Halting Hypoxia

To address hypoxia in the Gulf of Mexico, the enormous amounts of nutrients entering the water body via the Mississippi River must be reduced. Achieving this goal will require an array of actions and strategies across a broad swath of America's heartland. Despite their enormous financial and technical challenges, these activities are also likely to generate environmental benefits extending well beyond the Gulf itself. **By Jay Landers**

The Gulf of Mexico's immense "Dead Zone"—an annually recurring phenomenon characterized by hypoxia, or low levels of dissolved oxygen—illustrates the extent to which land uses, in some cases thousands of miles away, can affect one of the world's largest bodies of water. Nutrients released from farm fields or urban areas throughout much of the United States travel via the Mississippi River downstream to the Gulf, creating a zone of hypoxia larger than some small states. Although the problem has been recognized for more than two decades, solutions have been slow in coming. Today, an awareness of the myriad efforts that will be needed to halt hypoxia in the Gulf is beginning to take shape. But will this awareness turn into action anytime soon?

Draining approximately 40 percent of the contiguous United States, the Mississippi is the largest river in North America. Given its size, its influence on the Gulf is significant. The Mississippi and its major distributary—the Atchafalaya River, which enters the Gulf approximately 125 mi (200 km) to the west of the Mississippi's delta—together supply roughly 80 percent of all freshwater entering the Gulf. The two rivers are also the predominant sources of nitrogen and phosphorus entering the Gulf, contributing 91 percent of the estimated annual nitrogen load and 88 percent of the estimated phosphorus load.

Between 1985 and 2005, annual nitrogen loads to the Gulf ranged from 893,000 to 2.4 million tons (810,000 to 2.2 million metric tons), while phosphorus loadings during that period ranged from 89,000 to 198,000 tons (80,700 to 180,000 metric tons). This extensive influx of nutrients into the Gulf can trigger excessive algal growth in the upper water column, a process known as eutrophication. As this growth dies and sinks to the seabed, aerobic bacteria feed on the algae and other decaying matter, consuming oxygen in the process. Unless oxygen present in surface waters is diffused to the deeper areas, dissolved oxygen concentrations in the bottom waters can decline to hypoxic levels—typically defined as 2 mg/L or less—or even to anoxic levels. Hypoxic conditions typically begin during the spring and continue through the

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fall, although such major weather systems as hurricanes and tropical storms can decrease hypoxic conditions by mixing surface water containing higher dissolved oxygen concentrations with lower water levels. Hypoxia is usually absent during the winter.

Since 1985, when scientists began regularly monitoring hypoxia in the Gulf, the size of the Dead Zone has averaged 5,200 sq mi (13,500 km²). However, the extent of hypoxic conditions has grown in recent years. Between 1985 and 1992, the Dead Zone on average encompassed 3,170 sq mi (8,200 km²). Since then, it has averaged 6,140 sq mi (15,900 km²), although the past five years have seen an average hypoxic zone of 4,050 sq mi (10,500 km²). The largest area of hypoxia so far, 8,500 sq mi (22,000 km²), was in 2002. During midsummer, hypoxic conditions can extend laterally from the Mississippi west to the upper Texas coast and as far as 78 mi (125 km) offshore.

Prolonged exposure to low levels of dissolved oxygen stresses marine animals. Faced with hypoxic conditions, bottom-dwelling fish, crabs, and shrimp will seek areas with higher levels of dissolved oxygen. Depending on its size and duration, the Dead Zone can have severe local effects on the Gulf's otherwise lucrative commercial fishing industry.

Concerns regarding hypoxia in the Gulf are not new. In 1997 the U.S. Environmental Protection Agency (EPA) created the Mississippi River/Gulf of Mexico Hypoxia Task Force to bring together representatives of federal agencies, states, and tribes to evaluate options for addressing the problem. In 2000 the Committee on Environment and Natural Resources, part of the White House's National Science and Technology Council, released its *Integrated Assessment of Hypoxia in the Northern Gulf of Mexico*, a report that concluded that excess nitrogen from the basin of the Mississippi and Atchafalaya rivers, combined with stratification of the Gulf's waters, was the cause of the hypoxia. The following year, the task force issued its *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*. Among other goals, the plan called for reducing the hypoxic zone's areal extent so that by 2015 the yearly average over any five-year period will be less than 1,930 sq mi (5,000 km²).

This goal has not been met.

In 2005 the task force set out to update the science underpinning the two reports given above. As part of this process, the EPA asked its Science Advisory Board (SAB) to review recent findings regarding hypoxia in the Gulf and to evaluate certain issues and questions. The SAB's Hypoxia Advisory Panel released its report—*Hypoxia in the Northern Gulf of Mexico: An Update by the EPA Science Advisory Board*—this past January.

The 333-page report finds that "scientific understanding of the causes of hypoxia has grown while actions to control hypoxia have lagged" since publication of the *Integrated Assessment of Hypoxia in the Northern Gulf of Mexico*. Because of this inaction, the goal enunciated in the *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico* to reduce the hypoxic zone to 1,930 sq mi (5,000 km²) by 2015 "may no longer be possible," says the SAB's report. Whereas the National Science and Technology Council's assessment attributed hypoxia in the Gulf to elevated levels of nitrogen, the SAB's report presents a more complicated picture, implicating phosphorus as well: "Contrary to conventional wisdom that [nitrogen] typically limits phytoplankton production in near-coastal waters, the [northern Gulf of Mexico] exhibits an unusual phenomenon whereby [phosphorus] is an important limiting constituent during the spring and summer in the lower salinity, near-shore regions."

