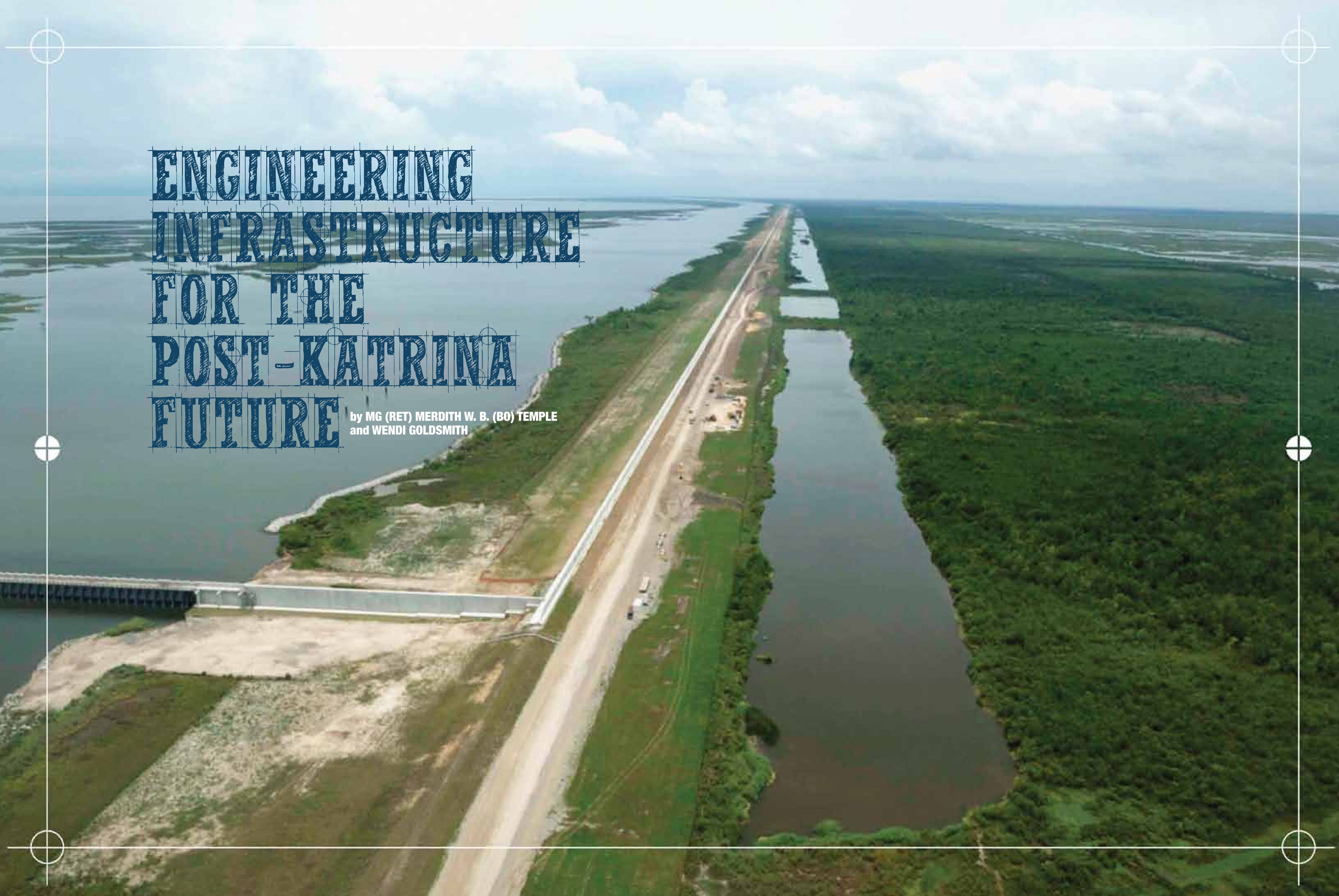
ENGINEERING INFRASTRUCTURE FOR THE POST-KATRINA FUTURE

by MG (RET) MERDITH W. B. (BO) TEMPLE
and WENDI GOLDSMITH



TWO LEADERS OF THE POST-KATRINA HURRICANE STORM DAMAGE RISK REDUCTION SYSTEM *share insights on why and how the massive program was able to embrace innovation, defy convention, and achieve unprecedented success. The former Acting Commanding General of the U.S. Army Corps of Engineers and Managing Member of the Joint Venture each played substantial roles in facilitating the process of creative problem-solving and programmatic change that enabled the project to forge a new standard in climate change adaptation and resilience. Here, these two individuals share insight into the project's success and also outline additional efforts that, although not adopted at the time, should be evaluated as standard program elements for future similar infrastructure systems. Heeding the lessons learned in New Orleans along with further modifications on future projects could take our national infrastructure to a new level of sustainability, relevance, and value even during challenging financial times.*

After Hurricane Katrina devastated the New Orleans area in 2005, Congress appropriated more than $14 billion to provide an infrastructure system capable of addressing risk from future flooding and charged the U.S. Army Corps of Engineers (USACE) with executing the program. The many innovations born through the design and construction for this massive effort represent a significant departure from prior conventions about engineering and project execution for civil works projects. As a result, the program was completed in a fraction of the normal time, allowing communities, families, and businesses to make practical decisions about relocating or reinvesting locally. Where pain and loss had taken hold of a community, collaboration and a restored sense of worth emerged ahead.

The countless lessons learned throughout this massive undertaking can improve future design and construction programs—including lessons derived from methods and approaches that were considered but not incorporated. Future large-scale infrastructure projects are unlikely to receive similar federal funding levels; nevertheless, they can benefit from methods that streamline planning, engineering, and construction while providing for cost-effective maintenance programs. Projects that offset portions of their construction or maintenance costs, along with reducing overall environmental impacts and improving community resilience will be compared favorably over those that merely perform one function at significant taxpayer cost. Especially for communities grappling with the looming risks of climate change and ever-increasing flood concerns, a new fusion of science, engineering, construction, and financing will be necessary to develop infrastructure projects that make business sense today and tomorrow.

CLIMATE RISKS INFORM DESIGN

