Healthier Water Through

Chesapeake Bay, a national treasure, suffers from having too many nutrients. Restoring the bay means putting the 64,000-square mile watershed on a strict diet. Other rivers, lakes, and estuaries are signing up for the treatment, too.

By Mohsin Siddique, and James Anderson

The Chesapeake Bay's main stem is almost 200 miles long, and it averages 5 to 10 miles across. In an average summer, about one-fourth of that main stem "deep trench" area becomes a "dead zone" that lacks enough dissolved oxygen to support fish or aquatic vegetation. Atlantic oysters, once abundant enough to filter the algae out of the bay every three to four days, are now so sparse that they take a year to filter the same volume. The population of the bay's famous blue crabs has declined by 80 percent since 1990.

The problem arises, not surprisingly, from pollution—particularly nitrogen and phosphorus. These two nutrients nourish algae blooms. The algae block sunlight, preventing growth of beneficial aquatic vegetation. In summer, the algae die and decay, consuming the oxygen in the water and leaving too little to sustain the bay's living resources.

Nitrogen and phosphorus enter the bay in several ways. Among the largest sources of nutrients are atmospheric deposition and overland runoff, which carries nutrients deposited on the land from the agricultural use of commercial fertilizers as well as from natural sources such as plants and animal waste. Deforestation and increased imperviousness associated with growth also contribute to this problem. Next are point sources, primarily wastewater treatment plants (WWTPs). These plants contribute only about one-fifth of the nutrient pollution to the bay, but they are the easiest sources to identify, monitor, and regulate.

The Chesapeake Bay Program

Faced with dramatic losses of shellfish, finfish, and aquatic vegetation, the bay area jurisdictions of Maryland, Virginia, and the District of Columbia formed an alliance in 1983 with nearby Pennsylvania and the EPA to restore the health of the nation's largest estuary. After four years of study and planning, the group, collectively known as the Chesapeake Bay Program (CBP), formulated a pollution reduction program that employs strategies ranging from educating the public to setting effluent quality goals for WWTPs. A key component of the 1987 Chesapeake Bay Agreement (CBA) was a commitment to reduce, by the year 2000, the annual loads of nitrogen and phosphorus entering the bay by at least 40 percent (compared to a 1985 baseline). At the same time, CBP embarked on an ambitious plan to undertake extensive monitoring, research, and modeling of the bay to better identify the causes of its decline and possible technical and management options to restore it.

In 2003, the CBP was revised in two ways. Three additional states in the Chesapeake Bay watershed—Delaware, New York, and West Virginia—joined the alliance. And new nutrient reduction goals, targeted for 2010, were set to reduce the annual nutrient loads to no more than 175 million lb of nitrogen and 12.8 million lb of phosphorus. These amounts represent 52 percent and 47 percent, respectively, of the 1985 amounts. In addition, to implement these reduction goals, EPA and the CBA states are developing water quality standards for nutrients to meet the water quality and living resources needs of the bay. These are expected to be incorporated in the NPDES permits of WWTPs of these states in the not too distant future.

Exactly what those goals mean for the

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Fewer Nutrients

watershed's 304 major WWTPs is still under consideration. Various jurisdictions are developing specific guidelines, some of which nudge the current limits of technology. Typically, biological nutrient removal (BNR) processes can lower the effluent's nitrogen and phosphorus concentrations to 8 mg/L and 3 mg/L, respectively, while enhanced nutrient removal (ENR) can get the concentrations as low as 3 mg/L and 0.3 mg/L, respectively. According to a CBP report, the basin-wide costs of achieving nitrogen levels of 5mg/L and 3 mg/L at all significant WWTPs are estimated to be $2.7 billion and $4.4 billion, respectively.

