Spring 2006

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
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The
BRIDGE

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Editor in Chief (interim): George Bugliarello

Managing Editor: Carol R. Arenberg

Production Assistant: Penelope Gibbs

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THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

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Editor's Note

George Bugliarello is President Emeritus and University Professor at Polytechnic University in Brooklyn, New York, and foreign secretary of NAE.

The Aftermath of Katrina

This is the second issue of *The Bridge* in the past year devoted to disasters caused by forces in our environment. The summer 2005 issue was focused on the Indian Ocean tsunami, and this issue is focused on Hurricane Katrina. As human populations continue to grow in areas vulnerable to earthquakes, volcanic eruptions, tsunamis, floods, fires, and landslides, we can expect that the effects of disasters will also be more severe. In the face of enormous natural forces, prevention is seldom possible, but with rational planning and a collective will, we can mitigate damages and losses.

The 2004 Indian Ocean tsunami showed the consequences of gaps in global warning systems, the absence of local warning systems and evacuation plans, and inadequate or nonexistent codes and regulations to strengthen structures and infrastructures. The tsunami also showed the enormous challenges of providing relief after a disaster has struck. Before Katrina, New Orleans had trusted in its flawed containment structures and its good luck to withstand the most powerful hurricanes. The lack of coordinated city, state, and federal policies undermined emergency responses to Katrina and the evacuation of New Orleans, which left hundreds of thousands stranded.

Many important lessons have been learned from these and other disasters. First, realistic plans must be made in advance to ensure the adequacy of defenses and to ensure that everyday services can be restored as soon as possible. Second, decision making at all levels must be rapid and to the point in an emergency. Third, the population must have accurate information and clear directions for action. Finally, major disaster mitigation, restoration, and recovery require the intervention of organizations with the logistical capacity to address very large-scale problems, usually beyond the capabilities of local jurisdictions. Unlike the well known dictum, "think globally, but act locally," a major disaster may be local, but the response must be global.

Engineers and scientists must not only provide much needed expertise, but must also advocate decision making based on dispassionate assessments and realistic long-range views. The papers in this issue address some aspects of the Katrina disaster and suggest policies for mitigating the consequences of future disasters. Brian Wolshon, a traffic engineer at Louisiana State University, analyzes the evacuation of New Orleans and demonstrates the importance of proactive traffic management to facilitate large-scale evacuations. Billy Ball, senior vice president of transmission planning and operations for Southern Company, describes the restoration of the multistate electric-power infrastructure in the Gulf region and suggests improvements in emergency planning for the future. **Robert Dean**, a coastal engineer, describes wetland formation and the history of wetland-system losses in the Mississippi Delta and outlines some options for future wetlands restoration. He argues not only for restoration of the Louisiana wetlands system, but also for a program to identify vulnerable areas throughout the country.

Gerald Galloway, an expert in water policy, decries the lack of a national policy for coastal zones to provide direction for coordinated long-term plans for the Gulf region. Paul Mlakar of the U.S. Army Corps of Engineers (USACE) describes the progress of the USACE task force analyzing the behavior of hurricane protection structures. **Danny Reible** (an environmental health engineer) and his colleagues describe the toxics and contaminants in the floodwaters that inundated New Orleans in the wake of Katrina and discuss the pros and cons of various criteria for making uniform, equitable decisions about rebuilding specific areas and structures.

Inefficiencies, unrealistic promises, and wishful thinking can add to the difficulties and expense of rebuilding habitats and economies. In New Orleans and along the Gulf Coast, recovery has become a political balloon, with promises being made before rational analyses have been completed. Many fundamental questions remain to be answered. If another major catastrophe hits our nation, how much can we realistically afford for mitigation and recovery? Should we continue to build or rebuild in proven high-risk areas? How can we create safer communities and infrastructures for the future? The answers to these and many other questions should guide the development of policies for future disasters.

George Bugliarello

Decisions about rebuilding are based more on the potential for reflooding than on the overall health of the New Orleans area.

Toxic and Contaminant Concerns Generated by Hurricane Katrina

Danny D. Reible, Charles N. Haas, John H. Pardue, and William J. Walsh


Danny D. Reible


Charles N. Haas


John H. Pardue


William J. Walsh

When Hurricane Katrina flooded the city of New Orleans, one of many concerns in its wake was contamination. Several chemical plants, petroleum refining facilities, and contaminated sites, including Superfund sites, were covered by floodwaters. In addition, hundreds of commercial establishments, such as service stations, pest control businesses, and dry cleaners, may have released potentially hazardous chemicals into the floodwaters. Figure 1 shows potential petroleum-related release points, including refineries, oil and gas wells, and service stations near the city.

Danny D. Reible is Bettie Margaret Smith Chair of Environmental Health Engineering in the Department of Civil, Architectural and Environmental Engineering at the University of Texas at Austin and an NAE member. Charles N. Haas is the L.D. Betz Professor of Environmental Engineering and head of the Department of Civil, Architectural and Environmental Engineering at Drexel University in Philadelphia. John H. Pardue is the Elizabeth Howell Stewart Professor of Civil and Environmental Engineering and director of the Louisiana Water Resources Research Institute, Louisiana State University, Baton Rouge. William J. Walsh is a lawyer with Pepper Hamilton, LLP, in Washington, D.C.

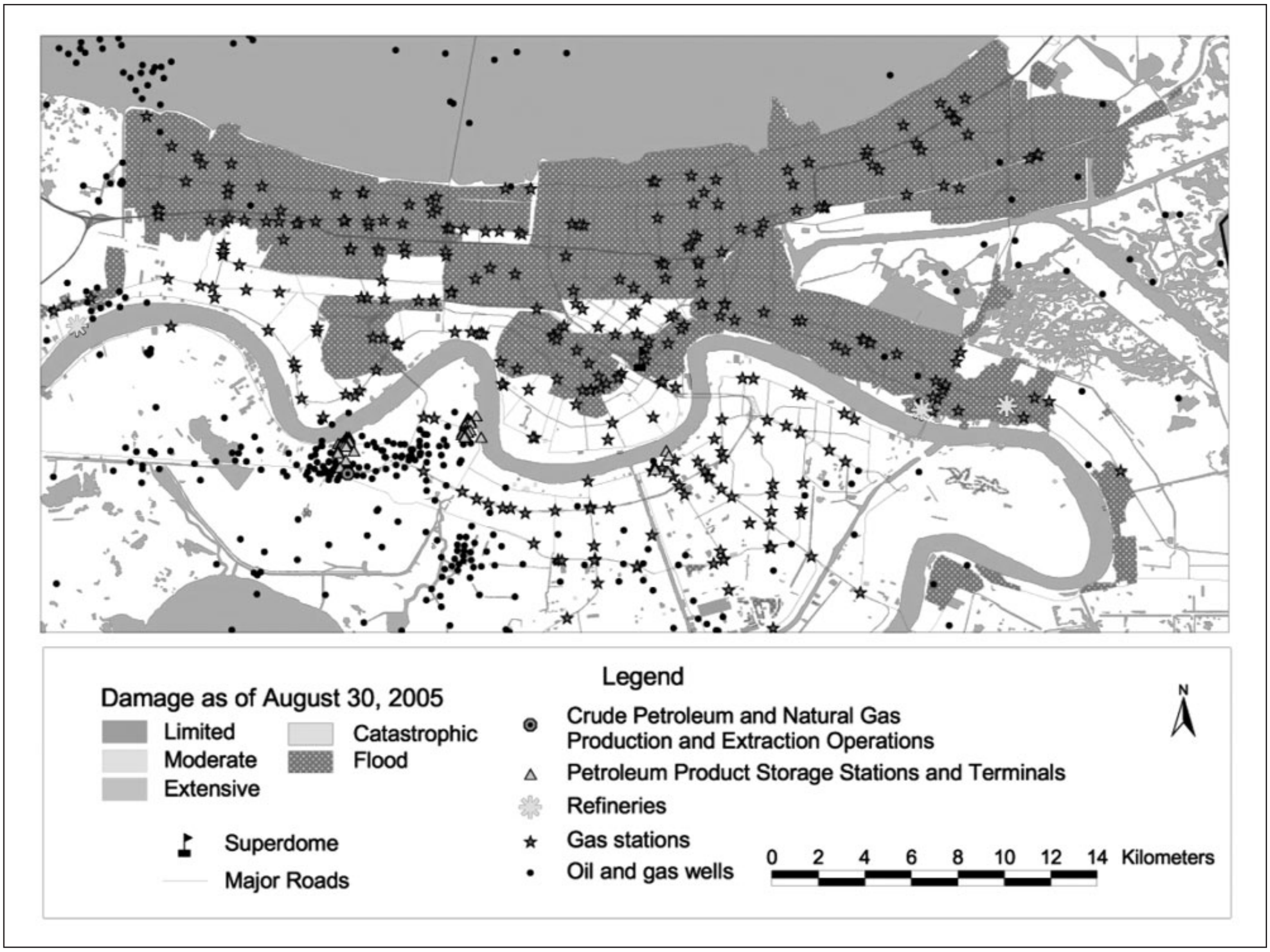

FIGURE 1 Map of New Orleans showing flooded areas and petroleum and natural gas extraction, refining, and distribution facilities. Source: NIEHS, 2005.

Figure 2 shows the major hazardous-materials storage locations, Superfund sites, and Toxic Release Inventory reporting facilities.

Adding to the potential sources of toxics and environmental contaminants are metal-contaminated soils typical of old urban areas and construction lumber preserved with creosote, pentachlorophenol, and arsenic. Compounding these concerns is the presence of hazardous chemicals commonly stored in households and the fuel and motor oil in approximately 400,000 flooded automobiles. Uncontrolled biological wastes from both human and animal sources also contributed to the pollutant burden in the city.

In the confusion immediately after the flooding, the amount of contamination was not known. Oil slicks near some service stations and flooded automobiles and wastes floating or suspended in floodwaters provided clear evidence of some environmental releases. A 250,000-barrel above-ground storage tank at the Murphy Oil USA Meraux Refinery in St. Bernard Parish southeast of the downtown area was dislodged and lifted by the floodwaters, spilling approximately 25,000 barrels (more than one million gallons) of crude oil and impacting a one square mile area containing approximately 1,700 homes (EPA, 2005c).

Several efforts were made during and after the flooding to monitor and quantify chemical and biological contamination and assess exposures to, and risks from, toxics and contaminants. Federal agencies, including the Environmental Protection Agency (EPA) and National Oceanographic and Atmospheric Administration, collected environmental samples both in New Orleans and from the surrounding area impacted by Hurricane Katrina. Initial concerns in the city were focused on acute exposures for stranded residents and relief workers. Subsequent efforts have been focused on acute exposures for returning residents and initial assessments of chronic exposures. The results

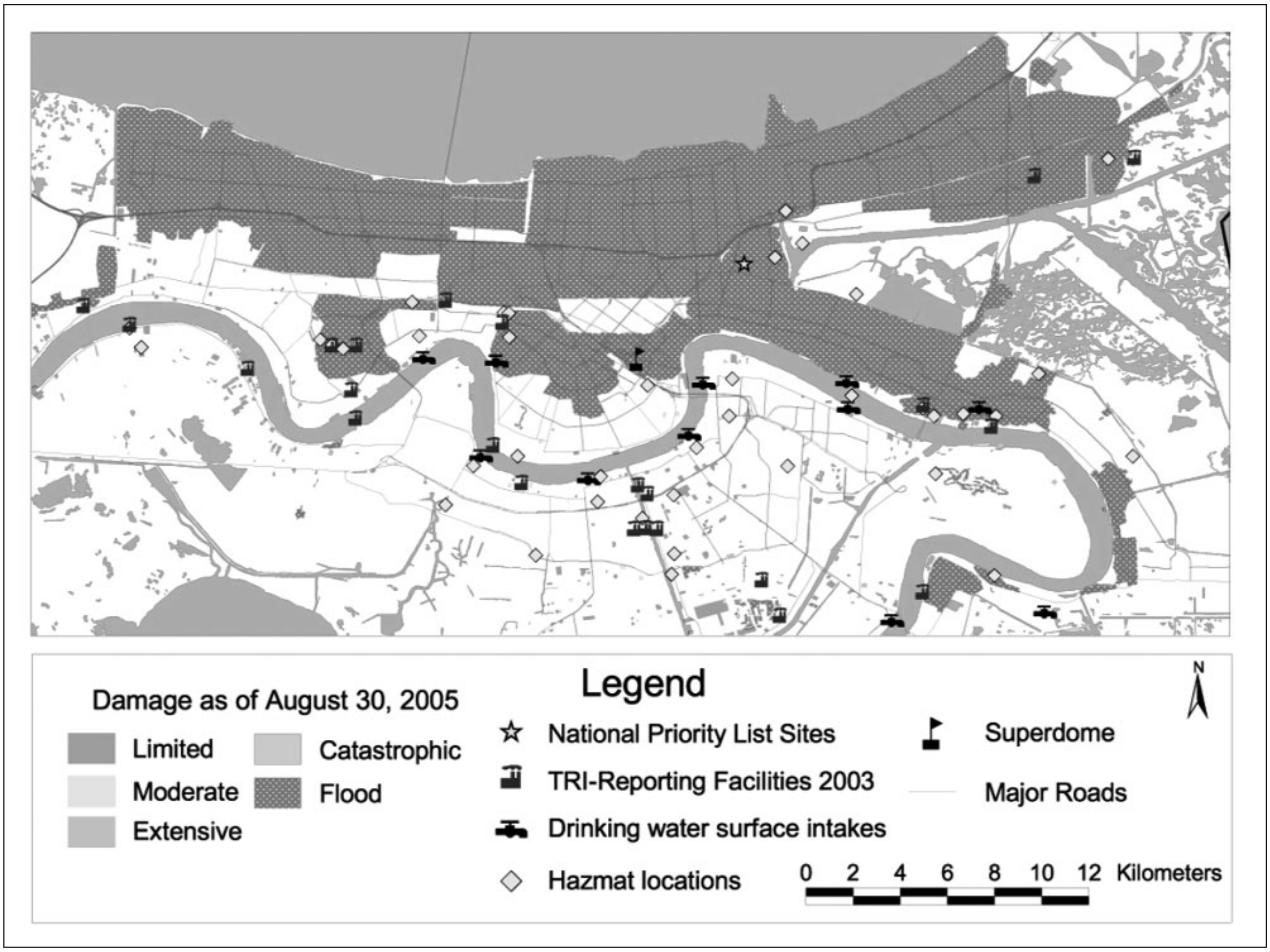

FIGURE 2 Map of New Orleans showing flooded areas and hazardous-material release, storage, and disposal areas. Source: NIEHS, 2005.

of independent sampling have been reported by Pardue et al. (2005), Presley et al. (2006), and the National Resources Defense Council (NRDC, 2005b).

Studies to date have generally painted a consistent picture of contamination in the air, water, and soils and sediments of New Orleans both during and after the flood. Thus, they provide a reasonable characterization of the general quality of the floodwaters and the soils and sediments that remain. The data are relatively sparse, however, and therefore may not fully characterize localized problems.

Regulatory agencies typically assess risk on the basis of 95-percent upper confidence limits in concentrations of media to which exposure occurs. However, for the sake of simplicity and because of the difficulty in characterizing contamination from sparse data, we focus on maximum observed concentrations. Our goal is to summarize key results from the available data to suggest the general character of the toxics and contaminant exposure during and after the flooding and to put in perspective findings for the rebuilding of New Orleans.

Exposures during Flooding

Floodwaters were present in the city from the passage of the storm on August 29, 2005, until the city was declared dewatered by the U.S. Army Corps of Engineers on October 11. Sampling showed elevated levels of inorganic and organic contaminants and biological constituents, including pathogens. The level of inorganic contaminants was generally low, even compared to drinking water standards. Presley et al. (2006) found no floodwater samples with concentrations higher than those designated for drinking water or acute and chronic threshold concentrations. Pardue et al. (2005) noted consistently high levels of arsenic in the floodwaters (mean of 30 µg/L compared to a maximum contaminant level in drinking water of 10 µg/L). Drinking water standards, however, are not an appropriate indicator of water quality for floodwaters because they are based on the assumption that a person drinks two liters of water every day for 70 years, whereas much less floodwater is ingested or absorbed through dermal exposure.

Organic constituents in floodwaters were also at relatively low concentrations. This observation was initially met with some surprise because of the evident oil and hydrocarbon fuel spills in many locations. Soluble petroleum oils and fuel constituents, such as benzene, however, are typically volatile, leading to rapid release to the air; less-soluble constituents partition to sediments left behind by the floodwaters. EPA concluded that inorganic and organic chemical concentrations in floodwater were generally below levels of concern for short-term (90 days) dermal contact and incidental ingestion (EPA, 2005b).

Bacterial contamination in the floodwaters was a source of great concern. Median concentrations of fecal coliform of approximately 10^4 MPN/100 mL were detected in the floodwaters (Pardue et al., 2005). This can be compared to a water quality standard for primary contact of 200 MPN/100 mL. The detection of human pathogens, such as *Aeromonas* spp., at concentrations on the order of 10^7 CFU/mL at two locations in the downtown area, raised even greater concern (Presley et al., 2006). Members of the genus *Aeromonas*, which have been associated with diarrhea and wound infections in humans (Janda and Duffey, 1988), have also frequently been isolated from soils and fresh water.

Katrina floodwaters were similar in character to normal storm waters.

Contaminants in Lake Pontchartrain

Another major concern is the immediate and long-term impacts of the discharge of floodwaters into Lake Pontchartrain. From September 6 to October 11, floodwaters, which had largely originated in the lake, were returned to their source. Lake Pontchartrain is a brackish, shallow lake with a surface area of approximately 1,630 km^2 and an average depth of about 4 m; there is an active commercial fishery on the lake. Pardue et al. (2005) detected low levels of dissolved oxygen in floodwaters and in discharged water, which likely resulted in low oxygen levels in the immediate vicinity of the discharge point but had a minimal impact on the lake as a whole. Similarly, the generally low levels of inorganic and organic contaminants in the floodwaters were unlikely to have significant impacts on Lake Pontchartrain.

The sediments at the mouth of the discharge canals contained some contaminants prior to the flooding as the result of normal wastewater and stormwater discharges from the city. The Katrina floodwaters were similar in character, although significantly larger in volume, to the normal stormwaters discharged into the lake (EPA, 2005b). Bacterial contamination of the discharge waters was typically an order of magnitude higher than prior to discharge (as measured by fecal coliform concentration). But in more than 100 samples collected by EPA in September and October, bacterial levels in the lake were within recreational limits (EPA, 2005b).

In summary, with the possible exception of biological pathogens, direct exposure to floodwaters either in the city or in Lake Pontchartrain appeared likely to have minimal toxic or contaminant impacts.

Exposures to Post-Flooding Soil and Sediment

Although floodwaters were removed from the city by October 11, 2005, their legacy of contaminated soils, sediments, debris, and houses remains. In addition, sediment mobilized from storm surge through Lake Pontchartrain and the Mississippi River Gulf Outlet/Industrial Canal was deposited in the city. Additional sampling was done to assess the concentrations of chemical and biological contaminants in these media. Presley et al. (2006) found several inorganic constituents (arsenic, iron, and lead) and organic constituents (mostly polycyclic aromatic hydrocarbons [PAHs]) in sediments from New Orleans that exceeded EPA Region 6 Human Health Specific Screening Levels for soils, which are used to evaluate the "relative environmental concern for a site or set of environmental data. The values are not regulatory, but are derived using equations from EPA guidance and commonly used defaults" (EPA, 2005a).

The Screening Levels, which are "not generated to represent action levels or cleanup levels but rather as a technical tool" (EPA, 2005a), are "chemical concentrations that correspond to fixed levels of risk (i.e., either a one-in-one million [10^6] cancer risk or a noncarcinogenic hazard quotient of one, whichever occurs at a lower concentration) in soil, air, and water," based on assumptions of lifetime exposures to general, but not uniform, exposure values at the upper end of the range of possible exposures (EPA, 2005f).

Of the 430 sediment samples collected by EPA between September 10 and October 14, a number exceeded screening criteria of the local regulatory authority, the Louisiana Department of Environmental Quality (LDEQ Risk Evaluation/Corrective Action Program or RECAP) (LDEQ, 2005). These criteria were developed to meet objectives similar to those of the EPA Health Specific Screening Levels and are similarly derived. The constituents most often found to exceed the RECAP screening criteria were arsenic, lead, several PAHs (including benzo[a]pyrene), and diesel range organics.

On November 19 and 20, EPA resampled areas where previous sampling had indicated contaminant concentrations in excess of screening criteria and where sediment depth equaled or exceeded 0.5 inches (EPA, 2005b). Because of the complex nature of the storm surge and levee breaches and overtoppings, the amount of sediment deposited in flooded areas varied widely, and only 14 of the 145 locations had sufficient sediment depth. Three samples showed arsenic concentrations higher than 12 mg/kg (14.4–17.6 mg/kg); one sample showed benzo[a]pyrene concentration of 0.77 mg/kg; and one sample showed a concentration of diesel range organics of 2,100 mg/kg. Other samples were below applicable screening values.

Samples were also collected at specific sites where there were known or potential leaks of hazardous materials. Elevated concentrations of total petroleum hydrocarbons and a variety of crude oil-associated contaminants were observed in the vicinity of the Murphy Oil crude oil tank failure and spill, which had a clearly identifiable source and could be easily differentiated from the general flooding-related contamination. This area is being managed separately from the rest of the flooded area and is not considered further here.

EPA also collected 74 soil samples at the site of the Agriculture Street Landfill, a closed Superfund site that was flooded by Katrina. The samples were collected immediately above the geotextile liner (12 to 24 inches below ground), which was installed as part of the site remedy. All samples were analyzed for lead, which was the contaminant of concern that defined the cleanup, but none showed concentrations that exceeded the lead cleanup standard or EPA screening standards for lead. EPA concluded that the flooding did not impact the effectiveness of the remedy (EPA, 2005d).

NRDC analyzed samples for other contaminants at the Agriculture Street site and found arsenic at levels similar to those found at other New Orleans sites and a variety of high molecular weight PAHs at somewhat elevated levels (NRDC, 2005c). They ascribed the presence of the high molecular weight PAHs to leachate from the landfill, although, because of the hydrophobic nature of these compounds, they would more likely be transported by resuspended soil from the site or elsewhere. Further assessment of this area might be warranted.

Pre-Katrina contamination has complicated post-flooding assessments of soils and sediments.

Background Contamination

The presence of a pre-Katrina background of contamination has complicated the assessment of concentrations in soils and sediments. For example, background concentrations of arsenic throughout the Mississippi River Delta region of south Louisiana is on the order of 10 mg/kg (Gustavsson et al., 2001), and LDEQ has reported a background arsenic concentration of 7 mg/kg. Pre-Katrina concentrations of arsenic could be even higher in residential areas because of arsenic in lawn fertilizers (WSDA, 2001).

Lead has also long been a concern in inner city New Orleans. About 40 percent of nearly 5,000 soil samples showed lead levels in excess of 400 mg/kg (Pelley, 2006). Presley et al. (2006) found lead in excess of 400 mg/kg (405 and 642 mg/kg) in two of 12 sediment samples, consistent with the pre-Katrina observations of Mielke et al. (2004). The latter also showed elevated levels of PAHs in pre-Katrina soils of New Orleans and positive correlations between PAH levels and metal contamination.

With only 12 sediment samples collected by Presley et al., 14 that met the depth and previously detected contamination criteria by EPA in the November 19 and 20 sampling, and even fewer samples reported in other analyses, it is impossible to differentiate statistically the current observations from pre-Katrina contamination levels. Thus, except in areas impacted by specific events, such as the failure of the oil storage tank and the Superfund site, there was no general contamination of New Orleans to clearly unacceptable levels—especially with respect to acute exposures.

Evaluating risks to human health is complicated by the lack of clearly applicable standards.

Current Risks

Residents attempting to return to the city must be aware of the level of risk and the need for remediation prior to their return. The uniqueness of the short-term exposure pathways complicates the assessment. Not only are home owners faced with removing both wet and dry sediment from their homes and yards, but exposure to airborne hazards, such as mold and dust from these sediments, has also occurred, exacerbated by demolitions and home "gutting" activities throughout the region.

Soils and Sediments

Evaluating the risk to human health associated with contaminant levels in post-Katrina soils and sediments is complicated by the lack of clearly applicable standards, which typically apply to the risk of inhalation, or, in the case of water standards, to use-related risk (e.g., drinking water vs. recreational-use water). For soil and sediment concentrations, however, pathways of exposure may be incomplete (e.g., direct exposure to buried soil not subject to significant erosion) or variable (e.g., soil in a park vs. residential soil), or contaminants may be present in forms that are largely unavailable for uptake (e.g., metals largely associated with low-solubility metal sulfides). Therefore, screening or threshold values are being used to assess the need for soil and sediment remediation and to guide the development of cleanup standards.

