1999).

Financing Flood Protection

Federal policies and responsibilities for flood control were first established in 1917 with the Flood Control Act. Although this act was mostly related to flood control along the Mississippi River, a Sacramento River flood-control project was included with federal obligations limited to navigation (Harding 1960).

Over time, the role of the federal government in flood-control was broadened. The 1936 Flood Control Act included the construction of dam
and reservoir projects as a federal responsibility. Gradually, by the mid-twentieth century, the federal government had assumed responsibility for most of the costs of flood control construction with the exception of payments for local right-of-way, which states typically cover. Local costs for flood control were limited to some maintenance (Harding 1960).

Today, the state of California has assumed much of the financial burden for levee maintenance (DWR Website). In 2006, voters passed a $4.09 billion bond measure (Proposition 1E) for levee repairs and flood control system maintenance, with $3 billion allocated for levee improvements. Repayment of these bonds will cost the state government approximately $8 billion over 30 years.

Local reclamation district funding ranges from slightly more than $50,000 in Yuba City to more than $2.1 million in Natomas (suttertaxpayers.com). In Sutter County, homeowners pay approximately $25 per year in Reclamation District taxes. In Yuba City, this funding goes to mostly administrative costs, and levee inspections and repairs are done by volunteers.

The California State Water Code Section 8400, Flood Hazard, requires that relevant local governments participate in the National Flood Insurance Program, as supplemented with state provisions (May 1993). To receive federal disaster aid following flooding, FEMA requires participation in the Program (FEMA 2002). In turn, the California state requirement ensures that local areas will receive aid in the event of a flood.

Insurance covers much of flood losses in the U.S. For the period of 1985-1999, although North America sustained only one-third of economic losses due to natural disasters, it accounted for over two-thirds of the insurance-protected losses sustained worldwide (Linnerooth-Bayer and Amendola 2003). The U.S. has approximately 4.3 million flood insurance policies covering over $606 billion in property (FEMA 2002).

The National Flood Insurance Program has been one of the most effective measures at reducing economic loss during a flood because of the safety standards required of insured properties. FEMA estimates that $1 billion in flood damages are avoided each year for new construction meeting its regulations, and that the new structures suffer 80 percent less loss during a flood event (FEMA 2002).

However, there is a need for more consistent maintenance of the levee systems. The Army Corps of Engineers estimates the cost of levee improvements in the Natomas area at more than $1 million per levee mile. With 43 miles of levees in this area, even one of the largest reclamation districts’ operating budgets is insufficient to meet minimum standards. Emergency bond measures and disaster relief funding become overly expensive as interest rates and payback periods double the cost of the levee improvements, as in the case of Proposition 1E.

California shares a flood protection funding crunch with the Netherlands. However, two financial resources used in the Netherlands may aid California. Public - private partnerships might aid areas of high development like Natomas. By requiring land developers to provide flood protection funding as part of the permitting process, levee improvements can be made. Although it places a premium on the real estate being developed (theoretically equal to the cost of the flood protection provided), the results can be positive. One example of a developer funded levee project is the 1.3 mile set-back levee along Bear River near Plumas Lake (Dickey 2007). A $29,345 fee was assessed for each home in the new development. Builders were also required to fund each homeowner’s first year of flood insurance to ensure they were aware of the flood risk in the Plumas Lake area.

Making Room for the River: Bear River and Yolo Bypass

The levee along Bear River near the Plumas Lake developments provides a Californian example of the Dutch technique of “making room for the river.” The set-back levee has provided an additional 600 acres of habitat that will ease pressure on the river during floods (Dickey 2007).

The Yolo Bypass is also an example of making room for rivers; it is an example of a “green river.” At 59,000 acres, the Yolo Bypass is the largest...
bypass in the Sacramento Valley, and during flood events can discharge to the estuary much more than the main channel of the Sacramento River (up to 14 to 15 thousand m³/s) (Schemel et al. 2002). During the winter and spring, the Yolo bypass is flooded, offering shallow-water habitat to aquatic species. Then, during the late spring and summer, when the bypass is not flooded, the land is used for irrigated agriculture (Schemel et al. 2002). Bypass construction started in 1917 after federal funding was approved to help the state government coordinate reclamation, navigation, and flood control projects (Kelley 1989). Since its completion, the bypass has been the main floodway for the Sacramento Valley (Jones and Stokes 2001).

Summary and Conclusions

Floods are a problem of too much and not enough – too much water and not enough money or space. The Dutch have centuries of experience trying to maintain the balance between flood damage and control. Advances in risk-analysis of flood defense systems and the accuracy of the valuations used in making economic decisions have been applied by the USACE in the last decade. The National Economic Development decision-rule directs federal funding to projects with the greatest economic value to the U.S. Reliability-based standards (using a predetermined failure probability) fails to account for the value of the land and lives being protected. Applying the same level of protection to agricultural land as to heavily populated cities is economically inefficient. The inadequacies of reliability-based design have been exposed, but continue to be used for flood insurance and, thus, many design purposes in California.

Public-private partnerships, which are in the early stages in both the Netherlands and California, have shown more potential in California. The Plumas Lake example shows that when developers assume some of the risk and cost of flood management, there can be economic benefits to the local government. The local government was able to save on the cost of the levee construction and establish a tax base for future levee maintenance.

Flood insurance in the United States and California goes far beyond insurance in the Netherlands. In the Netherlands, much of the burden for flood damage is on the government, including all damage caused by a failure of the flood defense systems to adequately protect homes. The increase in national and local economic values occurs faster than the government can develop adequate flood protection infrastructure (Ermolieva et al. 2003, Haveman 1965, James and Lee 1971).

In the U.S., the National Flood Insurance Program has provided an economic stimulus for more responsible construction and development that local and state governments would otherwise ignore. Additional state and federal funding from bond measures aids local governments in maintaining adequate flood protection and lowering insurance premiums for residents. The Natomas area provided an example of local and state failure to upgrade agricultural levees and to adequately protect new urban development.

Finally, “making room for the river,” has been used for decades in the example of the Yolo bypass and then was revisited to improve Plumas Lake flood protection. The bypass solution also incorporates the environmental value that Californians place on wildlife habitat and open, green space. However, it will not work in all locations. Much like congested areas of the Netherlands, making room for the river will not work in California’s populous areas or areas where development along the river already exists (i.e., Natomas in the Sacramento area).

This review of flood protection methods in the Netherlands and California has reestablished the importance of land-use planning and risk-based analysis. It is expensive to build haphazardly in floodplains (Mount 1995). The costs of flood protection (a levee the size of the 90 m x 32 km Afsluitdijk) and the loss following a flood disaster (especially one that does not meet FEMA and National Flood Insurance Program criteria for federal disaster relief) both have the potential to drain the economic resources of the state of California.

