

NESTLED AMIDST residential streets on the Bygdøy peninsula, in Oslo, Norway, is the Vikingskipshuset, the Viking Ship Museum, a cross-shaped structure housing three ninth-century Viking vessels. Visitors to the museum can also examine the artifacts that were discovered with the ships when the latter were unearthed in the late 19th and early 20th centuries. With an annual visitor count that has varied from 375,000 to 500,000 over the past 20 years, vastly surpassing the 40,000 design capacity of the existing building, the museum is more than ready for increased space. Rather than move the ancient ships, which could damage them, the museum will be expanded while the ships remain on-site. A new wing is to be carefully engineered so that the fragile ships are not affected by dust or debris during construction or by vibrations induced by construction, weather, or visitors.

The Viking Ship Museum, part of the University of Oslo's Museum of Cultural History, is known for having the richest archaeological collection from the Viking age in the world, according to Synnøve Lyssand Sandberg, the director of the department of construction and project development at Statsbygg, the Norwegian directorate of public construction and property. Sandberg wrote in response to written questions posed by *Civil Engineering*.

The museum's collection includes the

CONSTRUCTION Ninth-Century Artifacts to Be Protected from Construction Vibration

The museum has the richest collection of Viking-era artifacts in the world. The Oseberg was built in approximately 820 and discovered in a burial mound in 1903. Visitors will be able to view the collections from upper-level mezzanines and the floor level.

Oseberg, built in approximately 820 and discovered in a burial mound in 1903, and the *Gokstad*, built in approximately 890 and discovered in a burial mound in 1880. These two ships are the best preserved Viking ships in the world and are part of a collection that is of significant national and international importance, according to Sandberg.

Although the ships will remain on-site during construction, they will be placed within frames, currently being designed, that will isolate them from vibrations.

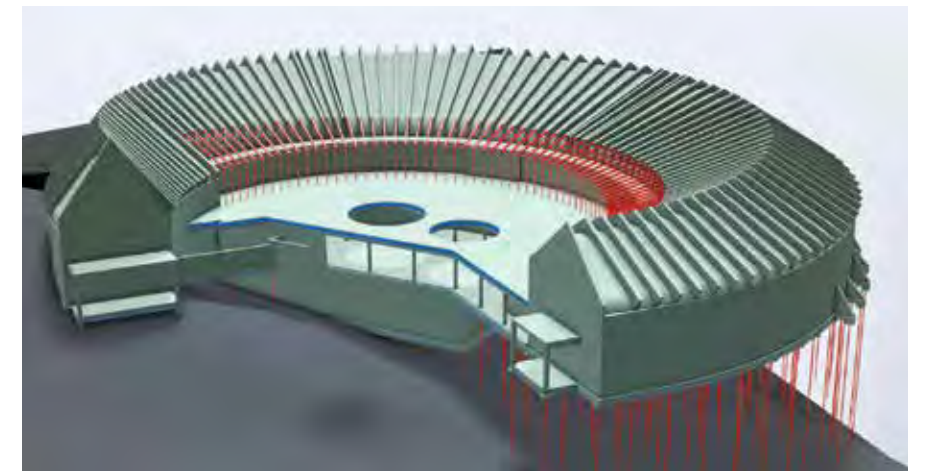
The new, 9,300 m² wing that will house the ships upon its completion was designed by AART architects, which has offices in Denmark and Norway and won a design competition held by Statsbygg. It will be a "bold circular structure," AART's website states. The circular sweep of the new wing will connect the north and west wings of the existing cross-shaped building while preserving outdoor space within a courtyard nestled at the center of the three wings.

The new wing is currently planned to be entirely of cast-in-place concrete, according to Guillaume Koelsch, the project's building design manager for Oslo-based Hjellnes Consult, a multidisciplinary consulting engineering firm that is leading the design team for the new building. Koelsch too wrote in response to questions posed by *Civil Engineering*. A second team, led by Oslo-based Brekke & Strand Akustikk AS, a consulting engineering firm

that specializes in vibration technology, is establishing safe threshold values for vibrations for the existing building and its contents.

Given the need to minimize vibrations inside the museum and the fact that the new wing is to have column-free spans of as much as 100 ft, cast-in-place concrete is seen as the best option. Upper-level mezzanines in the new wing will offer rooms for exhibits grouped by theme and will enable visitors to look down on the ships; a lower-level space will accommodate the ships and give visitors closer views. The concrete slab underlying the new wing is currently expected to be founded on drilled piles that will extend to bedrock.

"Every single aspect of the design on this particular project has to fulfill a set of criteria which is broader and more complex than usual," said Koelsch. "Top of the list is to minimize the potential risks for the ships and the other fragile elements of the collection, [because] the building has to be able to provide them a safe place for future generations." The team must protect the collection not only from the effects of time but also from fire, water, earthquakes, and vibrations, including those created by visitors. Its members also had to consider how future maintenance work on the building itself could affect the ships.



It is expected that, to protect the museum's artifacts, cast-in-place concrete will be used for the wing to minimize vibrations during construction and after the museum is opened, as well as to accommodate the wing's geometry.

The new wing planned for the Viking-skipshuset, the Viking Ship Museum, in Oslo, Norway, will be circular, connecting the north and west wings of the existing cross-shaped museum.

The site's ground conditions are typical for large parts of Scandinavia. The soil for the most part comprises consolidated marine clays deposited after the last ice age, and the depths to bedrock vary from 0 to 30 m, according to Jenny Langford, the principal geotechnical engineer and a project manager with the Oslo-based Norwegian Geotechnical Institute (NGI), who wrote in response to questions posed by *Civil Engineering*. NGI, which was brought onto the project by Hjellnes Consult, is a private, independent commercial foundation and international center for geoscience research and consulting and is responsible for the geotechnical and geological engineering aspects of the project.

Because the project is still in its early stages, the main focus for NGI thus far has



AART ARCHITECTS, ABOVE AND OPPOSITE BELOW

HJELLNES CONSULT, TOP

Civil Engineering NEWS

been on evaluating different excavation methods and foundation solutions, as well as potential vibration levels during construction and how those vibrations could be mitigated. These vibration evaluations have been based on data from NGI's database of measured vibrations from construction work, according to Karin Norén-Cosgriff, a vibration expert at NGI, who also wrote in response to questions posed by *Civil Engineering*.

"Construction methods to limit vibrations such as drilled piles, sheet-pile wall installation with [a] silent piler, [and] bedrock excavation using drill-and-split or wire sawing are planned for," Langford explained. "In addition, it might be necessary to perform lime-cement stabilization of the clay under the construction roads and as a wall around the existing museum," she noted. Lime cement will be used to stabilize the clay inside the excavation pit for construction vehicles as well.

Vibrations will also have to be limited when the connecting walls between the new structure and the existing building wings are opened. "By chance, one of two gables already has an opening big enough for the ship: the one [in the west wing] used in 1932 to move the second ship inside the building," Koelsch wrote. "We just have to re-open the original arch-formed opening," he noted. "The other gable, on the north wing, is more challenging and the works...have to be planned with care in the next phase, in very close cooperation with the vibrations expert team."

The doubly curved, semicircular roof of the new museum wing poses geometrical challenges from both an engineering and a vibration control perspective, according to Koelsch. "It is a concrete structure with a huge span," he noted.

