Nutrients

THE CHALLENGE

Nutrients, such as nitrogen and phosphorus, occur naturally in the environment and play a key role in a healthy aquatic system. But problems start to develop when everyday human activity introduces additional nitrogen and phosphorus into our waterbodies through sources such as municipal wastewater, fertilizers, soaps, and detergent—and in some cases even the products used to treat our water. These excess amounts can throw off the natural balance, prompting excessive algal growth, hypoxia, and other negative effects on the water supply.

While regulations designed to maintain this natural balance are set using the best available knowledge, as new health data, analytical methods, or treatment technologies become available, these regulations can become more stringent and more difficult to achieve. The challenge is exacerbated by the fact that both nitrogen and phosphorus come in a variety of forms that can behave differently in the environment, so an across the board solution for reducing or removing them and keeping up with regulations is not that simple.

THE RESEARCH

With a body of nutrient research that spans more than 30 years and 200 projects, WRF is developing the needed scientific knowledge to manage sources, more effectively identify and determine the real impact of various nutrient species in water, and improve nutrient treatment and removal processes. And as more and more wastewater utilities are realizing the value of nutrients as a renewable commodity, WRF is also helping to develop ways to recover nutrients during the treatment process.

Partnering with strategic organizations, including the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention, and state regulatory agencies, WRF has focused on nutrient treatment optimization, water quality impacts and modeling, algal metabolite detection and treatment, and nutrient recovery.

Sources

Because preventing extra nitrogen and phosphorous from entering our waterways is the first line of defense against increased nutrient levels and the potential negative effects on water supplies, WRF is exploring various ways to manage sources. In-depth research on stormwater and agricultural runoff, as well as nutrient discharges from treatment facilities, is helping to advance knowledge and prevent additional loadings. Key areas that tie into this body of knowledge include integrated water and urban land planning, green infrastructure, stream restoration, and agricultural best management practices.

In 2017, WRF released findings from *Enhanced Removal of Nutrients and Trace Organic Contaminants in Pilot-Scale Stormwater Treatment Systems* (4567), providing guidance on the design and operation of systems for controlling nutrients released into surface waters. The research tested combinations of media that capture and treat urban stormwater, highlighting a highly effective process for removing nutrients that involves the use of woodchips to biologically degrade nitrate.

While managing sources is key, understanding the true impact of these sources is arguably even more important. WRF research is providing better insight into the impacts and sources so that utilities can more effectively manage discharges and regulators can set appropriate criteria. In 2010, WRF provided the water sector with one of the first methods for calculating and addressing these impacts in *Linking Receiving Water Impacts to Sources and to Water Quality Management Decisions* (WERF3C10). The research lays out an approach for establishing water quality impacts, linking those impacts to nutrients, quantifying sources, weighing costs and benefits of available nitrogen controls, estimating responses to controls, and finally, implementing a nitrogen control strategy and assessing the improvements.

Zeroing in on nutrient sources can also help prevent unnecessary practices, like costly nutrient treatment technologies, or protect beneficial uses. In 2018, as part of *Bridging the Gap Between TMDL and Assignment of Reuse Effluent Load Allocations* (4758), WRF released a marker-based tool to help water agencies track the extent to which their reuse practices contribute to nutrient impairment of surface waters, which could help utilities maintain reuse applications.