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Author Bios and Contact Information

Dana Woodall is an officer with the US Coast Guard in Seattle, Washington. She completed her joint MS in
Civil and Environmental Engineering and MBA at the University of California - Davis. She can be reached at Dana.L.Woodall@uscg.mil.

Jay R. Lund is the Ray B. Krone Professor of Environmental Engineering at the University of California - Davis. He can be reached at jrlund@ucdavis.edu.

References


Commentary

The Levee Risk: If All Players Understood the Hazard, We Would See More Action

Clive Goodwin

FM Global, Johnston, RI

Reading the technical articles that accompany this issue, you may arrive at three conclusions: (1) there are many issues surrounding the aging condition of many U.S. levees, (2) there are potential risks such systems may pose to those located behind them, and (3) there are many varied and sound solutions available to reduce the risk of flooding.

Sixteen years ago, following the 1993 U.S. Midwest floods, there was a loud call for action to improve levees and floodplain management (Interagency Floodplain Management Review Committee 1994). Since then, similar studies have followed in the aftermath of many floods, with the most publicized ones coming in the wake of Hurricane Katrina (Interagency Performance Evaluation Task Force 2008). How can such little progress have been made to address very similar flood-related recommendations? Perhaps it is because the majority of studies focus primarily on identifying problems and developing solutions. Influential key government players and decision makers are all too often presented with the solutions and associated costs which then become the primary focus. Decisions cannot easily be made without truly understanding the risk and consequences. This translates across the nation into a widespread lack of demand for action. If the consequences were better understood, the outcome could have been quite different.

For example, once a business owner truly comprehends that there is a real possibility that one day his or her factory could be three-feet deep in muddy, contaminated flood waters, and concludes that the potential business impact is unacceptable, that person is more likely to ask “What solutions are there to reduce the potential impact of a flood that strikes my facility?” In effect, the business owner, by understanding the risk first hand, is much more motivated to find a solution, even before he knew what the precise solution or associated cost might be. How many of us know we “should” exercise more but we only do it when it becomes a “must” — such as after receiving a dire diagnosis about our health condition from a physician.

The flood risk management community must become more effective at ensuring that the residual flood risk behind levees is explained in an effective manner (i.e., so that people can visualize the scenario if a levee is overtopped or fails and easily picture the impact to the livelihood of those relying on its protection). If business owners, community leaders and emergency managers understand the consequences, they are more likely to support the need for adequate funding for levee maintenance and keeping emergency action plans up-to-date. Engaging key decision makers in developing a consensus on the consequences of foreseeable flood events, including levee overtopping or failure, is the key to starting a movement of change.

Hurricane Katrina provided a clear example of what happens when people do not understand the risk or potential impact of a levee overtopping or failing. Three years later, the New Orleans’ flooding, due to levee failure, is primarily seen as a unique and local problem, when, in fact, levee-
related risks are systemic across the nation. In an interconnected world, where information is more easily available than ever before, it is unacceptable that anyone not be aware of, understand or be exposed to levee-related risks.

Existing national flood plain management policy continues to lead to commercial and residential development in areas located on the fringes of flood zones and behind levees, because these locales are considered, according to present-day flood maps, to be outside of high hazard flood zones (i.e., special hazard flood areas). Without policy changes, financial and operational risk may continue to escalate.

The good news is, as a result of the emerging National Levee Safety Program (National Committee on Levee Safety 2009), the public will, in the future, be able to more easily identify areas at risk of levee failure on future flood maps. This is an excellent first step. However, in isolation this alone will not result in the change needed to address the levee risk across the nation.

The momentum of change will increase rapidly if all flood risk management professionals collectively focus their efforts on ensuring that people understand the risk and personalize the consequences.

Now is the time to work together to make this happen. If we don’t, shame on us.

Author Bio and Contact Information

Clive Goodwin is assistant vice president and manager, flood and wind peril underwriting, for FM Global (www.fmglobal.com), one of the world’s largest business property insurers. In this position, Goodwin manages worldwide underwriting of wind, flood and collapse perils. Prior to his current appointment in 2007, Goodwin served as assistant vice president and manager of natural hazards engineering. Goodwin has held several engineering positions, in the U.K., the Netherlands and the USA, since joining FM Global in 1988 as a field engineer. He has been the leader of FM Global’s efforts to collaborate with the U.S. Army Corps of Engineers, Federal Emergency Management Agency (FEMA) and other agencies to highlight the concerns regarding the aging inventory of levees while supporting their efforts to change U.S. national policy concerning the levee risk. He can be reached at clive.goodwin@fmglobal.com.

References


“Floods are ‘acts of God,’ but flood losses are largely acts of man.”  Gilbert White (1945)

The importance of a society, conceived at all levels – individual, family, neighborhood, organizational (bureaucracy, business), and community – knowledgeable about natural hazard risk, motivated to incorporate actions and (self) informed about important actions to take, and working together to reduce such risk, is an ideal towards which we all must strive. These papers make an important contribution to these goals. However, the papers vary in their recognition of the importance of community dynamics as a key factor in achieving these risk reduction goals.

The most important actions that humans can take to achieve risk reduction from natural hazards are:

1. to undertake a serious, systematic assessment of the risk from natural hazards that development of a locale will have on what is placed there, and

2. to assess each decision that society makes to impact the environment – such as taking a wetland to develop a residential subdivision – to determine what present and future enhanced risk that action will have on the human activities of the ecological region, for example, not just to the homes in the subdivision but the impact on human settlement in the surrounding area that is no longer protected by the storm-absorptive capacity of the wetlands.

Mark Davis’s article forcefully supports the words of President Lyndon Johnson “The key…lies in…regulation of use of lands exposed to flood hazard” (House Document Number 465, 89th Congress, 2nd Session 1966).

In simpler phrasing, society places itself in harm’s way from natural hazards and we harm the environment so that it cannot continue to protect us from natural hazards. When we fail to appreciate these two “laws” of risk – which we do daily, repeatedly, and without pause, in fact with hubris – the only follow-on steps remaining are to mitigate our actions by piecemeal efforts. Mitigative actions, such as levees and flood insurance act to put more people at risk rather than to reduce risk in the most robust manner. When human populations are already in a risky place and the environment has been compromised, because the two cautionary actions specified above were not followed, then the full palate of risk reduction efforts, which we call “mitigation” or “non-structural” actions (not just one or two) must be implemented. And this must be done in a systematic, comprehensive fashion with structural measures to form an integrated system of risk reduction. This is the third law of risk. Earthea Nance iterates these efforts: “Urban planning decisions, enforcement of building standards (such as elevating structures above flooding and constructing them with wind resistance), floodplain management and emergency management.” These are the “multiple lines of defense” (Lopez 2008) that must be joined.