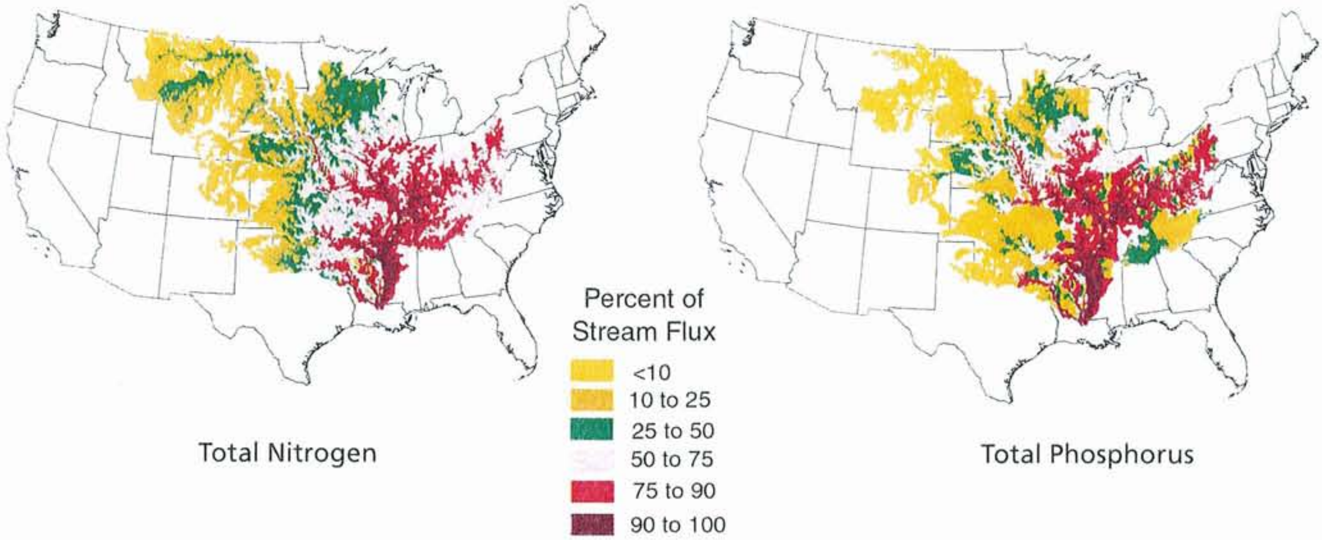
EPA Science Advisory Board

Nutrients released from farm fields and urban areas throughout much of the United States travel via rivers and watersheds to the Mississippi River and then proceed downstream to the Gulf of Mexico, creating a zone of hypoxia larger than some small states. This "Dead Zone," an annually recurring phenomenon characterized by low levels of dissolved oxygen, is detrimental to marine animals and threatens the lucrative fishing industry.

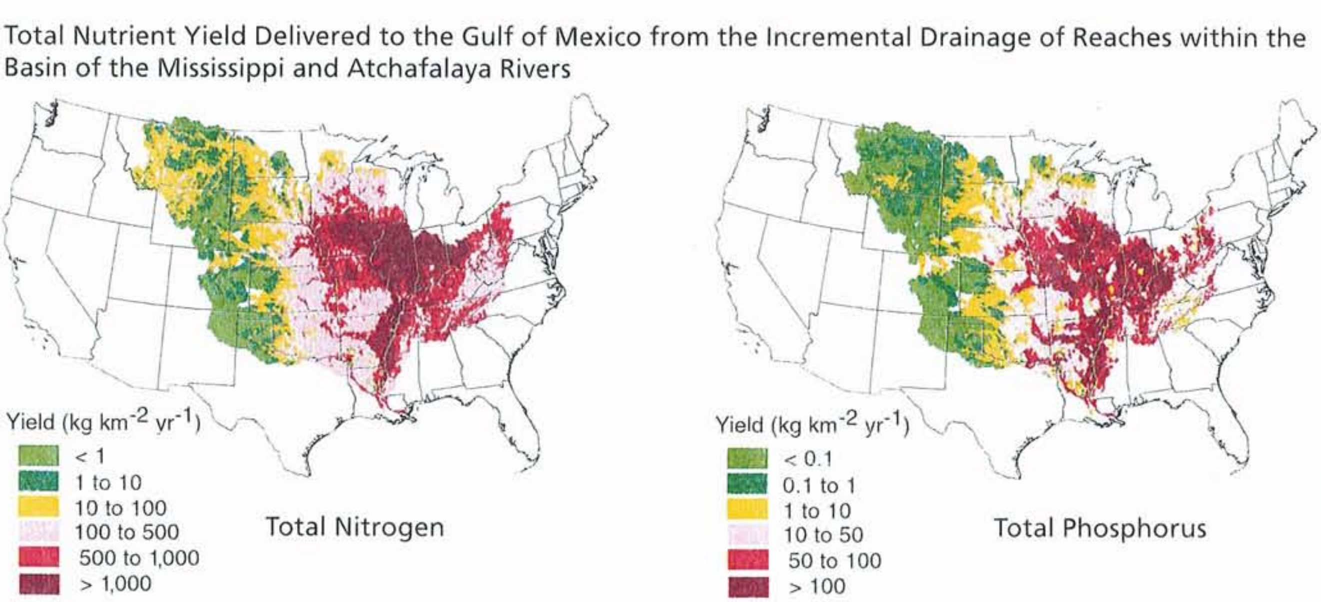
Because both nutrients "contribute to [the] excess phytoplankton production and hypoxia associated with such production," the SAB's report states, nitrogen and phosphorus "will need to be reduced concurrently to make progress in reducing the size of the hypoxic zone." To this end, the SAB calls for a "dual nutrient strategy" that seeks to reduce nitrogen and phosphorus loadings from the Mississippi to the Gulf by 45 percent.

Of course, decisions about how to meet this or any goal for reducing nutrients in the Gulf require a detailed understanding of their sources and amounts, particularly in light of the vast size of the Mississippi basin. Recent findings by the U.S. Geological Survey (USGS) help to shed some light in this area. According to a

Percentage of Stream Nutrient Load Delivered to the Gulf of Mexico from the Incremental Drainage of Reaches within the Basin of the Mississippi and Atchafalaya Rivers



Total Nutrient Yield Delivered to the Gulf of Mexico from the Incremental Drainage of Reaches within the Basin of the Mississippi and Atchafalaya Rivers



USGS report published this year in the February 1 issue of *Environmental Science & Technology*, agricultural sources contribute more than 70 percent of the nitrogen and phosphorus delivered to the Gulf. The findings, which are based on a water quality model developed by the USGS, indicate that 52 percent of the nitrogen and 25 percent of the phosphorus come from corn and soybean crops. Meanwhile, urban sources contribute approximately 9 percent of nitrogen and 12 percent of phosphorus. Another 16 percent of the nitrogen delivered to the Gulf is a result of atmospheric deposition.

The USGS study also examined nutrient contributions from individual states located within the Mississippi watershed. The study estimated that nine states—Illinois, Iowa, Indiana, Missouri, Arkansas, Kentucky, Tennessee, Ohio, and Mississippi—which constitute only one-third of the watershed, contribute more than 75 percent of the nitrogen and phosphorus to the Gulf. The study highlights the fact that a "disproportionate amount of nutrients is coming from a relatively small area within the Mississippi basin," says Richard Alexander, a USGS research hydrologist and the principal author of the *Environmental Science & Technology* article.

The study also estimated the percentages of the nutrient loads in streams in the Mississippi basin that are delivered to the Gulf. In the central and eastern regions, most small to

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midsized streams deliver 50 to 75 percent of their nutrients to the Gulf, whereas streams in the western region deliver less than 25 to 50 percent of their nutrients, according to the study. These findings reflect the fact that lower flows and longer river distances in western waterways enhance in-stream removal of nutrients via denitrification and other natural processes. Reservoirs also were found to play a significant role in reducing the amount of phosphorus delivered to the Gulf.