From the outset of the project, a fresh way of thinking was needed. This new paradigm involved novel procedures in analysis and design, expanded patterns of communication, and many technical and administrative innovations that allowed the project to compress the execution schedule from decades to four very busy years. The team at the newly established USACE Hurricane Protection Office in New Orleans quickly reinvented and more tightly defined the terminology of their efforts: The program became known as the Hurricane Storm Damage Risk Reduction System (HSDRRS).

What may seem a superficial fascination with words deserves deeper focus. The design team and the public needed to be straight on the fact that "protection" implies certainty. All parties needed to closely address the key areas of uncertainty and residual risk—without which key considerations could be missed. It would be fair to say that through the history of large infrastructure programs, engineers have relied on data from past conditions (such as precipitation, flood elevations, and terrain elevations) to inform analysis and design. In this sense, engineering has normally been done "looking in the rear view mirror." While this practice is considered standard and is consistent with academic training, professional practice, and organizational custom, for many types of projects, it should be called into question—as it was for HSDRRS. The combination of forensic studies, institutional scrutiny and reform, and future risk scenario development that USACE took into account drove the adoption of many new and improved practices. Though not always comfortable along the way, this forward-looking approach offers great value to many projects, and arguably is the appropriate way to address climate adaptation and resilience for the many communities in the United States and elsewhere that remain vulnerable to significant loss of life and property.

Many weighty implications arise during risk-based engineering to address future conditions related to climate change and other factors that contribute to hazards. Recognizing that Congress had mandated the development of an infrastructure system that would shield New Orleans and the surrounding parishes from a 100-year storm, the team had to sort out the many consequences of that definition. For instance, what was the expected service life of the infrastructure system, and how might the basis of design change over time due to land subsidence, sea level rise, and increased storm intensity among other factors? Land subsidence was understood to have caused locations of levee overtopping when Katrina struck. These findings led to profound change in USACE practices going forward. Nationally, precipitation patterns were recognized to be going through statistically significant patterns of change, yet it remained customary to rely on historic data for analysis and design. For HSDRRS, a team of the top U.S. and international scientists evaluated the best current science in order to develop scenarios and computer-simulated models, spearheaded by the U.S. Army Corps of Engineers Engineer Research and Development Center,