To achieve this effort we need respect by government officials and physical science and engineering professionals that high quality social science research conducted on societal risk in its most comprehensive form is necessary in order to
accomplish a *cultural shift*, a new culture of risk reduction and management, as has been achieved in support of the energy conservation movement. For example, Denise Reed, in her article, recognizes well the importance of a leadership group that includes not only government officials but also engineers and natural scientists. Social scientists are not mentioned. Managing risk is a human problem; without respecting the need to study human behavior with regard to risk response in conjunction with the structural (engineering) and environmental (physical science), progress will continue to be slow.

I’m always amazed that these “laws” of risk and risk response requirements are not obvious to most who address water-related natural hazards and the reduction of risk from them. Realizing the importance of the social scientist at the table of natural hazard risk reduction may be one **key** to their successful promulgation.

**Notes**

1. *Mitigation* is used by FEMA and *non structural* by the Corps, the “structure-building” arm of the federal government.

**Author Bio and Contact Information**

Shirley Laska is Director of the Center for Hazards Assessment, Response and Technology (CHART) and Professor of Sociology at the University of New Orleans, New Orleans, LA. Her work has drawn attention to the need for more sub-regional analysis of hurricane evacuation behavior; more consideration to flood-proofing structures for less than 100-year floods to complement more stringent protection; more attention to considering local area drainage solutions to repetitive flood loss rather than demolition of individual repeatedly flooded structures; inclusion of the human/social impacts of coastal restoration rather than only the ecological; and also improving hazard mitigation outcomes by including community members and stakeholders as full participants in efforts to reduce the human risk. She may be reached at SLaska@uno.edu.

**References**


I decided to write this article after the sixth or seventh time a student or colleague glanced at the cover of the June 2008 issue of the *Journal of Contemporary Water Research and Education* (Issue 139, entitled: A Creative Critique of U.S. Water Education”) and asked me, “Why does this cover feature only elderly white men?” followed by, “aren’t there any distinguished women (or minorities) in this field?”

Let me begin by saying that there is nothing wrong with honoring those whose photographs currently grace the cover of the *JCWRE* Issue 139. We just need another row or two to make room for engineers and scientists like Linda Abriola, Diane McKnight and Christine Shoemaker; or perhaps for Sylvia Bozeman, a professor at Spelman College and co-founder of the Enhancing Diversity in Graduate Education (EDGE) program, or S. George Philander, professor of oceanic and atmospheric sciences and one of the few African-American members of the National Academy of Sciences (Figure 1). We have made progress in becoming a more diverse community – we should let the world know!

The need to include some discussion of diversity when we are exploring ways to address the problems facing U.S. Water Resources Education was reinforced as I read through the articles in the journal issue. While documenting the increasing demand for engineers, hydrologists, and water resource professionals, and concerns over the ability of the U.S. educational system to supply those needs, the articles neglected to discuss the great potential to increase that supply through recruitment of women and minorities. For example, in an article examining the reasons why the U.S. is not producing enough engineers at all levels, Rogers (2008) fails to mention that if more women and minorities pursued bachelor’s degrees and careers in engineering and physical sciences, we could greatly increase the number of U.S. engineers and water resources scientists. In addition, none of the articles in this issue mentioned the benefits of the new perspectives, research directions, and innovative approaches that could result from the recruitment of a more diverse cohort of students, and eventually colleagues, in the water resources professions.

In this article I wish to make four points:

1. There are women, Hispanic Americans, Native Americans, and African Americans in water resources engineering and the hydrologic sciences, and some of them have achieved distinguished careers worthy of recognition on the cover of *JCWRE*.
2. It is important that we present a more accurate and inclusive view of Water Resources professionals in our communications.
3. Increased diversity within the profession has many potential benefits for water resources science, engineering, management, and policy. We have a ways to go to achieve equity in recruitment of students and faculty, salaries and funding, as well as institutional rewards and professional recognition.
4. Efforts to enhance the diversity of the students recruited into water resources science and engineering could be a key strategy in meeting national needs for engineers, hydrologists, and water resources professionals.

Present Diversity of Scientists and Engineers in Water Resources

The community of scientists, engineers, and educators in water resources includes distinguished women and minorities. While they are still underrepresented, women, African Americans, Hispanic Americans, and Native Americans are a part of the water resources professional community, and increasing the diversity of that community should be one of the goals of water resources educators. For example, in 2006, the officers of the Hydrophiles, the student chapter of the American Water Resources Association at Oregon State University, organized a seminar series entitled: “World-Class Women in Water” (Hydrophiles 2006). We had no trouble filling all the slots. Students attending these seminars listened to presentations by Ellen Wohl (Colorado State University), Carol Kendall (USGS), Irena Creed (Univ. of Ontario), Diane

Figure 1. Some additional distinguished water resources scientists, engineers, and educators in science and mathematics clockwise from top left: Linda Abriola, Tufts University; Sylvia Bozeman, co-founder of the EDGE program, Spelman College; Diane McKnight, University of Colorado, INSTAAR; S. George Philander, Harvard University; Christine A. Shoemaker, Joseph P. Ripley Professor of Engineering, Cornell University.
McKnight (University of Colorado), Eileen Poeter (Colorado School of Mines), Susan Hubbard (Lawrence Berkeley Natl. Labs), Susan Riha (Cornell University), and Janet Hardy (US Army Corps of Engineers). Some of these speakers (and many other prominent scientists, engineers, and educators such as Christine Shoemaker of Cornell University or Linda Abriola of Tufts University) could easily have been included on the cover of *JCWRE* as a more inclusive reflection of the face of water resources education in the U.S today.

The student response to this seminar series was overwhelmingly positive, and their enthusiasm was shared by faculty members, regardless of gender.

A number of exemplary efforts are being made to foster greater diversity in engineering and science. For example, the American Society of Civil Engineers has developed programs to build a more inclusive profession, which can be reached via an excellent web site devoted to issues of diversity (American Society of Civil Engineers 2008), with links to their programs that promote recruitment of women and under-represented minorities.

The Enhancing Diversity in Graduate Education (EDGE) program founded by Sylvia Bozeman of Spelman College and Rhonda Hughes of Bryn Mawr College has succeeded in developing an approach and mentoring strategies that have guided dozens of promising students in the critical transition from promising undergraduate to successful graduate student in mathematics and the physical sciences.

We need to continue and expand upon these efforts in communications about the water resources professions if we are to increase the diversity of our membership. More examples are out there – the point here is, we have made gains in diversity, we need to increase public awareness of these gains in our communications.