As a result, efforts to reduce nutrient loads in streams and rivers in the central and eastern regions of the Mississippi basin can be expected to have a greater effect than similar efforts to reduce loads in western waterways. "The most efficient way to have an impact downstream on removal is to focus on areas where there is very little natural removal of nitrogen or phosphorus," Alexander says. "That's an important notion."

In other words, it makes more sense economically to seek nutrient reductions in, say, the Midwest, where in-stream removal of nutrients is low, than in the western fringes of the Mississippi's watershed. The study's results also indicate that efforts to reduce phosphorus are likely to be more effective if located downstream of reservoirs.

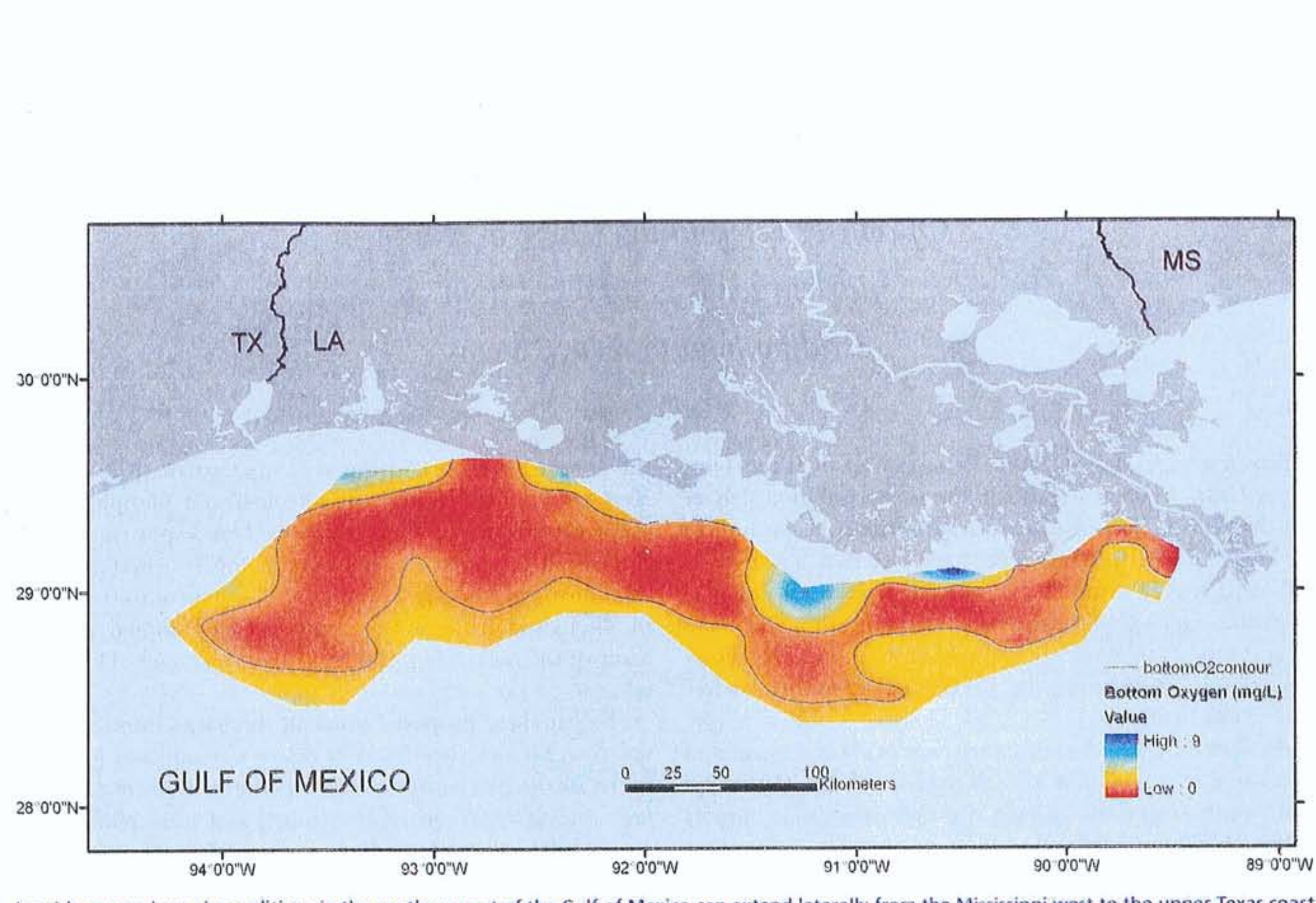
Of course, determining where to reduce nutrient loads is a far cry from deciding how to reduce them. Although science plays a role, political and economic considerations tend to dominate such determinations, a fact that is reinforced by the vastly different regulatory approaches under which point sources and distributed sources operate. Point sources, including municipal wastewater treatment plants (WWTPS), are strictly regulated under the Clean Water Act, the nation's foremost law for protecting water quality. Except for certain confined animal feeding operations, agriculture is not subject to the Clean Water Act. States, meanwhile, may prescribe limits on, say, the amounts and location of manure applied to fields, but typically little direct regulation of agricultural activities occurs.

From a regulatory perspective, then, municipal WWTPS offer a relatively straightforward avenue for reducing nutrient loadings. Because they are subject to the Clean Water Act, treatment facilities can be required to reduce nutrient loadings as a condition of their discharge permits. In fact, the SAB, in its report to the EPA, suggests that the agency consider "tighter limits" on nitrogen and phosphorus in discharges from WWTPS within the Mississippi watershed. According to the SAB's report, reducing concentrations of total nitrogen to 3 mg/L and total phosphorus to 0.3 mg/L in discharges from WWTPS could reduce annual average loads of the nutrients to the Gulf by respectively 11 and 21 percent.

To put these proposed nutrient discharge limits in perspective, the SAB assumes in its report that advanced WWTPS in the Mississippi basin currently discharge effluent containing concentrations of total nitrogen and total phosphorus on the order of respectively 11.2 and 2.02 mg/L. However, most plants in the Mississippi basin do not have treatment processes to remove phosphorus, and efforts to address nitrogen are typically limited to converting ammonium to nitrate to comply with effluent limits for ammonia, according to the SAB's report. Meanwhile, plants with less than advanced treatment are assumed to discharge effluent containing concentrations of total nitrogen and total phosphorus on the order of respectively 15 and 4 mg/L.

The SAB's estimates regarding the reductions in annual nutrient loads that could be expected from tighter nutrient discharge limits are based on its calculations that point sources contribute more nutrients to the Gulf than previously thought. The *Integrated Assessment of Hypoxia in the Northern Gulf of Mexico* estimated that point sources supply approximately 11 percent of total nitrogen and an undefined though presumably lower amount of total phosphorus. Based in part on subsequent studies, the SAB significantly increased these estimates, calculating that point sources contribute approximately 22 percent of total nitrogen and 34 percent of total phosphorus to the Gulf.