Under the Louisiana RECAP standards, a site with concentrations below the levels defined on the basis of default lifetime-exposure assumptions and without site-specific exposure or availability data can be considered safe; thus, remedial action is not required. As is typical with such approaches, however, concentrations that exceed the level defined by default assumptions also may not require cleanup. "To prevent misuse of screening levels," EPA Region 6 normally considers other factors, such as "[a]pplying screening levels to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios . . . [n]ot considering background concentrations when choosing screening levels . . . [using] screening levels as cleanup levels without the consideration of other relevant [remedy selection] criteria", and "[using] screening levels as cleanup levels without verifying numbers with a toxicologist/risk assessor" (EPA, 2005a). For example, a review of the arsenic soil cleanup levels at Superfund or state sites indicates a wide range of concentrations, from background levels to hundreds of parts per million (ppm), depending on site-specific conditions (EPA, 2005e).

Under RECAP, there are two management options (in addition to using a tabulated screening level) for defining alternative concentration standards that might apply to a particular site. One option includes site-specific information with specified analytical fate and transport models and default exposure assumptions as a basis for defining concentration standards different from screening values. The other option is based on site-specific exposure and environmental fate and transport data. All site-screening approaches have a similar structure and allow for modifications so that site-specific information can be used to refine estimates of exposure and risk and inform remedial planning.

According to LDEQ policy, a total lifetime cumulative carcinogenic risk level of more than 10^6 may be acceptable, as long as the cumulative risk associated with residual constituent concentrations following corrective action is at or below 10^4 (LDEQ, 2003). Even using conservative default exposure assumptions, an arsenic concentration of approximately 40 ppm may be deemed acceptable if arsenic is the predominant contaminant.

Thus the need for remedial action at any particular site in New Orleans must be assessed on the basis of an evaluation of that site for (1) average concentrations that exceed screening values in an area where a resident or worker might be regularly exposed and (2) pathways and attenuation along routes of exposure that lead to unacceptable risk.

Even screening values based on generally conservative default assumptions may not be fully protective in all cases, however. In general, EPA, states, and the scientific community regularly reassess whether the methodologies used in the risk assessment process are adequate to protecting children and other sensitive populations, even when default exposure values are used. Currently, this question is supposed to be addressed on a case-by-case basis.

Although the sampling and analysis required for a site-specific assessment and evaluation approach can be costly, using screening levels as remedial goals could also be costly unless there is some assurance of a commensurate reduction in risk. An individual home owner can assess the contamination on his or her property, but, in the absence of government support for testing and cleanup, the responsibility and cost would fall disproportionately on the poor. Thus, home owners would naturally avoid testing. However, a generic response to potential contamination would undoubtedly lead to the destruction of property that does not pose excessive risks and would further delay the return of people to their homes.

Mold

Another concern is the presence of mold and airborne mold spores in homes. Unlike air, water, and soil contamination, there is little scientific basis for evaluating the potential effects of mold on human health or for developing risk-based action or cleanup levels. Mold counts of 50,000 spores/m^3 are considered very high; spore counts as high as 650,000 spores/m^3 were observed by NRDC in a home in mid-city New Orleans (NRDC, 2005a). Because there are no standards to which these mold counts can be compared, there is no clear regulatory responsibility among federal agencies for indoor air. High mold counts are cause for concern, however, and both NRDC and EPA recommend that returning residents use respiratory protection and remove all porous construction materials, including carpets and drywall, from flooded homes. The pervasive mold contamination of New Orleans in the aftermath of Hurricane Katrina and the lack of knowledge about the risks of mold and airborne mold spores suggests that additional research is needed to respond effectively to this problem.

Outlook

The flooding in New Orleans resulted in the potential for unparalleled exposure to toxics and contaminants. Initial concerns about a "toxic gumbo," however, have not been supported by sampling and analyses to date. Although floodwaters did contain significant short-term biological hazards that posed risks to stranded residents and relief workers, they did not contain chemical toxicants at levels that are expected to lead to long-term impacts on the surroundings beyond the impacts expected of a similar volume of stormwater from the city. The floodwaters undoubtedly redistributed some contaminants, but the contaminant burden in soils and sediments appears to have generated few concerns for acute exposure and risk. However, although acute generalized hazards have not been identified, the population of New Orleans faces localized areas of more serious contamination, such as the neighborhoods impacted by failure of a crude-oil storage tank in St. Bernard Parish.

The most serious short-term issue facing most residents is the presence of high concentrations of mold and airborne mold spores. However, respiratory protection during the removal of all mold-contaminated materials and reconstruction can mitigate the risk.

The results of long-term chronic exposure to contaminants are uncertain, and chemical contamination that exceeds screening guidelines for chronic exposure has been found in some areas. Apparently elevated levels of contaminants can be found in nearly all samples for some constituents, such as arsenic, or, less frequently, PAHs or other hydrocarbons. Exceedences of screening values do not in themselves confirm significant future risk, however, and neither the public nor the local government is likely to accept further delays in rebuilding the city.

There is little scientific basis for evaluating the health effects of mold.

The frequency and distribution of exceedances may not differ from pre-Katrina conditions in the city. Thus the question arises as to whether individuals might be willing to delay their return, and even support decisions about which neighborhoods might be rebuilt, based on pre-Katrina contamination levels. The cleanup might be an opportunity to reduce exposure to toxics and other contaminants, regardless of whether the contamination was pre- or post-Katrina. This would undoubtedly require, however, that the citizens of New Orleans accept a diversion of reconstruction funds to environmental cleanup. Other questions involving contamination concerns will influence decisions about which neighborhoods might be changed to lower exposure parklands or other uses, the appropriate balance of expenditures for environmental restoration and flood protection, administrative or legal mechanisms for government to make decisions and for citizens to appeal them, and the role of government condemnations in these decisions.

Unfortunately, currently available data do not show a serious enough contamination problem to encourage government and the public to answer these questions. In the absence of a clear driver for action, decisions about rebuilding are being based on more clearly defined risks, such as the potential for reflooding, and they are being made largely by individuals and third parties, such as insurers, banks, mortgage companies, and, eventually, the courts (in condemnation proceedings). At the same time, governmental entities are trying to build public consensus for governmental proposals.

The critical test of a legal process is whether the public perceives it as fair.

Principles for Further Assessments and Rebuilding Decisions

Louisiana RECAP standards call for further assessments and evaluations of areas with contaminants in concentrations that exceed adopted screening standards. Normally (i.e., with no massive catastrophic event, such as Hurricane Katrina), existing institutions (local government, insurers, banks, etc.) could handle the volume of site-specific assessments. However, in the wake of Hurricane Katrina (and, by analogy, other large-scale disasters), decisions must be made based on uniform standards and equity.

First, the scale of decision making in this case and the number of people impacted by decisions about reconstruction are unprecedented. Thus, "off-the-shelf" models cannot be applied.

Second, rules by which decisions are made should be uniform, transparent, and consistent with existing hazardous waste and natural disaster cleanup criteria. History suggests that implementation will be easier if a consensus is reached (at least among governmental entities). Although the destruction in New Orleans is on a very large scale, tools that have been developed and used in the past to make habitability decisions (e.g., Love Canal, Times Beach, World Trade Center, and previous hurricane recoveries) can be adapted.

Third, there must be a balance between the cost of maximizing equity by making case-by-case determinations and the need for making many decisions in a relatively short period of time. In the absence of rapid decisions and answers to the many outstanding questions, individuals will proceed to define the future of New Orleans based on their own circumstances and desires. In that event, uniformity and equity are likely to suffer. In one scenario, individuals or local governments might use reconstruction funds to conduct property owner-by-property owner assessments and use the conclusions to determine remedial action or reconstruction planning. In another scenario, representative sampling might be used by government to make community decisions, and individual property owners might obtain independent samples only to demonstrate the inappropriateness of a community decision as applied to their property.

Finally, there must be a system of checks and balances to ensure that government does not simply "take" individual properties.[1] Checks and balances should be based on existing methodologies, such as scientific peer review, public involvement, cooperative efforts between local, state, and federal agencies, and public-private partnerships. The critical test of a legal process is not whether an agency chooses the alternative preferred by the public, but whether the public perceives that the process is fair.

Lessons of Katrina

Ultimately, the lessons learned (or missed) from Katrina should be crystallized in a generic form so that the country as a whole will be better prepared for the next natural disaster, major industrial accident, or act of terrorism. Thus, every effort should be made to put aside partisan concerns to solve real, significant problems in

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[1] The U.S. Constitution Takings Clause states: "Nor shall private property be taken for public use without just compensation." Thus, there may be legal proceedings at some point about "takings" of property and "just compensation." Many of the technical issues in such a proceeding are likely to be affected by the policies adopted by the government and private sector to determine the risk associated with each property.

the way information is processed in emergency situations and to make sensible, safe, and equitable cleanup/habitability decisions in an environment of great uncertainty. Because existing institutions were largely unprepared for a disaster of the scale of Katrina, it may not be possible to implement these principles in New Orleans. However, we can learn from Katrina and provide more effective responses to future catastrophes.

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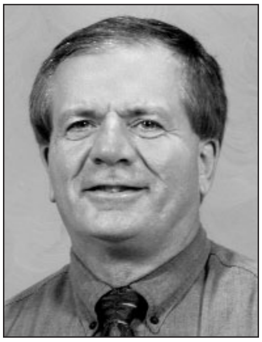
The U.S. Army Corps of Engineers is analyzing what went wrong (and right) during and after Hurricane Katrina.

The Behavior of Hurricane Protection Infrastructure in New Orleans

Paul F. Mlakar



Paul Mlakar is a senior research scientist at the U.S. Army Corps of Engineers Engineer Research and Development Center in Vicksburg, Mississippi.

In terms of flooding, Hurricane Katrina was one of the strongest storms to hit the coast of the United States in the past century. Katrina first made landfall on the southeast coast of Florida as a Category 1 hurricane, then crossed Florida into the Gulf, where it grew in size and strength and became a Category 5 hurricane, then weakened again before it made a second landfall in southeast Louisiana. The storm then moved northward, pushing storm surge into coastal areas of Louisiana, Mississippi, and Alabama, and finally made a third landfall as a Category 3 storm in Mississippi.

Katrina caused the greatest loss of life and damage to property to the New Orleans metropolitan area, St. Bernard Parish, Plaquemines Parish, and the Mississippi Gulf Coast in recorded history. The hurricane created breaches in the floodwalls along the 17th Street Canal, the London Avenue Canal, and the Inner Harbor Navigation Canal (IHNC). Water flowed from Lake Pontchartrain through these breaches and inundated large urban areas in New Orleans to depths of as much as 20 feet. The levees in St. Bernard Parish and Plaquemines Parish were also overtopped, causing the inundation of substantial additional urban areas. The magnitude of the destruction, the extensive damage to the hurricane-protection system, and the catastrophic failure of a number of structures raised significant questions about the integrity of the flood-protection system prior to the storm and the capacity of the system to provide future protection, even after repairs.

Immediately following Katrina, the U.S. Army Corps of Engineers (USACE) undertook four important missions. The first was to rescue survivors and "unwater" the city so that it could begin to recover. Second, the chief of engineers established an Interagency Performance Evaluation Task Force (IPET) to provide credible, objective scientific and engineering answers to questions about the reliability of hurricane protection. Third, the reconstruction of the damaged protection infrastructure to the authorized level began as soon as possible based on the best information available. Finally, Congress directed USACE to study the feasibility of providing a higher level of protection in the future.

This article describes the progress of IPET on the second mission. The task force had to act swiftly to collect ephemeral data necessary for its study, such as water levels as a function of space and time in the affected region inferred from observations of residual evidence and eyewitness accounts. IPET also had to document the physical condition of the damaged infrastructure before it was changed by cleanup and reconstruction activities.

IPET collected this information in a completely open and transparent way. When approached by teams from the American Society of Civil Engineers (ASCE), National Science Foundation, and Louisiana Department of Transportation and Development, who had similar purposes, IPET integrated these teams into a joint endeavor to collect information for all of the interested parties.

This article includes (1) a general description of the hurricane-protection system in New Orleans and preliminary observations about the effectiveness of three representative cases of infrastructure and (2) a discussion of IPET's study of these cases, the review by ASCE, and further scrutiny by the National Research Council (NRC).

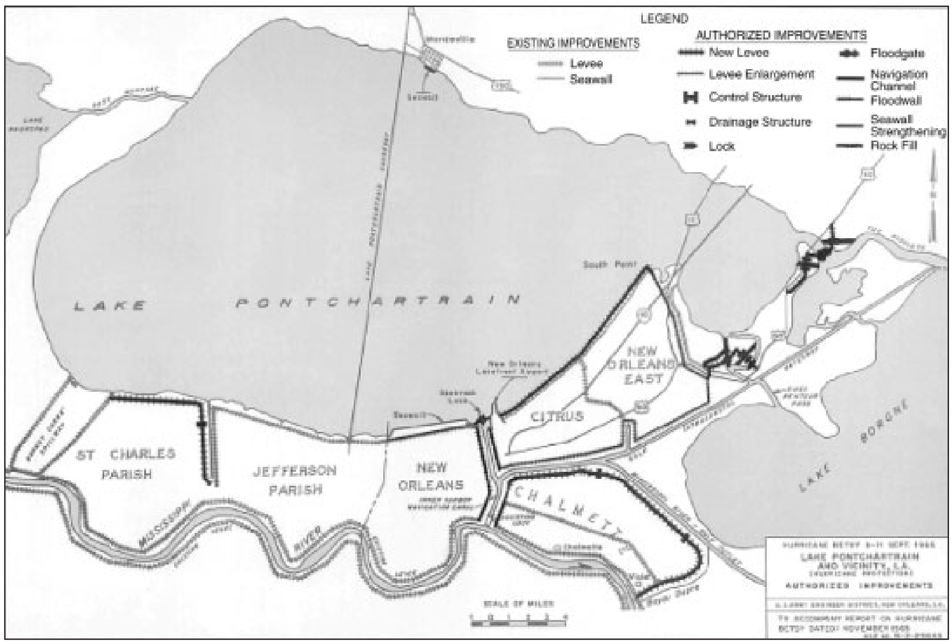


FIGURE 1 Hurricane and flood protection in 1965.

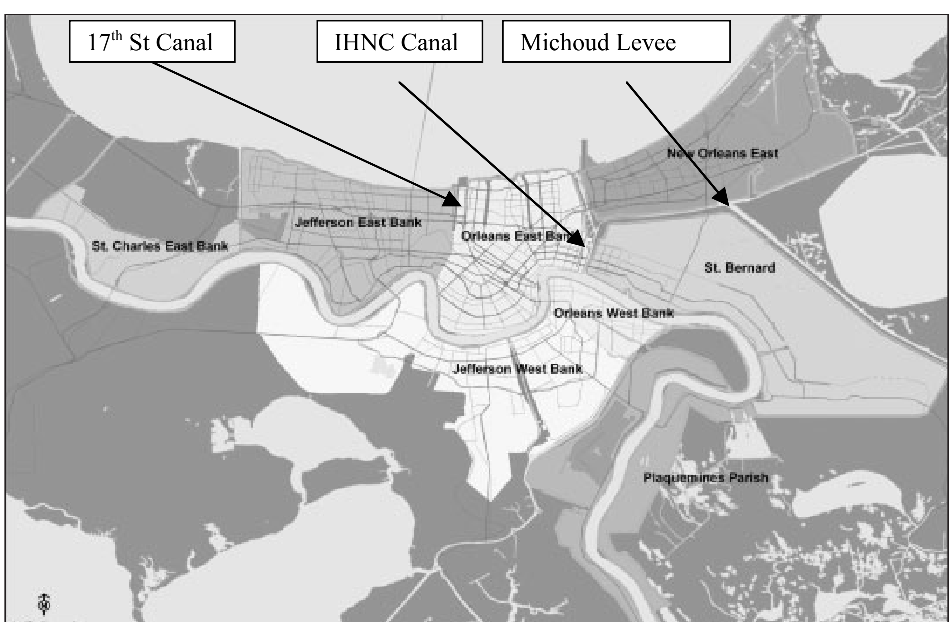


FIGURE 2 Hurricane and flood protection in 2005.

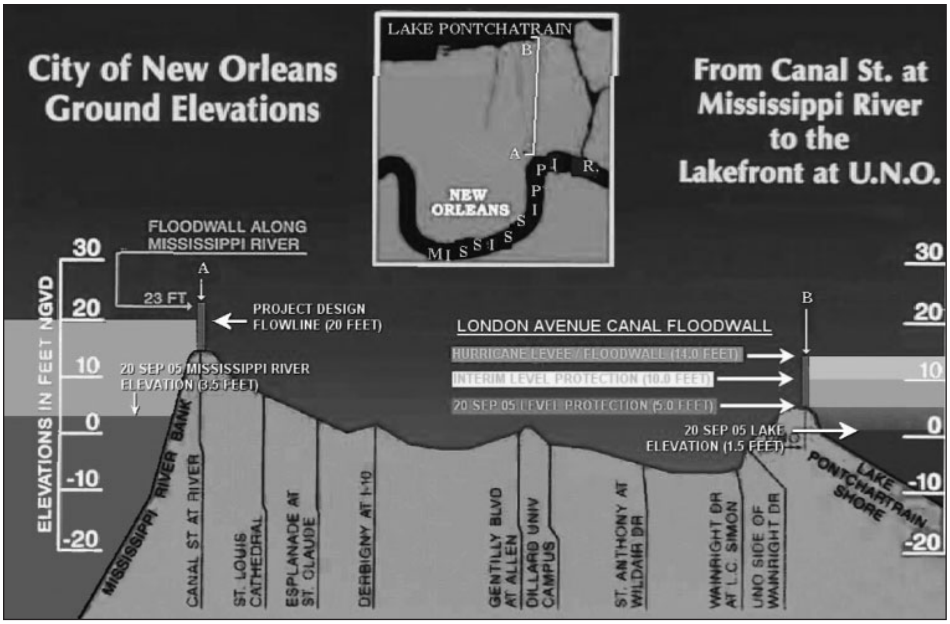


FIGURE 3 Cross section of New Orleans on September 20, 2005.

Hurricane-Protection System

New Orleans was founded in 1718 by the French explorers Iberville and Bienville. According to one anecdote, their engineer advised against settling on this particular parcel of land, which lies below sea level. Nonetheless, by the middle of the nineteenth century, the settlement had grown into the "Crescent City" surrounded by swampland and the Mississippi River. The environment was characterized by muddy streets, stagnant water, pathological conditions, frequent flooding, and limited room to grow.

In the progressive years around the turn of the twentieth century, a public consensus was reached in support of a serious drainage effort, and by the 1920s, a comprehensive system of gutters, drains, sewer mains, outfall canals, and pumping stations was in place. These measures saved lives, improved the quality of life, and became a model for the protection of low-lying regions worldwide. These improvements also allowed the city to expand outward from the higher ground close to the river into the lower area near Lake Pontchartrain.

By 1965, further enhancements were made in response to this growth. The major features of the hurricane and flood-protection system were substantial levees along the Mississippi River and the shore of Lake Pontchartrain (Figure 1). A number of other levees were planned along the lakefront and the recently completed Mississippi River Gulf Outlet. Gates to control the inflow of hurricane surges into Lake Pontchartrain and a lakefront lock on the IHNC were also authorized but were not yet funded.

On September 9, 1965, Hurricane Betsy struck the Louisiana area, causing major flooding, loss of life, and property damage in New Orleans. A higher level of hurricane protection was subsequently authorized by Congress. In the ensuing four decades, the construction of those improvements had progressed (Figure 2). Many of the levees planned in 1965 were in place, but the gates and lock on Lake Pontchartrain had not been constructed. Additional protection was provided through floodwalls atop the levees along the canals at 17th Street, London Avenue, Orleans Street, and the IHNC Canals.

The "saucer-like" topography of metropolitan New Orleans is shown clearly in Figure 3, a cross section of the city from Lake Pontchartrain to the Mississippi River on September 20, 23 days after Katrina struck. The ground slopes gradually down from the river flood protection to the lakefront hurricane protection. At that time, the lake level was at an elevation of 1.5 feet, and the river was at 3.5 feet. The flooding in the bowl of the city was still higher than 5.0 feet. Protection along the London Canal had been restored to 10.0 feet.

Michoud Levee

The Michoud Generating Plant of Entergy Corporation, located near the intersection of the Gulf Intracoastal Waterway and the Mississippi River Gulf Outlet (Figure 3), is protected from hurricane surge by a levee

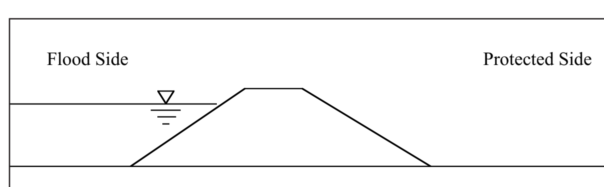


FIGURE 4 Levee section.

FIGURE 5 Overtopping of Michoud levee during Katrina.

along the waterfront. Levees around the world are generally constructed of soil (Figure 4) and designed to provide protection to lowlands for a short time during seasonal flooding, high tides, or tropical storms. Basically, a levee is an embankment of soil that has been placed and compacted to form a barrier against high water. The soil for the levee is generally taken from shallow pits adjacent to the levee, termed "borrow pits." Unlike a dam, which is usually sited on a favorable foundation, levees are placed according to flood control needs regardless of the suitability of the foundation conditions. The grass on levee slopes helps protect the soils against erosion during flooding.

FIGURE 6 Condition of Michoud levee after Katrina.

In a photo at the Michoud levee (Figure 5) taken by an Entergy security camera during Hurricane Katrina, the levee is invisible under the severe overtopping surge from the storm. Preliminary observations of residual high-water marks and hydrodynamic analyses of hurricane surge by IPET are consistent with the degree of overtopping shown in the photo.

Figure 6, taken by the teams jointly collecting ephemeral data in early October, shows a photo of the same levee from a slightly different angle. The chain link security fence has been damaged, and the back slope of the levee shows minor erosion, but the section of the levee itself is largely intact and still capable of providing protection from lesser surges.

This levee is representative of many that were overtopped by a loading higher than their design level but remained relatively intact. We often associate lessons learned with poor performance, but there is also something to be learned from cases of excellent performance. What was it about the embankment material, slope, protective vegetation, surge, and other conditions at the Michoud levee that resulted in its remaining intact? This will be a subject of comprehensive study as IPET proceeds.

Inner Harbor Navigation Canal Floodwall

The IHNC is an important commercial waterway that links Lake Pontchartrain, the Gulf Intercoastal Waterway, the Mississippi River Gulf Outlet, and the Mississippi River (Figure 2). In 1965 when Hurricane Betsy hit the area, the earthen levees that lined the IHNC were overtopped and breached. In an attempt to provide a higher level of protection, a floodwall was built atop the existing levees (Figure 7). These I-walls, so named because of their shape in cross section, are

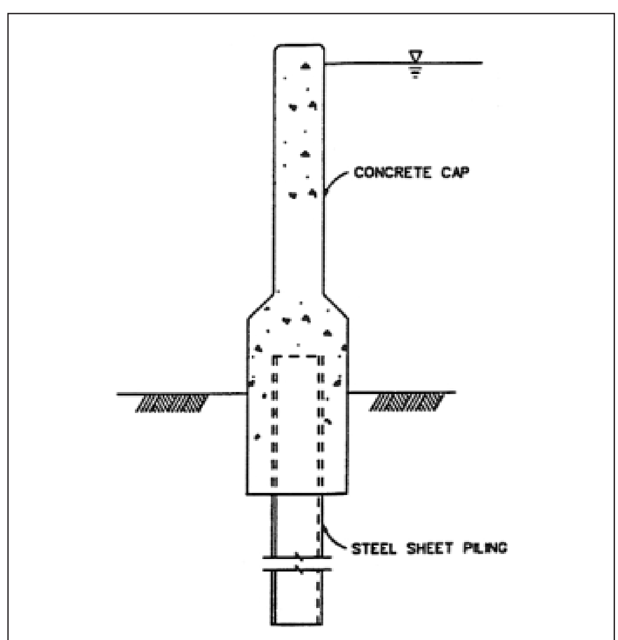


FIGURE 7 I-wall section.

FIGURE 8 Breach of IHNC floodwall.

cantilevered structures that derive support solely from the soil in which they are founded. An I-wall consists of sheet pile embedded in the foundation that protrudes into a monolithic concrete wall above.

Like the Michoud levee, the initial indication is that the loading from Hurricane Katrina exceeded the level for which the I-wall was designed. This conclusion is based on observations of residual high-water marks and accounts by eyewitnesses, and corroborated by preliminary hydrodynamic calculations of the hurricane surge.