**The Importance of an Accurate and Inclusive View of Water Resources Professionals**

Does it matter who is on the cover of this journal issue? Or that all of the articles on research and education in the physical sciences and engineering were by men, whereas those articles by women authors focused on the human dimensions of water resources?

I believe that it does matter. First, because a more diverse image of the scholars and teachers in this field would more accurately reflect the composition of the profession. Second, because the perception of engineering and the physical sciences as primarily the purview of white men is an obstacle to recruitment of women and minorities (AXXS 1999). Third, because the presence of role models has been shown to be important in promoting a climate that fosters the success of women and under-represented minorities in science and engineering (Arnold 1995, AXXS 1999).

A cover that features only white men reinforces the myth that the only ones who have achieved greatness in science and engineering are white men. When this is the face of our profession, we reinforce the stereotypes that make it difficult to recruit promising female or minority high school students or soon-to-be college graduates into our undergraduate and graduate programs. They simply do not see a place for themselves among us.

Three of the five core obstacles to advancing the careers of women in science and engineering identified by participants in a 1999 Workshop on Achieving Excellence in Science and Engineering (AXXS 1999) are relevant here. These obstacles include entrenched gender bias and cultural expectations, the male model of career success in science, and women’s self-perception. The report goes on to state that “…women in science often feel isolated, which likely results from (and exacerbates) other obstacles.”

Does it really make a difference who does the research? Why do we need women, Native American, African American, and Hispanic American hydrologists and engineers? Besides the obvious reason of equality of opportunity as a basic human right, we can learn from the example of the natural and health sciences, which have been more successful than engineering, for example, at recruiting minorities and women. Their experience? Researchers from different backgrounds are interested in different questions. For example, as more and more women obtained their M.D. or doctorate in health sciences research, their advocacy eventually led to more research on women’s health issues and representation of women as subjects in clinical trials (Keitt 2003, LaRosa 1994). People from different backgrounds have an interest in and a passion for studying different research questions.
and their unique perspective may lead them to take a unique approach to investigating those problems and developing solutions (Arnold 1991, Hitchcock and Hughes 1995). We need a full complement of perspectives and experience if we are to explore all the important research questions of the future.

**How Close are We to Achieving Equity?**

There have been numerous studies concerning the gaps in educational achievement, recruitment into undergraduate and graduate programs, salary, research funding, and the professional reward system (AWIS 2008, U.S. Department of Education 2000, 2001, 2005, NSF 2008a, Proudfoot 2008). A discussion of all the relevant studies is beyond the scope of this article. Rather, this section will focus on some data and recent studies that illustrate important points.

A study on the assessments of gender differences in science completed in 2000 (U.S. Department of Education 2001, AMS 2004), revealed that there is now little difference in the scores of boys and girls in math and science in the U.S. A more recent study of high school seniors in the U.S. (Hyde et al. 2008) indicates that there is no significant difference in their performance on standardized math tests. But despite similar performance on assessments in math and science, and the fact that more women than men currently enroll in college following high school in the U.S., women and minorities still lag behind Caucasian males in achieving undergraduate and graduate degrees in engineering and the physical sciences (including hydrology and other science fields in water resources). According to the National Science Foundation (NSF) Overview of Science, Engineering and Health Graduates: 2006 (Proudfoot 2008), “The recent bachelor’s degree fields of study with the highest percentage of male graduates were engineering (78 percent) and computer and information sciences (77 percent). Results at the recent master’s degree-level were similar; … engineering, computer and related sciences, and physical and related sciences had the highest levels of male graduates (77 percent, 66 percent, and 66 percent, respectively).”

While these statistics document a ten-fold improvement towards equal numbers of graduates when compared to data from 1970, when only about 2 percent of engineering degrees were earned by women, we can do better. In addition, when we look at college degrees awarded to minorities, there has been less progress (U.S. Department of Education 2000). Any critique of water resources education in the U.S. must address the need to recruit and retain women and underrepresented minorities into the water resources fields.

Is there equity in research support for women, men, and minorities? What would an equitable distribution of research funding look like? These are difficult questions to answer. If one is working with large enough numbers of grants, all else being equal, one would expect that the proportion of success in obtaining research funding by any one group would parallel the proportion of applicants in that group. Of course, all else is not equal. Women and men do not enter research positions in proportion to the number of graduates, they do not apply for research funding in equal numbers, and anyone who has sat on a review panel for any funding entity would probably agree that despite all our best intentions and the heroic efforts of dedicated program directors, our methods for objective evaluation of proposals are imperfect, regardless of gender issues. However, a look at some data on funding for the hydrologic sciences may be instructive.

As a first step towards investigating the relationship of gender to current success rates for hydrologists in obtaining research funding from NSF, I downloaded and examined the data on recent NSF awards in Hydrologic Sciences from the NSF web site (NSF 2008b). It is not possible to discern the race or ethnicity of the Principal Investigator (PI) from this data set, so I focused here on gender differences. I excluded from my analysis three very large program awards to hydrologic centers and organizations - SAHRA ($30 M) and CUAHSI (two awards totaling $8 M) except to note that all three of these very large awards listed had male PIs. Serving as PI for such awards reflects not only personal achievement but also a commitment of service to the hydrologic community. Of the 204 remaining recent awards listed, 75 percent were awarded to male PIs (Figure 2). Further exploration of the 139 collaborators listed as co-PIs showed that 115 (86 percent) were male and only 19 were female.
When one specifically examines NSF CAREER awards, intended to help launch the careers of promising young scientists, the proportion of awards is nearly equal. Of the thirteen CAREER awards, seven were awarded to men and six to women, although the average total amount awarded to men was higher by about $75,000.

This analysis is not intended to be a criticism of NSF, past or current program directors, or previous review panels. I am not suggesting that these data imply any intentional bias in the proposal review process. After all, the proportion of awards made to male and female PIs is similar to the proportion of women and men doctoral graduates in the physical sciences and engineering. Furthermore, it is only fair to note that the pattern of lower average CAREER award amounts provided to female PIs could result from strategic efforts to increase the number of CAREER awards to members of underrepresented groups, through small awards made at the discretion of the program director.

Understanding the reasons behind the differences in the number of awards made by gender would require a much more thorough analysis of long-term data on number and demographic characteristics of applicants, relative success rate, and objectives and methods for evaluation of proposal quality. The point here is that we have not achieved gender equity in funding when female PIs receive only 25 percent of the total awards and 39 percent of the funding.