The height of the roof's ridge varies from one end to the other because the two existing wings to which it will connect are at different heights. Furthermore, "for architectural reasons on the inside, the bearing beams have to be reversed [and] placed on the outside as ribs above the vaulted concrete [roof]

structure," Koelsch explained. "These concrete ribs will also support the secondary roof structure, which itself will bear the roofing."

At this stage, the design team is planning to use a typical Norwegian slate roof, but it is possible that a photovoltaic roof will be installed instead. Regardless of what the secondary roof contains, "the first concrete structure has to be waterproof, so that future maintenance works or any defect on the outer roof will have no consequences for the museum's collection inside," Koelsch noted.

The current plan is for the connection points between the existing wings and the new wing to be formed from glass so that the architectural qualities of both structures will remain visible and the new construction will touch lightly in a visual sense on the existing museum building, according to Koelsch.

It is hoped that construction on the new museum wing will begin in the first half of 2020 and be completed by 2023, but first the Storting, Norway's parliament, will have to approve the plans to expand the museum.

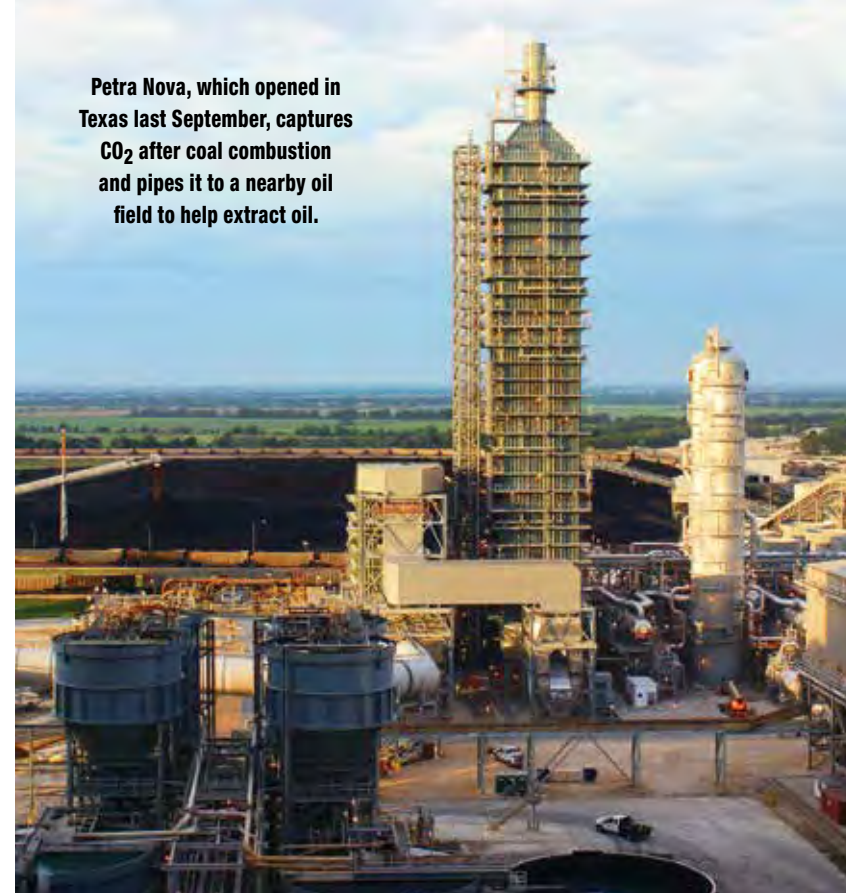
—CATHERINE A. CARDNO, PH.D.

ENERGY

Two Coal Plants Pursue Different Approaches to Capturing Carbon Dioxide

TWO NEW coal-based power plants are showcasing different technological approaches for preventing pollution from the coal they burn. The methods conserve energy, generate less carbon dioxide (CO₂), and recapture more of the CO₂ and other pollutants that are produced.

One of these plants, the Kemper County Energy Facility, in eastern Mississippi, is pioneering a method that uses coal gasification. At press time, the plant was scheduled to become commercially operational at the end of February. According to Lee Youngblood, the communications manager for Mississippi Power Company, the plant takes Mississippi lignite, a virtually untapped form of coal that is abundant in the area, and converts it into a synthesis gas, or "syngas,"



Petra Nova, which opened in Texas last September, captures CO₂ after coal combustion and pipes it to a nearby oil field to help extract oil.

COURTESY OF NRG ENERGY



The Kemper County Energy Facility, in Mississippi, uses an innovative technique to gasify coal in an inexpensive and efficient way.

that then runs a combustion turbine to generate electricity. However, before the gas is used to run Kemper's turbines, its CO₂ is removed, compressed, and sent via pipeline to help extract oil from mature fields, a process known as enhanced oil recovery. The plant also produces such commercially viable by-products as anhydrous ammonia and sulfuric acid.

Youngblood explained by email that what makes Kemper unique is not gasification, which is hardly new, but rather a new process called transport integrated gasification, or TRIG. Kemper represents the nation's first commercial-scale application of the technology, which Youngblood described as the "only gasification system that can process high-moisture lignite efficiently for power production."

TRIG, developed by Southern Company (the parent company of Mississippi Power), KBR, Inc., of Houston, and the U.S. Department of Energy, has several advantages over other gasification systems, Youngblood explained. It runs cooler and doesn't melt solid particles, or "ash," into slag, which is costly to remove. What is more, the TRIG gasifier relies on blown air, while other systems must be constantly fed with pure oxygen, which is expensive.

Operating on syngas, the Kemper plant will have a generating capacity of 582 MW and will be able to capture approximately 3 million tons of CO₂ a year, which is 65 percent of the CO₂ the plant produces.

Kemper's CO₂ removal system is a precombustion approach. At Petra Nova, a carbon capture facility southwest of Houston that went onstream last fall, NRG Energy, Inc., headquartered in Princeton, New Jersey and Houston, and its partner—JX Nippon Oil Exploration (U.S.A.) Limited, of Houston—are using a postcombustion approach to capture CO₂ from NRG's W.A. Parish Electric Generating Station. While carbon capture technology dates to the 1930s, "it's never been done at this scale on a coal plant, around an entire systems approach," says David Knox, the senior director of external communications for NRG.

Petra Nova diverts 40 percent of the facility's flue gas, the equivalent of a 240 MW plant. This gas, which has already been scrubbed to remove roughly 90 percent of its mercury, sulfur, and nitrous oxide and 99.9 percent of its particulate matter, is then polished to remove nearly all of its sulfur dioxide. Amine is then used to help separate CO₂ from the gas.

The nearly pure CO₂ is pressurized and transported, via an 80 mi pipeline, to the West Ranch oil field, in Jackson County, and there it is injected underground to help extract more oil. About 20 percent of the CO₂ remains in the ground, and the rest is recovered and reinjected to obtain yet more oil, which means that 20 percent of this remainder will stay in the ground. Petra Nova has the capacity to sequester and reuse 1.6 million tons of CO₂ a year.

While both plants hold promise for ushering in a new era of large-scale carbon capture, the current price of oil and natural gas makes it unlikely that similar plants will be rolled out in the near future. The decision to move ahead with Petra Nova was made in 2009, when oil was fetching \$100 a barrel. "Right now oil prices are just north of 50 dollars a barrel," Knox says. "At 50 dollars a barrel, we make enough money to pay for the system, but we're not really making a whole lot of return on it at this price." Still, he has hopes for the future. "As oil prices increase, the economics will improve," Knox says.