Unfortunately, the response of this wall was catastrophic (Figure 8). Significant stretches of the wall were breached on both sides of the canal, contributing to the flooding of the metropolitan area. Figure 9, taken shortly after the region was unwatered in October, shows the condition of the breached I-wall and the missing levee. Figure 10, immediately adjacent to the largest breach, shows that the remaining wall clearly tilts away from the canal. The significant trench was probably scoured by the water overtopping the wall. The extent of this scour diminishes with distance from the breach.

This wall is representative of walls throughout the system that were overtopped and failed to some degree and probably exacerbated the flooding. Thus, this I-wall will be the focus of intense study by IPET to determine how various hydraulic, geotechnical, and structural factors affected its performance. The study will include both state-of-the-art physical hydraulic modeling and analytic modeling on high-performance computers.

17th Street Canal Floodwall

The 17th Street outfall canal is on the boundary of Orleans and Jefferson Parishes (Figure 2). Water that collects in the interior basin of metropolitan New Orleans is evacuated to Lake Pontchartrain through this canal with the assistance of one of the largest pumping stations in the world located at the interior end of the canal. After Hurricane Betsy, an I-wall was constructed on top of the existing levee to increase protection against hurricane surges entering the canal from the lake.

Unlike the Michoud levee and the IHNC floodwalls, indications at this time are that the water in the 17th Street Canal did not reach the top of the I-wall. This conclusion, supported by hydrodynamic calculations of the storm surge and wave height, has been further substantiated by observations of the high-water marks following Katrina.

Regrettably, a portion of the wall lining the east side of the canal was breached. A photo (Figure 11) taken during the emergency closure of the breach shows that substantial flooding ensued. There is some evidence that the levee and floodwall may have translated as a unit away from the canal (Figure 12). The location and condition of the floodwall monoliths in the breach (Figure 13) are consistent with this hypothesis.

A comprehensive study by IPET will include state-of-the-art calculations of soil structure interaction on high-performance computers and physical modeling in large centrifuges. This will be a high-priority item for IPET, because some other parts of the system behaved similarly.

FIGURE 9 Condition of breached IHNC floodwall.

Further Study

IPET is working toward completing a comprehensive analysis before the start of the next hurricane season on June 1, 2006. The work of IPET includes a number of interrelated tasks, each of which is being investigated by a team led jointly by an expert from USACE and an expert from an external organization. IPET is also working with other organizations conducting related studies and analyses to maximize its effectiveness within the short time frame of the study. Comprised of individuals from more than 40 organizations, IPET teams have a diversity and depth of knowledge and experience.

FIGURE 10 Floodwall adjacent to IHNC breach.

The activities of IPET are focused on answering five strategic questions:

1. What were the design criteria for the pre-Katrina hurricane protection system, and did the design, as-built construction, and maintained condition meet these criteria?
2. What storm surges and waves were used as the basis of design, and how do these compare to the storm surges and waves generated by Hurricane Katrina?
3. How did the floodwalls, levees, pumping stations, and drainage canals, individually and as an integrated system, perform in response to Hurricane Katrina, and why?
4. What have been the societal-related consequences of Katrina-related damage?
5. Following the immediate repairs, what will be the quantifiable risk to New Orleans and vicinity from future hurricanes and tropical storms?

FIGURE 11 Emergency closure of 17th Street canal breach.

In the process of answering these questions, IPET is also continuously providing insights and findings to the USACE team reconstituting the damaged portions of the flood-protection system to authorized levels of protection by June 1.

IPET will determine the performance of the flood-protection system by examining primary inputs, responses, and outputs. Inputs are the surge, waves, and rainfall from the storm. Responses are the behavior of the structural components of the system, the components designed to unwater protected areas, and the degree of flooding in the protected areas. Outputs are primarily the context of principal failure mechanisms, the consequences of flooding due to component failures, and the risk and reliability of the flood-protection system.

IPET is using the most appropriate tools and data available to determine the forces on the New Orleans flood-protection structures during the storm and why they performed as they did. Katrina and other storms are being modeled to help scientists and engineers determine the magnitude and variability of surge and wave conditions as a function of location and the character of the storm. This information, detailed modeling of the canals, and the physical evidence will

FIGURE 12 Block movement of levee and floodwall.

FIGURE 13 Floodwall monoliths in 17th Street breach.

indicate the magnitude and nature of the forces that individual structures experienced.

The performance of individual structures is being examined by first analyzing their design and how they were intended to operate. Next, this information is compared to how they were built and maintained, which is used as input for physical and numerical models examining expected responses to the storm-generated forces. Once the most likely causes of failures and successes have been determined, the insights gained can inform decisions for reconstituting flood-protection standards to be more resilient.

Work is proceeding on all of these tasks in parallel. At critical junctures, the results are integrated to meet the overall goal of completing the structural performance analysis by May 1, 2006, and producing a final report by June 1, 2006. An interim report of progress as of January 10, 2006, is available at <*https://ipet.wes.army.mil/*>; this website also has design and construction documents related to the hurricane-protection system of the area.

A continuous detailed review of IPET is provided by an external review panel (ERP) under the auspices of ASCE. The ERP reviews every major decision, assumption, or analysis to ensure credibility as the study progresses. In addition, the ERP has assigned at least one expert as the principal contact for each IPET team. The ERP also meets periodically to provide integrated reviews of IPET activities and a review of the final report. Ultimately, the full scope of IPET activities will be reviewed by the ERP.

Further strategic oversight and synthesis of the findings is being provided by an independent NRC panel, the New Orleans Regional Hurricane Protection Committee, which is reviewing interim reports of IPET activities, as well as the structural performance report to be completed by May 1. The initial NRC review, held on January 18, was focused on the adequacy of data collection and the strategy for using the data to answer the primary questions concerning the physical performance of the flood protection system. The next NRC review, scheduled for mid-March, will focus on the adequacy of the analysis to address the principal structural performance questions. The NRC will issue its final report in late summer 2006.

A proactive approach to disaster preparation is crucial to disaster recovery.

Rebuilding Electrical Infrastructure along the Gulf Coast: A Case Study

Billy Ball is senior vice president of Transmission Planning and Operations for Southern Company.[1]

Billy Ball

Hurricane Katrina made landfall near the Mississippi-Louisiana state line on the morning of August 29, 2005, with an estimated intensity of 120 mile per hour (mph) winds and a storm surge of at least 30 feet (Figure 1). Tropical-storm-force winds extended out about 230 miles, and hurricane-force winds extended out more than 100 miles (Knabb et al., 2005). Katrina presented Southern Company with one of the biggest operational challenges in its more than 80-year history (Table 1). According to the Insurance Information Institute, total insured losses from Katrina were estimated at $40 billion—almost twice as much as the next most expensive storm in U.S. history.

Hurricane Katrina was the worst natural disaster in the history of Southern Company's Mississippi Power subsidiary. After making landfall, Katrina moved north northeast at about 15 mph, with winds exceeding hurricane force in all major cities in Mississippi Power's service territory. All 195,000 Mississippi Power customers lost power, nearly two-thirds of the transmission and distribution system was damaged or destroyed, and all but three of the company's 122 transmission lines were out of service. More than 300 transmission towers were damaged, 47 of them metal towers in the 230-kV bulk power system.

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[1] Southern Company, which has 40,000 megawatts of electric-generating capacity and 26,000 employees, provides electricity to more than 4 million customers in Alabama, Georgia, southeastern Mississippi, and the Florida panhandle.

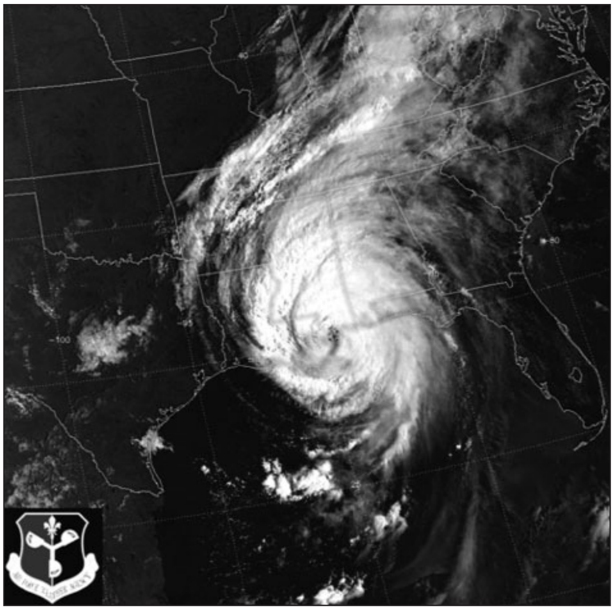

FIGURE 1 A satellite image of Hurricane Katrina as it made landfall on the Gulf Coast of the United States on August 29, 2005. Image courtesy of the Air Force Weather Agency.

In the distribution system, about 65 percent of facilities were damaged; 9,000 poles and 2,300 transformers were lost; and 23,500 spans of conductor were down.

All generation equipment at Plant Watson, Mississippi Power's second-largest electricity generating plant, was damaged by floodwaters, which affected the company's emergency operations center and backup control center located in the plant. Seven other buildings also sustained significant damage, including the corporate headquarters in Gulfport (Figure 2), the building housing the distribution and transmission departments, the substation construction headquarters, the Biloxi service center, and the Pass Christian office. The corporate headquarters was damaged so severely that it will not be fully operational again until late 2006.

TABLE 1 Peak Customer Outages as a Result of Hurricane Katrina

Southern Company Subsidiaries	Number of Outages	Total Customers
Alabama Power	637,000	1,385,374
Georgia Power	10,000	2,078,127
Gulf Power	129,000	394,772
Mississippi Power	195,000	195,000

In Alabama, Katrina caused the second highest number of customer outages, trailing only the 825,000 outages from Hurricane Ivan in 2004. Although most of the outages were in the Birmingham area, the heaviest damage was in Mobile and along the Gulf Coast (Table 2).

Planning for Disasters

Southern Company relies on extensive pre-planning, the ability to communicate internally and externally immediately after a storm, effective execution of disaster-recovery plans (including receiving significant help from external and internal resources), and the capturing of lessons learned to prepare for the next storm response.

The company's operating subsidiaries—Alabama Power, Georgia Power, Gulf Power, Mississippi Power, and Savannah Electric—maintain detailed disaster-recovery plans with specific responses and actions identified for each. Every year before the start of hurricane season on June 1, storm training is provided for employees, whose assignments differ from their regular jobs. Training is designed to ensure that everyone involved understands every aspect of the recovery plan.

FIGURE 2 The severely damaged Mississippi Power headquarters in Gulfport, Mississippi.

Subsidiary companies share the lessons learned from storm or hurricane experience, and plans are revised accordingly. Because Mississippi Power participated in Gulf Power's assessment of its plan following Hurricane Ivan in 2004, Mississippi Power was better prepared to respond to Katrina. Continuous learning is a critical aspect of superior performance.

Recovery plans provide for flexible, decentralized authority so decisions can be made as close to the disaster as possible. Storm teams start taking action two weeks

TABLE 2 Transmission Lines Outages as a Result of Katrina

	Alabama Power		Mississippi Power	
	Total Lines	Out after Katrina	Total Lines	Out after Katrina
500 kV	12	0	1	1
230 kV	94	8	23	20
161 kV	11	0	N/A	N/A
115 kV	289	32	80	80
46 kV	234	27	18	18
Totals	640	67	122	119

before a potential disaster, and every day new decisions are made depending on the latest track and severity of the storm. Mississippi Power began track-ing Katrina as it developed in the Caribbean and followed events as the storm tracked across southern Florida, impacting utilities there, before entering the Gulf of Mexico.

Three days prior to landfall, Mississippi Power, assuming a direct hit from a major hurricane, began making requests for manpower, material, and logistics—including almost 3,000 linemen and 1,750 tree trimmers. However, damage in Florida and the risk posed to utilities along the northern Gulf of Mexico in the projected path of Katrina's second landfall reduced the regional pool of qualified line workers. Mississippi Power also placed orders for additional transformers, poles, conductor, line hardware, and fuel over and above its normal storm-season stocking levels.

Arrangements were made for nearly 4,800 beds variously located in mobile sleeper trailers, military facilities, college facilities, tents, cots in company facilities, and motels as far away as Pensacola, Montgomery, and Dothan. A pre-arranged plan with a logistics vendor, which included provisions for tents, caterers, portable toilets, showers, and dumpsters to be set up at predetermined staging sites, was implemented on Friday, August 26, three days before the storm hit. By the time Katrina made landfall, the company had spent $7 million in securing equipment and logistical support.

Details of the Plan

As it does with any major hurricane, Mississippi Power took a proactive approach to disaster preparation and recovery. The company has a detailed, flexible, "scalable" disaster procedure that has been developed over many years and is applicable to a variety of disaster types, such as winter storms, tornadoes, and straight-line winds. Mississippi Power critiques its performance after every storm and updates its procedures based on lessons learned both from its own experiences and the experiences of other utilities.

All employees have storm assignments, frequently different from their day-to-day jobs. Storm assignments include functions related to system restoration, such as disaster coordination, manpower coordination, responsibility for specific geographic areas, acting as crew guides, tending to the needs of outside personnel (such as lodging and meals), and tracking restoration efforts.

As part of the overall preparations, the company maintains weather consultants on retainer, participates in regional mutual-assistance organizations, maintains pre-arranged contracts with logistics vendors, staging-site owners, line-construction and vegetation-management contractors, and maintains pre-arranged agreements for materials, fuels, and equipment.

Disaster directors coordinate and direct activities related to specific functional areas. In addition, every disaster director has a designated backup. Each functional area undergoes an annual review, beginning with an evaluation of steps to ensure that the company is prepared to respond:

- Discussions are held with surrounding utilities and contractors to determine the availability of line crews and tree-trimming personnel.
- Logistics activities related to housing, food, and laundry are reviewed. (Before Katrina, more than 100 potential staging sites were identified, and detailed layouts were prepared of how those sites would be used. At the peak of the restoration, 30 sites were used—18 for a combination of feeding, lodging, fueling, materials, showering, and parking, and 12 as material lay-down yards. Also at peak, approximately 11,000 personnel were being housed, 32,500 meals were provided in one day, 93,000 pounds of fabrics were laundered, and 65 buses were put into service.)

- A detailed distribution-restoration plan is established and continually updated. Each substation is assigned a substation-restoration coordinator who reports to the area-restoration coordinator. One or more feeder-restoration coordinators, who are responsible for each circuit, report to the substation coordinator. Because these coordinators know their areas of responsibility in advance, they are able to become familiar with their facilities. This unique operational framework was extremely effective in the aftermath of Katrina.
- Stocking levels of critical materials are increased as storm season approaches. (During Katrina, arrangements were made with other companies to provide at least five deployed storerooms at various staging areas. In one day, as many as 60 tractor trailer loads of materials were delivered, and 5,000 vehicles were fueled. Average daily fuel consumption was about 80,000 gallons, with a peak one-day consumption of more than 110,000 gallons.)

Employees Helping Employees

Hurricane Katrina had an unprecedented impact on the employees of Mississippi Power. Many homes were destroyed, flooded, or severely damaged (Table 3). In response, Southern Company's Family Services immediately mobilized support teams from around the company system to provide services and help employees' families arrange places to stay, repair homes, clean up debris, and move furniture to storage facilities, among many other necessary tasks. Knowing that their families and homes were being taken care of enabled many employees to return to work quickly.

Communication

Communication is crucial in responding to disasters, especially communication with thousands of extra workers. Immediately following Katrina, neither land-based nor cellular phone service was available, and communication with outside restoration resources was very difficult. For most of the 12 days it took to restore electric service, the only communication system in operation on the coast of Mississippi was SouthernLINC Wireless, a wholly owned subsidiary of Southern Company. Through this system, Mississippi Power was able to communicate internally and with other operating companies, which relayed messages to outside resources.

The SouthernLINC Wireless system was built with considerable redundancy. Therefore, even though it sustained catastrophic damage, it was functioning at near pre-Katrina levels within three days, even with the added capacity to accommodate the dramatic spike in demand. Mississippi Power also installed its own microwave capability to 12 remote staging areas in order to transmit material inventory data into the company's automated procurement process. If communication circuits of another company were down, the information technology group found a way to bypass those circuits and restore critical communications.

Crews are prepared to function for two days without communications—including field-to-field or field-to-HQ communications and logistics/procurement communications for taking on and coordinating outside resources. Vendors procured prior to Katrina were given instructions on where to set up and what to be prepared for, even if communications with Mississippi Power were not available after the storm.

TABLE 3 Impact of Hurricane Katrina on Mississippi Power Employees

		Percentage of Employees
Homes destroyed	86	7%
Homes flooded	196	16%
Homes damaged	441	35%
Total	721	58%

Executing the Plan

Mississippi Power began its damage assessment—the first phase of the disaster-restoration plan—as soon as the winds subsided to a safe level. The assessment indicated that the system had sustained far more damage than anticipated. It was immediately apparent that the 5,000 outside personnel the plan had assumed for a worst case "Camille-like" storm would be inadequate. The company needed more than twice that number.

Even as Katrina was still pounding Mississippi and Alabama, repair crews and trucks were rolling in from other states to begin immediate work on damage assessment and restoration. Approximately 2,400 outside workers were pre-positioned on the fringe of the storm area ready to move in where needed, with clear authority and accountability for the jobs assigned. Within 24 hours after Katrina, more than 75 percent of the electric system had been inspected on the ground and from the air. This was possible because of the pre-positioning of outside workers and advanced contracting with several aircraft for inspections.

Through mutual-assistance agreements with utilities across the nation, workers from other utilities and contracting companies joined hundreds of company employees. Within seven days after Katrina, 10,800 workers from 23 states and Canada were assisting Mississippi Power. These emergency workers were provided with housing, food, tetanus shots, and other necessities to make life as comfortable as possible for them under the circumstances. Six full-service tent cities were erected as temporary homes (Figure 3).

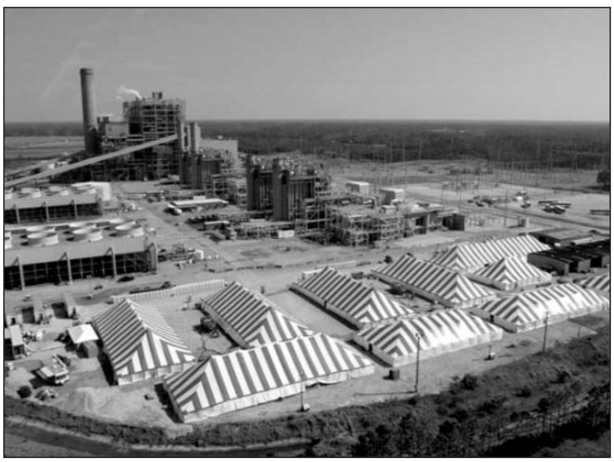

FIGURE 3 A tent city for emergency workers.

Many line-crew personnel were put in charge of directing outside crews and handling restoration for feeder lines or entire areas. Because they were accustomed to making decisions, they were prepared to handle the increased responsibilities.

The company's approach to storm recovery is based on self-sufficiency. For example, backup plans are in place for when outside suppliers for critical items, such as cots, tents, and food, are not available. After Katrina, the company brought in its own 250-person armed security force to protect people and equipment.

By the end of Day 5 (September 3), Mississippi Power was able to communicate to the public its commitment to restore service to every customer who could receive it by September 11. This goal motivated everyone involved, and service was actually restored by September 10—just 12 days after Katrina hit.

Priorities for repairing electric facilities are based on the stability of the electric system and restoring service to critical customers, such as hospitals, emergency responders, and water systems. Life-threatening situations, of course, have top priority. During Katrina, the focus was on restoring generation, transmission, and distribution with priority customers in mind. Mississippi Power's first priority in transmission was to establish a 230-kV path from an interconnection point with Alabama Power in Jackson County across the Gulf Coast and upstate through Hattiesburg, Laurel, and Meridian to a northern interconnection point with Alabama Power east of Meridian. The transmission was hindered by flooding in several key substations on the coast in addition to extensive salt contamination on substation and transmission-line facilities.

On the first day after the storm (August 30), Mississippi Power was informed of the importance of the pipeline pumping stations in Collins, Mississippi, to the gasoline supply of the eastern United States. Working virtually around the clock, crews restored service to key facilities in the Hattiesburg area, including the pumping stations, by the end of Day 2 (August 31). By the end of Day 6 (September 4), a transmission source had been established to all substations from which customers were able to take service.

When the transmission line into the Hattiesburg area was energized, power was also restored to a critical regional hospital. The company helped refuel hospital generators until service could be restored.

By the end of Day 1, 2,800 outside personnel were working on restoring distribution, and service had been restored to 600 customers. By the end of Day 9 (September 7), 10,800 outside personnel were working on restoration, and service had been restored to 126,200 customers, or 75 percent of the total.

As for generation, Plant Watson's combustion turbine unit was back on line on September 8. Coal yard operations resumed in 34 days, and Unit 4 came back on line in 46 days. Unit 5 was back on line in December, and units 1, 2, and 3 are expected to be back on line by mid-2006. By the end of Day 12 (September 10), service had been restored to every customer who could receive it, and the number of outside personnel working on restoration had been reduced to 5,300.

The total cost of restoration in Mississippi has been estimated at more than $250 million—the costliest in the company's history. Remaining costs include rebuilding distribution facilities in areas decimated by the storm surge where there are few or no customers able to take service and completing repairs to flooded and damaged substations, Plant Watson, various buildings, and a 230-kV transmission line across the Pascagoula River swamp.

Substation and transmission line repairs will be largely complete in the first half of 2006. Generation repairs and repair work on damaged buildings should be primarily complete by the end of 2006. Distribution reconstruction is likely to continue for years as the most heavily damaged areas are rebuilt and customers are able to take service.

Lessons Learned

The greatest cost savings resulted from the effective use of outside resources and the effective use of time. The establishment and operation of staging areas and the procurement of food, shelter, fuel, and security are critical to the efficient use of resources. Mississippi Power is a vertically integrated utility, and the coordinated restoration of damaged generation, transmission, and distribution facilities enabled optimum use of scarce services and other resources.

Close coordination with, and support from, government agencies and officials was also crucial. By staying in close contact with state legislative and regulatory agencies, law enforcement, local governments, and disaster-recovery agencies, including the Federal Emergency Management Agency and the Mississippi Emergency Management Agency, conflicts between restoration and recovery efforts were avoided, and much-needed support for traffic control was available.

Other federal agencies also provided assistance. The Federal Energy Regulatory Commission granted a waiver for utilities affected by Katrina in reporting requirements under their standards of conduct. This allowed the utilities to focus entirely on restoring the electric grid and service. The U.S. Department of Energy offered its support and is following up by studying the technology and technological advancements that would facilitate electric-system restoration after major events like hurricanes and ice storms.

Evaluation

Continuous learning is a disciplined process. In preliminary findings, the following issues have been identified for improvement:

- The acquisition of "initial showing" resources and their division among the affected areas should be refined.
- Evaluations of the resources needed "on the ground" for initial showing can be improved. First-day resources do not have to be line resources; they may be tree crews or evaluators.
- Potential improvements in storm prediction and storm damage models should be explored.
- Backups for all positions, including storm leadership positions, should be identified.

Many customers suffered significant personal losses, were without homes, food, water, and sewer services, and were faced with looting and other conditions that were unimaginable under normal conditions. At times, hope itself was a scarce commodity. As every electric utility knows, municipalities, law enforcement, and local, state, and federal agencies need electric power before they can begin the process of recovery. When the lights come back on and vital services return, hope seems to make a comeback.

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The evacuation of New Orleans had some unprecedented successes . . . and glaring failures.

Evacuation Planning and Engineering for Hurricane Katrina

Brian Wolshon

Brian Wolshon is associate professor, Department of Civil and Environmental Engineering and the LSU Hurricane Center, Louisiana State University.

The hurricane season of 2005 will go down in the record books. It included 14 hurricanes (a new record), three of which were among the most powerful and costly in the 154-year history of record keeping in the Atlantic Basin. In addition, there were 27 named systems—the latest, Tropical Storm Zeta, continued to move through the Atlantic even as this article was being written in January 2006. Some meteorologists suggest that this pattern may last for at least another decade.

Although little can be done to alter the weather, we can prepare for the eventuality of hurricanes and other natural and man-made hazards. For decades, engineers and scientists have been developing techniques, strategies, and materials to help the built environment withstand the effects of hurricanes. In addition, building and zoning codes have been changed to keep critical infrastructure away from hazardous areas to minimize the risks of flood and wind damage. The only way to protect people, however, is to evacuate them when threats arise, but this is often easier said than done.