The topic of disparity in salary, recognition, and professional rewards among men and women scientists and engineers has been studied and reported on by numerous individual researchers as well as government agencies. An excellent set of statistical summaries on a variety of metrics (from salary and education statistics to relative number of appearances as a scientist on prime-time television) has been compiled and is available through the Association for Women in Science or links to their web site (AWIS 2008). I will note

![NSF Hydrology Funding by Gender](image)

**Figure 2.** Proportion of recent grants awarded to male (light gray bar) and female (dark gray bar) principal investigators (PIs) through the National Science Foundation Hydrologic Sciences program. Note the larger number of grants awarded to male PIs overall, especially in the range of awards of less than $200,000 as well as the four awards of more than $1 M to male PIs compared to one awarded to a female PI.
only a few highly relevant differences below.

Rogers (2008) notes that lack of financial incentive may be one factor responsible for lack of enrollment in engineering programs - salaries for engineers are significantly lower than salaries of medical doctors or attorneys. However, salaries for women engineers lag even farther behind. Recent figures show that salaries for women engineers tend to be only about 86 percent of the salaries of their male counterparts (AWIS 2008). There is even less of a salary incentive for women than for men to enter the engineering professions.

Election to the National Academy of Science (NAS) or the National Academy of Engineering (NAE) is among the highest honors for U.S. scientists and engineers. Caucasian males dominate the membership in both the NAS and NAE. At present, there are 2036 Active Members of the NAS (217 of them women) and 76 Emeritus (non voting) Members (3 of them women). One woman is an honorary member; she received the Public Welfare Medal, the highest award bestowed by the NAS. The NAS does not track information regarding minorities.

What would equity in professional recognition and reward look like? This is a matter for debate among members of the various professional societies and academe itself. The point is that we are not there yet.

Increasing Diversity in the Water Resource Professions

How can we increase the diversity of students and faculty members in Water Resources? Well, as the saying goes, the first step is to realize that you have a problem. The next step is to frame the problem properly. As the presidents of MIT, Princeton and Stanford noted in an opinion piece in the Boston Globe:

The question we must ask as a society is not “can women excel in math, science and engineering?” – Marie Curie exploded that myth a century ago--but “how can we encourage more women with exceptional abilities to pursue careers in these fields?” While no one has all of the answers yet, listed below are some integral components for increasing diversity in our undergraduate and graduate programs, and professional careers.

- We need to encourage students from diverse backgrounds to consider water resources science and engineering as a profession that is open to them,
- We need to give all students the tools to succeed (strong math and science education and the ability to read, write, think critically and creatively),
- We need to welcome colleagues of both genders and diverse racial, cultural, and ethnic backgrounds into the profession and work to build an inclusive community,
- We need to provide positive role models and mentors for all,
- We need to provide equal support (funding) for research and equal opportunity for publication of research results, and
- We need to reward members of our profession equally, by working towards equal salary for equal work, and equity in professional recognition for their equal successes in water resources research and education.

Summary

In summary, I would like to reiterate the point that those whose photographs are included on the cover of the JCWRE Issue 139 are deserving of this honor. Many wonderful scholars, engineers, and educators happen to be elderly white men, (including my own doctoral advisor, a champion of equity in graduate education, limnologist and NAS member Eville Gorham). There are also many wonderful scholars, engineers, and educators who are women and men of varied racial, ethnic, and cultural backgrounds. Improving water resources education in the U.S. must include increasing the diversity of students recruited into the field. We can increase the supply of water resources engineers and scientists by recruiting more members from under-represented groups. Highlighting our gains in diversity in our communications can help to
recruit an even more diverse community, and will reinforce existing efforts to increase the representation of women and minorities in the water resources professions.

Acknowledgements

I wish to thank the colleagues and students who encouraged me to write this article, and George King and Denise Lach who reviewed it prior to submission. I also wish to thank all the educators whose mentoring led me pursue a doctorate and a career in science, beginning with Mr. Troubonis, (my seventh grade science teacher) who taught me to keep a lab notebook and loved Star Trek because it envisioned a world in which women and men of all races and backgrounds could achieve great things. I also thank Margaret Davis, Donald B. Lawrence, Herbert and Florence Wagner, and Eville Gorham whose example and encouragement were instrumental to my success in graduate school, and my students and colleagues at Oregon State University who inspire me daily.

Author Bio and Contact Information

Mary V. Santelmann received her Ph.D. in Ecology from the University of Minnesota. She currently serves as the Director of the Water Resources Graduate Program at Oregon State University. Her research interests include interdisciplinary studies of the influences of land use and management on ecosystems, wetlands biogeochemistry, and the relationship between hydrology and plant species distributions in wetlands. She has served as Principal Investigator for interdisciplinary research projects through the EPA Water/Watersheds Program and the US NSF Biocomplexity in the Environment Program. Her publications include papers in the Journal of the American Water Resources Association, Journal of Contemporary Water Resources Research and Education, Ecology, Journal of Ecology, and Landscape Ecology. Email: santelmm@science.oregonstate.edu.

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gwoodard@sahra.arizona.edu

Richard Warner
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The first of these events, An International Perspective on Environmental & Water Resources, serves as a follow-up to EWRI’s first international conference in India of the same name. Held in January 5-7, 2009, this conference in Bangkok, Thailand featured a wide variety of topics largely focused on water resources and the environment in developing countries in Asia and Africa. Among those topics were the issues of Climate Change and Natural Hazards; Water Resources and Water Supply; and Environment, Ecology, and Waste Management. For more information on this event, visit the conference website at http://content.asce.org/conferences/thailand09/.

The next of EWRI’s international conferences will be in co-sponsorship with the International Association of Hydraulic Engineering & Research (IAHR) on August 10-14, 2009. The 33rd IAHR Congress, titled Water Engineering for a Sustainable Environment, will be co-located in Vancouver, British Columbia, Canada, with the 2009 Canadian Society for Civil Engineering Canadian Hydrotechnical Conference & Symposium. The technical session topics chosen for the Congress will include:

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To learn more about the 33rd IAHR Congress, please visit http://www.iahr2009.org.

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- Accessibility for all agency staff to all sections of the UCOWR website (www.ucowr.org) that hosts over 50 issues of the *Journal of Contemporary Water Research and Education*.
- Information about conferences and discounts for registration at UCOWR’s annual conference
- Collaboration with leading U.S. researchers on water resources
- Voting rights in UCOWR affairs for up to 8 individual delegates

Membership is subject to approval by UCOWR Board of Directors and is based on the July 1 - June 30 fiscal year.