As the SAB points out in its report, its calculations "assume that the point-source load is delivered" to the Gulf "without any in-stream losses." In other words, a pound of nitrogen discharged from a WWTP in Chicago, for example, is assumed to reach the Gulf intact, with no reductions from denitrification or other processes. By contrast, the USGS study—which estimated much smaller nutrient contributions from "urban sources," a broader category that includes point-source dischargers as well as such other sources as septic systems—attempted to account for in-stream losses. Because of the SAB's assumption, its calculations amount



In midsummer, hypoxic conditions in the northern part of the Gulf of Mexico can extend laterally from the Mississippi west to the upper Texas coast. The extent of the Dead Zone as it was recorded in late July 2002 was vast.

to the "upper estimate" for point-source contributions of nutrients, according to its report.

Setting aside questions about the actual nutrient contributions of point sources, the practicality of the SAB's suggestion to implement enhanced nutrient removal on a widespread basis merits scrutiny. Upgrading WWTPs throughout the Mississippi basin to achieve the nutrient reductions envisioned by the SAB is "technically feasible," acknowledges Alan Vicory, P.E., the executive director and chief engineer of the Ohio River Valley Water Sanitation Commission (ORSANCO), an interstate commission that works to improve water quality in the Ohio River and its tributaries. "But what about the cost aspect of being able to achieve it technically?" Vicory asks. Along with the expense of constructing new treatment facilities, mandating supplemental treatment is likely to boost energy usage significantly, he notes. Such a move would increase the "carbon footprint" of WWTPs at a time when many facilities are trying to find ways to reduce the extent to which their actions may contribute to global warming, Vicory says.

Furthermore, the higher operating costs associated with enhanced treatment techniques capable of achieving the limits outlined in the SAB's report could prove prohibitive for many facilities, says Peter Tennant, P.E., ORSANCO's deputy executive director. Nutrient removal should be pursued, Tennant says, but "perhaps not to the levels that are envisioned" in the SAB's report. "We're looking toward other, less energy intensive, less expensive ways to remove nitrogen," he says.

Efforts by states to adopt numerical water quality standards for nitrogen and phosphorus are eventually expected to result in more stringent nutrient limits in discharge permits for WWTPs. Although states have been developing them at a glacial pace, such standards, when adopted, will probably force many WWTPs to enhance their ability to remove nutrients. In fact, in at least one state the prospect of these standards has prompted some point sources to consider future methods for reducing nutrients or even to begin implementing such methods now.

As required by the U.S. EPA, the Illinois EPA is developing water quality standards for nutrients. While it still must overcome many hurdles before it can release its nutrient standards, the Illinois EPA has been encouraging point-source dischargers to "leave a footprint at their site where they can add nutrient removal," says Bob Mosher, the supervisor of the water quality standards unit in the Illinois EPA's water pollution control division. As a result, some facilities have already begun removing nitrogen by means of oxidation ditches or other treatment approaches. However, no figures are available regarding the amount of nitrogen removal by Illinois facilities, Mosher says.

Because of the virtual absence of regulatory controls to address farming's effects on water quality, financial incentives are the primary means for inducing farmers to decrease

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nutrient loadings. By far the largest such financial incentives take the form of the conservation programs under the purview of the U.S. Department of Agriculture (USDA) that are overseen by its Natural Resources Conservation Service (NRCS) and the Farm Service Agency. As is the case with the rest of the federal government's agricultural policies, the conservation programs are reauthorized every five years or so in legislation commonly referred to as the farm bill. At press time, House and Senate negotiators were attempting to iron out differences regarding new farm bill proposals that would boost spending on conservation programs significantly.

Such programs include the NRCS's Wetlands Reserve Program, the Environmental Quality Incentives Program, and the Conservation Technical Assistance Program, all of which seek to work with farmers to set aside land to benefit water quality and wildlife or otherwise improve conservation practices on farms. Although such programs were not established with Gulf hypoxia in mind, they can be part of the solution, says Arlen Lancaster, the chief of the NRCS. "I think it's fair to say that Congress, when it looked at creating these conservation programs, intended for us to address resource concerns wherever they are," Lancaster says. "Certainly, examples like hypoxia in the Gulf of Mexico or water quality in the Chesapeake Bay are examples of the types of projects that they anticipate these programs helping with."

Given the size of its conservation programs, the farm bill offers the largest source of federal funding for efforts that can help to reduce nutrients and address the Gulf's water problems. "It's quite conceivable that at this moment in time the farm bill is more significant for cleaning up the Gulf of Mexico and the Mississippi River valley than is the Clean Water Act," says Tracy Mehan III, a former EPA assistant administrator for water and now a principal with the Cadmus Group, Inc., a Boston-based consulting firm.

However, the farm bill's programs must do a better job of "directing existing conservation subsidies toward those areas" that provide the "most water quality impact," Mehan says. "We're not getting all the water quality benefits we should," he says, noting that funding is sometimes allocated more on the basis of politics than on maximizing environmental benefits. "Greater and more effective targeting of existing agricultural conservation dollars in the farm bill would be a step in the right direction," he says.

Given its status as a major contributor of nutrients to the Mississippi, the Midwest is a natural place to seek reductions in nutrient losses from farmland. However, the vast scale and the diffuse nature of nonpoint-source pollution necessitate a variety of solutions. Of greater importance, any attempts to reduce nutrient losses in the Midwest must account for the fact that the region's hydrology has been dramatically altered as part of an ambitious effort to drain the landscape. Although this transformation has created one of the world's most productive agricultural areas, its resulting untoward effects on water quality, locally and all the way down to the Gulf, have been profound.

The Midwest has lost approximately 80 percent of its wetlands. According to one estimate, a total of about 35 million acres (14.1 million ha) was drained between the 1780s and the 1980s in Indiana, Illinois, Iowa, Minnesota, Missouri, Ohio, and Wisconsin. As a result, millions of acres of land that once absorbed and cleansed water naturally now rapidly shunt water containing high levels of pollutants. What is more, fields are commonly leveled to prevent water from ponding, and ditches are used to remove any excess. Meanwhile, riparian zones along streams and rivers have in many cases been reduced or eliminated, compromising their ability to buffer waterways from runoff.

Just as important are the modifications below the ground's surface. Throughout the Midwest, an estimated 32 million acres (13 million ha) are now underlain with subsurface drainage systems, typically in the form of perforated tubes installed 2 to 4 ft (0.6 to 1.2 m) below the surface. Originally made from clay pipes known as tiles, the tubes are still called tiles today even though they typically take the form of plastic pipes. Installed to improve crop yields, tile systems rapidly draw down the water table beneath a field to the level of the tile.