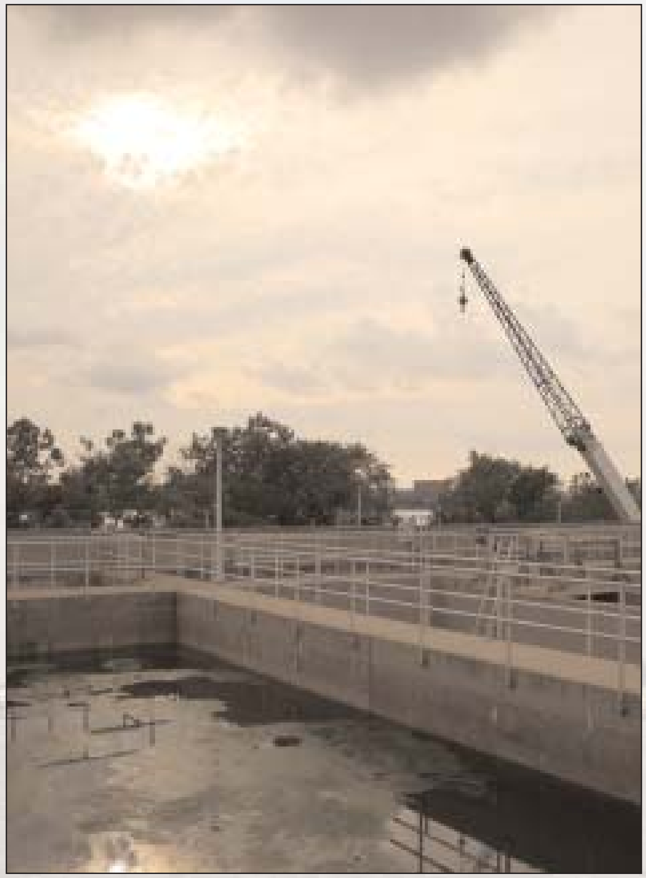
The last extensive WWTP construction program took place in the 1970s and 1980s, spurred by the Clean Water Act. At that time federal grants paid for three-fourths of the cost of a nationwide program to build secondary treatment plants. Today, with little or no federal funding available, local ratepayers may have to bear the burden of upgrading plants into advanced treatment facilities that can remove excess nutrients. Additionally, operators of treatment facilities will have to deal with problems of adjusting to population growth (the established nutrient reduction load limits do not allow for any exclusions due to growth), space constraints, and retrofitting new technologies. Overcoming such obstacles will require innovation.

Technological Innovation

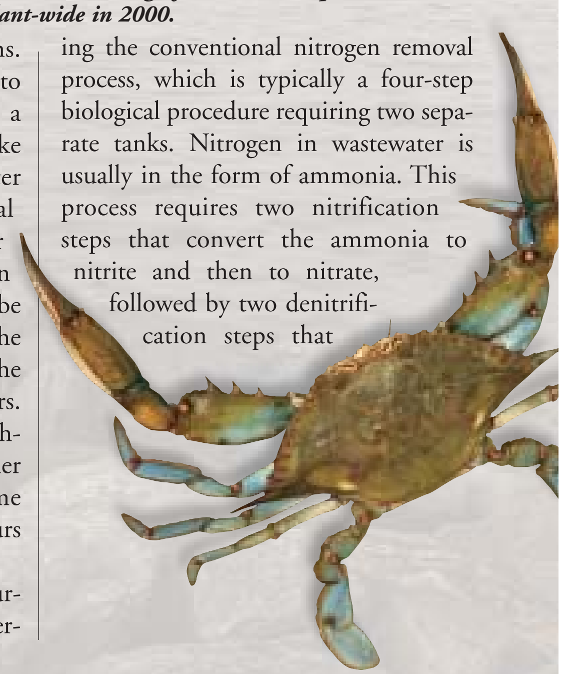
Nutrient management technology has been the focus of many scientists and researchers throughout the world, including those who have been involved in the efforts to restore the Chesapeake Bay. CBP is currently targeting technologies that can achieve total nitrogen (TN) concentrations of 5 mg/L and 3 mg/L (considered to be the limit of technology, or LOT). Researchers are developing plant-specific process modifications to maximize the use of existing WWTP facilities—an endeavor some call infra-stretching. The objective is to speed the nutrient removal process, effectively increasing the plant's capacity by processing more wastewater in a given amount of time.