Knox estimates that the lessons learned in the process of engineering and building Petra Nova would make it possible for a similar plant to be built at a cost that would be 5 to 20 percent less.

The most significant cost associated with carbon capture and storage (CCS) is capturing the CO₂ in the first place. "From a research standpoint, the area we're most focused on is driving down costs of CO₂ capture," says Ron Munson, the global leader for carbon capture at the Global CCS Institute, which, according to its website, is working toward "the adoption of CCS as quickly and cost effectively as possible by sharing expertise, building capacity, and providing advice and support so that this vital technology can play its part in reducing greenhouse gas emissions."

Both Kemper and Petra Nova benefited from significant subsidies from the

Civil Engineering NEWS

Department of Energy: \$190 million for the \$1-billion Petra Nova facility and \$407 million in total cost sharing (including \$270 million in original federal assistance) for the \$7-billion Kemper facility. “You’re trying to change the equation,” Knox says, “so that you’re not saying, ‘Why would I want to put a carbon capture system on my power plant?’ but, with a high enough revenue, why would you not want to do that?”

A federal tax credit for carbon storage enacted in 2008 (and amended in 2009) is set to expire when 75 million metric tons of CO₂ have been sequestered, a figure that the industry is now approaching. The program provides a \$10 credit per metric ton for enhanced oil recovery

or a \$20 credit per metric ton for saline storage. Although there are proposals in Congress to extend or expand the credit, Jeff Bobeck, the Global CCS Institute’s senior adviser for policy for the Americas, says that the industry is taking a wait-and-see approach. “The expected expiration of the tax credit negatively affects the economics of constructing a new carbon capture project, so no new large-scale projects are currently moving forward,” he says.

Munson is of the opinion that if the CCS industry were granted incentives similar to those available to the renewable energy industry, “we’d see the same types of cost reductions we see in renewables as well.”

Coal constitutes roughly 33 percent of U.S. electricity generation, according to the U.S. Energy Information Administration, and that figure is falling. How-

ever, Munson notes that International Energy Agency projections indicate that fossil fuels, including coal, will remain a significant part of the global energy mix for decades. But even if those projections are wrong by half, he says, “there’s still a lot of CO₂ that’s going to be emitted to the atmosphere unless you have some kind of mitigation method.”

According to Youngblood, Southern Company and KBR have signed half a dozen agreements for developing TRIG systems in Asia. Moreover, there are hundreds of coal plants in the United States that could eventually be retrofitted with CCS technology. “If we can develop a technology that is economic and can be retrofitted on existing coal plants,” Knox says, “there’s a whole lot of them out there that are new and are going to be around for a long time.”

—T.R. WITCHER



edge of an expansive, rounded plaza, and a low, curved building will partially encircle the other edge. The towers will house a 490-room Hyatt Regency hotel, cultural workshop space, and 52,000 m² of office space, while the low building will offer, among other amenities, new variations on the museum-going experience, including interactive movie- and exploration-based attractions. For example, it will include Lionsgate Entertainment World, a 22,000 m² interactive and immersive attraction based on movie themes, and the National Geographic Ultimate Explorer, a 4,500 m² center for education and entertainment that will combine elements from museums, gaming, and role-playing with state-of-the-art technology to offer virtual travel excursions to sites around the globe, according to the website. The development will also contain a luxury wedding venue alongside garden space; a glitzy performance hall that can host gala

New Town Offers the Latest in Entertainment

Designed to suggest an open palm and thus symbolize innovation, Novotown will be a 120,000 m² integrated tourism and entertainment project located on an island in Zhuhai, China, next to Macau (Macao). The development is planned as a cultural hub and incubator for creative entrepreneurs as well as those in search of recreation, according to Novotown’s website. Three towers arranged like fingers around a courtyard will rise along one

events, fashion shows, small concerts, and conference events for as many as 1,500 people; an 8,000 m² health care and beauty center; and retail and dining space. The development will be arranged to reflect the human brain, according to the website. The “left” zone of the development will focus on science and technology, while the “right” zone will host arts and culture. Hong Kong-based Lai Sun Group commissioned the development, which is expected to be complete in 2019, according to Beijing-based Aedas, the design and project architect for the development.

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WATER

Number of U.S. Households Unable to Afford Water Could Triple

LAST YEAR'S water contamination crisis in Flint, Michigan, has begun a nationwide conversation on Americans' access to clean water. A recent study by Elizabeth Mack, Ph.D., an assistant professor of economic geography at Michigan State University, has added another dimension to that conversation with her analysis of water affordability in the United States. She has found that, within the next five years, water and wastewater services could be unaffordable for as many as 36 percent of U.S. households.

Mack's study is one of the first nationwide investigations of water affordability, according to material released by Michigan State University.

"[Water] is one of those necessities that we take for granted," Mack says. Her study, conducted in conjunction

with Sarah Wrase, an honors student in accounting at the university, analyzed water consumption, pricing, and demographic and socioeconomic data across the United States. A paper setting forth the results of the study, "A Burgeoning Crisis? A Nationwide Assessment of the Geography of Water Affordability in the United States," was published early this year in *PLOS ONE*, a peer-reviewed, open-access scientific journal.

Mack, who as an economic geographer analyzes various economic phenomena as they change with time and geography, refers to water and wastewater services as "invisible infrastructure," much like broadband services, which she also has studied. This is because the majority of consumers simply do not think about where their water comes from or where their wastewater goes until the systems break down.

To be considered affordable, water and wastewater services should cost no more than 4.5 percent of a household's income, according to the U.S. Environmental Protection Agency. Using that criterion, Mack discovered that 13.8 million U.S. households, 11.9 percent of the total, have annual incomes below \$32,000 and therefore may find

their current water bills unaffordable. (This calculation is based on the Environmental Protection Agency's definition of "average consumption," which equates to 12,000 gal of water a month for a household of four.)

"A lot of people in poverty have difficulty paying for a variety of items," Mack says. "[Water] is just one of a basket of household purchases that is going up over time." But the speed at which water and wastewater prices are increasing is striking.

In 2016 the price of water increased by as much as 5 percent in 30 major cities, the median being 3.5 percent, according to findings published by Circle of Blue, a group founded in 2000 to provide frontline reporting about the world's resource crises. Overall, these cities have seen a whopping 48 percent increase in water prices since 2010. "The increase continues a steady upward climb in water prices that reflects investment in new infrastructure and a response to declining water sales," according to material on the Circle of Blue website about its annual survey.