Although subsurface drainage can help to reduce erosion and surface runoff, tiles are notorious conduits for nitrate, a highly soluble form of nitrogen. Throughout the Midwest's agricultural areas, the combination of extensive tile systems and the use of nitrogen fertilizer leads to substantial nitrate concentrations in tile drainage, particularly during winter and spring but especially after fertilizer has been applied. Compared with surface runoff, water discharged from tile systems typically contains roughly 10 times more nitrate, *Another approach that has shown promise as a means of reducing nitrate losses from tiled fields involves so-called denitrification bioreactors.*

says Don Pitts, an agricultural engineer and state water quality specialist in the Champaign, Illinois, office of the NRCS. "I can tell you how much tile is in a watershed based on the nitrate concentration" in local waterways, he says.

In the 1960s, farmers in the Midwest and, indeed, throughout the country began using greater amounts of nitrogen fertilizer, particularly on corn crops. After peaking in the early 1980s, the average amount of nitrogen applied per acre of corn has remained relatively steady despite significant increases in yields, says Don Parrish, the senior director of regulatory relations for the American Farm Bureau Federation, of Washington, D.C. In fact, Parrish says, recent studies have indicated that in some Midwestern states more nitrogen is being removed from fields in the form of harvested grain than is being applied as fertilizer. Although more research on this topic is needed, Parrish says, such findings cast doubt on the prospects for significant reductions of nitrogen fertilizer use. Yet Parrish acknowledges that nitrate concentrations remain a problem in waterways receiving agricultural runoff. Rather than seek to reduce nutrient inputs in farming, "we have to figure out how to manage the hydrology," he maintains.

However, the sheer size and scope of the Midwest's tile networks pose a daunting challenge to efforts to reduce the region's effects on Gulf hypoxia, says William Mitsch, a professor at Ohio State University. "The Midwest is tiled better than most cities are drained," he says. "It's a system that's perfectly designed to get nitrogen down to the Gulf of Mexico."

It is also a system that continues to expand as tiles are added in new locations or existing subsurface drainage systems are enlarged. "Tile-drained soils are the most productive in the region," Pitts says, "and without tile drainage these fields would not be economically farmable." Because tiles can boost crop yields, he says, "there's a big economic force to put more tiles in." In Illinois, where roughly 10 million acres (4 million ha) of farmland are underlain with tiles, "the intensity of the drainage from these soils and fields continues to increase," Pitts says.

Despite tile drainage's significant contributions of nutrients to waterways, conservation practices traditionally have done little to address the problem, says Dennis McKenna, the manager of the pesticide labeling and technical services section within the Illinois Department of Agriculture's environmental programs bureau. "Historically, conservation programs have been targeted toward erosion control," McKenna says. However, "the greatest nitrate losses are in flat, black, tile-drained landscapes that have very little erosion occurring," he says. Until recently, such areas "have not surfaced as priorities because they don't have an erosion problem," McKenna notes.

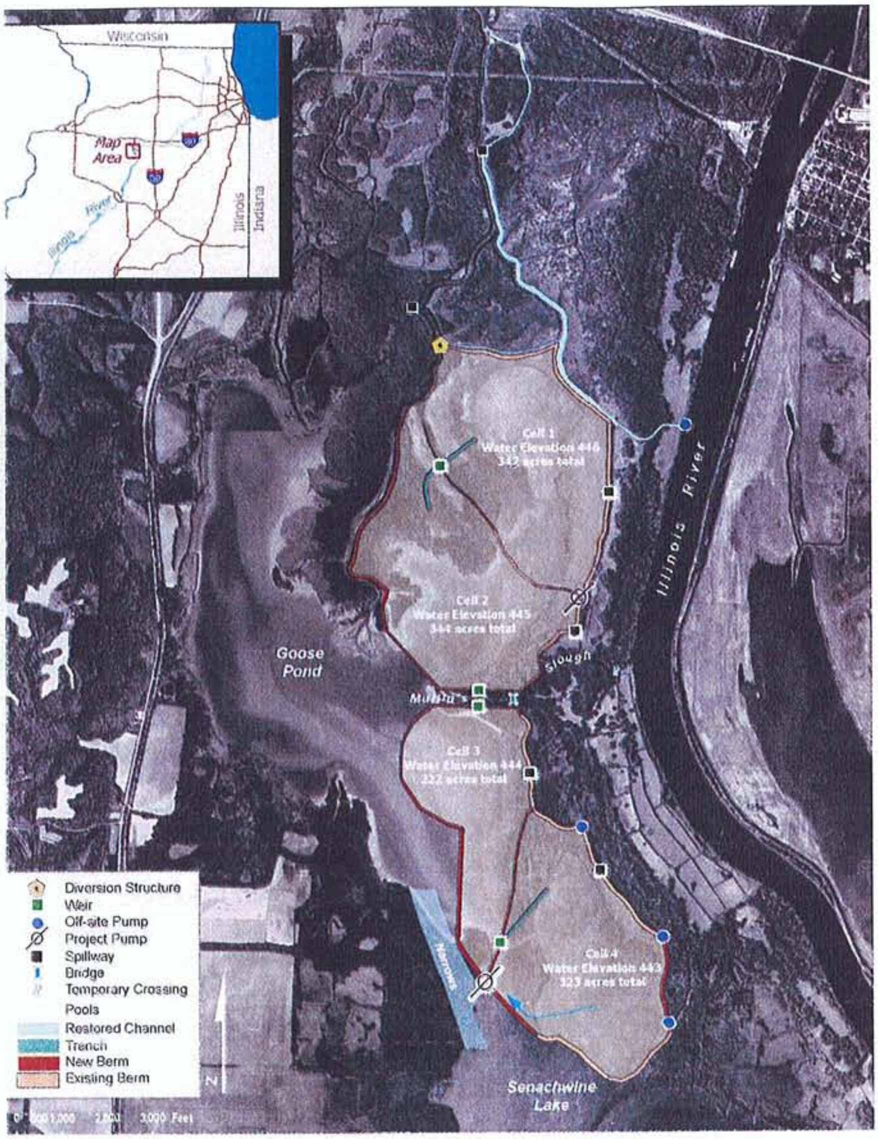
Fortunately, efforts to reduce nitrate losses from subsurface drainage systems have gathered pace in recent years. Along with growing winter forage or cover crops and improving fertilizer application rates and timing, the practice known as drainage water management has received additional attention. Essentially, the approach uses a water control structure within a pipe or drainage outlet to vary the depth to which the water table is drained in a field. After harvest, the control structure is raised, increasing a field's water table and decreasing the amount of water discharged from the outlet. When a farmer needs to drain the field, the control structure is lowered. After planting, a farmer can raise the structure to store water below the surface for the growing crops.