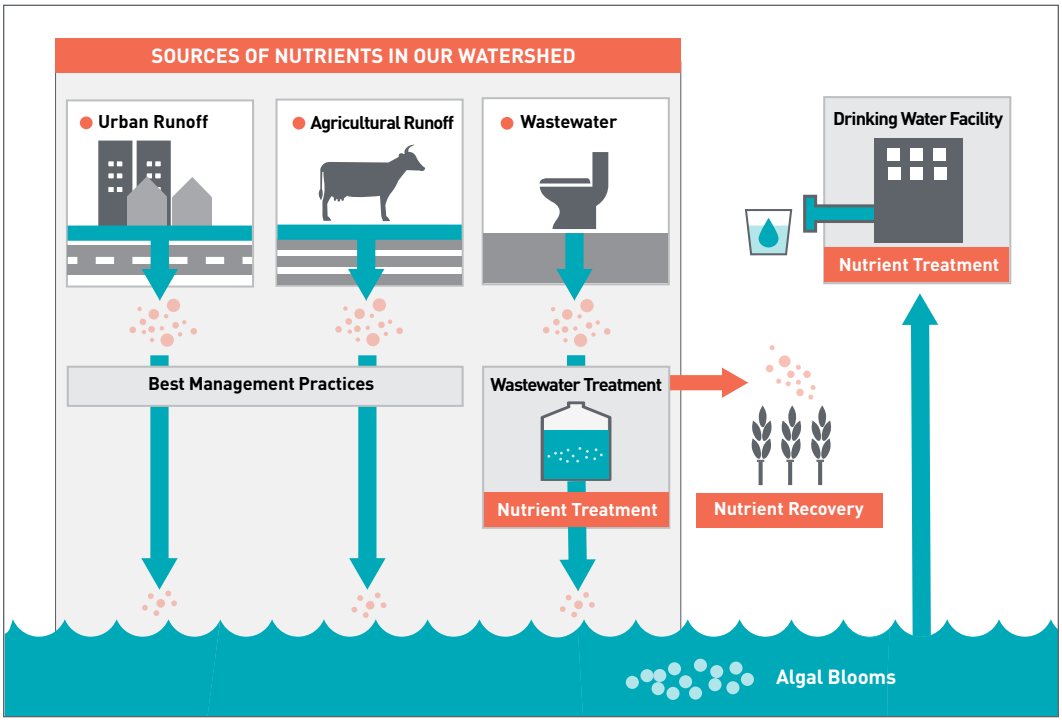
Treatment

To further drive down elevated nutrients in our waterbodies, WRF became an early pioneer in advancing the treatment and removal of nutrients in wastewater—helping to improve water quality before it is returned to our rivers and streams. Research explores ways to improve commonly used processes, such as biological nutrient removal, through technologies like membrane bioreactors and online analyzers, as well as novel technologies that are challenging conventional treatment.

In 2007, WRF embarked on an unprecedented 10-year collaborative initiative to build a foundation of work on nutrients and their fate during treatment. Engaging nearly 250 partner organizations and led by 36 investigators, this research helped provide a better understanding of nutrients and improve the reliability of nutrient removal, including aspects such as cost, energy, chemicals, and greenhouse gas emissions. Results from these efforts, which can be found in the *Nutrient Removal Challenge Synthesis Report* (NUTR5R14g), cover such issues as the occurrence and measurement of nutrient species, facility design and operations to achieve low nutrient limits, and process optimization and strategies.

While utilities have traditionally used biological and chemical processes to remove nutrients, they are increasingly turning to alternate treatment methods that don't require the use of expensive chemicals or large amounts of energy. WRF is leading the way in solutions like deammonification, a process that doesn't rely on external carbon—eliminating the need for chemical purchases such as methanol—and requires significantly less oxygen, which translates to less power consumption.

WRF research is also shining a light on when advanced treatment might not be the best solution. In *Striking the Balance Between Nutrient Removal in Wastewater Treatment*



TRACKING NUTRIENTS IN OUR WATER: Sources, Treatment & Recovery

and Sustainability (NUTR1R06n), research demonstrates how getting down to lower limits can call for excessive chemical additives and huge amounts of energy, suggesting that a point of diminishing returns might be reached after enhanced nutrient removal. The additional chemicals and energy needed beyond that point caused a 70% spike in greenhouse gas emissions—and resulted in only a 1% drop in nutrient levels. A more effective solution might be managing these nutrients before they make it to the facilities.

Resource Recovery

Because a growing number of facilities are taking nutrient treatment a step further and extracting these valuable resources, WRF is exploring the best practices to make the most of everything from nutrient-rich biosolids to the phosphorus and ammonia in liquid waste. In 2014, WRF was awarded a $2.2 million Science to Achieve Results (STAR) grant from EPA to create a National Research Center for Resource Recovery and Nutrient Management. Working with some of the top universities and non-profit organizations in the United States, including the University of California at Berkeley, Columbia University, the University of Michigan, and Stanford University, WRF is helping to create a shift in the water sector where nutrients are not regarded as waste but rather valuable products.

The research center is a hub for groundbreaking science, demonstrating breakthroughs such as the application of urine separation to collect nutrients for agricultural use and commercial-scale generation of energy and bio-fertilizers. Research has also helped utilities meet regulatory goals for nitrogen reduction at much lower costs, with less energy, and with a smaller chemical footprint.

The recent *Intensification of Resource Recovery (IR^2)* initiative is also helping to push this movement forward, finding new ways to recoup valuable resources and getting the technologies that can make it happen into the field faster. As part of this effort, WRF evaluated more than 30 emerging technologies, including many that are helping to revolutionize biological nutrient removal. The results include a ranking of each technology's readiness level, which can assist facilities in finding the right solution for their site.