Since Mack's study of water affordability was conducted before the 2016 survey results were published, she used

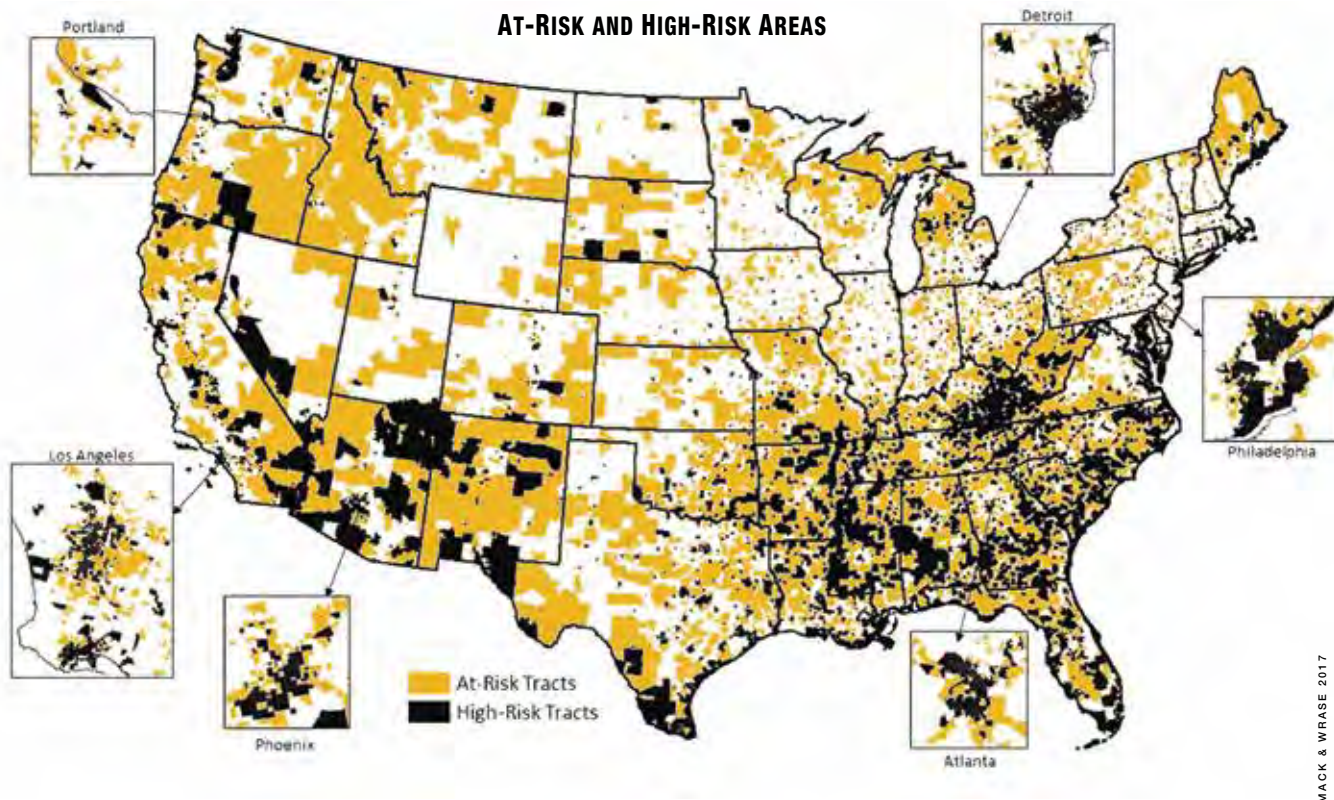
the results from the organization's 2015 survey, which found a 41 percent increase in water prices from 2010 to 2015. If water rates continue to rise at this pace over the next five years, an estimated 40.9 million U.S. households, or 35.6 percent of the total, may not be able to afford their water and wastewater bills within five years, according to the study.

Many of these households are clustered in pockets of "water poverty" within individual counties, "which is a concern for individual utility providers servicing a large proportion of customers with a financial inability to pay for water services," according to the study. Indeed, the mass shutoffs in Detroit that began in 2014 as part of an effort to hold delinquent residents to account have meant the end of service for 50,000 households, according to Mack's study.

But it is not only lower-income households that will be affected. In areas in which a large number of households are unable to pay their water bills, rates could be increased as utilities seek to recover what they lose when lower-income households find themselves unable to pay their bills, according to the study.

Three factors "push against" water utilities as they seek to set fair prices for their water services: earnings, conservation, and equity, according to Circle of Blue. Utilities must earn enough to maintain and upgrade their infrastructure and to make investments to ensure future service. Prices are set on the basis of the number of consumers and their expected water consumption patterns. Utility revenue, however, can be significantly eroded by water conservation efforts. For example, indoor water usage in the United States has dropped 22 percent since 1999 because of such conservation efforts, Circle of Blue reports. This is where equity, the third factor, becomes crucial. Water must be affordable but must also be priced in such a way as to be punitive in the case of waste. Rates that penalize waste must be structured so that they do not place too great a strain on households of modest means.

Secondary considerations can



affect the severity of these factors. Climate change, for example, is raising expenses for utilities in the near term. "Climate change is part of the reason that necessitates new infrastructure or better infrastructure [because it's necessary] to manage floodwater, increased storms, and the increased incidence of major storms that overwhelm water systems," Mack says. Shrinking populations in major cities also can have a pronounced effect on a utility's ability to earn enough revenue to maintain and upgrade its systems, according to the study.

The study merely scratches the surface of water affordability issues. Mack's future work will explore how and why water pricing varies within metropolitan areas; how increasing water prices affect the way that households allocate their spending; the effect that those budgetary decisions have on local businesses, regional incomes, employment, and output; and how trends in privatizing water utilities are affecting users' water costs.

The study, which was funded by the National Science Foundation, is available online at <http://journals.plos.org/>.
—CATHERINE A. CARDNO, PH.D.

ENVIRONMENTAL ENGINEERING

U.S. EPA Releases \$1-Billion Plan For Cleaning Up Portland's Harbor

AS PART OF A RECORD of decision it issued in January, the U.S. Environmental Protection Agency (EPA) will oversee an estimated \$1-billion effort to remove contaminated material from a nearly 10 mi stretch of the lower Willamette River in Portland, Oregon. Located just above the waterway's confluence with the Columbia River and downstream of downtown Portland, this section of the lower Willamette is a key portion of the Portland Harbor Superfund Site. More than a century of industrial and commercial activity in and around the harbor, as well as upstream of the site, has contributed to the presence of pollutants that pose a risk to humans and wildlife. Remediation activities conducted as part of the cleanup will include dredging more than 3 million cu yd of contaminated sediment from the lower Willamette.

The record of decision details the actions to be taken to address contamination

SITEWIDE TECHNOLOGY ASSIGNMENT

tion within a section of the lower Willamette extending roughly from river mile 1.9 to mile 11.8 (see map). A federal navigation channel extends nearly the entire length of this section of the river, and Portland's harbor is home to various industrial and commercial operations. However, this stretch of the river also includes neighborhoods and areas of green space that provide habitat for such wildlife as bald eagles, peregrine falcons, otters, and minks. In addition to providing opportunities for boating and other recreational activities, the waterway is a popular location for fishing.

Throughout its history, Portland's harbor has been the site of a "whole suite of different types of operations," says Cami Grandinetti, P.E., a program manager for the remedial cleanup branch, part of the EPA Region 10 Office of Environmental Cleanup. Such activities included shipbuilding, wood treatment, manufactured gas production, pesticide production, and storage of bulk fuels. Because past chemical-handling practices were not as rigorous as those today, such activities tended to release pollutants into the nearby Willamette. "Historically, a lot of the waste ended up in the river," Grandinetti notes. Additional contamination entered the waterway as a result of the use of polluted waste as fill in or near the river, the disposal of contaminated

material in upland areas that drain to the river, and discharges from storm sewers and combined sewers. Under the terms of a 2001 agreement, Oregon's Department of Environmental Quality is responsible for addressing upland sources contributing pollution to the harbor, and the EPA is responsible for addressing contamination within the lower Willamette and its riverbanks.

Among the 64 contaminants of concern at the site, "most of the human health and ecological dietary risks" result from the presence of polychlorinated biphenyls, polycyclic aromatic hydrocarbons, the chemicals commonly known as dioxins and furans, and pesticides, according to the record of decision. For humans, eating fish from the harbor poses the greatest risk to health, although contact with contaminated sediment and river water could carry risks as well.