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<th>Annual</th>
<th>2-Years</th>
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<tbody>
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<td>$ 450</td>
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For additional information call Christopher Lant, Exec. Director, UCOWR (618) 453-6020

PAYMENT MUST ACCOMPANY APPLICATION  UCOWR FEIN – 47-0617822

Amount $_______ for the period July 1, 20___ to June 30, 20___

[ ] Visa  [ ] Master Card  [ ] American Express  [ ] Discover

[ ] P/O or Check # __________________________

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Cardholder’s Name: ___________________________ Signature: ___________________________

Cardholder’s email address if not the contact person: __________________________ zipcode__________

Mail completed form to:
UCOWR, 4543 Faner Hall – Mail Code 4526, Southern Illinois University Carbondale, 1000 Faner Drive, Carbondale, IL 62901
Phone: (618) 536-7571   FAX: (618) 453-2671   E-Mail: UCOWR@siu.edu   Website: http://www.ucowr.org
Non-Academic Organizations Membership Application

UNIVERSITIES COUNCIL ON WATER RESOURCES

(Please Type or Print Clearly)

Date: ______________________

Organization/Company Name: ______________________________________________________________

Mailing Address: _______________________________________________________________________
_____________________________________________________________________________________

City: ______________________________ State: ___ Zip: _________ Country: __________________

Contact Person: _______________________________________________________________________

Phone: __________________ Fax:____________________ E-mail: _____________________________

MEMBERSHIP BENEFITS (based on fiscal year July 1 - June 30)

• A subscription of the Journal of Contemporary Water Research and Education, with its concise analysis of pressing water resources issues (8 copies for small organizations, 16 for medium organizations, 32 for large organizations and 64 for very large organizations).
• Accessibility for all agency staff to all sections of the UCOWR website (www.ucowr.org) that hosts over 50 issues of the Journal of Contemporary Water Research and Education.
• Information about conferences and discounts for registration at UCOWR’s annual conference.
• Collaboration with leading U.S. researchers on water resources.
• Membership is subject to approval by UCOWR Board of Directors.

Membership Rates

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<th>Organization Description</th>
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For additional information call Christopher Lant, Executive Director, UCOWR (618) 453-6020

PAYMENT MUST ACCOMPANY APPLICATION________________________UCOWR FEIN – 47-0617822

Amount $ ______ for the period July 1, 20__ to June 30, 20__

☐ Visa ☐ Master Card ☐ American Express ☐ Discover

☐ P/O or Check # ______________________________

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Cardholder’s Name: _____________________________ Signature: _____________________________

Cardholder’s email address if not the contact person: ___________________________ zipcode _______

Mail completed form to:
UCOWR, 4543 Faner Hall – Mail Code 4526, Southern Illinois University Carbondale, 1000 Faner Drive, Carbondale, IL 62901
Phone: (618) 536-7571     FAX: (618) 453-2671     E-Mail: UCOWR@siu.edu     Website: http://www.ucowr.org

UCOWR
Individual Membership Application

UNIVERSITIES COUNCIL ON WATER RESOURCES

(Please Type or Print Clearly)

Date: ______________________

Last Name _____________________________  First Name ____________________________________

Institution/Company Name: ______________________________________________________________

Mailing Address: ______________________________________________________________________

_____________________________________________________________________________________

City: ______________________________ State: ___ Zip: ___________ Country: _________________

Contact Person:  ______________________________________________________________________

Phone: _______________ Fax:__________________ E-mail: ___________________________________

Recommended (if applicable): ____________________________________________________________

YEARY MEMBERSHIP (Based on the calendar year, January 1 – December 31)

• A subscription to the Journal of Contemporary Water Research & Education, with its concise
  analysis of pressing water resources issues
• Electronic access to all issues of Water Resources Update and JCWRE
• Information about conferences and discounts for registration at UCOWR’s annual conference
• Joining with leading U.S. academic researchers on water resources

☐ Regular Membership..............................................................................................................$70.00
☐ Student Membership (electronic access only to all issues of Water Resources Update and JCWRE).................$20.00
☐ International Membership............................................................................................................$115.00

Payment must accompany order

UCOWR FEIN – 47-0617822

☐ Visa  ☐ Master Card  ☐ American Express  ☐ Discover
☐ P/O or Check # ______________________________

Card Number: __ __ __ __/__ __ __ __/__ __ __ __/__ __ __ __  Expiration Date: __ / __ CVVS __

Cardholder’s Name: _____________________________ Signature: _____________________________

Cardholder’s email address if not the contact person: ___________________________ zipcode ______________

Mail completed form to:

UCOWR, 4543 Faner Hall – Mail Code 4526, Southern Illinois University Carbondale, 1000 Faner Drive, Carbondale, IL 62901
Phone: (618) 536-7571  FAX: (618) 453-2671  E-Mail: UCOWR@siu.edu  Website: http://www.ucowr.org
# Journal Order Form

**Universities Council on Water Resources**  
*Journal of Contemporary Water Research and Education*  
(formerly *Water Resources Update*)

(Please Type or Print Clearly)  

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### YEARLY SUBSCRIPTION  
minimum 3 issues starting month:________________ year:_________  

- [ ] Annual domestic subscription rate $ 35.00  
- [ ] Annual international subscription rate $ 80.00  

### PAST ISSUES  
can be purchased for $15 per copy (domestic), $30 per copy (international), subject to availability. Call UCOWR Headquarters for discount pricing on orders of 10 or more of the same issue.  

<table>
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</table>

**total for past issues $ ___________**

To view a list of past issues, please visit the UCOWR website www.ucowr.siu.edu and click on DATABASES AND PUBLICATIONS, then scroll down to PUBLICATIONS, and click on the first entry.

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- [ ] American Express  
- [ ] Discover  

- [ ] P/O or Check # ________________  
- [ ] total purchase amount $ ____________

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Expiration Date: __ __ / __ __  
CVVS __  

Cardholder’s Name: __________________________  
Signature: __________________________

Cardholder’s email address if not the subscriber: __________________________  
zipcode ____________

Mail completed form to:  
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Phone: (618) 536-7571  
FAX: (618) 453-2671  
E-Mail: UCOWR@siu.edu  
Website: http://www.ucowr.org
Urban Water Management: Issues and Opportunities

**SPECIAL EVENTS**

*See program for details.*

**TUESDAY July 7**

<table>
<thead>
<tr>
<th>REGISTRATION</th>
<th>7:00AM-4:00PM</th>
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</thead>
<tbody>
<tr>
<td>Cont. Breakfast</td>
<td>7:30AM-8:00AM</td>
</tr>
</tbody>
</table>

**PLenary Session 1**

*8:00AM-10:00AM*

- Welcome and Keynote Speakers
  - Michael Sturtevant
  - David Naftzger

**Break 10:00AM-10:30AM**

**Technical Sessions 1**

*10:30AM-12:00PM*

- 2 Stormwater Management I
- 3 Human Impacts on Water Resources
- 4 Agricultural Methods, Practices and Policy

**Lunch on Your Own**

*12:00PM-1:30PM*

**Technical Sessions 2**

*1:30PM-3:00PM*

- 5 Stormwater Management II
- 6 Ecosystem Impacts and Management Practices
- 7 International Water Supply Policies and Practices