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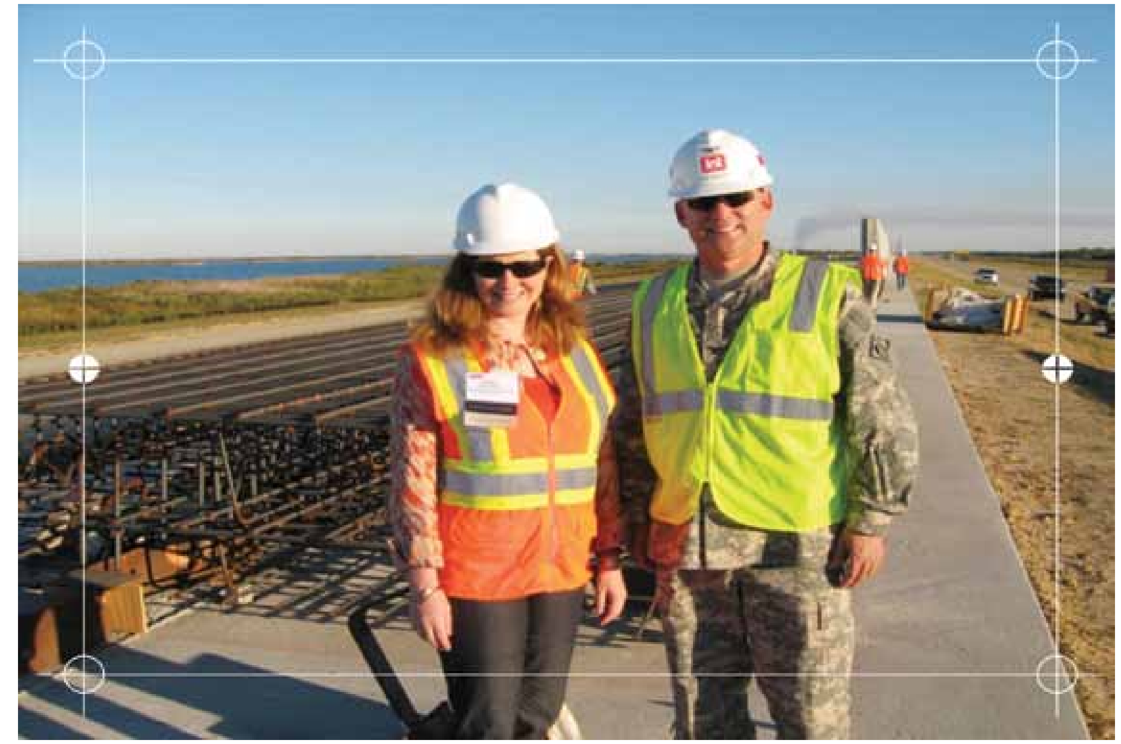


TITLE SPREAD: *Looking south along the Chalmette Loop Levee from its connection to the Lake Borgne Surge Barrier.* USACE PHOTO

LEFT: *Wendi Goldsmith and COL Bob Sinkler visit the site during segmented construction of rebar and concrete.* USACE PHOTO

BELOW: *Tons of steel reinforce the wall segments and secure them to driven steel H-piles up to 150-ft long.* USACE PHOTO based on rain, wind, air pressure, sea level rise, and land subsidence in order to forecast the possible depths of future storm surge and forces of waves at locations throughout the region. These forecasts, rather than past data, were used to develop design criteria that supported the idea of reliable infrastructure performance throughout the 50-year service life of the system, and led to design elevations up to 15-ft higher than existing structures.