At present, the EPA has finalized a feasibility study for the project, Grandinetti says, but has not yet begun preliminary design work. Given the size of the overall project, "design could take a few years," she notes. Meanwhile, construction is expected to take up to 13 years, in part because concerns regarding the presence of certain threatened or endangered fish species will restrict work in the river to just four months per year.

Active remediation through dredging, capping, or enhanced natural recovery

will be conducted on 394 acres within the river and approximately 23,300 linear ft of riverbank. All told, more than 3 million cu yd of contaminated sediment and approximately 123,000 cu yd of contaminated soil will be removed and disposed of off-site. Contaminated sediment will be removed from the river through environmental dredging so as to limit the release of material "to the greatest extent practical," Grandinetti says. At the same time, sheet-pile walls and silt curtains, together with procedures generally acknowledged to be highly effective ("best practices"), may be used to control the release of contaminated material during dredging. Enhanced natural recovery will entail adding a layer of sand or a combination of sand and activated carbon to dilute contaminant concentrations and accelerate the recovery process.

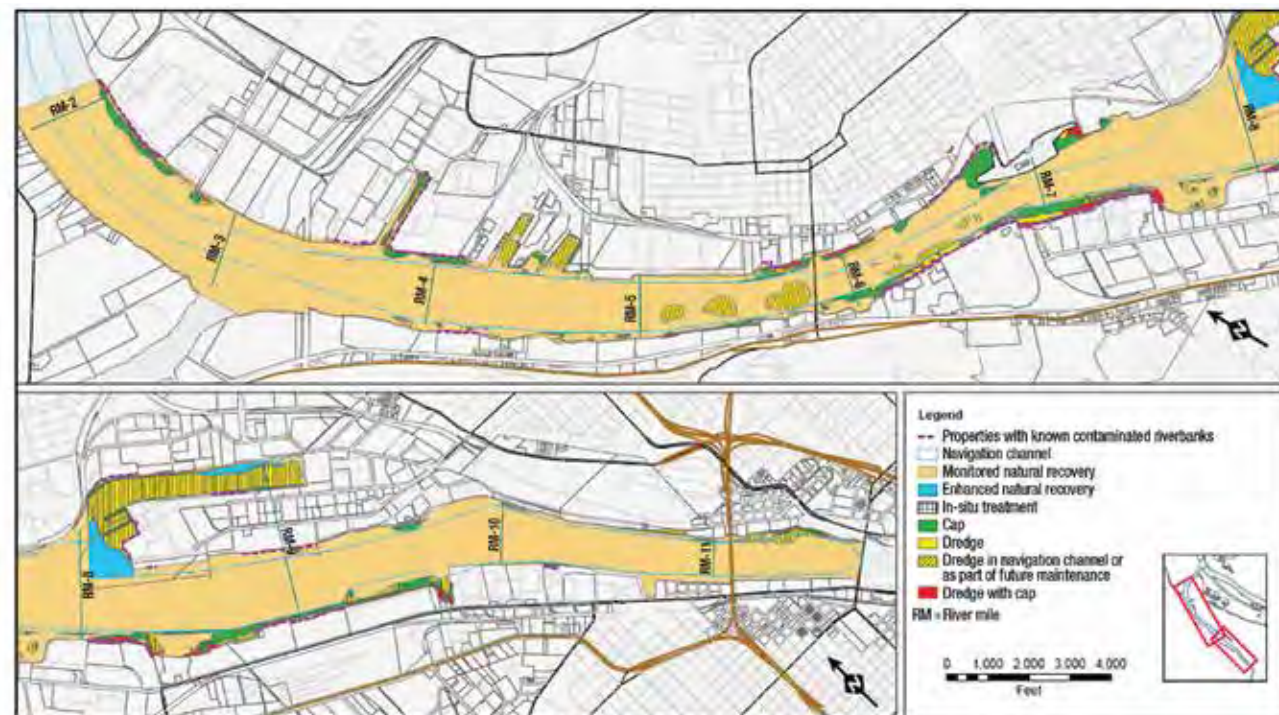
Approximately 133 acres of sediment will undergo in situ treatment to control the migration of contaminants. This treatment will involve efforts to stabilize and sequester contaminants by such means as mats made of activated carbon or organoclay. On the order of 1,774 acres having lower levels of contamination are expected to recover naturally over time. Known as monitored natural recovery, this process is expected to occur primarily as a result of dispersion and mixing, as well

as from the deposition of cleaner sediment from upstream sources. In these areas, monitoring will be conducted to ensure that the anticipated progress occurs. Where possible, riverbanks containing contaminated material will be excavated and reconstructed. In locations at which all contamination cannot be practically removed, capping will be used to prevent the remaining pollutants from entering the waterway.

The actions called for by the record of decision will permit greater human consumption of fish from the river, except among subsistence fishers and such sensitive groups as breast-feeding infants whose mothers consume fish. The plan is also designed to decrease the potential for direct contact with contaminated sediment. What is more, removing pollutants from Portland's harbor will ensure that less contamination makes its way downstream to the Columbia River.

Funding for the project is expected to come from parties found by the EPA to have contributed to the existing pollution in the river. Thus far the EPA "has identified about 150 parties as potentially responsible for releases of hazardous substances to the river," according to the record of decision. Meanwhile, the agency continues to investigate other parties that may bear some responsibility, Grandinetti says.

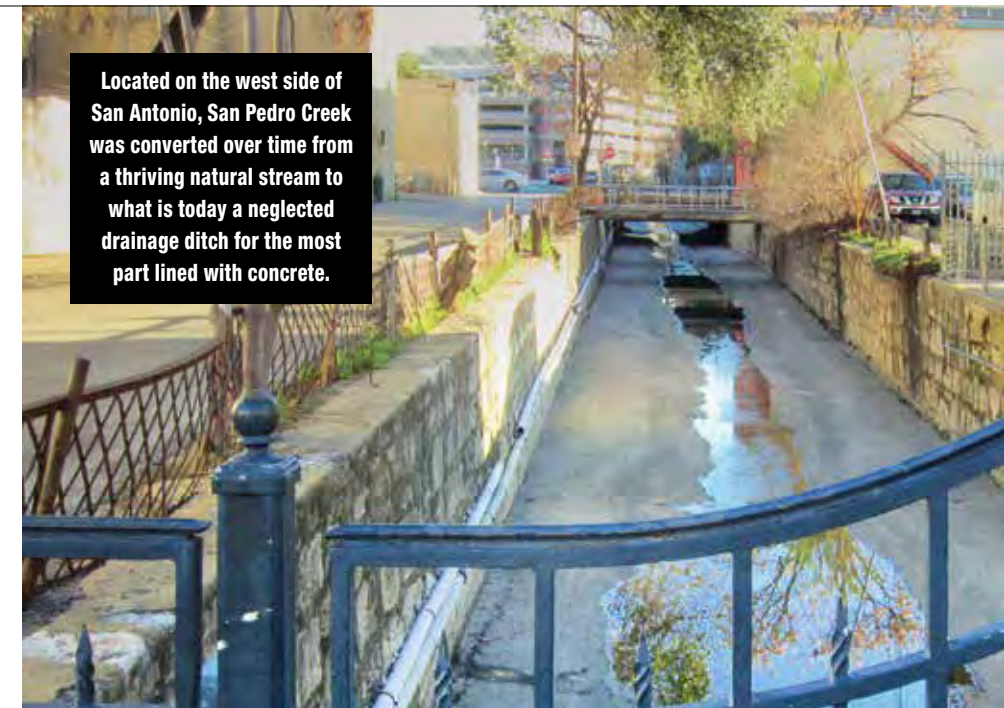
—JAY LANDERS



U.S. ENVIRONMENTAL PROTECTION AGENCY

FLOOD CONTROL San Antonio Creek Project Combines Flood Relief with Urban Renewal

SAN PEDRO CREEK played a key role in the development of San Antonio, reliably providing clean, spring-fed water that enticed first Native Americans and later Spanish colonists to settle in what was otherwise a semiarid land. However, San Antonio's growth over the centuries took its toll on San Pedro Creek as the waterway, which flows on the city's west side, went from being a thriving natural stream to what is today a neglected drainage ditch that for the most part