At the fundamental level, the concept of evacuation is simple—move people away from danger. In reality, evacuations, particularly evacuations on a mass scale, are complex undertakings. As the nation clearly saw during Hurricanes Katrina and Rita, it is not always possible to evacuate everyone who is in danger. The most obvious problem is the sheer scope of the event. Hurricane evacuations may involve millions of people over hundreds of thousands of square miles. In addition, because evacuations are inconvenient and disruptive, evacuees often delay travel decisions until the threat appears imminent, thus compressing the enormous travel demand into shorter time periods.

Transportation infrastructure is not designed to accommodate evacuation-level demand.

One complicating factor is that transportation infrastructure is neither planned nor designed to accommodate evacuation-level demand; building enough capacity to move the population of an entire city in a matter of hours is simply not economically, environmentally, or socially feasible. Roadways are not even designed to be delay-free under routine peak-period conditions. The effectiveness of an evacuation is also greatly affected by human behavior and socioeconomics. No matter how threatening the conditions, some people refuse or are unable to leave.

Despite these difficulties, the evacuation of New Orleans for Hurricane Katrina was widely viewed as a success; data show that more people were able to leave the city in a shorter time than had been thought possible. There were also apparent failures, however, particularly in the evacuation of low-mobility groups.

This article highlights the development of the evacuation management plan for Hurricane Katrina and summarizes some of the facts, findings, and unresolved issues. The discussion is presented from the perspective of a transportation engineer and centers primarily on the highway-based aspects of the evacuation, including demand, capacity, and issues related to the non-evacuees. This article also presents some lessons learned and how they may be applied to other locations and other threat scenarios and identifies unanswered questions and research needs that should be addressed in the future.

The Katrina Evacuation Plan

The city of New Orleans has long been considered "a disaster waiting to happen." For those who prepare for, respond to, and study such events, the level of death and destruction wrought by Katrina was not outside the realm of possibility. Although a complete evacuation of the city has been the cornerstone of hurricane preparedness planning for the region, the highway evacuation plan used for Katrina evolved over a period of many years based on valuable lessons learned from prior storms in Louisiana and elsewhere.

Fortunately for New Orleans, officials in Louisiana were able to evaluate and refine their evacuation plan based on two "practice runs." In 1998, Hurricane Georges appeared to be heading directly for the city, leading to the first major evacuation in some 20 years. From that experience, it was apparent that making conventional use of available routes in the region was not an adequate strategy. As a result, the Louisiana State Police (LSP) developed a plan to implement two short segments of contraflow (LSP, 2000).

Six years later, Hurricane Ivan threatened another direct hit on the city, triggering an implementation of the new plan and the first-ever implementation of evacuation contraflow in Louisiana. Like Georges, Ivan tracked east prior to landfall and largely missed Louisiana. The evacuation that it precipitated, however, revealed numerous deficiencies in the plan that resulted in monumental congestion and delays on several key evacuation routes. After a period of considerable public criticism, the Louisiana Department of Transportation and Development (LA DOTD) and LSP formed a Louisiana Evacuation Task Force with input from consultants in industry and academia to identify where and how the congestion occurred and to develop and test ways to reduce it.

After a review of traffic volume and speed data, traffic videos, media accounts, and interviews of evacuees, the task force identified four primary issues that had hampered the evacuation: (1) over-reliance on westward traffic movement; (2) inefficient loading of the contraflow freeway segment out of New Orleans; (3) extreme congestion resulting from the confluence of multiple regional evacuation routes in Baton Rouge, Hammond, Lafayette, Covington, and Slidell; and (4) the lack of real-time, accurate traffic information.

New Orleans Analyses

In New Orleans, the goal was to get as many people as possible out of the threat zone as quickly as possible by making full use of the available traffic lanes. The movement of traffic out of the city can be pictured as sand moving through an hourglass. The outflow of sand (evacuation demand) is controlled by the neck of the glass (over-water elevated freeway segments). Given the limitations and the infeasibility of constructing additional lanes on outbound bridges in the foreseeable future, efforts were focused on making the most effective use of available capacity by using engineering and operations techniques to open the neck of the hourglass as wide as possible.

The analysis after Ivan showed that the movement of traffic was further hindered by the configuration of the contraflow initiation point. As shown in Figure 1, contraflow was initiated by crossing the left two lanes of the outbound side of I-10 into the inbound lanes. The traffic control strategy at this location resulted in a capacity restriction that effectively regulated flow into the downstream section thereby preventing full use of the contraflow lanes. While traffic upstream of this location was heavily congested, traffic downstream moved much more freely.

FIGURE 1 Westbound I-10 contraflow initiation point during Hurricane Ivan. Photo source: Alison Michel, Urban Systems Inc.

Traffic modeling was used to assess loading techniques and identify a method that would allow for optimal use of the contraflow lanes without limiting the capacity of the normal lanes or vice versa. It was hypothesized that direct access to the contraflow lanes, similar to normal entrance ramps to a freeway, would avoid the friction and, therefore, lost capacity of a crossover/decision point for drivers. It was thought that, if decision points were located on the surface-street system, the interstate would not experience the loss of capacity. It was also believed that by using multiple loading points with direct access to the contraflow lanes, the demand would be spread spatially throughout the surface-street system rather than being limited by the capacity of a single loading point (as happened during the Hurricane Ivan evacuation).

Based on these assumptions, simulation was used to evaluate several alternatives. One of the first ideas was to move the first loading point of the contraflow upstream and to add two contraflow loading points downstream. This configuration would prevent the normal outbound and contraflowing traffic streams from ever merging. The additional loading points would provide direct access by using existing exit ramps as entrance ramps to the contraflow. Overall, this configuration was expected to accomplish several objectives. First and foremost, it would spatially spread the loading of the demand. Next, it would not only give evacuees routing choices, but would also locate decision points on the surface-street system instead of the interstate system, where maximizing capacity was a necessity.

This plan was thought to be ideal, not only from the standpoint of efficiency, but also for balancing traffic on the separate sides of the freeway, eliminating a major merge point, removing the decision point from the interstate, and providing access from both Orleans and Jefferson Parishes to both evacuation routes. To spread traffic demand spatially, vehicles would enter freeway lanes via six downstream interchanges, rather than at a single point, as in the earlier plan. The anticipated benefits of this plan were clearly supported by the results of traffic simulation modeling, which showed a potential increase in outbound volume of more than 60 percent, or 30,000 vehicles, over a 12-hour period.

Ultimately, this concept was rejected, however, because of the cost and time required to build the crossover, but the knowledge gained about the benefits of using multiple loading points with direct access was used to develop a plan with three interchanges and a single lane crossover. Simulation modeling showed that with this plan outflow volumes would be only marginally (about 15 percent) lower than for the original plan. The final access points (interchanges) were selected based on input from both LSP and LA DOTD, as well as other factors, such as interchange configurations, construction requirements, emergency access, and population distribution.

Efforts were also made to evaluate alternatives on the east side of the city. Although eastbound routes were not affected by Hurricane Ivan to the same degree as westbound routes, significant congestion was evident on eastbound routes as evacuees moved east to avoid congestion in the city. To remedy the situation, a contraflow alternative was developed and tested to route all westbound traffic entering from Mississippi north back into Mississippi, thus precluding entry into Louisiana. Interstate contraflow had never been implemented before, and the state of Mississippi would have to accommodate hundreds of thousands of evacuees from Louisiana. Fortunately, an agreement was reached between officials in Louisiana and Mississippi just months before Katrina. Realizing the enormous threat posed to New Orleans, the state of Mississippi also permitted Louisiana to reroute traffic back into Mississippi and initiate contraflow on another freeway route.

Baton Rouge Analyses

Because of the level of demand generated by mass evacuations, impacts to the transportation network often occur far away from the source of the demand. In Louisiana, significant increases in volume were clearly apparent in downstream locations, such as Baton Rouge, Lake Charles, and even Shreveport, nearly 300 miles from New Orleans. The focus of regional improvements following Ivan was centered in Baton Rouge where the merge point of two major freeway evacuation routes (I-10 and I-12) had created a bottleneck that restricted flow and caused traffic congestion and delay over many miles. The most radical and interesting proposal to address this problem involved the use of an eight-mile-long segment of freeway contraflow through the heart of Baton Rouge to eliminate the merging of intersecting evacuation flows. As diagrammed in Figure 2, the contraflow segment would keep the I-10 and I-12 traffic streams separate, sending them onto two different freeways and eliminating congestion associated with merging. Simulation modeling showed that such a plan would eliminate all congestion from the area (where delays as long as 14 hours had previously been reported).

Despite its potential benefits, it was decided that contraflow through Baton Rouge was not a viable alternative. The main objection was that it would have required closure of the sole interstate freeway route through the city, raising concerns about the movement of commercial and hazardous cargo outside of the I-10 corridor, local traffic from the west side of the Mississippi River, loss of access to property or family east of Baton Rouge, and loss of access for emergency and service vehicles.

Interestingly, the plan that was ultimately decided upon and refined by LSP was potentially even more radical. In fact, in terms of its scale and level of strategic control, it was unprecedented. As shown in the schematic diagram in Figure 3, the final plan eliminated confluence traffic by forcing evacuees to use northward evacuation routes and prohibiting cross-state westbound traffic into the Baton Rouge area. The plan featured the reversal of approximately 100 miles of interstate freeway from Louisiana into Mississippi, forcing the northbound movement of traffic instead of the usual congestion-causing westbound movement. It also restricted access to nearly 100 additional

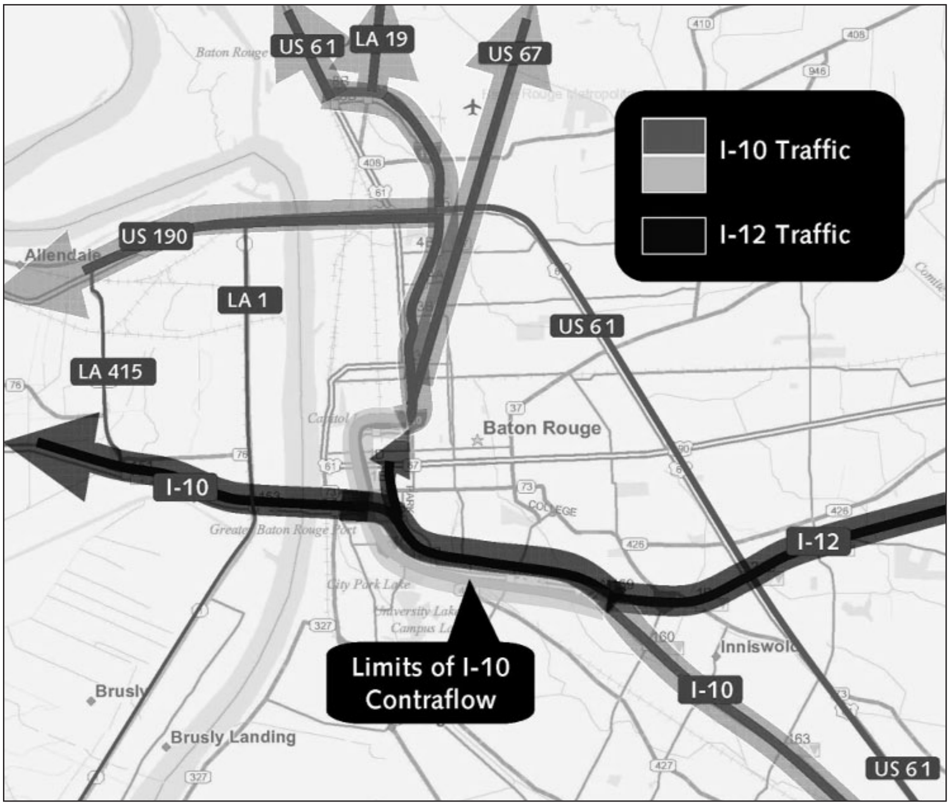

FIGURE 2 Suggested Baton Rouge contraflow plan. Source: ABMB Engineers Inc.

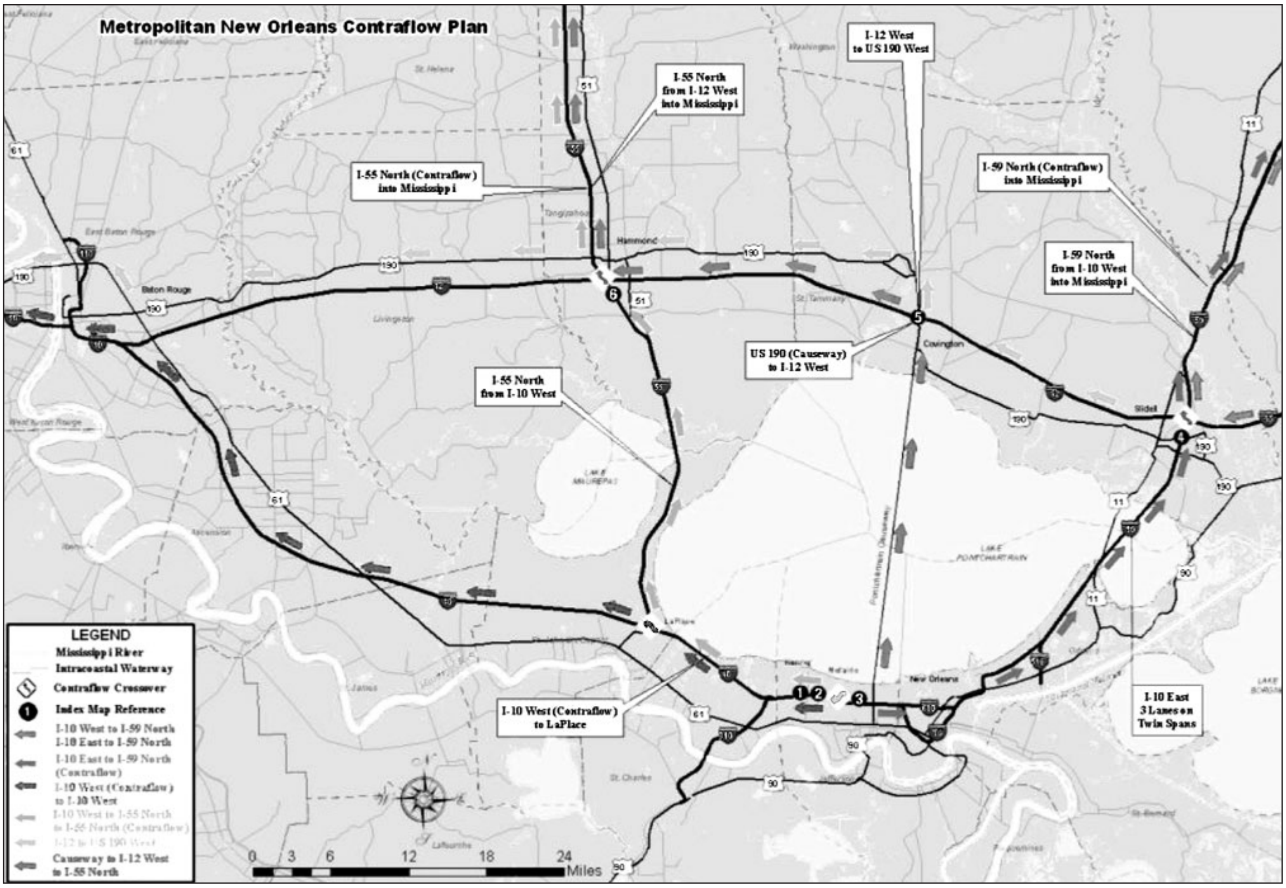

FIGURE 3 New Orleans metropolitan area evacuation map (2005 update). Source: LA DOTD, 2005b.

miles of freeway to prevent a regional bottleneck in Baton Rouge. Combined with the improved loading plan in New Orleans and the coordination of transportation assets on a regional basis, the plan was expected to enable a rapid, orderly exodus of more people than was ever possible before.

Successes

Soon after the storm, efforts were initiated to assess and evaluate traffic impacts associated with the evacuation, including how, when, where, and how long it took evacuees to move along the road network of the Gulf Coast, how contraflow impacted the efficiency of the evacuation, and, in particular, how some of these impacts were related to the revisions in the plan. Early indications of these analyses have revealed the number of vehicles involved, when evacuations started and ended at key locations, the geographic extent of the evacuation in Louisiana, the directions of travel, the capacity gains made through contraflow, and some of the implications of the modifications to the Louisiana evacuation highway management plan.

Traffic-count data recorded as part of the LA DOTD traffic monitoring network showed elevated volumes at every station throughout the state, even on lightly traveled roads through sparsely populated areas hundreds of miles from the storm landfall location. Increases in volume were evident as early as Friday evening as some travelers moved into the New Orleans area and as late as early Monday morning as traffic was winding down through more distant areas like Monroe and Shreveport. During the peak 48-hour period of evacuation, more than 430,000 outbound vehicles were recorded on the six freeway and major arterial roadways in southeast Louisiana. Although this total does not include several other primary highways, it has been assumed to mean that about 80 to 90 percent of the population evacuated the area.

Figure 4 graphically illustrates the progression of the New Orleans evacuation over time. In the figure,

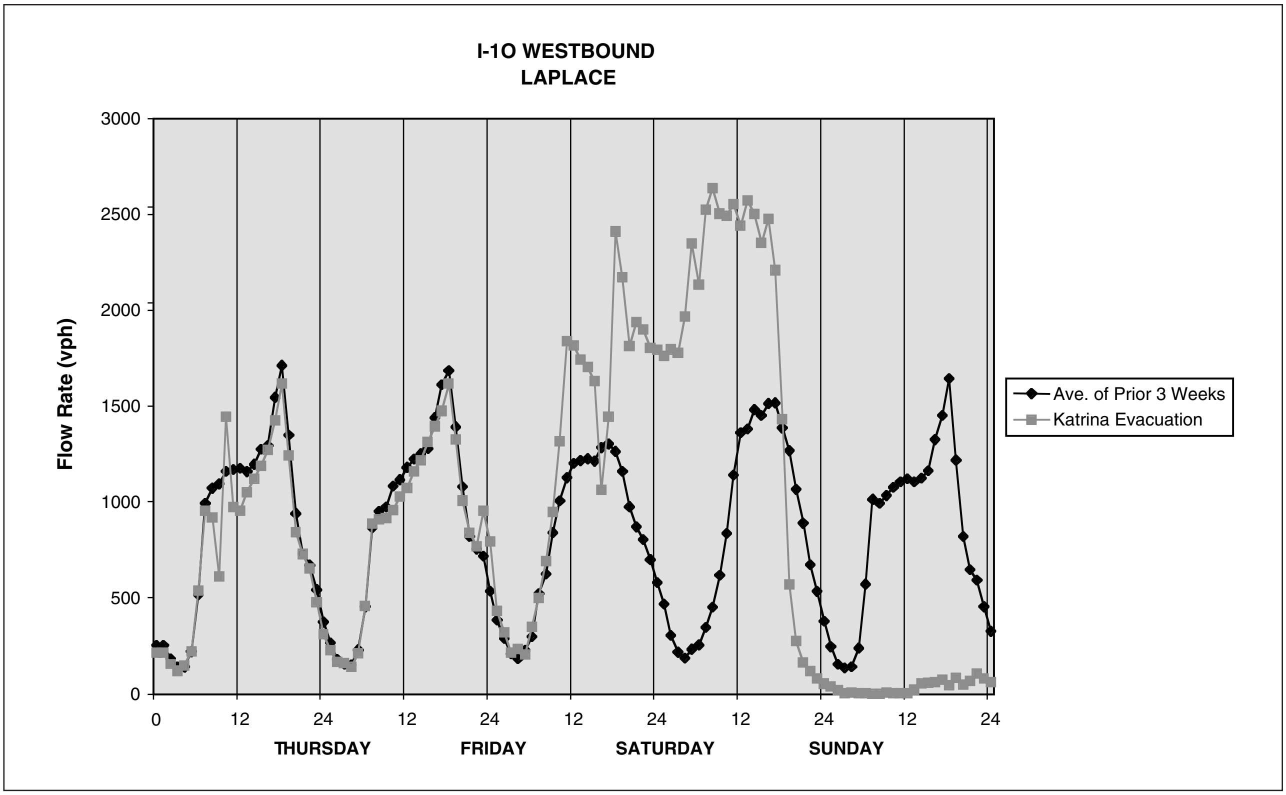

FIGURE 4 Traffic flow volume on westbound I-10 (LaPlace, Louisiana).

the heavier line represents the average traffic volume between Thursday and Monday in the two westbound lanes of I-10 during the three weeks prior to Katrina. The lighter line shows the volume at the same location during the four-day period preceding the storm landfall. The graph clearly shows that the volume increased significantly in the late morning hours of Saturday, August 27 and that traffic volume decreased for a brief period as contraflow was implemented some 20 miles upstream at around 4:00 p.m. Volumes increased again and remained far above average throughout the night. The flow peaked at more than 2,500 vehicles per hour and remained at that level throughout the day. It dropped dramatically the evening before the storm made landfall.

Temporal analyses supported by Figure 4 also show that the duration of the evacuation required only about half of the 72-hour clearance time that had historically been assumed prior to the 2005 modifications. Given the limited number of roadways, this was a tremendous achievement. The accomplishment was even more significant because of the small number of traffic-related injuries or deaths directly resulting from the evacuation. Preliminary analyses also reveal other indications of the effectiveness of the plan, including better use of low-volume routes and significant gains from contraflow.

Failures

Not all of the evacuation news was positive, however. Images of thousands of desperate people being plucked from rooftops by helicopter, stranded at the New Orleans Convention Center and Superdome, and awaiting rescue on freeways have overshadowed the successes of the highway-based evacuation plan. It has been estimated that between 100,000 and 300,000 people did not or could not be evacuated from the city.

The most serious questions, however, relate to the city's poor populations. Local governments have been blamed for poor planning and not providing adequate transportation to shelters of last resort. For example, it was widely known that some 112,000 people did not have access to personal vehicles at the time of the storm (Russell, 2005). Given these numbers and the limited capability of moving this enormous number of people quickly, public officials have long advocated "neighbor helping neighbor" policies, urging low-mobility individuals to arrange for transportation with friends, family, neighbors, and church members. Local plans also included using Regional Transit Authority buses to carry people to the Superdome from 12 locations around the city (Russell, 2005).

A major failure of the plans for evacuating the low-mobility population was the lack of communication. Evacuation plans can only be effective if people are aware of them, and evacuation orders can only be heeded if they are received in time.[1] Thus, the of problem evacuating low-mobility populations will be one of the most important issues for all levels of government in future evacuation plans.

Lesson Learned and Future Needs

In Louisiana, three major traffic modifications significantly improved the evacuation. First, a staged evacuation plan identified the order of evacuees, starting with the lowest lying areas, and suggested a time line for the initiation of contraflow. Second, multiple interchanges and a crossover were used for the contraflow loading plan to minimize congestion and maximize the capacity of bridges; this spread the traffic demand to several critical roadway segments. Third, the access management plan made maximum use of major arterial roadways; this helped spread demand to many highways instead of concentrating demand on the freeways. Although these changes may have limited flexibility and caused some inconveniences to evacuees and pass-through traffic, they accomplished their primary goal of saving lives.

Coastal populations are expected to continue to grow while available roadway capacity remains relatively unchanged. As a result, future efforts must also focus on controlling evacuation travel demand. This may be accomplished through better public information and education programs, including educating the public about which areas are truly at risk and working with the news media to provide more accurate descriptions of threat levels.

During Hurricane Floyd, the Florida Division of Emergency Management estimated that about 35 percent of the approximate 2.0 million evacuees on the road in that state did not have to leave (Collins, 2002). This so-called "shadow evacuation" also contributed to the enormous congestion in Houston. Phased evacuations may help, although they may be difficult to implement, and measures can be taken to strengthen building codes and encourage in-place sheltering practices to reduce the need for people to leave.

Emergency management and transportation officials involved in evacuations most often cite a need for better communication and coordination among emergency management, transportation, and law enforcement agencies and the public. Many states are working to combine emergency management personnel into single facilities and to establish coordinated evacuation policies. Evacuation plans can be communicated throughout the year through public information campaigns, public service announcements, and tourist information centers. In addition, the collection and transfer of traffic information during an evacuation is critical to the management of evacuation routes and the allocation of transportation resources.

LA DOTD and LSP are already working to communicate evacuation plans via news media and public service announcements urging people to prepare for future evacuations by (1) developing personal evacuation plans before the need for an evacuation arises and knowing which routes will be available; (2) being prepared for traffic delays; (3) leaving as early as possible; and (4) encouraging people on the Gulf Coast to make northward travel plans and shelter arrangements (e.g., Jackson, Mississippi; Memphis, Tennessee; and Birmingham, Alabama), rather than westward plans (Houston or Dallas) (LA DOTD, 2005a). Overall, people must be encouraged to take a more active role in planning for their own safety.