By reducing the amount of water discharged from a field, drainage water management helps to decrease the amount of nitrate that otherwise would enter the nearest waterway. In areas of the Midwest where significant amounts of water drain from tile systems during the fallow season, when the need for drainage is much lower, significant reductions in nitrate loadings can be achieved. "It's the most effective practice that we have for the reduction of nitrate in the Midwest," Pitts says. It also has the potential to benefit farm production by enabling farmers to manage drainage during the growing season in an attempt to make more water available to meet the needs of their growing crops.

Because drainage water management requires fairly flat fields in which tile systems have been laid out in a particular manner, "the amount of acreage that we can impact with this practice is not as much as I'd want," Pitts says. Although the practice offers a relatively straightforward method for reducing nitrate loads from agricultural areas, convincing farmers to try a new approach can be difficult. "This technology has made some inroads," he says, "but it's not easy changing people's behavior."

Another approach that has shown promise as a means of reducing nitrate losses from tiled fields involves so-called denitrification bioreactors. Designed to be relatively inexpensive and easy to install, the bioreactors employ wood chips or another readily available carbon source to supply energy to denitrifying bacteria present below the surface. Placed in trenches constructed along either side of a tile drain, the wood chips facilitate denitrification of the nitrate-laden water as it passes through the trenches on its way to the tile. Such systems can also be constructed at the outlet of a drainage pipe.

As part of an ongoing study, a denitrification bioreactor installed on an Iowa State University research farm in central Iowa has been found to significantly reduce nitrate concentrations in subsurface drainage, says Dan Jaynes, a soil scientist at the National Soil Tilth Laboratory, part of the USDA's Agricultural Research Service. Compared with a control field with a conventional tile system, the bioreactor was found after five years of operation to have discharged 55 percent less mass nitrate on an annual basis, according to an article published by Jaynes and three of his Agricultural Research Service colleagues in the March/April 2008 issue of the *Journal of Environmental Quality*. Crop yields were not affected in the field outfitted with the bioreactor.



The Illinois River Nutrient Farm Pilot Project will involve transferring water from the river to four constructed wetland cells that will remove nutrients before the water can flow downstream. Pumps will be used to remove and return the water unless the river level becomes high enough for water to flow to the wetlands naturally.

Because researchers are still in the process of determining how long the wood chips can be expected to last before having to be replaced, the life-cycle costs of a denitrification bioreactor have yet to be developed. "The real issue is, how long will these systems be effective?" Jaynes asks. "The carbon has to be replaced eventually." However, he notes that the carbon at the test bioreactor in Iowa has been in use since 1999. "We have seen no loss of efficacy," he says.

Although he is certain that denitrification bioreactors can be effective in reducing nitrate losses, Jaynes notes that such systems are more likely to be used to treat drainage from nitrate "hot spots" than to be installed on tiled fields throughout the Midwest. "I don't think that this kind of approach is going to be universally adapted to the entire Corn Belt," he says. "It's more of a focused application."

However, if cost-sharing programs were to help cover installation costs, Jaynes says, farmers would probably be more motivated to install them. To that end, he notes, a handful of groups, including conservation and farm organizations, are looking to help farmers employ bioreactors.

Water quality trading programs could be another means of helping farmers implement methods for reducing nutrient losses from agricultural land. In general, it often costs significantly more to remove an equivalent amount of a pollutant from a point source than from a distributed source. Therefore, trading programs offer a potential mechanism whereby point sources could cost-effectively comply with discharge requirements by paying distributed sources to reduce their pollutant loadings by a certain amount. Although few states have developed regulatory frameworks for such programs, the U.S. EPA views the concept as a potentially viable approach to reducing nutrient loads to the Gulf. "We think in the Mississippi and Atchafalaya river basin, as well as other areas of the country, one of the most promising policies and innovative financing solutions is through water quality trading," says Benjamin Grumbles, the EPA's assistant administrator for water.

Photograph courtesy of N. N. Rabalais, Louisiana Universities Marine Consortium

The Mississippi's brown, sediment-laden plume travels downstream until it meets the clearer waters of the Gulf. Rich in nutrients, the water promotes the growth of algae in the Gulf. The algae's eventual decomposition leads to low levels of dissolved oxygen in a broad swath of the Gulf along the Louisiana coast.

While acknowledging the promise of water quality trading, many states continue to have concerns about the feasibility of such an approach, says Rob Morrison, P.E., the chief of the water pollution control branch within the Missouri Department of Natural Resources. Such concerns include the question of how to determine "appropriate credits and ratios" among participating point sources and distributed sources, he says, as well as how to ensure that promised reductions actually occur. Until such questions have been explored more fully, Morrison says, water quality trading is not likely to play a major role in helping to reduce nutrient loads in waterways.

Because of their ability to effect denitrification, wetlands and riparian areas can act as highly effective "nitrogen sinks." Plants and other organisms in wetlands can also sequester nitrogen, while phosphorus can be curtailed via sedimentation or other physical processes common to wetlands. For these reasons, many view the restoration or creation of wetlands as a vital step in the effort to shrink the Dead Zone. To be effective, however, this approach must be conducted on a vast scale.

To this end, Ohio State's Mitsch has called for the restoration or creation of more than 5 million acres (2 million ha) of wetlands throughout the Mississippi basin, an amount that he estimates could reduce nitrogen loads to the Gulf by 40 or even 50 percent. Although such a goal may seem overly ambitious, Mitsch notes that it amounts to less than 1 percent of the land area in the Mississippi basin. And given the historical loss of wetlands throughout the watershed, "there are plenty of places [in which] to put them back," he says.

However, Mitsch is also realistic, acknowledging that such a goal exceeds the current pace of efforts to conserve and restore wetlands in the United States. In a 2005 article, Mitsch noted that wetland mitigation and enforcement actions overseen by the U.S. Army Corps of Engineers under the Clean Water Act resulted in an estimated net gain of only 83,000 acres (33,600 ha) throughout the entire nation between 1995 and 2005. Such an amount is "trivial" in relation to the number of acres of wetlands needed to reduce hypoxia in the Gulf, Mitsch says. The farm bill's conservation programs, however, have been more successful. Between 2000 and 2006, the NRCS created, enhanced, or restored 1.4 million acres (567,000 ha) of wetlands in the Mississippi basin, says the NRCS's Lancaster.

Whatever their pace, programs to create and restore wetlands must locate such features strategically, Mitsch says, to maximize their ability to reduce the amount of nutrients that end up in the Gulf. In particular, two strategies for restoring and creating wetlands should be pursued, Mitsch says. The first is the creation and restoration of so-called farm runoff wetlands expressly designed to intercept water as it leaves agricultural areas but before it enters nearby streams and rivers. The second involves diverting river water into wetlands constructed in a river's floodplains.