Located on the west side of San Antonio, San Pedro Creek was converted over time from a thriving natural stream to what is today a neglected drainage ditch for the most part lined with concrete.



is lined with concrete. As part of efforts to address flooding along the final 2 mi of San Pedro Creek, a coalition of local governments aims to restore the waterway to a position of greater prominence, converting the largely forgotten channel into a linear park that will feature walkways and other attractions. In January construction began on the first of four phases to be carried out as part of the estimated \$175-million San Pedro Creek Improvements Project.

Industrialization and flood control projects profoundly affected San Pedro Creek, which largely retained its configuration until the early 20th century even as development crowded it on both sides. In 1917 a section of the creek several blocks long was enclosed within underground box culverts to facilitate the construction of rail lines. Throughout the 20th century, efforts to reduce flooding along the creek resulted in it being widened, deepened, or straightened along much of its length. Such efforts culminated in the 1990s when the U.S. Army Corps of Engineers completed the San Pedro Creek bypass tunnel to reduce flooding along the waterway in downtown San Antonio. The project included an inlet structure that diverts flood flows from the creek north of downtown into an approximately 24 ft diameter, 150 ft deep tunnel. Functioning as an inverted si-

As part of efforts to address flooding along the final 2 mi of San Pedro Creek, a coalition of local governments aims to convert the largely forgotten channel into a linear park.

phon, the approximately 1.1 mi long tunnel conveys flows beneath San Pedro Creek before returning them to the waterway south of downtown by means of a tunnel outlet.

The bypass tunnel significantly reduced flooding along the length of the creek served by it. During major rain events, localized flooding occurs as a result of runoff entering the channel from adjacent areas, says Kerry Averyt, P.E., a senior engineer and the project manager for the San Pedro Creek project at the San Antonio River Authority, a state entity responsible for flood management and watershed improvements within the basin of the San Antonio River. For its part, the river authority is the project manager for the San Pedro Creek Improvements Project. “That’s our major goal, to mitigate that runoff,” Averyt says.

Along the channel’s downtown stretch, approximately 30 acres of densely developed property alongside the creek reside in the 100-year floodplain, Averyt says. With the completion of the San Pedro Creek Improvements Project, the channel will contain flows associated with a 100-year storm.

“All that property will be taken out of the 100-year floodplain,” Averyt says.

Achieving this goal will require a combination of widening and deepening, says Jeff Mitchell, P.E., a senior project manager and the structural team leader in the San Antonio office of HDR, Inc. The firm, which has its headquarters in Omaha, Nebraska, is serving as the prime consultant for the San Pedro Creek Improvements Project and is performing structural engineering and hydrologic and hydraulic analysis. Pape-Dawson Engineers, Inc., of San Antonio, is providing services related to civil design, utility relocation, and environmental work. Muñoz and Company, of San Antonio, is the architect of record for the project. A joint venture comprising the San Antonio office of Sundt Construction, Inc., and Davila Construction, Inc., of San Antonio, is serving as the construction manager at risk.

Complicating the project’s design and construction, the creek is “hemmed in on all sides,” Mitchell says, by existing development and utilities that run along the channel and, in some cases, are carried by bridges spanning the creek. As a result, the project team must contend with a “very narrow right-of-way” in many locations, he notes. All told, the project will entail the removal and replacement of eight bridges that

SAN ANTONIO RIVER AUTHORITY

span the creek. The new bridges, which include two-lane and four-lane spans, are needed to accommodate the wider channel and to facilitate the passage of pedestrians on planned walkways below. The project also requires significant efforts related to utility relocations in the vicinity of the channel.

Improvements to the nearly 2 mi stretch of San Pedro Creek will be conducted in four phases, which are named in the order in which they will be carried out. Phase 1 will involve a section of the channel approximately 4,000 ft long extending south from the bypass tunnel inlet to where the creek enters the underground culverts. The roughly 1,700 ft long stretch that will be the focus of phase 2 is located to the south of the underground culverts, while the approximately 2,800 ft long section addressed in phase 3 picks up where phase 2 ends and continues to the stream's confluence with Apache Creek. Phase 4 deals with the approximately 1,800 ft long section within the underground culverts. This phase, which will involve "daylighting" the section of the channel that currently flows underground, will be conducted last because it will confer the least amount of improvement in terms of flood reduction, Averyt says.

Where possible, the channel will be widened to increase its capacity. However, the physical limitations imposed by the urban setting preclude widening in many locations, Mitchell says. Therefore, some areas of the channel that cannot be widened will instead be deepened by as much as 6 ft. Certain locations that are to receive a paseo, or sidewalk, may be simultaneously widened and deepened. In some cases, channel deepening is to occur next to the foundation or wall of an existing structure. In these locations, concrete soldier shafts will be used to support the structures, Mitchell says.

Because the bypass tunnel and the channel function as a linked system, the design had to account for a "very complex storm network" that includes areas upstream and downstream of the bypass tunnel, says Ronald Branyon,

P.E., the water resources leader in the San Antonio office of HDR. To this end, the design team used an unsteady-state hydrodynamic model to analyze the expected timing and storage of water on the surface and within the storm sewer system. This approach "gave us a better idea" of how the modified channel would perform, Branyon says.

Along with adding such features as sidewalks, pathways, and an amphitheater, the project will facilitate public interaction with San Pedro Creek by maintaining certain water levels in the channel. Three steel hydraulic crest gates with bottom hinges will be placed at certain locations along the channel to ensure that the water level remains at a set elevation, Branyon says. As the water rises in the channel, the gates will drop, maintaining the desired elevation.

To improve water quality within the channel, the project will employ hydrodynamic separator systems underground to capture stormwater runoff at the street level and remove trash, sediment, and debris by means of a vortex system before conveying flows to the creek. At certain locations at which runoff enters the channel directly, bioretention cells will be used to remove contaminants while also providing habitat.

Together, the various improvements will convert what today amounts to little more than an urban drainage ditch into a valuable feature for San Antonio residents, Averyt says. Rather than simply implementing a flood control project, "we're using the opportunity to create a public amenity," he says. By reducing flooding and beautifying the existing channel, the project is also expected to foster local economic development.

Bexar County has committed \$125 million for the design of the project's four phases and construction of the first two, Averyt says. This May voters in San Antonio will decide whether to support a bond measure that would provide \$20 million for the project. Construction of an initial segment of phase 1 of the project is scheduled to be completed by early May 2018, when San Antonio plans to celebrate its tricentennial.