Conclusion

The experiences of the 2005 hurricane season have shown that overall evacuation readiness in the United States has improved in the past decade, although a great deal remains to be done. We now have evidence of the significant gains that can be made through large-scale, aggressive, proactive regional traffic management. Policy makers and plan developers must understand that evacuations are not business as usual and cannot be considered local events. Evacuations are life-and-death scenarios, and planning decisions must be made with preserving lives in mind. This may mean that convenience, accessibility, route choices, and perhaps even

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[1] "Many said that mandatory evacuation orders came too late, or that leaving, even with transportation, was not a simple matter for older residents. LeShawn Hains could not find a special-needs shelter for her mother, Gilda, who was on oxygen and had heart and lung trouble. Eddie Cherrie Jr. stayed behind with his mother, Onelia, who relied on a walker and blood pressure medication. 'It's true nothing stopped us from leaving,' he said. 'But also, it's not that easy to leave with a 91-year-old woman'" (Russell, 2005).

safety, may have to be compromised somewhat to maintain the most efficient traffic flow.

As we move forward and prepare for the next hurricane season, the search for solutions will extend far beyond the realm of engineering. The lessons learned, information exchanged, and new knowledge that will be created in this field will have implications far beyond hurricane evacuations. Temporary reversible lanes, unconventional spatial and temporal loading strategies for freeways, and the use of mass transit under emergency conditions have applications for homeland-security scenarios, major-event traffic management, and traffic congestion during peak commuter periods.

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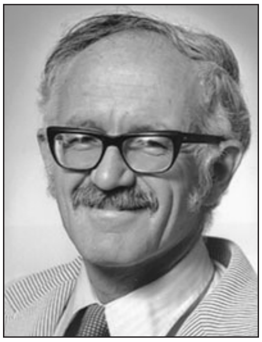
The greatest uncertainties for wetland restoration will be political will and stakeholder response.

New Orleans and the Wetlands of Southern Louisiana



Robert G. Dean is Graduate Research Professor, Department of Coastal and Oceanographic Engineering, University of Florida, and an NAE member.

Robert G. Dean[1]

The New Orleans-Mississippi River and associated wetland system are central to the well-being of the nation. The Mississippi River drains 41 percent of the water in the continental United States, and every year the system provides some one billion pounds of seafood and 25 percent of the nation's oil and gas. In addition, $15 billion worth of cargo passes through the Port of New Orleans. Barrier islands and wetland systems[2] provide habitat for much of the finfish and shellfish consumed in the United States as well as a degree of protection for New Orleans against the effects of hurricanes.

Estimates of the size of the wetlands range from 6,000 to 12,000 square miles (in this paper, I use 9,000 square miles). This article is about (1) the degradation of these valuable wetlands and the diminishment of their protection against hurricanes and (2) the prognosis for restoring them and rebuilding New Orleans. To understand and, ideally, reverse wetland loss, three salient features of the area must be kept in mind: (1) the immensity of

[1] The author recently chaired the National Research Council (NRC) Committee on Restoration and Protection of Coastal Louisiana, which evaluated the so-called "LCA plan" a near-term, $2-billion program formulated by the U.S. Army Corps of Engineers and the state of Louisiana Department of Natural Resources. The plan was a scaled-down version of two much more comprehensive and ambitious earlier plans. Unless otherwise indicated, the views expressed in this article are those of the author and do not necessarily reflect those of the committee or the NRC.

[2] Barrier islands in this area, elongate features generally formed by sediments from the Mississippi River, are coarser than similar features in the landward wetlands. In this article, the term wetland systems includes the barrier islands.

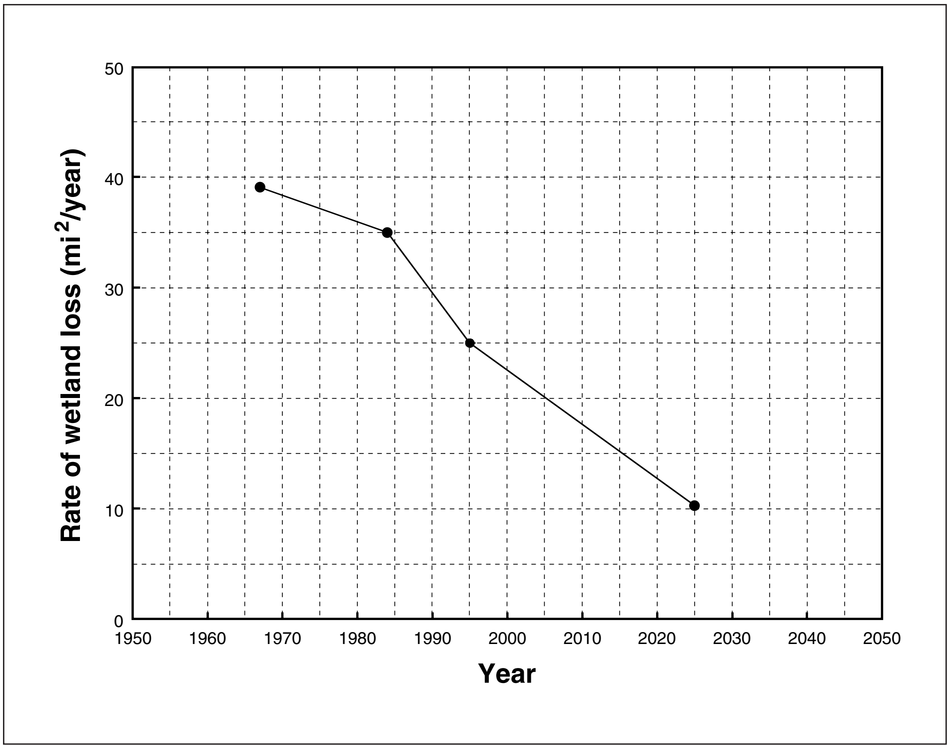


FIGURE 1 Measured (1956 to 2000) and projected (2000 to 2050) rates of wetland loss without the LCA Plan. Note the rapid decrease over the last several decades. Source: NRC, 2005; USACE, 2004.

the area of concern; (2) the pervasiveness of the natural forces that tend to degrade the wetlands (particularly the rate of subsidence and the rise in sea level); and (3) the interests of entrenched stakeholders.

Wetland Loss

Background

The wetlands of southern Louisiana, the largest in the United States, which provide a buffer against storm surges and waves, are being lost at an unprecedented rate—approximately 1,900 square miles since 1930. Figure 1 shows the documented historic and projected future losses of wetlands. Reduction in the loss rate from 1990 to 2000, an average of 25 square miles per year in 1995, is probably the result of several factors: (1) the more readily eroded wetlands had already been lost, and the remaining wetlands are more resistant; (2) there were fewer major storms in recent years; and (3) limited remedial measures have had some beneficial results. A preliminary assessment by the U.S. Geological Survey established that 100 square miles of wetlands were lost due to Hurricanes Katrina and Rita (NWRC, 2005), and it is not known if some of these wetlands will recover, as they have after other major storms.

The Natural System

In its natural condition, the Mississippi River can be considered a vast, "leaky" plumbing system; the leaks increase during higher flows (Figure 2 shows the associated river distribution systems in 1880 and 1990). Under the influence of natural forces (Figure 2a), Mississippi River waters spilled over its banks during periods of high flow, depositing coarser sediments close to the river and finer sediments farther inland. The sediments deposited near the river formed natural (elevated) levees. The finer sediments provided a rich matrix for agriculture over broad flooded areas, as well as sediment that enabled the land to maintain its elevation in the presence of rising relative sea level.[3]

In some areas, the overflow was more or less uniform; in other areas, the overflow was concentrated into channels with deposits forming "splays" on the lee sides of the natural levees. After the river returned to its normal flow, the incipient channels formed during high flows would usually heal, leaving the sediments in place.

During high flows, the river also deposited sediments in the vicinity of its terminus. If this terminus were in relatively shallow water, the river mouth would advance toward the Gulf through deposition and the formation of natural levees. Figure 3 shows the advancement of Southwest Pass (historically, the main shipping channel) by 15 kilometers in 215 years, an average rate of about 70 meters per year! Today, the terminus of Southwest Pass is at the edge of the continental shelf where the sediment load is discharged into deep water, considered a favorable process by those responsible for maintaining navigation depths.

[3] Relative sea level rise is the sum of the eustatic (worldwide average sea level rise) component and local effects, which include subsidence. Land subsidence in the delta region, both natural and anthropogenically induced, can be as much as 2 centimeters per year, approximately 16 times the eustatic rate.

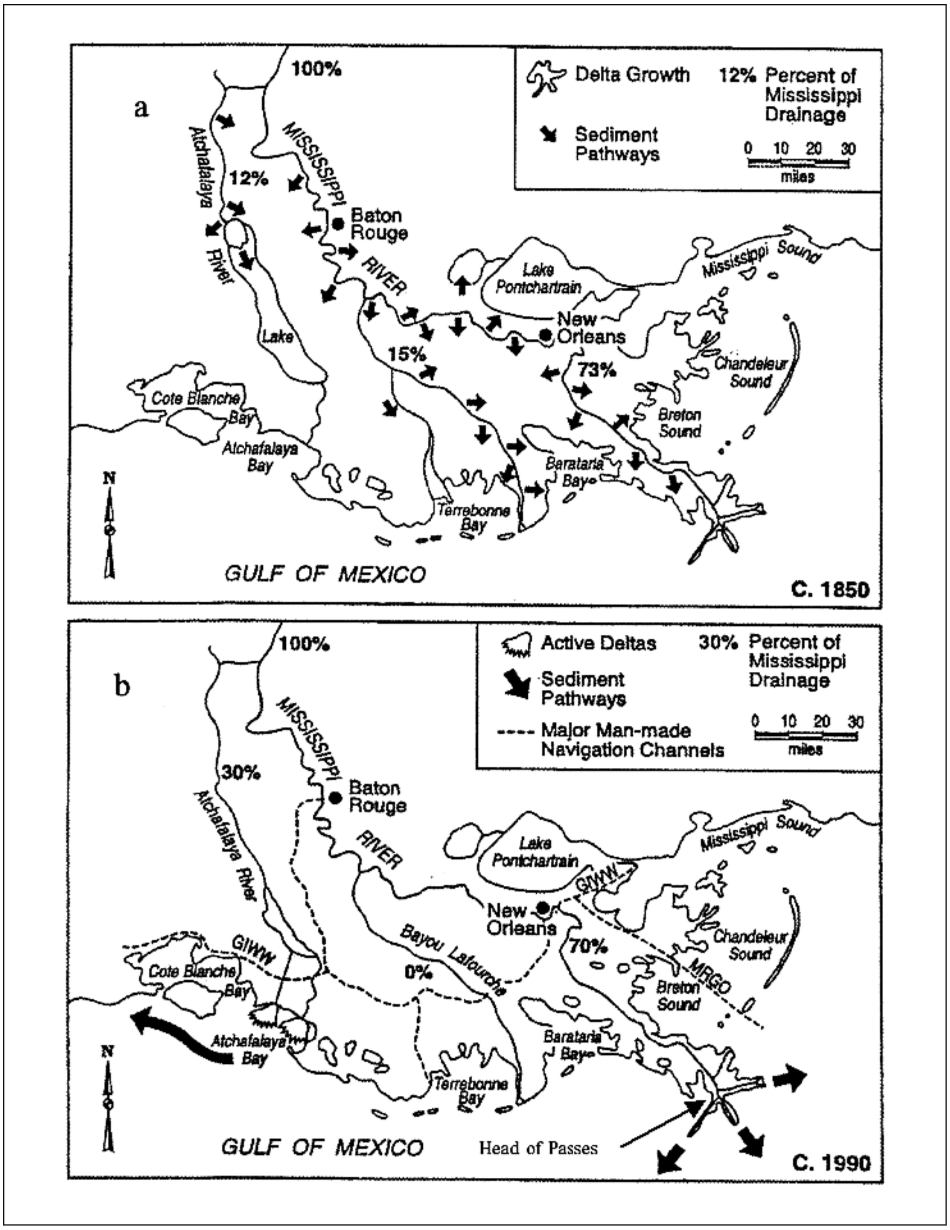


FIGURE 2 Comparison of the percentage of Mississippi River discharge flowing into the adjacent wetlands and distributary channels on the Mississippi River deltaic plain (2a) for 1850 and (2b) for 1990. Source: Kesel, 2003.

As the length of the channel increases, it becomes less efficient hydraulically and during high flows more susceptible to channel "switching," when a breach can become the predominant channel that delivers water and sediments a shorter distance to the Gulf. The creation of a new, hydraulically preferred channel and the abandonment of a previous channel has been documented to occur, on average, approximately once every thousand years. When channel switching occurs, the sediments and fresh waters that nourished the previous channel levees and wetlands are "switched" to the new area where wetlands formation, natural levee building, and river channel extension are active processes. Thus, the area of previous wetland growth and maintenance is subject to rapid erosion and wetland drowning as a result of relative sea level rise, and the area of new sediment delivery undergoes vigorous wetland formation. It is possible to observe this natural process of wetland growth in the modern delta system (albeit in a controlled setting) where sediments delivered by the Atchafalaya River result in the annual net production of 180 acres of wetlands and would produce more if it weren't for the dredging and disposal in deep water of 8 million cubic meters per year of sediment to maintain the Atchafalaya River Navigational Channel.[4]

In summary, under natural conditions, the uncontrolled Mississippi River delivered its waters and sediments toward the Gulf of Mexico through channels that were subject to overflow during floods, thereby providing the nutrients and sediments necessary to maintaining wetland elevations in the presence of relative sea level rise. Channel switching caused the sediments to be routed to shallow waters, resulting in rapid wetland growth in the areas of new sediment supply and

[4] As seen in Figure 2, the Atchafalaya River, a distributary of the Mississippi River, discharges into Atchafalaya Bay. The flow volumes in the Atchafalaya River are controlled at 30 percent of the total flow in the Mississippi River. Without control, the Atchafalaya River would by now have captured the main flow of the Mississippi River.

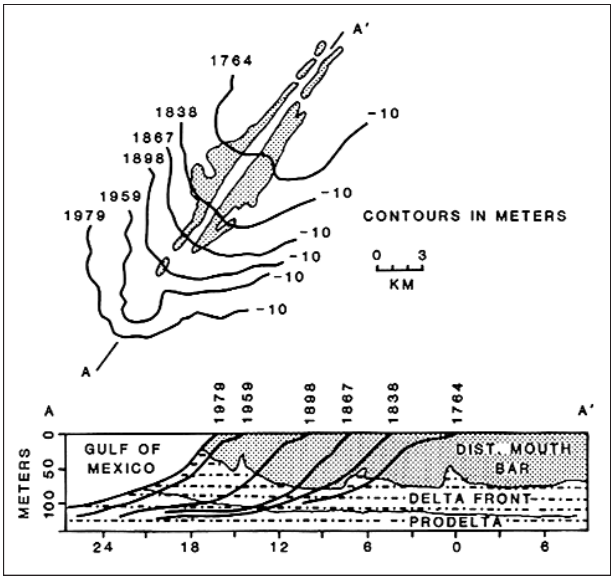


FIGURE 3 Advancement of Southwest Pass of the Mississippi River from 1764 to 1979. Source: Coleman, 1988; Gould, 1970.

rapid wetland degradation in areas of channel abandonment. Thus, under natural conditions, the wetland systems were dynamic. However, to the best of our ability to determine, the net wetland area was stable over the long term.

The Altered System

A comparison of Figures 2a and 2b shows how the "leakiness" of the Mississippi River has changed under modern systems. The flows through Bayou La Fourche have been essentially eliminated, and practically all of the flows over and through the natural levees have ceased as a result of levee construction for flood protection. Thus, the supply of sediments that formerly spilled over the banks along the length of the river has been all but eliminated. Similarly, the river now discharges most of its sediment load into deep water rather than depositing it where it can offset the effects of relative sea level rise. This has had a significant negative impact on the barrier islands and wetlands.

The extraction of large quantities of hydrocarbons has also had a significant effect. The first successful oil well in southern Louisiana was drilled in 1901. The earliest oil fields were developed on land, but as those fields became depleted and larger and more productive offshore fields were discovered, and as new technologies became available, the offshore resources were developed.

Unless water is injected to replace the oil, gas, and water extracted, the pressure in oil fields decreases substantially, which can contribute to subsidence in the area. Morton and colleagues (2002, 2003) have conducted careful studies correlating areas of high subsidence with decreases in bottom-hole pressures in oil fields. Their studies strongly support a link between hydrocarbon extraction and *local* subsidence. Not everyone agrees, however. Gagliano et al. (2003), for example, have argued that local subsidence effects are due to natural thrust faults; even without hydrocarbon extraction, they say, it is well known from geological evidence that faulting (called "thrust faults") in the region has been caused by sediment loading of the delta region.

Other anthropogenic causes of wetland loss include channels cut for hydrocarbon exploration and production, the consumption of wetland vegetation by nutria (fur-bearing animals introduced into the region), the alteration of wetland areas for agriculture, and so on.

In my view, and the view of many, but not all, other investigators, the dominant causes of wetland loss are the channelization of the Mississippi River to ensure that sediments are discharged offshore into deep water and the restraint of the river to eliminate natural overbank flooding and channel switching. Thus, substantial progress in large-scale restoration of the wetlands will require that large-scale sediment processes be reinstated to the degree possible.

Subsidence, Sediment, and Relative Sea Level Rise

Two unique physical features of wetland loss in southern Louisiana are the pervasiveness of natural "forces" and the vastness of the affected area. The dominant natural force is subsidence, which ranges from approximately 0.25 centimeters per year near the southern limits of New Orleans to nearly 2 centimeters per year near the terminus of the river. This is 2 to 16 times the worldwide average rate of sea level rise (based on a rate of 1.2 millimeters per year). The wetlands must accrete vertically at the rate of local relative sea level rise to maintain their viability, which requires substantial quantities of sediment. Keep in mind that the wetlands cover approximately 9,000 square miles, with an east-west dimension of 300 miles from the Mississippi state boundary on the east to the Sabine River at the Texas border on the west. The north-south dimension averages 30 miles.

Because essentially all of this area is experiencing some degree of subsidence, to maintain the present wetland area, mineral (i.e., inorganic) and organic sediment volumes must be sufficient to maintain the elevation against relative sea level rise. However, the sediment delivery of the Mississippi River has been reduced in historic times by the upstream construction of impoundments and by agricultural practices to control erosion. In fact, these reductions raise the question of whether the river now delivers enough sediment to stabilize or increase the present wetland area.

To address this question, we consider an annual mineral sediment delivery of approximately 100 million cubic meters and that the proportions of mineral to organic sediment volumes necessary to form wetlands vary from 1:10 to 1:4. A simple calculation suggests that to maintain elevation of this 9,000-square-mile area in the presence of an (assumed) average 0.25 centimeter per year relative sea level rise, the present rate of mineral sediment delivery is approximately 8 to 20 times the amount required—but only if the sediment can be delivered to the areas in need.

Unfortunately, targeted delivery is not economically possible for several reasons, such as the energy costs and long distances of these areas from the Mississippi River, which is the primary source of sediment. In addition, many communities have been built on the natural levees of the river, making it almost impossible to raise the general elevations of these areas; the building of manmade levees remains the only means of protecting them against flooding.

Stakeholders

A great many stakeholders will be involved in a wetland restoration plan that incorporates the optimum characteristics of a natural system. The stakeholder most likely to be resistant to large-scale sediment delivery to the areas in need and to channel switching is the navigation industry. At present, the shunting of sediments offshore through Southwest Pass to deep water provides substantial benefits for the industry. First, it reduces the amount of dredging necessary for channel maintenance. Second, vessels now enter the protective shelter of the levees of Southwest Pass immediately after leaving the deeper waters of the Gulf of Mexico. Thus, the present system provides both economic and safety benefits that the navigation industry will certainly not want to compromise. Third, the long distance from New Orleans to the Gulf of Mexico effectively limits the encroachment of saltwater from the Gulf up the river to the municipal water intakes of New Orleans.

In addition to the navigation industry and, perhaps, the city of New Orleans, the many communities located on natural levees, the elevations of which are decreasing, are facing difficult choices. They can (1) do nothing to change the situation, thus awaiting another disaster, (2) eventually abandon their communities, or (3) build levees to protect themselves. Agricultural interests will also require substantial compensation, if they agree at all, to participate in a plan that floods their lands with the sediments necessary to maintain elevations equal to rising relative sea level.

Looking Ahead

We can now identify the conceptual elements of a viable wetland restoration plan, as well as some of the uncertainties. Capturing and delivering large quantities of sediment to areas conducive to the development of barrier islands and wetlands must be the centerpiece of the plan. If the sediment is made available, the opportunistic nature of the wetlands will ensure their formation. To accomplish this objective, the plan must mimic the natural system of sediment delivery as closely as possible. The greatest uncertainties will be the willingness of the nation to provide adequate financial resources and the acceptance or resistance of stakeholders, such as communities built on natural levees, to meaningful action.

A wetlands restoration plan must mimic the natural system of sediment delivery as closely as possible.

Proposed Plan

Previous efforts to reduce the rate of wetland loss have been partly successful. In 1990, Congress passed the Coastal Wetlands Protection and Preservation Act or CWPPRA (also known as the Breaux Act) to provide federal funding (approximately $50 million per year) for coastal restoration. This program has consisted primarily of the diversion of fresh water and sediments to allow for wetland building. Partly because of limited resources, however, none of the CWPPRA projects has attempted to capture a major portion of the

TABLE 1 Land-Change Projections for the Next 50 Years with the CWPPRA and Other Projects and the LCA Plan

Program	Land Changes (mi^2/year)
Loss-rate reduction attributable to funded CWPPRA and other projects	+2.6
Existing situation with existing funded CWPPRA and other projects	–10.3
Anticipated decrease with the LCA plan	+1.7
Net Change with the LCA plan	–8.6

Source: USACE, 2004.

river sediments. The Louisiana Coastal Area (LCA) plan (developed by the U.S. Army Corps of Engineers [USACE] and the Louisiana Department of Natural Resources and reviewed by the National Research Council [NRC]) is a $2 billion proposal that includes five major projects to be constructed within a 10-year period —the initiation of a science and technology program, several smaller scale demonstration projects, and preliminary evaluations of a few large-scale long-term projects, one of which is discussed below. The purpose of the science and technology program is to provide an organizational framework for the monitoring and evaluation of constructed projects and to assist in the selection and design of future projects. Table 1 shows estimates of the reduction in wetland-loss rates as a result of CWPPRA and other projects and the predicted effects of implementation of the proposed LCA plan.

A major component of the overall LCA plan that would be evaluated, but not constructed during the 10-year project, is the so-called "third delta," originally proposed by Gagliano and van Beek (1999). A channel would be constructed from near Donaldsville, Louisiana, some 55 miles from the Gulf of Mexico. The channel would be aligned approximately parallel to Bayou La Fourche, the natural conveyance that, under natural conditions, carried approximately 15 percent of the Mississippi River discharge (see Figure 2a). This project appears to be feasible from an engineering perspective and would mimic to some degree the natural sediment and water delivery processes of the river. Stakeholders may be the major limitation to this plan, although a substantial educational program might persuade them to consider the idea.

In the NRC report, *Drawing Louisiana's New Map: Addressing Land Loss in Coastal Louisiana*, a committee of experts recommends some modifications to the LCA plan (NRC, 2005). Instead of locating the point of diversion near Donaldsville, the committee suggests locating it farther south (north of Head of Passes),[5] thus diverting water and sediments to the west. In this way, almost all of the discharge could be diverted without affecting the navigational function of Southwest Pass. The smaller sediment fractions would flow predominantly to the west under natural forces; coarser sediments (called "bed load") would require substantial dredging from the river bed with predominant placement to the west.

The NRC committee also suggests that the LCA plan proceed with the aid of an evolving map of future landscapes for various time horizons under alternative options for remediation. Predictions of future landscapes, although somewhat limited, can be made with a reasonable degree of confidence without additional restoration efforts. Capabilities for predicting the effectiveness of various restoration options are already sufficient to initiate a program, and these capabilities will improve with future monitoring of the wetlands and their response to remedial measures.

With the modifications recommended in the report, the LCA plan would focus first on large-scale projects that could provide economies of scale in delivering sediments to the areas in need. If stakeholder concerns and political consequences render the first choices infeasible, expectations could be adjusted accordingly through revisions to the map.

To evaluate this approach and demonstrate its benefits (and perhaps gain broad approval), a scaled-down version could be put in place. The diversion could be limited in magnitude with dredging still capturing and delivering coarser sediments to the west. Ideally, these sediments could be discharged a sufficient distance to the west that the waves, through natural processes, would continue to carry them in that direction, thus nourishing the present barrier islands.