At this technological frontier is the potential use of genetics-based biotechnology, for example, which offers the potential of doubling the nutrient removal capability of any BNR application-without expanding the WWTP's footprint. This development is the result of applying research from another field to wastewater treatment. During the first Gulf War, scientists at Northwestern University developed a DNA-based process for quickly identifying biological warfare toxins. Programming similar RNA probes to identify the bacteria present in a WWTP—rather than agents like anthrax or sarin—leads to a better understanding of the biological processes taking place in a particular plant. With this detailed information in hand, the plant operation can be adjusted to promote the growth of the most useful bacteria and discourage the growth of unproductive competitors. Research has shown that such techniques, when combined with nitrifier seeding, can help reduce the time required for nitrification from ten hours to about five hours.

One advanced technology that is currently being applied entails reengineering the conventional nitrogen removal process, which is typically a four-step biological procedure requiring two separate tanks. Nitrogen in wastewater is usually in the form of ammonia. This process requires two nitrification steps that convert the ammonia to nitrite and then to nitrate, followed by two denitrification steps that



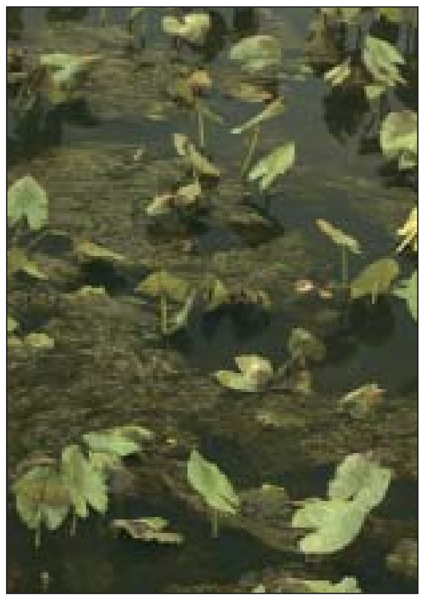
WASA's most recent BNR upgrade to the Blue Plains plant was an innovative methanol-assisted denitrification process, which was initially implemented on only half the plant's operations in 1997. Positive results were so significant that the process was then deployed plant-wide in 2000.



convert the nitrate back to nitrite, and then to inert nitrogen gas that is released to the atmosphere. The particular type of bacteria necessary for the third step (converting nitrate back to nitrite) is extremely difficult to grow. That step, which requires the addition of chemicals, is also expensive and time-consuming. Pilot projects have shown that controlling factors such as temperature, sludge age, and pH can prevent nitrate formation. Reducing the original four-step process to two steps that can take place in a single tank decreases the time, space, chemicals, and electricity needed. The New York City Department of Environmental Protection expects to save $3.3 million a year in the cost of chemicals and power by introducing the innovative SHARON process to its Wards Island water pollution control plant (SHARON is an acronym for "single-reactor system for high ammonia removal over nitrate," a system that employs the reengineered nitrogen removal process described above.)

Technological innovation is the focus of a strategic planning process being conducted for the Blue Plains WWTP in the District of Columbia. The 150-acre plant, operated by the DC Water and Sewer Authority (WASA), is a regional facility with a capacity of 370 mgd. The largest advanced wastewater treatment plant that feeds into Chesapeake Bay, it serves a 725-sq mi. area of the District of Columbia and parts of surrounding jurisdictions, and a population of more than two million people. One of the first plants in the region to achieve the CBP's goals for 2000, it uses BNR to produce effluent with an annual average nitrogen concentration of 7.5 mg/L, and it keeps the phosphorus concentration within its permit limit of 0.18 mg/L. The plant treats sewage from several jurisdictions, with 38 percent of its flow coming from the District of Columbia, 46 percent from two counties in Maryland, and 16 percent from two counties in Virginia. When those jurisdictions establish the nitrogen load reduction requirements for their share of the flow to the facility, the plant is expected to comply with those limits. Because that will certainly result in a mandated effluent concentration of TN of less than 7.5 mg/L, the plant's operation must be enhanced.