Any plan that calls for converting millions of acres, much of it farmland, into wetlands must overcome two major hurdles: the need for funding and an unwillingness on the part of farmers to withdraw land from production.

To ensure maximum effectiveness, farm runoff wetlands should be located as close to fields as possible so that they can collect water before it enters a ditch or stream. "You have to intercept the tiles," Mitsch says. Citing previous studies conducted in Illinois and Ohio, he notes that such projects have succeeded in retaining significant quantities of nitrates. Bottomland hardwood forests along streams and rivers also can be used to intercept subsurface drainage. However, such forests typically retain less nitrogen per unit area than wetlands.

So-called river diversion wetlands, the second type advocated by Mitsch, are designed to intercept large quantities of nutrients present in rivers during floods. Situated in a river's floodplain, these wetlands can be located behind a levee or can take the form of such features as oxbow lakes and backwater swamps. Water is either pumped over the levee into the wetlands or it enters the wetlands naturally via gravity flow.

Having constructed and studied just such a diversion wetland, Mitsch is a believer in their ability to remove nutrients and improve water quality. In 1994 a pair of 2.5 acre (1 ha) diversion wetlands were completed at an Ohio State site in Columbus adjacent to the Olentangy River. Known as the Wilma H. Schiermeier Olentangy River Wetland Research Park, the facility uses pumps to continuously transfer water from the river to the wetlands. The water then flows via gravity back to the river through a swale and stream system. Other wetland features have since been added to the research park, including an oxbow wetland. Research at the facility thus far has found that the diversion wetlands have acted as nutrient sinks, retaining on average 35 percent of nitrate by mass and concentration.

Significantly larger diversions have also been found to help remove nutrients from river flows. John Day, a professor emeritus in Louisiana State University's oceanography and coastal sciences department, has evaluated the extent to which wetlands in the Mississippi's delta remove nitrate from water diverted from the river. In particular, Day has studied the performance of wetlands receiving freshwater from the Caernarvon diversion structure, which is located about 10 mi (16 km) south of New Orleans. Among the largest diversions on the Mississippi, the structure delivers water to a 100 sq mi (260 km^2) wetland that discharges to Breton Sound, in southeastern Louisiana. Depending on the sampling location, the Caernarvon wetland retained between 39 and 92 percent of nitrate by mass and concentration.

Nutrient removal, however, was not the reason that the Caernarvon diversion was constructed. Instead, the structure was built to help restore Louisiana's diminishing coastal marshlands by enabling the river to deliver sediment to wetlands. Yet the results thus far indicate that large-scale diversions along the Mississippi could play a role, albeit a small one, in helping to curb hypoxia in the Gulf. With the State of Louisiana and the Corps of Engineers seeking to create more diversions, Day notes that "diverting water in the Mississippi delta can help a little bit" in terms of reducing nutrients, possibly addressing on the order of 5 to 10 percent of the hypoxia problem.

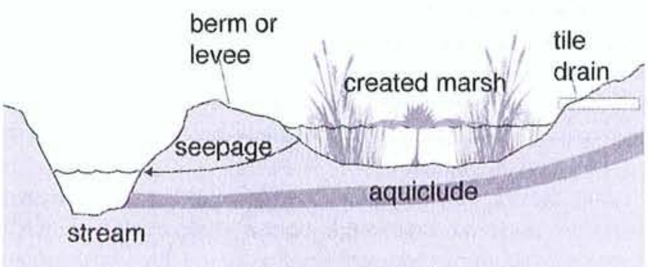
Day agrees with Mitsch that widespread restoration and creation of wetlands throughout the Mississippi basin will be of paramount importance in reducing hypoxia in the Gulf. In fact, the two have implemented a formal partnership between their universities—one of which is located in the Corn Belt and the other not far from the Gulf itself—to facilitate research into ways of addressing hypoxia. "The only economic way to deal with this nutrient problem is to use wetlands," Day says. Because of the basin's vast size and the diffuse nature of runoff from agricultural land, wetlands will need to be returned to the landscape "in thousands and thousands of places," Day says, "from anywhere from a few acres to a hundred acres to a thousand acres."

Any plan that calls for converting millions of acres, much of it farmland, into wetlands must overcome two major hurdles: the need for funding and an unwillingness on the part of farmers to withdraw land from production. Donald Hey, Ph.D., Aff.M.ASCE, the president of The Wetlands Initiative, Inc., of Chicago, believes that his organization has found a way to address both concerns. The solution, as Hey sees it, involves what he calls "nutrient farming." A variant on the concept of water quality trading, nutrient farming entails returning agricultural areas, particularly bottomland areas now used for row crops, to wetlands. Landowners, meanwhile, would then sell credits for nutrients removed by the wetlands to entities, for example, municipal WWTPs, that must reduce their own discharges of nitrogen and phosphorus but cannot do so as cost-effectively as can the wetlands.

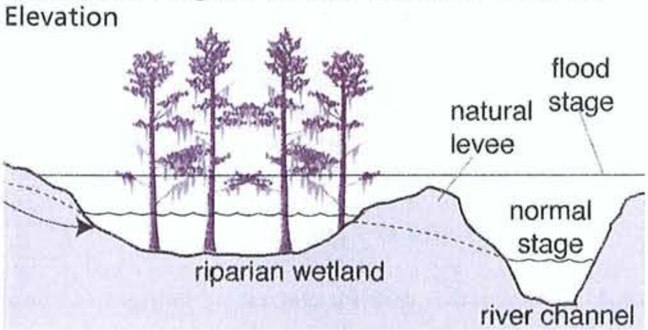
This, at least, is the concept, as nutrient farming has yet to be attempted. To test the idea, The Wetlands Initiative is preparing to conduct a pilot project at a 1,300 acre (530 ha) site on the Illinois River near Hennepin, Illinois. Known as the Illinois River Nutrient Farm Pilot Project, the effort will involve the construction of a river diversion wetland along the lines of what Mitsch advocates. To be located on floodplain property belonging to two duck hunting clubs, the project will transfer water from the Illinois River to wetlands constructed by using four cells, each ranging in size from 222 to 344 acres (90 to 139 ha). (See the map on page 61.)