Rationale for an Integrated Plan

Whatever protective system is selected, two essential components must be levee construction and wetland and barrier island restoration. Without the latter

[5] Head of Passes is the location shown in Figure 2b where the main river divides into three main distributaries.

component, the protective capability of levees will continue to decrease with time. Wetlands reduce hurricane storm surge and wave impact partly by bottom friction, which dampens waves and reduces storm surge from rapidly moving hurricanes. Robust wetlands preserve their buffering capability and contribute to the effectiveness of the levees protecting New Orleans and other areas by maintaining vertical elevation in the presence of relative sea level rise. Although various "rules of thumb" have been developed for gauging the effectiveness of wetlands in reducing storm surges and waves, this is a complicated process that depends on the translational speed of the hurricane, among other factors.

However, deferring wetland restoration because of a quantitative uncertainty of their effectiveness would be ill advised. With further wetland degradation and continued relative sea level rise, future hurricane-generated waves and surges in the New Orleans area are certain to be larger and more destructive. The degree of protection will certainly diminish with time as the wetlands degrade, and restoration from an even more degraded condition will be more difficult and more costly than maintaining present conditions.

Hurricanes Katrina and Rita and the associated tragedies have raised several questions for the engineering, scientific, and political communities, especially the best way to protect New Orleans from a recurrence of flooding. The design of a new levee system could benefit substantially from lessons learned from recent events. First, partitioning the areas at risk with additional levees would make it less likely that a single failure would cause widespread flooding. Second, for areas where ground elevations are reasonably high, low surrounding levees should be considered to isolate these areas from flooding. Existing roads and other infrastructure could provide rights of way for this purpose.

Conclusion

A general question for the engineering and political communities is how to identify areas of extreme vulnerability and address these vulnerabilities before disasters occur. It was well known that New Orleans was vulnerable to hurricanes of magnitudes that had occurred in the past and would recur in the future. In fact, if Hurricane Ivan in 2004 had maintained its course, it is likely that severe flooding of New Orleans would have occurred then. Thus, the scientific/engineering question was not whether, but when, such a disaster would occur.

If the warnings had been heeded, the estimated cost of prevention would have been less than 1 percent of the cost of reconstruction, and many lives would have been saved. The cost of debris removal alone as of November 2005 was more than the preventive cost of upgrading the levees and restoring the wetlands.

In the wake of Hurricanes Katrina and Rita, many questions remain to be answered. Might the tragedy have been prevented if the technical community had conveyed realistic, convincing scenarios of the impending disaster? Or, was the political community unwilling to take proactive action to avoid certain disaster because of the uncertainty of its timing? More important, will appropriate steps be taken to avoid preventable disasters in the future?

I believe a program to identify vulnerable areas throughout the United States is warranted. Once these areas have been identified, the associated risks and failure consequences can be ranked objectively and the costs of disaster prevention evaluated. Finally, the agencies and organizations responsible for the safety and financial future of our nation should establish schedules for upgrading infrastructure and risk management plans to avoid future disasters.

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No policies or standards are in place for individual water sectors or for water resources as a whole.

Restoring Coastal Louisiana: Planning without a National Water Policy

Gerald E. Galloway is Glenn L. Martin Institute Professor of Engineering, University of Maryland, and an NAE member.

Gerald E. Galloway

Hurricane Katrina focused the nation's attention on the fragility of our built environment and, perhaps, on the limitations of engineering. As people in New Orleans and the rest of coastal Louisiana struggle to deal with the aftermath of Katrina and her sister hurricane, Rita, we all worked together to respond to the immediate needs of the victims, develop plans for short-term recovery of the communities and their inhabitants, and set a direction for the future use of lands devastated by nature's forces and the compromise of the levee systems that were supposed to protect them. As a nation, we moved forward quickly with the first task and are moving now to assist with short-term recovery. But we appear to be stumbling as we attempt to develop long-term plans for the region.

Among other things, Katrina sent us a wake-up call about the water policy issues facing coastal Louisiana and the nation. Unfortunately, unless you consider the jumble of conflicting, outdated federal laws, regulations, and procedures that deal with water, a national policy, the United States is operating without a water policy that would help us establish goals, objectives, and priorities to meet the significant challenges of reconstructing coastal Louisiana and address other challenges in the future.

Coastal Louisiana

Coastal Louisiana sits at the end of a natural funnel that carries the waters of the Mississippi River Basin into the Gulf of Mexico, draining 41 percent

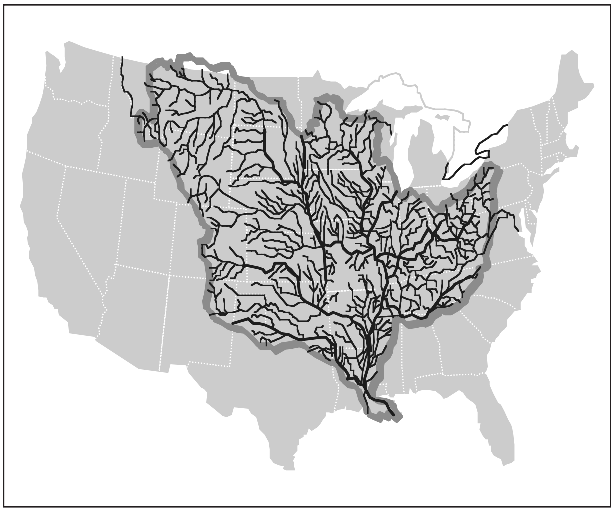

FIGURE 1 The Mississippi River Basin.

of the coterminous United States and parts of two provinces of Canada (Figure 1). The quality and quantity of these flows are determined by natural and human-induced actions far from Louisiana.

People have lived on the banks of the Mississippi at New Orleans since 1718 and before that were scattered across the large deltaic plain south of the city (Figure 2). People originally lived along the Mississippi on the higher ground, the natural levees. Faced with periodic rises in the river, they gradually increased their protection against flooding by building levees on top of the natural levees. The Mississippi Delta provided an extensive buffer that reduced the impact of hurricanes on the city; the distance from the Gulf and the nature of the wetland terrain worked together to limit the size of storm-created surges that moved toward the city from the Gulf of Mexico.[1] Over time, the original settlement of New Orleans grew into the backwater wetlands north of the natural levees by filling lowlands (land below sea level) between the Mississippi River and Lake Pontchartrain. By the end of the twentieth century, most of the lowlands were occupied.

As the extraction of energy from the coastal region became more feasible, the oil and gas industry moved throughout the delta, crisscrossing it with channels for pipelines and boat access to remote extraction sites. The coastline itself became home to a significant proportion of the nation's petroleum industry, offering ports, processing plants, and support facilities for off-shore oil drilling platforms. Most of the region was protected from massive flooding of the Mississippi River by a carefully developed flood-control system that efficiently moved Mississippi River waters past New Orleans and, during critical periods, diverted some of the rising waters around New Orleans though three floodways that sent them on other paths to the Gulf.

Hurricane Betsy, which hit New Orleans in 1965, showed clearly, however, that the back door to New Orleans, Lake Pontchartrain, was open and that storm surges moving into the area through Lakes Pontchartrain and Borgne would flood low lying areas north and east of the original settlement.

This led to congressional authorization for hurricane protection and the construction, over the next 20 years, of several projects designed to protect the area against 0.5 percent to 0.33 percent annual chance hurricane events.[2] Given that coastal areas in the Netherlands and Japan are protected against the 0.01 percent event (10,000 year), many considered the 0.5 to 0.33 level of protection too low.

Post-Katrina

When Katrina ripped into the Gulf Coast, several levees and floodwalls failed, and many more were overtopped. Levees protecting the city of New Orleans against the Mississippi remained intact.

Immediately after the hurricane, attention was focused on rebuilding levees. The president of the United States stood in downtown New Orleans and declared, "Protecting a city that sits lower than the water around it is not easy, but it can, and has been done." He went on to promise that ". . . the Army Corps of Engineers will work . . . to make the flood protection system stronger than it has ever been." But what does that mean?

While the president was speaking in New Orleans, others were raising the issue of protection for the rest of coastal Louisiana and the need for restoration of the delta wetlands. For more than two decades, people who lived in, worked in, or enjoyed the natural wonders of the deltaic plain had been pointing out the yearly loss of 40 square miles of wetlands and the shrinking coastline that was daily reducing the flood protection for greater New Orleans, delta communities, the oil and gas industry, and the commercial fishermen who work in

[1] According to anecdotal data, every mile of marsh reduces storm surge by three inches (Working Group, 2006).

[2] The 0.5 percent annual chance event is frequently cited as having a 200-year recurrence interval; the 0.33 percent, a 300-year interval; and the 1 percent, a 100-year interval.

the Gulf and contribute $2.8 billion to the state and national economy (USACE, 2004).

After Katrina, there were also concerns about getting the world-linked navigation industry back in business. Southern Louisiana, the nation's largest port complex, annually handles nearly 200 million short tons of cargo. It is also a transfer point for barges bringing millions of tons of bulk commodities from farmlands, mines, and factories throughout the Midwest and the terminus of the 12,300-mile Mississippi River inland waterway system. Shipping in Louisiana depends on having deep-draft channels from Baton Rouge to the Gulf and a well maintained inland waterway system (USACE, 2005).

Dealing with Multiple Challenges

The restoration of wetlands, protection from floods, and the maintenance of navigation are not stand-alone issues. Much of the deterioration of the wetlands has taken place because Mississippi River sediment, which for thousands of years had been spread across the delta forming one delta lobe after another, is being channeled into the Gulf of Mexico by the levees that line much of the Mississippi from Cairo, Illinois, to the Gulf. These levees keep the water off of the land and, together with dikes and concrete revetments, maintain deep channels that support navigation. In addition, the once-rich sediment load of the river has been cut nearly in half over the last half-century by large dams built on the Missouri and Arkansas Rivers to support navigation, flood control, irrigation, and hydropower in those basins (Kesel, 1989).

At the same time, nutrients in the waters flowing from the rich farmlands of the Midwest have created a hypoxic dead zone where the Mississippi enters the Gulf of Mexico (NOAA, 2006). Upstream agricultural and industrial activity has sent pollutants into the Mississippi and has threatened the quality of the water supply for communities in the lower Mississippi Valley. In fact, the Environmental Protection Agency has identified surface water and groundwater quality in the delta as subjects of concern. Both New Orleans and the delta also suffer from natural and human-induced subsidence that lowers the landscape; at the same time, accelerating sea level rise is covering more and more wetland areas and moving back the shoreline (Working Group, 2006).

It would be logical to deal with all of these problems in an integrated way so the solution to one problem is balanced against its impact, positive or negative, on the others. The ultimate solution must deal concurrently with all of these issues. Long before Katrina, there were pleas that hurricane protection be increased to a level in keeping with the threat, and Congress had authorized a study to look into increasing protection. In addition, both federal and state agencies were developing plans for the restoration of coastal Louisiana, and an *AMERICA'S WETLAND* campaign to bring the coastal restoration challenge to the attention of the public had already begun.

When the hurricane hit, legislation for a Louisiana coastal-area restoration project was awaiting action in the Office of Management and Budget; similar legislative initiatives were under way in Washington and Baton Rouge to enhance the navigation system and address ongoing water quality issues. But these actions were proceeding on parallel paths with little or no coordination. The goals of each action were being developed on the fly with no master plan of how these efforts would relate to each other.

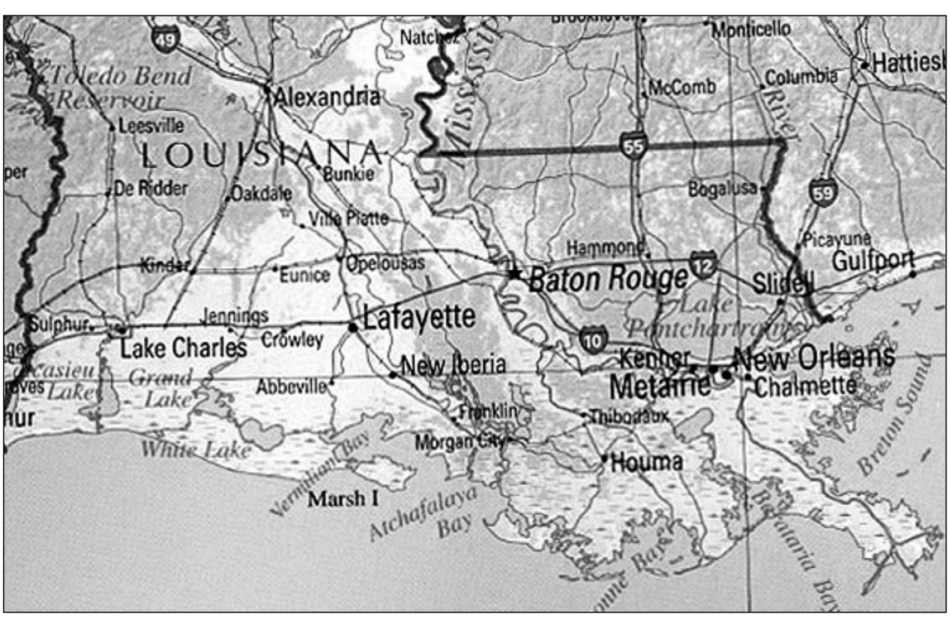

FIGURE 2 Louisiana Gulf Coast.

Establishing Direction

Decisions about restoring coastal Louisiana and New Orleans must be based on a comprehensive vision embedded in national policies. Programs and standards developed for New Orleans and the Mississippi Delta may well have to be applied to programs in other parts of the country. In Congress, precedents do matter. Unfortunately, neither visions nor policies nor standards have been established for individual water sectors or for water resources as a whole.

The approach to water policy has varied over time and, with few exceptions, has focused on water sectors as opposed to water as an integrated whole. More than 125 years ago, Congress made known its goal of supporting navigation on the Mississippi River when it formed the Mississippi River Commission and chartered it to ". . . improve and give safety and ease to navigation . . . and promote and facilitate commerce, trade, and the postal service" (33 USC 647). Over the years, Congress has authorized the construction of lock and dam navigation systems on many other rivers. The Reclamation Act of 1902 put forward a vision for encouraging settlement of the arid West and the use of western lands for agriculture. Putting aside questions about the uses of water, the vision of 1902 did, in fact, look beyond a five- or ten-year horizon to establish a program in keeping with a policy, accomplished a defined goal, and brought people and water to the West.

Water policy has focused more on water sectors than on water as an integrated whole.

In 1927, the lower Mississippi Valley was hard hit by a "flood of record" that killed hundreds of people and displaced thousands. Congress responded with the Flood Control Act of 1928 (PL 70-391), which assigned the U.S. Army Corps of Engineers (USACE) and the Mississippi River Commission the mission of preventing a repetition of the event, indicated that the control of floods was ". . . in the interests of national prosperity, the flow of interstate commerce, and the movement of the United States mails . . . ," and acknowledged that this was a province of the federal government. Eight years later, when much of the nation was hit by disastrous floods, Congress passed the 1936 Flood Control Act, stating that ". . . destructive floods upon the rivers . . . constitute a menace to national welfare; it is the sense of Congress that flood control is a proper activity of the Federal Government." The act went on to posit that ". . . the Federal Government should improve or participate in improvements . . . for flood control purposes if the benefits to whomsoever they accrue are in excess of the estimated costs . . ." (33 USC 701).

The 1928 and 1936 acts provided a clear national policy, and federal agencies quickly took on the mission of flood control. They understood this mission to be keeping floodwaters away from people by building structures to prevent flood damage.[3] Given these marching orders, USACE set out to protect communities from the largest probable flood that might occur in the river basin under consideration, a flood that generally is larger than a 0.2 percent annual chance event.

Similar broad, water-related legislation was passed in the mid-twentieth century to deal with hydropower, the formation of a Tennessee Valley Authority, and the protection of endangered species and a number of related environmental issues. The National Environmental Policy Act, National Flood Insurance Act, Clean Water Act, and Safe Drinking Water Act provided sectoral goals for the water community.

In an effort to bring together water-resource activities and establish standards for federally supported water-development activities, Congress passed the Water Resources Planning Act of 1965 (42 USC 1962), which established river-basin commissions to undertake comprehensive, multi-objective planning. The law established a federal Water Resources Council that was charged with coordinating government water policies and promulgating "principles and standards" to guide the development of water resources. In 1973, the Water Resources Council released *Principles and Standards* for water-resources development, which required that federal agencies take into account national and regional economic development, environmental quality, and social effects in their planning (USWRC, 1973).

A Change in Course

Although efforts were being made to broaden the basis for considering water projects, pressures on the federal

[3] Because floods are natural events that will continue to occur, flood control can only reduce the effects of floods on the population.

budget and a raft of studies about government inefficiency led to the tightening of federal standards for cost-benefit analyses and a focus on the economic component of analyses to the detriment of other factors. In 1981, the Reagan administration provided no funds for the Water Resources Council and abolished the river basin commissions. In place of *Principles and Standards*, the administration issued *Principles and Guidelines*, which stated that the "... Federal objective of water and related land resources project planning is *to contribute to national economic development* [emphasis added] consistent with protecting the Nation's environment" (USWRC, 1983).

In 1986, Congress and the administration greatly increased the cost-sharing requirement for states and localities requesting that federal water projects be built in their regions. Although this ensured that the local sponsors would be invested in the projects, it also gave local governments the right to have more say in how projects might be developed and to object to aspects of projects, such as environmental restoration, that they might see as meeting federal goals as opposed to local needs.

By the end of the 1980s, the water-resources share of the federal budget had been severely reduced. The USACE water budget had been cut nearly in half, and the Bureau of Reclamation had moved into an operations and maintenance mode. The net result of 30 years of focusing attention on economic benefit-cost analyses, cost-sharing, and the virtual elimination of comprehensive planning led to an almost exclusive focus on individual projects that met the national economic-development test.

Between 1965 and 2005, in the flood-control arena, levels of protection provided by new projects were designed less to protect against the large events envisioned in the 1930s than to provide the most favorable benefit-cost ratios; little consideration was given to the non-quantifiable social and human safety costs of the lack of protection.

Because new projects do not fully consider the environmental and social consequences of a lack of protection, most of them hover at the 1 percent (100-year) level of protection, the level that exempts those protected by the project from the mandatory purchase requirements of the National Flood Insurance Program. So as New Orleans and coastal Louisiana moved into the twenty-first century in search of a higher level of protection for area residents, they were up against a federal government operating on an ad hoc basis with no set standards.

In addition to the policy drought, there is a growing serious backlog of maintenance and upgrades of the nation's infrastructure, as is apparent from internal government reports. The American Society of Civil Engineers (ASCE), in its fifth *Report Card* on the condition of the nation's infrastructure that included water, gave the nation's infrastructure a grade of D (ASCE, 2005). The cost of addressing the backlog of maintenance and required upgrades, much of it water related, is more than $1.0 trillion. But the backlog has received little attention (or funding).

Since 1983, there has been no central direction or coordination of water-related activities.

Examining the Problem

The last comprehensive look at how we manage our water was undertaken in 1973 by a National Water Commission (NWC, 1973), and no major technical assessment of the status of water has been done since 1976. Flood-damage reduction programs were addressed in a 1994 study (Interagency Floodplain Management Review Committee, 1994), but little was done in response to the report. A recent report of the U.S. Commission on Ocean Policy (2004) has received similar treatment in Washington.

Since 1983, when the Water Resources Council was effectively abolished, there has been no central direction to or coordination of federal water efforts among the many departments that deal with water issues. Congress remains locked in a turf-conscious committee system that does not encourage coordination. Except for enforcing water quality standards, there is little federal guidance, other than budgetary or ad hoc initiatives, on other water issues.

Given the present policy vacuum and the reluctance on the part of Congress and the administration to support comprehensive planning, New Orleans and coastal Louisiana will have to develop, in coordination with federal agencies, their own vision for the future and move ahead in a way that brings together solutions to the many water challenges facing the region. This comprehensive plan must address all aspects of coastal Louisiana's water challenges.

- A flood-damage reduction strategy must be developed that provides a high level of protection for the people of New Orleans and key centers in the deltaic plain by building higher and stronger levees, constructing surge gates similar to the ones used on coastal Netherlands, and restoring the coastal wetlands that protect the region from hurricanes. The strategy must also consider land use along the coast and limits on redevelopment where occupancy might once again result in tragedy.
- The plan must take advantage of natural processes to reverse the receding coastline and restore coastal wetlands and the environmental vitality of this incredible natural resource.
- The overall plan must meet the needs for flood control and navigation while concurrently increasing the movement of sediments and fresh water from the Mississippi into wetland areas. A recent report by a committee of the National Research Council (2005) reviews plans for restoration and suggests ways the program might be improved.
- There must be a strategy to develop state and federal support to address the ongoing issues related to improving the water quality in the Mississippi, as well as local water quality in the delta.
- The comprehensive plan should include a review of the need for maintenance and upgrades to existing infrastructure for navigation, flood-damage reduction, environmental remediation, and water supply and treatment. It will be important that new work be integrated with structures that can survive well into the twenty-first century.
- An institutional structure should be developed, in partnership with the federal government, to prepare and oversee integrated plans and execute these activities, establish priorities, and develop innovative funding mechanisms.

A working group of scientists and engineers, many with close ties to coastal Louisiana, has recently reviewed the challenges faced by the region and recommended not only specific restoration activities, but also new approaches to ensure an integrated approach. The group has suggested the establishment of a Coastal Louisiana Authority to carry out the planning and supervision of the overall program (Working Group, 2006).

Avoiding Temptation

The temptation will be to fall back on previous experience and relationships and deal with the future development of the region as a series of individual, unrelated activities. However, if those responsible can use this time as an opportunity to demonstrate the efficacy of comprehensive planning, goal setting, and policy development, their efforts to deal with the plight of coastal Louisiana may provide a much-needed impetus for the country as a whole to move toward the development of truly national water policies.

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NAE News and Notes

NAE Newsmakers

Norman R. Augustine, retired chairman and CEO, Lockheed Martin Corporation, will receive the National Academy of Sciences (NAS) most prestigious award, the **Public Welfare Medal**, during the NAS Annual Meeting in April 2006. The medal is being awarded in honor of Dr. Augustine's "contributions to the vitality of science in the United States by bringing to industry and government a better understanding of the crucial role that fundamental scientific research must play in our long-term security and economic prosperity."

Zdeněk P. Bažant, McCormick Institute Professor and W.P. Murphy Professor of Civil Engineering and Materials Science at Northwestern University, was awarded the **Theodore von Kármán Medal** by the American Society of Civil Engineers (ASCE) in recognition of his distinguished achievement in engineering mechanics. Dr. Bažant was cited "for substantive contributions to the understanding and solution of a multitude of problems in engineering mechanics involving structural stability, behavior of concrete, and uncertainty and scale effects in materials and structures."

Eugene E. Covert, T. Wilson Professor of Aeronautics, Emeritus, Massachusetts Institute of Technology, is the recipient of the 2005 **Daniel Guggenheim Medal**. The medal will be presented by the American Institute of Aeronautics and Astronautics (AIAA) in Washington, D.C., on April 25, 2006. Dr. Covert will be honored "for exemplary leadership in aeronautics teaching and research, the development of state-of-the-art aerodynamic testing techniques, and outstanding public service."

Charles B. Duke, vice president and senior research fellow, Xerox Innovation Group, Wilson Center for Research and Technology, has been awarded the American Physical Society 2006 **George E. Pake Prize**. Granted annually, the Pake Prize honors individuals for their work combining original research and leadership in industrial research and development. Dr. Duke was cited for "groundbreaking theoretical contributions to the understanding of tunneling in solids and inelastic scattering of low-energy electrons in solids and for outstanding contributions to Xerox Corporate Research, both as an intellectual and a research manager."

Bonnie Dunbar, president and CEO, Seattle Museum of Flight, is this year's recipient of the **Society of Women Engineers (SWE) 2005 Achievement Award**. Dr. Dunbar is being recognized for her visionary contributions to ceramic tiles for the space shuttle and her biomedical research. "Dr. Dunbar's career is a testament to her incredible contributions and influence to the field of engineering," says Ronna Robertson, SWE president. "She has made huge advances in commercial and government aerospace research and development."

Liang-Shih Fan, Distinguished University Professor and C. John Easton Professor in Engineering at Ohio State University will be awarded the **E.V. Murphree Award in Industrial and Engineering Chemistry** for "pioneering contributions to fluidized bed technology." The award will be presented at the national meeting of the American Chemical Society in March 2006. He also received the **Joseph Sullivant Medal** (JSM) at the 2005 fall commencement of Ohio State University. JSM, the highest honor bestowed by the university upon one of its faculty members or alumni, is given once every five years in recognition of eminent achievement. Professor Fan was also elected to the **Mexican Academy of Sciences** in September 2005.