ACCELERATED DESIGN OF LEVEES, FLOODWALLS, AND RELATED STRUCTURES

One place within HSDRRS where the forecasted conditions were most extreme was the Chalmette Loop Levee in St. Bernard Parish. Part of the Lake Pontchartrain and Vicinity System, the Chalmette Loop Levee consisted of 23-mi of levee and floodwall, including sector gates, highway and railroad closure gates, and a pumping station. USACE retained Bioengineering ARCADIS LLC, a small business joint venture, to provide key planning, engineering, and construction management roles for this project. The team performed field inspections of the existing levee systems to identify areas of potential concern, developed alternative studies, and evaluated innovative designs and delivery methods. In addition to working with multiple USACE districts on design coordination for all project components, the team also collaborated with contractors and local and state sponsors as well as USACE on construction and sequence methods under the Early Contractor Involvement (ECI) building approach for several reaches.

When the existing earthen levee was overtopped and breached by Katrina's storm surge, more than 90 percent of structures in St. Bernard Parish were flooded. The team confronted a litany of obstacles in working to raise the system by the required 10- to 15-ft, including North America's weakest deep organic soils, remote rural locations, adjacent channels and lakes, limited site access, constraints of cost and schedule, as well as some of the region's highest estimated wave loads based on USACE's in-house hydraulic modeling. Various engineering solutions were considered to enlarge or strengthen the earthen levees including deep soil mixing, stability berms, high strength geotextile fabric, and wick drains. Ultimately, given cost and schedule constraints, the team selected the structural option of T-walls constructed on top of existing levees due to the minimal footprint required which simplified environmental and right-of-way considerations. However, designing these walls with enough resilience to withstand the required loads and site effects created substantial design challenges. Proper consideration of potential future conditions led to extreme factors related to seepage, scour, breaking wave forces, and also slamming forces derived from impacts from barges carried by waves.

The speed and magnitude of these projects was staggering—miles of wall, two sector gate structures, pumping station fronting protection, and closure gates had to be incorporated throughout the system, and nearly 20 major utility or gas lines needed to be relocated. Much of the design was completed within a year and vetted through numerous reviews to ensure independent verification. The design and construction management team literally worked shoulder to shoulder with multiple USACE districts throughout the process, being co-located in the same office space. Key decision-makers met regularly to discuss progress and design issues, changing the historical USACE design process as the team united to meet the June 2011 completion target. This unprecedented teamwork yielded extraordinary results in quality, schedule, cost control, and efficiency.