WASA's most recent BNR upgrade introduced an innovative methanol-assisted denitrification process. Because the technology had not been tested on such a large scale, it was implemented as a pilot project on only half of the plant's operation in 1997. Comparisons with effluent from the modified and unmodified halves of the plant proved that the new system was successful, and it was implemented across the entire plant in 2000. The upgrade, which reduced the effluent's nitrogen concentration by about 60 percent, used much of the plant's excess capacity to keep the construction cost to $30 million. Basically, the excess capacity was used to add a denitrification process in the facilities originally built for nitrification alone. Now, however, the plant is operating at nearly 90 percent of capacity, so WASA must develop a different strategy for its next upgrade. Alternatives include adding more BNR tanks or adding separate denitrification facilities. Taking advantage of new technologies that can operate in smaller-area facilities could reduce capital costs required to meet lower nitrogen discharge levels. Alternative processes might use biologically active filters, or various configurations of suspended-growth or fixed-film systems.



Nitrogen and phosphorus nourish algae blooms, which block the growth of beneficial aquatic vegetation before the algae dies, decays, and consumes oxygen in the water to the further detriment of the Chesapeake's living resources.

The extent to which the individual jurisdictions will remove nitrogen from their share of the flow to Blue Plains will be determined by their specific obligations under the CBA; options for nutrient reductions statewide; water quality needs of the local effluent-receiving waters; and, most important, financial considerations. For the District of Columbia, an important factor will be its regulatory obligations to control combined sewer overflow (CSO) that has severe impact on its rivers, especially the Anacostia River. A third of the district is served by a combined sewer system that commingles rainwater with raw sewage. Storms can cause this system to overflow and carry the mixture of rainwater and raw sewage into the Potomac River as well, the second-largest tributary feeding into Chesapeake Bay. Under the EPA CSO regulations, WASA has prepared a long-term control plan (LTCP) that proposes to construct a tunnel system to capture, store, and treat the overflows at Blue Plains. BNR processes do not work as effectively on diluted sewage; the storage facilities will create a more consistent inflow to the WWTP by gradually releasing watered-down sewage into the plant after a storm. "Introducing this additional flow changes the internal hydrology of our facility," says Leonard Benson, director of WASA's Department of Engineering and Technical Services, "and we have to make sure we meet our effluent limitations on a consistent basis while accommodating this fluctuating flow. We have to run process models to see how this is all going to work out, and we would want to do some pilot studies as we did in the previous upgrade."

Alternative treatment strategies will be evaluated with a computer simulation of the plant's operation. Using the model, engineers can determine how a process will vary with changes in parameters such as loading rates, time, temperature, and alkalinity. "These models are quite accurate, if you get them calibrated correctly," says Ed Locke, Metcalf & Eddy's (www.m-e.com) program manager for the Blue Plains project. "We can use the model to home in on what the existing process can do, and it can help us determine how we might modify that process. Then it will help us determine what additional facilities we might need."

Financial Issues

The financial implications of modifying facilities such as the Blue Plains WWTP to meet the new nutrient removal goals are huge. What makes planning particularly difficult is that the requirements have not been finalized. The watershed states are still deciding how their 2010 goals translate into nutrient concentrations for treated effluent. Furthermore, the EPA and the states have not yet decided if compliance with the goals will be voluntary or if it will be enforced through permit restrictions, and if so, when. "Without the permit requirement, we are looking at an investment of $300 million to $400 million," WASA's Benson says. "Under a permit condition, it would be $800 million to $900 million. Flows and processes vary, so we would have to over-design the facility to ensure consistent compliance."

Cost is a serious issue, particularly since plant upgrades may not be the only expense facing a particular jurisdiction. At WASA, for instance, the LTCP project will cost District of Columbia residents at least $2 billion over a 25-year period. Upgrading the Blue Plains plant could increase that burden on ratepayers by 40 percent. District residents are also paying a stormwater fee introduced in 2000 to meet the requirements of a municipal separate storm sewer system (MS4) NPDES permit. It is expected to go up as new requirements are imposed by local and federal laws for additional stormwater pollution control.