Edwin N. Lightfoot Jr., Emeritus Hilldale Professor of Chemical Engineering, Department of Chemical Engineering, University of Wisconsin, was one of eight individuals honored with the **2004 National Medal of Science**. Dr. Lightfoot was recognized for "vigorous and sustained leadership in biochemical and biomedical engineering, particularly in the areas of blood oxygenation, oxygen diffusion into tissue, mathematical modeling of biological reaction pathways, bioseparations, and studies of diabetic responses." The medal was presented to Dr. Lightfoot by President Bush in a ceremony on February 13, 2006.

Kurt E. Peterson, chief executive officer, SiTime, received the **Best of Small Tech Award for Lifetime Achievement** from *Small Times Magazine* for his more than 30 years as a founder, researcher, and entrepreneur in microelectromechanical systems (MEMS).

Dennis Ritchie, member of the technical staff, Lucent Technologies, has been awarded the 2005 **Industrial Research Institute Achievement Award**. The award is given for outstanding individual creativity and innovations that contribute to the development of industry and the benefit of society. Dr. Ritchie was cited for his "immeasurable impact on the computing world with the UNIX operating system and programming language inventions."

Al Romig Jr., senior vice president, deputy laboratories director, Integrated Technology Programs, Sandia National Laboratories, will receive the **National Materials Advancement Award** from the Federation of Materials Societies at a reception at the National Press Club in Washington, D.C., on December 7. The award is given to individuals who have advanced the use of materials and the multidisciplinary field of materials science and engineering generally and who have contributed to the application of materials science to national problems and policy.

Class of 2006 Elected

In February, NAE elected 76 new members and 9 new foreign associates, bringing the number of U.S. members to 2,216 and the number of foreign associates to 186. Election to NAE honors individuals who have made outstanding contributions to "engineering research, practice, or education, including . . . significant contributions to the engineering literature" and to "new and developing fields of technology, . . . major advancements in traditional fields of engineering, [and] innovative approaches to engineering education." A list of newly elected members and foreign associates follows, with primary affiliations at the time of election and brief descriptions of principal accomplishments.

New Members

Ilesanmi Adesida, interim dean, College of Engineering, University of Illinois, Urbana-Champaign. For contributions to the nanometer-scale processing of semiconductor structures and applications in high-performance electronic and optoelectronic devices.

Rakesh Agrawal, IBM Fellow and senior manager, IBM Almaden Research Center, San Jose, California. For the development of techniques for extracting information from very large databases.

Cristina H. Amon, Raymond J. Lane Distinguished Professor and director, Institute for Complex Engineered Systems, Carnegie Institute of Technology, Carnegie Mellon University, Pittsburgh, Pennsylvania. For advances in heat transfer and thermal design of portable electronics and for contributions to engineering education.

Mary Pikul Anderson, professor, Department of Geology and Geophysics, University of Wisconsin, Madison. For leadership in the development of groundwater-flow models.

Dimitri A. Antoniadis, Ray and Maria Stata Chair of Electrical Engineering, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge. For contributions to microelectronics in field-effect devices and for silicon process modeling.

R. Lyndon Arscott, management consultant, Danville, California. For making health, safety, environmental protection, and sustainable development higher priorities in the oil industry.

Gregory B. Baecher, professor of civil and environmental engineering, University of Maryland, College Park. For the development, explication, and implementation of probabilistic and reliability-based approaches to geotechnical and water-resources engineering.

Egon Balas, Thomas Lord University Professor of Operations Research, Department of Mathematical Sciences, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions to integer programming and its applications to the scheduling and planning of industrial facilities.

Mark A. Barteau, Robert L. Pigford Professor and chair, Department of Chemical Engineering, University of Delaware, Newark. For advancing the fundamental understanding of surface chemical-reaction mechanisms and for the design and invention of new catalysts.

Toby Berger, Irwin and Joan Jacobs Professor of Engineering, Cornell University, Ithaca, New York. For contributions to the theory and practice of lossy data compression.

Madan M. Bhasin, senior

scientist, Union Carbide Corporation, a subsidiary of Dow Chemical Company, South Charleston, West Virginia. For the development of efficient catalysts for the production of ethylene oxide and for contributions to the fundamental understanding of catalysts.

Manuel Blum, Bruce Nelson Professor of Computer Science, Computer Science Department, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions to abstract complexity theory, inductive inference, cryptographic protocols, and the theory and application of program checkers.

Samuel Wright Bodman, secretary of energy, U.S. Department of Energy, Washington, D.C. For leadership and innovation in materials science and technology and for outstanding cabinet-level service to the U.S. government.

William J. Boettinger, fellow, National Institute of Standards and Technology, Gaithersburg, Maryland. For the application of rigorous principles of thermodynamics and kinetics to the design and control of critical industrial materials and processes.

Adrian R. Chamberlain, manager, Parsons Brinckerhoff, Denver, Colorado. For innovations in the mobility, aesthetic, safety, and environmental aspects of transportation systems.

Josephine Cheng, IBM Fellow and vice president, IBM China Development Laboratories, Beijing. For sustained leadership and contributions to relational database technology and its applications to a wide range of digital operational systems.

W. Peter Cherry, chief analyst, Science Applications International Corporation, Vienna, Virginia. For contributions to national security through planning and operational analyses of military forces, systems, and force-employment concepts.

Archie R. Clemins, owner and president, Caribou Technologies Inc., Boise, Idaho. For the creation and initial fielding of the U.S. Navy's transformational use of information, which has enabled net-centric operations.

Danny Cohen, Distinguished Engineer, Sun Microsystems Inc., Menlo Park, California. For contributions to the advanced design, graphics, and real-time network protocols of computer systems.

Robert Paul Colwell, independent consultant, Portland, Oregon. For contributions to turning novel computer architecture concepts into viable, cutting-edge commercial processors.

Gary L. Cowger, vice president, Global Group, General Motors Corporation, Detroit, Michigan. For contributions to the development and implementation of systems and methods that have dramatically improved flexibility, quality, and productivity in automobile manufacturing.

Robert A. Dalrymple, Willard and Lillian Hackerman Professor of Civil Engineering, Department of Civil Engineering, Johns Hopkins University, Baltimore, Maryland. For contributions to theories and their application to coastal and ocean engineering.

L. Berkley Davis, chief engineer, Systems/Accessories, General Electric Company, Schenectady, New York. For innovations leading to the development and worldwide implementation of low-NO_X-emission gas turbines for electric-power generation.

Vijay K. Dhir, Distinguished Professor and dean, Henry Samueli School of Engineering and Applied Science, University of California, Los Angeles. For work on boiling heat transfer and contributions to nuclear reactor thermal hydraulics and safety.

Daniel W. Dobberpuhl, president and chief executive officer, P.A. Semi Inc., Menlo Park, California. For the innovative design and implementation of high-performance, low-power microprocessors.

Susan J. Eggers, Microsoft Professor of Computer Science and Engineering, University of Washington, Seattle. For contributions to the design and evaluation of advanced processor architectures.

Menachem Elimelech, Roberto C. Goizueta Professor of Environmental and Chemical Engineering, Yale University, New Haven, Connecticut. For contributions to the theory and practice of advanced filtration technologies for the treatment and reuse of potable water.

Richard G. Farmer, faculty research associate, Department of Electrical Engineering, Arizona State University, Tempe. For solving problems in the dynamic operation of electric power systems, including subsynchronous resonance and system stabilization.

Katharine G. Frase, vice president of technology, IBM Corporation, Somers, New York. For engineering contributions, inlcuding the use of lead-free materials and the development of other electronic packaging materials and processes.

Gary Harold Glover, professor of radiology and director, Radiological Sciences Laboratory, Stanford University, Stanford, California. For research and engineering in the development of computed tomography and magnetic resonance imaging.

David J. Goodman, professor of electrical and computer engineering, Polytechnic University, Brooklyn, New York. For contributions to the theory and practice of wireless communications and digital signal processing.

Leslie Greengard, professor of mathematics, Courant Institute of Mathematical Sciences, New York University, New York City. For work on the development of algorithms and software for fast multipole methods.

Michael D. Griffin, administrator, National Aeronautics and Space Administration, Washington, D.C. For technical leadership of the Delta 180/181/183 flight experiments that led to the first quantitative measurements of space intercept physics.

George M. Homsy, professor of mechanical and chemical engineering, University of California, Santa Barbara. For innovative experimental and theoretical studies of multiphase and interfacial flow phenomena and for the development of educational materials in fluid mechanics.

Davorin D. Hrovat, corporate technical specialist, Ford Research Laboratory, Dearborn, Michigan. For contributions to the development of automotive controls that have led to improvements in performance, comfort, and safety.

Stephen B. Jaffe, retired Distinguished Scientific Adviser, ExxonMobil Research and Engineering Company, Paulsboro, New Jersey. For the development of computer models describing complex petroleum-processing chemistry and kinetics and for contributions to the optimization of refining operations.

Frederick Jelinek, Julian Sinclair Smith Professor, Johns Hopkins University, Baltimore, Maryland. For contributions to statistical language processing with applications to automatic speech recognition.

M. Frans Kaashoek, professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge. For contributions to computer systems, distributed systems, and content-distribution networks.

Linda P.B. Katehi, dean of engineering, Purdue University, West Lafayette, Indiana. For contributions to three-dimensional integrated circuits and on-wafer packaging and to engineering education.

Pradeep K. Khosla, dean of engineering and Phillip and Marsha Dowd Professor, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions to design and sensor-based control in robotic systems for the assembly of high-precision electronics and for leadership in engineering education.

David B. Kirk, chief scientist, NVIDIA Corporation, Santa Clara, California. For work on high-performance graphics for personal computers.

Martin Klein, president, Martin Klein Consultants, Andover, Massachusetts. For the development of underwater imaging systems that have contributed to ocean exploration and the recovery of high-value objects.

Thomas L. Koch, Daniel E. '39 and Patricia Smith Chair and director, Center for Optical Technologies, Lehigh University, Bethlehem, Pennsylvania. For contributions to optoelectronic technologies and their implementation in optical communications systems.

Demetrious C. Koutsoftas, associate principal and Geotechnical Group leader, Ove Arup & Partners, San Francisco, California. For advancing the state of practice and for the innovative design of soft-ground engineering and deep foundations.

John M. Kulicki, chief executive officer, president, and chief engineer, Modjeski and Masters Inc., Harrisburg, Pennsylvania. For the design of major bridges and for leadership in the development of load- and resistance-factor design specifications.

Sau-Hai (Harvey) Lam, Edwin Wilsey '04 Professor Emeritus of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey. For contributions to aerospace engineering in the areas of plasma flows, combustion, turbulence, and adaptive controls.

James C.M. Li, professor, Department of Mechanical Engineering, University of Rochester, Rochester, New York. For contributions to micromechanics and mesoscopic mechanisms in materials and to the commercialization of amorphous metals.

John H. Linehan, vice president, Whitaker Foundation, Arlington, Virginia. For research on the pulmonary mechanics and metabolism of critical bioactive agents and for innovations in bioengineering education and professional development.

Verne L. (Larry) Lynn, consultant, Naples, Florida. For outstanding leadership and vision in the development and application of unmanned aerospace vehicles, sensors, and systems.

Krzysztof Aleksander Matyjaszewski, J.C. Warner Professor of Chemistry and director, Center for Macromolecular Engineering, Chemistry Department, Carnegie Mellon University, Pittsburgh, Pennsylvania. For expanding the capabilities of controlled/living polymerizations and developing ATRP, a robust catalytic process for the radical polymerization of monomers.

M. Douglas McIlroy, adjunct professor, Department of Computer Science, Dartmouth College, Hanover, New Hampshire. For fundamental contributions to the development of computer operating systems and programming languages.

Paul V. Mockapetris, chairman and chief scientist, Nominum Inc., Redwood City, California. For contributions to the Internet, including pioneering and standardizing the Domain Name System.

Albert F. Myers, corporate vice president, Strategy and Technology, Northrop Grumman Corporation, Los Angeles, California. For contributions to the fly-by-wire control system for NASA research aircraft and for leadership in the development of the flight-control system for the B-2 Stealth aircraft .

Devaraysamudram R. Nagaraj, research fellow, Cytec Industries Inc., Stamford, Connecticut. For contributions to the development and commercialization of novel reagents that have advanced the science of froth flotation.

Robert M. Oliver, chairman of the board, ANSER Corporation, Arlington, Virginia. For leadership in the development of financial engineering and for the application of operations research to public problems.

Roberto Padovani, executive vice president and chief technology officer, QUALCOMM Inc., San Diego, California. For innovations in wireless communication, particularly the evolution of CDMA for wireless broadband data.

Bernhard O. Palsson, professor, Department of Bioengineering, University of California, San Diego. For scholarship, technological advances, and entrepreneurial activities in metabolic engineering.

Jean-Yves Parlange, professor of biological and environmental engineering, Cornell University, Ithaca, New York. For fundamental contributions to the formulation of water flow and solute transport in soils and groundwater.

Arogyaswami Joseph Paulraj, professor of electrical engineering (research), Stanford University, Stanford, California. For contributions to the theory and practice of MIMO smart-antenna wireless technology.

Nicholas A. Peppas, Fletcher Stuckey Pratt Chair in Engineering, University of Texas, Austin. For contributions to the development of biomedical and drug-delivery applications of polymer networks and hydrogels.

Priyaranjan Prasad, Ford Technical Fellow and manager, Safety Research Department, Ford Research Laboratory, Dearborn, Michigan. For advances in automotive safety and impact biomechanics that have led to safer vehicles.

Lanny A. Robbins, research fellow, Dow Chemical Company, Midland, Michigan. For the development of novel commercial separation and purification processes for environmental control that have greatly improved the removal of trace impurities.

Hans Thomas Rossby, professor of oceanography, Graduate School of Oceanography, University of Rhode Island, Narragansett. For the development of deep-ocean instruments for ocean observing systems.

William S. Saric, professor of aerospace engineering, Texas A&M University, College Station. For contributions to the fundamental understanding and control of shear flow and boundary-layer transition.

Eric Schmidt, chairman of the Executive Committee and chief executive officer, Google Inc., Mountain View, California. For the development of strategies for the world's most successful Internet search engine company.

Ricardo B. Schwarz, fellow, Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico. For contributions to the fundamental understanding of the synthesis and behavior of metallic glasses.

Surendra P. Shah, Walter P. Murphy Professor, Department of Civil and Environmental Engineering, and director, Center for Advanced Cement-Based Materials, Northwestern University, Evanston, Illinois. For work on advanced cement-based materials and for promoting interdisciplinary research and education on concrete materials.

Alvy Ray Smith, consultant, Seattle, Washington. For the development of digital imaging, compositing, and painting that have led to fundamental changes in the graphic arts and motion picture industries.

Ching Wan Tang, Distinguished Research Fellow, Research and Development, Eastman Kodak Company, Rochester, New York. For the invention of the organic light-emitting device and organic bilayer solar cell, the bases of modern organic electronics.

Alan I. Taub, executive director, Research and Development, General Motors Corporation, Warren, Michigan. For contributions to the development of innovative electrical materials and automotive technologies and leadership in the globalization of automotive research.

Ali Galip Ulsoy, William Clay Ford Professor of Manufacturing, University of Michigan, Ann Arbor. For research on the dynamics and control of axially moving elastic materials and their implementation in automotive and manufacturing systems.

Vladimir N. Vapnik, fellow, NEC Laboratories America Inc., Princeton, New Jersey. For insights into the fundamental complexities of learning and for inventing practical and widely applied machine-learning algorithms.

Vaclav Vitek, professor, Materials Science and Engineering Department, University of Pennsylvania, Philadelphia. For work in the development of the atomistic modeling of crystalline solids and their application to materials engineering.

Tommy M. Warren, director, Casing Drilling Research, Testco Corporation, Houston, Texas. For pioneering inventions in drilling technology.

G. Paul Willhite, Ross H. Forney Distinguished Professor and chair; codirector, Tertiary Oil Recovery Project; and codirector, Kansas University Energy Research Center, University of Kansas, Lawrence. For research, technology, and education outreach in tertiary oil-recovery processes.

Dusan Zrnic, senior scientist, National Severe Storms Laboratory, Norman, Oklahoma. For the development of potent radar methods that have greatly improved operational weather detection and warning and advanced meteorological research.

New Foreign Associates

Charles Anthony Richard Hoare, senior researcher, Microsoft Research, Cambridge, United Kingdom. For fundamental contributions to computer science in the areas of algorithms, operating systems, and programming languages.

Evert Hoek, independent consulting engineer, North Vancouver, British Columbia, Canada. For major contributions to the development and application of rational design procedures for engineered systems in rock.

Jörg Imberger, professor of environmental engineering and chair, Centre for Water Research, University of Western Australia, Nedlands, Australia. For contributions to and international leadership in the environmental fluid dynamics of lakes, reservoirs, estuaries, and coastal seas.

Markus V. Pessa, professor and research director, Optoelectronics Research Centre, Tampere University of Technology, Tampere, Finland. For outstanding contributions to optoelectronic devices and for leadership in establishing new semiconductor industries in Finland.

Andrea Rinaldo, professor of civil engineering, University of Padova, Padova, Italy. For contributions toward the understanding of the structure and organization of river basins and hydrologic transport processes.

Man Mohan Sharma, Emeritus Professor of Eminence, Mumbai University Institute of Chemical Technology, Mumbai, India. For contributions in multiphase reactions leading to the rational design of reactive separations and leadership in the development of the Indian chemical industry.

Anthony P.F. Turner, head, Cranfield University, Silsoe, Bedfordshire, United Kingdom. For the development of technology for glucose sensors, environmental monitors, and synthetic recognition molecules.

Kuang-Di Xu, president, Chinese Academy of Engineering, Beijing. For contributions to the efficient manufacturing of quality steels with minimal environmental impact.

Miranda G.S. Yap, executive director and professor, Bioprocessing Technology Institute, Singapore. For outstanding achievements in education, research, and management in the field of mammalian cell culture.

Report of the Foreign Secretary

George Bugliarello

A number of noteworthy events have taken place since my last report. I am happy to report that NAE members have elected nine new Foreign Associates: one each from Australia, Canada, China, Finland, India, Italy, and Singapore, and two from the United Kingdom.

Before the holidays, President Wulf and I traveled to China for meetings at the Chinese Academy of Engineering (CAE) and Chinese Academy of Sciences (CAS) to discuss collaborative projects. President Wulf and CAE President **Xu Kuangdi** (a newly elected foreign associate) renewed the agreement for collaboration between our academies in a formal ceremony attended by CAE officers and staff. At CAS we met with Vice President Li, with whom we had a broad discussion, ranging from education to issues related to interdisciplinary research. We also met with the leadership and some distinguished faculty of Tsinghua University; we discussed issues of common interest in engineering education and research, as well as U.S. restrictions on foreign students. We then visited some of the university's impressive environmental engineering and networks laboratories and noted the enormous expansion of the campus. Later during our visit, NAE foreign associates Dr. **Song Jian** (former CAE president) and Dr. **Wang Dianzuo** (CAE vice president) hosted a dinner for a further exchange of views.

In December, Dr. Paula Dobriansky, deputy secretary of state; Dr. George Atkinson, science advisor to the secretary of state; and Anthony Rock, acting assistant secretary for the Bureau of Oceans and International Environmental and Scientific Affairs, met with the presidents and foreign secretaries of the National Academies, as well as other experts in international relations, to discuss areas of common interest and invite suggestions.

On December 11 and 12, the International Advisory Board to the Foreign Secretaries of the Academies held its semiannual meeting to advise the secretaries on future international activities. The December 12 meeting was devoted largely to presentations and discussions by speakers on three topics: zoonotic epidemics (the growing number of human infectious diseases from contacts between humans and animals), natural disasters, and the Academies' Rapid Urbanization Project (funded by the Moore Foundation).

NAE member **Jerome Rivard**, on behalf of NAE, worked with the U.S.-Mexico Foundation for Science (FUMEC) to organize a tri-national meeting on automotive electronics in Michigan and Windsor, Ontario. The meeting was held on November 28–December 2 (see p. 58).

George Bugliarello
Foreign Secretary

NAE Regional Meeting on Energy in the 21st Century

Trevor O. Jones, chairman and founder, BIOMEC Inc., and NAE member.

A National Academy of Engineering regional conference, "Energy: A 21st Century Perspective," hosted by Case Western Reserve University in Cleveland, Ohio, on June 2, 2005, drew more than 1,200 attendees from 17 states and the District of Columbia and seven countries, as well as 1,000 webcast viewers.

Steven Koonin, chief scientist, British Petroleum, and former provost at the California Institute of Technology, gave the keynote address, "Technological Aspects of Energy for the 21st Century." He noted that "Global energy demand is set to grow by over 60 percent over the next 30 years [with] 74 percent of the growth . . . anticipated to be in transitional economies and developing countries." Koonin concluded that: (1) "[h]ydrocarbons will continue to dominate transportation" with some improved efficiencies and emissions, but technical and economic hurdles will delay or prevent the adoption of hydrogen-fueled vehicles; (2) coal and gas will still provide most heat and power, although nuclear power will be a significant part of the mix, and renewable technologies will occupy a small niche; (3) demand will be reduced by economics or CO_2 policies, but (4) "CO_2 emissions (and concentrations) will continue to rise absent dramatic global action."

Subsequent speakers elaborated on the themes of Koonin's talk. Paul Portney, departing president of Resources for the Future, spoke on the profound implications (especially climate changes) of energy use by the United States and other world powers for local, regional, national, and, indeed, the global environment. In fact, he said, everything from run-of-the-mill economic issues to national security issues will be affected by energy policy.

Lawrence Papay, NAE member and retired sector vice president for integrated solutions, Science Applications International Corporation, concluded that nuclear power will be an essential and growing energy resource, especially in light of global climate change and restraints on carbon emissions. He also noted that policy changes concerning the reprocessing of spent nuclear fuel would mitigate the problems of nuclear fuel disposal.

Joan Ogden, co-director, Hydrogen Pathways Program, Institute of Transportation Studies, University of California, Davis, addressed the issue of a hydrogen economy. Although conversion to hydrogen would have major societal benefits, she said, the shift to hydrogen will require significant breakthroughs in technologies for fuel cells and storage, production, and distribution facilities, as well as changes in attitudes. She estimated it would take 25 years to make these changes.

Rodger McKain, president of SOFCo-EFS Holdings LLC and chairman of the Ohio Fuel Cell Coalition, predicted that, in the near term, fuel cells will be widely used for portable, stationary, and auxiliary power but will not be consequential for vehicle use for another 25 years.

Scott M. Klara, manager, Carbon Sequestration Program, and deputy director, Office of Coal and Power R&D, National Energy Technology Laboratory, presented a global perspective on carbon-based fuels. He argued that coal, the most plentiful resource both globally and in the United States, will remain an economical and environmentally compatible, stable source of energy. This will be possible, he said, because of clean coal technologies driven by regulations of CO_2 and other emissions and the need for new power plants in the next decade.

Samuel F. Baldwin, chief technology officer, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, described achievements to date and ongoing research in (1) energy efficiency in buildings, industry, and transportation and (2) renewable energy, such as biomass, wind, and solar sources.

The conference concluded with a speakers' panel moderated by Ira Flatow, host of NPR's "Science Friday" show. The majority of speakers agreed that both coal and nuclear power will be in our energy future. They also agreed that, until there is a crisis, our energy usage and policies are not likely to change.

The conference was cochaired by NAE members **Trevor O. Jones**, chairman and founder of BIOMEC Inc., and **Arthur H. Heuer**, Kyocera Professor of Ceramics, Case Western Reserve University. Organizational and program responsibilities were shared by NAE members **John C. Angus**, Professor Emeritus, Department of Chemical Engineering, and **P. Hunter Peckham**, professor of biomedical engineering, both of Case Western Reserve University.

Papers from the conference will be published in the September issue of *The Bridge* and on the NAE website. Additional information is available at: *http://www.energy05.org/index.html*.

Tri-national Meeting on Industrial Competitiveness in North America

Jerome G. Rivard, retired chief engineer, Ford Motor Company, and NAE member.

A meeting in Dearborn, Michigan, of the Mexican Academy of Engineering, the National Academy of Engineering, and the U.S.-Mexico Foundation for Science (FUMEC) focused on the future of North American competitiveness and steps to improve technical cooperation between Canada, Mexico, and the United States. After a general session on November 28, the group spent several days meeting with local universities, research institutes, and private companies to get a better understanding of their problems and to identify potential areas of cooperation.

The biggest problem facing the North American automotive industry is the decline in competitiveness of the "Big 3" automakers and their suppliers. Reasons for the decline in market share include decreasing technical competitiveness in engineering, design, and manufacturing; out-of-control labor costs; a corporate structure dominated by bureaucracy; and production overcapacity.

The group agreed that three major challenges must be addressed: (1) lack of awareness on the part of government of the problems facing the industry; (2) near-term thinking of investment bankers and stock market people who worry only about the next quarterly earnings; and (3) lower educational standards and the lack of motivation for young people to pursue careers in math, science, and engineering. Addressing these long-term, widespread problems will require strong leadership in government, industry, and academia, but change will not come easily, and the consequences to our society are likely to be severe.