Normally a pumping station will lift water from the river several feet in elevation over an outer berm and bring it into

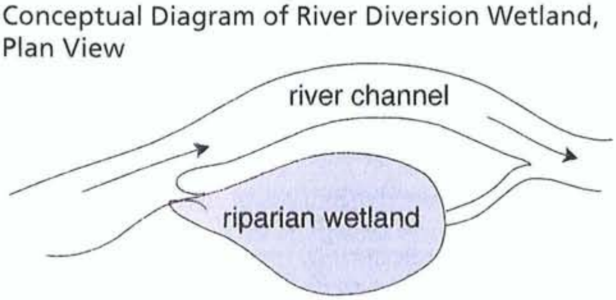
Conceptual Diagram of Farm Runoff Wetland



Conceptual Diagram of River Diversion Wetland, Elevation



Conceptual Diagram of River Diversion Wetland, Plan View



the wetlands, where it will then flow sequentially through the cells by gravity. A second pumping station will then return the treated flows to the Illinois River. However, the pumps will be turned off when the river is high enough for water to enter and exit the project unassisted.

Intended to be a research facility as well as a pilot project, the effort will entail a thorough examination of various facets of nutrient removal, Hey says. For example, although the treatment wetlands are expected to provide a detention time of seven to eight days, the pumps will have the ability to shorten detention times to less than a day. "The idea behind that is we want to see exactly what the outer limits of nutrient removal are," Hey explains. "This facility is designed as a research site, as a living laboratory. We're not pretending that this is a commercial nutrient farm."

The Wetlands Initiative expects to receive the remaining permits associated with the project this summer, Hey says, and construction could begin before year's end. All told, the project is expected to cost $60 million over a 10-year period, a figure that includes the cost of construction as well as several years of operations, maintenance, and monitoring.

Ultimately, Hey says, nutrient farming can make it possible for farmers to stop growing crops on flood-prone sites while continuing to generate revenue from the land. "The whole point of this exercise is to provide the agricultural community with an alternative source of income on these bottomlands that they're trying to grow corn and soybeans on and which get wiped out by floods," Hey says.

As an indication of the interest that wastewater treatment providers may have in nutrient farming, the project's construction expenses are expected to be borne by the Metropolitan Water Reclamation District of Greater Chicago (MWRD), the entity that owns and operates the Chicago metropolitan area's seven WWTPs, including the world's largest treatment plant, the 1.2 bgd (4.5 million m^3/d) Stickney Water Reclamation Plant. As the largest point-source discharger of nutrients in the Mississippi basin, the MWRD anticipates that eventually it will be required to reduce its nutrient loadings beyond existing requirements, says Richard Lanyon, P.E., D.WRE, F.ASCE, the MWRD's general superintendent. Compared with conventional measures for removing nutrients from wastewater, constructed wetlands offer a potentially less expensive alternative that can provide such additional benefits as improved local water quality, wildlife habitat, and flood protection, Lanyon notes. "That's why we're interested in participating" in the nutrient farm pilot project, he says.

A 2005 report authored in part by Hey and published by the Water Environment Research Foundation, of Alexandria, Virginia, concluded that the MWRD could comply with potential nutrient requirements using constructed

For their part, some states would like to see a greater federal role when it comes to developing strategies for combating Gulf hypoxia.

wetlands at significantly less cost than would be incurred in conventional treatment approaches for biological nutrient control. The report assumed that the MWRD would be required to comply with one of two sets of effluent standards: 3.0 mg/L of total nitrogen and 1.0 mg/L of total phosphorus or 2.18 mg/L of total nitrogen and 0.5 mg/L of total phosphorus. The report then estimated the costs that the MWRD would incur in reducing nutrient loadings in the effluent of its seven WWTPs to meet both standards and compared those costs with the expenditure that would be incurred in removing comparable amounts of nutrients with constructed wetlands.

Given the size of the MWRD's treatment facilities, any attempt to limit nutrients to either of the two standards will prove costly. In fact, the report determined that, depending on the nutrient standard to be met, between 189,000 and 322,000 acres (76,000 and 130,000 ha) of treatment wetlands would be needed to effect the necessary nutrient reductions, entailing a present-value cost of either \$870 million or \$1.4 billion. As expensive as that option sounds, the present-value cost to upgrade the MWRD's treatment plants was estimated to be between \$2.4 billion and \$2.9 billion, depending on the nutrient standard to be met. Moreover, the report estimated that nutrient farming would bring annual savings of 51 to 63 percent compared with the cost of constructing and operating conventional treatment facilities.

The potential savings, along with the added benefits associated with the creation and restoration of wetlands, make nutrient farming an option worth investigating fully, Lanyon says. "We're trying to use this pilot project as a demonstration project so that the technology would be available to anyone who wanted to use it," he says.

The Mississippi River/Gulf of Mexico Hypoxia Task Force is scheduled to have an updated version of its *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico* ready this month, according to the EPA's Grumbles. "We've spent the last several years gathering the latest in scientific information to get a needed update on the science of hypoxia and the most appropriate actions," he says. The revised document will include "annual operating plans" detailing "specific actions and time frames" to be carried out by task force members, Grumbles notes.

According to a draft of the updated report, a key step to be taken by federal agencies will be describing "opportunities to align existing programs with hypoxia efforts." While conducting similar efforts, states also will develop "nutrient reduction strategies" for watersheds "with the largest contributions" to the Gulf.

For their part, some states would like to see a greater federal role when it comes to developing strategies for combating Gulf hypoxia. "There needs to be some federal involvement in terms of what are appropriate goals for states to reach" regarding nutrient reductions, says the Missouri Department of Natural Resources' Morrison. The U.S. EPA "needs to set that benchmark," he says, and help states understand what they need to do to meet their goals. Because the sources of nutrients are so widespread, the Gulf will not benefit if only one or two states act to reduce nutrients. Ideally, Morrison says, "everybody takes out their proportional share" of nutrients entering the Gulf.

The Illinois EPA's Mosher agrees: "I really see that there has to be a mandate from the federal government to get the states to remove nutrients to protect the Gulf." Furthermore, such a mandate, he says, would also "open the door" to water quality trading.

Halting hypoxia in the Gulf will require sustained effort drawing in a broad swath of the American heartland, and this will create logistical as well as financial challenges. For this reason, ORSANCO's Vicory believes that a greater commitment by the federal government is needed. "When you have a geographic area that large, it just simply requires a strong federal leadership presence," he contends. Unfortunately, that leadership has not been in evidence, Vicory maintains. Given the absence of significant accomplishments thus far, "I don't think anybody can say that [addressing Gulf hypoxia] would appear to be a priority of the United States," he says.

Despite report after report addressing Gulf hypoxia, The Wetlands Initiative's Hey notes that actions to address its causes remain elusive. "It's not that we don't know how to solve the problem," he says. "We seem not to have the courage or the interest to come to grips with the problem." Of course, additional research is needed regarding the factors that influence hypoxia in the Gulf. Yet action is needed even more, Hey says. Instead of merely continuing to formulate solutions, he says, "it is time to start work on the solution." ■