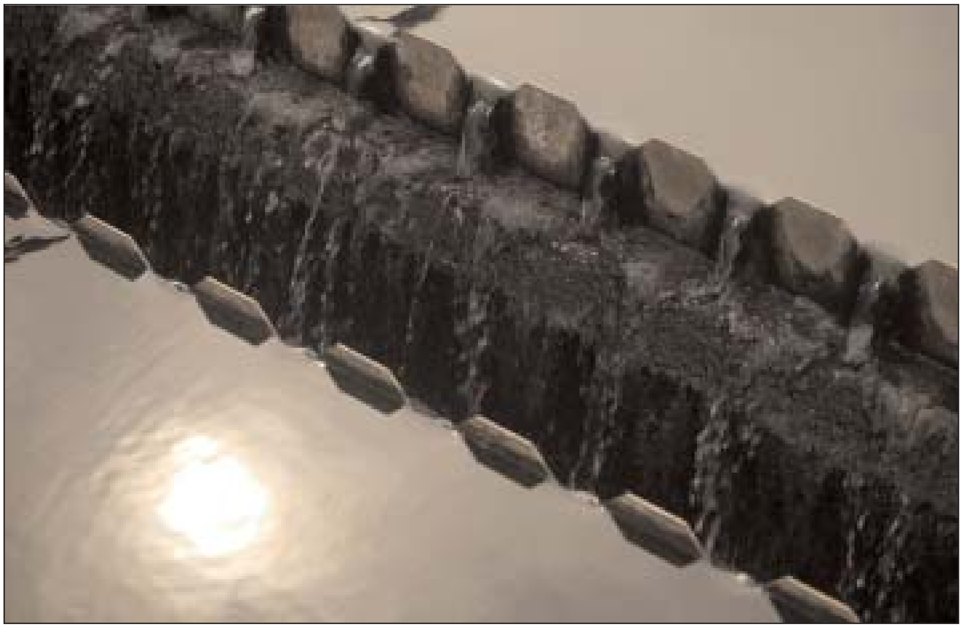
Opportunities for financial innovation exist with both expenses and revenues. On the expense side, the smallest direct cost might be achieved by upgrading a plant just to the minimum level required to meet the new guidelines. Contrary to intuition, though, investing in a more rigorous upgrade could create other financial opportunities. For instance, since the District of Columbia, Maryland, or Virginia may set goals that are less stringent than 3 mg/L of nitrogen, WASA might not be forced to upgrade to that level. "With each sequential fractioning down of nutrient discharge, the cost goes up disproportionately," explains Locke. "One of the things we will be looking at is going to that lowest level, and the potential for nutrient trading. It may be more cost-effective for Blue Plains, because it is so large, to go to the limit of technology and sell credits to other jurisdictions where it would be too expensive for them to implement similar technologies themselves."

Financing the necessary upgrades is a largely unresolved issue throughout the basin. The exception is Maryland, which authorized a Chesapeake Bay Watershed Restoration Fund in May 2004. Beginning in January 2005, residential and commercial sewer system customers will pay a monthly surcharge of $2.50 per home or equivalent dwelling unit. The $65 million expected annually from this so-called "flush tax" will be used to support $750 million to $1 billion in revenue bonds. That money will pay for ENR upgrades at the state's 66 major WWTPs that discharge into the bay; other plants may also apply for funds (but at a lower priority). Eligible uses for the funds include up to 100 percent of the costs of planning, design, and construction of ENR upgrades that will achieve concentrations not exceeding 3 mg/L of nitrogen and 0.3 mg/L of phosphorus. The fund will also provide plants with up to $5 million for combined or separate sewer overflow corrections and sewer rehabilitation-related upgrades through fiscal year 2009. After FY 2009, it will disburse up to $6.5 million a year to help plants pay for ENR operation and maintenance.

This type of assistance is crucial to cities like Cumberland, MD. The city upgraded its 15 mgd WWTP to BNR in July 2002, at a cost of $10 million. Now it is working with Metcalf & Eddy and wastewater engineers Whitman, Requardt and Associates (www.wrallp.com) to design an ENR upgrade that will cost around $25 million—about $1,000 per city resident. The Chesapeake Bay Agreement and the potential for total maximum daily load limits for the bay may not leave them any choice. "Our perception is that it's not if you're going to have to upgrade, it's when you're going to have to upgrade," says Nancy Hausrath, the city's environmental specialist. "With Maryland funding 100 percent of the projects through the Chesapeake Bay Restoration Fund, this is the time to go ahead and do it."