The next phase of this tri-national initiative is to solidify an action plan. The group decided to focus its efforts on automotive electronics, an evolving technology that will have a huge impact on the global transportation industry. The first focus area will be on strengthening academic, industrial, and government research and development capabilities and recommending steps for collaborative, interdisciplinary projects. To explore the possibility of North American centers of excellence, some participants visited the Auto21 Program at the University of Windsor, Ontario, and the NSF WIMS (wireless integrated microsystems) Engineering Research Center at the University of Michigan.

A second focus of the action plan is to recommend changes in curricula and the teaching of the sciences, mathematics, and engineering. By focusing on improving education for the advancement of transportation electronics and recommending specific actions to align education and industry needs, the group hopes to come up with an approach that can be used as a model for change in other areas.

NAE member **Jerry Rivard** represented NAE in helping to organize the meeting and plan the program.

Christine Mirzayan Science and Technology Policy Graduate Fellows


Melissa Dupree


Nicole Ann Reynolds

Melissa Dupree (NAE/CASEE), who received a B.S. in materials engineering from Brown University, is currently completing a Ph.D. in bioengineering at the University of Pennsylvania. In her dissertation, which is focused on the development of a mathematical model describing the proliferative effect of fibroblast growth factor 2 on bone cells, she will attempt to evaluate and connect the kinetic, metabolic, and structural analyses published in the literature to actual whole-cell in vitro response. Throughout her college years, Melissa has been a tutor, instructor, and mentor in the arts and sciences through various organizations and the public schools. Her career goals are to be involved in the advancement of biological science and to encourage improvements in science and engineering education and funding. A passionate participant in the arts, Melissa was a choreographer and performer as an undergraduate and graduate student.

Nicole Ann Reynolds (NAE/CDEW) recently completed requirements to receive her M.S. in pharmacology and experimental therapeutics from Tufts University. Her thesis research was focused on the proteolytic cleavage of Pro-Cholecystokinin by Prohormone Convertase 5. She received her B.S. in biochemistry from University of Maryland-Baltimore County. Her hobbies include reading, taking dance classes, and going to the movies. Nicole is interested in science policy analysis and hopes that her fellowship will help her decide if science policy is the right career choice for her.

Call for Awards Nominations

Every year NAE salutes engineering leaders whose lifetime work has advanced the human condition or who have made innovative changes in engineering and technology education. For more than 40 years, NAE has recognized these outstanding engineers by awarding five prizes (Founders Award, Arthur M. Bueche Award, Charles Stark Draper Prize, Fritz J. and Dolores H. Russ Prize, and Bernard M. Gordon Prize) worth more than $1.5 million biennially. We invite you to participate in this tradition by nominating outstanding engineers for next year's awards.

NAE Awards

The *Founders Award* honors an NAE member or foreign associate who has exemplified the ideals and principles of NAE through professional, educational, and personal achievement and accomplishment. The *Arthur M. Bueche Award* is given to an engineer who has been actively involved in determining U.S. science and technology policy, promoting U.S. technological development, and improving relations among industry, government, and universities. The Founders and Bueche Awards are presented at the NAE Annual Meeting in October. Each recipient receives a gold medallion, a hand-lettered certificate, and a $2,500 cash prize.

The *Charles Stark Draper Prize* is awarded for innovation and reduction to practice of an advancement in engineering or technology that contributes to the welfare and freedom of humanity. The *Fritz J. and Dolores H. Russ Prize* recognizes a widespread engineering achievement that has contributed to the advancement of the human condition. The prize, which is currently focused on bioengineering, encourages collaborations between engineers and the medical and biological disciplines. The *Bernard M. Gordon Prize for Innovation in Engineering and Technology Education* honors educators whose innovative programs have contributed to the quality of the engineering workforce by cultivating leadership skills. The focus is on innovations in curricular design, teaching methods, and technology-enabled learning. The prize is shared equally between the recipient(s) and their institution. The Charles Stark Draper Prize and Bernard M. Gordon Prize are awarded annually, and the Fritz J. and Dolores H. Russ Prize is awarded biennially. The prizes, which include a $500,000 cash award, a gold medallion, and a hand-lettered certificate, are awarded during National Engineers Week at the NAE Annual Awards Dinner. Nominators of the winning recipients are invited to attend.

To Submit a Nomination

Nominations for the 2006 Founders and Bueche Awards and the 2007 Draper, Gordon, and Russ Prizes will be accepted through April 7, 2006. A list of previous recipients can be found on our website (*www.nae.edu/awards*). Members and foreign associates have received nomination materials by mail. Nonmembers may obtain materials from the NAE Awards Office at (202) 334-1628 or *awards@nae.edu* or downloaded from our website.

Nominations should be mailed or faxed to: NAE Awards, National Academy of Engineering, 500 Fifth Street, N.W. (#1010), Washington, DC 20001, Fax: (202) 334-2290.

Message from the Vice President and Chair of the Development Committee

Sheila E. Widnall

Source	2004	2005
Individuals*	$1,332,551	$1,843,781
Foundations	$438,000	$83,500
Corporations	$40,750	$1,343,173
Other	$63,138	$624,132
Total	**$1,874,439**	**$3,894,586**

*Includes deferred gifts

In this issue of *The Bridge*, we recognize the generous support of NAE members, friends, corporations, and foundations. The list of NAE members is notable—30.7 percent made donations during 2005. Total fundraising was also impressive. The chart compares sources of gifts for 2004 and 2005.

As member and corporate giving has increased, NAE has proportionately increased its public and program activities. Members have expressed their approval of this increased visibility and the establishment of independent programs that meet critical, national needs through their comments at the Annual Meeting, National Meeting, and regional meetings, as well as through calls and correspondence.

A recent example of NAE's direct impact on society is the Academies' report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, which influenced the American Competitiveness Initiative announced by President Bush in his State of the Union Address in January. The report offers integrated recommendations for creating, high-quality jobs in the United States based on the development of industries made possible by new technologies. The American Competitiveness Initiative commits $5.9 billion in FY 2007, and more than $136 billion over 10 years, to increase investments in research and development, improve education, and encourage entrepreneurship and innovation. The report was completed in less than six months and was paid for from unrestricted funds.

The impact of this report and NAE's increased visibility on critical issues—supported largely by members' contributions—can contribute to America's economic strength and global leadership by supporting continued technological innovation and ultimately improving the lives and livelihoods of generations of Americans to come.

Much of NAE's current work—identifying, analyzing, and reporting on emerging technological issues, promoting technological literacy, encouraging diversity in the engineering workforce, supporting reform in engineering education—is only possible with support from private donors. In 2006, NAE will continue making special requests to members (through the Annual Fund) to donate to the independent, unrestricted fund.

Clearly, NAE members have so far risen to the challenge. On behalf of the NAE officers, councillors, and staff, thank you!

Sincerely,

Sheila E Widnall

Sheila Widnall
NAE Vice President
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The National Academy of Engineering gratefully acknowledges the following members and friends who made charitable contributions during 2005. Their collective, private philanthropy helps to advance NAE's service and impact as advisor to our nation.

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Calendar of Meetings and Events

March 3–4	Indo-U.S. Frontiers of Engineering Symposium Agra, India
March 14	NRC Executive Committee Meeting
April 6	NAE Regional Meeting University of Michigan
April 11	NRC Executive Committee Meeting
April 19	NAE Regional Meeting University of California, Santa Barbara
April 20	NAE Regional Meeting University of California, Berkeley
April 27	NAE Regional Meeting University of Virginia, Charlottesville
May 4–6	German American Frontiers of Engineering Symposium Murray Hill, New Jersey
May 9–10	NRC Governing Board Meeting
May 11–12	NAE Council Meeting Charlottesville, Virginia

All meetings are held in the National Academies buildings, Washington, D.C., unless otherwise noted. For information about regional meetings, contact Sonja Atkinson at *satkinso@nae.edu* or (202) 334-3677.

In Memoriam

RUTHERFORD ARIS, 76, Regents Professor Emeritus, Department of Chemical Engineering and Materials Science, University of Minnesota, died on November 2, 2005. Dr. Aris was elected to NAE in 1975 for contributions to the literature of chemical engineering on control theory and optimization and on the theory of reaction and diffusion.

WILLIAM O. BAKER, 90, retired chairman, Bell Laboratories, Lucent Technologies, died on October 31, 2005. Dr. Baker was elected to NAE in 1975 for contributions leading to the use of synthetic polymers in communications equipment, synthetic rubber, ablation heat shields, and rocket propellants.

JAMES B. COULTER, 85, retired secretary, Maryland Department of Natural Resources, and retired engineering director, U.S. Public Health Service, died on September 9, 2005. Mr. Coulter was elected to NAE in 1988 for contributions to the planning, design, and management of environmental resources systems.

KENNETH W. HAMMING, 87, retired senior partner, Sargent and Lundy, died on December 21, 2005. Mr. Hamming was elected to NAE in 1974 for leadership in the design of large-scale fossil-fuel and nuclear power plants.

HEINZ HEINEMANN, 92, Distinguished Scientist, D.C. Projects Office, E.O. Lawrence Berkeley National Laboratory, died on November 23, 2005. Dr. Heinemann was elected to NAE in 1976 for the conception and development of new petroleum processes and contributions to the advancement of catalysis.

EMMETT M. LEITH, 78, professor of electrical and computer engineering, University of Michigan, died on December 23, 2005. Dr. Leith was elected to NAE in 1982 for contributions to holography and to the field of optical data processing.

T.Y. LIN, 91, chairman, Lin Tung-Yen China, died on November 15, 2003. Dr. Lin was elected to NAE in 1967 for contributions to the theory and use of prestressed concrete.

BRUCE T. LUNDIN, 86, retired director, NASA Lewis Research Center, died on January 24, 2006. Dr. Lundin was elected to NAE in 1976 for leadership in aeronautical propulsion research and the development of launch vehicles.

JOSEPH B. MOORE, 79, retired director, Materials Engineering, Pratt and Whitney-United Technologies Corporation, died on January 7, 2006. Mr. Moore was elected to NAE in 1986 for contributions to the technology of rapid solidification and to the development of materials for gas-turbine engines.

NATHAN E. PROMISEL, 97, retired executive director, National Materials Advisory Board, National Research Council, and retired engineering consultant, died on December 15, 2005. Dr. Promisel was elected to NAE in 1978 for his leadership in materials development for aircraft and national materials policy.

RONALD S. RIVLIN, 90, Professor Emeritus, Lehigh University, died on October 4, 2005. Dr. Rivlin was elected to NAE in 1985 for formulating the large deformation elasticity theory and for verifying and applying the theory extensively to general nonlinear continua in the areas of viscoelasticities, electromagnetics, and thermodynamics.

ROBERT M. SNEIDER, 76, president, Robert M. Sneider Exploration Inc., died on October 29, 2005. Dr. Sneider was elected to NAE in 2000 for teaching and demonstrating the importance of synergistic geological, geophysical, and engineering in the exploration and development of hydrocarbon accumulations.

GEORGE E. SOLOMON, 79, retired executive vice president and general manager, TRW Electronics and Defense Sector, died on April 25, 2005. Dr. Solomon was elected to NAE in 1967 for contributions to the design and development of space and weapon systems.

DAVID TABOR, 92, Professor Emeritus of Physics, Cavendish Laboratory, Cambridge University, died on November 26, 2005. Professor Tabor was elected to NAE as a foreign associate in 1995 for contributions to the theory of tribology, hardness, and surface physics.

GERALD F. TAPE, 90, retired president, Associated Universities Inc., died on November 20, 2005. Dr. Tape was elected to NAE in 1986 for distinguished leadership in the national and international development and control of nuclear energy.

ALAN M. VOORHEES, 83, chairman of the board, Summit Enterprises Inc., died on December 17, 2005. Mr. Voorhees was elected to NAE in 2000 for the discovery and application of quantitative relationships between urban land uses and traffic flows.

JOHN V. WEHAUSEN, 92, Professor Emeritus of Engineering Science, Department of Naval Architecture and Offshore Engineering, University of California, Berkeley, died on October 6, 2005. Dr. Wehausen was elected to NAE in 1980 for using applied mathematics to solve engineering problems in ship design.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2005 Symposium. This proceedings volume from the 2005 U.S. Frontiers of Engineering Symposium includes the 14 papers that were presented at the symposium, as well as the dinner speech by **Shirley Ann Jackson**, president of Rensselaer Polytechnic Institute and NAE member. The papers cover topics in the areas of identification and verification technologies, engineering for developing communities, engineering complex systems, and energy resources for the future.

NAE member **Pablo G. Debenedetti**, Class of 1950 Professor in Engineering and Applied Science, Princeton University, chaired the organizing committee. Paper, $42.25.

Public Water Supply Distribution Systems: Assessing and Reducing Risks: First Report. This is the first of two reports on water quality issues associated with public distribution systems and their potential risks to consumers. Distribution systems, which are critical components of drinking water utilities, present significant operational and public health challenges. This first report was requested by the Environmental Protection Agency (EPA), which is considering revising the Total Coliform Rule to ensure the integrity of water distribution systems. The report identifies trends in the deterioration of drinking water quality in distribution systems and prioritizes the issues of concern. The study committee reviewed nine EPA white papers and identified (1) cross connections and backflow, (2) new or repaired water mains, and (3) finished water storage facilities as the highest priority issues based on their associated health risks. The committee also noted that premise plumbing and the training of distribution system operators should be given a high priority. The second report, a comprehensive evaluation of approaches to risk characterization and strategies for reducing risks posed by water-quality deteriorating events, will be published in about 18 months.

NAE member **Vernon L. Snoeyink**, Professor of Environmental Engineering Emeritus, University of Illinois, chaired the study committee. Paper, $18.00.

Managing Construction and Infrastructure in the 21st Century Bureau of Reclamation. Since the Bureau of Reclamation of the U.S. Department of Interior was formed more than 100 years ago, it has brought water, electricity, and recreational facilities to millions of people in the western United States. Attention has now been turned to the operation, maintenance, repair, and modernization of those facilities. Faced with the growing demand for water, increasing environmental concerns, rising maintenance and repair costs, congressional demands for accountability, increasing social concerns, and an aging workforce, the Bureau must reassess its activities and show that its actions are environmentally and economically sound. This report provides an assessment of the challenges to the Bureau, an analysis of good practices for meeting those challenges, and a review of workforce and human resource needs. The report also provides alternative organizational scenarios for the future.

NAE member **James K. Mitchell**, University Distinguished Professor Emeritus, Virginia Polytechnic Institute and State University, chaired the study committee, and **Lloyd A. Duscha**, retired deputy director of engineering and construction, U.S. Army Corps of Engineers, was a member of the study committee. Paper, $33.00.

Interim Design Assessment for the Blue Grass Chemical Agent Destruction Pilot Plant. Because of public concerns about the incineration of hazardous materials, the U.S. Department of Defense (DOD) plans to use alternative means to destroy the chemical agent stockpiles at the Pueblo and Blue Grass facilities. DOD contracted with Bechtel Parsons to design and operate pilot plants to demonstrate alternative technologies. The National Academies was asked to review and assess Bechtel's designs for both plants. This report provides a review of the Blue Grass Chemical Agent Destruction Pilot Plant based on a review of data and information about the initial design and some intermediate design data. Among other topics, the report addresses technical risk assessment, analyzes delivery and disassembly operations and agent destruction core processes, and examines the plans for treating waste.

NAE members **Harold K. Forsen**, retired senior vice president, Bechtel Corporation, and **Kenneth A. Smith**, Edwin R. Gilliland Professor of Chemical Engineering, Massachusetts Institute of Technology, were members of the study committee. Paper, $18.00.

Sustainability in the Chemical Industry: Grand Challenges and Research Needs—A Workshop Report. Through the innovative design, creation, processing, use, and disposal of substances, the chemical industry can play a major role in advancing sustainability in a way that will enable current environmental, economic, and societal needs to be met without compromising the progress and success of future generations. Based on a workshop held in February 2005 that brought together representatives of a broad cross section of disciplines and organizations in the chemical industry, this report identifies overarching "grand challenges" for sustainability research in chemistry and chemical engineering to help the chemical industry define a sustainability agenda. The grand challenges include life-cycle analysis, renewable chemical feedstocks, and education.

NAE member **James A. Trainham III**, vice president, science and technology, PPG Industries Inc., chaired the study committee. Paper, $38.00.

Polar Icebreaker Roles and U.S. Future Needs: A Preliminary Assessment. The advanced age and deteriorating condition of the U.S. Coast Guard's polar icebreakers are jeopardizing national security and scientific research in the Arctic and Antarctic. Because of a shortfall in funding, long-term maintenance on icebreakers has been deferred for several years, making the ships inefficient and rendering their technological systems outdated. Congress asked the National Academies to provide a comprehensive assessment of the role of U.S. Coast Guard polar icebreakers in U.S. operations in the Antarctic and the Arctic and to recommend ways to continue those operations, as well as alternative approaches. This brief interim report highlights the most urgent and time-dependent issues. A final report is expected to be released in summer 2006.

NAE member **Anita K. Jones**, Lawrence R. Quarles Professor of Engineering and Applied Science, University of Virginia, chaired the study committee. Paper, $18.00.

Water Resources Planning for the Upper Mississippi River and Illinois Waterway. The U.S. Army Corps of Engineers (USACE) recently completed a feasibility study for the Upper Mississippi River-Illinois Waterway, one of the longest and most complicated studies in its history. The first two reports by this National Research Council (NRC) Water Science and Technology Board committee reviewed analytical aspects of the feasibility study. This report addresses the broader issue of managing the multiple resources of the Upper Mississippi River and Illinois Waterway in light of several, recently issued NRC reports on USACE planning procedures. The committee finds that a key problem is the ambiguity of several pieces of legislation that govern river management and recommends that the administration and Congress clarify the federal intent for management of this river and waterway system. The report also recommends (1) that an independent, retrospective review be conducted of the work of the federal Interagency Principals Group, which was established to provide guidance for the USACE study, and (2) that USACE strive to incorporate flexible, adaptive management principles throughout its water planning program, including planning operations of the lock and dam system.

NAE members **Gerald E. Galloway Jr.**, Glenn L. Martin Institute Professor of Engineering, University of Maryland, College Park, and **Soroosh Sorooshian**, UCI Distinguished Professor and director, Center for Hydrometeorology and Remote Sensing, University of California, Irvine, were members of the study committee. Paper, $12.00.

Tank Wastes Planned for On-Site Disposal at Three Department of Energy Sites: The Savannah River Site—Interim Report. In response to a request from Congress, the U.S. Department of Energy (DOE) asked the National Academies to evaluate plans for managing radioactive wastes from spent nuclear fuel at sites in Idaho, South Carolina, and Washington. This interim report evaluates storage facilities at the Savannah River site in South Carolina, with a particular focus on DOE's plans to seal the tanks with grouting. The report finds that the tanks do not necessarily have to be sealed shut as soon as the bulk of the waste has been removed. Postponing permanent closure would allow more time for the development and application of emerging technologies for removing and immobilizing residual waste, without increasing risks to the environment or delaying final closure of the "tank farms." The report also recommends alternative strategies for addressing the lack of tank space at the site, focused research and development activities to reduce the amount and improve the immobilization of residual waste in the tanks, and testing of some of the assumptions used in evaluating long-term risks.

NAE member **Frank L. Parker**, Distinguished Professor of Environmental and Water Resources Engineering, Vanderbilt University, chaired the study committee. Other NAE members on the study committee were **Hadi A. Abu-Akeel**, senior vice president and chief engineer (retired) and technical advisor, FANUC Robotics America Inc., and **Milton Levenson**, consultant and retired vice president, Bechtel International. Paper, $18.00.

An International Perspective on Advancing Technologies and Strategies for Managing Dual-Use Risks: Report of a Workshop. This National Research Council/Institute of Medicine report provides a summary of a workshop sponsored by the Committee on Advances in Technology and the Prevention of Their Application to Next Generation Biowarfare Threats. The purpose of the workshop was to gather information about global perspectives on current advances in technology. Experts from around the world were asked to present "snapshots" of the current global science and technology landscape, the forces driving globalization and technology transfer, and new capabilities that may emerge from globalization, particularly the generation and application of dual-use knowledge in the life sciences. The information summarized in these five "snapshots" is the basis for a consensus study on the subject that will be released in 2006.

NAE member **C. Kumar N. Patel**, chairman, Pranalytica Inc., was a member of the study committee. Paper, $33.50.

Linkages: Manufacturing Trends in Electronics Interconnection Technology. In the past two decades, the U.S. Department of Defense (DOD) has been moving toward commercial-military integration in manufacturing. At the same time, the printed circuit board (PrCB) industry has been moving steadily off shore. To help DOD promote understanding of the importance of high-quality, trustworthy PrCBs for weapons and other defense systems, DOD requested that the National Academies conduct a study to identify and assess key issues affecting PrCBs for military use. This report includes a discussion of how DOD can ensure continued access to reliable PrCBs; an assessment of DOD's vulnerability to the global PrCB supply chain; and suggestions for securing the design and manufacture of PrCBs. With reasonable cost constraints and evolving environmental regulations in mind, the recommendations focus on helping DOD (1) preserve existing system capabilities, (2) increase access to currently available PrCBs, and (3) ensure access to future PrCB technology.

NAE member **Dennis F. Wilkie**, retired chief of staff, IESS, Motorola Corporation, was a member of the study committee. Paper, $18.00.

An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Years 2004–2005. The National Institute of Standards and Technology (NIST) Measurements and Standards Laboratories (MSL) provide technical leadership in measurement and standards infrastructure and ensure the availability of essential reference data and measurement capabilities. At NIST's request, the National Research Council conducts biennial assessments of the technical quality, merit, and effectiveness of the seven MSL laboratories. The assessments also evaluate the relevance of each program and how well facilities, equipment, and personnel are configured to fulfill its mission. This report includes an overall assessment of MSL and detailed assessments of the seven laboratories.

NAE member **Kenneth H. Keller**, Charles M. Denny Jr. Professor of Science, Technology and Public Policy, University of Minnesota, chaired the study committee. NAE member **Eugene Sevin**, independent consultant, Lyndhurst, Ohio, was a committee member. Paper, $33.00.

Superfund and Mining Megasites: Lessons from the Coeur d'Alene River Basin. The Coeur d'Alene River Basin has long been one of the most productive silver, lead, and zinc mining areas in the United States. Over time, high levels of metals (including lead, arsenic, cadmium, and zinc) have accumulated in the local environment, and elevated levels of lead have been found in the blood of children in communities near the metal-refining and smelter complex. In 1983, the Environmental Protection Agency (EPA) listed a 21-square mile area in northern Idaho as a Superfund site; in 1998, EPA extended the boundaries of the site to include other areas in the 1,500-square mile Coeur d'Alene River Basin. The first phase of EPA's plan to clean up the contaminated area will cost an estimated $359 million over a period of 30 years. In this report, an independent committee of experts concludes that the scientific and technical practices used by EPA to make decisions about human health risks at the Coeur d'Alene River Basin Superfund site are generally sound. However, the committee has substantial concerns about long-term plans for environmental protection.

NAE member **Corale Brierley**, principal, Brierley Consultancy LLC, was a member of the study committee. Paper, $75.00.

Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report. In response to a request from Congress, the Nuclear Regulatory Commission and the U.S. Department of Homeland Security sponsored a National Academies study to assess the safety and security risks of spent nuclear fuel stored in cooling pools and dry casks at commercial nuclear power plants. In this unclassified public summary of a more detailed, classified report, a committee of experts explores the probability of terrorists using spent fuel for a radiological dispersal device and concludes that attacks on spent fuel pools would be difficult but not impossible. A fire in a pool, for example, could release large amounts of radioactive material. However, rearranging spent fuel in the pool during storage and providing emergency water spray systems would reduce the likelihood of a propagating fire, even if the pool were severely damaged. Dry casks have advantages over cooling pools, but pools are necessary at all operating nuclear power plants to store recently discharged fuel. The committee concludes that it would be difficult for terrorists to steal enough spent fuel to construct a significant radiological dispersal device but suggests that additional studies be conducted.

NAE member **Louis J. Lanzerotti**, Distinguished Professor for Solar-Terrestrial Research, New Jersey Institute of Technology, chaired the study committee. NAE members **Robert P. Kennedy**, consulting engineer, RPK Structural Mechanics Consulting; **Richard T. Lahey Jr.**, Edward E. Hood Professor of Engineering, Rensselaer Polytechnic Institute; **Frederick J. Moody**, independent consultant; and **Loring A. Wyllie Jr.**, senior principal, Degenkolb Engineers, were members of the committee. Paper, $30.00.

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