ECI PROCESS ENHANCED CONSTRUCTABILITY AND SPEED

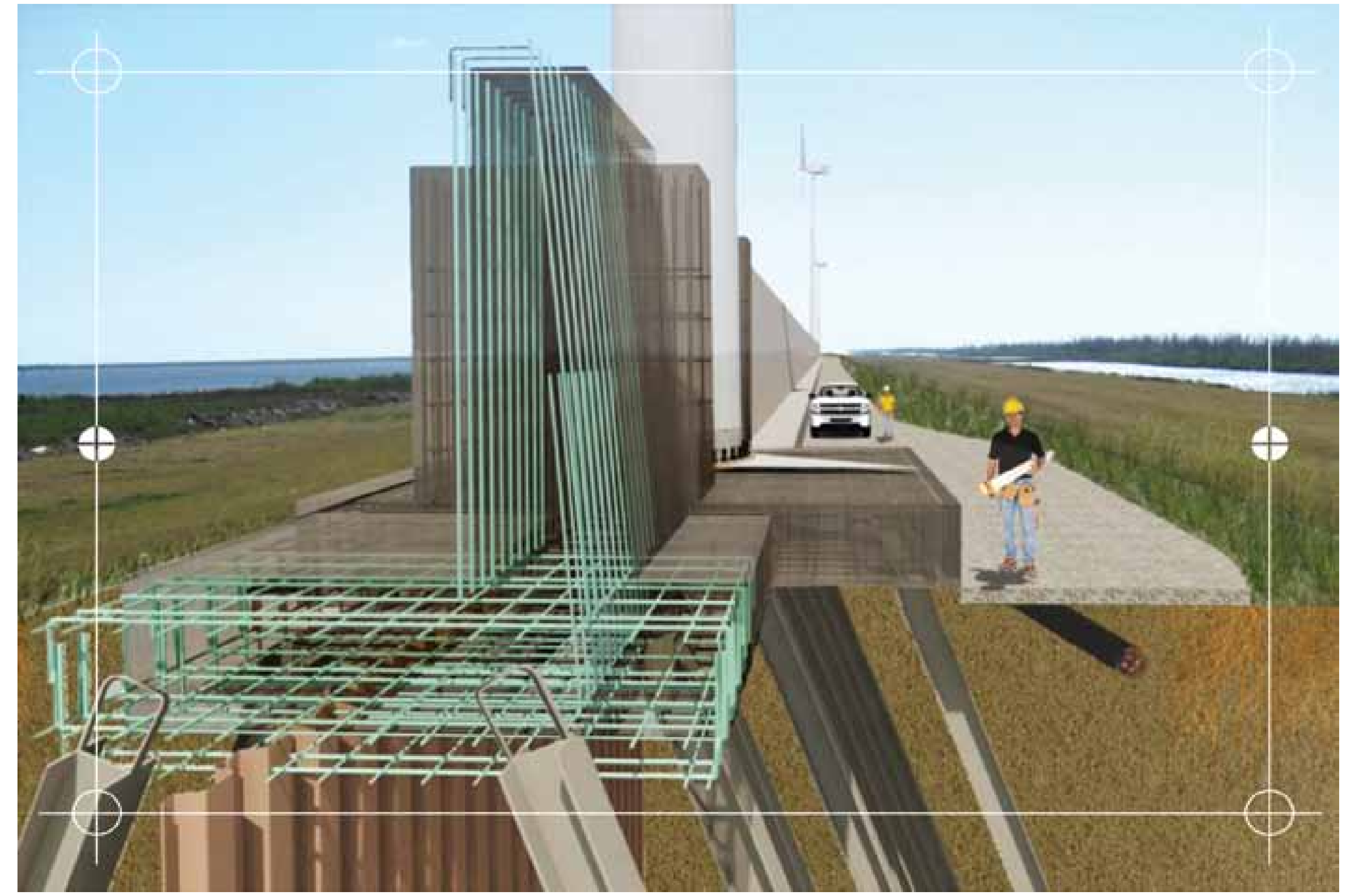
The design of the main levee reaches incorporated the ECI process for the first time in a major civil works project. USACE selected the contractors and brought them on board during the design phase to provide critical input to improve the cost and delivery. Working closely with designers, contractors developed recommendations such as wall monolith length and pile types. They also devised the method of constructing wall footings above the levee crest, rather than embedded, which enhanced efficiency and constructability of the designs and helped meet the accelerated construction schedule.

In early 2010, multiple contractors converged in the parish to tackle issues including site access, equipment, labor, housing, and proximity to other projects, with materials delivered by truck and barge. The project team provided Engineering During Construction (EDC) as well as Construction Management services. The EDC team reviewed shop drawings, contractor submittals, responded to requests for information, and performed site visits to help ensure adherence to design. Each reach had multiple headings underway with several crews for sheet pile, pile driving, reinforcement, and forming activities—at 8-mi long, the longest reach had more than 100 cranes on site. In all, some 250 local construction workers were employed to place extraordinary quantities of materials, including 115,000-ft^2 of steel sheet pile and more than 5-million-ft^2 of steel H-piles—28 times the amount of metal used in the Eiffel Tower. The project's success reflects hundreds of people working seamlessly and safely to get the job done on time.

ADDRESSING COMMUNITY AND ENVIRONMENTAL NEEDS

The improved Chalmette Loop Floodwall system represents a crucial infrastructure addition to not only address safety for the residents of St. Bernard Parish, but the adjoining communities of Greater New Orleans that benefit from the improved line of defense. With 81 percent of homes damaged or destroyed, 3,000 businesses inundated, and a past history of flooding and destruction, residents needed a prompt solution to provide assurance that they could rebuild their lives. A delayed solution using standard timeframes would have failed to deliver this confidence.