—JAY LANDERS

ENVIRONMENTAL ENGINEERING

Settlement Addresses Nearly 100 Abandoned Uranium Mines on Navajo Lands

A RECENTLY proposed settlement involving two mining company subsidiaries, the U.S. government, and the Navajo Nation is expected to result in measures to address nearly 100 abandoned uranium mines on Navajo land. Announced in mid-January, the proposed settlement requires the two firms—the Cyprus Amax Minerals Company and Western Nuclear, Inc.—to clean up 94 abandoned uranium mines within the Navajo Nation. The two companies are subsidiaries of Freeport-McMoRan, Inc., a global mining concern that has its headquarters in Phoenix. Under the terms of the settlement, the U.S. government will pay half the cost of the estimated \$600-million cleanup effort, while the two companies will pay the other half. The remediation work will be overseen by the U.S. Environmental Protection Agency (EPA) and the Navajo Nation Environmental Protection Agency.

The Navajo Nation comprises more than 27,000 sq mi within Utah, New Mexico, and Arizona. The territory is home to more than 500 abandoned uranium mines, the result of a mining boom that began in the 1940s in response to the U.S. government's efforts to develop atomic weapons and energy. Approximately 30 million tons of uranium ore were mined within or near the Navajo Nation between 1944 and the mid-1980s. The U.S. Atomic Energy Commission was the sole purchaser of uranium until 1966, when commercial sales of uranium began. The commission stopped buying uranium in 1970, and the last uranium mine in the Navajo Nation closed in 1986.

From roughly 1950 through the late 1960s, two corporate predecessors of Cyprus Amax—the Vanadium Corporation of America and the Climax Uranium Company—together with Western Nuclear, "operated at least 77 uranium mines" on Navajo Nation lands, according to a January 17 complaint filed by the U.S. Department of Justice in the U.S.

District Court for the District of Arizona. The mining involved "exploratory activities, digging open pits, and mining underground pit walls," according to the complaint. These activities "resulted in waste piles, exploration drill holes, and mine equipment debris" at the mine sites, the complaint noted. The waste piles "contain low-grade uranium, associated radioactive materials (including radium-226), and other heavy metals that were not separated from the overburden" that was removed as part of the mining activities, according to the complaint. Navajo Nation communities are located close to the mine sites, and some are downstream and downwind from waste piles at the mine sites. "The residents graze sheep, cattle, and horses, and collect herbs in the vicinity" of the mine sites, according to the complaint.

Also submitted on January 17 to the same court, the proposed settlement resolves the claims of the United States against the two companies, the claims of the Navajo Nation against the United States and against the two companies, and the claims of the two companies against the United States. Ultimately, Cyprus Amax and Western Nuclear "agree to perform removal site evaluations, engineering evaluations and cost analyses, and cleanups at the 94 mines," according to a January 17 news release jointly issued by the U.S. Department of Justice and the U.S. EPA. The consent decree was subject to a 30-day comment period and approval by the court.

After the settlement has been finalized, the "first component of work will include the assessment of 31 mines," according to Margot Perez-Sullivan, a U.S. EPA spokesperson, who provided written responses to questions from *Civil Engineering*. "After assessment, a cleanup decision will be made for each mine, with design and construction to follow, if required," Perez-Sullivan said. "Throughout this process, [the U.S.] EPA will work closely with the Navajo Nation, the affected communities, and local chapter governments," she said.

"This remarkable settlement will result in significant environmental restoration on Navajo lands and will help build a healthier future for the Navajo people," said John Cruden, the

Civil Engineering NEWS

assistant attorney general for the U.S. Department of Justice's Environment and Natural Resources Division, in a January 17 news release.

"This historic settlement will clean up almost twenty percent of the abandoned mines on the Navajo Nation," said Alexis Strauss, the acting administrator for the U.S. EPA's Region 9, in the same January 17 news release. "Cleaning up the uranium contamination continues to be a top environmental priority for our Regional office," Strauss said. (The Navajo Nation Environmental Protection Agency did not return calls from *Civil Engineering* requesting comment for this article.)

"The decree is the culmination of an extensive, arms-length negotiating process between [the U.S.] EPA, [the U.S. Department of Justice], and the Freeport-McMoRan affiliates that started several years ago and reflects a shared commitment to a fair compromise that will be funded by the Freeport-McMoRan affiliates and the U.S. government," said Eric Kinneberg, the director of external communications for Freeport-McMoRan, in a written response to questions from *Civil Engineering*. "It will allow all parties to cooperatively address an environmental issue that has long been an important concern to the Navajo people and, furthermore, will provide job opportunities for members of the Navajo Nation for environmental investigation and remediation work at 94 former uranium mine sites," Kinneberg said. In terms of surface area, the 94 sites range in size from 0.6 to nearly 180 acres.

Since 2008, the federal government has spent more than \$130 million on remediating abandoned uranium mines in the Navajo Nation. Meanwhile, other agreements continue to facilitate additional cleanup work on Navajo lands. For example, a 2014 settlement involving Anadarko Petroleum Corporation, of The Woodlands, Texas, provided \$985 million to the U.S. EPA to clean up approximately 50 former uranium mines that had been operated by the corporation's subsidiaries. The agency began fieldwork associated with these locations last year. —JAY LANDERS

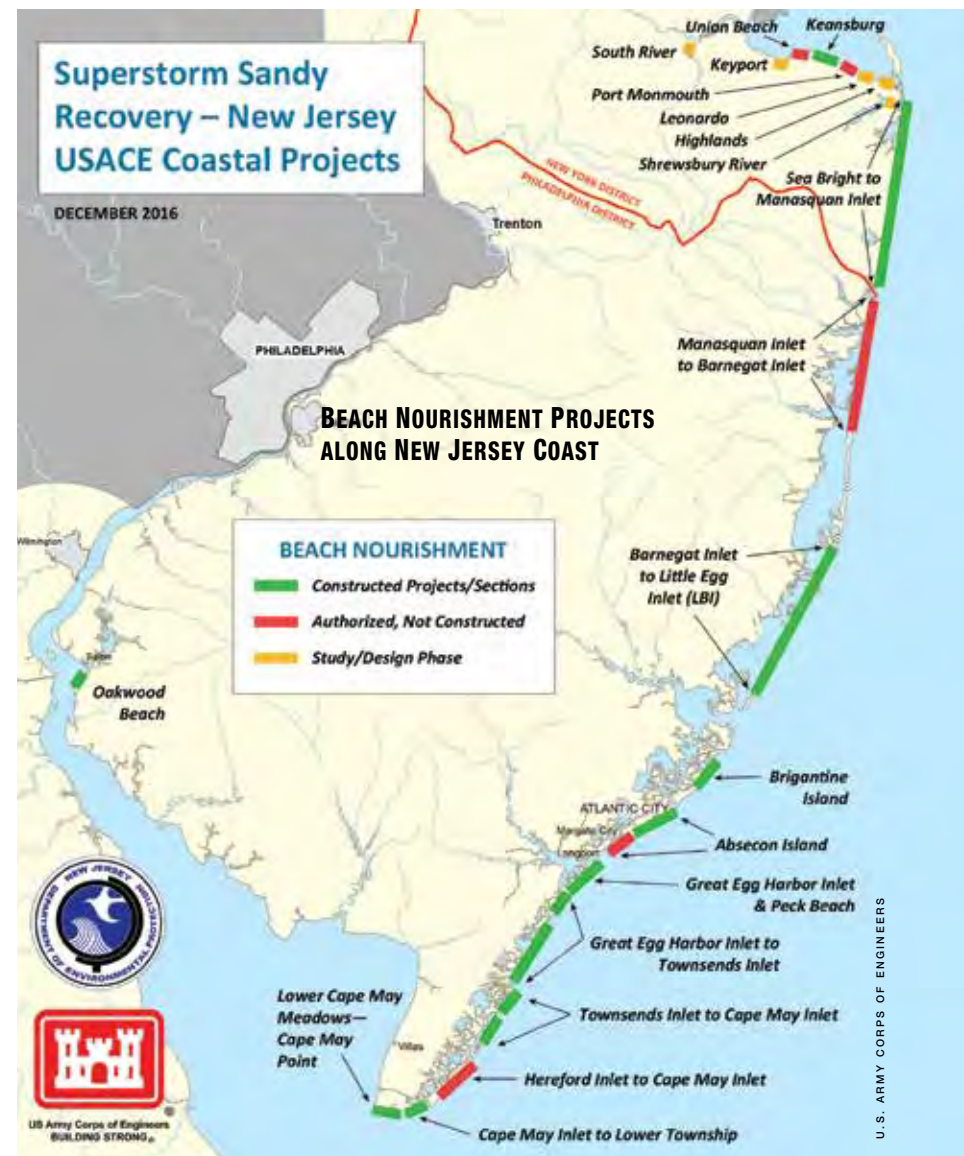
RESILIENCY Army Corps Completing Post-Sandy Risk Reduction Projects