"We're looking at the best available technology that will apply to our facility," Hausrath says. Changes will probably include modifying the reactors, adding a system to introduce methanol as a food source for the nitrogen removal, and installing denitrification filters. One important factor influencing the design is that most of the city uses a combined sewer system. Converting to two separate sewer systems would be prohibitively expensive, so the city plans to construct a holding facility similar to WASA's LTCP.

John DiFonzo, Cumberland's city engineer, emphasizes the importance of customizing upgrade designs to reflect local conditions. "If there is something unique about your plant—for us it's the combined sewage—you have to deal with that," he says. "Both BNR and ENR will be affected by our combined sewage. If it's not addressed, then our system is not going to work." He also stresses the importance of considering operating costs as well as construction costs when evaluating proposed designs. Construction costs are paid only once,but operating costs continue year after year.



Innovation will be required by treatment plant operators to overcome problems of expanding populations, limited space for plant growth, and retrofitting existing operations with new technologies.

Beyond Nutrient Removal

The effect of nitrogen and phosphorus on water quality is well known, and nutrient concentration has been measurable and treatable for decades. The so-called "emerging contaminants," the next pollutants of concern, are not currently regulated. They appear in extremely small concen-tra-tions—parts per billion and parts per trillion—and researchers are just beginning to learn about them as they develop techniques that can detect such low concentrations. These contaminants fall into three categories: toxins, carcinogens, and endocrine disruptors. They come from such diverse sources as antibiotics and fire retardants, and some—such as caffeine and fragrances—are so commonplace that they seem intrinsically innocuous. Yet their potential health effects are unknown. In various parts of the United States, for example, sex anomalies that jeopardize the ability to reproduce are appearing in fish, frogs, and alligators; the causes are still under investigation, but various pollutants are commonly suspected (if not proven) to be the cause.

The next wave of WWTP regulations may well target these pollutants, perhaps over the next 15 or 20 years. Bacterial action, if properly optimized and programmed, seems to do a good job with these emerging contaminants. Conventional wastewater treatment is effective on fewer than half of the known emerging contaminants, but state-of-the-art ENR treatment may be effective for 70 to 80 percent of them. So the strategies that engineers are using now to optimize the biology for the nutrient removal process will probably pave the way for compliance with the next round of regulations as well. GE

Beyond the Bay

"The Chesapeake region is ahead of the curve because of the concerns about eutrophication of the bay," says Dr. David Zenz, a senior associate at Consoer Townsend Envirodyne Engineers, Inc. (CTE Engineers, www.cte-eng.com). "At the national level, too, nutrient removal from wastewater treatment plant effluents is becoming more and more of an issue." In response to guidelines issued by the federal government in 2000 and 2002, all of the states must develop nutrient water-quality standards. These regulations will impose nitrogen and/or phosphorus removal requirements for the first time on many of this country's sewage treatment plants. "I think this new requirement could be the single biggest capital expenditure they may have in the next ten years or so," Zenz says.

In preparing for this, investing time and money in a thorough plant evaluation and planning exercise can pay large dividends in terms of reducing the ultimate cost of upgrading to nutrient removal. For example, the Genesee County Drain Commission initiated a full-scale stress test of the biological phosphorus removal process at one of its wastewater treatment facilities near Flint, MI. The testing program showed that the plant's rated capacity could be increased without constructing additional tankage. "Their plant was rated at 25 mgd, and we showed through our testing program that it should really be rated at 30 mgd," explains Tony Bouchard, senior vice president of CTE Engineers. "As flows increase in the future, they will be able to use their existing plant for a longer time without further capital expenditures."

As another example, the Wheaton Sanitary District near Chicago commissioned an evaluation of future nutrient removal processes as part of the district's rehabilitation planning for its treatment plant. "One of the challenges was to figure out which of their existing processes they should spend their money on, and which didn't fit into a future nutrient removal scheme very well and therefore shouldn't undergo any substantial modification," says Zenz. "The evaluation helps them understand what the range of capital costs will be in the future so they can make financial plans, and it also helps them understand what processes need to be continued in operation and maintained because they will be useful in a future nutrient removal scheme."

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