From an engineering perspective, the solutions that met key community needs also had many advantages in terms of environmental sustainability. An earthen levee would have required



ABOVE: *This rendering illustrates modified slab and wall segments suited for wind tower attachment and power cable, as well as deep-rooted biomass crop that adds extra erosion control.* GRAPHIC BY BIOENGINEERING GROUP

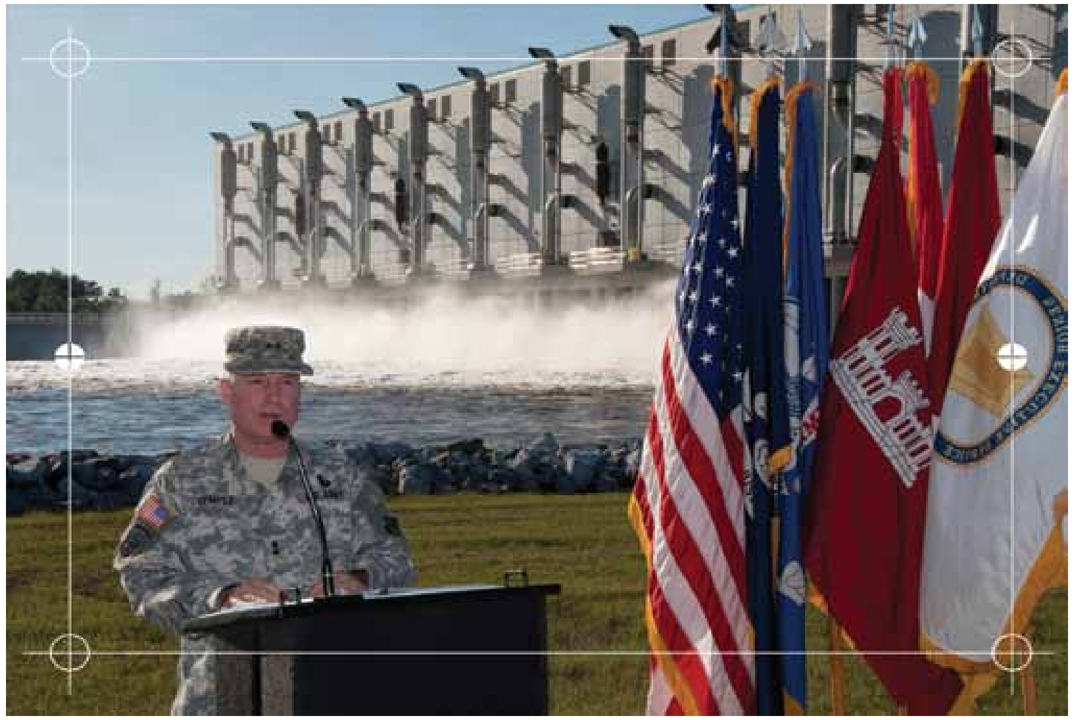
millions of cubic yards of embankment material, hundreds of acres of borrow pits, and additional rights-of-way leading to exponentially higher environmental impacts. To avoid damaging impacts to fish passage and salinity concentrations that healthy marshes rely on, the team designed open bypass channels to maintain flow through the cofferdam during construction. This provided a path for fish and maintained fresh water flow to adjacent marshlands. In recognition for the outstanding achievements of the project, USACE and the joint venture received the prestigious 2013 American Council of Engineering Companies Honor Award.

OVERCOMING CHALLENGES OF MAINTENANCE AND RENEWAL COSTS

Congress funded full execution of HSDRRS as a comprehensive system, covering 100 percent of the initial cost of the regional infrastructure solution to flood risk. However, ongoing operations and maintenance (O&M) still had to be covered by non-federal parties that benefited from the system. These significant costs were not something that could be easily absorbed into the budgets of municipalities still reeling from Katrina's impacts and facing uncertainties about the health of the future tax base.

St. Bernard Parish was one of the local communities with substantial concern about addressing O&M costs throughout the service life of the floodwalls, gates, and other complex components. To help alleviate this funding concern, Bioengineering Group introduced various options to incorporate renewable energy within the Chalmette Loop right-of-way that would be capable of generating revenue streams to offset maintenance costs. The technical, financial, and programmatic feasibility of incorporating various measures required close examination, due to the unique nature of the proposed solution. In order to use the existing right-of-way and proposed new footings and access roads to serve multiple purposes, many parties would have to sign off on the engineering, real estate, legal, and contracting details. The team recommended both wind power and biomass crops as viable solutions that would harness locally available energy resources, promote reduced carbon emissions, and increase energy supply resilience. While the main driver was the opportunity to reduce financial burdens on local communities and ensure adequate inspection, maintenance, and repair over the long term, incorporating renewable energy into the project delivered many additional benefits that are consistent with national policy and local interests in terms of resilience, sustainability, and climate change mitigation.