**Break 3:00PM-3:30PM**

**Technical Sessions 3**

*3:30PM-5:00PM*

- 8 Balancing Urban Water Supply and Demand
- 9 Stormwater Management Models
- 10 Pharmaceuticals and Personal Care Product Impact on Water Quality

**Welcome Reception and Poster Session**

**Marriott Lower Foyer**

*6:00PM-8:00PM*

**TUESDAY July 7**

**MONDAY July 6**

- Stickney Water Reclamation District 1:30PM-4:00PM
- Metropolitan WRD Cruise 4:00PM-7:00PM
- Registration 4:00PM-7:00PM

**TUESDAY July 7**

- Welcome Reception and Poster Session 6:00PM-8:00PM

**WEDNESDAY July 8**

- UUCWR Awards & Banquet
  - Marriott Ballroom
  - Cash Bar 6:30PM
  - Banquet 7:00PM-9:00PM

**THURSDAY JULY 9**

- Racine Pumping Station 1:30PM-3:30PM
<table>
<thead>
<tr>
<th><strong>WEDNESDAY July 8</strong></th>
<th><strong>THURSDAY July 9</strong></th>
<th><strong>2009 UCOWR AWARD WINNERS</strong></th>
</tr>
</thead>
</table>
| **REGISTRATION** 7:30AM-4:00PM | **REGISTRATION** 7:30AM-9:00AM | **Warren A. Hall Medal**  
Gerald E. Galloway  
University of Maryland |
| **Break** 10:00AM-10:30AM | **Break** 10:00AM-10:30AM | **Friends of UCOWR**  
Gretchen Rupp and  
M. J. Nehasil  
Montana Water Center  
Ronald D. Lacewell and  
Michele Zinn  
Texas A & M University |
| **PLENARY SESSION 2**  
8:00AM-10:00AM | **TECHNICAL SESSIONS 6**  
8:30AM-10:00AM | **Ph.D. Dissertation**  
Natural Science and Engineering  
To be announced  
**Ph.D. Dissertation**  
Water Policy and Socioeconomics  
To be announced  
**Education and Public Service**  
Alliance for Water Efficiency  
Illinois-Indiana Sea Grant |
| **Keynote Speakers**  
- Mary Ann Dickinson  
- Ed Archuleta  
- Alice Miller Keyes | **Keynote Speakers**  
- Jim Heaney  
- David Douglas  
- Vladimir Novotny | **UCOWR BANQUET**  
**AND AWARDS CEREMONY**  
Marriott Ballroom  
**CASH BAR 6:30PM**  
**BANQUET 7:00PM-9:00PM**  
**WEDNESDAY JULY 8** |
| **TECHNICAL SESSIONS 4**  
10:30AM-12:00PM | **TECHNICAL SESSIONS 5**  
1:30PM-3:00PM | **2009 UCOWR AWARD WINNERS** |
| **Break** 3:00PM-3:30PM | **Break** 3:00PM-3:30PM | **Ph.D. Dissertation**  
Water Policy and Socioeconomics  
To be announced  
**Education and Public Service**  
Alliance for Water Efficiency  
Illinois-Indiana Sea Grant |
| **TECHNICAL TOURS**  
Racine Pumping Station  
1:30PM-3:30PM | **END OF TECHNICAL PROGRAM** | **2009 UCOWR AWARD WINNERS** |
Welcome Reception & Poster Session

**Marriott Lower Level Foyer**
Tuesday July 7, 6:00 PM - 8:00 PM

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**UCOWR Banquet & Awards Ceremony**

**Marriott Ballroom**
Wednesday July 8, Cash Bar 6:30 PM, Banquet 7:00 PM-9:00 PM

- **Dissertation Awards** - UCOWR recognizes two outstanding Ph.D. dissertations in (1) Water policy and socio-economics and (2) Natural science and engineering.

- **Education and Public Service Awards** - These awards are given to recognize individuals, groups, or agencies that have made significant contributions to increased public awareness of water resources development, use, or management.

- **Friends of UCOWR Awards** - UCOWR recognizes individuals or groups who have made outstanding contributions to the organization and names them Friends of UCOWR.

- **Warren A. Hall Medal** - UCOWR presents the Warren A. Hall Medal to acknowledge distinguished achievements of an individual in the field of water resources.

---

**Technical Tours**

- **Stickney Water Reclamation District/Biosolid Drying Fields/McCook Water Reservoir**
  Monday July 6, 2009, 1:30 PM - 4:00 PM  
  Cost $40

  The Stickney Water Reclamation Plant is the largest wastewater treatment facility in the world. The Plant serves 2.38 million people in a 260 square mile area including the central part of Chicago and 43 suburban communities. Research labs connected with the facility will also be toured. The tour then moves to the MWRDGC’s biosolids drying field where the solid byproducts of wastewater treatment are transformed into a substance resembling top soil that can be used to provide organic matter and nutrients to fields and other natural settings. The final stop on this tour will be at the McCook Reservoir. Currently under construction, this reservoir will hold 7 billion gallons of stormwater and sewage from the Chicago deep tunnel system once completed. Coupled with two other reservoirs and the deep tunnel system, McCook will be part of the largest storm and sewage storage system in the world. (Water & snacks provided)

- **Metropolitan Water Reclamation District Boat Cruise**
  Monday July 6, 2009, 4:00 PM - 7:00 PM  
  Cost $25

  Enjoy the Chicago skyline while you learn about the Metropolitan Water Reclamation District of Great Chicago and how Lake Michigan and the Chicago River function as urban water resources. Refreshments will be served. Cash bar may be available. Participants will be required to walk a few blocks from the hotel to the boat.

- **Racine Pumping Station**
  Thursday July 9, 1:30-3:30 PM  
  Cost $40

  Tour the Racine Pumping Station where 14 massive pumps can process up to 3.9 billion gallons of storm and wastewater. Tour participants will see the massive pumps and learn about how Chicago deals with its excess storm and sewer water, sometimes more effectively than others. (Water & snacks provided)
Chicago Area Attractions

Chicago is one of the greatest cities in the world. With its sparkling lakefront, exciting downtown, cultural and shopping districts, and quality options for dining, entertainment, and relaxation, it’s a city that delights individual visitors and families alike. As the crossroads of the nation and the world, it is easily and affordably accessible from any spot on the planet. With world famous museums, Millennium Park, Navy Pier, the Magnificent Mile, Second City Comedy, and Wrigley Field, Chicago has the perfect venue for our conference. Well known as a food-lover’s paradise, Chicago offers everything from hot dogs to haute cuisine with world famous stuffed pizza in between. For more information, visit the Chicago Convention & Tourism Bureau website: http://www.choosechicago.com/Pages/default.aspx.