AS THE FOURTH anniversary of Hurricane Sandy and its effects on the northeastern seacoast of the United States passed in late October, the U.S. Army Corps of Engineers was working to complete the majority of some 159 projects and studies undertaken to provide better protection from future storms from Maine to Virginia. The Corps's goal is to complete approximately 85 percent of the remaining work by the fifth anniversary of the storm this year.

Congress appropriated more than \$5.1 billion to the Corps for post-San-

dy repairs under the Disaster Relief Appropriations Act of 2013. More than \$4.1 billion of that amount was appropriated to the Corps's North Atlantic Division to fund those 159 projects, explains Joseph Forcina, P.E., the chief of that group's Hurricane Sandy Coastal Management Division.

Within the Corps's Flood Control and Coastal Emergencies program, 25 existing projects were approved for repair or restoration, and all 25 have been completed, Forcina says. These involved previously constructed beach nourishment projects that had been battered by Sandy, most of them in New York and New Jersey. As part of these Flood Control and Coastal Emergencies efforts, the Corps placed more than 26 million cu yd of sand, more than half of the total 50.1 million cu yd



of sand that it used for all of its post-Sandy efforts, according to an October 27 Corps press release.

Likewise, some 79 of 86 projects in the Operations and Maintenance program, which deals with navigation channels that were silted in by the storm or piers and hurricane barriers that were damaged, had been completed by the end of 2016. Another such project was completed early this year, and five more are scheduled for completion by the summer, Forcina says. The sole

Coney Island beaches were replenished as part of the risk reduction projects carried out by the U.S. Army Corps of Engineers in the aftermath of Hurricane Sandy. Offshore, a dredging vessel pumps sand onto a New Jersey beach via a pipe with a screening basket to filter out foreign objects. Bulldozers then use the dredged sand to construct a dune and berm system to provide protection from storms.

project remaining, the Caven Point Marine Terminal, in Jersey City, New Jersey, was so heavily damaged by the 5 ft high wall of water generated during Sandy and the changing conditions at the site that it will probably not be restored until the end of the year, Forcina explains.

Nineteen projects designated as authorized but unconstructed (ABU) also are in the works and are expected to require more than \$2 billion of the total appropriation, Forcina notes. These projects do not involve



Civil Engineering NEWS

repairs or restoration; rather, as their designation implies, these are projects for reducing the risk of storm damage that had been approved before Sandy and either had not been initiated at the time of the storm or were not yet completed, Forcina explains. They involve beach fill, dune construction, floodwalls, detention basins, and the raising of some structures, he adds. One lesson learned from Sandy is that sites that have sand dunes, either natural or man-made, perform better in terms of flood control and storm damage than sites without them, Forcina notes.

Four ABU projects were completed by the end of 2016, eight were under construction at press time, and the remaining seven will be ready to construct once the Corps can coordinate the work with state and local officials.

Difficulties in obtaining the lands necessary to construct some of the ABU projects, however, have slowed parts of the program, Forcina notes. To move forward with the ABU projects, the Corps also had to verify key criteria regarding these projects.

“Basically, we went back and looked at the authorizing documents that were in place at the time these projects were authorized and updated them to reflect the current science and to ensure they had the three *Es*,” Forcina says, which means that the projects were economically justified and environmentally acceptable and that the engineering was technically feasible.

As part of the long-term recovery and restoration efforts, the Corps will also be working on some 17 studies dealing with coastal storm damage and risk reduction that had been in progress at the time the storm struck. These studies will seek to characterize the post-Sandy conditions at the designated study areas in New York, New Jersey, Rhode Island, and Delaware and to develop alternative approaches for reducing risks, Forcina says. Two of the studies were completed at press time; six more had been or will be removed from the program because there was no nonfederal sponsor (a requirement for

all Corps projects); one had been shifted to the Corps’s Continuing Authorities Program, which covers smaller projects; and the remainder were in various stages of completion, Forcina says, with the last expected to be completed during the summer of 2018.

A dozen other projects under the Continuing Authorities Program are being completed as part of the post-Sandy efforts using existing authorizations from Congress.

The Corps will also be investigating nine coastal areas demarcated as part of the North Atlantic Coast Comprehensive Study, a \$19-million collaborative effort that involved the

ONE LESSON LEARNED
from Sandy is that sites that have sand dunes, either natural or man-made, perform better in terms of flood control and storm damage than sites without them.

Corps, government and academic experts, and others. The results of that study, which examined risk reduction measures along the 31,000 mi of coastline that had been affected by Sandy, were presented to Congress in January 2015.

The North Atlantic Coast Comprehensive Study considered a systemwide, “general, broad overview of the coast,” Forcina says, whereas the new studies will “be more targeted to specific communities.” For example, studies will consider issues ranging from subsidence and rises in sea level around Norfolk, Virginia, to the inundation experienced during Sandy in the back bay areas of New Jersey. At the same time, the new studies will try to adhere to a systems approach in developing alternative plans and courses of action, as opposed to merely recommending individual projects in one location or another, Forcina says.

—ROBERT L. REID

BUSINESS BRIEFS

Jacobs, a 54,000-employee multidisciplinary engineering firm that is based in Dallas and operates globally, has purchased Aquentia Consulting, a 220-person firm based in Australia. Aquentia focuses on project and risk management, asset management, and project planning services and operates not only in Australia but also in New Zealand, the Middle East, and Europe. The acquisition will help Jacobs target the growing Australian transportation market, among other sectors.

ERRATUM

A statement in the History Lesson of the December issue, “Jones Island Sewage Plant” (pages 42–45), reads, “The Jones Island Sewage Plant was accorded landmark status in ASCE’s Historic Civil Engineering Landmark Program in 1974 and is the only sewage treatment plant to be so honored.” In fact, the River des Peres Sewage and Drainage Works also became a civil engineering landmark in 1988. We regret the error. ASCE’s Historic Civil Engineering Landmark Program acknowledges achievements of national or international significance. Sections and branches of the Society also have programs to recognize projects of local importance.