RIGHT: *MG Temple stands in front of the Gulf Intracoastal Waterway West Closure Complex pump station, one of the largest—if not the largest—of its type in the world, at a 9 September 2011 dedication ceremony. The pump station, capable of pumping a maximum of 19,140 cubic feet per second (cfs), is part of a system of levees, flood/sector gates, Algiers Canal deepening, and environmental restoration features to reduce the risk of storm damage south of New Orleans.*



As the final vegetative cover on the earthen levees supporting the new floodwalls, vigorously growing native plantings of switchgrass were recommended. These plants have deep roots and dense shoots capable of reinforcing and strengthening soils and resisting erosion even during extreme events, far outperforming standard turf grasses. Various earthen embankments and levees in the United States have incorporated switchgrass with good results, even tolerating drought, flooding, and salinity conditions. The grass is highly efficient at converting solar energy into living plant material that cumulatively provides strength and protection to earthen structures, even when leafy material is harvested through periodic mowing. Unlike turf grass that has no commercial value, switchgrass grown in the region yields highly productive biomass crops that can be marketed at a profit as baled hay for use as feedstock at the local Big Cajun II coal-burning power plant. Adding biomass to coal not only reduces fossil fuel consumption and greenhouse gas emissions, it also promotes a cleaner burn with fewer smog-causing emissions. In other markets, switchgrass easily can be processed for use in pellet stoves which sell at roughly $100 per ton. Sold as pellets or bales, switchgrass biomass crops could likely net $5,000 per year of revenue per mile of levee (more than $100,000 per year for the Chalmette Loop system alone). Conversion of switchgrass to ethanol or other liquid biofuels is currently under development and promises great productivity, though it is not now commercially available. Some aspects of using switchgrass that would require adjustment include the standard ground cover specification for levees used by USACE, which calls for 6- to 8-in grass height, whereas switchgrass grows to heights of 6- to 10-ft. However, when freshly mown once or twice annually to harvest biomass, switchgrass would easily allow for visual inspection of levee conditions.

A much larger potential revenue source also was recommended in the form of wind power development. Through a public–private partnership, a developer would own and operate the generation equipment, with the USACE flood infrastructure project setting the stage for its construction. The site was found to be capable of generating an estimated 100,000-MWH of renewable energy, enough to power 20,000 homes with a competitively priced and disaster resilient power supply, by incorporating wind turbines attached to modified floodwall monoliths along the levee reach with the highest wind exposure.

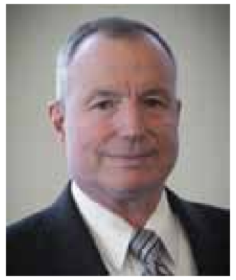
Any large-scale wind development requires significant cost related to geotechnical and structural elements, especially in offshore or soft soil locations where wind resources are often most attractive. St. Bernard Parish hosts some of the best documented wind resources in Louisiana. A meteorological tower near the levee system that had been operated for decades by the National Oceanic and Atmospheric Administration provided useful data to substantiate the reliability of wind patterns and suitability for development. Additionally, a nearby coal-fired power station flooded during Katrina remained closed, offering convenient infrastructure for interconnection with the power grid. Recommended equipment included 15 turbines of 660-kW or greater capacity mounted on 165-ft towers. The Chalmette Loop design team identified modifications to the pile groups and also the slab and wall structures that would allow integration of wind turbines with only small incremental cost increases. In turn, significant revenues could be achieved by leasing the site to a developer who would assume responsibility for details of wind technology selection, investment, and operations. The recommended design called for creating jogs in the wall to accommodate turbine attachment and modifying steel and concrete structures to address wave loads at an anticipated additional cost of roughly $250,000 per turbine. This design added strength to the entire wall system and reduced wave loads on the foundations without changing the alignment of the proposed T-wall design. It also offered ease of access to the monopole tower for maintenance, including an access door at the tower base. The steel tower structures would not be exposed directly to salinity or wave loads, which would minimize corrosion and provide better durability. Transformers would be housed within the towers and transmission lines would be located below grade.