SUGGESTED RECREATIONAL TRIPS

H20=Life exhibit at the Field Museum

Discover the importance of Earth’s most vital and fleeting resource. Examine how living things adapt to extremes of wet and dry environments, and learn how human behavior alters precious aquatic ecosystems. Become inspired by conservation efforts from around the world and discover what you and your family can do to protect and conserve our planet’s water. Through hands-on activities, immersive dioramas, artifacts, and multi-media, this exhibition presents life’s essential element that unites us, surrounds us, and challenges us, now on display at The Field Museum, http://www.fieldmuseum.org/

Chicago Architecture River Cruise

Chicago’s most popular River Cruise! CAF-certified expert docents interpret the world-class architecture along the Chicago River. Marvel at Chicago’s soaring towers while enjoying a 90-minute, narrated river cruise. This tour spotlights more than 50 architecturally significant sites where you will discover a new perspective on the city. Come aboard the vessels of Chicago’s Finest Fleet: Chicago’s First Lady, Chicago’s Little Lady and Chicago’s Fair Lady where both open-air and climate-controlled indoor seating make the journey comfortable. Snacks and beverages are available for purchase on board each vessel. http://www.architecture.org/tour_view.aspx?TourID=8.

Conference Location & Hotel

RESERVATIONS

The Courtyard Chicago Downtown/River North Marriott is offering rooms at $179 plus tax per night (single or double). To make reservations, call 1 (800) 321-2211 or (312) 329-2500 and ask for the Universities Council on Water Resources room rate. There are a limited number of rooms available at the Federal Employee rate for eligible participants (email gardr@siu.edu to be put on the eligible list). There are also a limited number of rooms available over the 4th of July weekend at the UCOWR rate. Please make your arrangements as early as possible to guarantee conference rates. Regular hotel rates will go into effect when UCOWR’s block of rooms is filled or by noon Friday, June 12, 2009, whichever happens first.

ACCOMMODATIONS AND GUEST SERVICES

The Courtyard Chicago Downtown/River North Marriott, just 3 blocks from Michigan Avenue, offers easy access to Navy Pier, shopping on the Magnificent Mile, and Theater and Museum Districts. While many attractions are within comfortable walking distance, the Chicago Free Trolley system offers complimentary rides throughout the majority of the city’s most popular tourist areas including Millennium Park, the Field Museum, and the Adler Planetarium. Aside from it’s great location, the hotel offers its guests a fitness center with an indoor pool, luxurious oversized rooms, and free high-speed internet access. Visit their website, http://www.marriott.com/hotels/travel/chiwb-courtyard-chicago-downtown-river-north/ to find out more!
**URBAN WATER MANAGEMENT: ISSUES AND OPPORTUNITIES**  
**UCOWR/NIWR Conference Registration June 7-9, 2009**

For secure On-Line Registration visit: [http://www.ucowr.org](http://www.ucowr.org)

(Please Type or Print Clearly)

| Last Name: _____________________________ | First Name: _____________________________________ |
| Dr. _ | Mr. _ | Mrs. _ | Ms. _ | Other _ | Nickname (for badge): _____________________________ |

| Institution/Company Name: _____________________________ |

| Mailing Address: _______________________________________ |
| City: ___________ | State: ___________ | Zip: ___________ | Country: ___________ |

| Phone: _____________________________ | E-mail: _______________________________________ |

| Spouse/Guest Name: _______________________________________ |

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**REGISTRATION FEES**

(Member rate applies only to UCOWR/NIWR members and faculty/staff of UCOWR institutions)

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| **Total** | $ ______ |

Probable banquet choice [ ] Beef [ ] Fish [ ] Veggie

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**REGISTRATION INCLUDES**

- Sessions
- Tues. Reception
- Weds. Banquet
- Daily Breakfast
- Proceedings

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**PAYMENT $ ______

UCOWR FEIN – 47-0617822

Check# _____________________________

Government/University P.O.# _____________________________

Credit Card Number: (Visa, MasterCard, Discover, or American Express)

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Expiration Date (Month/Year) ___ / ___ CVVS ___

Cardholder’s Name _____________________________

Cardholder’s Email __________________ Zipcode ________

Signature __________________

(I agree to pay the above amount according to the card-issuer agreement)

Make checks payable to the Universities Council on Water Resources. Checks must be issued in U.S. dollars, drawn on U.S. banks. Payments made by electronic (wire) transfer must be pre-arranged. Please contact Rosie Gard at gardr@siu.edu

On-site registration must be accompanied by payment or copy of purchase order. For pre-registration discount, form must be postmarked by June 7, 2009.

Cancellations must be submitted in writing by June 7, 2009.

A $50 processing fee will be deducted from the registration fee.

Mail to: Universities Council on Water Resources, Faner Hall, Room 4543, Mail Code 4526, Southern Illinois University Carbondale, 1000 Faner Drive, Carbondale IL 62901

Call in your registration to: (618) 536-7571 or Fax it in to: (618) 453-2671.
Conference Theme

Urban Water Management:
Issues and Opportunities

Cities face new and continuing challenges related to water. Expanding urban and suburban populations place increasing demands on limited water supplies in the East as well as the West. Infrastructures are decaying. Pharmaceuticals and other chemicals impact stream ecology. Climate change presents new uncertainties. This conference will address urban water management issues faced by cities in the U.S. and abroad. Topics will include water quality and quantity, storm water management, water conservation, local, state and regional water supply planning, water security, monitoring, and the ever-tightening relationship between water and energy. Participants will gain a broad understanding of the status of urban water management and research in the U.S.

Presentation Topics

- Urban Water Quality
- Urban Water Quantity / Demand
- Pharmaceuticals and other pollutants
- Urban stream restoration
- Conservation / harvesting
- Climate change / urban heat island drought
- Urban flash flooding
- Storm water management
- Monitoring
- Water reuse/gray water
- Public education and participation
- Water security/disaster preparedness
- Water and energy: biofuels, thermoelectric use
- Local, regional and watershed planning and economics

Featured Speakers

- John Spartz, DWM, City of Chicago
- Dave Naftzger, Council of Great Lakes Governors
- Mary Ann Dickinson, Alliance of Water Efficiency
- Ed Archuleta, El Paso Water Utilities
- Alice Miller Keyes, Georgia State Water Conservation Manager
- Jim Heaney, University of Florida

Conference Hotel

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Three Years after Katrina
Restoring and Protecting New Orleans and Coastal Louisiana

Issue Editor
Gerald E. Galloway

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Universities Council on Water Resources
Faner Hall, Room 4543 - Mail Code 4526
1000 Faner Drive
Southern Illinois University
Carbondale, IL 62901-4526
www.ucowr.org