Effects

While WRF is taking significant steps to reduce the amount of nutrients that make their way into our waterbodies, critical research is also looking at the other side of the coin—managing the impacts of these constituents once they are in our ecosystems. Relevant science helps utilities set appropriate criteria for nutrients as well as develop plans for total maximum daily loads, offsetting devastating effects like algal blooms, eutrophication, and loss of aquatic life—and ensuring our waterways can be enjoyed for years to come.

SOLUTIONS IN THE FIELD: The City of Boulder

In 2015, the City of Boulder was one of many utilities faced with increasing regulations on nutrient loads, raising questions about the real impact these limits would have on their receiving stream, Boulder Creek. In collaboration with Brown and Caldwell, the city signed on to test WRF's recently released Nutrient Modeling Toolbox (LINK1T11), a program that matches utilities with the most appropriate models to develop nutrient water quality criteria for their site. Using monitoring data from Boulder Creek they evaluated potential nutrient management scenarios, with the intent to craft an adaptive nutrient strategy.

According to Cole Sigmon, an engineering project manager at the City of Boulder, "This study, interestingly, showed that even if we eliminated our wastewater effluent, the receiving stream still would not meet the water quality standards being proposed in the next round of regulations. It was illuminating because it called into question some proposed water quality standards, illustrating that one standard might not be appropriate for a host of different receiving waters."

Cyanobacteria continues to be one of the most problematic organisms in our fresh water systems—with nearly a third of the United States reporting blooms—making it a top priority for WRF research. Without clear guidance or consensus regulations in place, many utilities struggle with responding to events. Since 1994, WRF has completed more than 30 research projects on these microscopic organisms and the cyanotoxins they produce, helping facilities detect, monitor, and manage these nuisance organisms—as well as communicate with the public.

Because cyanobacteria thrive in nutrient-rich conditions, excess nitrogen and phosphorus can promote unchecked growth, and lead to a list of negative impacts—including human health implications and negative effects on the taste and odor of drinking water. Because there is a narrow window of opportunity to detect taste and odor issues before complaints begin, WRF has been providing the science to stay on top of these events. *Early Warning and Management of Surface Water Taste-and-Odor Events* (2614) provides guidance on monitoring for taste and odor events before they even reach the facility. This first-of-its-kind research summarizes more than 25 years of work on isolating, culturing, and confirming production of MIB or geosmin, the off-putting organic chemicals emitted by cyanobacteria.

And as weather patterns change, WRF is continuing to track the impacts higher temperatures will have on cyanobacteria, which favor warmer environments. In *Impact of Climate Change on the Ecology of Algal Blooms* (4382), research underscores the importance of reducing nutrients in order to offset the advantage cyanobacterial blooms will gain from the increased temperatures that help them flourish.

LIFT

The Leaders Innovation Forum for Technology (LIFT) helps move water technologies to the field quickly and efficiently. Nutrient treatment and recovery technologies are a key LIFT initiative, which targeted biological nutrient removal as the program's first focus area and helped to advance deammonification technologies. Other nutrient-related focus areas include digestion enhancements and phosphorus recovery, which promoted the launch of TERRY, the Tool for Evaluating Resource Recovery, (NTRY1R12t), a tool that helps utilities determine their potential to recover phosphorus.

With more than 30 research projects on cyanobacteria, WRF is helping facilities detect, monitor, and manage these microorganisms—as well as communicate with the public about potential impacts.

WHAT'S NEXT?

Because nutrients come from more than just one source and their impacts are far reaching, WRF is broadening its research scope and looking at the bigger picture. This means tying together the work WRF has done with other available research and moving beyond the water sector, including the agricultural industry. New research will examine how to deal with nutrients on a broader level, including source water protection and land management. A comprehensive state-of-the-science document will pull together the entire body of knowledge, bringing together cross-sector stakeholders to map out a path for critical research going forward, including pollution prevention.

As energy consumption continues to be a top issue for utilities, WRF is also advancing treatment options and optimizing technologies, with a focus on low-energy, low-cost solutions. These solutions don't necessarily need to be high-tech—they just need to get the job done so that utilities can keep up with regulations and consistently meet nutrient limit requirements. A project on the horizon plans to take a look at next-generation approaches and technologies that combine reduced aeration energy and nutrient removal processes in an effort to help move more economical and sustainable solutions into the industry.

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