Though this practical approach was recognized for offering many benefits at the time, due to schedule constraints it was not adopted during the original project execution. However, the project sponsor has been pursuing the approach after construction in order to negotiate lease and O&M agreements with a wind power developer on a smaller scale. This action validated the out-of-box thinking that ultimately is what made the entire HSDRRS project a success.

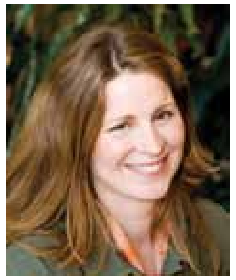
LOOKING AHEAD

Many leaders within USACE continue to explore how arrangements similar to this can address financial requirements of large-scale infrastructure projects related to climate change adaptation and resilience by taking forward-looking approaches. The solutions developed for the Chalmette Loop levee offer insight into the range of creative and effective options that could solve issues beyond just engineering function, including addressing reliable and sustainable energy supply for communities and optimizing the financial value of a project in ways that can offset portions of construction or maintenance costs. The project illustrates how it can be possible to organize a rapid process culminating in the execution and operation of a comprehensive risk mitigation infrastructure system at a regional scale. To be successful, project teams must draw stakeholders together—including government officials, planners, and the finance, insurance, energy, real estate, and construction industries—to generate a common vision of the scope and preferred design of creative multi-purpose structures; to identify alternative funding sources and mechanisms such as public–private partnerships to attract private capital in addition to traditional sources of public funding; and to establish methodologies and concrete steps for all aspects of a speedy implementation process.

Going beyond flood damage reduction, solutions that address other infrastructure needs (such as power supply) while reducing greenhouse gas emissions and generating revenue could craft truly systemic and long-lasting community resilience. Drawing on each region's unique resources, such plans could incorporate exemplary infrastructure design, financing, and governance. For instance, hydropower from new low-head turbine technology or enhanced existing dams shows promise in many locations. Offshore wind and tidal energy are being tapped overseas, and these could offer great value in the United States as well. Cost sharing, such as public–private partnerships, could span multiple jurisdictions who would benefit from lower upfront and lifecycle costs. Examples may include combining flood-related or navigation infrastructure with modernized power supply, renewable energy, recreation, or other multiple purposes. Lowering life-cycle costs and weather-related risks will benefit property owners, businesses, and taxpayers alike, especially in fiscally constrained times. An ecologically integrated flood infrastructure system will not protect against all future risks, but it may go a long way toward buying time to further secure against changing weather patterns and climate conditions, including retreat and reconstruction if necessary, with benefits throughout this century and beyond.



MG (RET) MERDITH W. B. (BO) TEMPLE *retired from the Army in September 2012 after more than 37 years of service as an engineer officer. He graduated in 1975 from Virginia Military Institute with a bachelor of science in civil engineering and later received a master of science in civil engineering from Texas A&M University. Before joining USACE in 2001, MG Temple held many combat engineer operational assignments to include Operations Desert Shield/Desert Storm. During his tenure with USACE, he served as the Transatlantic Center and North Atlantic Division commander and the Theater Engineer in Baghdad, Iraq. He later served as the Deputy USACE CG for Military Programs, Civil Works, the Deputy, and finally as the Acting CG/Chief of USACE.*



WENDI GOLDSMITH *is a Yale-trained geologist and CEO of Bioengineering Group, whose mission is "Building Sustainable Communities on an Ecological Foundation." A pioneer in natural resource restoration and the application of sustainability principles to planning, development, and infrastructure, Goldsmith has led R&D programs for DOD, developing methods for evaluating and optimizing renewable energy and efficient and resilient infrastructure and building and site design. She played a lead role on the planning, design, and program management of the $14 billion post-Katrina Hurricane Storm Damage Risk Reduction System, the first regional-scale climate adapted infrastructure system in the United States.*